Updates on the Dynamical Core Model Intercomparison Project (DCMIP)

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DCMIP

PDEs on the Sphere Workshop, Boulder, 4/11/2014

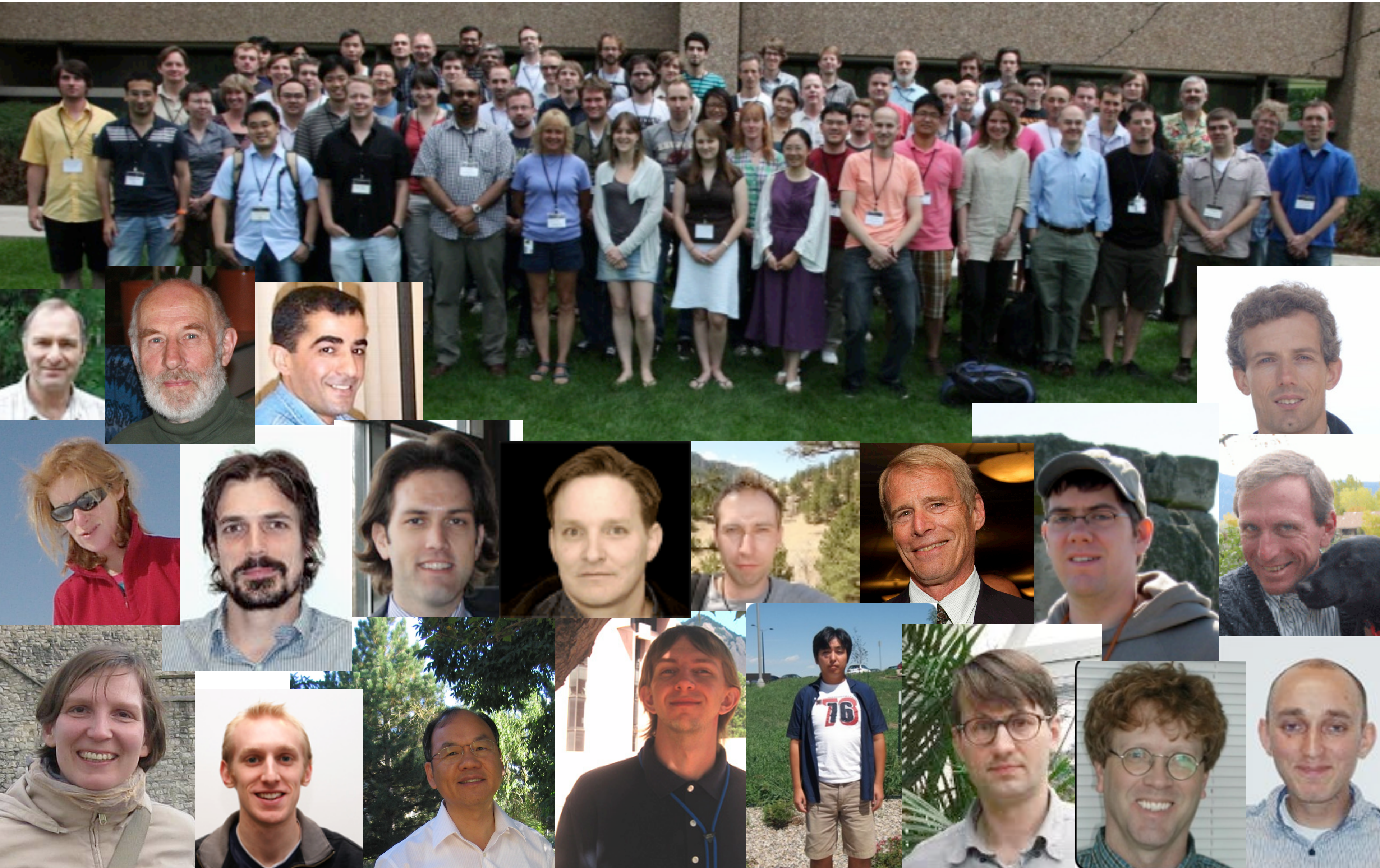
The Ideas behind DCMIP

- The 2-week summer school and model intercomparison project DCMIP-2012 highlighted the newest modeling techniques for global climate and weather models
- Took place at NCAR from July/30-August/10/2012
- Brought together over 26 modeling mentors and organizers, 37 students, and 19 speakers
- DCMIP-2012 paid special attention to emerging non-hydrostatic dynamical cores
- Hosted 18 participating dynamical cores (3 remote groups)

The Ideas behind DCMIP

- DCMIP-2012
  - Taught students, postdocs and the GCM community, both via lectures and hands-on sessions, at NCAR and elsewhere in the world (via the webcast and recordings): http://earthsystemcog.org/projects/dcmip-2012/lectures
  - Conducted an international dynamical core model intercomparison
  - Defined, tested and probably established new dynamical core tests
- Our vision: establish DCMIP as a long-term virtual community via the cyberinfrastructure-supported workspace
- Gateway to the virtual community, and open invitation to become a member and participate: http://earthsystemcog.org/projects/dcmip-2012/

DCMIP Participants & Modeling Mentors



DCMIP-2012


ICON-MPI-DWD
CAM-FV


CAM-SE
MCORE
UZIM
FV3-GFDL
IFS
MPAS
OLAM
ICON-IAP
DYNAMICO
ENDGame
FIM
NICAM
NIM

DCMIP: Some Outcomes & Thoughts

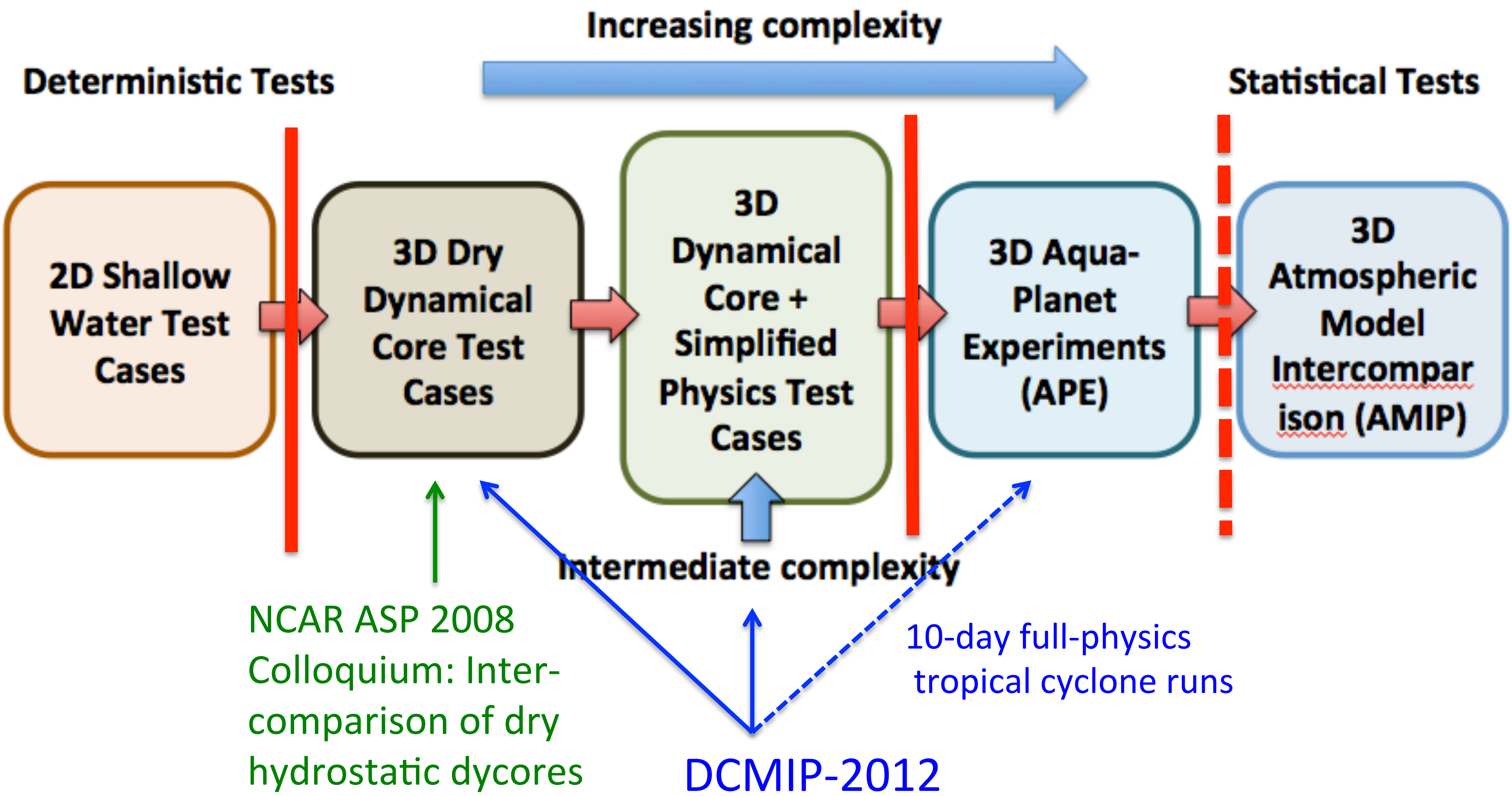
- DCMIP-2012 exposed very interesting agreements and spreads among the results, and exposed the characteristics of the numerical schemes
- Mentors have found bugs in the codes, DCMIP accelerated the modeling efforts of some groups
- We have found some issues in the DCMIP test cases: e.g. initialization of 3.1 (gravity wave) for models with pressure-based vertical coordinates had slight imbalance
- We might want/need to fine-tune the test cases, potentially replace some and/or add others to the list
- The responses we got from modeling mentors and student participants were very positive. Nevertheless, the DCMIP experience for all can be further optimized.

DCMIP Test Cases: Goals and Wish-List

Test cases should

- be designed for **hydrostatic** and **non-hydrostatic** dynamical cores on the sphere,
  ideally: for both **shallow** and **deep atmosphere** models
- be easy to apply: analytic initial data (if possible)
  suitable for **all grids**
  formulated for **different vertical coordinates**
- be as easy as possible, but as complex as necessary
- be cheap and easy to evaluate: **small Earth,** standard diagnostics
- be relevant to atmospheric phenomena
- reveal important characteristics of the numerical scheme
- have an analytic solution or converged reference solutions
- **deal with moisture in a simple way**
- find broad acceptance in the modeling community

DCMIP Test Cases: Hierarchy with increasing complexity

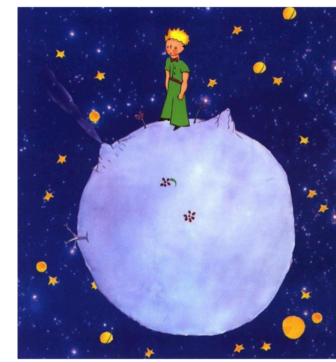


The Architecture of the DCMIP Test Suite

The tests are hierarchical and increase in complexity

http://earthsystemcog.org/projects/dcmip-2012/test_cases

- **3D Advection**
  - Pure 3D advection without orography
  - Pure 3D advection in the presence of orography
- **Dry dynamical core without rotation**
  - Stability of a steady-state at rest in presence of a mountain
  - Mountain-induced gravity waves on small planets
  - Thermally induced gravity waves on small planets



- **Dry dynamical core with the Earth's rotation**
  - From large (hydrostatic) to small (nonhydrostatic) scales, nonlinear baroclinic waves on a shrinking planet with dynamic tracers PV and θ
- **Simple moisture feedbacks**
  - Moist baroclinic waves with large-scale condensation
  - Moist baroclinic waves with simplified physics (simple-physics)
  - Idealized tropical cyclones

The DCMIP Test Case Hierarchy

Table 1: Overview of all DCMIP test cases

11	3D deformational flow
12	3D Hadley-like meridional circulation
13	2D transport of thin cloud-like tracers in the presence of orography
200	optional: Steady-state at rest in the presence of moderatley-steep orography
201	optional: Steady-state at rest in the presence of steep orography on a small planet (X=500)
21	Mountain waves over a Schaer-type mountain on a small planet without shear (X=500)
22	Mountain waves over a Schaer-type mountain on a small planet with shear (X=500)
31	Gravity wave on a small planet, along the equator (X=125)
410	Dry baroclinic instability with dynamic tracers EPV and Θ and X=1
411	Dry baroclinic instability with dynamic tracers EPV and Θ and X=10 (scaled small planet)
412	Dry baroclinic instability with dynamic tracers EPV and Θ and X=100 (scaled small planet)
413	Dry baroclinic instability with dynamic tracers EPV and Θ and X=1000 (scaled small planet)
42	Moist baroclinic instability (with large-scale condensation)
43	optional: Moist baroclinic instability (with simplified physics forcing)
51	Idealized tropical cyclone (with simplified physics forcing)
52	optional: Idealized tropical cyclone (with full physics forcing)

Check the DCMIP-2012 web page

DCMIP-2012 Results

DCMIP-2012 not complete (yet)!

Some data sets need to be updated (errors in the initial conditions or problems in runs) and further quality checked.

Some data sets are still not online due to formatting issues (non-CF- and DCMIP-compliant NetCDF format, missing metadata).

DCMIP-2012
- Home
- Announcements
- Organizers
- Sponsors & Host
- How to Use CoG
- Reimbursements
- Photo Gallery

Modeling Groups
- Info
- Mod
- Mod
- CAM-FV
- CAM-SE
- DYNAMICO
- ENDGame
- FIM
- FV3
- GE
- GE
- IFS
- ICO
- ICO
- MCORE
- MPAS
- NICAM
- NIM
- OLAM
- PU
- UZI
- ASA

Lec
- Spe
- Pres
- Lec
- Reading List

Test Cases
- Overview of Test Cases
- Fortran Routines
- Plots of Initial Data
- Example Results
- Results

Results by Model & Intercomparison

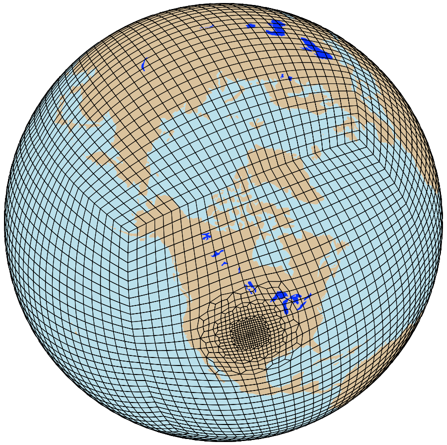
The following table contains links to the model result visualizations which can be found under each model page. For more interactive access to model data for comparison, please use the advanced data search.

