Idealized Nonhydrostatic Supercell Simulations in the Global MPAS

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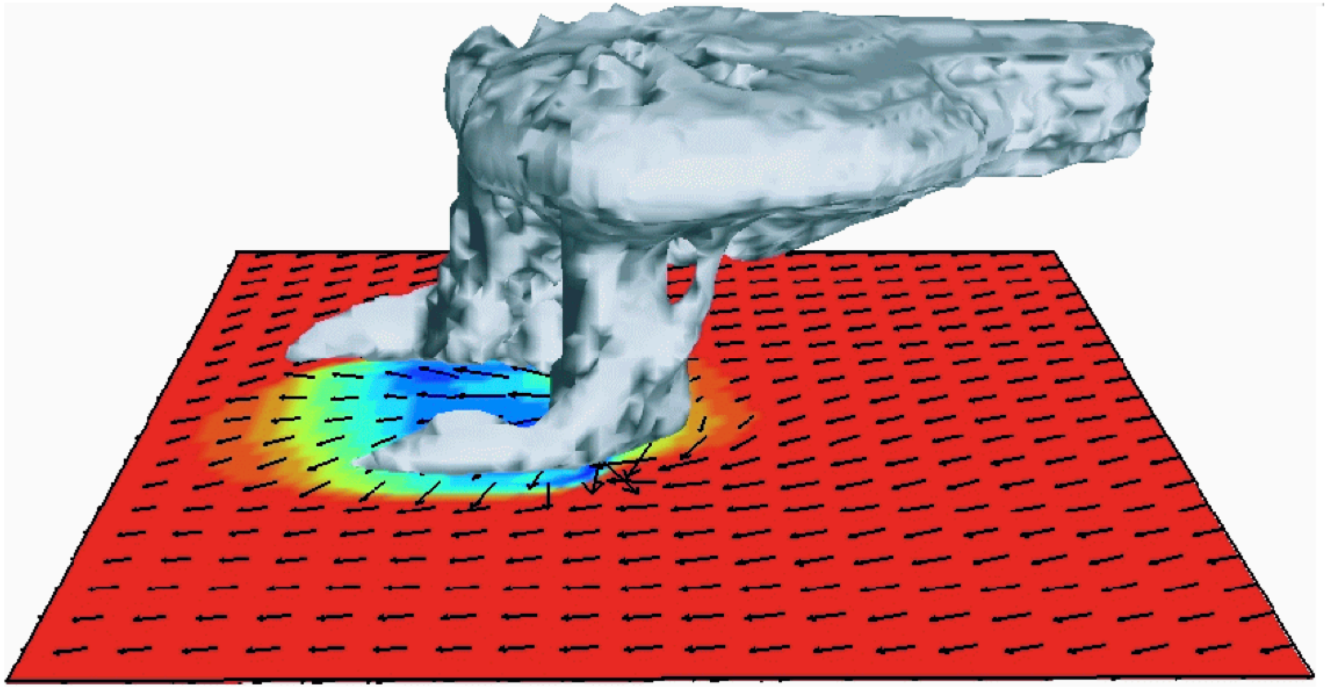
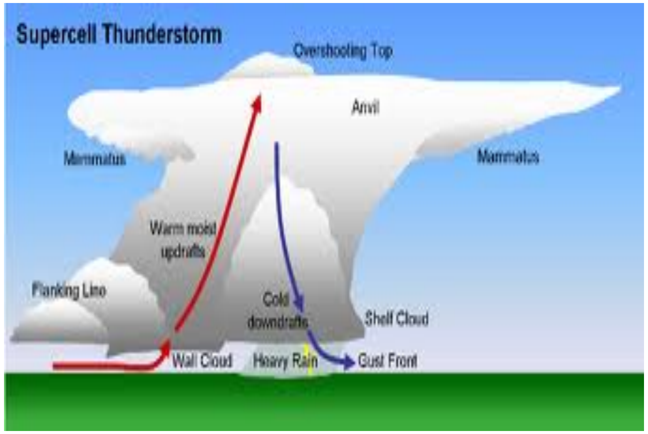


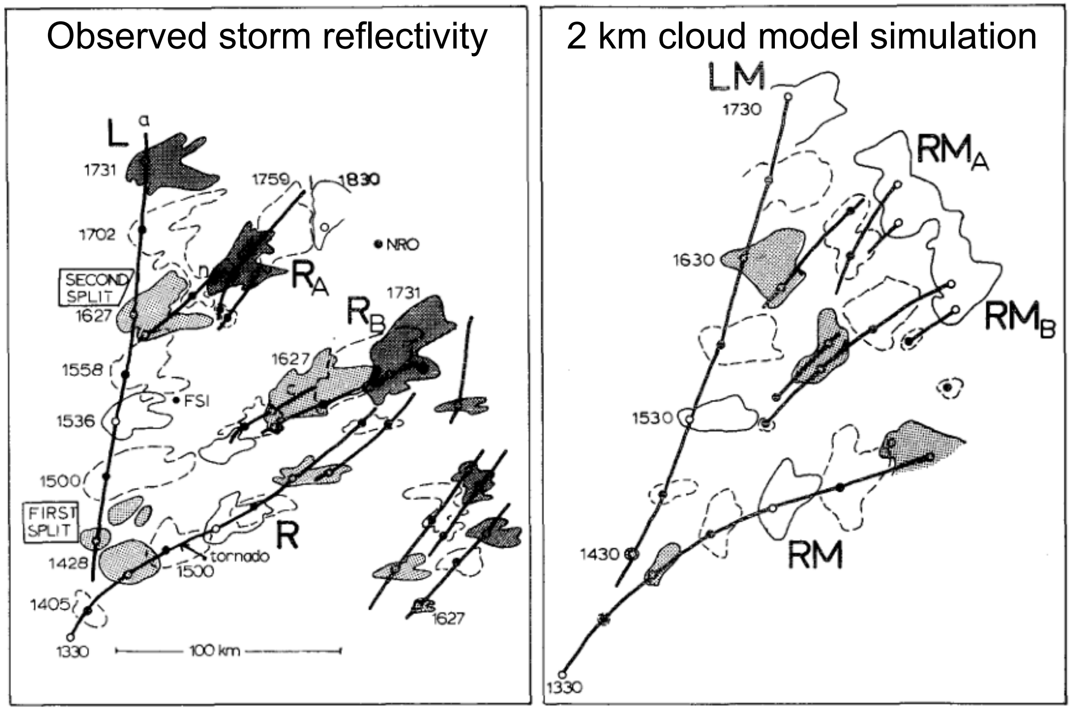
Supercell Thunderstorms

Typical characteristics:

