Gaining Insights into Dynamical Cores and their Physics-Dynamics Coupling via DCMIP Test Suites

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What is DCMIP?

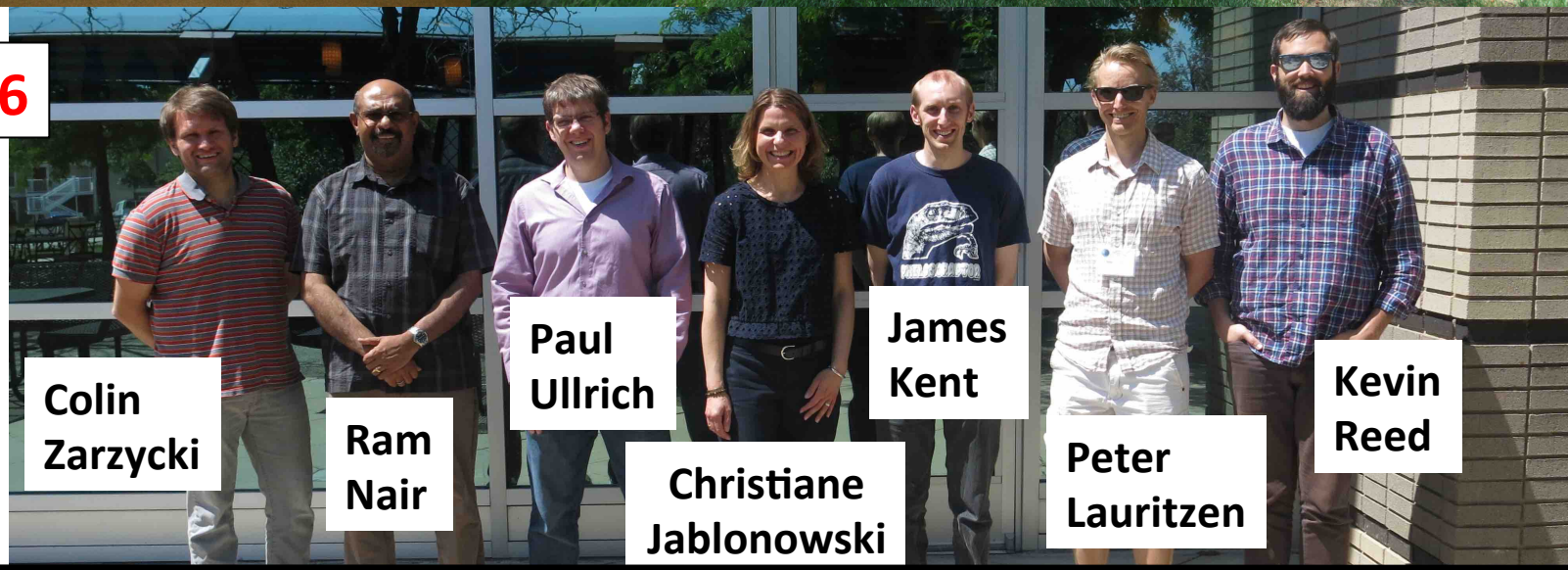
- The **Dynamical Core Model Intercomparison Project** in 2016 (**DCMIP-2016)** highlighted the newest dynamical core modeling techniques for climate and weather models.

- DCMIP-2016 emphasized **non-hydrostatic dynamical cores**, physics-dynamics coupling and variable-resolution modeling.

- DCMIP-2016 included (June/6-17/2016):
  - A morning "**summer school**" that incorporates lectures and hands-on sessions for students, postdocs and researchers.
  - An afternoon "**hands-on workshop**" that gives participants the opportunity to work with operational modeling systems from around the world.
  - An **international dynamical core intercomparison** to quantify difference in modern models via idealized test cases with analytically-prescribed initial conditions.

Brief History of DCMIP: Organizers

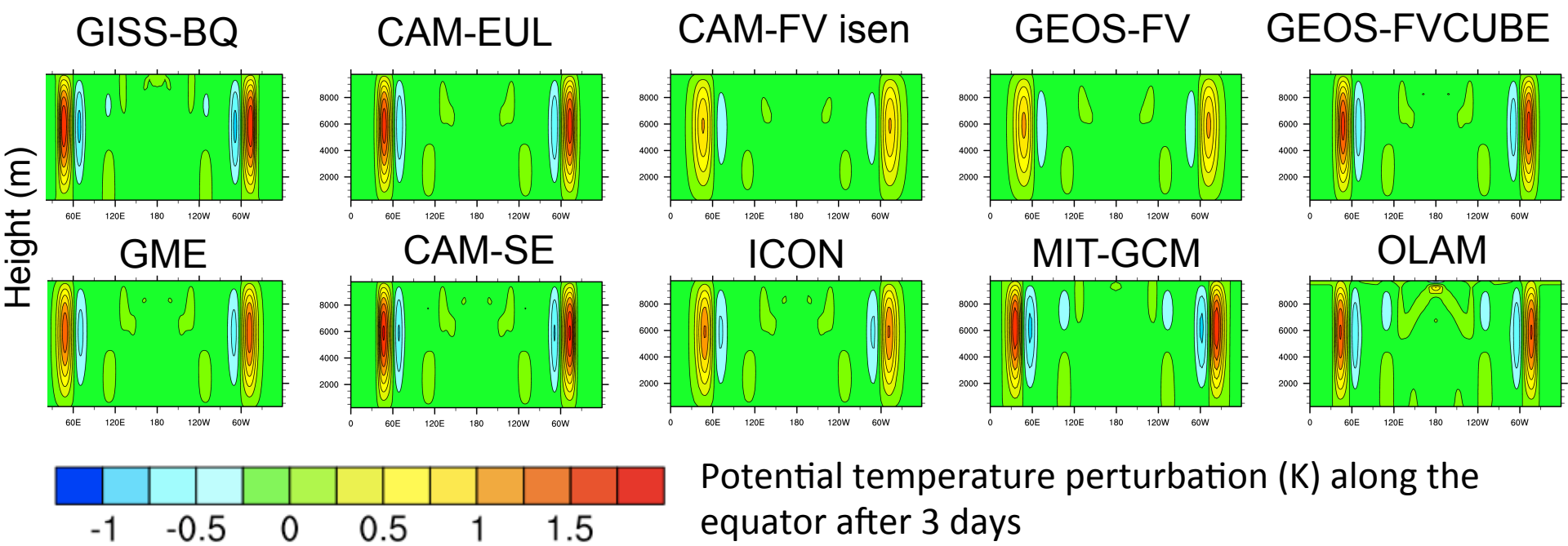
2016



Brief History of DCMIP: DCMIP-2008

DCMIP-2008: Building a first idealized test case suite for 3D **hydrostatic dynamical cores**. Test cases included gravity waves, baroclinic instability, 3D Rossby-Haurwitz, mountain-induced Rossby gravity wave and solid-body rotation (3D advection).

DCMIP-2008 Gravity wave test case measures diffusivity

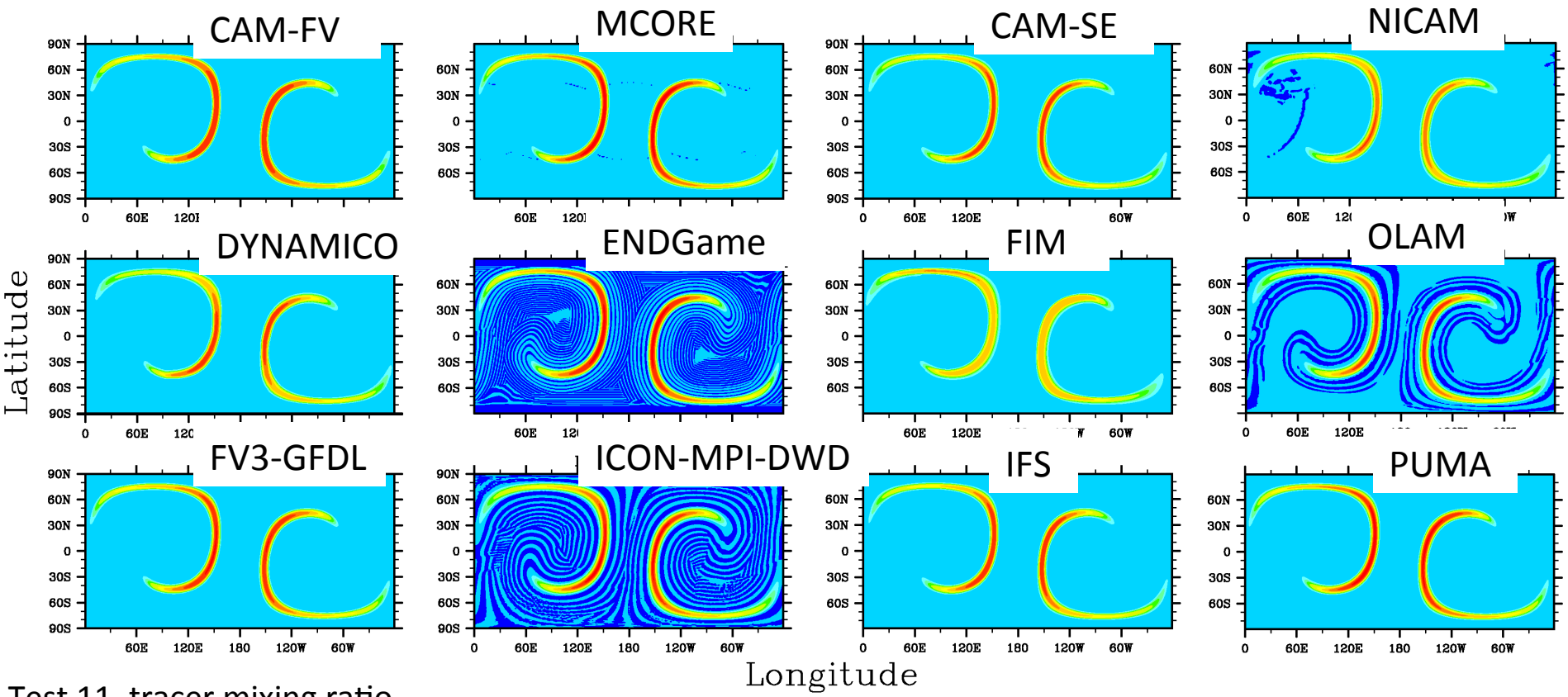


Potential temperature perturbation (K) along the equator after 3 days

Brief History of DCMIP: DCMIP-2012

DCMIP-2012: Focus on non-hydrostatic models. Advanced 3D advection test cases (e.g. 3D deformational flow), steady-state orography test, mountain waves, non-hydrostatic gravity waves, baroclinic instability with EPV, idealized tropical cyclone.

