

# The Advanced Research WRF (ARW) Dynamics Solver

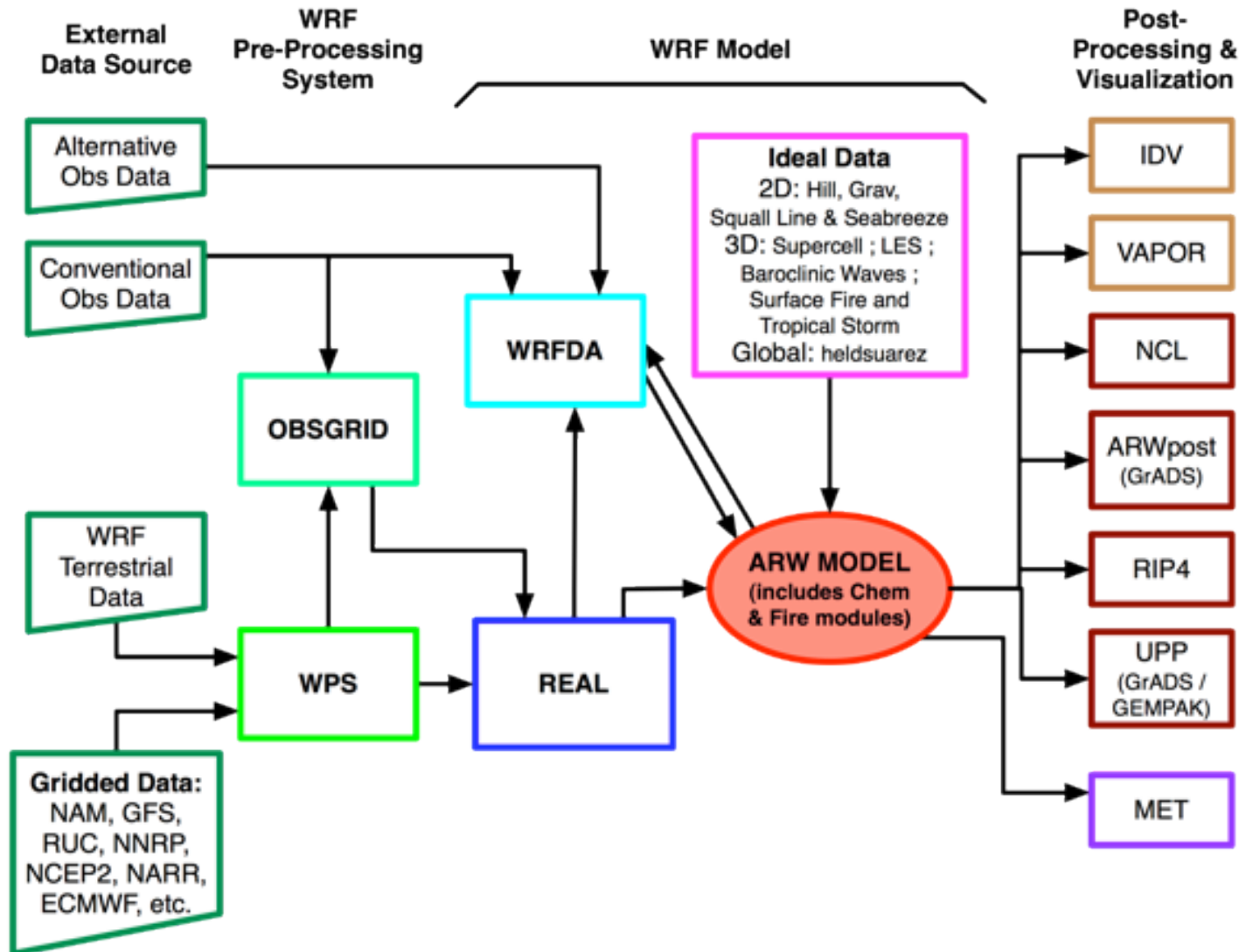
Bill Skamarock

[skamaroc@ucar.edu](mailto:skamaroc@ucar.edu)

Jimmy Dudhia

[dudhia@ucar.edu](mailto:dudhia@ucar.edu)

# WRF Modeling System Flow Chart



## WRF ARW Tech Note

A Description of the Advanced Research WRF Version 3

<http://www.mmm.ucar.edu/wrf/users/pub-doc.html>

# ARW Dynamical Solver

- Terrain representation
- Vertical coordinate
- Equations / variables
- Time integration scheme
- Grid staggering
- Advection scheme
- Time step parameters
- Filters
- Boundary conditions
- Nesting
- Map projections

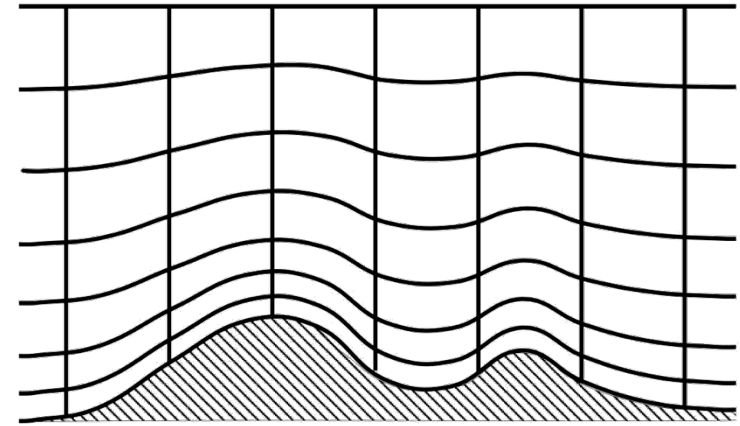
# Vertical Coordinate and Prognostic Variables

Hydrostatic pressure  $\pi$

Column mass  $\mu = \pi_s - \pi_t$   
(per unit area)

Vertical coordinate  $\eta = \frac{(\pi - \pi_t)}{\mu}$

Layer mass  $\mu \Delta \eta = \Delta \pi = g \rho \Delta z$   
(per unit area)



Conserved state (prognostic) variables:

$$\mu, \quad U = \mu u, \quad V = \mu v, \quad W = \mu w, \quad \Theta = \mu \theta$$

Non-conserved state variable:  $\phi = gz$

## 2D Flux-Form Moist Equations in ARW

Moist Equations:

$$\frac{\partial U}{\partial t} + \alpha \mu_d \frac{\partial p}{\partial x} + \frac{\alpha}{\alpha_d} \frac{\partial p}{\partial \eta} \frac{\partial \phi}{\partial x} = - \frac{\partial Uu}{\partial x} - \frac{\partial \Omega u}{\partial \eta}$$

$$\frac{\partial W}{\partial t} + g \left( \mu_d - \frac{\alpha}{\alpha_d} \frac{\partial p}{\partial \eta} \right) = - \frac{\partial Uw}{\partial x} - \frac{\partial \Omega w}{\partial \eta}$$

$$\frac{\partial \mu_d}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial \Omega}{\partial \eta} = 0$$

$$\frac{\partial \Theta}{\partial t} + \frac{\partial U\theta}{\partial x} + \frac{\partial \Omega\theta}{\partial \eta} = \mu Q$$

$$\frac{d\phi}{dt} = gw$$

$$\frac{\partial(\mu_d q_{v,l})}{\partial t} + \frac{\partial(U q_{v,l})}{\partial x} + \frac{\partial(\Omega q_{v,l})}{\partial \eta} = \mu Q_{v,l}$$

Diagnostic relations:

$$\frac{\partial \phi}{\partial \eta} = -\alpha_d \mu_d, \quad p = \left( \frac{R\Theta}{p_o \mu_d \alpha_v} \right)^\gamma$$

# Time Integration in ARW

## 3<sup>rd</sup> Order Runge-Kutta time integration

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

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

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

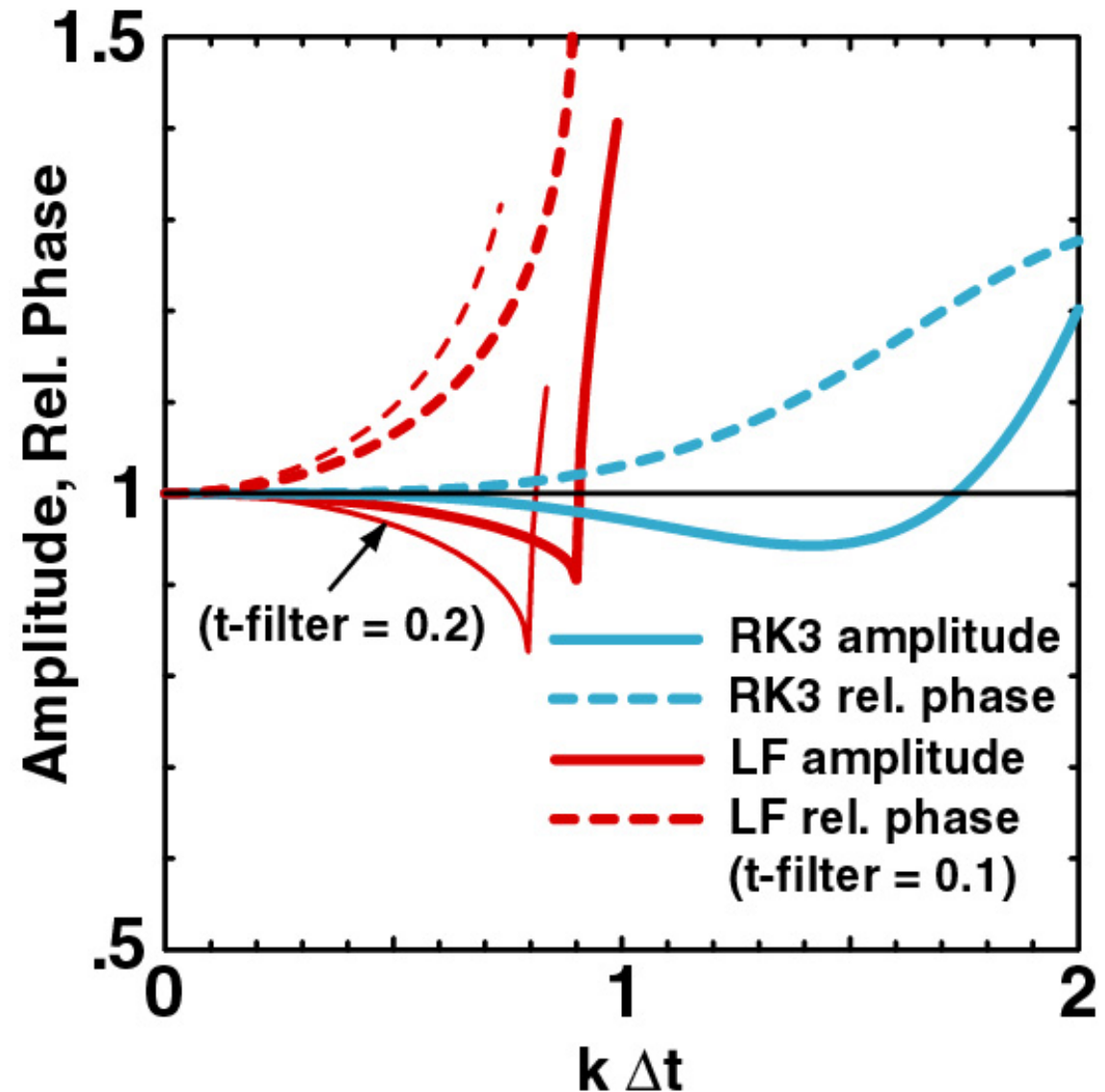
$$\phi^{t+\Delta t} = \phi^t + \Delta t R(\phi^{**})$$