- Strong, long-lived convective cells
- Deep, persistent rotating updrafts
- May propagate tranverse to the mean winds
- May split into two counter-rotating storms
- Produce most of the world’s intense tornadoes



3 April 1964 Oklahoma Splitting Supercell Storms

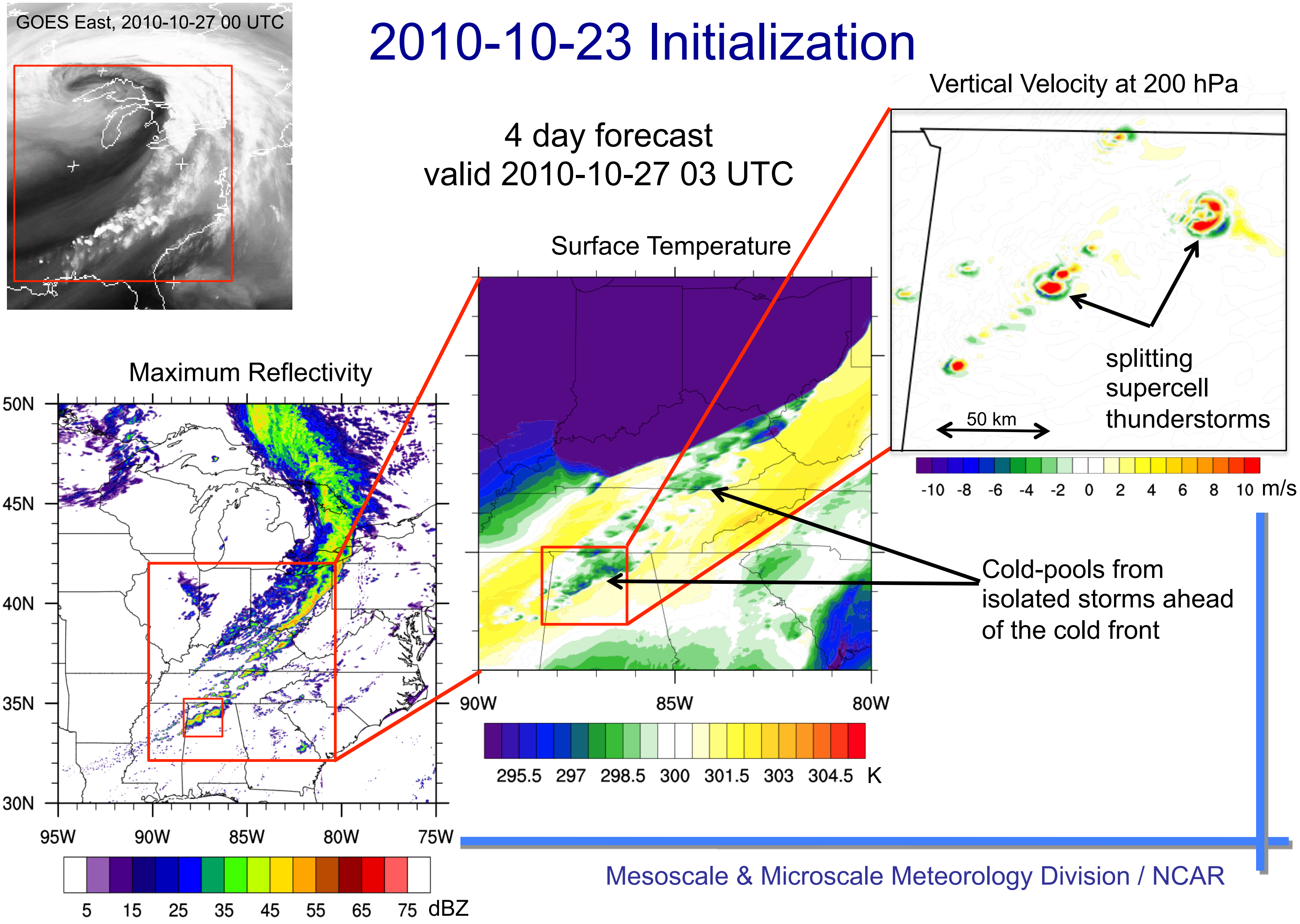

Observed storm reflectivity

2 km cloud model simulation

Wilhelmson & Klemp (JAS, 1982)

3 km Global MPAS-A Simulation
2010-10-23 Initialization

4 day forecast
valid 2010-10-27 03 UTC



splitting supercell thunderstorms

Cold-pools from isolated storms ahead of the cold front

Simulations on a Reduced-Radius Earth Sphere

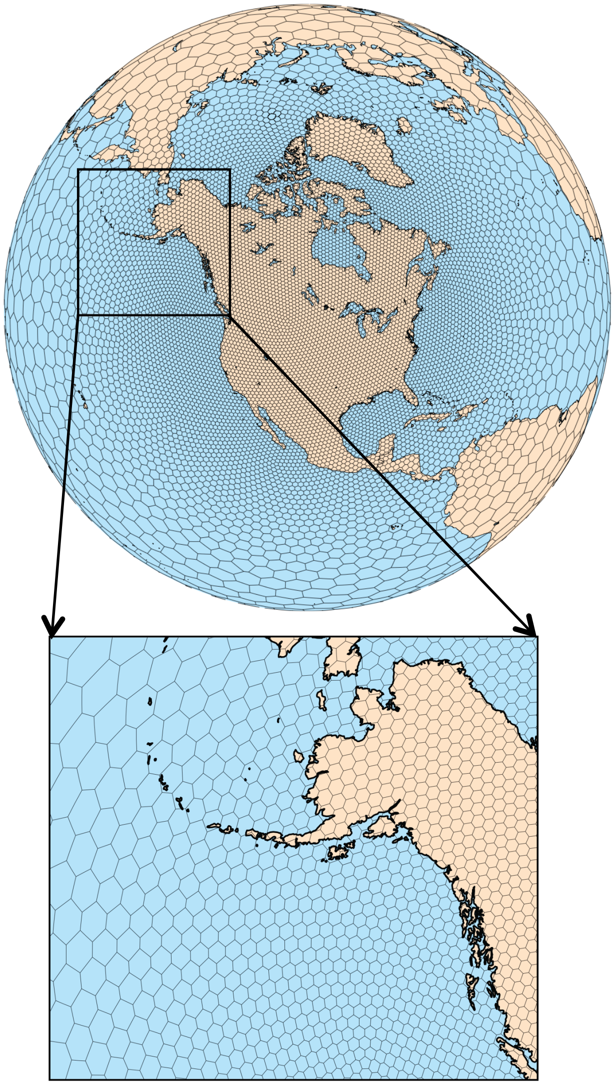
Observations:

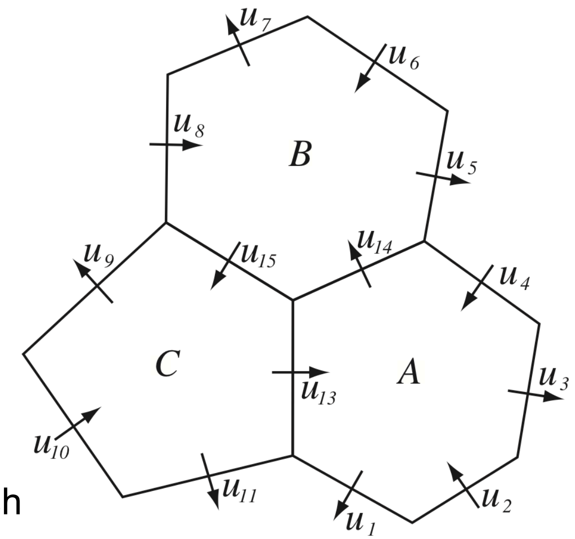
- Global grids required to resolve nonhydrostatic phenomena are often beyond the realm of feasibility (and not cost effective).
- Simulations on a reduced-radius sphere permit nonhydrostatic resolutions at reasonable computational cost.
- Phenomena on a reduced-radius earth sphere may have little physical relevance to the real atmosphere.

Our philosophy:

- Idealized small-planet simulations should exhibit strong similarity to physically relevant geophysical flows
- For nonhydrostatic phenomena ⇨ good correspondence with flow in a Cartesian geometry

MPAS - Atmosphere





Equations

- Fully compressible nonhydrostatic equations
- Permits *explicit* simulation of clouds

Solver Technology

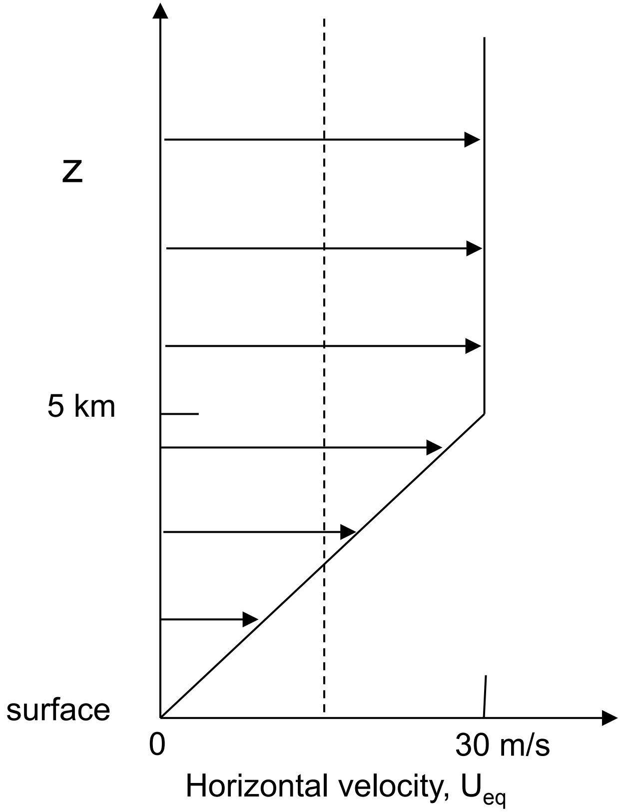
- C-grid centroidal Voronoi mesh
- Unstructured grid permits conformal variable-resolution grids
- Most of the techniques for integrating the nonhydrostatic equations come from WRF.

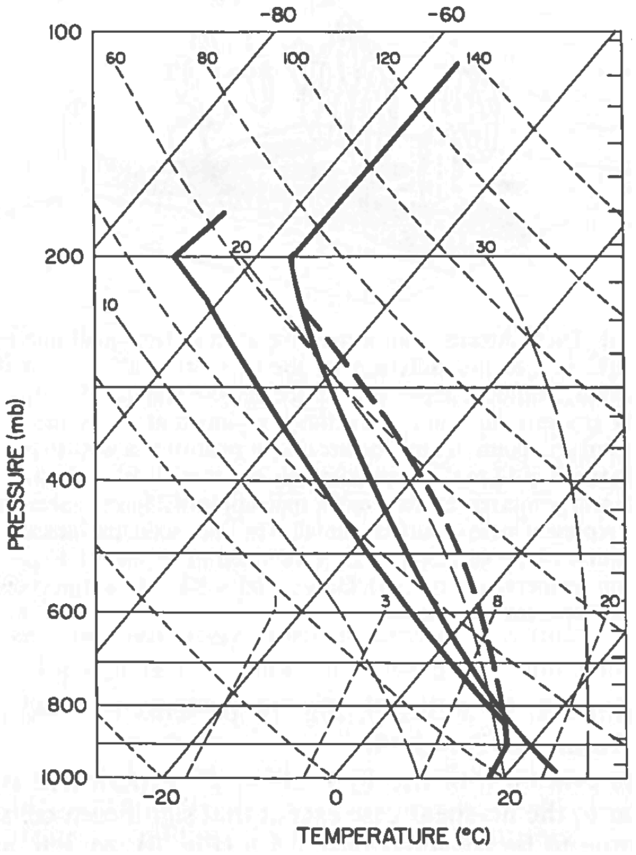
Supercell Simulation

- Initial sounding representative of supercell environment
- Convection initiated with low-level warm bubble (3^{o} K)
- Minimal model physics (simple Kessler microphysics)
- Constant 2nd order viscosity (500 m^2/s) – permits convergence
- z_t = 20 km, Δz = 500 m, No Coriolis force (f = 0)

Initial Sounding for Supercell Tests

Based on historical supercell simulations (Weisman and Klemp, 1982, 1984)