DCMIP-2012 Advection test case measures diffusivity & noise

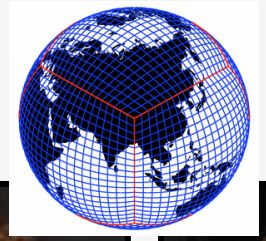


Test 11, tracer mixing ratio
dx= 110 km, dz = 200 m

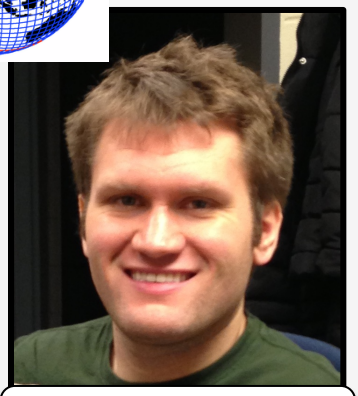
Kent et al. (QJ, 2014)

DCMIP-2016 Model Mentors

CAM-SE



David Hall



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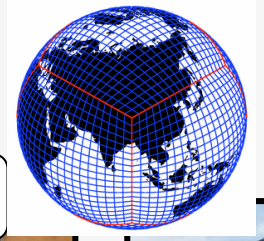

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Alex Reinecke

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David Randall

Don Dazlich

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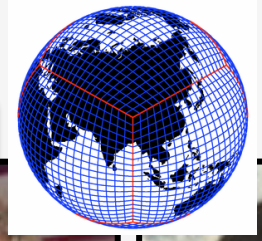
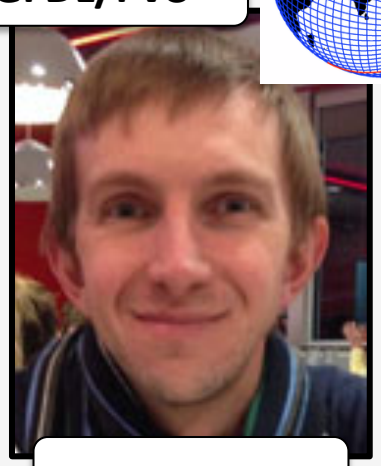
GFDL/FV3





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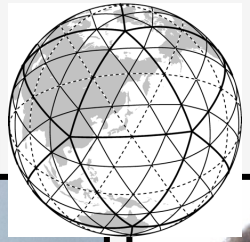

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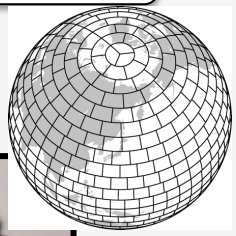

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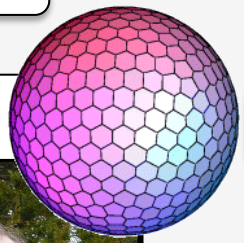

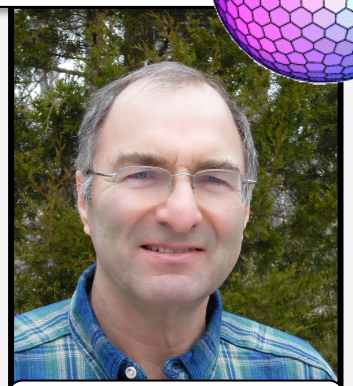

Bob Walko

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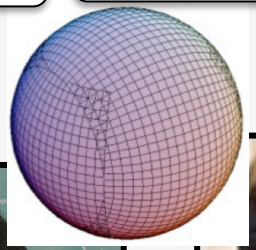

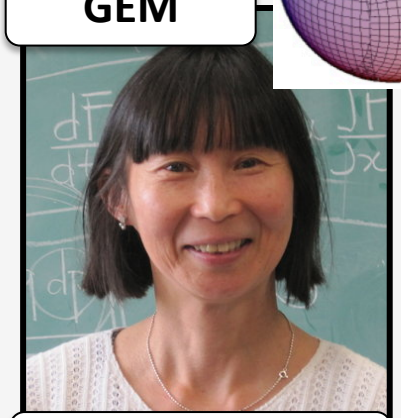

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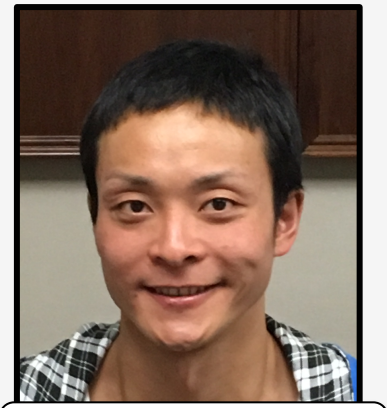

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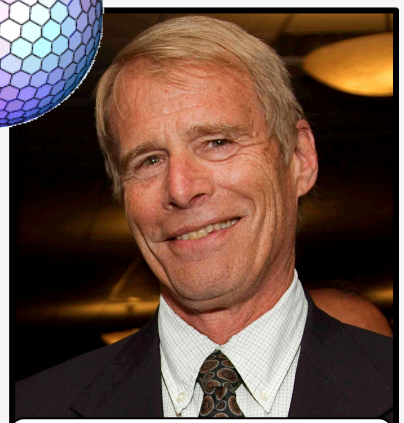

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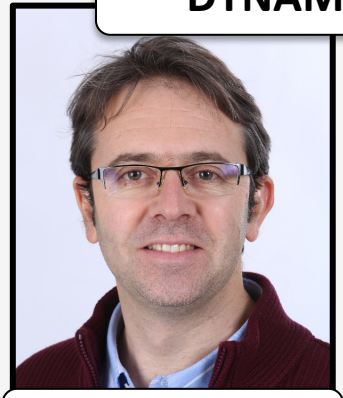
DCMIP-2016 Model Mentors
(Intercomparison Only)

DYNAMICO



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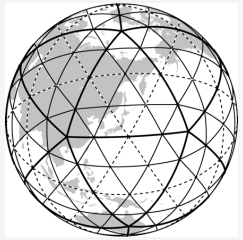
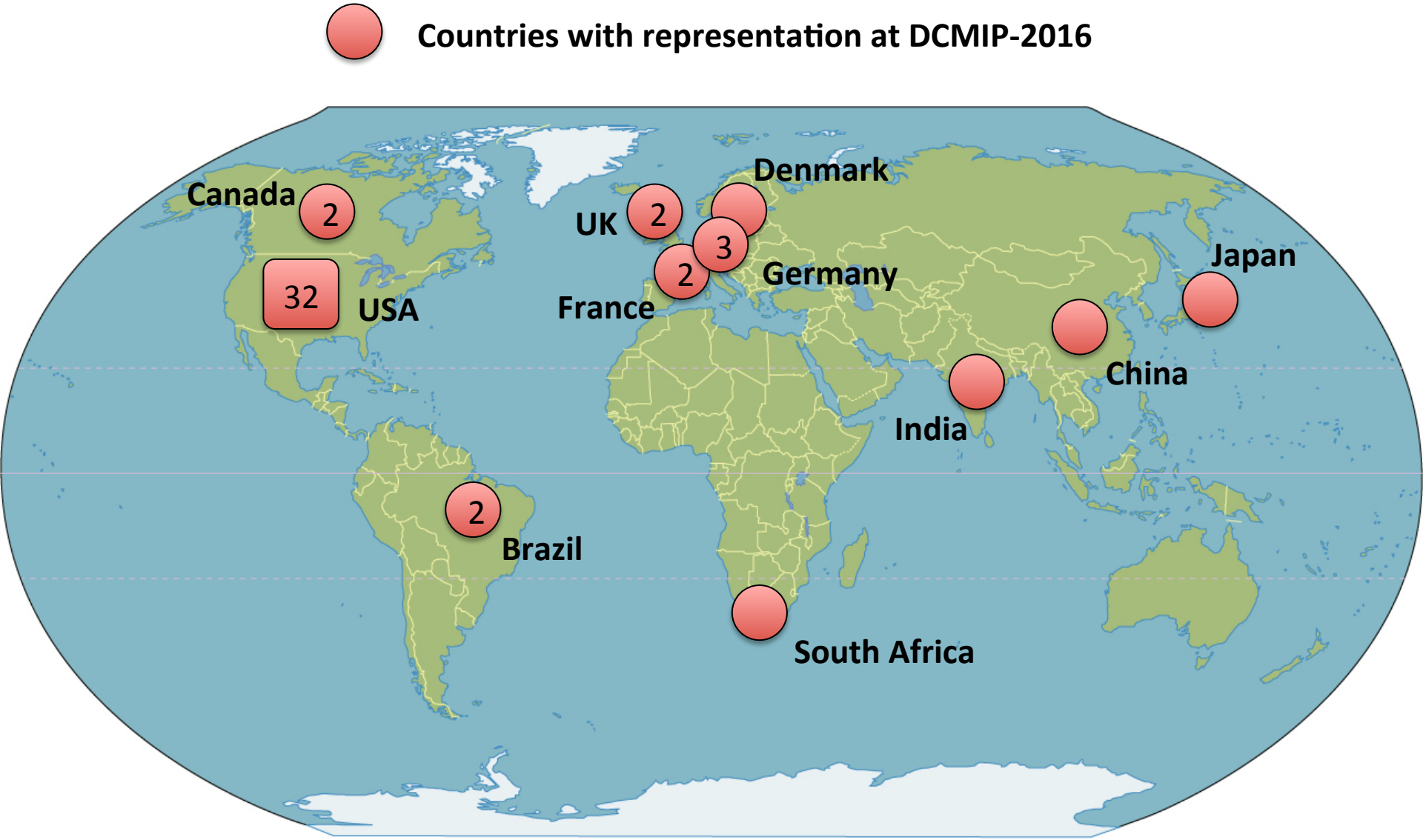


DCMIP-2016 Student/Postdoc Participants (48 Total)



DCMIP-2016 Sponsors

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National Oceanic and Atmospheric Administration NOAA U.S. Department of Commerce

NASA

MICHIGAN

Research Computing

UC DAVIS

Workshop

- Modeling teams stayed together for the two week period.
- The teams were given the task of running idealized simulations on the NCAR Yellowstone Supercomputer.
- Teams were given the option and ability to experiment with the models, with a focus on (a) physical parameterizations, (b) physics-dynamics coupling, and (c) variable-resolution.
- Teams analyzed and intercompared the data via GUI interfaces and prepared NCL scripts.
- Teams disseminated model results to the DCMIP2016 website.
- Organizers were present to assist with NCL, graphics, NCO, and NetCDF data formats.
- On Day 10 each teams presented their findings

DCMIP-2016 snapshots: The whole group

DCMIP-2016 snapshots: A typical workshop day

DCMIP2016 Test Suite

Focus on non-hydrostatic models, physics-dynamics coupling and variable-resolution modeling systems.

- **Test 1:** Moist baroclinic instability with “toy” Terminator chemistry
- **Test 2:** Moist tropical cyclone test
- **Test 3:** Moist supercell storm test

Physics Routines

Warm-Rain Kessler Microphysics: Requires water species for water vapor, cloud water and rain water. Computes tendencies for evaporation, autoconversion, collection and precipitation.

Boundary Layer and Surface Fluxes: A simple mixing parameterization that represents boundary layer processes and surface fluxes (based on Reed and Jablonowski, 2012).

Uniform diffusion: Used in the supercell to simulate turbulent mixing.

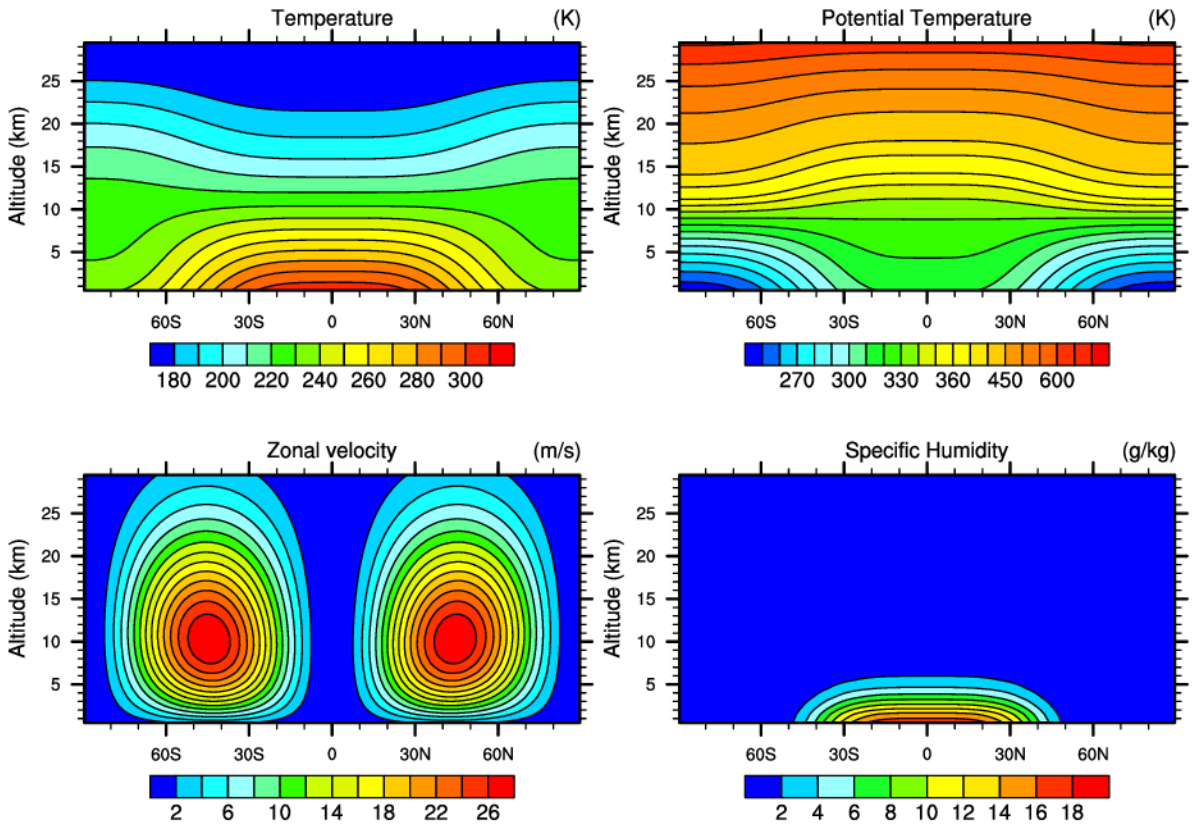
Reference: J. B. Klemp, W.C. Skamarock, and S.-H. Park (2015) "Idealized global nonhydrostatic atmospheric test cases on a reduced-radius sphere." *J. Adv. Model. Earth Syst.*, 07, doi:10.1002/ 2015MS000435

