The Dynamical Core Model Intercomparison Project (DCMIP-2016): Results of the Supercell Test Case

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Overview

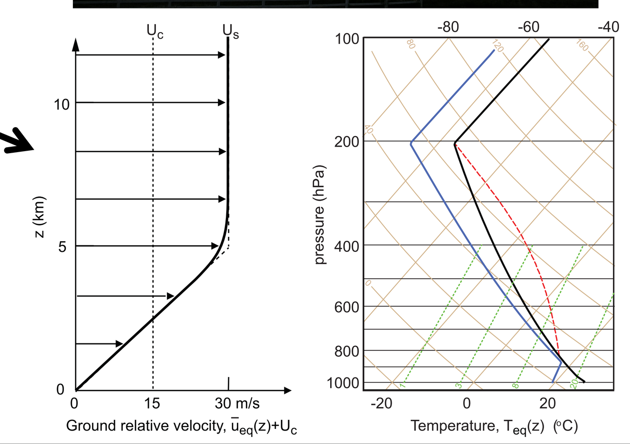
The 2016 Dynamical Core Model Intercomparison Project (**DCMIP-2016**) assesses the modeling techniques for global climate and weather models and was recently held at the National Center for Atmospheric Research (NCAR) in conjunction with a two-week summer school. Over 12 different international modeling groups participated in DCMIP-2016 and focused on the evaluation of the newest non-hydrostatic dynamical core designs for future high-resolution weather and climate models.

The paper highlights the results of the third DCMIP-2016 test case, which is an idealized supercell storm on a reduced-radius Earth. The supercell storm test permits the study of a non-hydrostatic moist flow field with strong vertical velocities and associated precipitation. This test assesses the behavior of global modeling systems at extremely high spatial resolution and is used in the development of next-generation numerical weather prediction capabilities. In this regime the effective grid spacing is very similar to the horizontal scale of convective plumes, emphasizing resolved non-hydrostatic dynamics. The supercell test case sheds light on the physics-dynamics interplay and highlights the impact of diffusion on model solutions.

Supercell test setup and initialization

- ***Supercell thunderstorms***: strong, long-lived convective cells containing deep, persistent rotating O(10km) updrafts
- Test case formulation based on Klemp et al., [2015]
- Models initialized on reduced radius Earth (X=120)
  - Δx~**4km (r400), 2km (r200), 1km (r100), 0.5km (r50)** resolution simulations
- Initial vertical profile: large CAPE (~2200 m²/s²) and strong low-level wind shear (30 m/s, linear shear below 5km, constant wind aloft)
- Near-surface thermal perturbation introduced to initiate convection
- Kessler-type parameterization used to represent cloud microphysics (see right)
- Uniform ∇² diffusion applied to ensure numerical convergence
- Models integrated for 120 minutes (7200 seconds)

Greg Lundeen, Wikipedia



from Klemp et al., [2015]

Kessler microphysics

- Simple microphysics parameterization that represents water vapor (q_v), cloud water (q_c), and rainwater (q_r) based on Kessler [1969].
- Called at the end of each physics timestep (Δt), updates (potential) temperature (θ) and moisture variables)
- ~100 lines of Fortran
- L – latent heat of condensation
- C_r – collection rate of rainwater
- E_r – rainwater evaporation rate
- V_r – rainwater terminal velocity
- c_p – specific heat capacity
- π – Exner function
- q_{vs} – saturation vapor mixing ratio
- A_r – autoconversion cloud -> rain