On the sphere: $U_i = U_{eq} \cos \phi$

CAPE ~ 2200 m^2/s^2

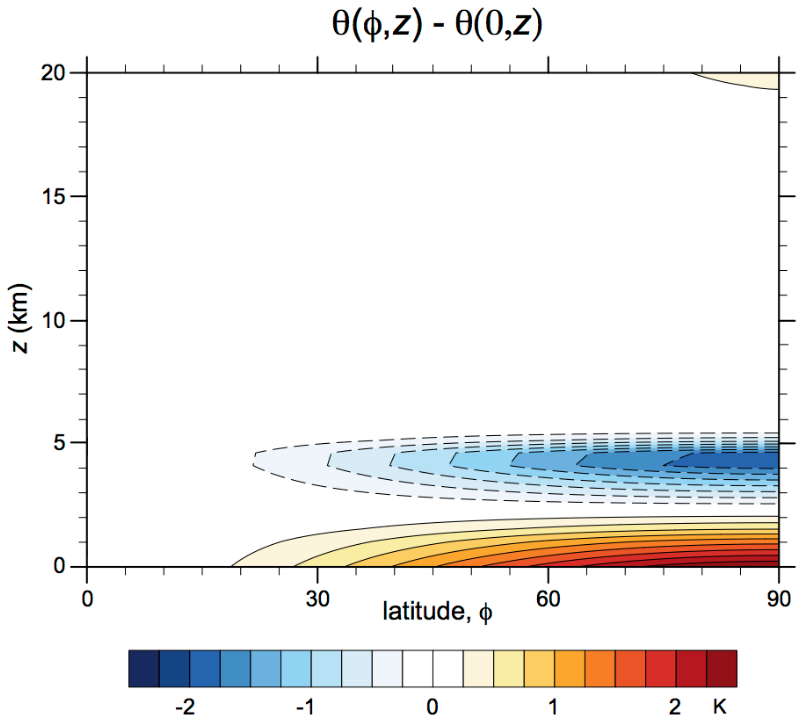
Balanced Initial Conditions on the Sphere (f = 0)

hydrostatic equation: $$\frac{\partial \pi}{\partial z} = -\frac{g}{c_p \theta_v}$$

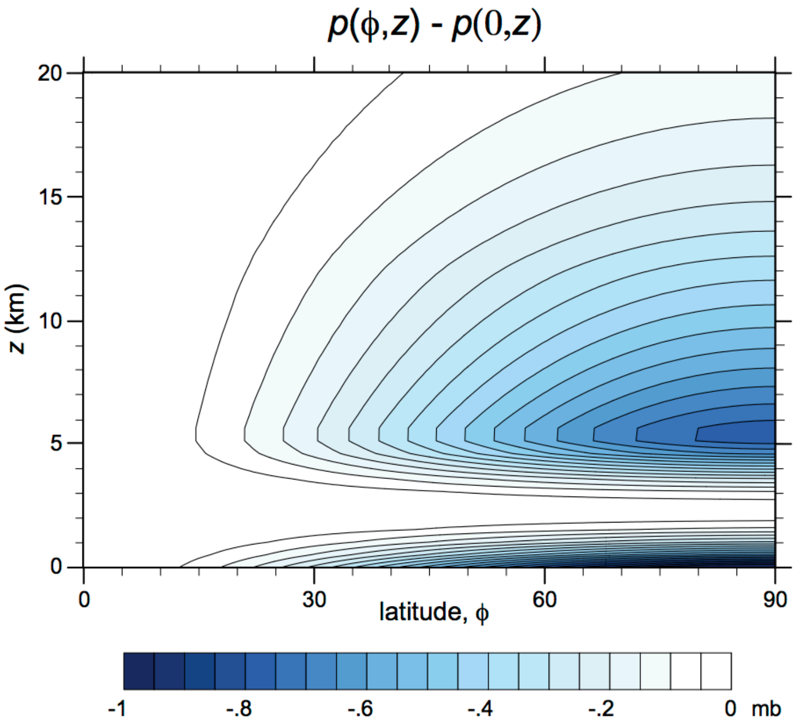
gradient wind equation: $$u^2 \tan\phi = -c_p \theta_v \frac{\partial \pi}{\partial \phi}$$

Cross differentiating and equating $\pi_{\phi z}$: $$\frac{\partial {\theta_v}^{(i+1)}}{\partial \phi} = \frac{\sin 2\phi}{2g}\left\{ U_{eq}^2 \frac{\partial {\theta_v}^{(i)}}{\partial z} - {\theta_v}^{(i)} \frac{\partial U_{eq}^2}{\partial z} \right\}$$

Converges in ~ 3 iterations



$\theta(\phi,z) - \theta(0,z)$



$p(\phi,z) - p(0,z)$

Kessler Cloud Microphysics

potential temperature

$$\frac{d\theta}{dt} = -\frac{L}{c_p \pi}\left(\frac{dq_{vs}}{dt} + E_r\right)$$

water vapor mixing ratio

$$\frac{dq_v}{dt} = \frac{dq_{vs}}{dt} + E_r$$

cloud water mixing ratio

$$\frac{dq_c}{dt} = -\frac{dq_{vs}}{dt} - A_r - C_r$$

rain water mixing ratio

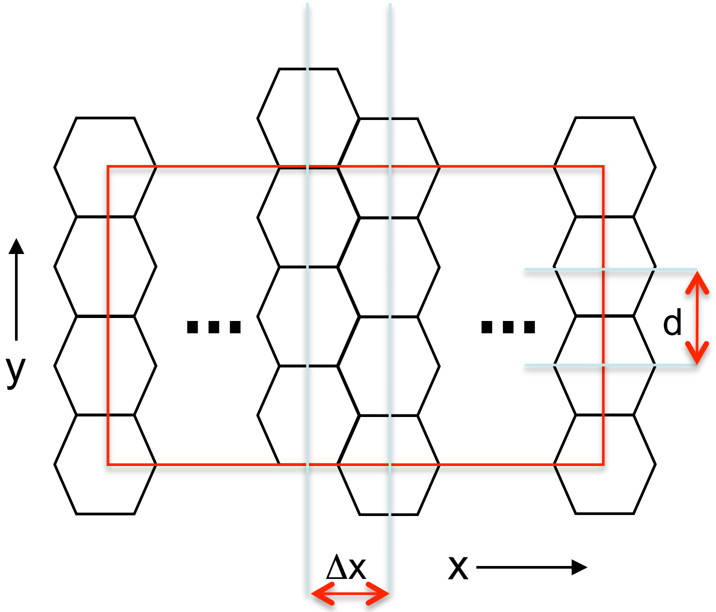
$$\frac{dq_r}{dt} = -E_r + A_r + C_r - V_r\frac{dq_r}{dz}$$

cloud evap. cond.	rain evap.	rain auto conv.	rain coll.	rain fall

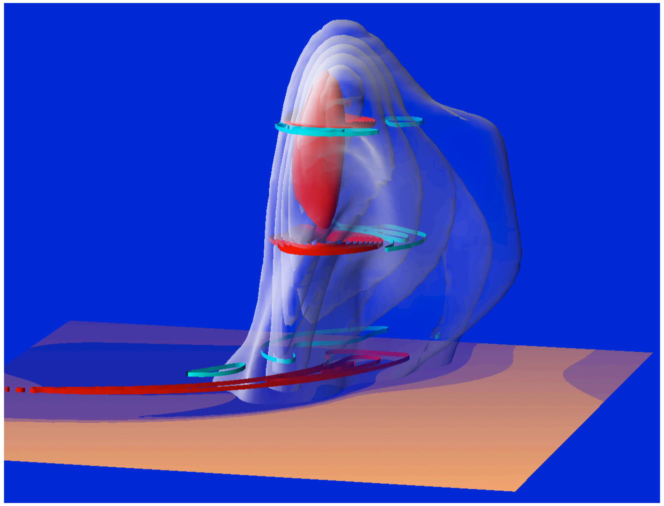
Kessler subroutine (~40 lines of code) computes increments to $\theta,\ q_v,\ q_c,\ q_r$ at the end of each time step