Test 1: Moist Baroclinic Wave

Initial conditions

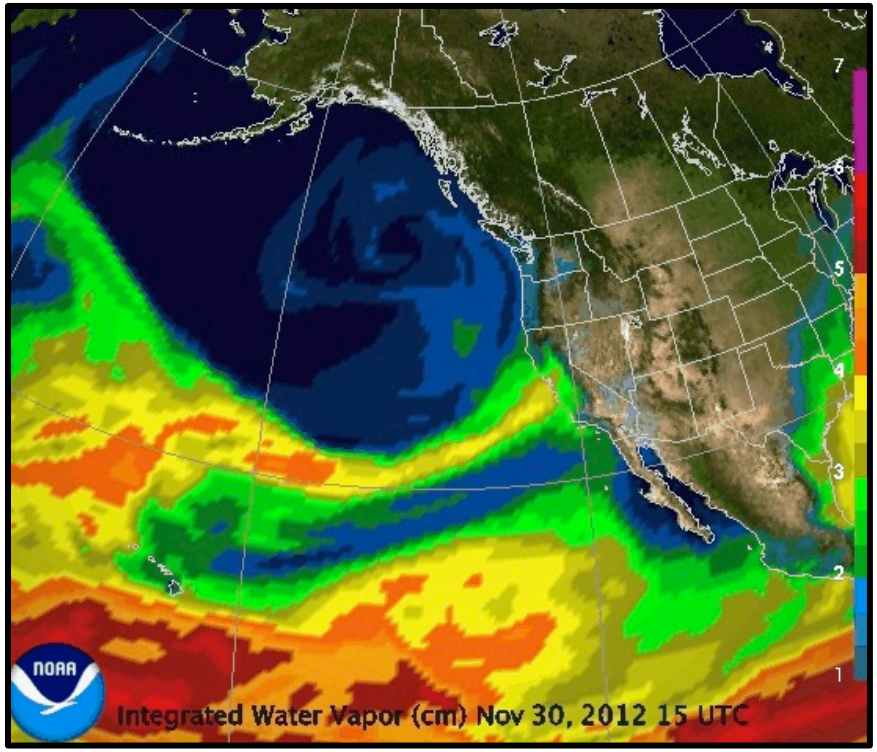
The moist baroclinic wave is a modified version of the UMJS (see reference) baroclinic instability featuring:

- Zero bottom topography
- Constant surface pressure
- No stratosphere
- Alternate deep atmosphere formulation
- Baroclinically unstable initial state
- Leads to atmospheric river-like features

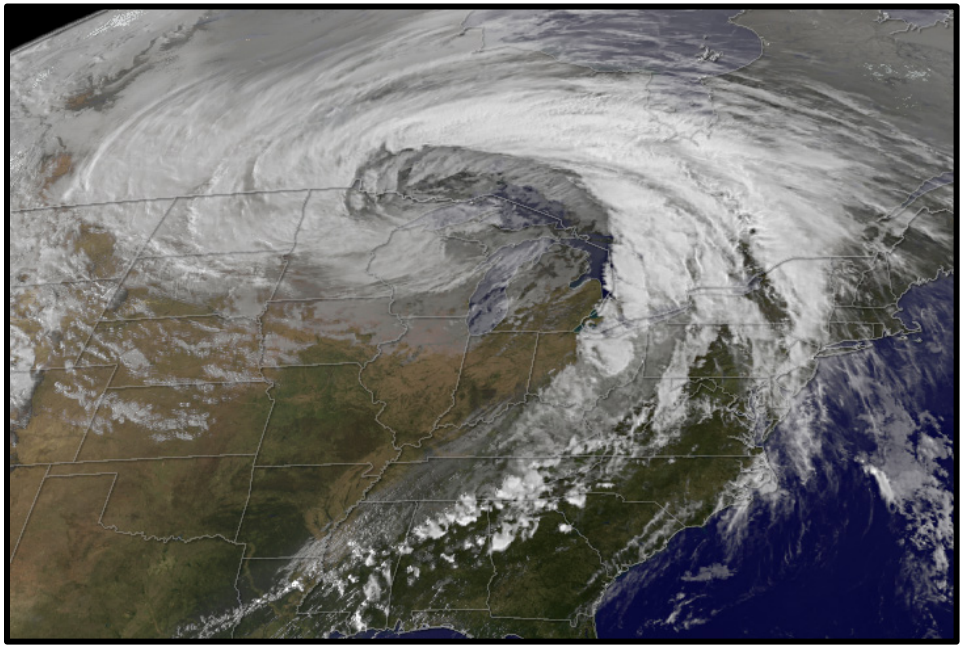


Reference: Ullrich, P.A., T. Melvin, C. Jablonowski and A. Staniforth (2014): A proposed baroclinic wave test case for deep- and shallow-atmosphere dynamical cores. *Quart. J. Royal Meteor. Soc.*, Volume 140, Issue 682, pp. 1590-1602, doi: 10.1002/qj.2241.