Model	Pure Advection			Small Earth					Baroclinic Wave			Tropical Cyclone	
				Mountain				G Wave					
					2-0-1	2-1	2-2	3-1	4-1-x	4-2	4-3	5-1	5-2
					2-0-1	2-1	2-2	3-1	4-1-x	4-2	4-3	5-1	5-2
DYNAMICO	1-1	1-2	1-3	2-0-0	2-0-1	2-1	2-2	3-1	4-1-x	4-2	4-3	5-1	5-2
ENDGame	1-1	1-2	1-3	2-0-0	2-0-1	2-1	2-2	3-1	4-1-x	4-2	4-3	5-1	5-2
IFS	1-1	1-2	1-3	2-0-0	2-0-1	2-1	2-2	3-1	4-1-x	4-2	4-3	5-1	5-2
ICON-IAP	1-1	1-2	1-3	2-0-0	2-0-1	2-1	2-2	3-1	4-1-x	4-2	4-3	5-1	5-2
ICON-MPI-DWD	1-1	1-2	1-3	2-0-0	2-0-1	2-1	2-2	3-1	4-1-x	4-2	4-3	5-1	5-2
OLAM	1-1	1-2	1-3	2-0-0	2-0-1	2-1	2-2	3-1	4-1-x	4-2	4-3	5-1	5-2
PUMA	1-1	1-2	1-3	2-0-0	2-0-1	2-1	2-2	3-1	4-1-x	4-2	4-3	5-1	5-2
UZIM	1-1	1-2	1-3	2-0-0	2-0-1	2-1	2-2	3-1	4-1-x	4-2	4-3	5-1	5-2
Intercomparison	**1-1**	**1-2**	**1-3**	**2-0-0**	**2-0-1**	**2-1**	**2-2**	**3-1**	**4-1-x**	**4-2**	**4-3**	**5-1**	**5-2**

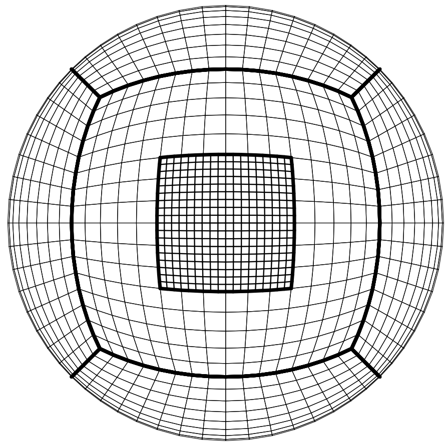
DCMIP – Going Forward

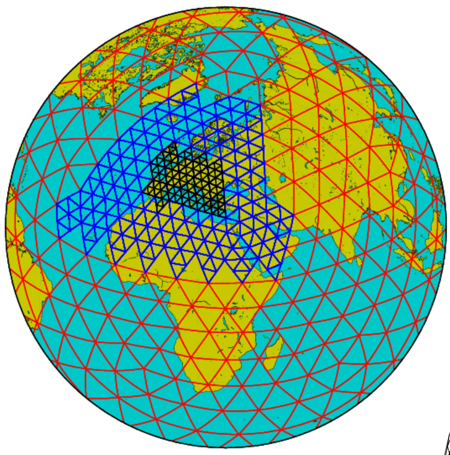
- Should there be another DCMIP, e.g. in June 2016?
- If there is interest, what are the scientific frontiers that we want to explore?
- What are the adequate test cases to answer our open model design questions? We need to address all scales (micro, meso, synoptic, planetary)!
- Should we change the format of DCMIP (e.g. fewer test scenarios run during DCMIP and submission of additional results ahead of time)? Longer? Shorter?
- Do we need stricter rules to determine the 'readiness' of model? The readiness of the DCMIP-2012 models and their mentors varied widely.

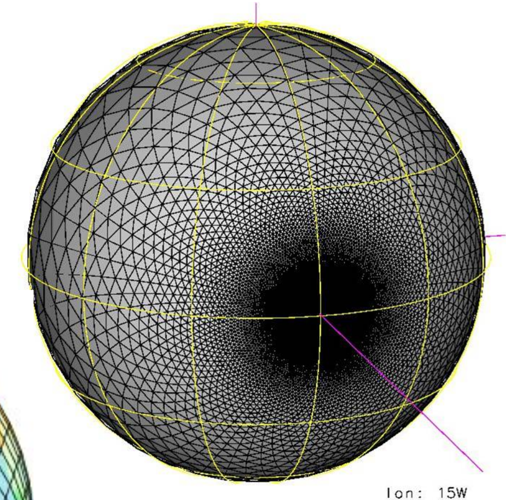
DCMIP-2016?

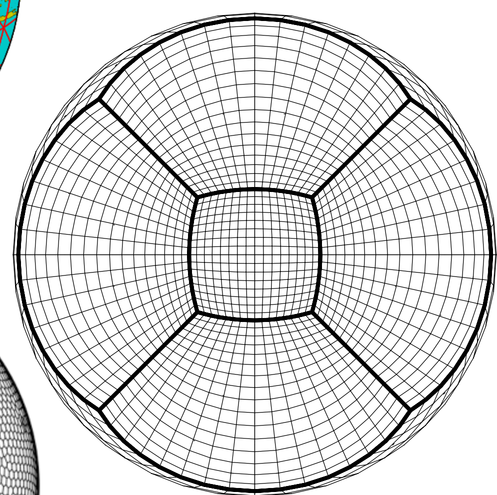


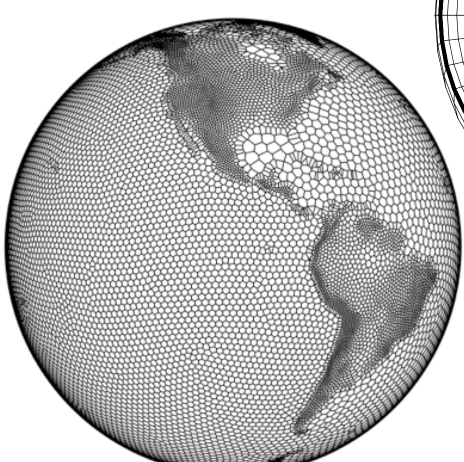
New Frontiers:
Nonhydrostatic models with **variable-resolution** static grids or **Adaptive Mesh Refinements (AMR)**

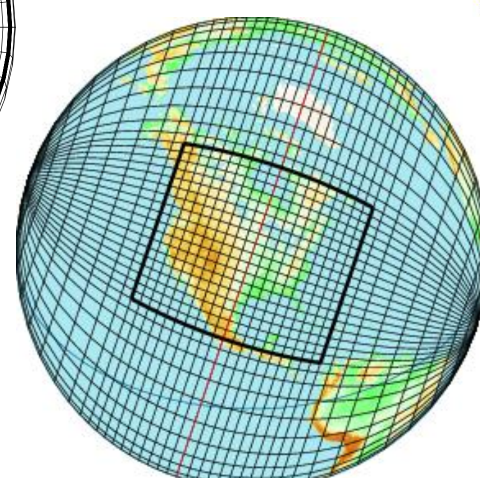










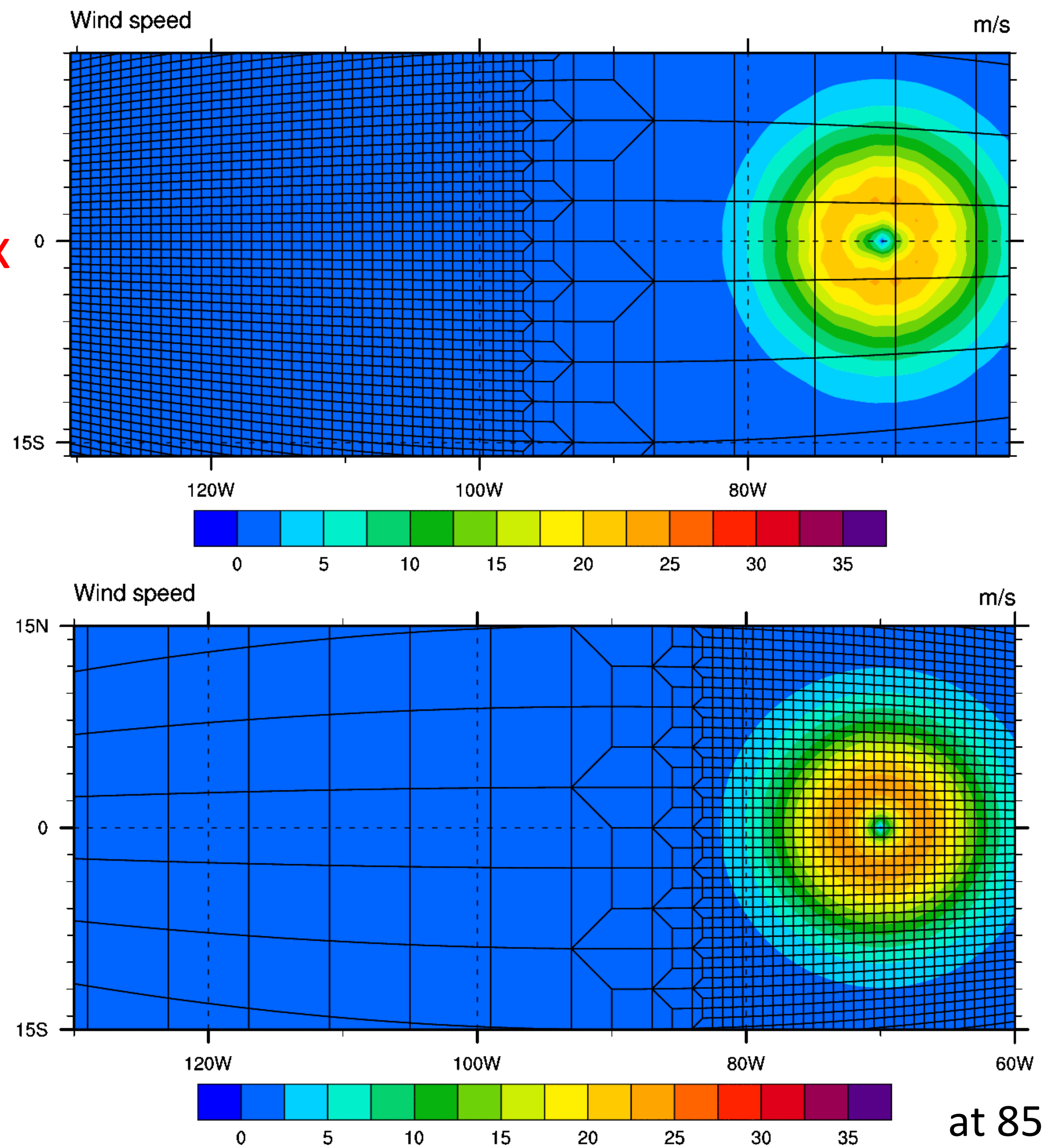


Variable-Resolution: Grid Transition Tests

Are there effects/ reflections in the grid transition area?
Translation of a dry vortex on a non-rotating Earth

Low to high transition

High to low transition



Zarzycki et al. (MWR, 2014)

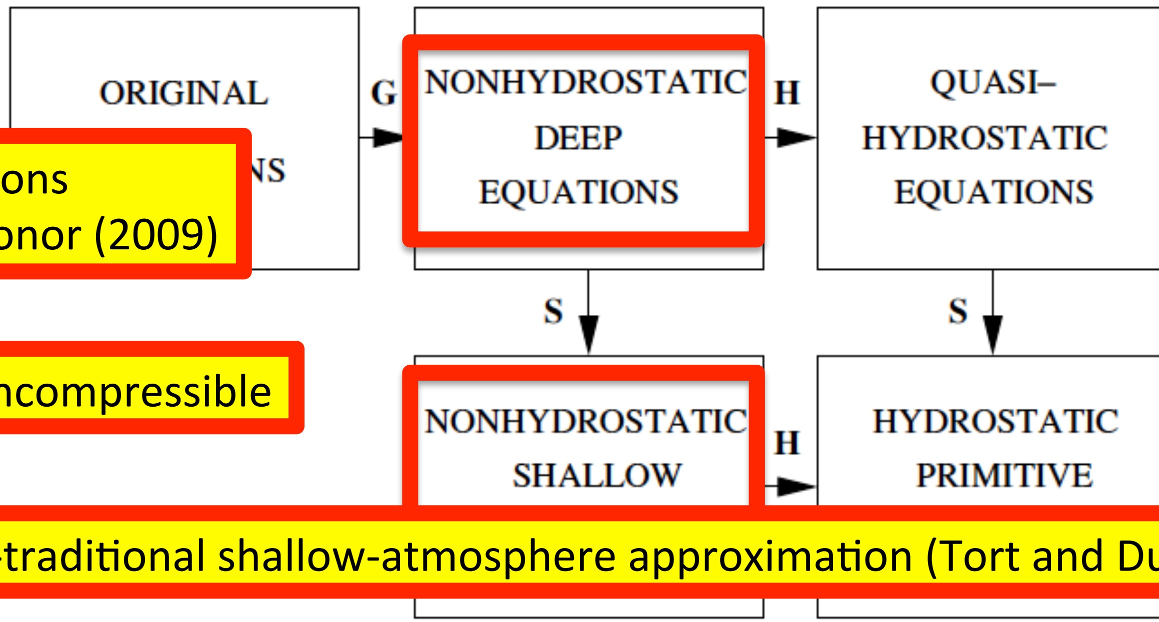
at 850 hPa

DCMIP-2016: New Equation Sets?