Supercell Simulations, MPAS & Reference Cloud Model

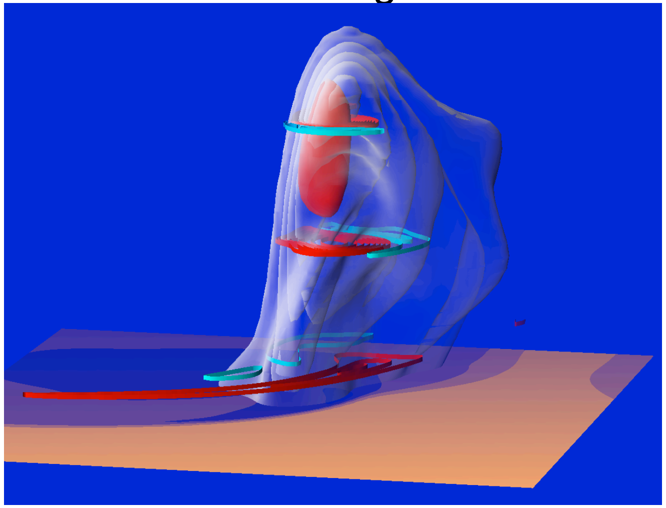
- Full MPAS model code used for idealized simulations
- Grid generated on flat plane with periodic boundaries