Test 1: Moist Baroclinic Wave

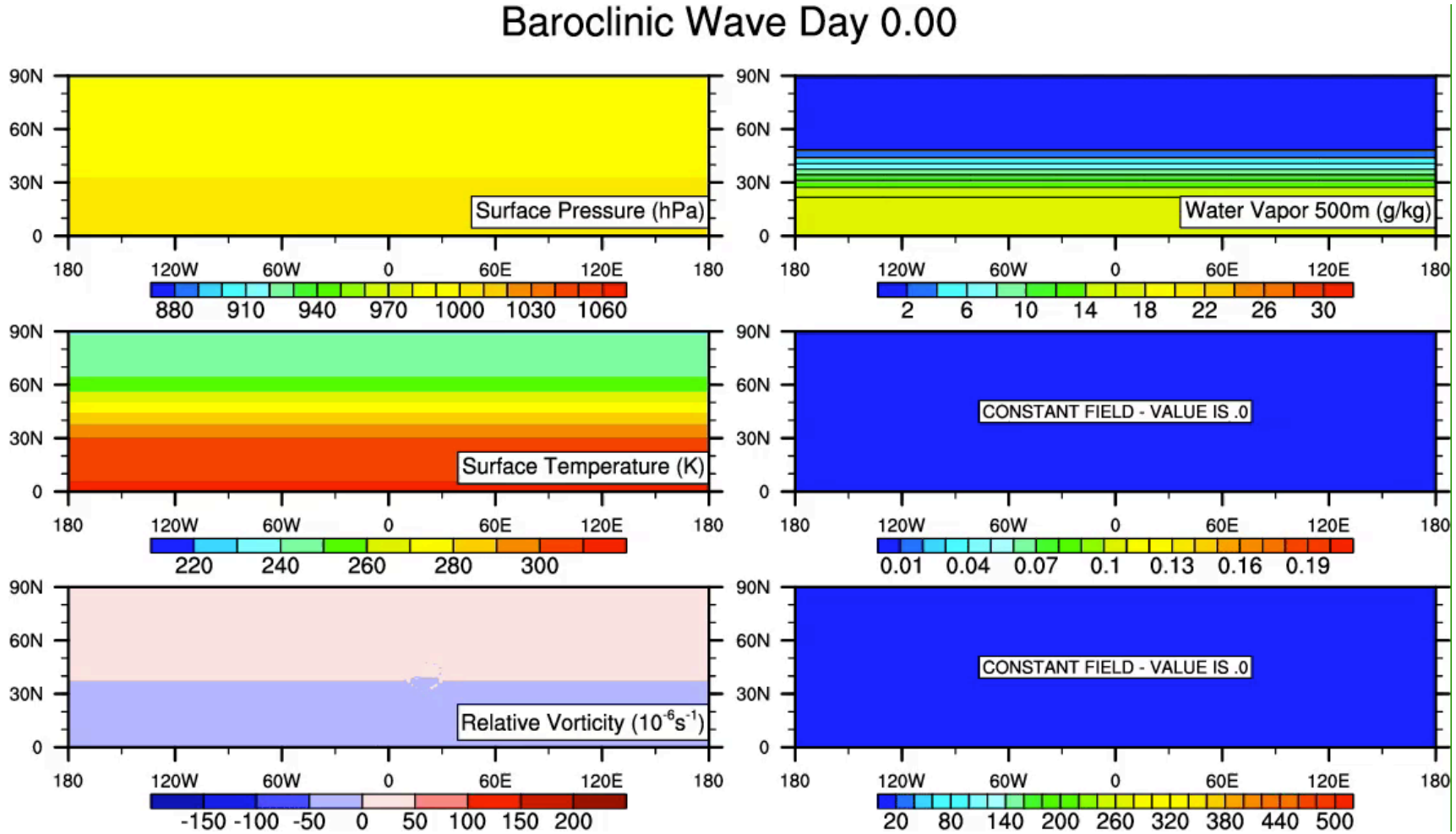


Atmospheric River



Extratropical Cyclone

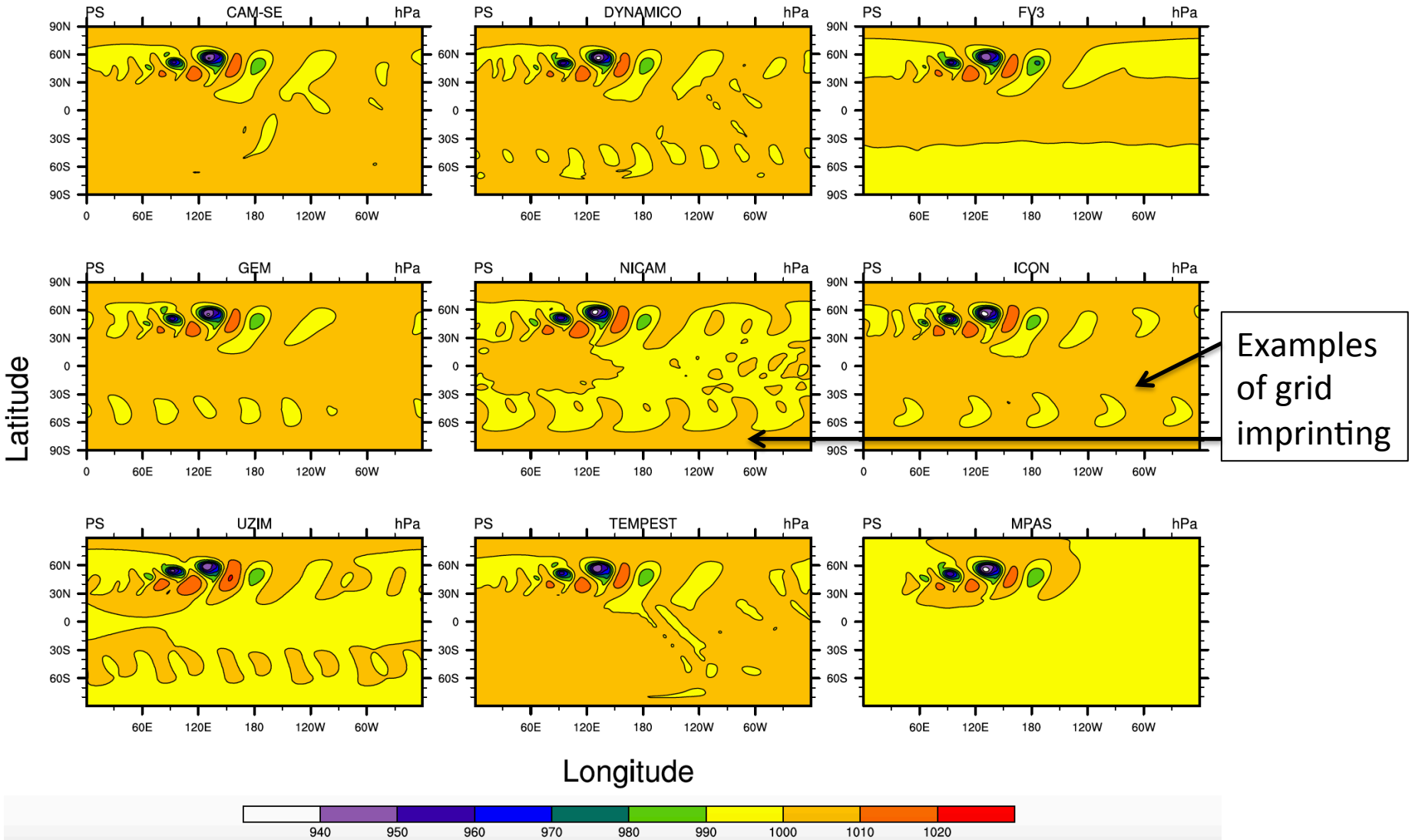
Test 1: Moist Baroclinic Wave



Planetary boundary layer and surface fluxes disabled, Kessler physics enabled

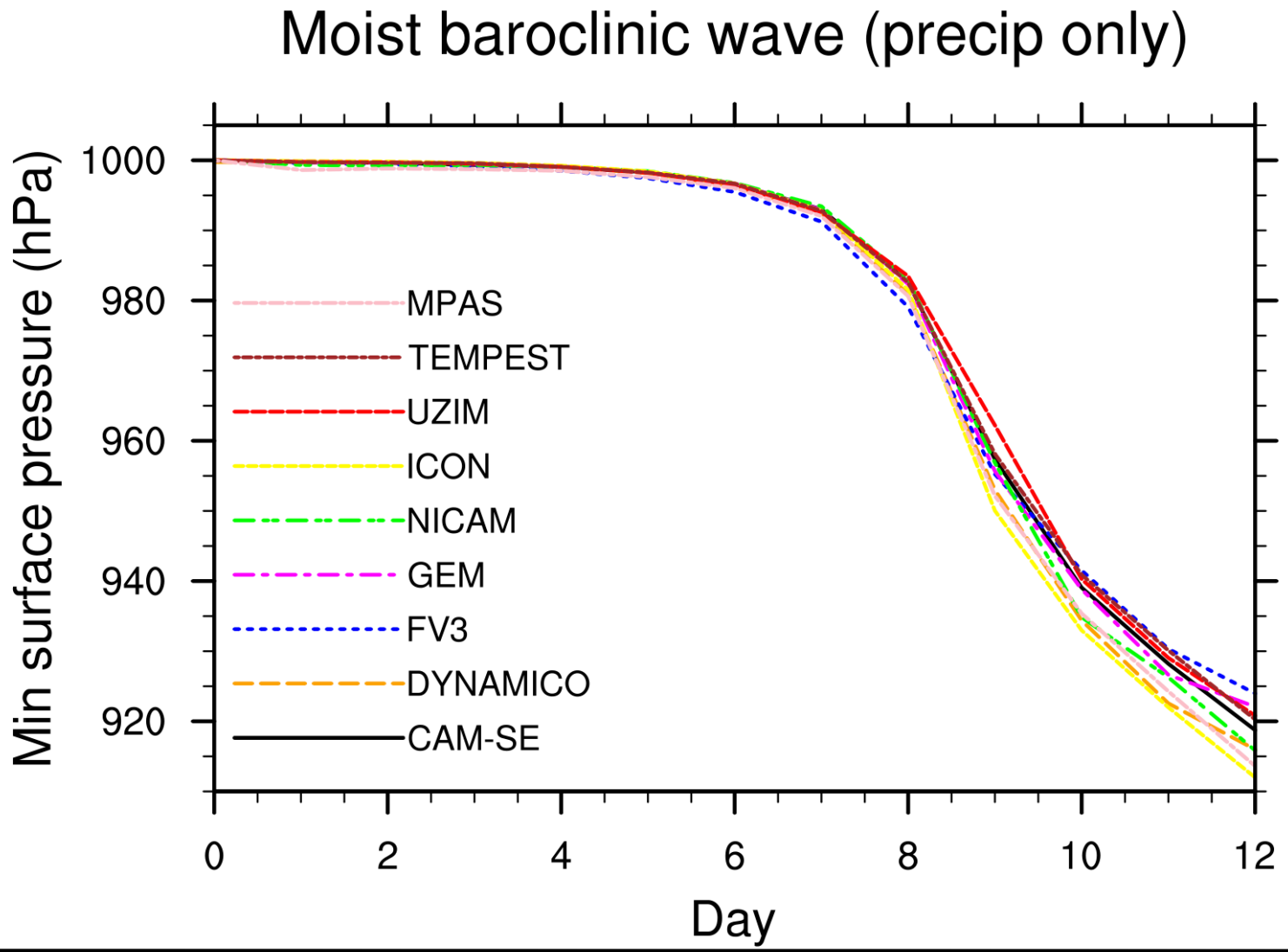
Test 1: Moist Baroclinic Wave

Surface pressure at day 10 (precip-only case with Kessler physics, no PBL)



Test 1: Moist Baroclinic Wave

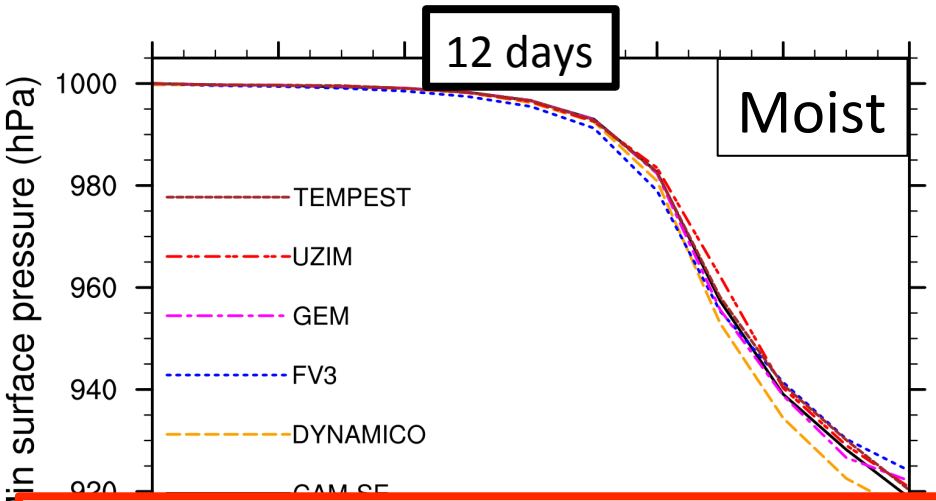
More quantitative analysis: Minimum surface pressure (time series)

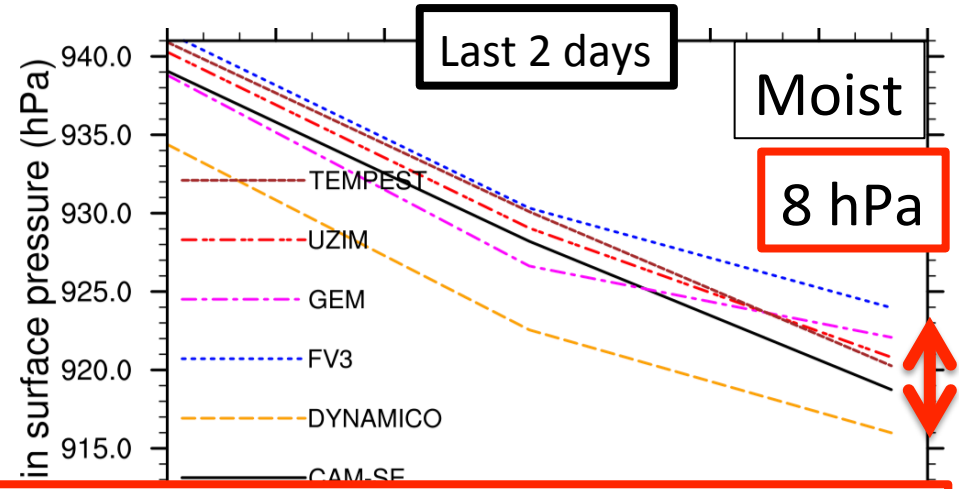


Model results spread out: does spread originate in the physics or dynamics?

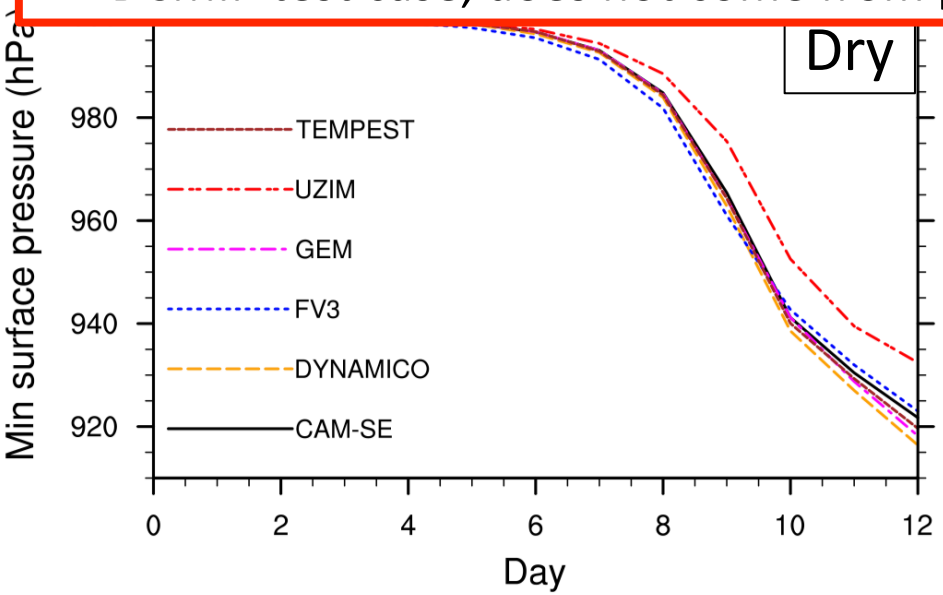
12 hPa

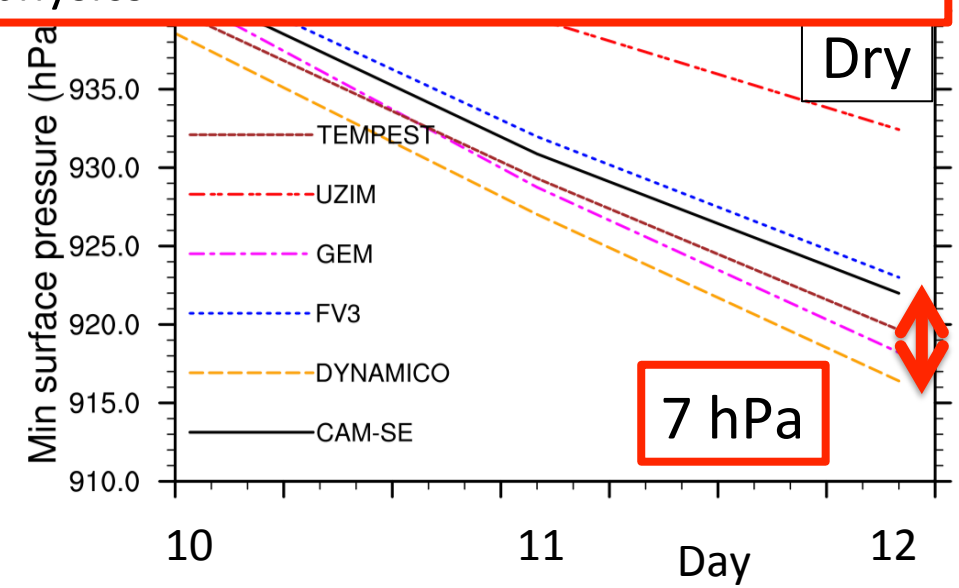
DCMIP-2016 Moist and Dry baroclinic wave