Amplification factor  $\phi_t = i k \phi$ ;  $\phi^{n+1} = A \phi^n$ ;  $|A| = 1 - \frac{(k\Delta t)^4}{24}$

# Phase and amplitude errors for LF, RK3

Oscillation  
equation  
analysis

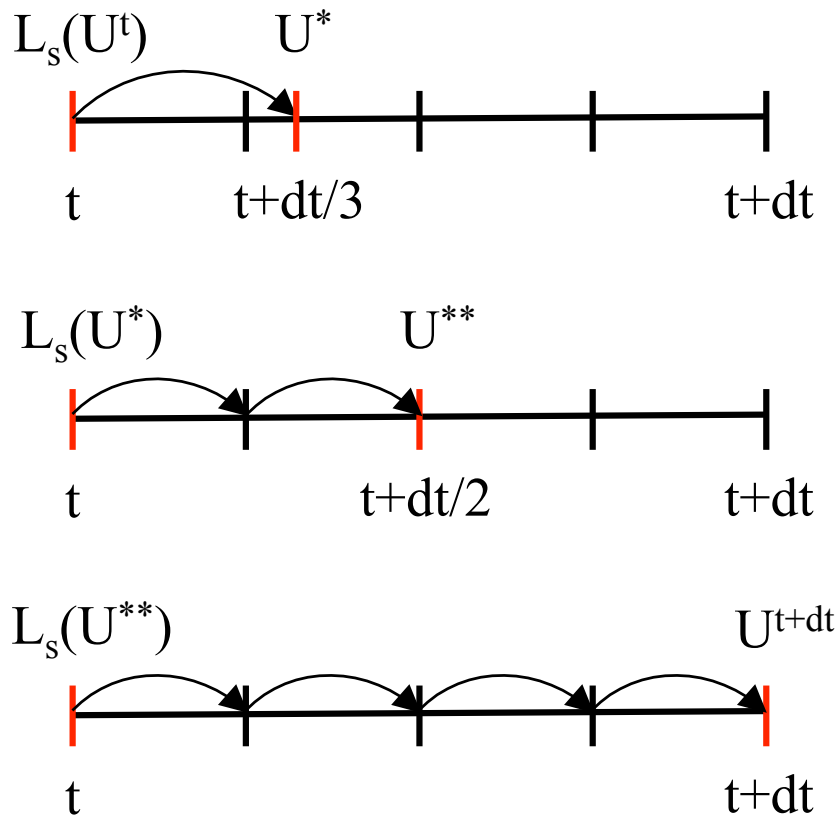
$$\phi_t = ik\phi$$



# Time-Split Runge-Kutta Integration Scheme

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

3rd order Runge-Kutta, 3 steps

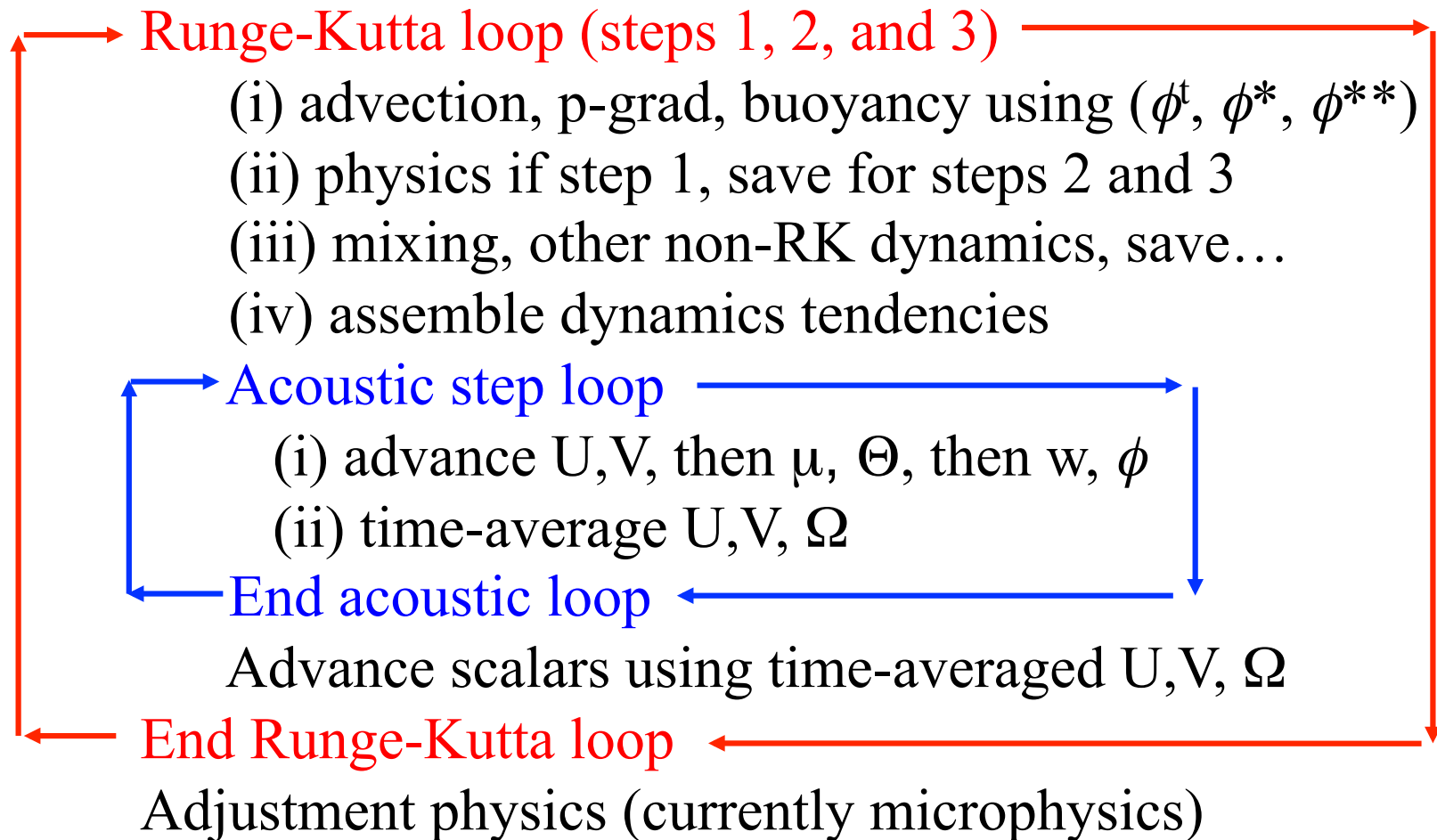


- RK3 is 3rd order accurate for linear eqns, 2nd order accurate for nonlinear eqns.
- Stable for centered and upwind advection schemes.
- Stable for Courant number  $Udt/dx < 1.73$
- Three  $L_{\text{slow}}(U)$  evaluations per timestep.



# WRF ARW Model Integration Procedure

Begin time step



End time step

# Flux-Form Perturbation Equations

Introduce the  
perturbation variables:

$$\phi = \bar{\phi}(\bar{z}) + \phi', \mu = \bar{\mu}(\bar{z}) + \mu';$$
$$p = \bar{p}(\bar{z}) + p', \alpha = \bar{\alpha}(\bar{z}) + \alpha'$$

Note –  $\phi = \bar{\phi}(\bar{z}) = \bar{\phi}(x, y, \eta),$   
likewise  $\bar{p}(x, y, \eta), \bar{\alpha}(x, y, \eta)$

Reduces horizontal pressure-gradient errors.

For small time steps, recast variables as perturbations from time  $t$

$$U' = U'^t + U'', \quad V' = V'^t + V'', \quad W' = W'^t + W'',$$
$$\Theta' = \Theta'^t + \Theta'', \quad \mu' = \mu'^t + \mu'', \quad \phi' = \phi'^t + \phi'';$$
$$p' = p'^t + p'', \quad \alpha' = \alpha'^t + \alpha''$$

Allows vertical pressure gradient to be expressed in terms of  $\phi''$ .