Q. J. R. Meteorol. Soc. (2005), **131**, pp. 2081–2107 doi: 10.1256/qj.04.49

Consistent approximate models of the global atmosphere: shallow, deep, hydrostatic, quasi-hydrostatic and non-hydrostatic

By A. A. WHITE[1]*, B. J. HOSKINS[2], I. ROULSTONE[1,3] and A. STANIFORTH[1]



'Unified' Equations
Arakawa and Konor (2009)

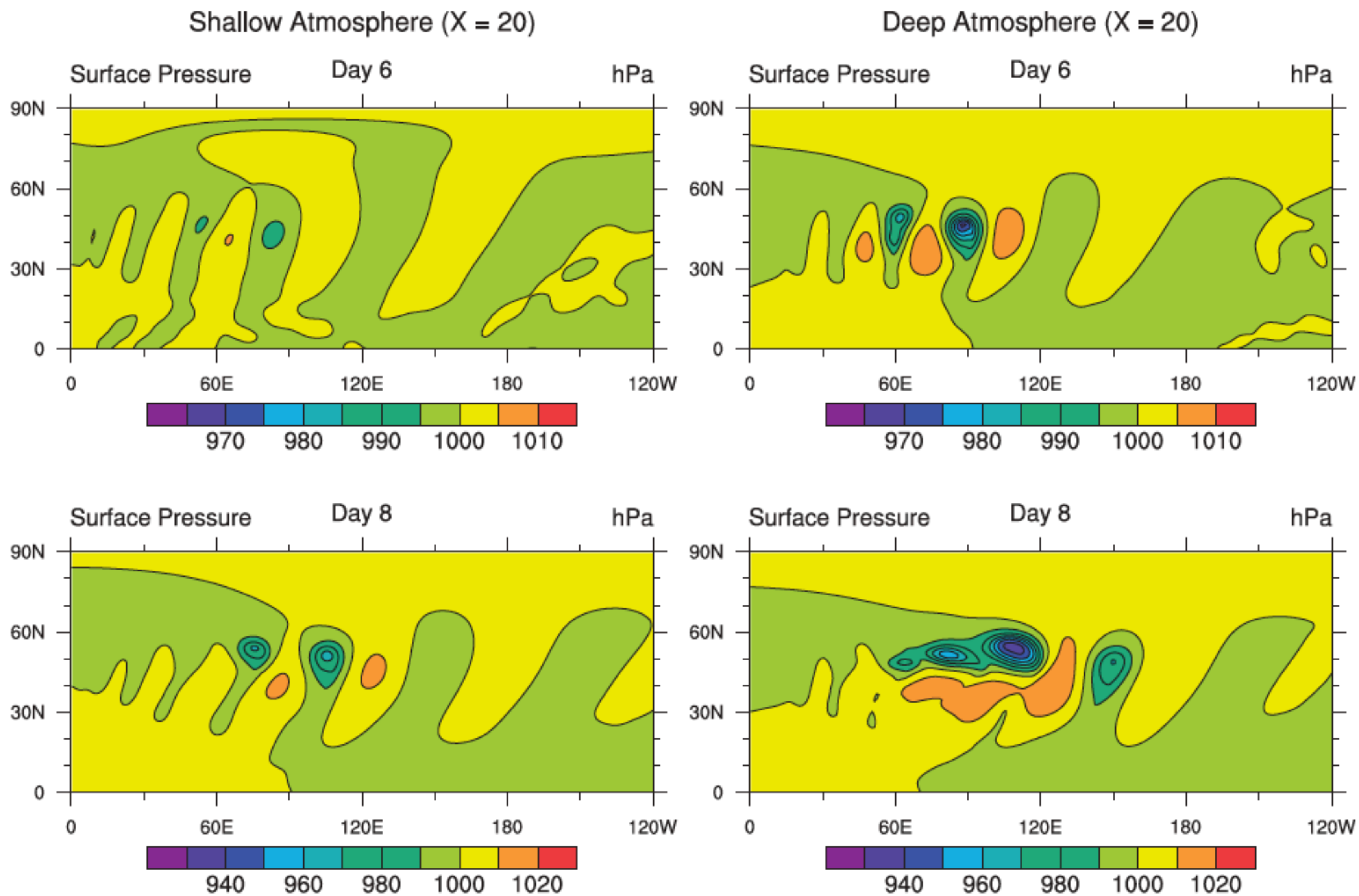
Pseudo-Incompressible

Non-traditional shallow-atmosphere approximation (Tort and Dubos, 2014)

Non-spherical Earth (White and Wood, 2012; Staniforth 2014)

Dw/Dt from the vertical component of the momentum equation, and **S** the approximations (see text).

Deep-Atmosphere Test: Baroclinic Wave



Small planet with reduction factor X=20

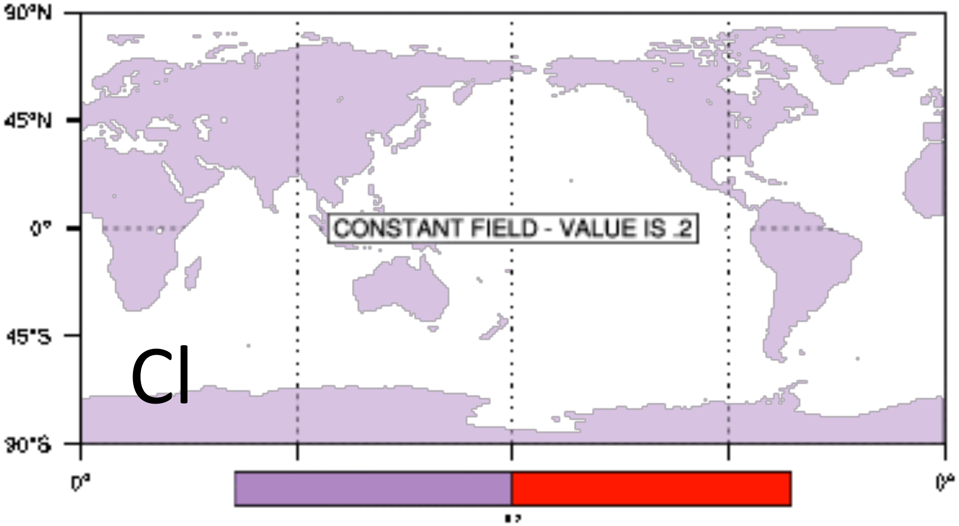
Ullrich et al. (QJ, 2014)

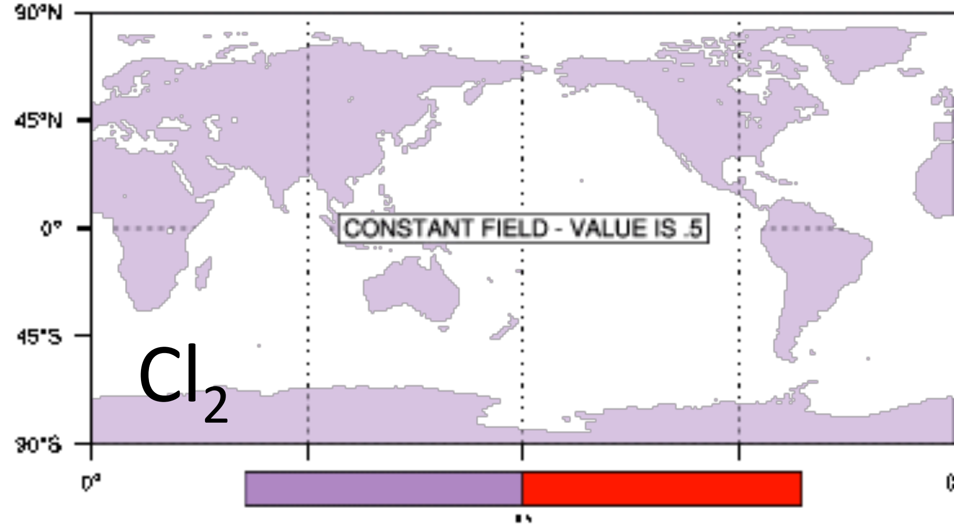
DCMIP-2016: Frontiers

- Consistent tracer transport
- (Linear) analytic solutions:
  - Gravity waves
  - Mountain-triggered gravity waves
- Vertical direction:
  - High model tops
  - Impact of vertical resolution
  - Consistency between horizontal and vertical resolutions, especially for small Δx, Δy grid spacings
- Pressure-gradient force (PGF) errors
- Extreme (steep) topography
- (Simple) moist interactions
- Long-term “climate-like” evaluations

Transport with toy-chemistry: The Terminator Test

Assess non-linearity of shape-preserving limiter and (maybe) physics-dynamics coupling



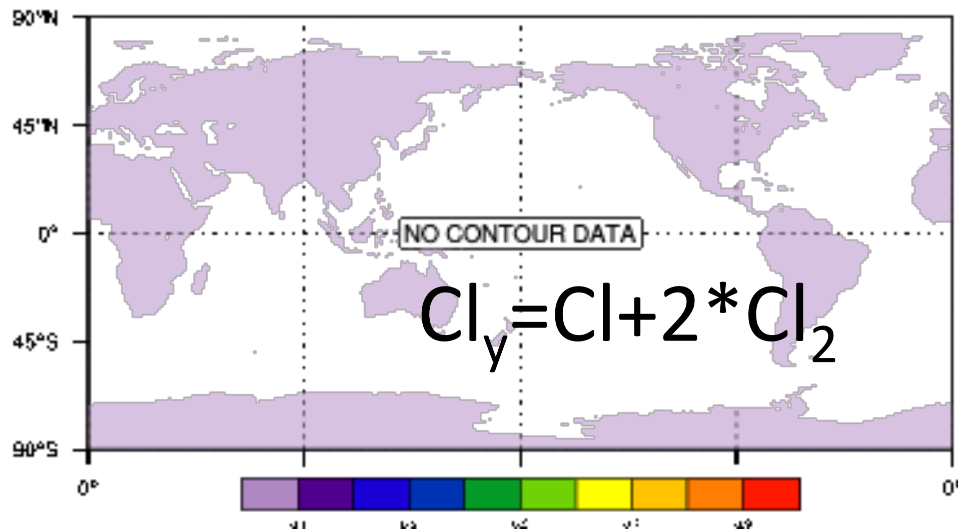


Non-linear "terminator-toy" chemistry:

$$Cl_2 \rightarrow Cl + Cl : k_1$$

$$Cl + Cl \rightarrow Cl_2 : k_2$$

Exact solution:
$Cl+2*Cl_2$ = constant



Animation: CSLAM with shape-preserving limiter

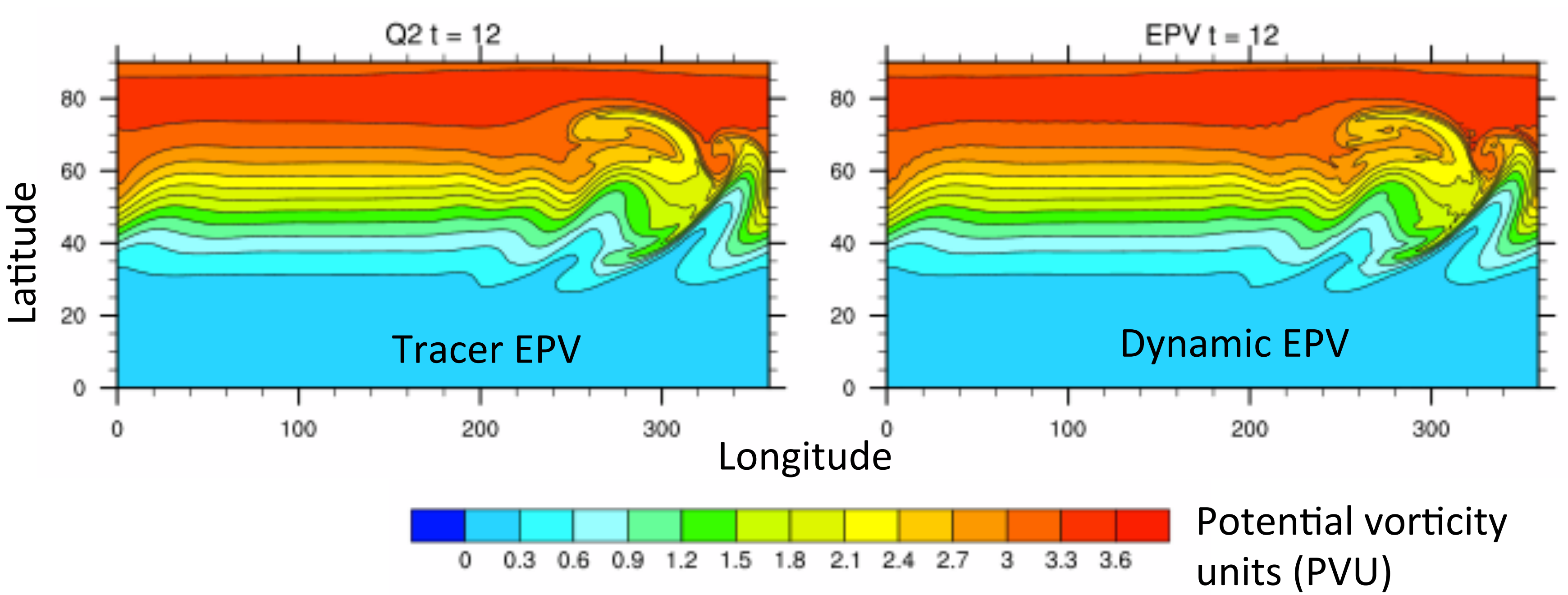
Prescribed flow: Nair and Lauritzen deformational winds

DCMIP-2016: 3D deformational flow by Kent et al. (2014) from DCMIP-2012

Research and slide by Peter Lauritzen

Baroclinic Wave: Dynamic Tracer Consistency

DCMIP Test 410:
Consistency of the Ertel potential vorticity (EPV) in CAM-FV (at day 12 on the 315 K isentropic level)



Compare the evolution of the dynamic EPV and EPV transported as a passive tracer

See also Whitehead et al. (QJ, in review)