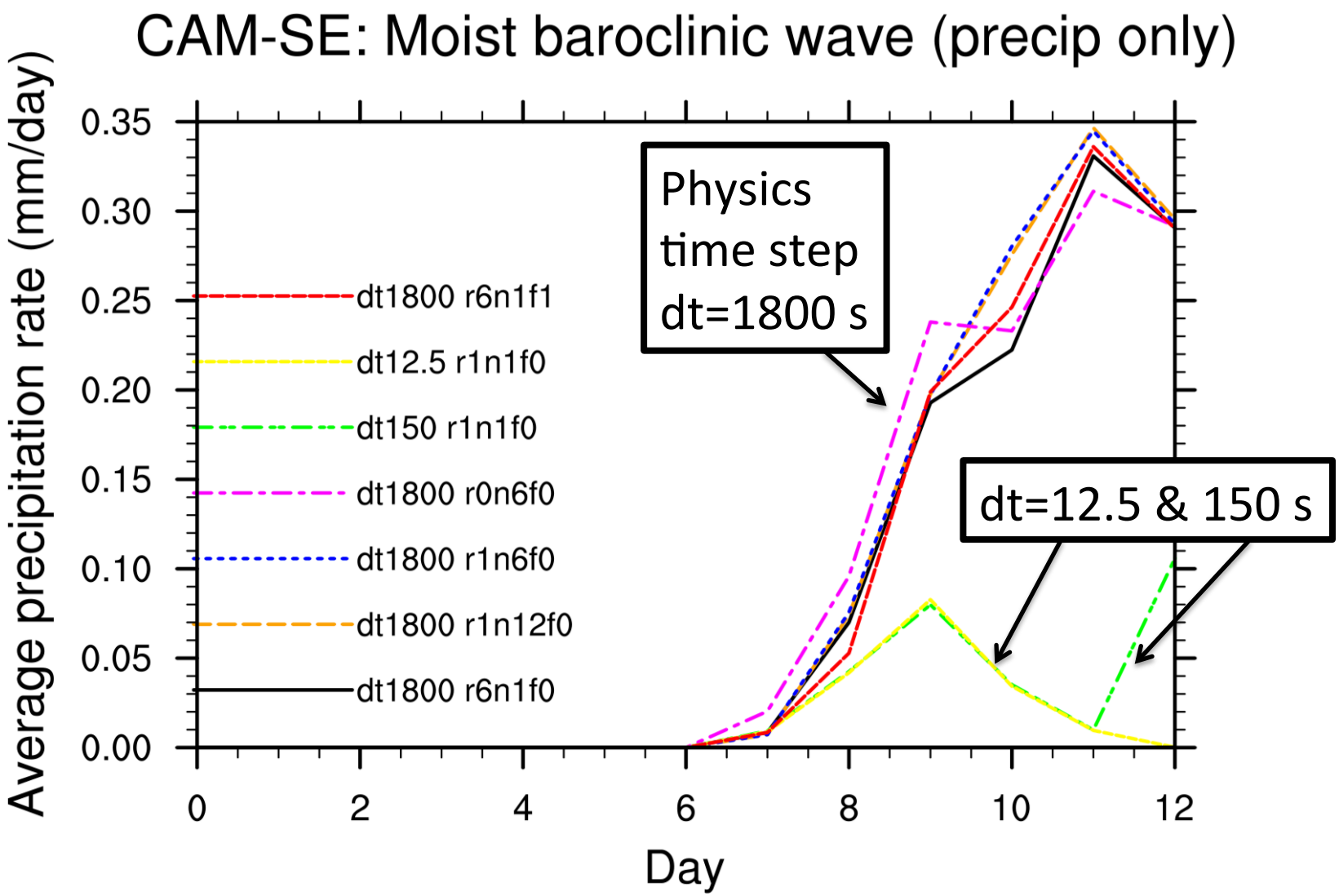
- The ps_{min} spread in moist simulations resembles the spread of the dry simulations
- Suggests that most of the model spread originates in the dynamical cores in this DCMIP test case, does not come from physics





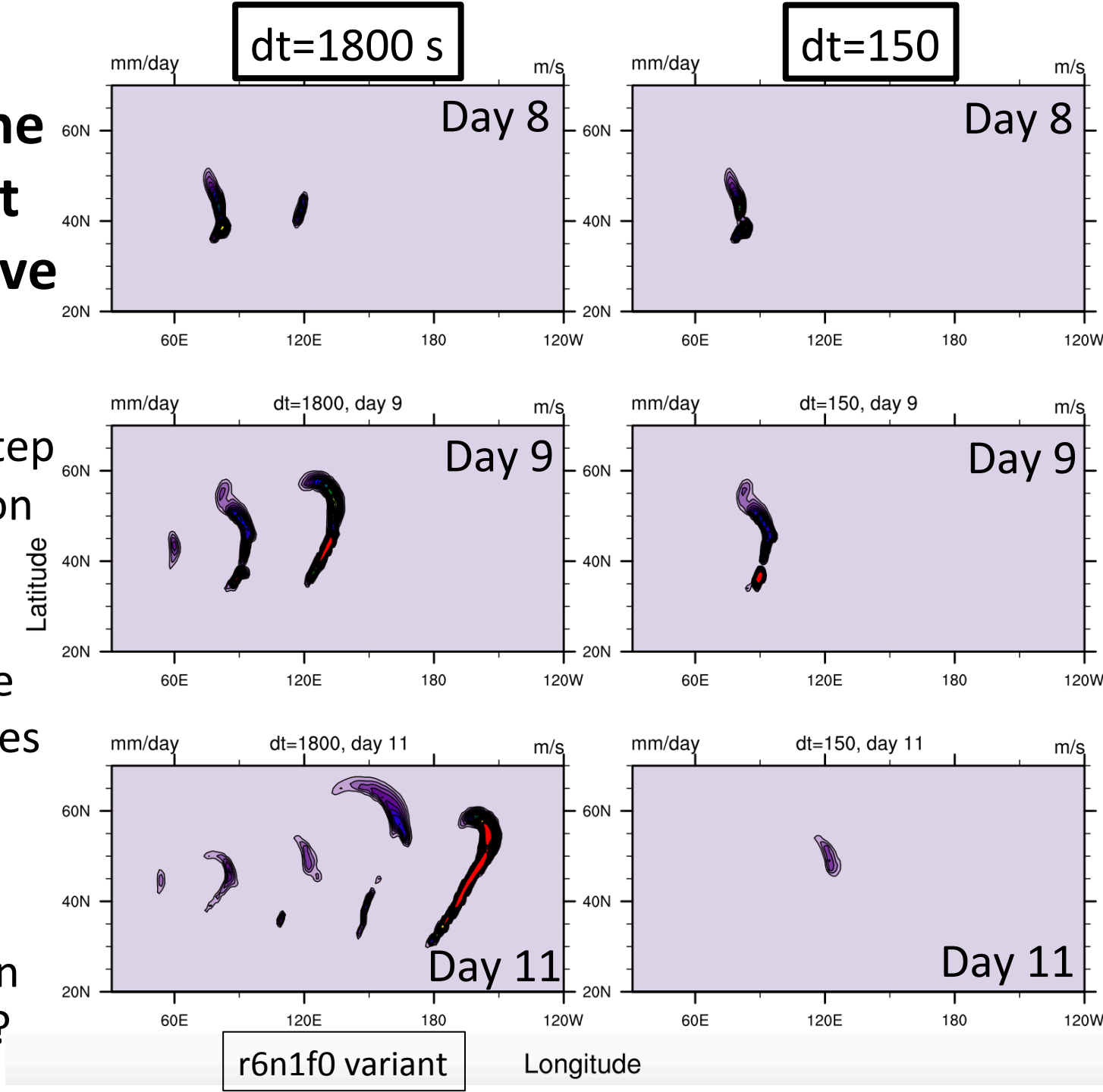
DCMIP-2016: CAM-SE Moist baroclinic wave

- How does the precipitation rate (averaged in the northern hemisphere) evolve? Distinctly different with shorter phys. time steps



DCMIP-2016: Coupling in the CAM-SE moist baroclinic wave

- With shorter physics time step dt: Precipitation almost shuts off after day 9
- Do similar time step sensitivities exist in more complicated precipitation schemes and in other dycores?



Test 1: Terminator Chemistry

Many chemical processes in the atmosphere have the form

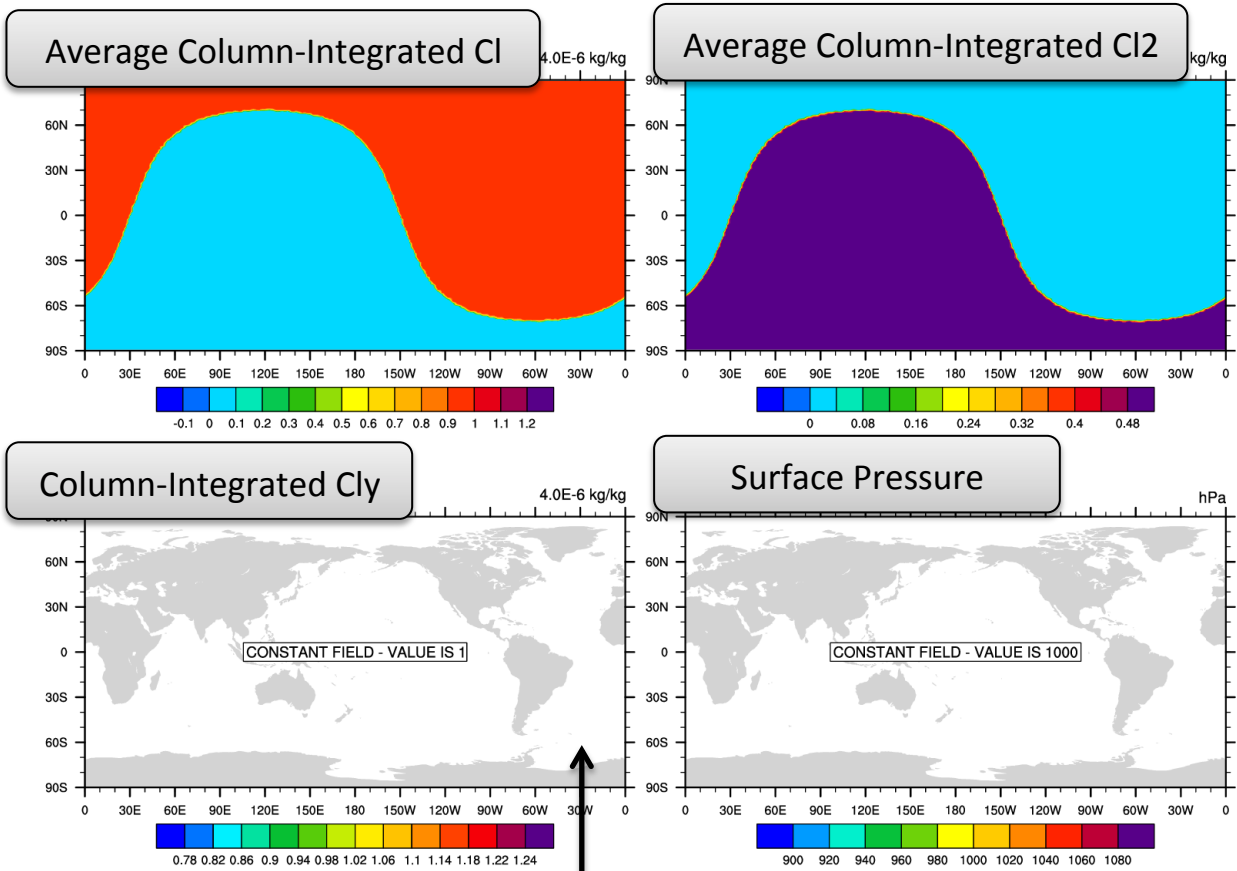
$$X_2 + \nu \rightarrow X + X \quad (k_1)$$
$$X + X \rightarrow X_2 \quad (k_2)$$