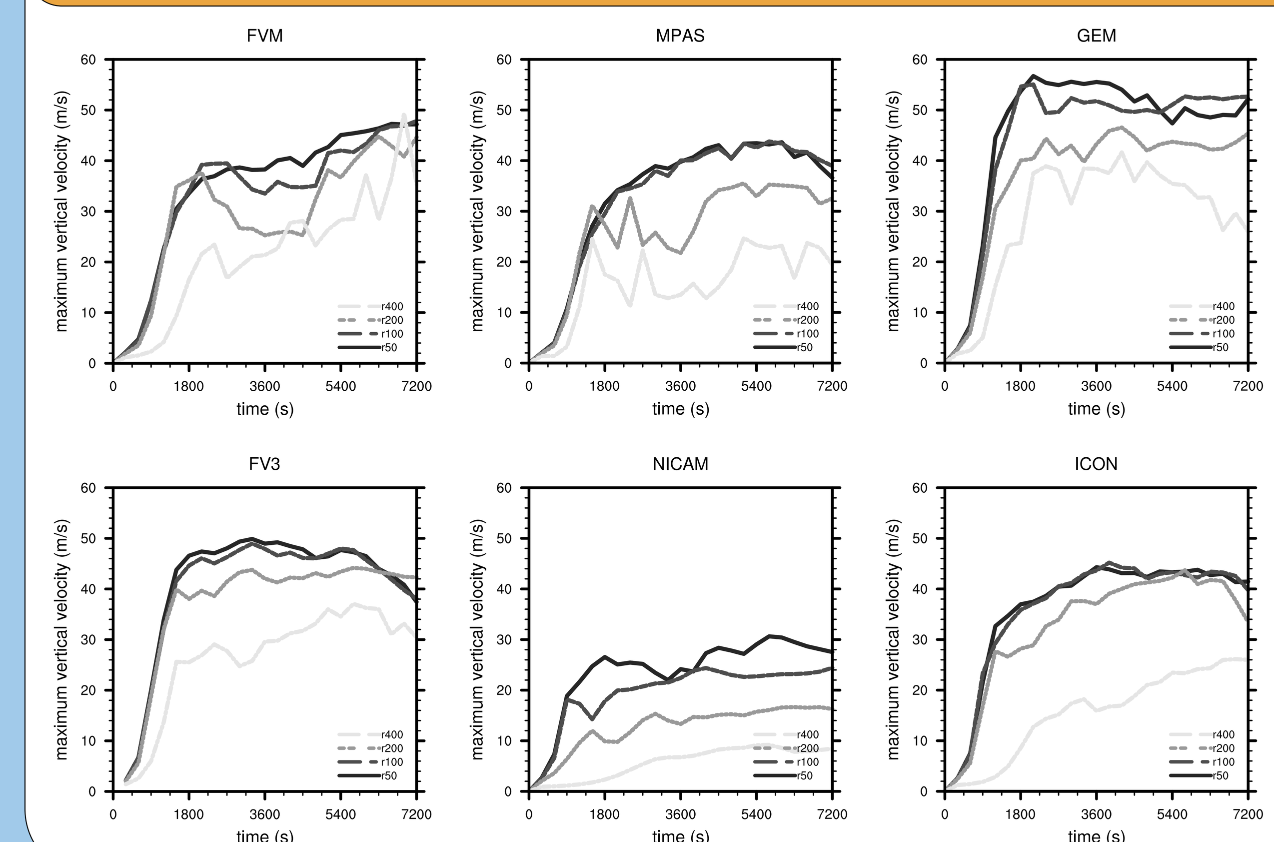
$$\frac{\Delta\theta}{\Delta t} = -\frac{L}{c_p\pi}\left(\frac{\Delta q_{vs}}{\Delta t} + E_r\right)$$

$$\frac{\Delta q_v}{\Delta t} = \frac{\Delta q_{vs}}{\Delta t} + E_r$$

$$\frac{\Delta q_c}{\Delta t} = -\frac{\Delta q_{vs}}{\Delta t} - A_r - C_r$$

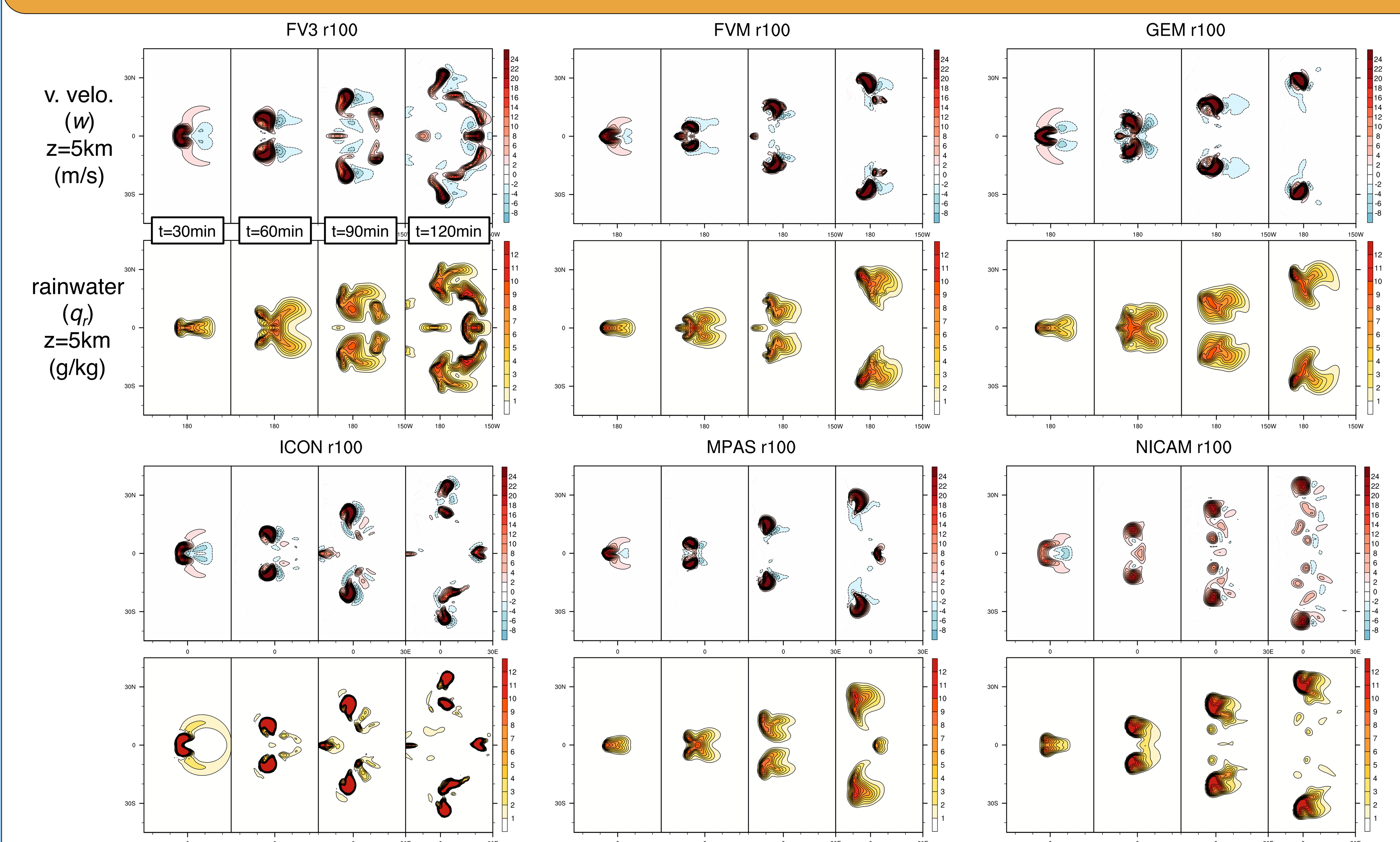
$$\frac{\Delta q_r}{\Delta t} = -E_r + A_r + C_r - V_r\frac{\partial q_r}{\partial z}$$