1°x1° L30
dx = 110 km

DCMIP-2016: Frontiers

- Consistent tracer transport
- (Linear) analytic solutions:
  - Gravity waves
  - Mountain-triggered gravity waves
  - 3D Unsteady solid body rotation (Staniforth et al.)
- Vertical direction:
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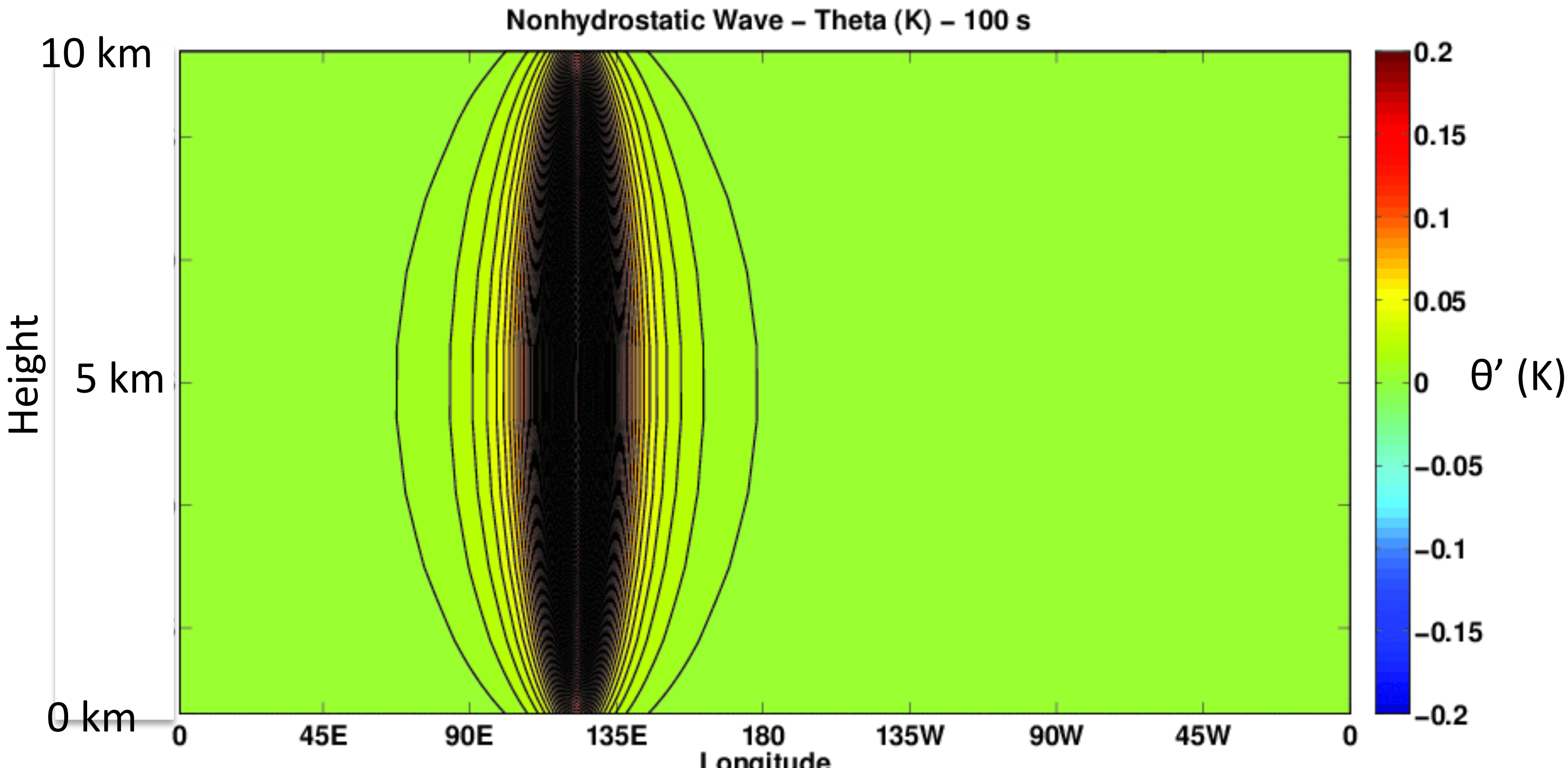
Warm Bubble Triggered Gravity Waves

Test 31 on reduced-size Earth with circumference ≈ 320 km:
with translating west wind: Example of nonhydrostatic response in the potential temperature perturbation θ’ (MCORE, animation)



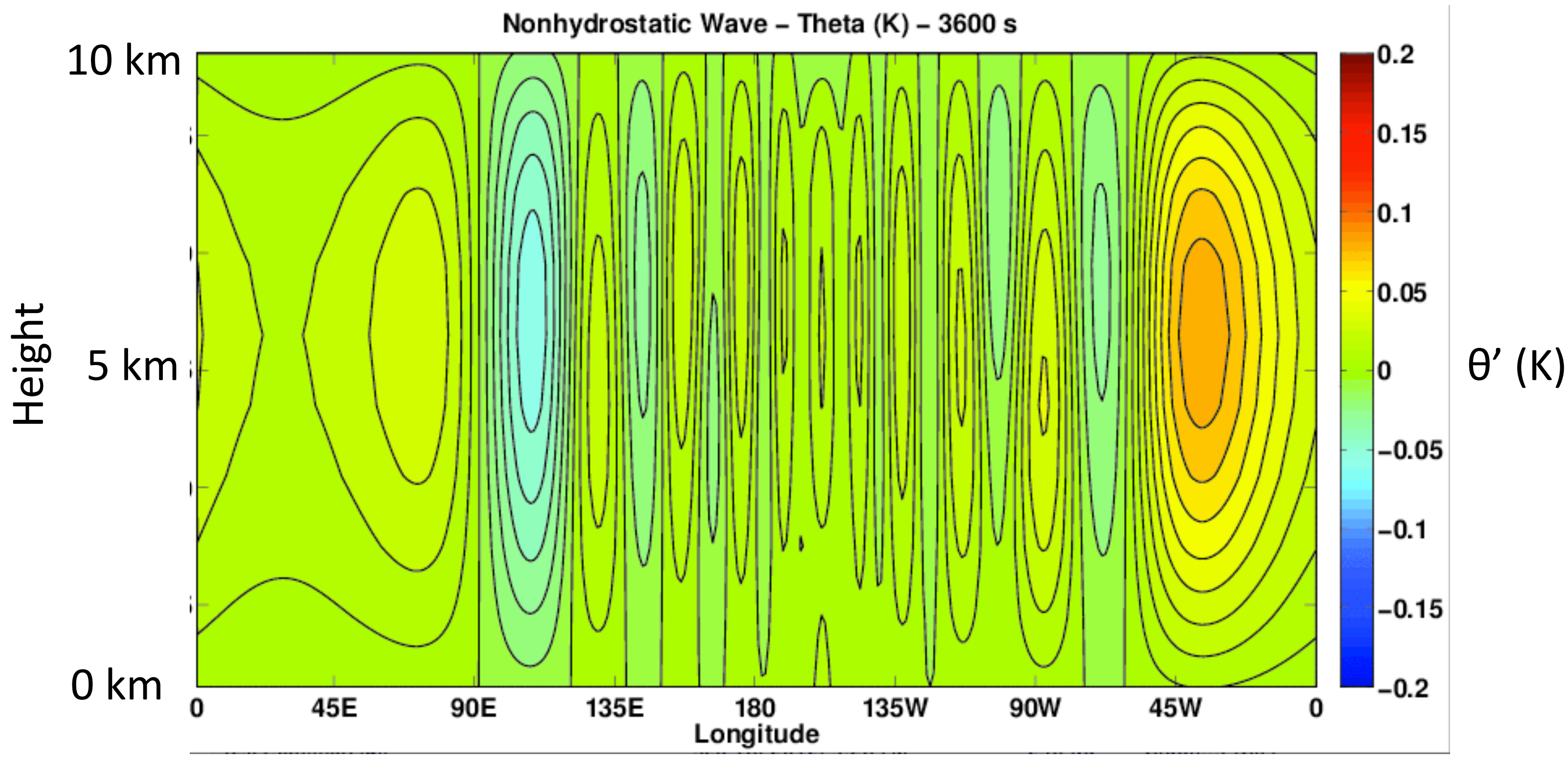
along the equator

dx= 1 km, dz = 1 km

Warm Bubble Triggered Gravity Waves

Test 31 on reduced-size Earth with circumference ≈ 320 km:

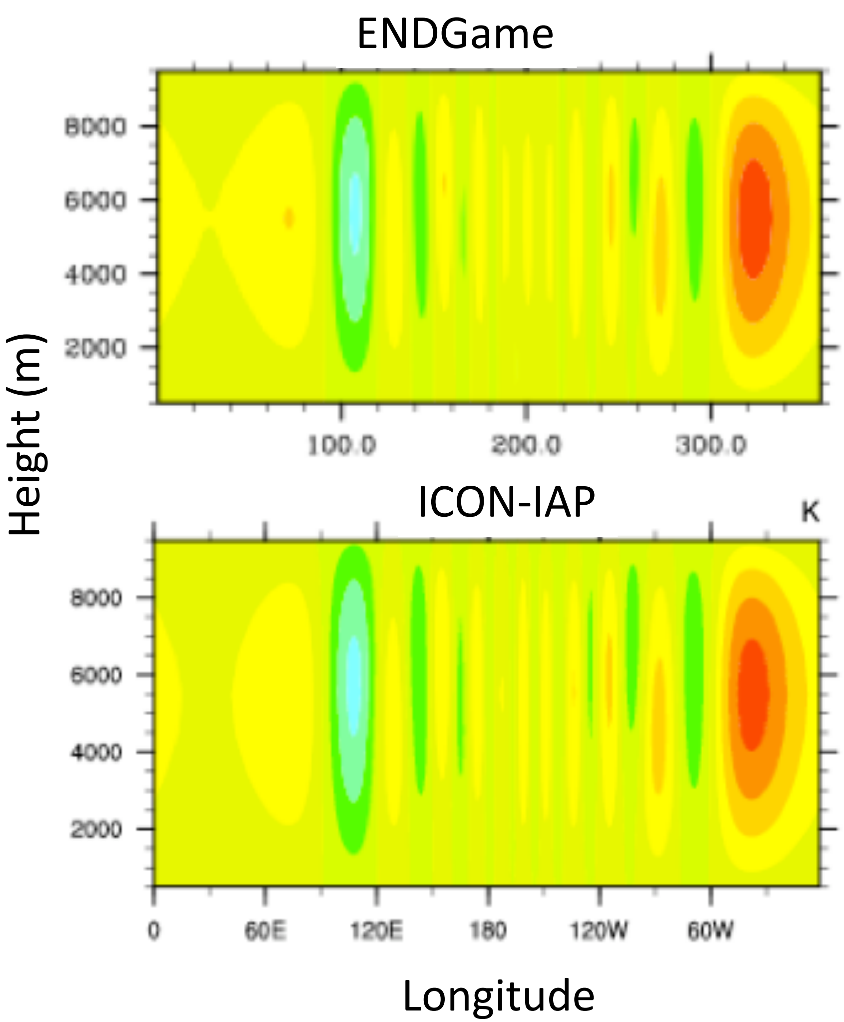
Potential temperature perturbation θ' (K) along the equator after 3600 s in MCORE

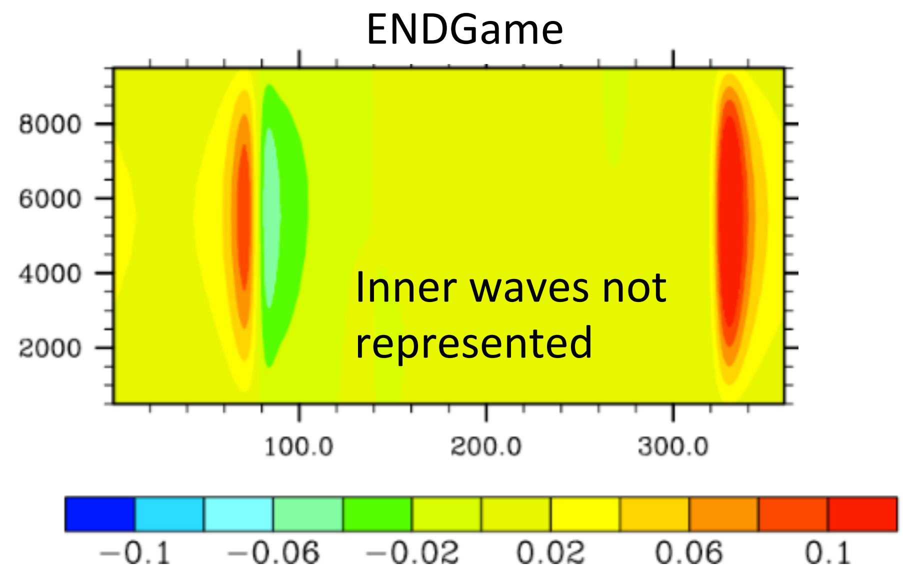


dx= 1 km, dz = 1 km

DCMIP Test 3.1: Gravity Waves

Non-hydrostatic | **Hydrostatic**



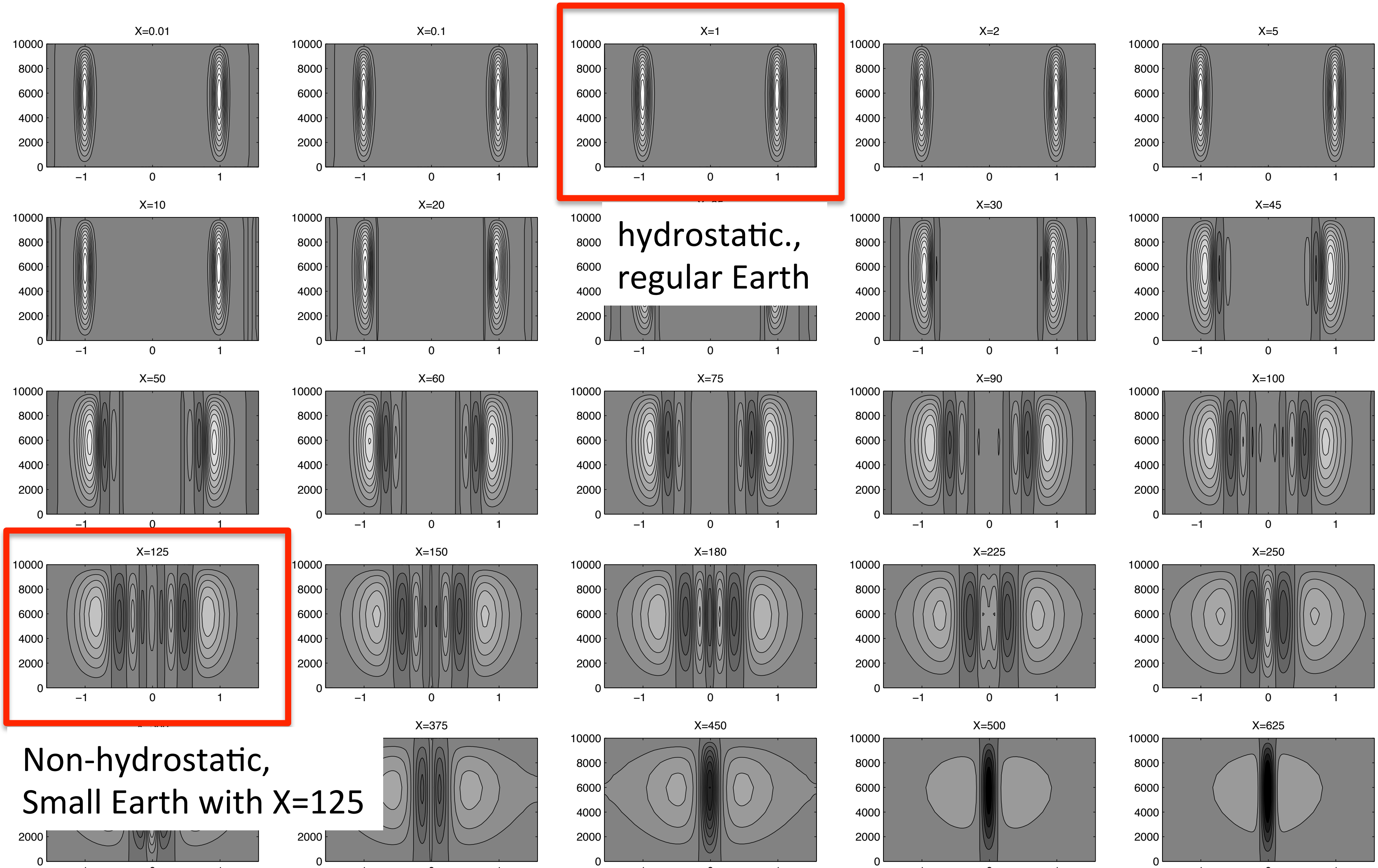


Potential temperature perturbation θ’ (K) at the equator after 3600 s

Compare: phase velocity, amplitude, symmetry properties, differences to hydrostatic solution

Test 31, dx= 1 km, dz = 1 km

Test Cases with Analytic Solutions: Gravity Wave



Should we modify DCMIP test 3.1 to match these linear solutions?
Or can we find an analytic solution to the existing test?