~500 m MPAS

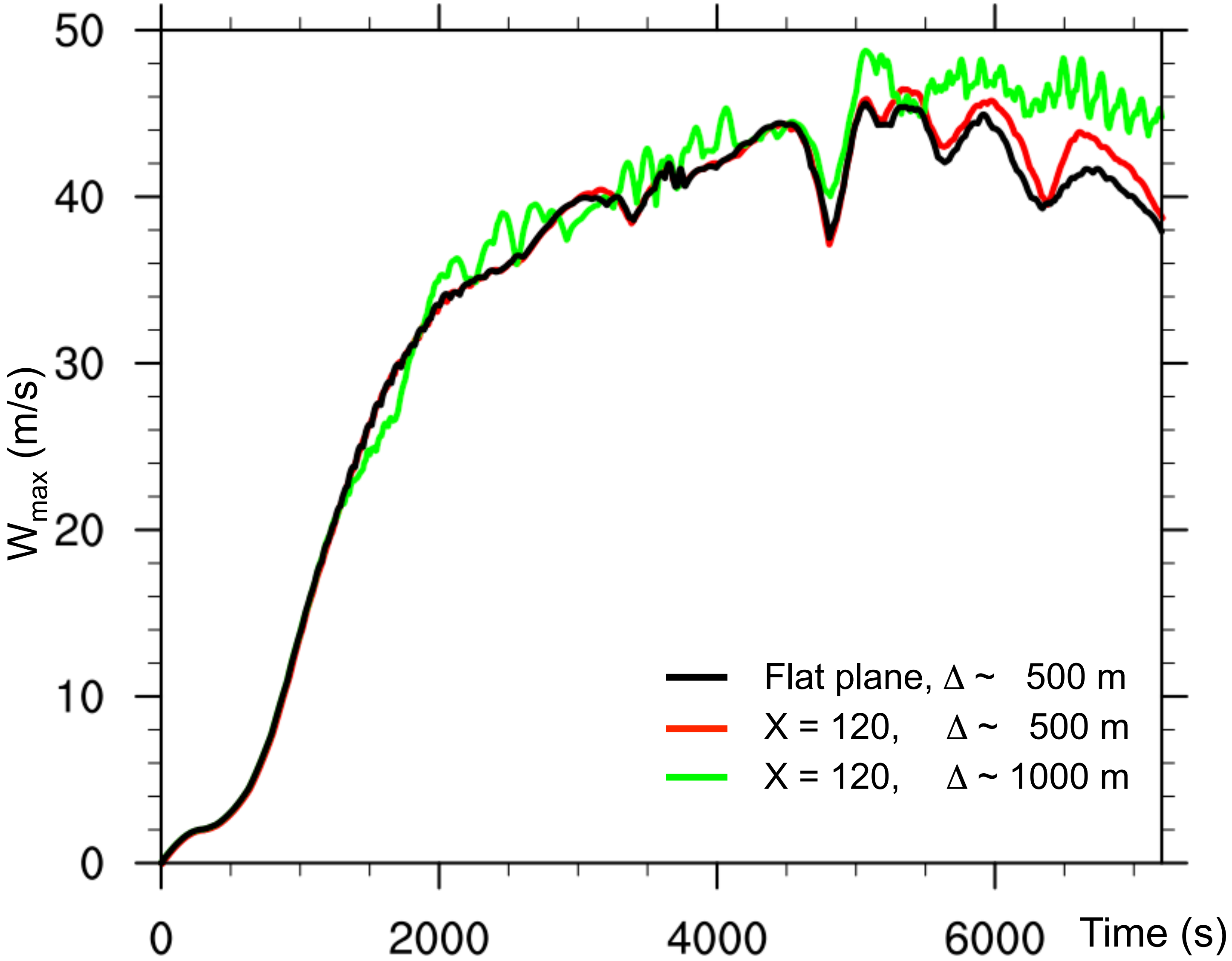


500 m Rectangular Grid

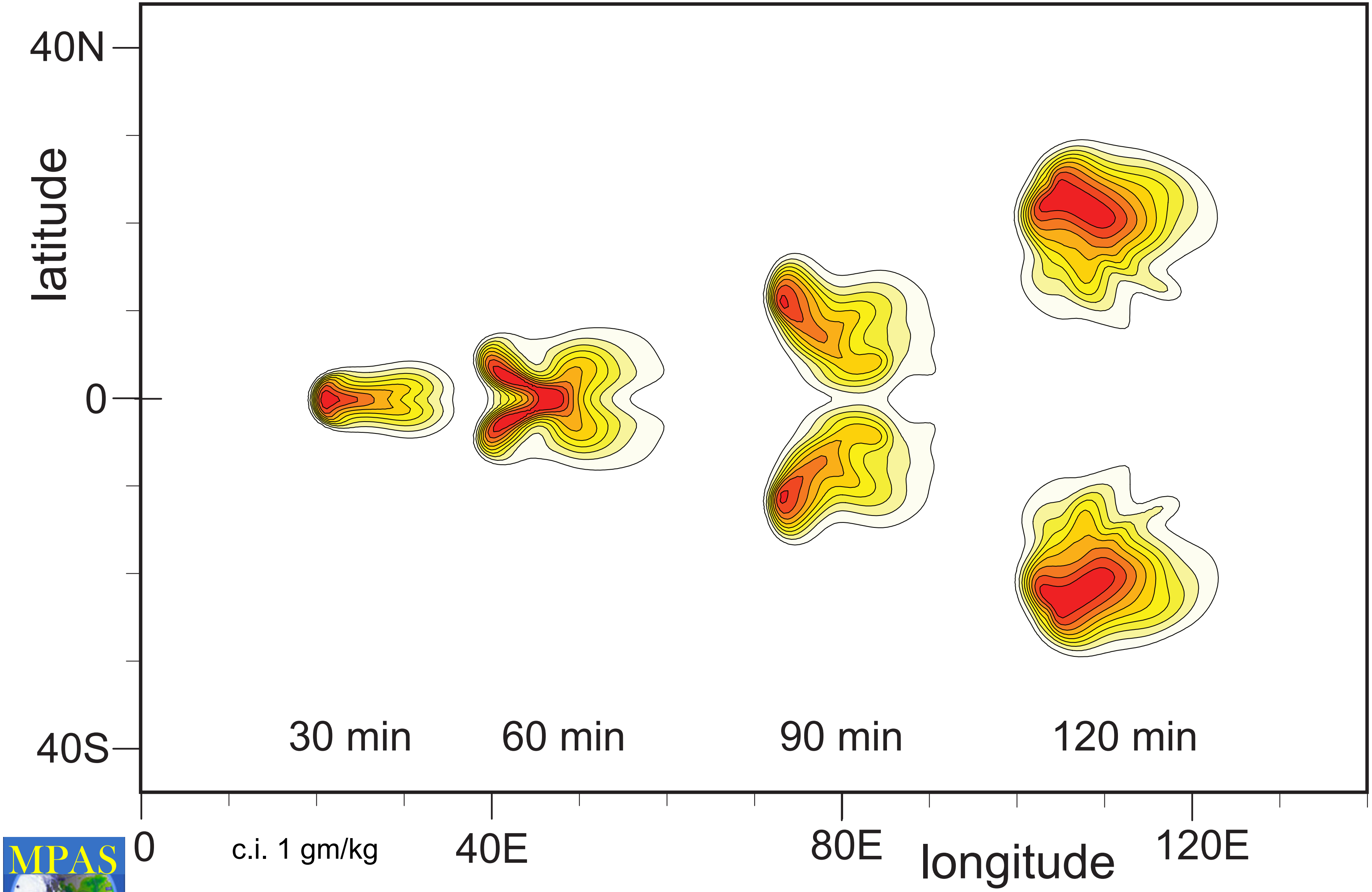


Vertical velocity contours at 1, 5, and 10 km (c.i. = 3 m/s)
30 m/s vertical velocity surface shaded in red
Rainwater surfaces shaded as transparent shells
Perturbation surface temperature shaded on baseplane