# Small Time Step Integration of Acoustic/Gravity Wave Terms

(Without expanding variables into perturbation form)

$$\begin{aligned}
 U^{\tau+\Delta\tau} & \quad \frac{\partial U}{\partial t} + \left( \mu_d \alpha \frac{\partial p}{\partial x} + \frac{\alpha}{\alpha_d} \frac{\partial p}{\partial \eta} \frac{\partial \phi}{\partial x} \right)^\tau = R_U^t \\
 \mu_d^{\tau+\Delta\tau} \quad \Omega^\tau & \quad \frac{\partial \mu_d}{\partial t} + \frac{\partial U^{\tau+\Delta\tau}}{\partial x} + \frac{\partial \Omega^{\tau+\Delta\tau}}{\partial \eta} = 0 \\
 \Theta^{\tau+\Delta\tau} & \quad \frac{\partial \Theta}{\partial t} + \left( \frac{\partial U \theta^t}{\partial x} + \frac{\partial \Omega \theta^t}{\partial \eta} \right)^{\tau+\Delta\tau} = R_\Theta^t \\
 W^{\tau+\Delta\tau} & \quad \frac{\partial W}{\partial t} + g \overline{\left( \mu_d - \frac{\alpha}{\alpha_d} \frac{\partial p}{\partial \eta} \right)^\tau} = R_W^t \\
 \phi^{\tau+\Delta\tau} & \quad \left\{ \begin{aligned} & \mu_d^t \frac{\partial \phi}{\partial t} + U^{\tau+\Delta\tau} \frac{\partial \phi^t}{\partial x} + \Omega^{\tau+\Delta\tau} \frac{\partial \phi^t}{\partial \eta} - g \overline{W}^\tau = R_\phi^t \end{aligned} \right.
 \end{aligned}$$

- Forward-backward differencing on  $U$ ,  $\Theta$ , and  $\mu$  equations
- Vertically implicit differencing on  $W$  and  $\phi$  equations

# Hydrostatic Option

Instead of solving vertically implicit equations for  $W$  and  $\phi$

Integrate the hydrostatic equation to obtain  $p$  ( $\pi$ ):

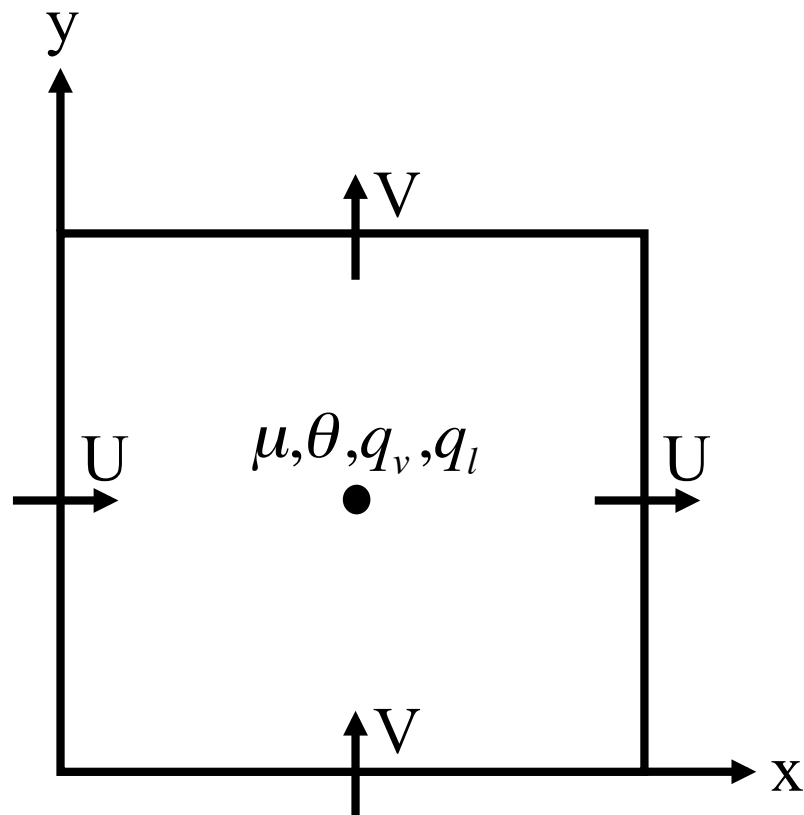
$$\frac{\partial p}{\partial \eta} = \left( \frac{\alpha_d}{\alpha} \right)^t \mu$$

Recover  $\alpha$  and  $\phi$  from:  $p = p_0 \left( \frac{R\theta}{p_0 \alpha_v} \right)^\gamma$ , and  $\frac{\partial \phi}{\partial \eta} = -\mu_d \alpha_d$

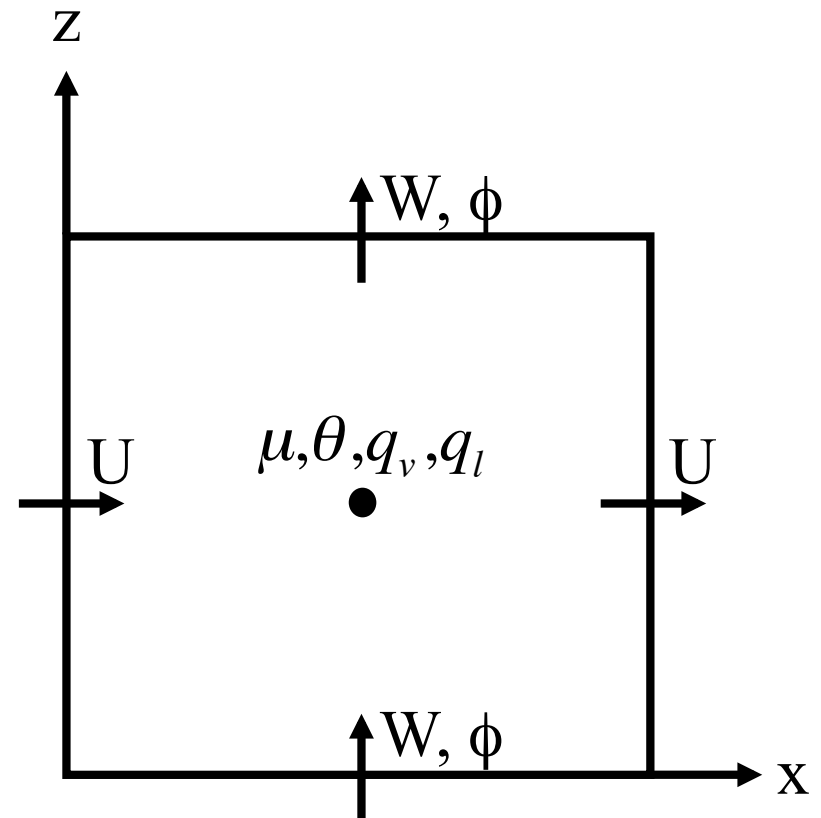
$W$  is no longer required during the integration.

# ARW model, grid staggering

## C-grid staggering



horizontal



vertical

## Advection in the ARW Model

2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> order centered and upwind-biased schemes are available in the ARW model.

Example: 5<sup>th</sup> order scheme

$$\frac{\partial(U\psi)}{\partial x} = \frac{1}{\Delta x} \left( F_{i+\frac{1}{2}}(U\psi) - F_{i-\frac{1}{2}}(U\psi) \right)$$

where

$$F_{i-\frac{1}{2}}(U\psi) = U_{i-\frac{1}{2}} \left\{ \frac{37}{60}(\psi_i + \psi_{i-1}) - \frac{2}{15}(\psi_{i+1} + \psi_{i-2}) + \frac{1}{60}(\psi_{i+2} + \psi_{i-3}) \right\} \\ - \text{sign}(1, U) \frac{1}{60} \left\{ (\psi_{i+2} - \psi_{i-3}) - 5(\psi_{i+1} - \psi_{i-2}) + 10(\psi_i - \psi_{i-1}) \right\}$$

# Advection in the ARW Model

For constant  $U$ , the 5<sup>th</sup> order flux divergence tendency becomes

$$\Delta t \frac{\delta(U\psi)}{\Delta x} \Big|_{5th} = \Delta t \frac{\delta(U\psi)}{\Delta x} \Big|_{6th} - \underbrace{\left| \frac{U\Delta t}{\Delta x} \right| \frac{1}{60} \left( -\psi_{i-3} + 6\psi_{i-2} - 15\psi_{i-1} + 20\psi_i - 15\psi_{i+1} + 6\psi_{i+2} - \psi_{i+3} \right)}_{\frac{Cr}{60} \frac{\partial^6 \psi}{\partial x^6} + H.O.T}$$

The odd-ordered flux divergence schemes are equivalent to the next higher ordered (even) flux-divergence scheme plus a dissipation term of the higher even order with a coefficient proportional to the Courant number.

# Maximum Courant Number for Advection

$$C_a = U \Delta t / \Delta x$$

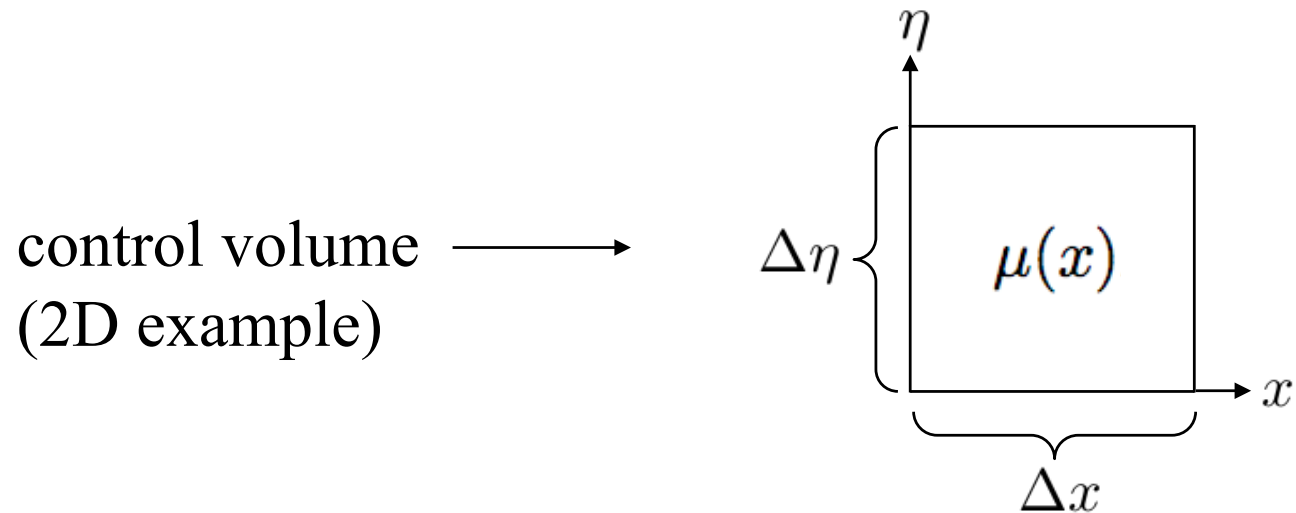
<i>Time Integration Scheme</i>	<i>Advection Scheme</i>				
	<i>2<sup>nd</sup></i>	<i>3<sup>rd</sup></i>	<i>4<sup>th</sup></i>	<i>5<sup>th</sup></i>	<i>6<sup>th</sup></i>
Leapfrog ( $\gamma=0.1$ )	0.91	U	0.66	U	0.57
RK2	U	0.90	U	0.39	U
RK3	1.73	1.63	1.26	1.43	1.09

U = unstable

(Wicker & Skamarock, 2002)



# Mass Conservation in the ARW Model



Mass in a control volume is proportional to

$$(\Delta x \Delta \eta)(\mu)^t$$

since  $\mu(x)\Delta\eta = \Delta\pi = -g\rho\Delta z$

# Mass Conservation in the ARW Model

Mass in a control volume  $(\Delta x \Delta \eta)(\mu)^t$   
2D example

Mass conservation equation

$$\Delta t^{-1}(\Delta x \Delta \eta) \cdot [(\mu)^{t+\Delta t} - (\mu)^t] = [(\mu u \Delta \eta)_{x-\Delta x/2, \eta} - (\mu u \Delta \eta)_{x+\Delta x/2, \eta}] + [(\mu \omega \Delta x)_{x, \eta-\Delta \eta/2} - (\mu \omega \Delta x)_{x, \eta+\Delta \eta/2}]$$