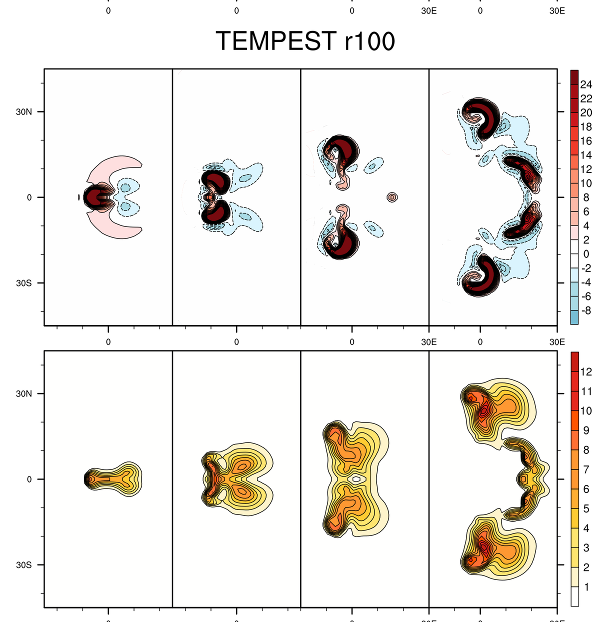
Maximum updraft velocity with grid resolution



- Maximum updraft evolution (0 – 120 min.) as a function of resolution
- Updraft velocity generally increases from Δx~4km -> 1km; "underresolved" dynamics at lower resolutions
- Convergence appears for most models between Δx~1km and 0.5km
- Maximum updraft velocities vary by x2 between models