These two species have associated transport eq'ns

$$\frac{D[X]}{Dt} = 2k_1[X_2] - 2k_2[X]^2,$$
$$\frac{D[X_2]}{Dt} = -k_1[X_2] + k_2[X]^2,$$

$$\frac{D}{Dt}([X] + 2[X_2]) = 0$$

Initial conditions

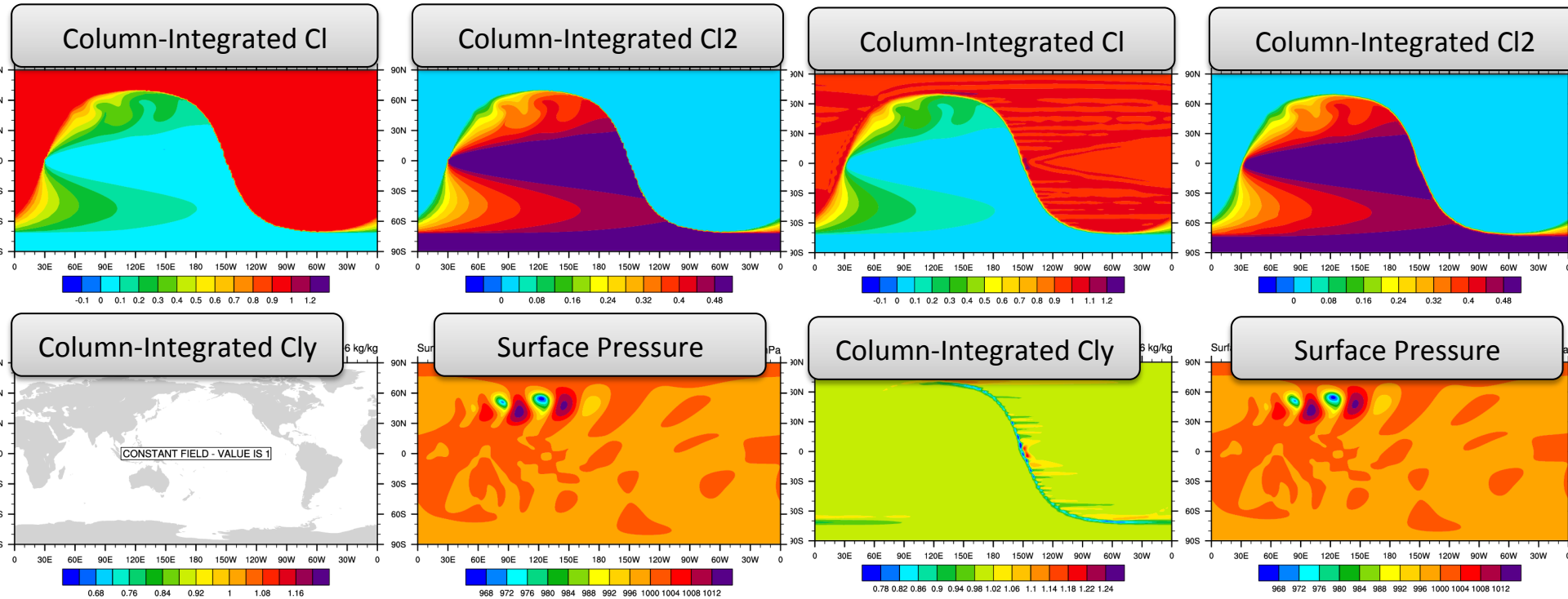


Correct (analytical) solution

Test 1: Terminator Chemistry

Day 9 results with baroclinic wave background dynamics.

HOMME-CSLAM | **HOMME-SE**



Correct Solution

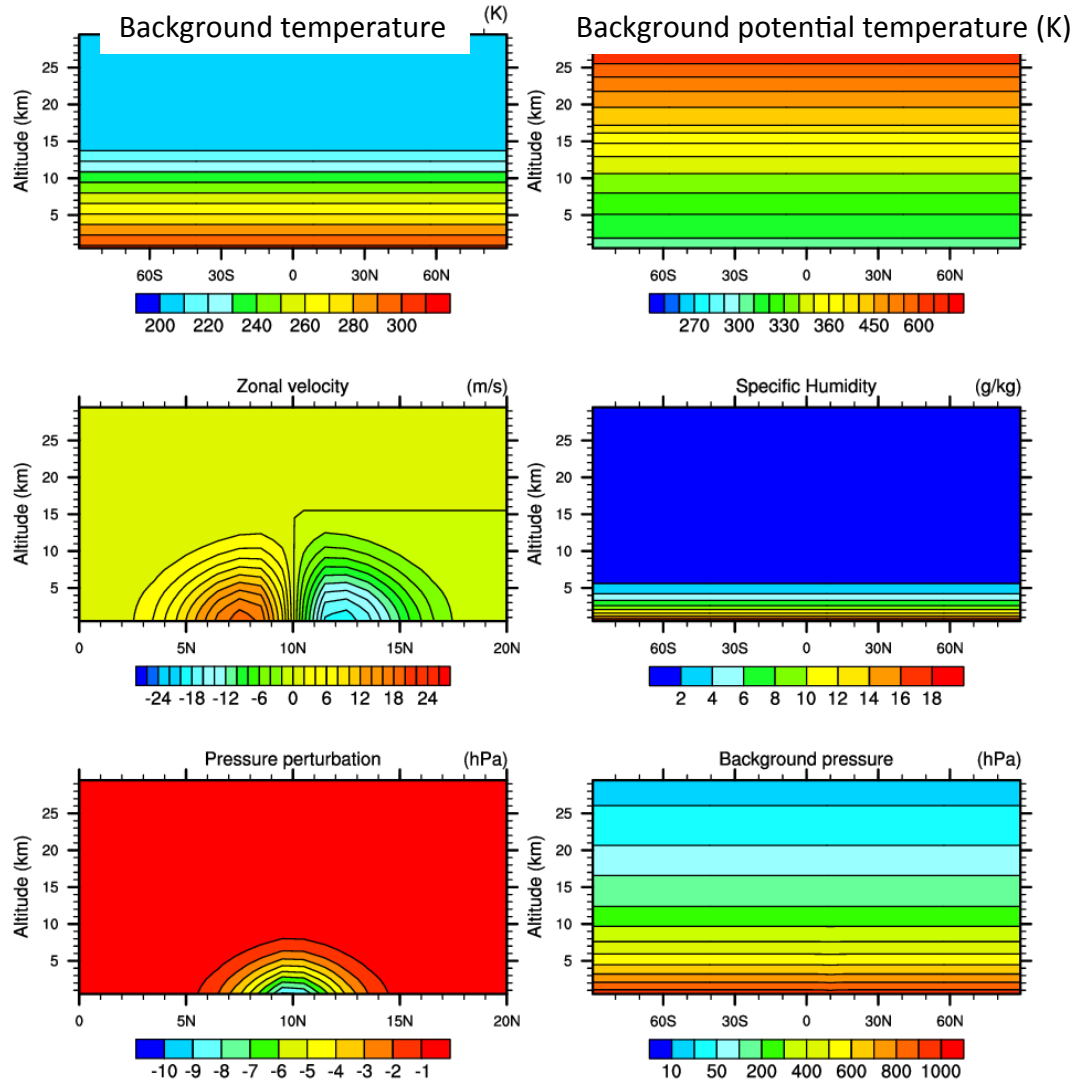
Spurious artifacts:
tracer correlation broken

Test 2: Tropical Cyclone

Initial conditions

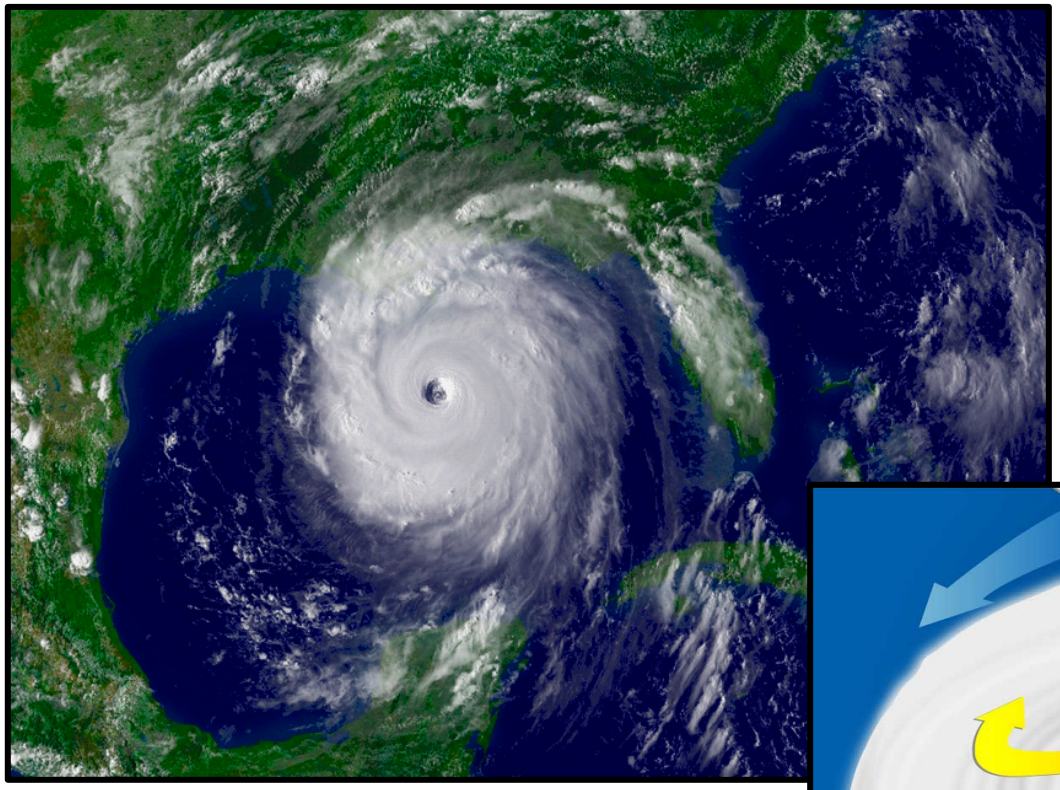
The moist tropical cyclone test incorporates a nearly convectively unstable atmospheric state using the Jordan tropical sounding:

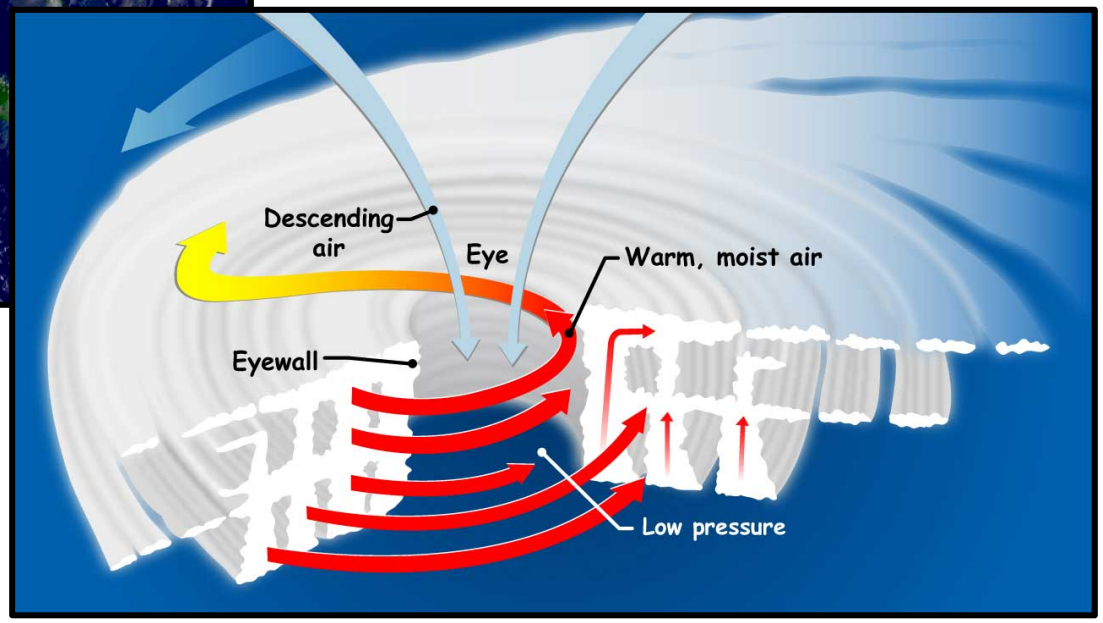
- Zero bottom topography
- Localized feature
- Initial profile in gradient wind balance
- Incorporates surface fluxes and boundary layer



Reference: Reed KA and Jablonowski C. "Idealized tropical cyclone simulations of intermediate complexity: a test case for AGCMs." *J. Adv. Model. Earth Syst.* 2012; 4:M04 001, doi:10.1029/2011MS000099.