Change in mass over a time step

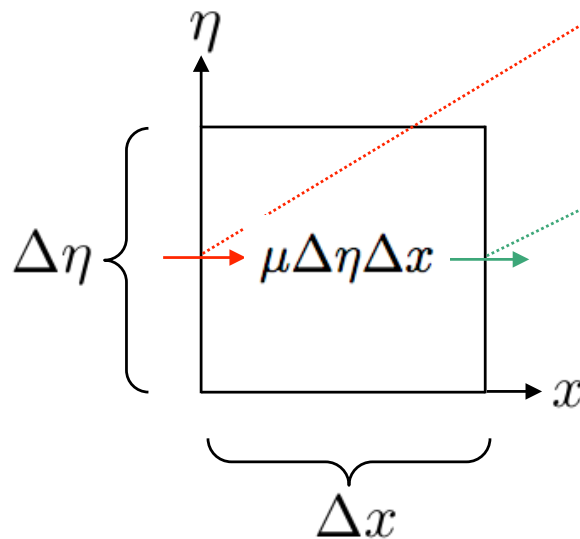
mass fluxes through  
control volume faces

# Mass Conservation in the ARW Model

Mass in a control volume  $(\Delta x \Delta \eta)(\mu)^t$

Mass conservation equation

$$\Delta t^{-1}(\Delta x \Delta \eta) \cdot [(\mu)^{t+\Delta t} - (\mu)^t] = \left[ (\mu u \Delta \eta)_{x-\Delta x/2, \eta} - (\mu u \Delta \eta)_{x+\Delta x/2, \eta} \right] + \left[ (\mu \omega \Delta x)_{x, \eta-\Delta \eta/2} - (\mu \omega \Delta x)_{x, \eta+\Delta \eta/2} \right]$$



Horizontal fluxes through the vertical control-volume faces

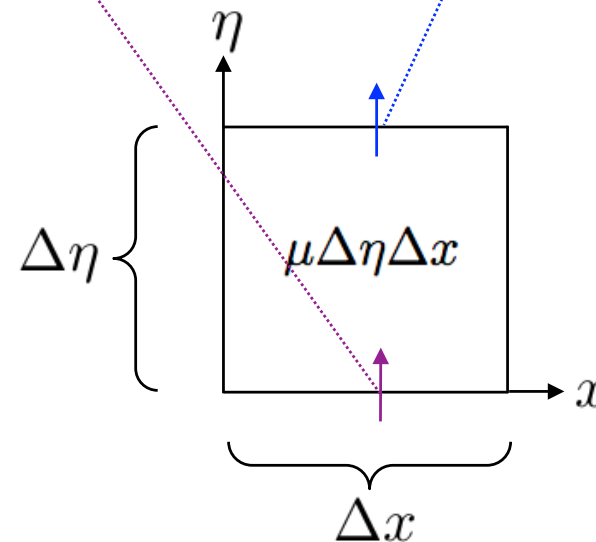
# Mass Conservation in the ARW Model

Mass in a control volume  $(\Delta x \Delta \eta)(\mu)^t$

Mass conservation equation

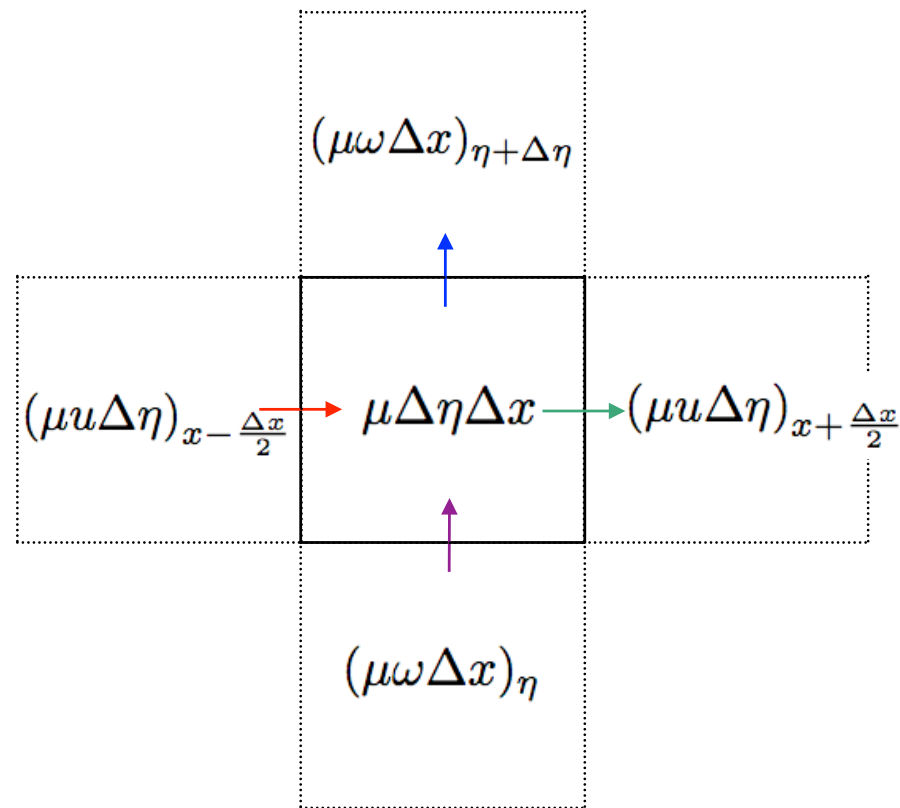
$$\Delta t^{-1}(\Delta x \Delta \eta) \cdot [(\mu)^{t+\Delta t} - (\mu)^t] = [(\mu u \Delta \eta)_{x-\Delta x/2,\eta} - (\mu u \Delta \eta)_{x+\Delta x/2,\eta}] + [(\mu \omega \Delta x)_{x,\eta-\Delta \eta/2} - (\mu \omega \Delta x)_{x,\eta+\Delta \eta/2}]$$

Vertical fluxes through the horizontal control-volume faces



# Mass Conservation in the ARW Model

The same mass fluxes are used for neighboring grid cells - hence mass is conserved locally and globally.



# Scalar Mass Conservation in the ARW Model

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Mass in a control volume	$(\Delta x \Delta \eta)(\mu)^t$
Scalar mass	$(\Delta x \Delta \eta)(\mu \phi)^t$

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Mass conservation equation:

$$\Delta t^{-1}(\Delta x \Delta \eta) \cdot [(\mu)^{t+\Delta t} - (\mu)^t] = [(\mu u \Delta \eta)_{x-\Delta x/2,\eta} - (\mu u \Delta \eta)_{x+\Delta x/2,\eta}] + [(\mu \omega \Delta x)_{x,\eta-\Delta \eta/2} - (\mu \omega \Delta x)_{x,\eta+\Delta \eta/2}]$$

↑
change in mass over a time step
mass fluxes through control volume faces

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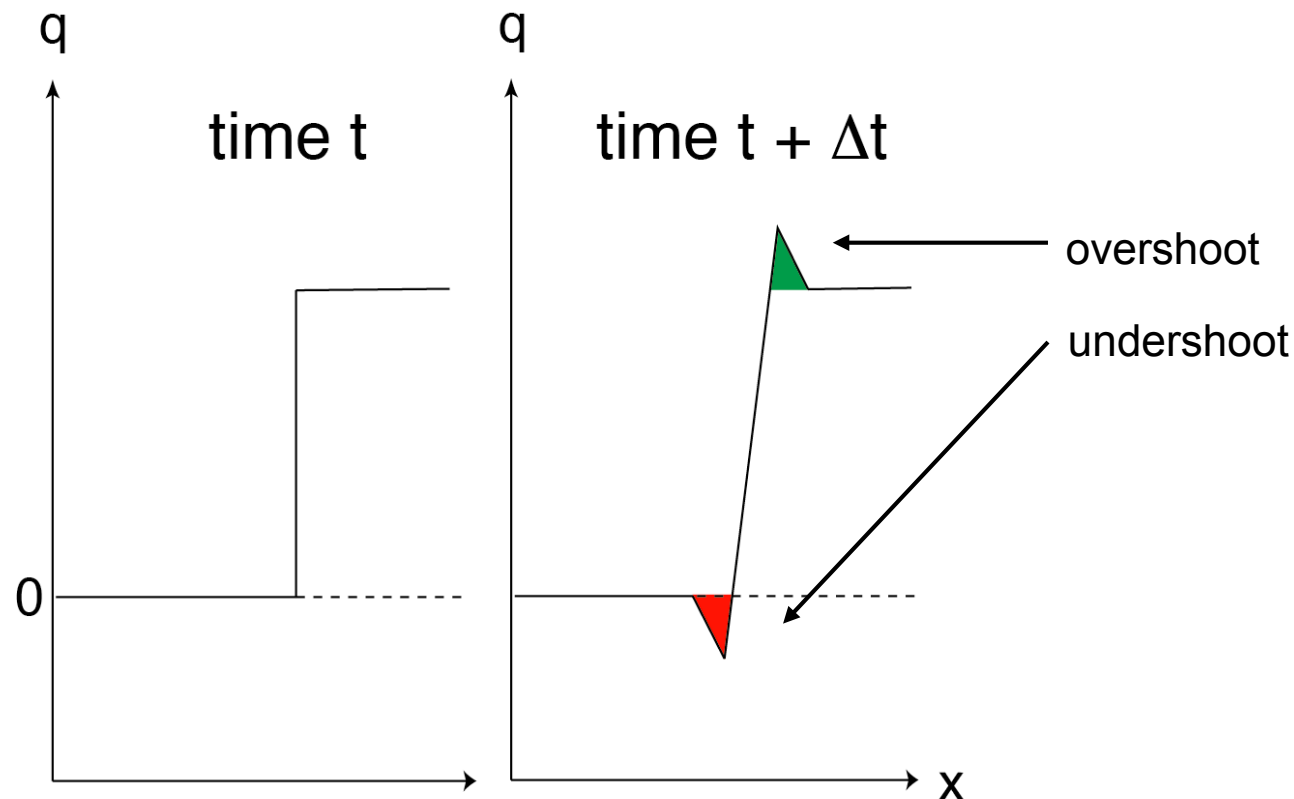
Scalar mass conservation equation:

$$\Delta t^{-1}(\Delta x \Delta \eta) \cdot [(\mu \phi)^{t+\Delta t} - (\mu \phi)^t] = [(\mu u \phi \Delta \eta)_{x-\Delta x/2,\eta} - (\mu u \phi \Delta \eta)_{x+\Delta x/2,\eta}] + [(\mu \omega \phi \Delta x)_{x,\eta-\Delta \eta/2} - (\mu \omega \phi \Delta x)_{x,\eta+\Delta \eta/2}]$$

↑
change in tracer mass over a time step
tracer mass fluxes through control volume faces

# Moisture Transport in ARW

## 1D advection



ARW scheme is conservative,  
but not positive definite nor monotonic.  
Removal of negative  $q$  ■  
results in spurious source of  $q$  ■ .