Time evolution of supercells at 1km resolution

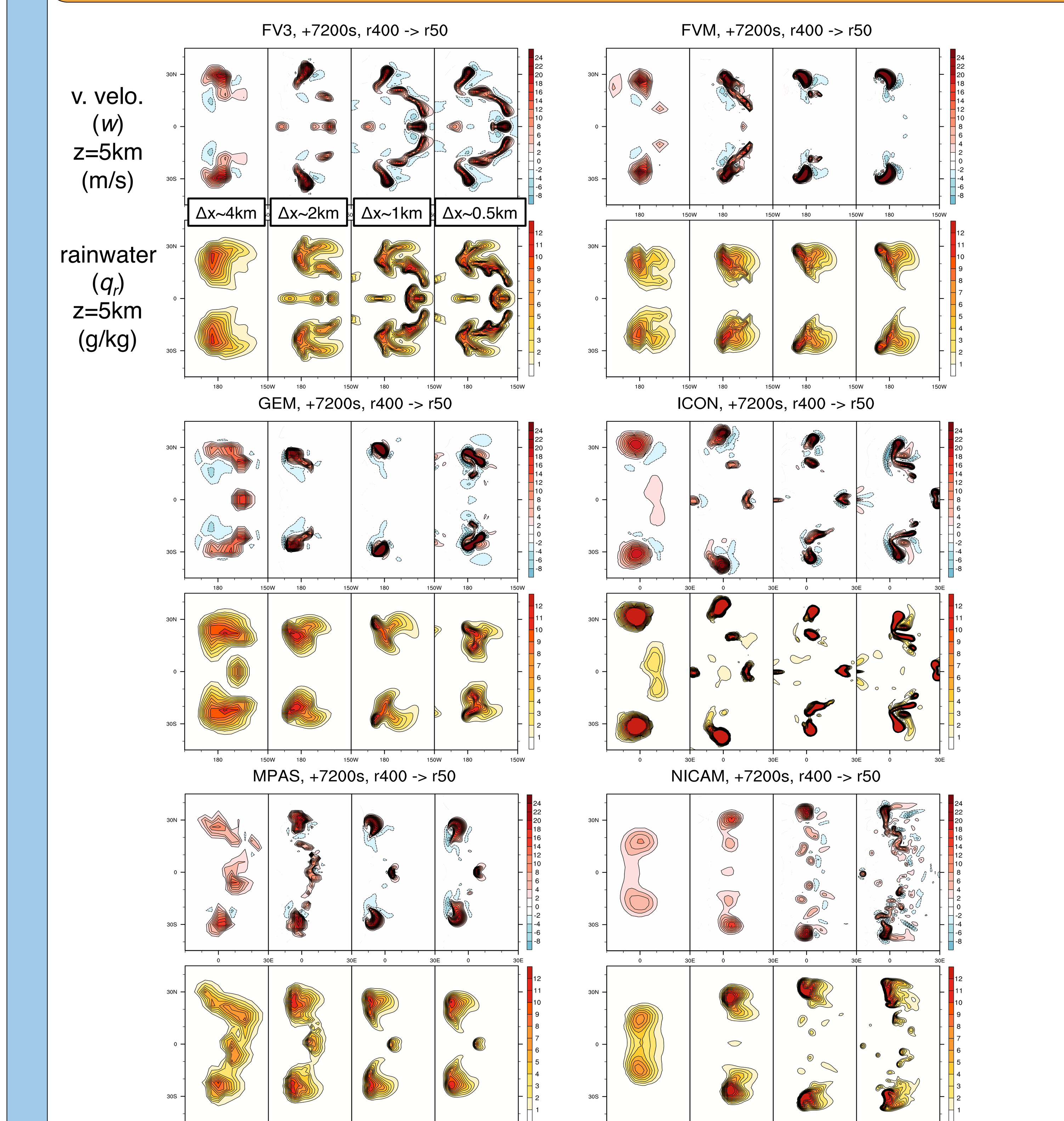




See DCMIP baroclinic wave test poster for model descriptions

- Cross-sections at 5km elevation of vertical velocity (w, top, m/s) and rainwater (q_r, bottom, g/kg) for **1km** (r100) simulations
- Panels (left-to-right) are **+30, 60, 90, and 120 min**. from initialization
- All models show single "connected" updraft at 30 minutes along the equator, collocated with single precipitation maximum
- By 60 min., signs of splitting, although some models (e.g., FVM, Tempest) show less bifurcation than others (e.g., ICON, NICAM)
- All supercells split and move equatorward through the second hour, with near-mirror symmetry
- Coherence of supercell updrafts as well as transverse distance from centerline (equator) vary significantly by end of simulations

Structural sensitivity to resolution



- Cross-sections at 5km height of vertical velocity (w, top, m/s) and rainwater (q_r, bottom, g/kg) at **+120 min.** from initialization
- Panels (left-to-right) are **4km, 2km, 1km, & 0.5km** grid spacing for each model
- Wide range of solutions between models, even at 0.5km resolution
- Some models appear to be structurally converged, others do not

Summary

- **Non-hydrostatic dynamics required for accurate representation of supercells**
- **Clear differences/uncertainties in storm evolution due to dynamical core**
- **Intramodel global convergence of maximum updraft velocity near ~0.5km grid spacing but intermodel differences are a factor of two**
- **Less convergence in structural representation as resolution is increased**
- **Uncertainties likely stem from *not only numerical discretization* but *form and implementation of diffusion/filtering mechanisms***
- **Critical to further investigate and understand behaviors given that variable-resolution global models *O*(1km) and globally-uniform models *O*(10km) in coming years**

References

Kessler, E. (1969), On the distribution and continuity of water substance in atmospheric circulation, Meteorol. Monogr., vol. 32, 84 pp., Am. Meteorol. Soc., Boston, Mass.

Klemp, J. B., W. C. Skamarock, and S.-H. Park (2015), Idealized global nonhydrostatic atmospheric test cases on a reduced-radius sphere, J. Adv. Model. Earth Syst., 7, 1155–1177, doi:10.1002/2015MS000435.