Baldauf et al. (QJ, 2014)

DCMIP-2016: Frontiers

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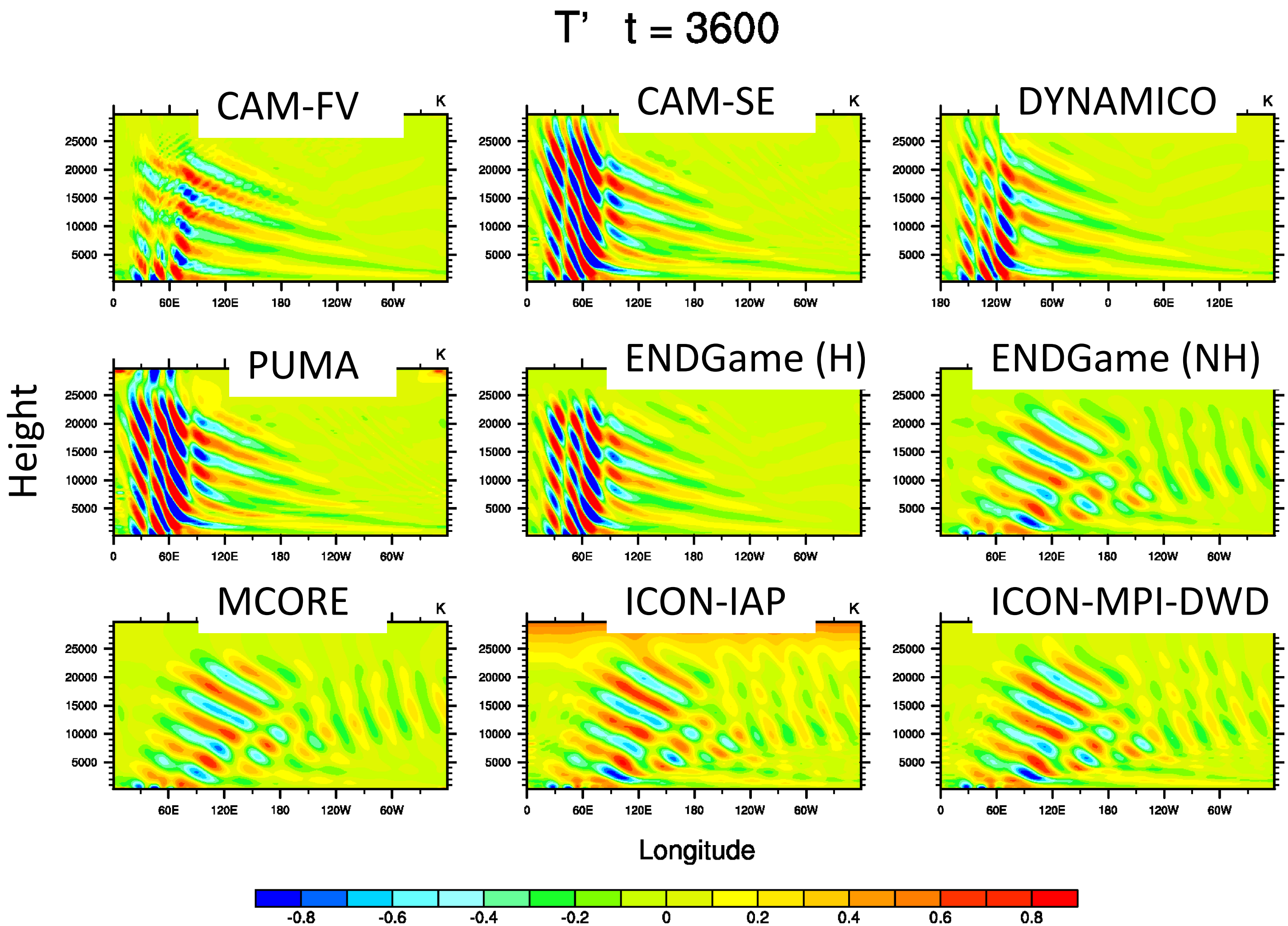
DCMIP Test 21: Flow over a circular mountain

Small-Earth test with a circumference at the equator of 80 km (X=500): Distinguishes between hydrostatic and nonhydrostatic gravity wave responses



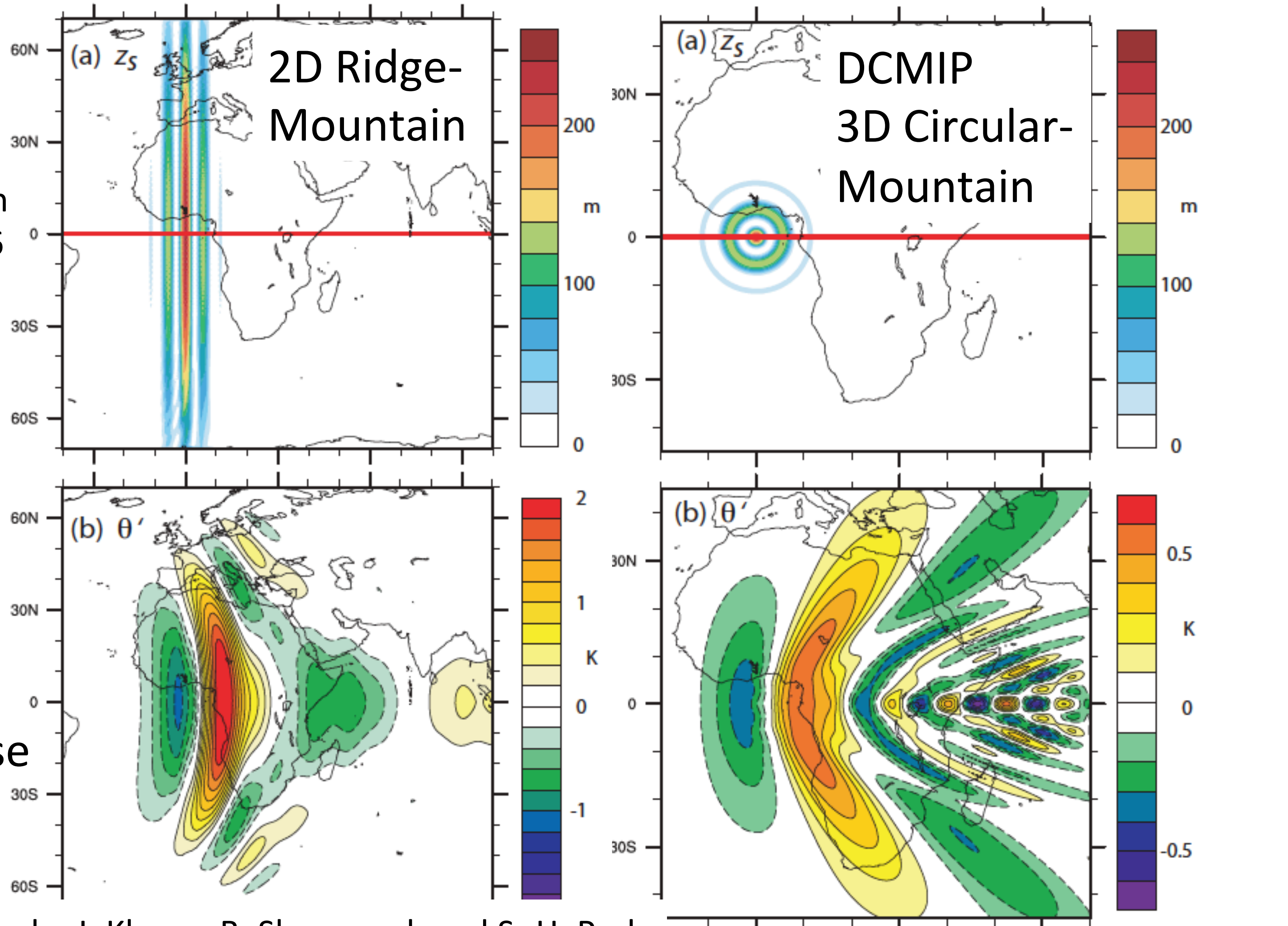
Should the test be improved?

dx=334 m, dz = 500 m

Mountain-Generated Gravity Waves

Small-earth with X=166

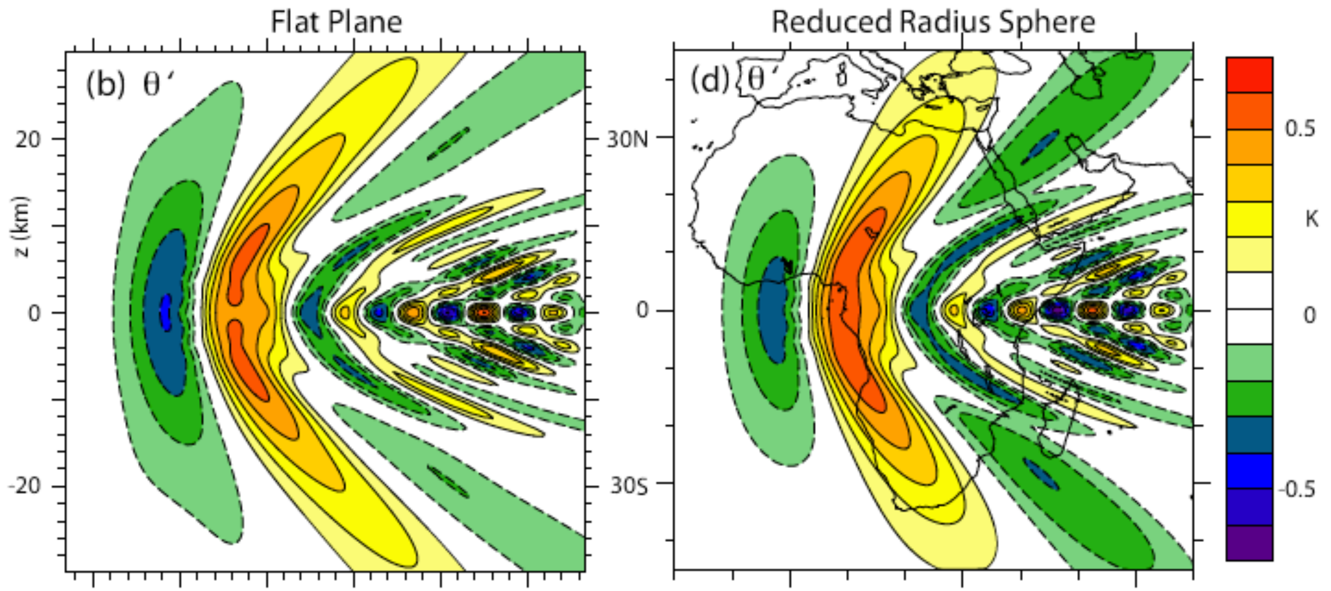
Gravity wave response



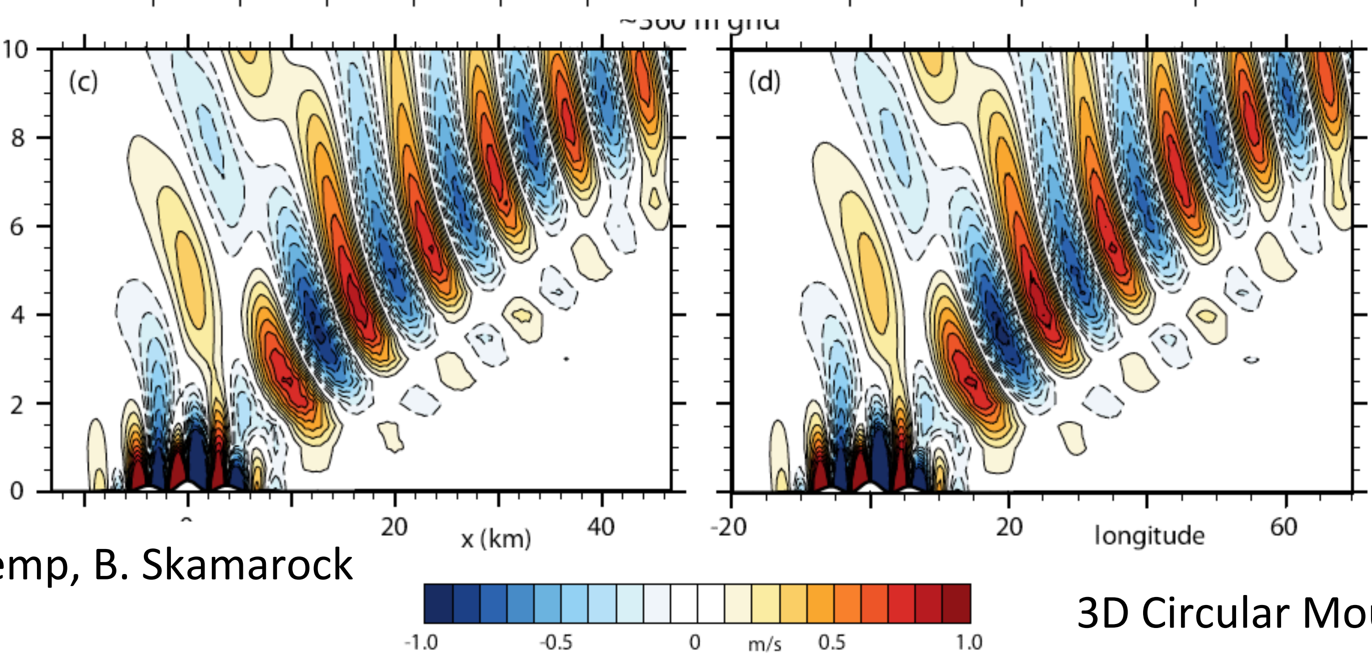
Simulations by J. Klemp, B. Skamarock and S.-H. Park