# Positive-Definite/Monotonic Flux Renormalization

Scalar update, last RK3 step

$$(\mu\phi)^{t+\Delta t} = (\mu\phi)^t - \Delta t \sum_{i=1}^n \delta_{x_i} [f_i] \quad (1)$$

- (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  $f_i = f_i^{upwind} + R(f_i^c)$

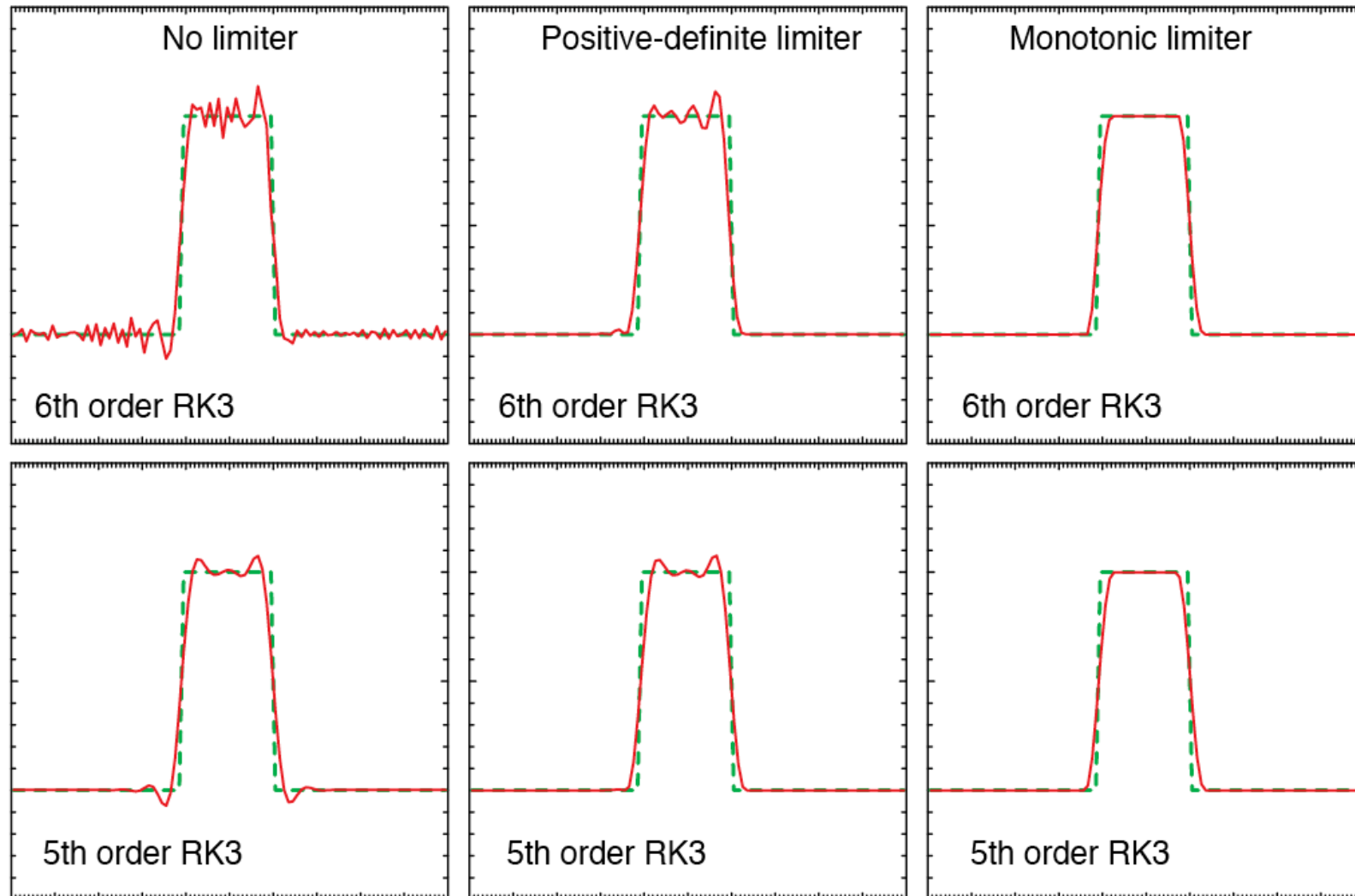
Skamarock, MWR 2006, 2241-2250



# PD/Monotonic Limiters in ARW - 1D Example

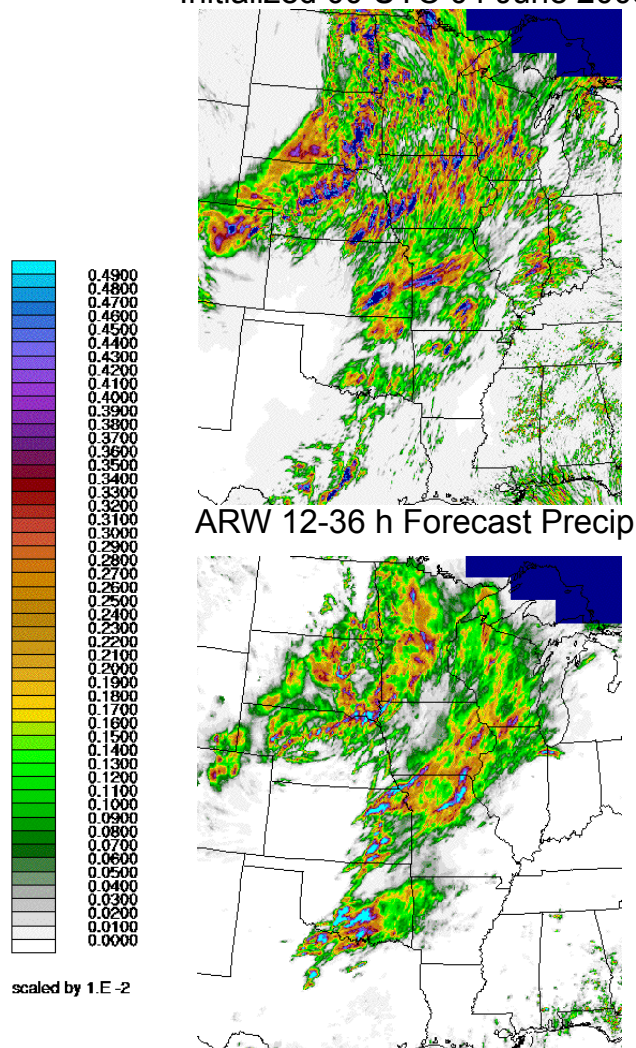
## Top-Hat Advection

1D Top-hat transport  $Cr = 0.5$ , 1 revolution, 200 steps

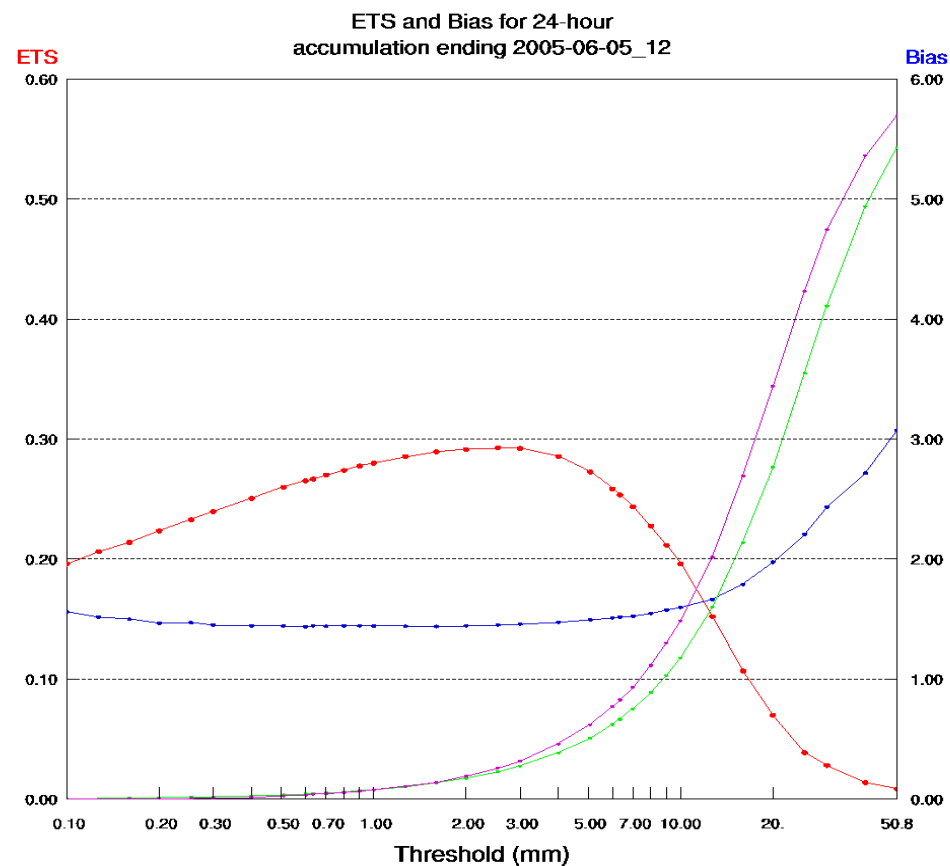


# Moisture Transport in ARW: High Precipitation Bias

Initialized 00 UTC 04 June 2005



2005 ARW 4 km Forecasts:

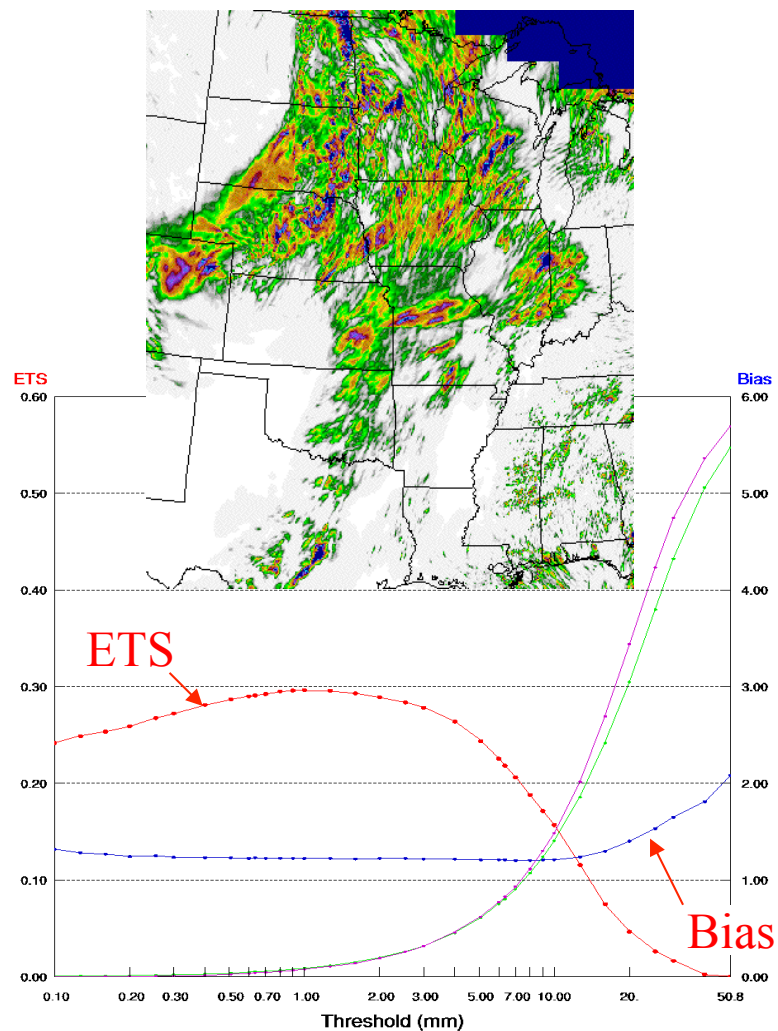
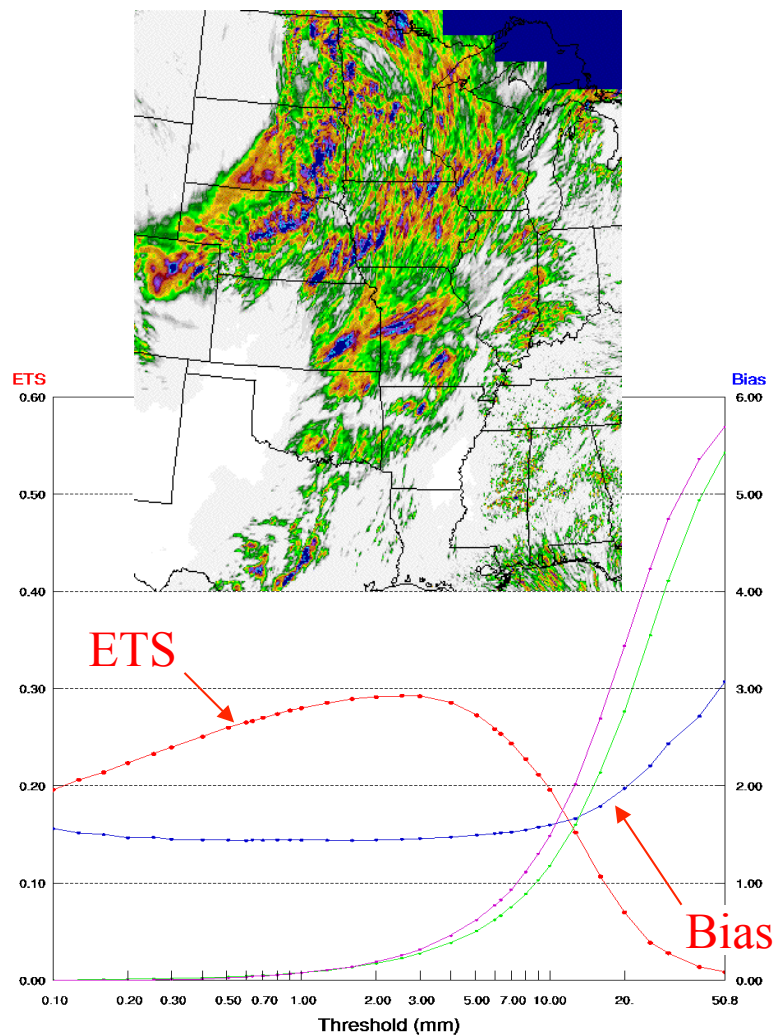


# Moisture Transport in ARW: 24 h ETS and BIAS

Initialized 00 UTC 04 June 2005

Standard advection

Positive-definite advection



# ARW Model: Dynamics Parameters

## 3<sup>rd</sup> order Runge-Kutta time step

Courant number limited, 1D:  $C_r = \frac{U\Delta t}{\Delta x} < 1.43$

Generally stable using a timestep approximately twice as large as used in a leapfrog model.

## Acoustic time step

2D horizontal Courant number limited:  $C_r = \frac{C_s \Delta \tau}{\Delta h} < \frac{1}{\sqrt{2}}$

$\Delta \tau_{sound} = \Delta t_{RK} / (\text{number of acoustic steps})$

## Guidelines for time step

$\Delta t$  in seconds should be about  $6 * \Delta x$  (grid size in kilometers). Larger  $\Delta t$  can be used in smaller-scale dry situations, but *time\_step\_sound* (default = 4) should increase proportionately if larger  $\Delta t$  is used.

# ARW Filters: Divergence Damping

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

$$\left\{ \frac{\partial \rho \mathbf{V}}{\partial t} + \nabla p + \dots = \gamma'_d \nabla D \right\}$$

$$\nabla \cdot \left\{ \right\} \rightarrow \frac{\partial D}{\partial t} + \nabla^2 p + \dots = \gamma'_d \nabla^2 D$$

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

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

$\gamma_d = 0.1$  recommended (default)

(Illustrated in height coordinates for simplicity)

# ARW Filters: Vertically Implicit Off-Centered Acoustic Step

*Purpose: damp vertically-propagating acoustic modes*

$$\frac{\partial W}{\partial t} + g \overline{\left( \mu_d - \frac{\alpha}{\alpha_d} \frac{\partial p}{\partial \eta} \right)}^\tau = \dots$$

$$\frac{\partial \phi}{\partial t} - \frac{g}{\mu_d^t} \overline{W}^\tau = \dots$$

$$\overline{(\quad)}^\tau = \frac{1 + \beta}{2} \overline{(\quad)}^{\tau + \Delta\tau} + \frac{1 - \beta}{2} \overline{(\quad)}^\tau$$