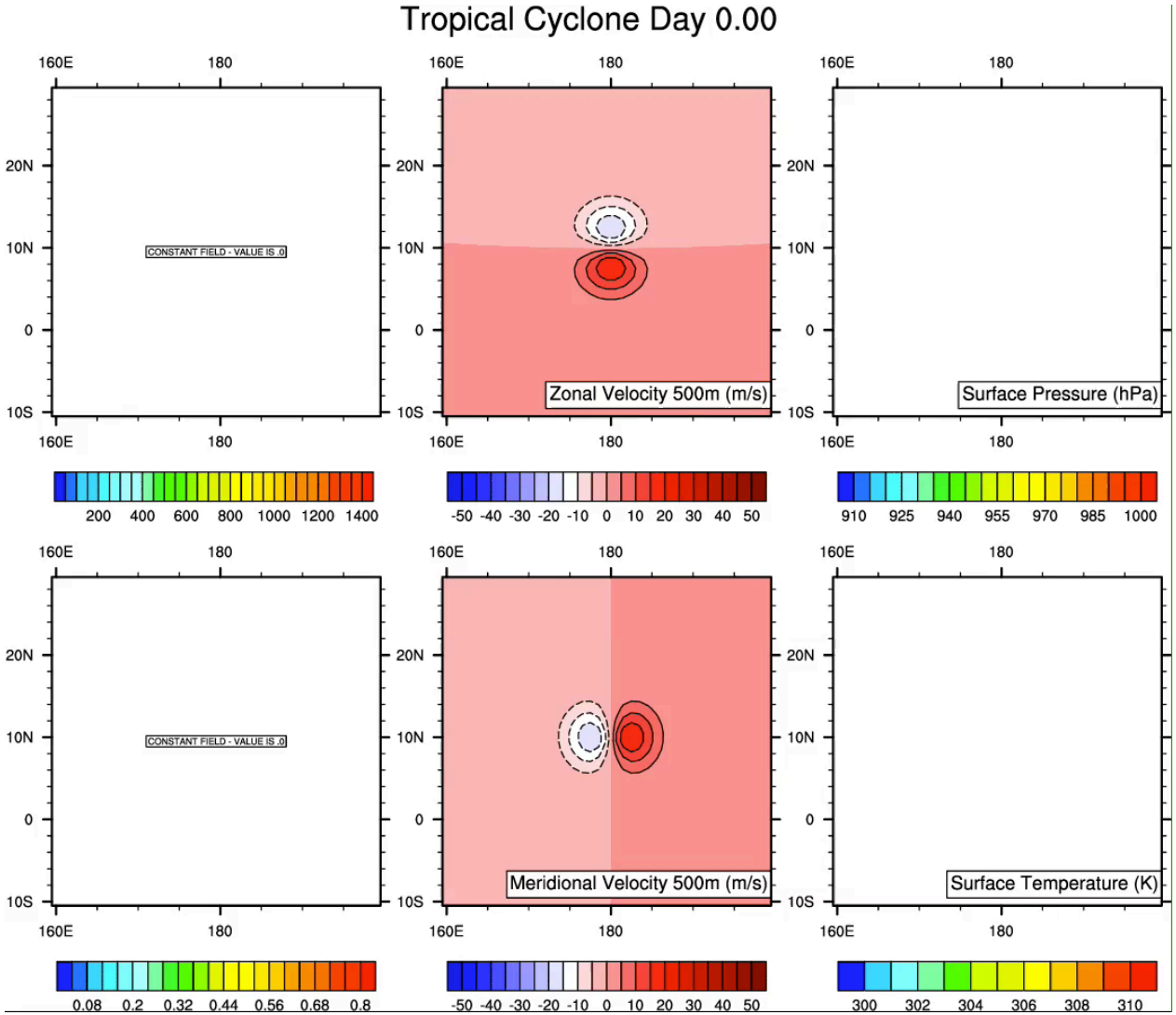
Test 2: Tropical Cyclone





Tropical Cyclone

Test 2: Tropical Cyclone



Reference: Reed KA and Jablonowski C. "Idealized tropical cyclone simulations of intermediate complexity: a test case for AGCMs." *J. Adv. Model. Earth Syst.* 2012; 4:M04 001, doi:10.1029/2011MS000099.

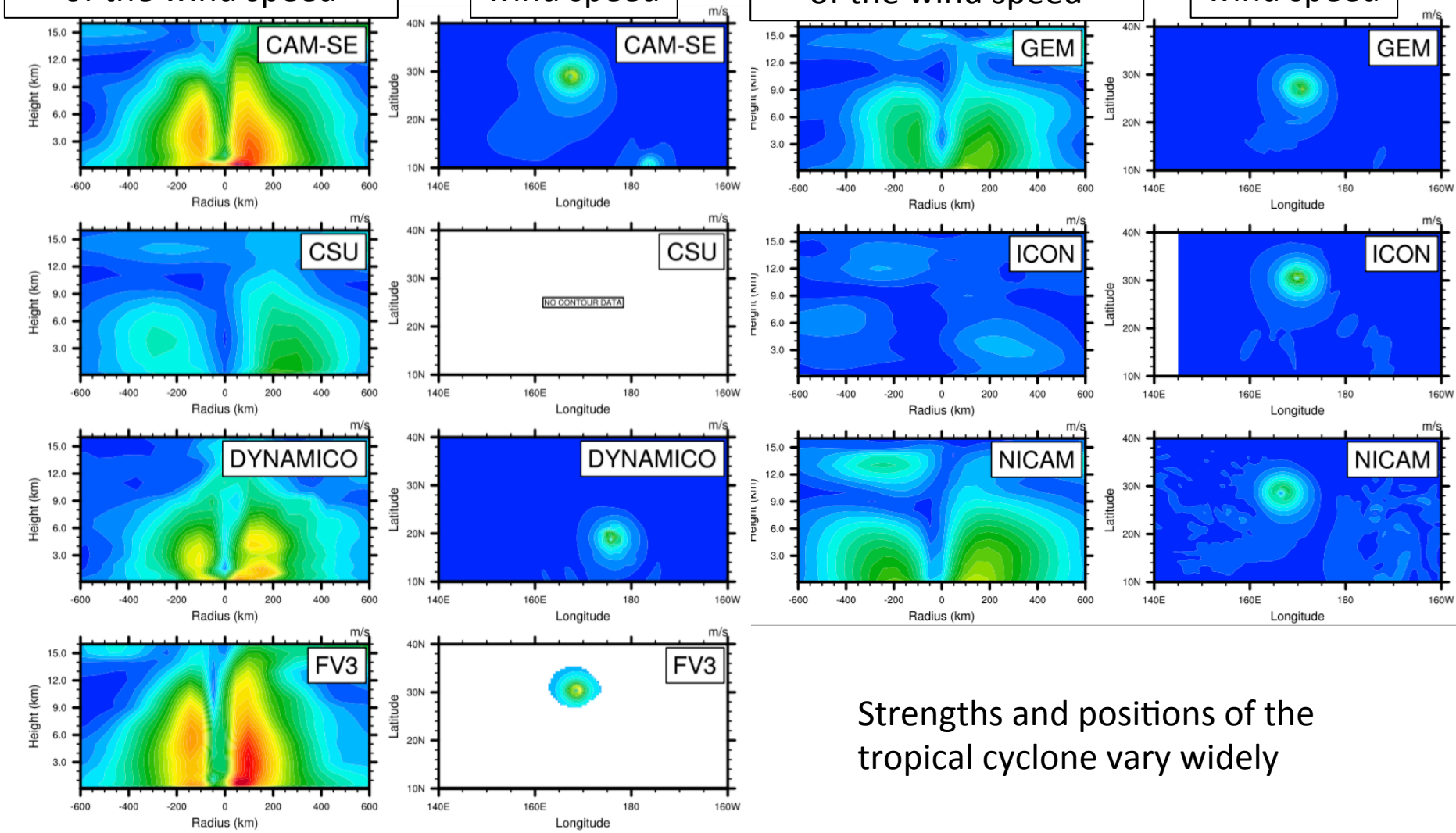
Test 2: Tropical Cyclone at Day 10

Lat-height cross section of the wind speed

850 hPa wind speed

Lat-height cross section of the wind speed

850 hPa wind speed



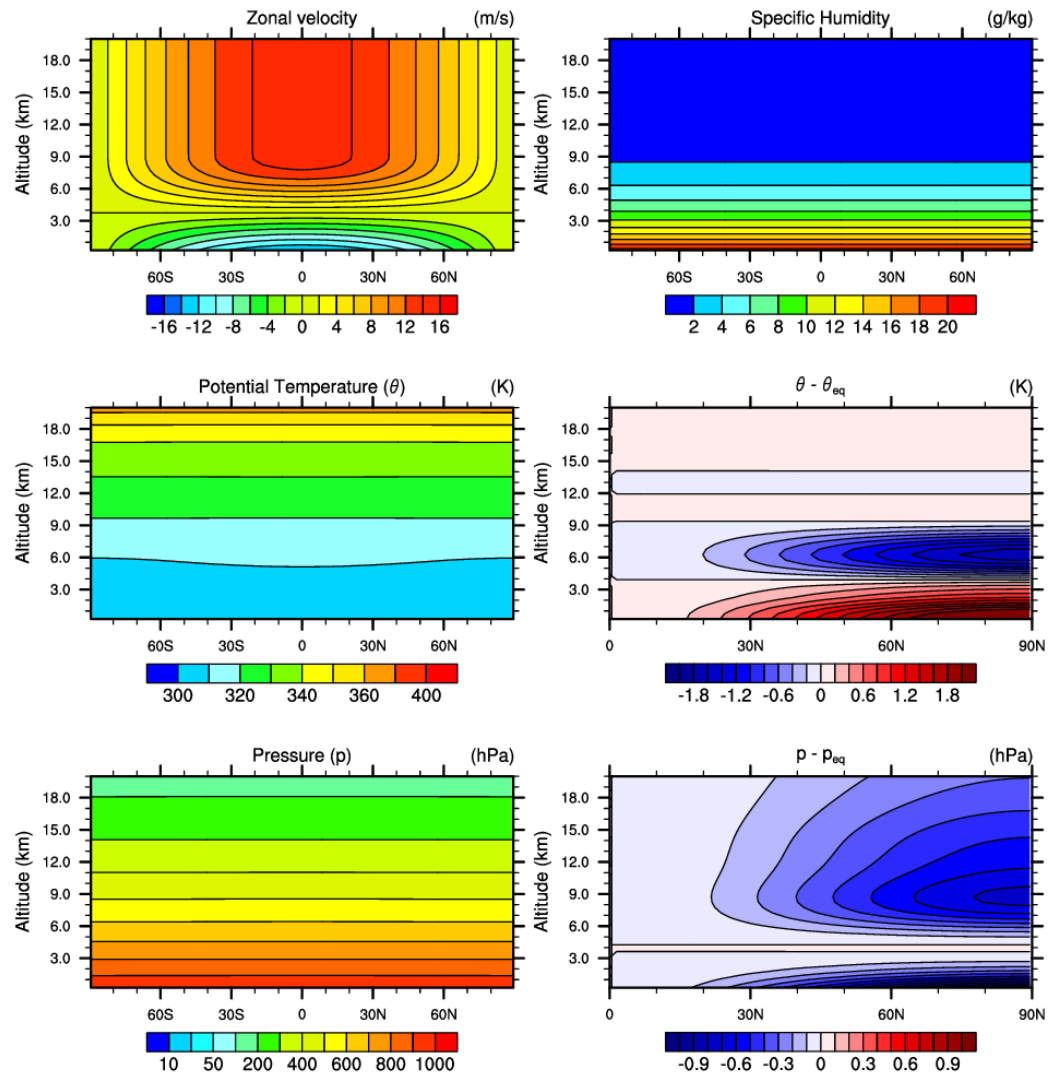
Strengths and positions of the tropical cyclone vary widely

Test 3: Supercell

Initial conditions

The supercell on a reduced radius sphere mimics a traditional test case for mesoscale dynamics.