Mountain-Generated Gravity Waves

Gravity wave response on a flat plane and on a small-sphere resemble each other along the equator. Analytic solution under development



Vertical velocity



Simulations by J. Klemp, B. Skamarock and S.-H. Park

3D Circular Mountain

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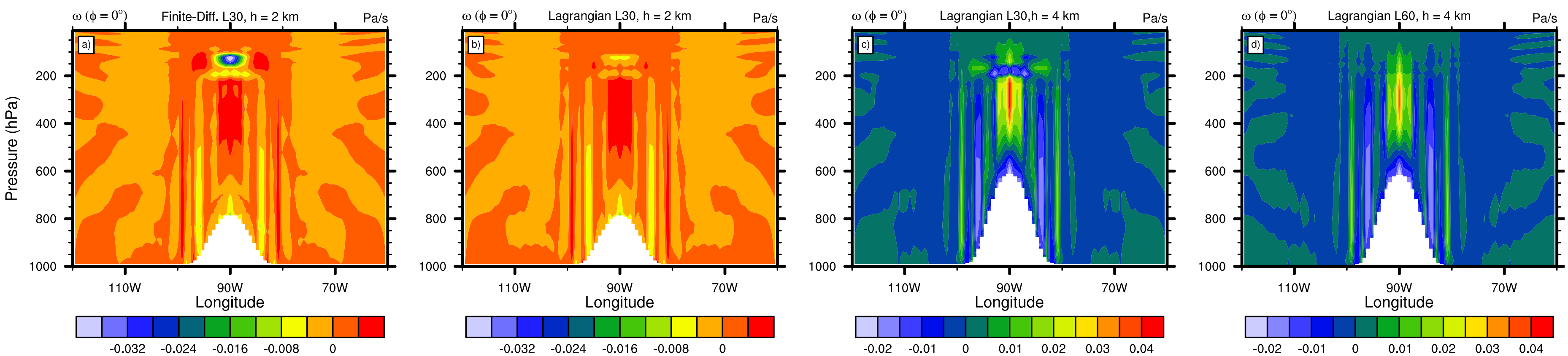
Accuracy of the PGF

Steady-state with stratified thermal structure (constant lapse rate):

Spurious vertical pressure velocity in the presence of topography

Finite-difference with 30 levels | **Floating Lagrangian** with 30 levels | Floating Lagrangian with **30 levels** | Floating Lagrangian with **60 levels**



Big errors

Errors reduced

Higher and steeper mountain:
Error almost insensitive to increased vertical resolution

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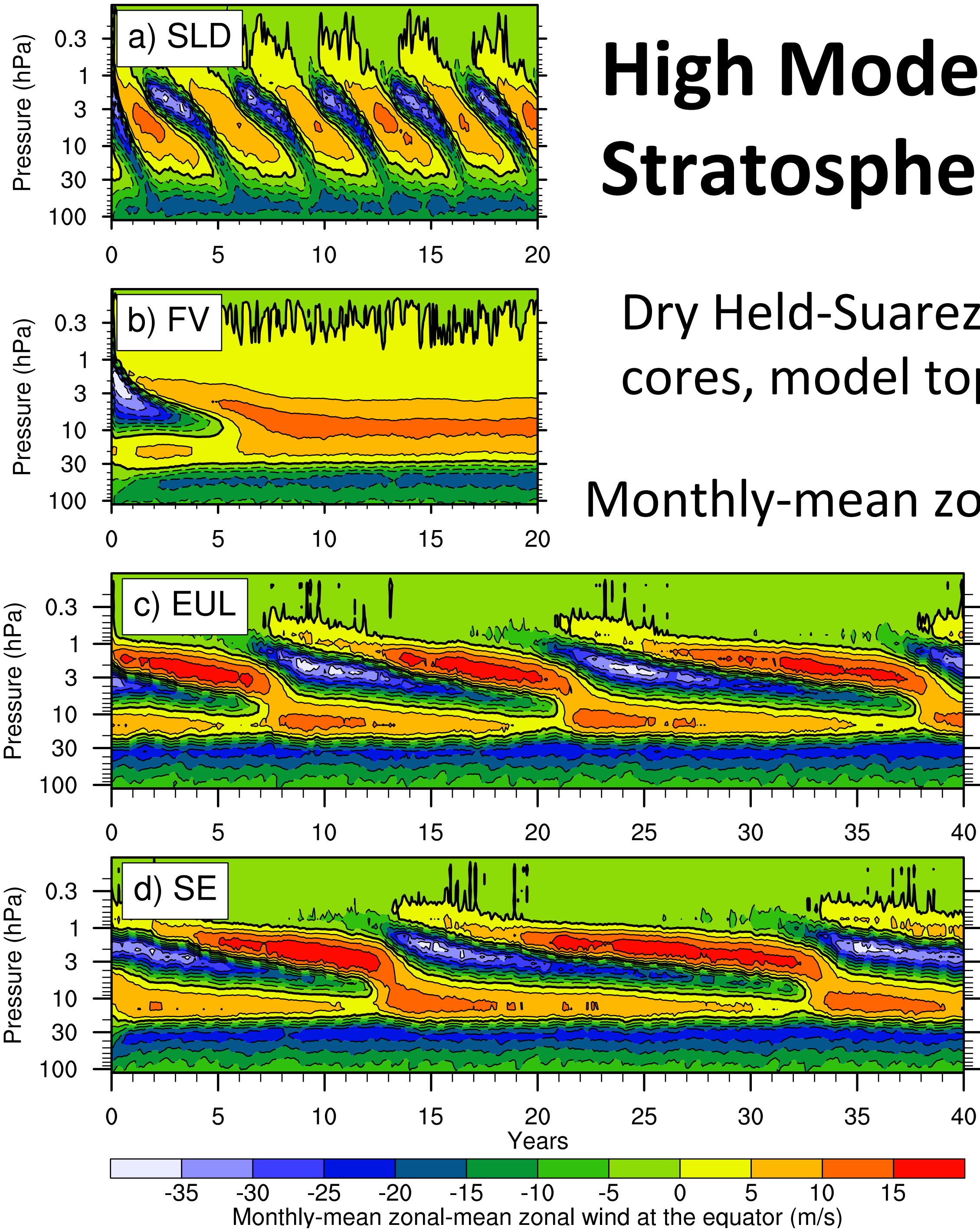
High Model Tops: Stratospheric Circulations

Dry Held-Suarez test with four dynamical cores, model top at 0.1 hPa (65 km)

Monthly-mean zonal-mean u at the equator



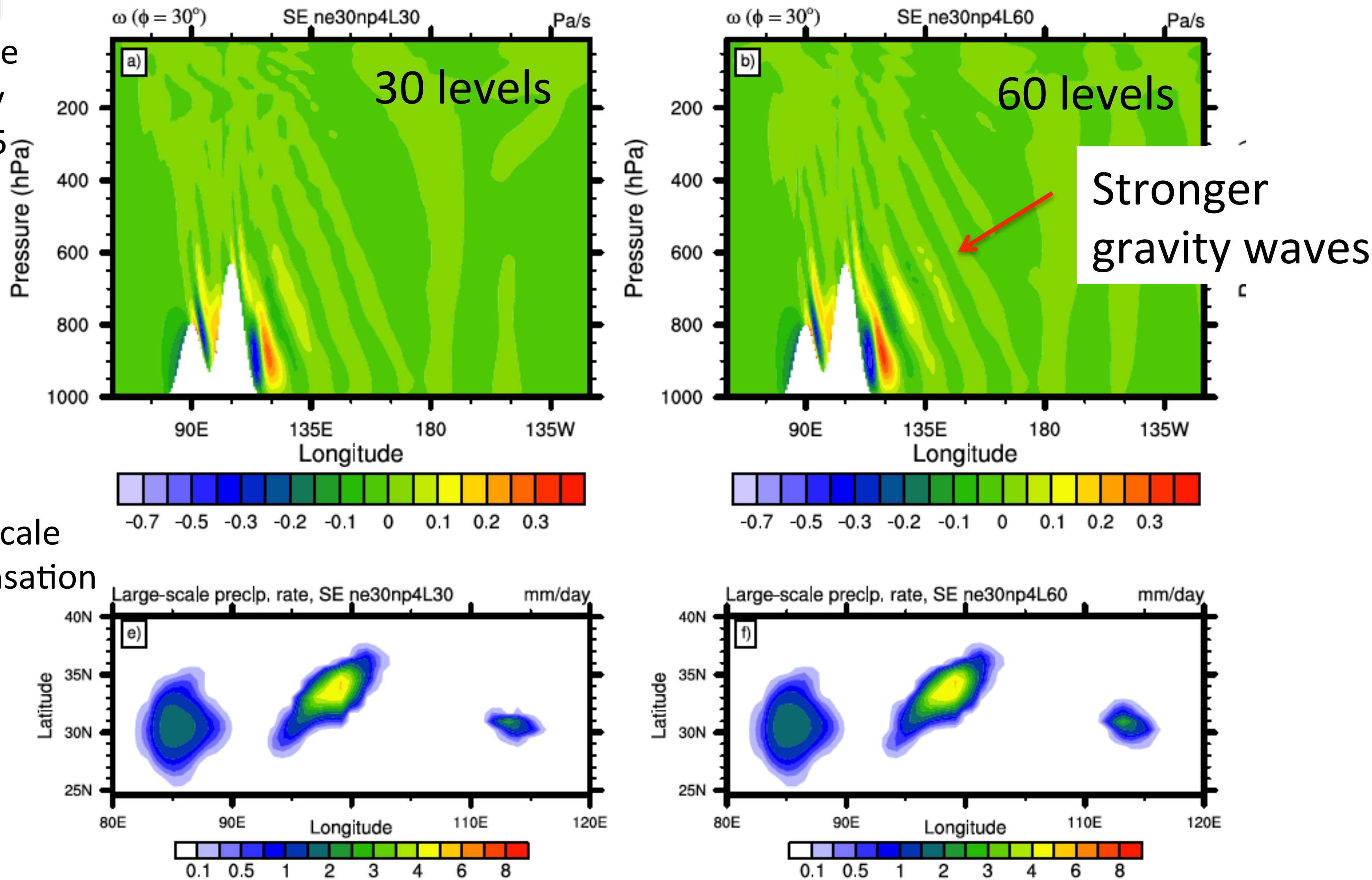
Exposes different Quasi-Biennial Oscillation (QBO)-like circulation and wave generation & propagation properties of the 4 CAM dycores

Yao and Jablonowski (GRL, 2013)
Yao and Jablonowski, in prep.