Maximum Vertical Velocity



Rain Water q_r, X = 120, Δ ~ 500 m, z = 5 km



MPAS

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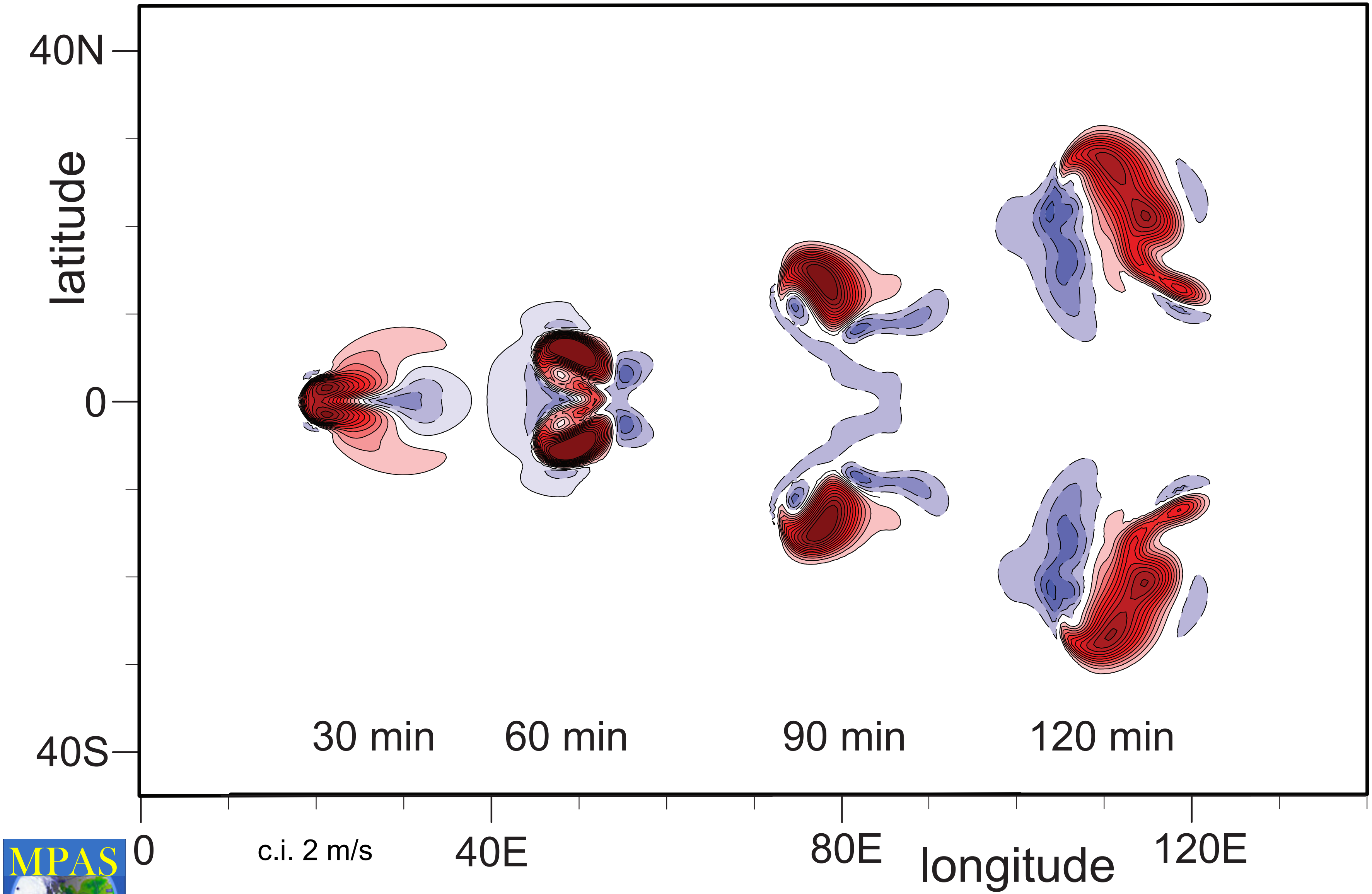
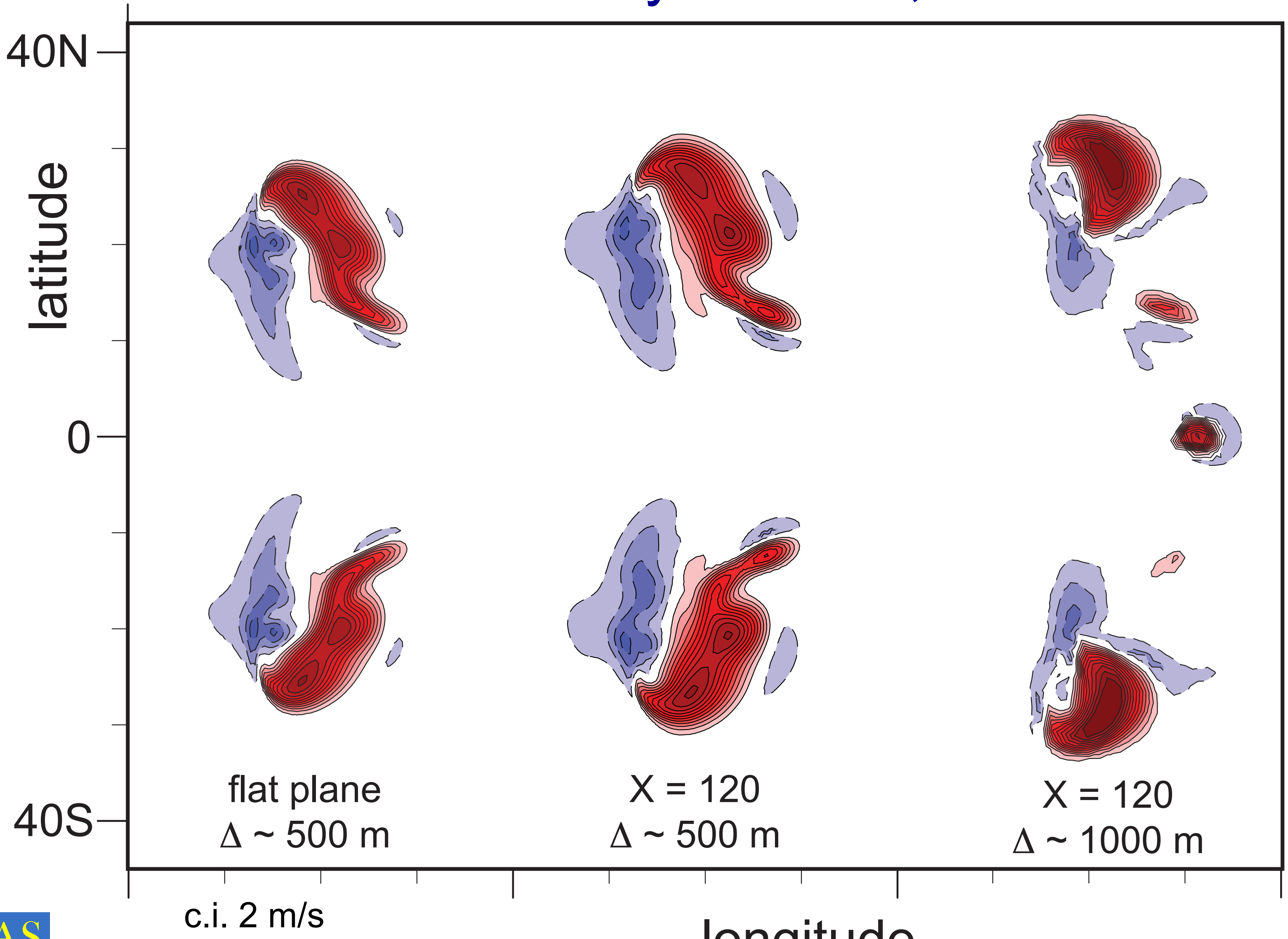
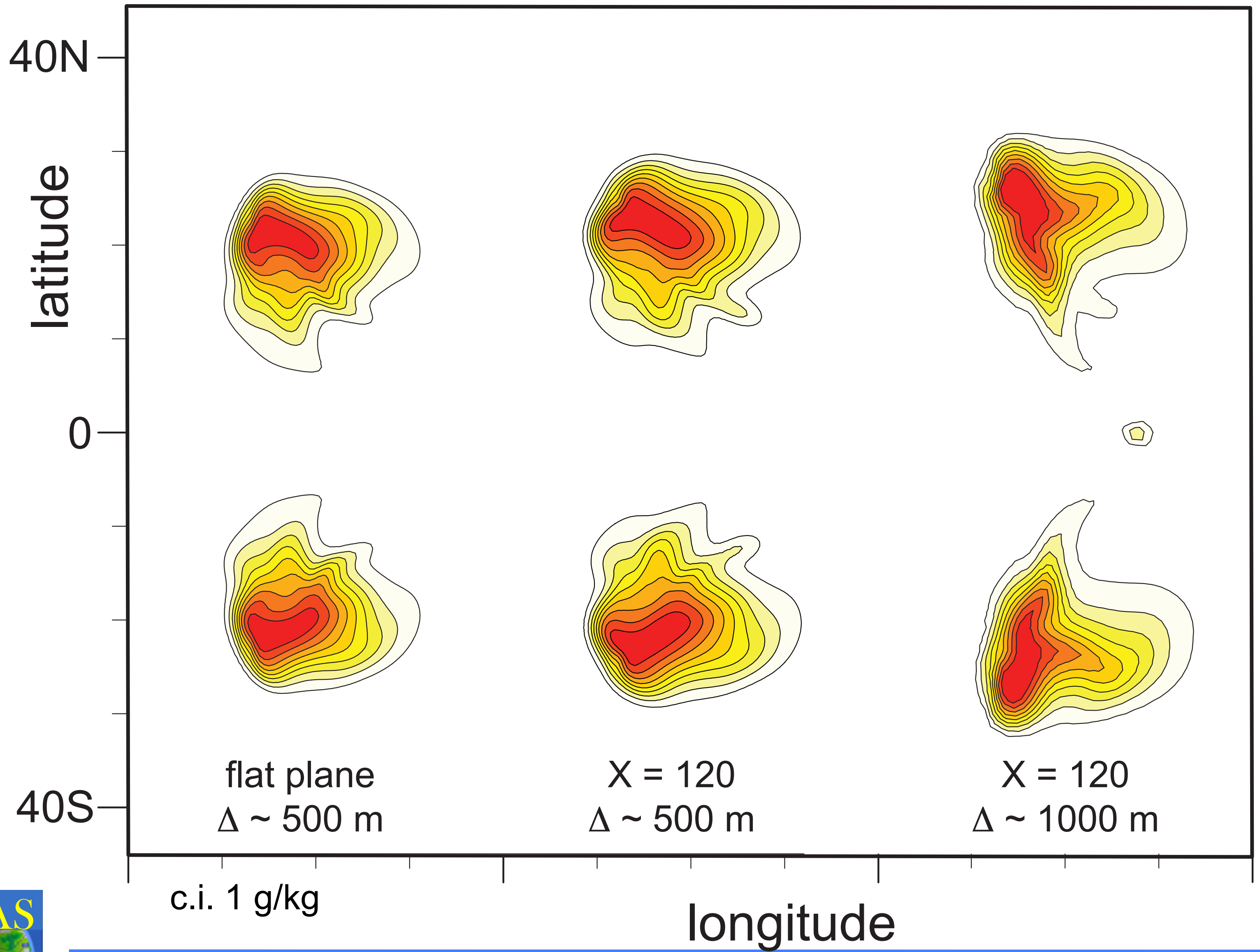
Vertical Velocity, X = 120, Δ ~ 500 m, z = 5 km