- Zero bottom topography
- Localized feature
- Non-hydrostatic dynamics
- Initial profile in gradient and hydrostatic balance
- Reduced radius (X=120)
- No Coriolis force

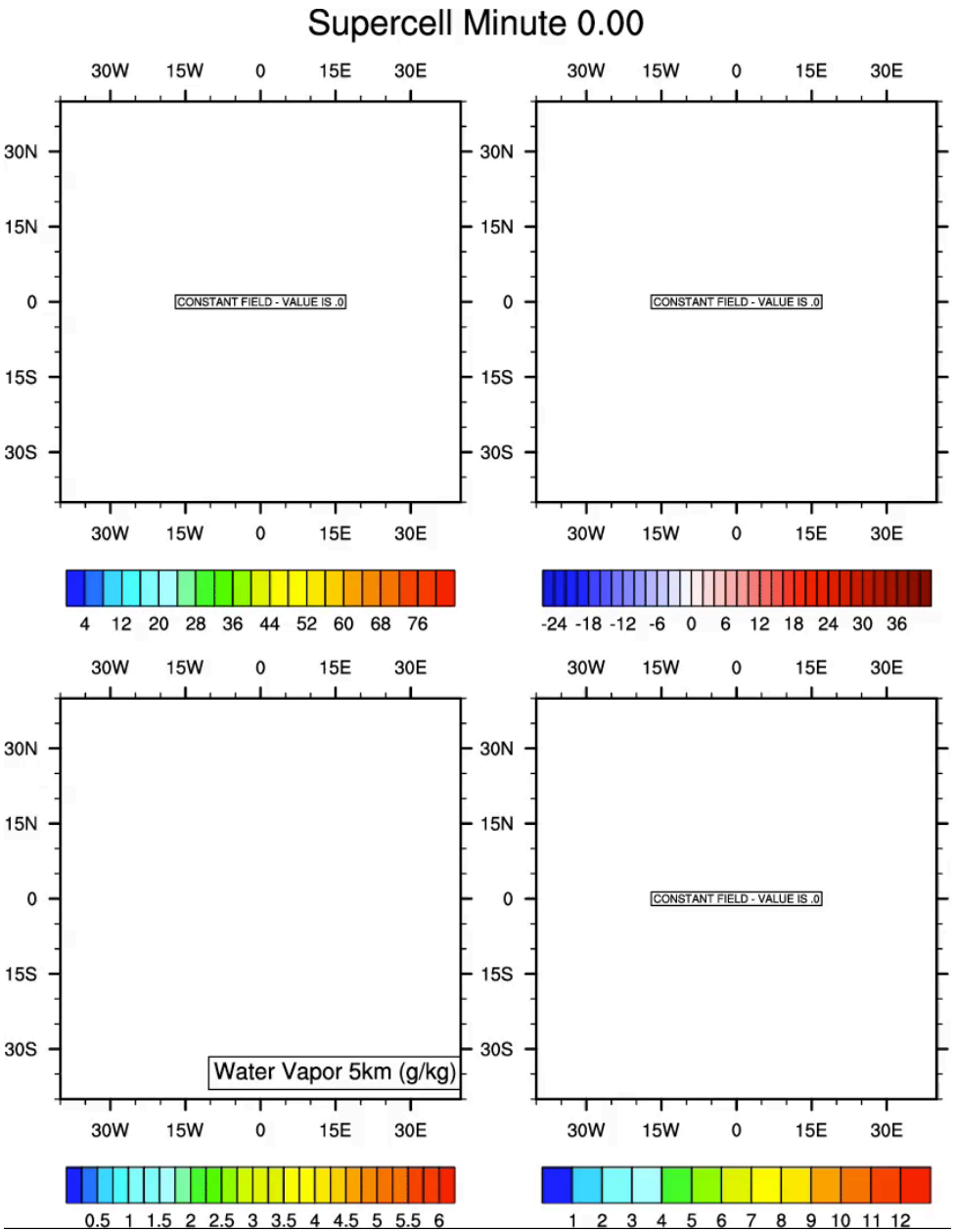


Reference: J. B. Klemp, W.C. Skamarock, and S.-H. Park (2015) "Idealized global nonhydrostatic atmospheric test cases on a reduced-radius sphere." *J. Adv. Model. Earth Syst.*, 07, doi:10.1002/ 2015MS000435

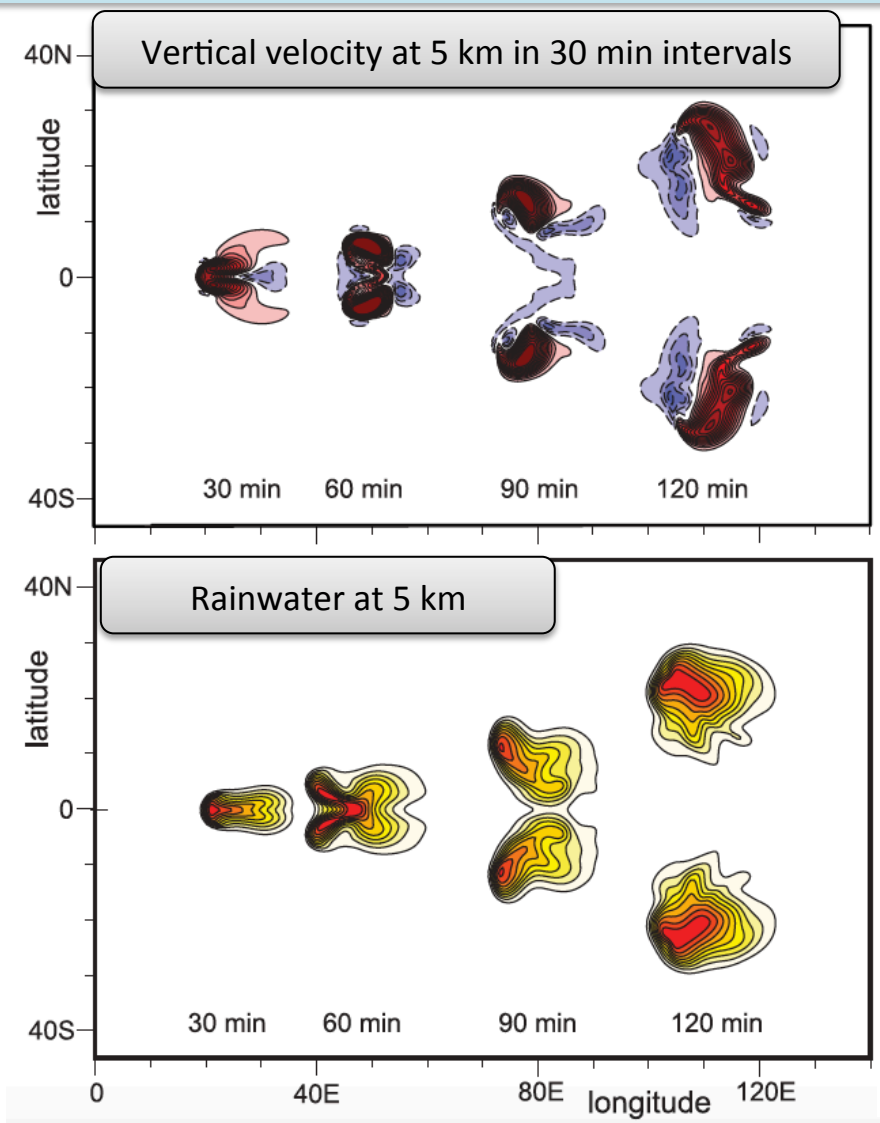
Test 3: Supercell

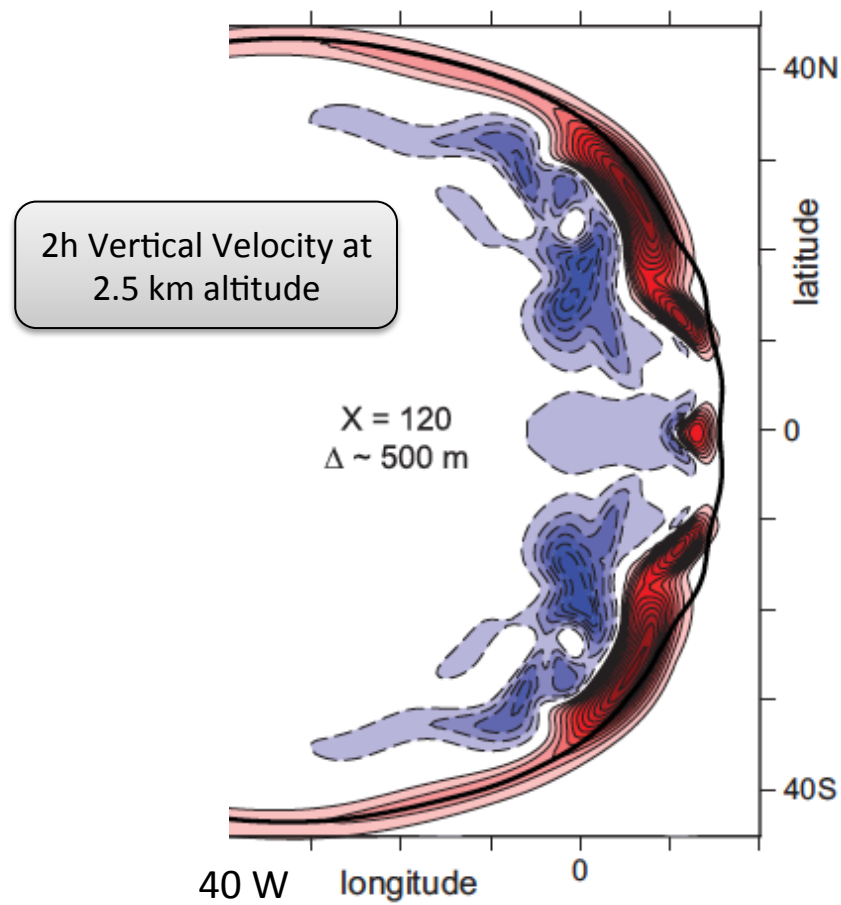
Test 3: Supercell

Right: Preliminary simulation of the supercell.



Test 3: Supercell

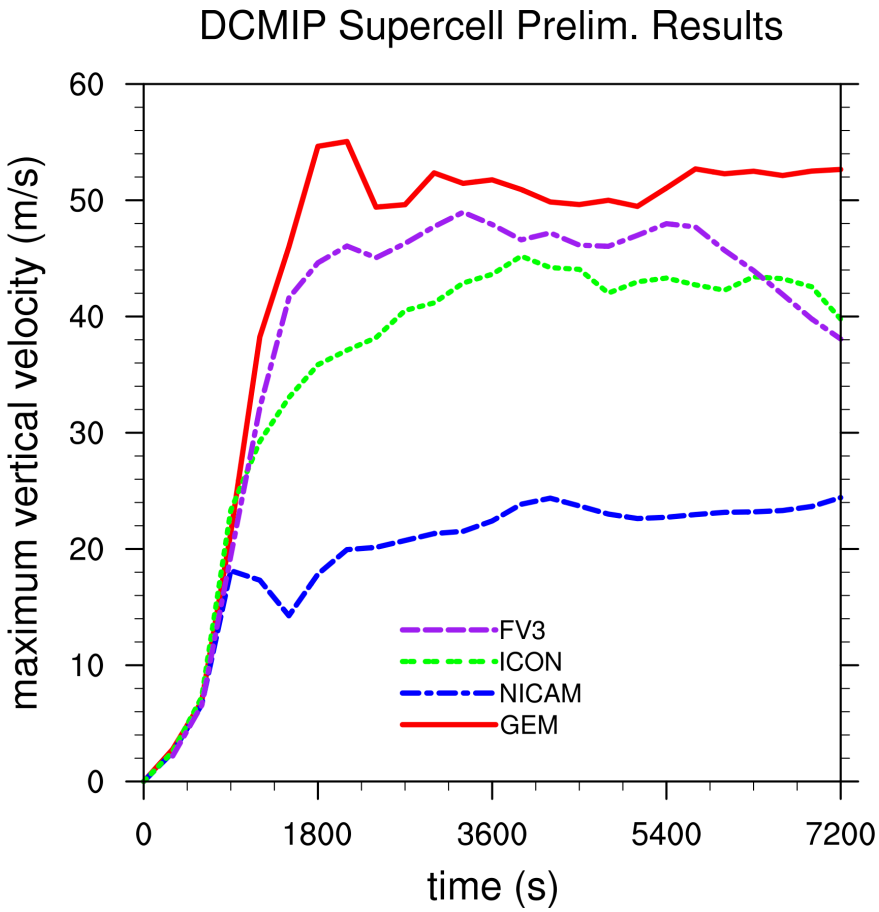




Reference: J. B. Klemp, W.C. Skamarock, and S.-H. Park (2015): Idealized global nonhydrostatic atmospheric test cases on a reduced-radius sphere. *J. Adv. Model. Earth Syst.*, 07, doi:10.1002/ 2015MS000435

Test 3: Supercell

Right: Maximum vertical velocity as a function of time. Few modeling groups were able to produce acceptable results for this test, emphasizing its inherent difficulty.



DCMIP-2016: Follow-up

- A survey was circulated among students and model mentors soliciting feedback on the workshop. Many students reported that DCMIP-2016 "**was the best workshop they had ever attended**."

- Work is ongoing on publications related to DCMIP-2016. As expected, model data had to be validated and tested to conform to our standards. Much of the data is published on the Earth System Grid Federation.

Publications (Under Development)

Four Peer-Reviewed Publications (Special issue of GMD)

- A review of modern technology underlying non-hydrostatic dynamical cores.
  https://github.com/DCMIP2016/DCMIP2016-Part1-Models

- Moist baroclinic wave test with Terminator chemistry
  https://github.com/DCMIP2016/DCMIP2016-Part2-BaroclinicWave

- Idealized tropical cyclone
  https://github.com/DCMIP2016/DCMIP2016-Part3-TropicalCyclone

- Idealized splitting supercell
  https://github.com/DCMIP2016/DCMIP2016-Part4-Supercell

Dynamical Core Model Intercomparison Project 2016

Thanks!

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