Vertical velocity and Topographic Precipitation: Impact of Vertical Resolution

Vertical pressure velocity at day 5

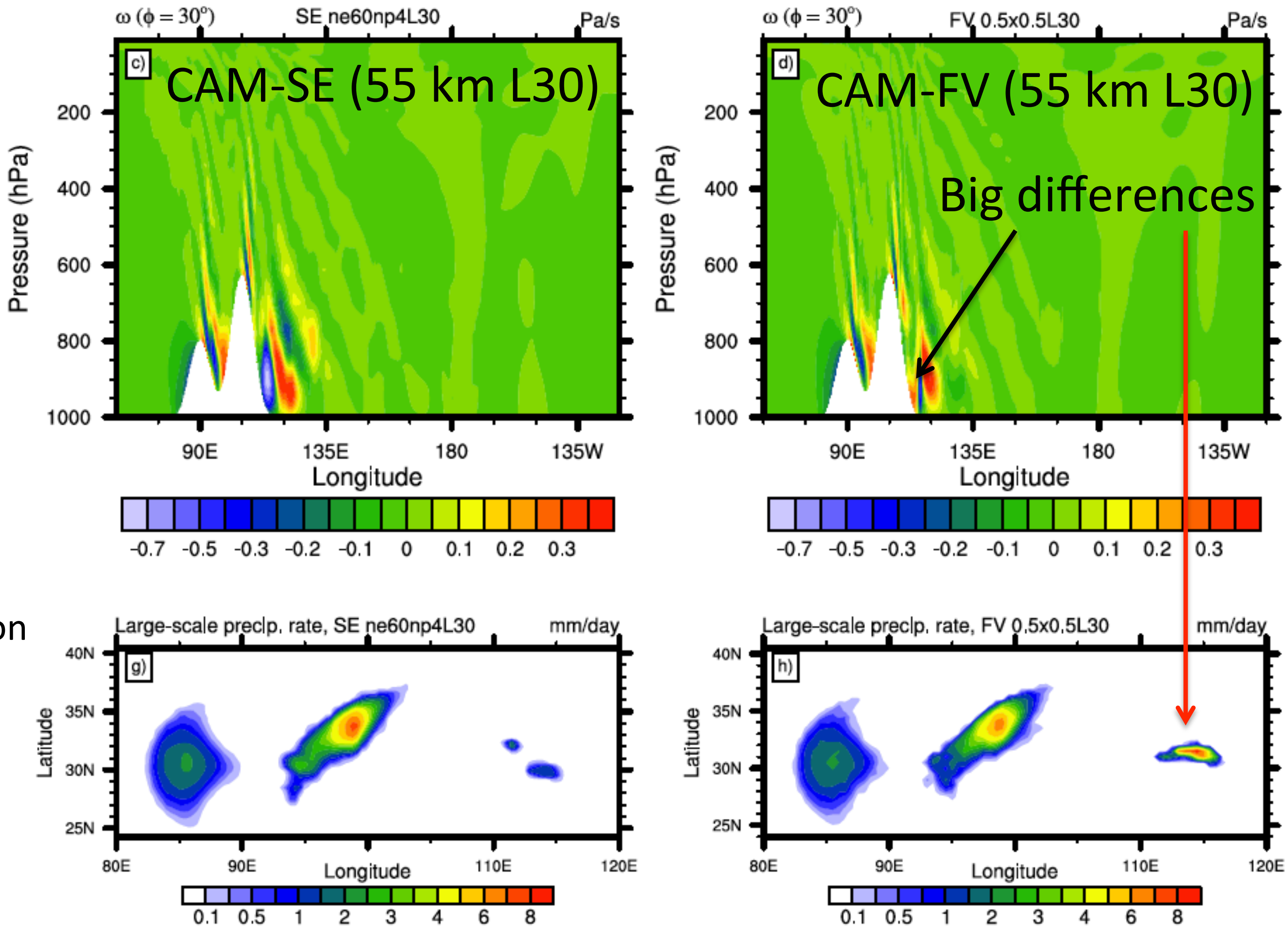
Large-scale condensation



Vertical velocity and Topographic Precipitation: Impact of the Dycore

Vertical pressure velocity at day 5

Large-scale condensation



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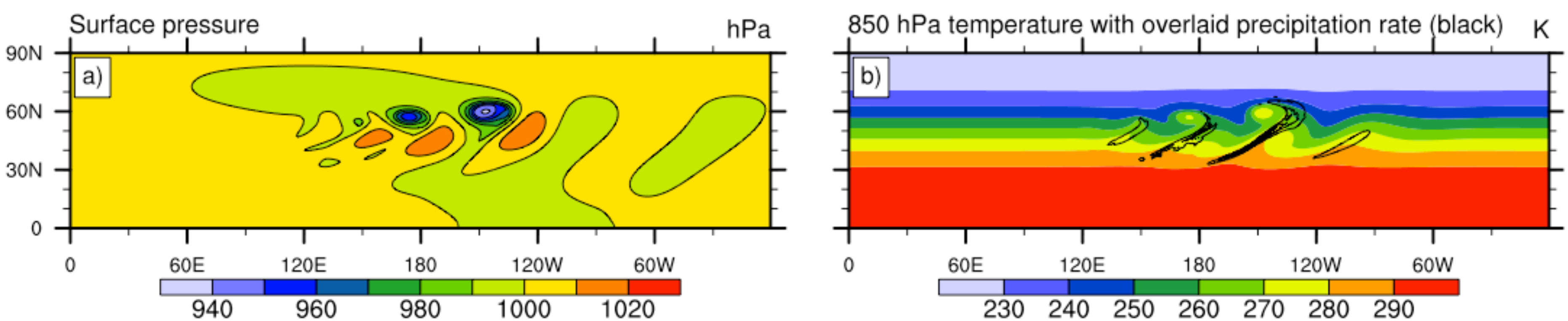
- Pressure-gradient force (PGF) errors
- Extreme (steep) topography
- Physics-Dynamics coupling: (Simple) moist interactions
- Long-term "climate-like" evaluations: Held-Suarez

Baroclinic Wave: Moisture and Large-Scale Condensation

DCMIP test 42

Large-scale condensation in a moist version of the JW'06 baroclinic wave leads to an intensification of the baroclinic wave in CAM-FV (1°x1° L30), here at day 9



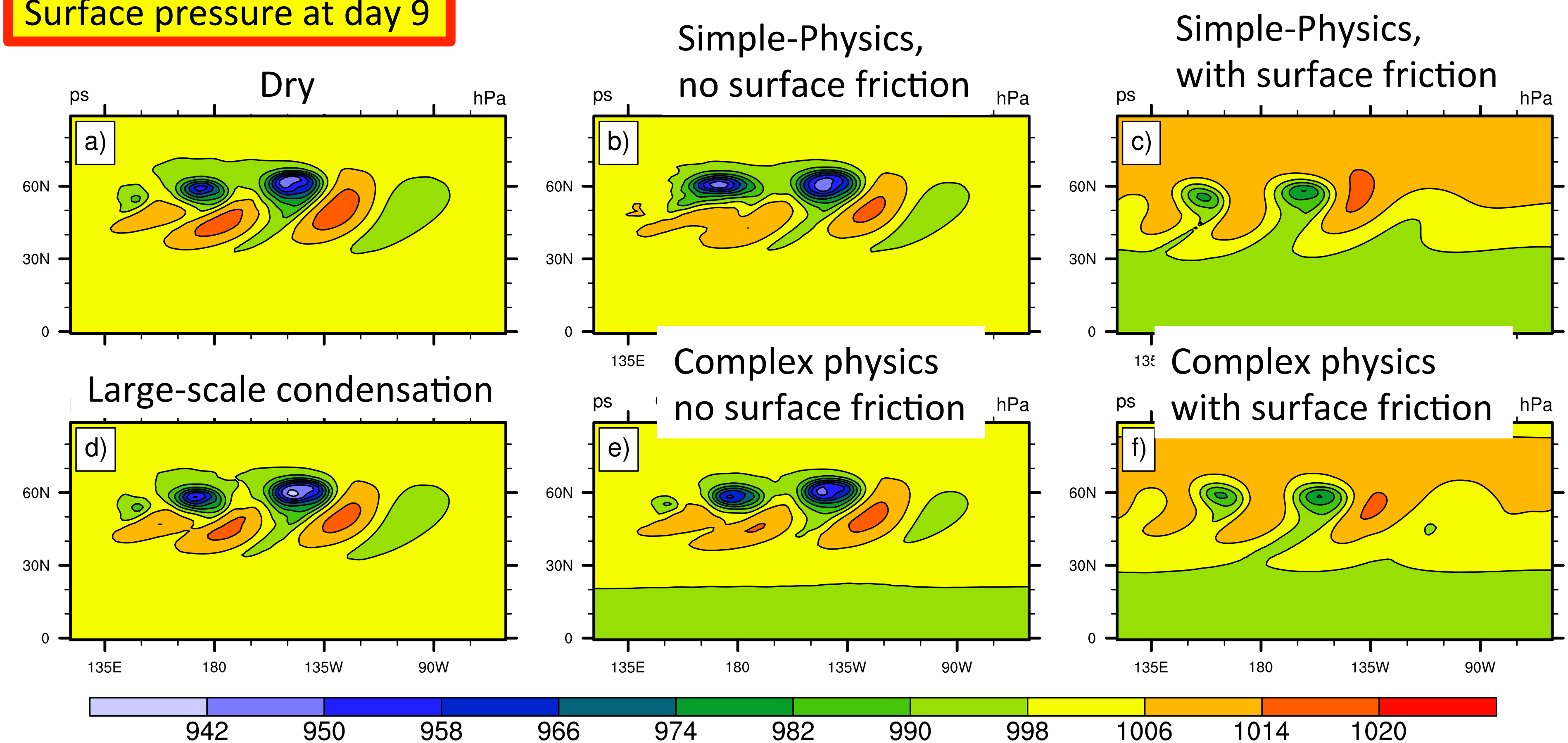
Provides a first glimpse at the non-linear physics-dynamics interactions in the presence of moisture

1°x1° L30
dx = 110 km

Moist Interactions: Baroclinic Wave

Idealized moist baroclinic wave tests expose the behavior of simulations with complex physical parameterizations

Surface pressure at day 9

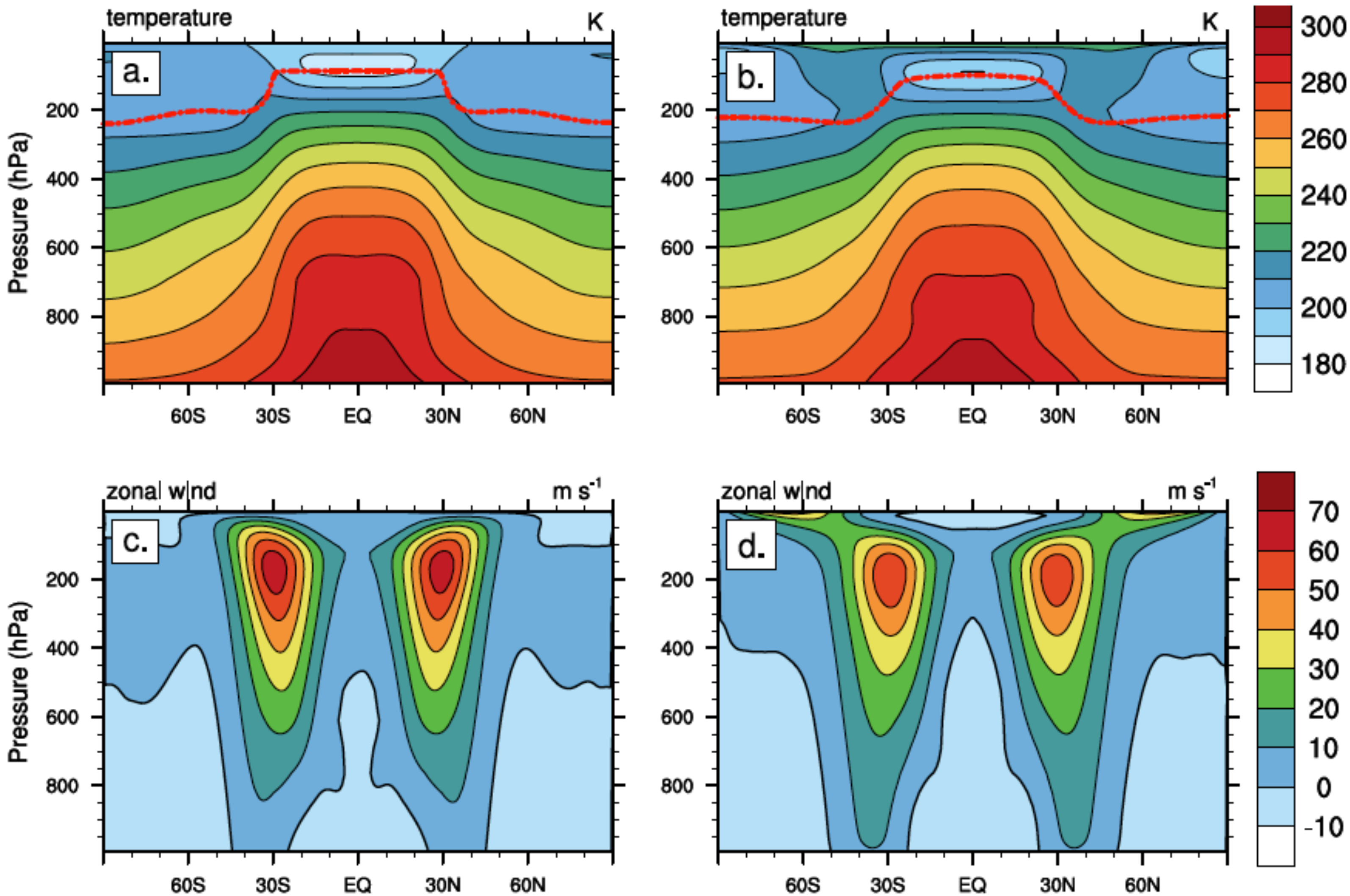


Tests based on Jablonowski and Williamson (2006), Simple-physics: Reed and Jablonowski (2012)