Slightly forward centering the vertical pressure gradient damps 3-D divergence as demonstrated for the divergence damper

$\beta = 0.1$  recommended (default)

# ARW Filters: External Mode Filter

*Purpose: filter the external mode*

Vertically integrated horizontal divergence,  $D_h = \int_1^0 (\nabla_\eta \cdot \mu \mathbf{V}_h) d\eta$

$$\left\{ \frac{\partial \mu \mathbf{V}_h}{\partial t} + \dots = -\gamma_e \nabla_\eta D_h \right\}$$

$$\int_1^0 \nabla_\eta \cdot \left\{ \right\} d\eta \rightarrow \frac{\partial D_h}{\partial t} + \dots = \gamma_e \nabla^2 D_h$$

Continuity equation:  $\frac{\partial \mu}{\partial t} = -\nabla_\eta \cdot \mu \mathbf{V}_h - \frac{\partial \mu \dot{\eta}}{\partial \eta} = D_h$

$$\frac{\partial \mu \mathbf{V}_h}{\partial \tau} + \dots = -\gamma_e \frac{\Delta x^2}{\Delta \tau^2} \nabla_\eta (\mu^\tau - \mu^{\tau - \Delta \tau})$$

$\gamma_e = 0.01$  recommended (default)

(Primarily for real-data applications)



# ARW Filters: Vertical Velocity Damping

Purpose: damp anomalously-large vertical velocities  
(usually associated with anomalous physics tendencies)

Additional term:

$$\partial_t W = \dots - \mu_d \operatorname{sign}(W) \gamma_w (Cr - Cr_\beta)$$

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$$Cr = \left| \frac{\Omega dt}{\mu d\eta} \right|$$

$Cr_\beta = 1.0$  typical value (default)

$\gamma_w = 0.3 \text{ m/s}^2$  recommended (default)



# ARW Filters: 2nd-Order Horizontal Mixing, Horizontal-Deformation-Based $K_h$

Purpose: mixing on horizontal coordinate surfaces  
(real-data applications)

$$K_h = C_s^2 l^2 \left[ 0.25(D_{11} - D_{22})^2 + \overline{D_{12}^2}^{xy} \right]^{\frac{1}{2}}$$

where  $l = (\Delta x \Delta y)^{1/2}$

$$D_{11} = 2 m^2 [\partial_x(m^{-1}u) - z_x \partial_z(m^{-1}u)]$$

$$D_{22} = 2 m^2 [\partial_y(m^{-1}v) - z_y \partial_z(m^{-1}v)]$$

$$D_{12} = m^2 [\partial_y(m^{-1}u) - z_y \partial_z(m^{-1}u) \\ + \partial_x(m^{-1}v) - z_x \partial_z(m^{-1}v)]$$

$C_s = 0.25$  (Smagorinsky coefficient, default value)

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

*Modification to small time step:*

- Step horizontal momentum, continuity, and potential temperature equations to new time level:

$$\begin{matrix} U^{\tau+\Delta\tau} & \mu^{\tau+\Delta\tau} \\ \Omega^{\tau+\Delta\tau} & \Theta^{\tau+\Delta\tau} \end{matrix}$$

- Step vertical momentum and geopotential equations (implicit in the vertical):

$$W^{*\tau+\Delta\tau} \quad \phi^{*\tau+\Delta\tau}$$

- Apply implicit Rayleigh damping on  $W$  as an adjustment step:

$$W^{\tau+\Delta\tau} = W^{*\tau+\Delta\tau} - \Delta\tau R_w(\eta) W^{\tau+\Delta\tau}$$