Vertical Velocity *w* at 2 h, *z* = 5 km



Rain Water q_v at 2 h, z = 5 km



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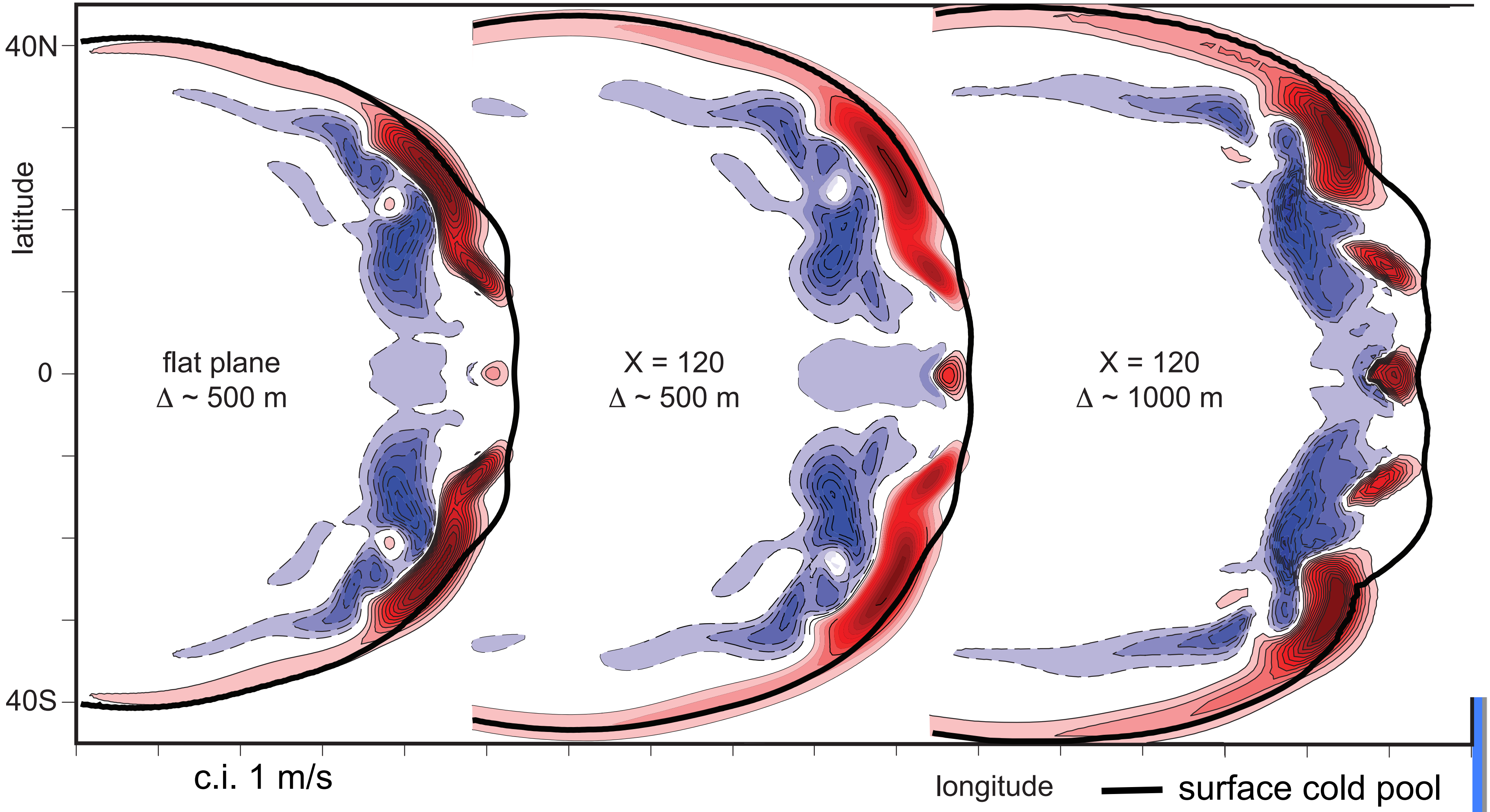
Vertical Velocity *w* at 2 h, z = 2.5 km



Supercell Testcase- Summary

- Realistic supercell storms can be simulated in an idealized atmospheric environment with simple physics.
- Good correspondence between simulation on reduced radius sphere (*X* = 120) and results in a Cartesian geometry.
- Grid size Δ ~ 1 km retains much of the supercell structure obtained with Δ ~ 500 m.
- Further simulations needed to explore behavior as resolution is further reduced.