Moist Held-Suarez ('climate-like') Test

Moist Held-Suarez closely mimics Aqua-Planet

Moist Held-Suarez with simple-physics | Aqua-Planet with complex CAM5 physics



Thatcher and Jablonowski, in preparation

Moist Held-Suarez ('climate-like') Test

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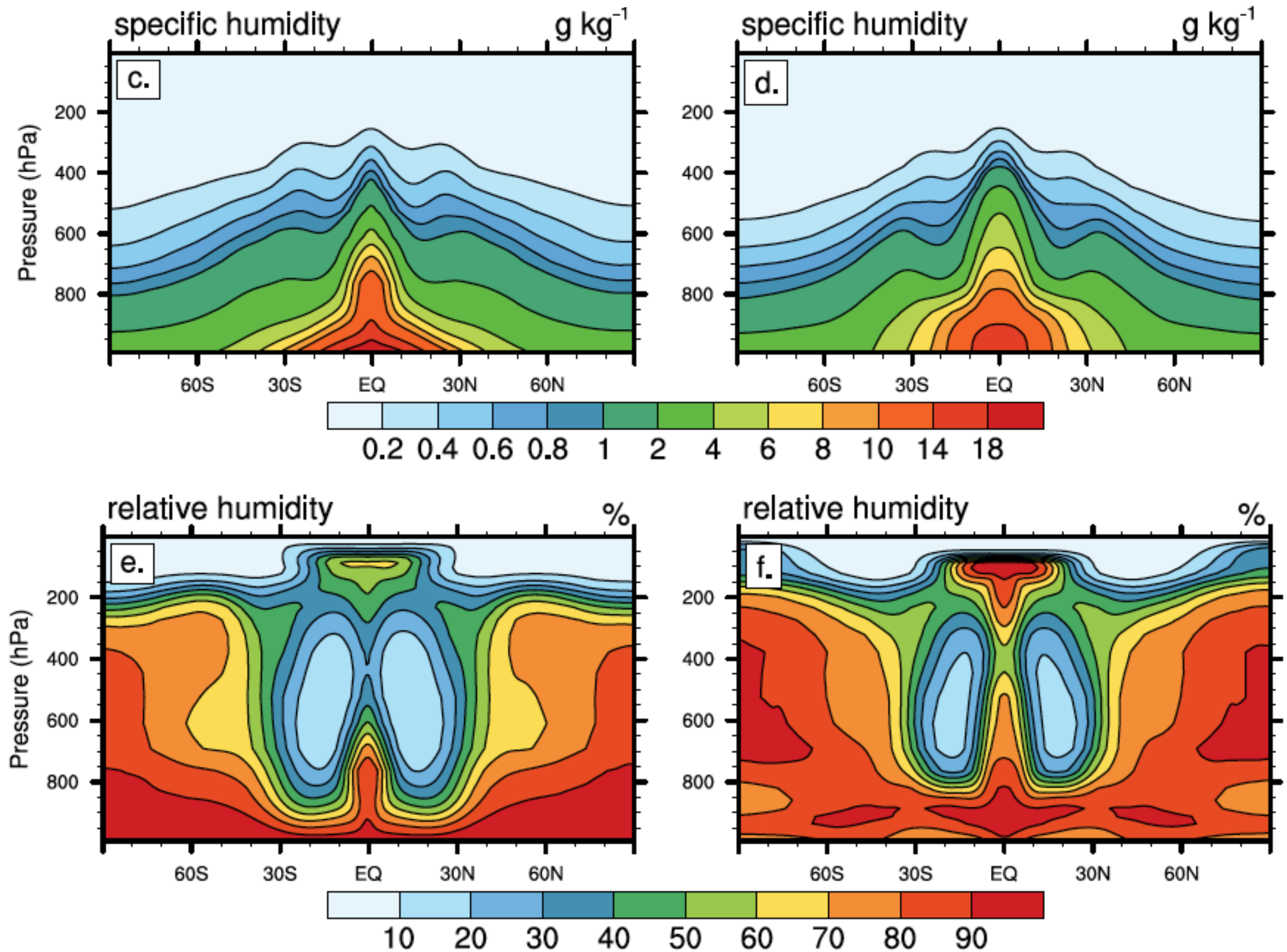
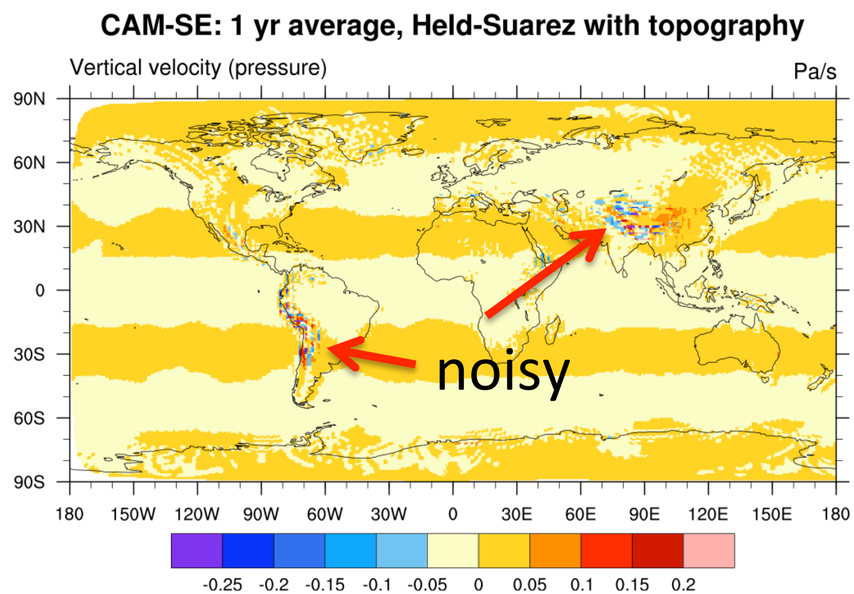
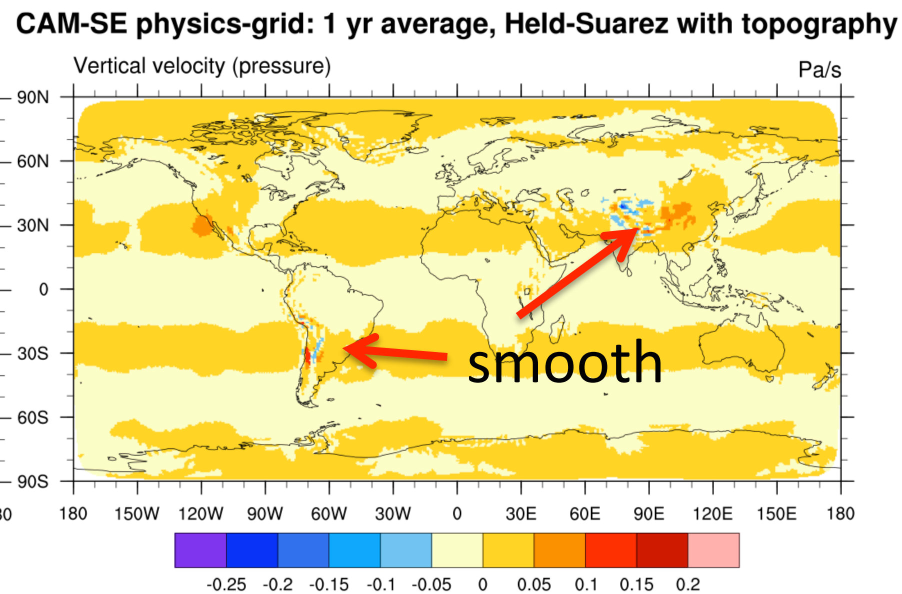


Thatcher and Jablonowski, in preparation

Dry Held-Suarez with Real Topography: Assessment of the physics-dynamics coupling





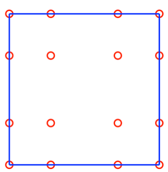
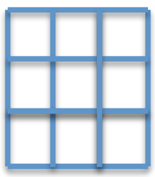
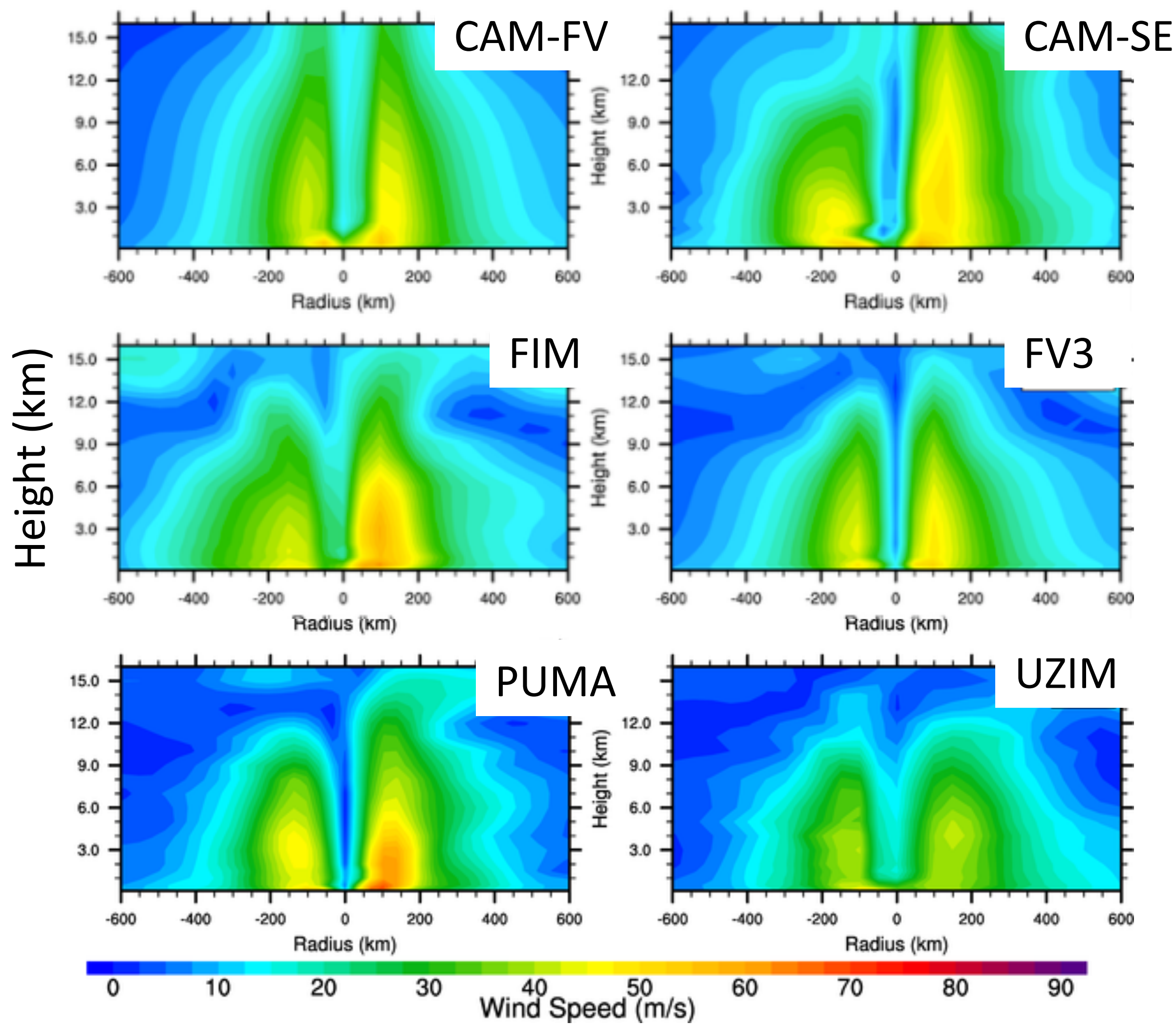


FIGURE 10. One-year average of vertical velocity (ω) using Held-Suarez forcing and 'real-world' topography using CAM-SE at approximately 2° horizontal resolution ($ne16np4$). Left plot is based standard CAM-SE setting where the sub-grid scale parameterization are computed on the spectral element quadrature grid and the right plot is based on the physics grid version in which tendencies are computed on a $3x3$ finite-volume grid inside each element. Note that the physics grid has the same number of degrees of freedom as the quadrature grid in this configuration.



Extreme Storms: Tropical Cyclones



DCMIP Test 51:
Idealized TC on an aqua-planet: Simulations with Simple-Physics

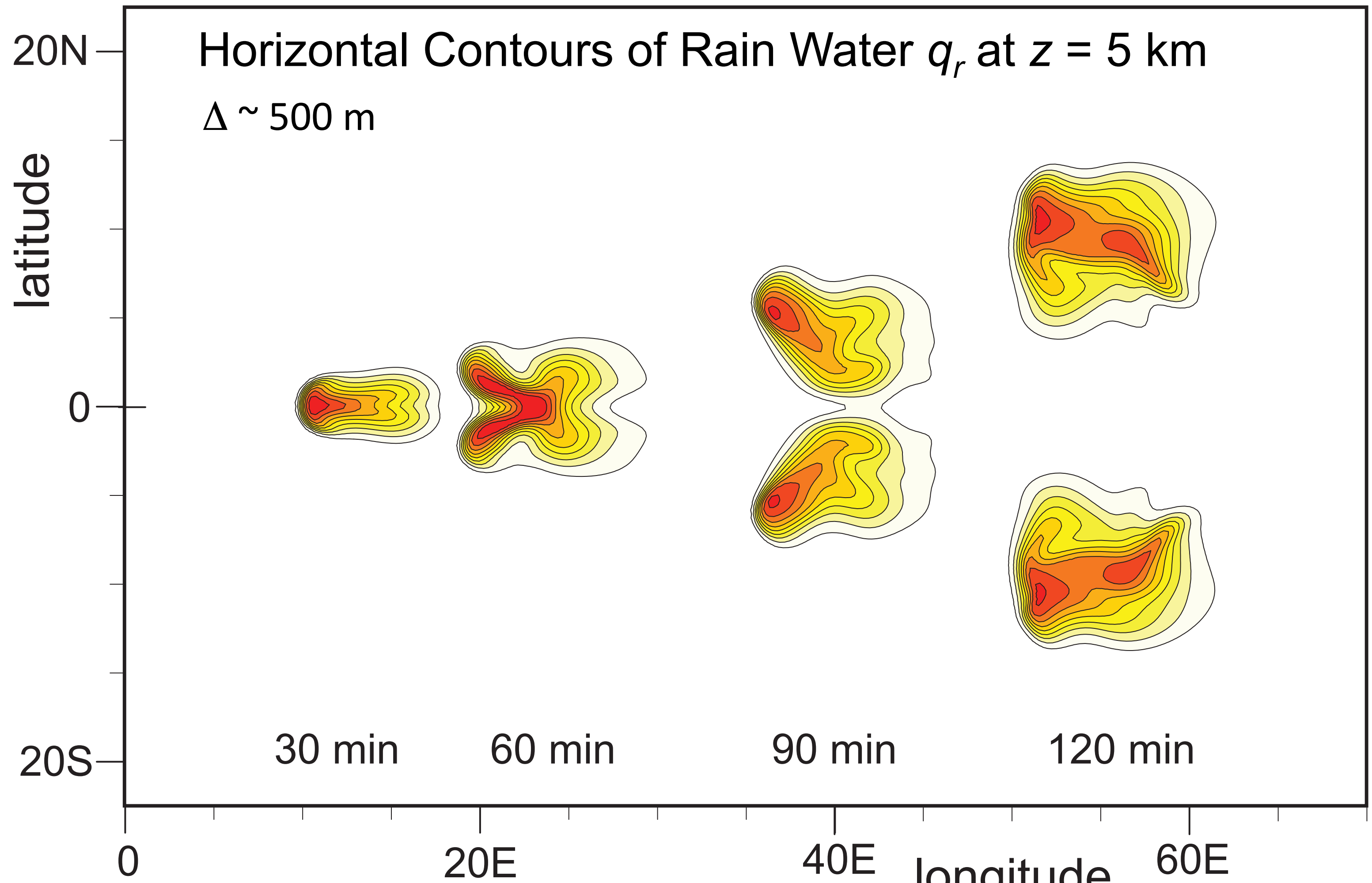
Height-longitude cross section of the wind speed (m/s) at day 10: wide spread in results

Reed and Jablonowski (MWR, 2011)
Reed and Jablonowski (James, 2012)

0.5° x 0.5° L30, dx= 55 km

Small-Scale Moist Interactions: Convective Cell

Splitting Supercell Thunderstorm on a Reduced-Radius Sphere ($X = 60$)



Test setup by Joe Klemp (warm bubble with Kessler physics)

Contour interval
1 gm/kg

DCMIP – Going Forward

- Should there be another DCMIP, e.g. in June 2016?
- If there is interest, what are the scientific frontiers that we want to explore?
- What are the adequate test cases to answer our open model design questions? We need to address all scales (micro, meso, synoptic, planetary)!
- Open invitation to participate in the planning process
- Should we change the format of DCMIP (e.g. fewer test scenarios run during DCMIP and submission of additional results ahead of time)? Longer? Shorter?
- Do we need stricter rules to determine the 'readiness' of model? The readiness of the DCMIP-2012 models and their mentors varied widely.

DCMIP – Test Cases

- Dry and moist idealized dynamical core test cases have the ability to mimic the complex behavior of the full atmosphere
  - They are relevant
- They give easier access to an improved understanding of the circulation and our modeling choices
- This provides the scientific basis for DCMIP

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DCMIP

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