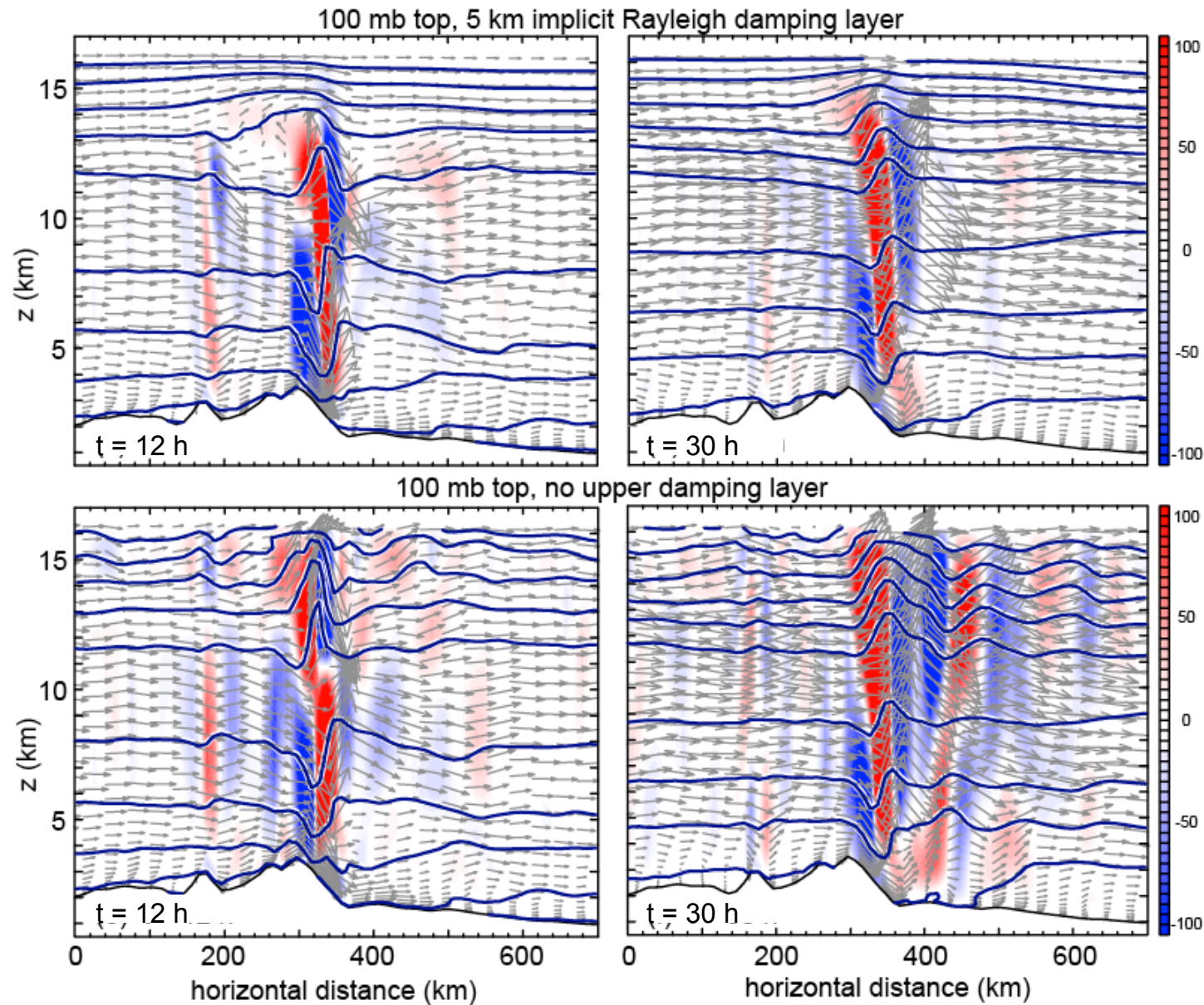
- Update final value of geopotential at new time level:

$$\phi^{\tau+\Delta\tau}$$

$$R_w(\eta) = \begin{cases} \gamma_r \sin^2 \left[ \frac{\pi}{2} \left( 1 - \frac{z_{top}-z}{z_d} \right) \right] & \text{for } z \geq (z_{top} - z_d); \\ 0 & \text{otherwise,} \end{cases} \quad \begin{matrix} R_w(\eta) \text{- damping rate (t}^{-1}\text{)} \\ z_d \text{- depth of the damping layer} \\ \gamma_r \text{- damping coefficient} \end{matrix}$$

# WRF Forecast over Colorado Front Range

Model Initialized 04 Dec 2007 00 UTC



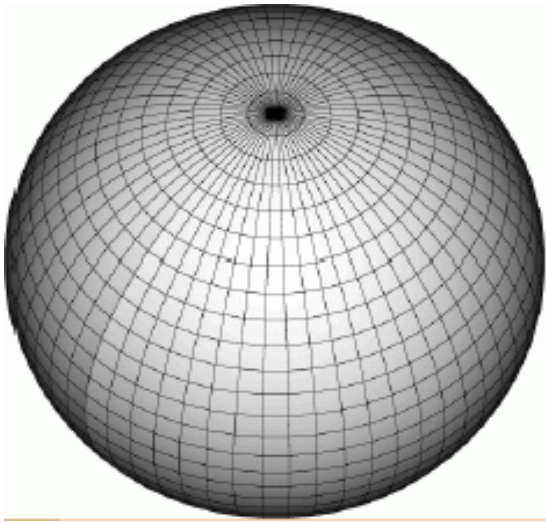
# ARW Model: Coordinate Options

1. Cartesian geometry:  
idealized cases
2. Lambert Conformal:  
mid-latitude applications
3. Polar Stereographic:  
high-latitude applications
4. Mercator:  
low-latitude applications
5. Latitude-Longitude (new in ARW V3)  
global  
regional

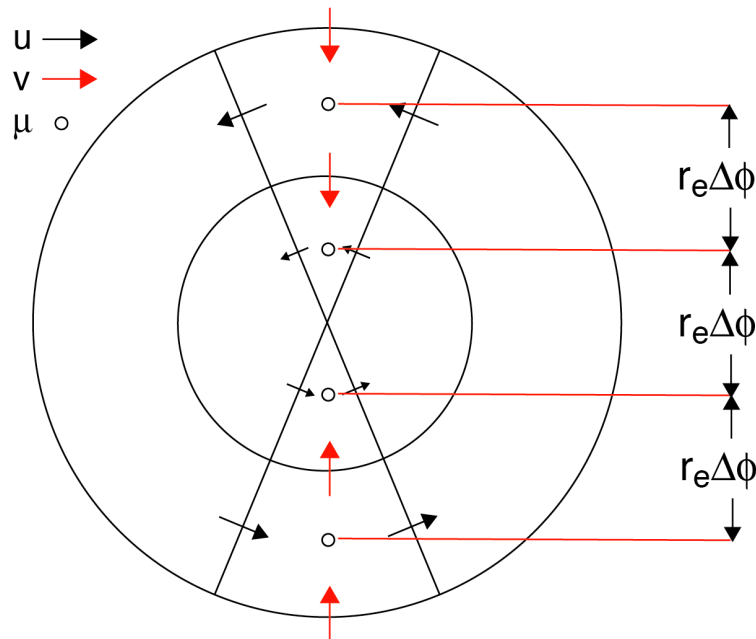
Projections 1-4 are isotropic ( $m_x = m_y$ )

Latitude-Longitude projection is anisotropic ( $m_x \neq m_y$ )

# Global ARW - Latitude-Longitude Grid



- Map factors -  $m_x$  and  $m_y$ 
  - Computational grid poles need not be geographic poles.
  - Limited area and nesting capable.
- Polar boundary conditions
- Polar filtering

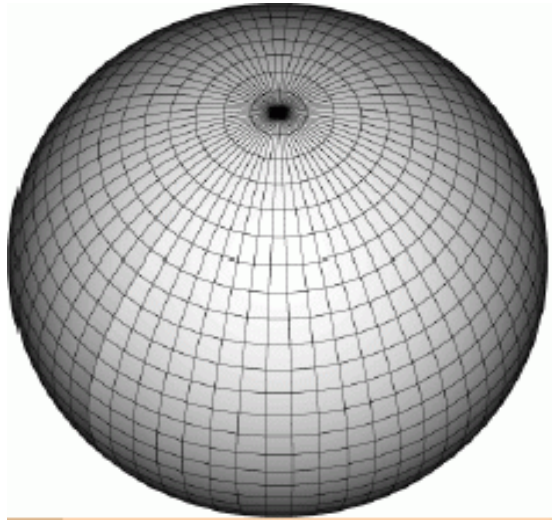


Zero meridional flux at the poles (cell-face area is zero).

$v$  (poles) only needed for meridional derivative of  $v$  near the poles (we interpolate).

All other meridional derivatives are well-defined near/at poles.

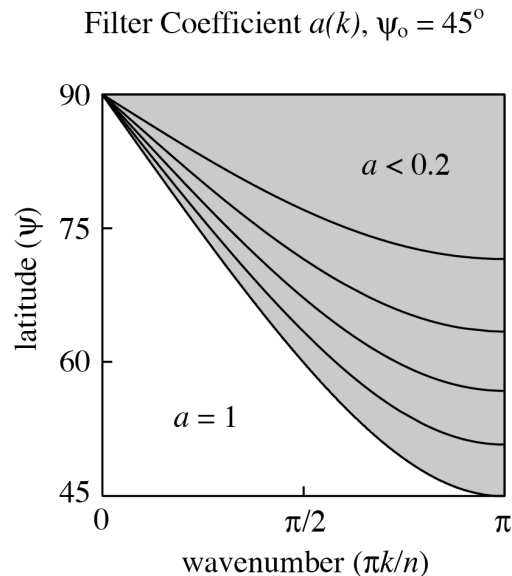
# ARW Filters: Polar Filter



Converging gridlines severely limit timestep.  
The polar filter removes this limitation.

Filter procedure - Along a grid latitude circle:

1. Fourier transform variable.
2. Filter Fourier coefficients.
3. Transform back to physical space.



$$\hat{\phi}(k)_{filtered} = a(k) \hat{\phi}(k), \quad \text{for all } k$$

$$a(k) = \min \left[ 1., \max \left( 0., \left( \frac{\cos \psi}{\cos \psi_o} \right)^2 \frac{1}{\sin^2(\pi k/n)} \right) \right]$$

$k$  = dimensionless wavenumber

$\hat{\phi}(k)$  = Fourier coefficients from forward transform

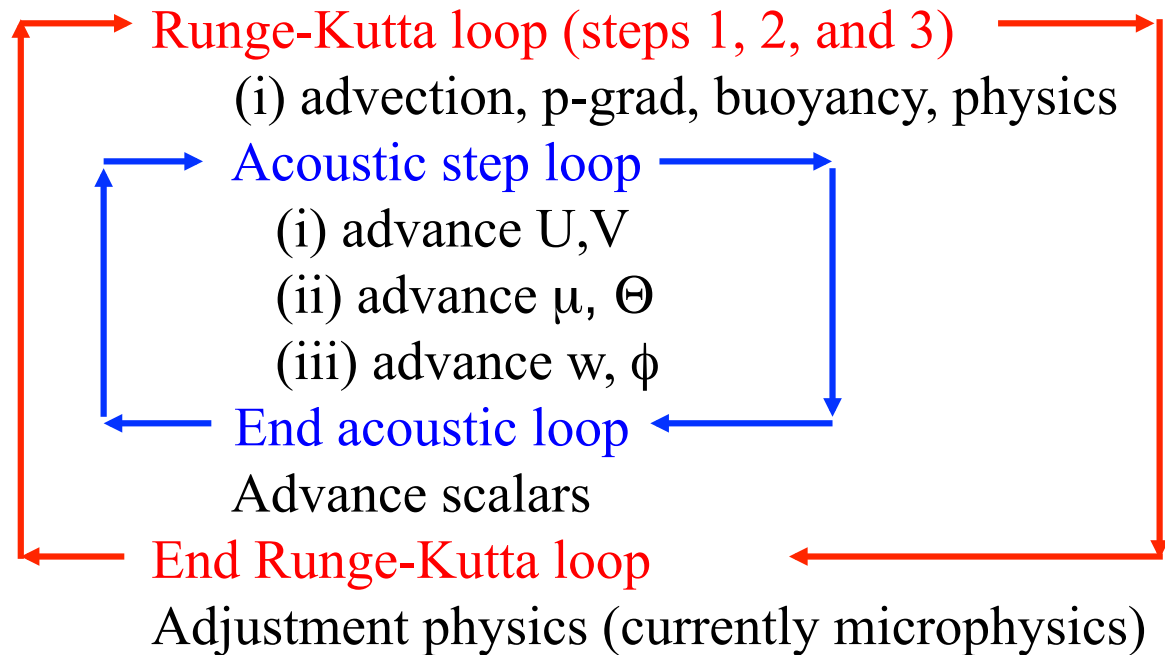
$a(k)$  = filter coefficients

$\psi$  = latitude  $\psi_o$  = polar filter latitude, filter when  $|\psi| > \psi_o$



# WRF ARW Model Integration Procedure

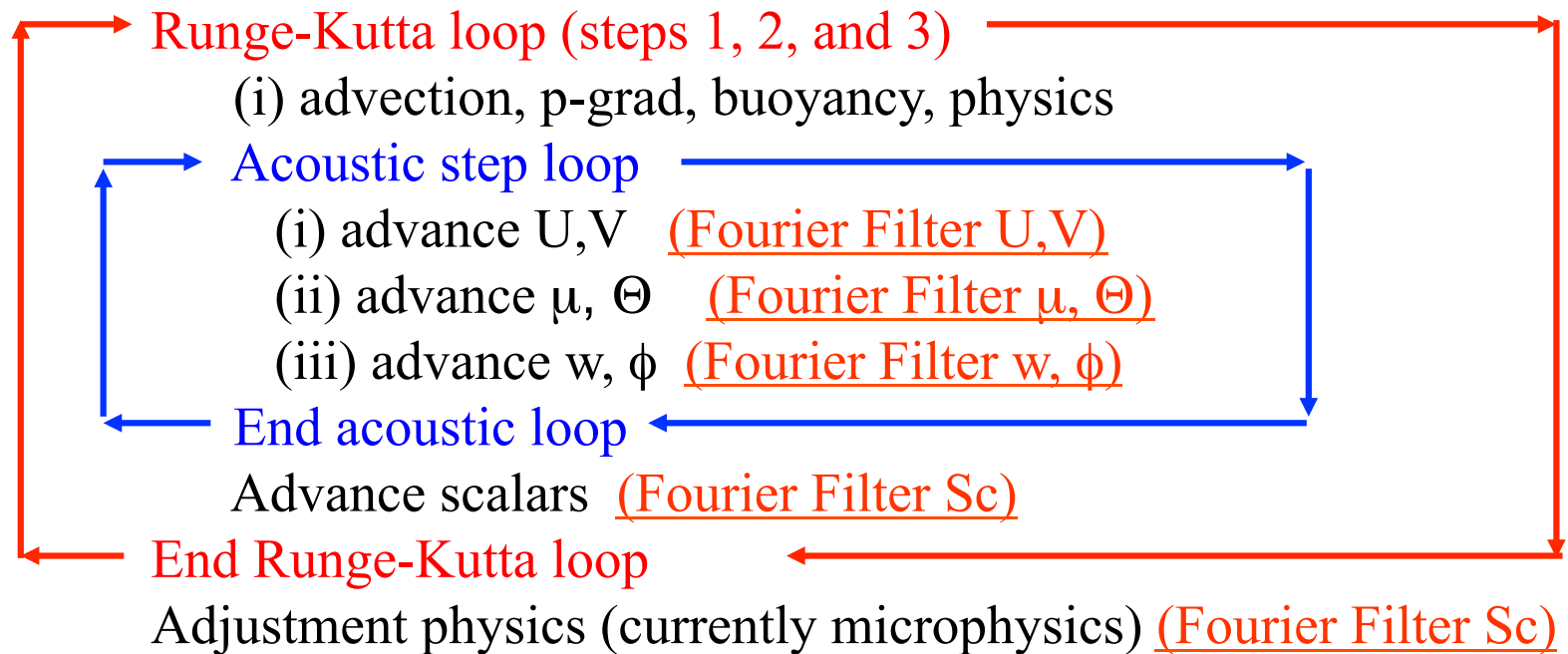
Begin time step



End time step

# WRF ARW Model Integration Procedure

Begin time step



End time step

Timestep limited by minimum  $\Delta x$  outside of polar-filter region.  
Monotonic and PD transport is not available for global model.



# ARW Model: Boundary Condition Options

## Lateral boundary conditions

1. Specified (Coarse grid, real-data applications).
2. Open lateral boundaries (gravity-wave radiative).
3. Symmetric lateral boundary condition (free-slip wall).
4. Periodic lateral boundary conditions.
5. Nested boundary conditions (specified).

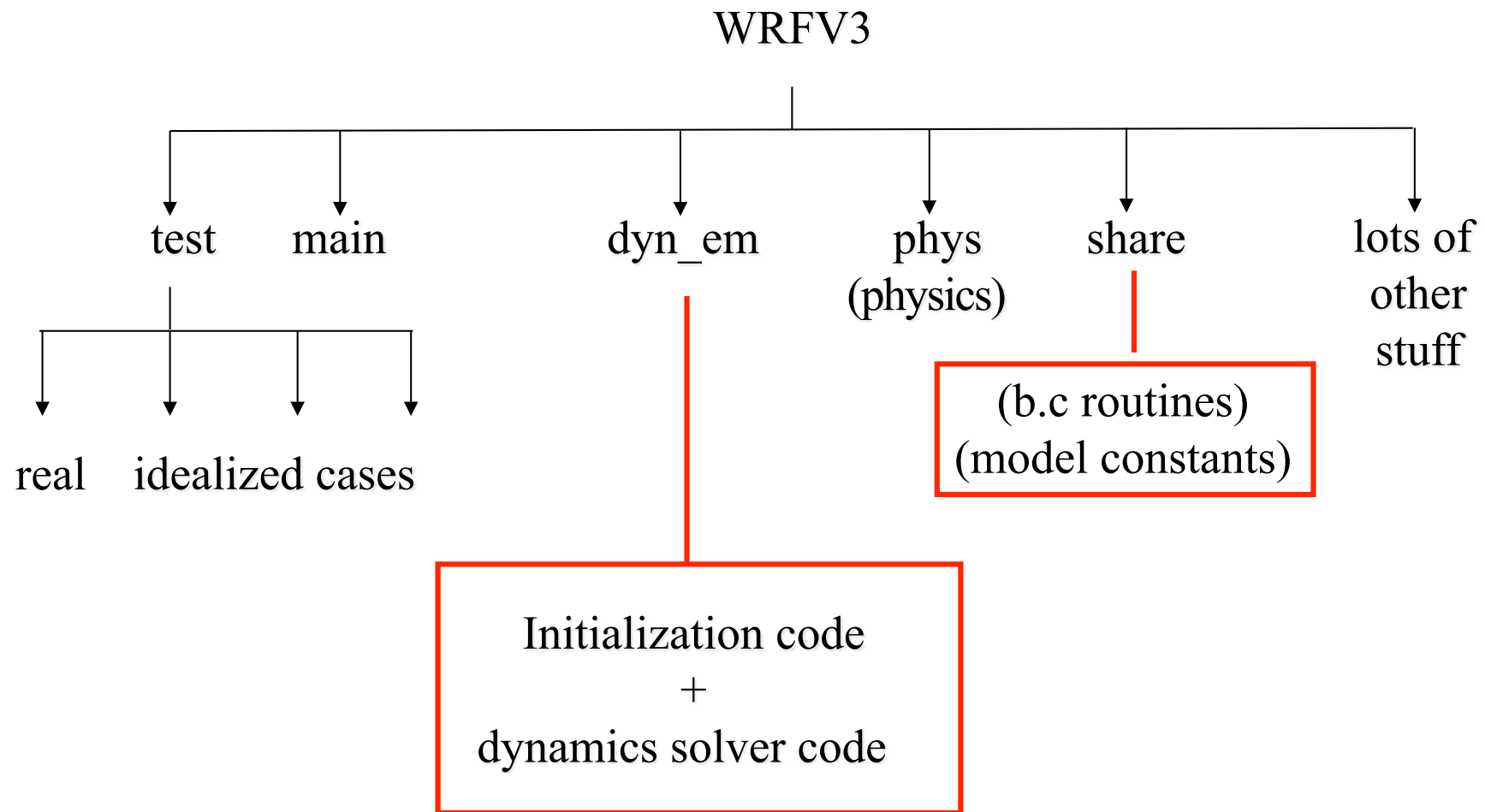
## Top boundary conditions

1. Constant pressure.

## Bottom boundary conditions

1. Free slip.
2. Various B.L. implementations of surface drag, fluxes.

# WRF ARW code



## WRF ARW Tech Note

A Description of the Advanced Research WRF Version 3 (June 2008, 2012 update)

<http://www.mmm.ucar.edu/wrf/users/pub-doc.html>