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Progress on the HOMME-NH nonhydrostatic atmosphere dycore

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E3SM Energy Exascale Earth System Model

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U.S. DEPARTMENT OF ENERGY

Overview

- Motivation: Nonhydrostatic effects important to resolve at horizontal grid-scales of <10km (target: 3km horizontal resolution).

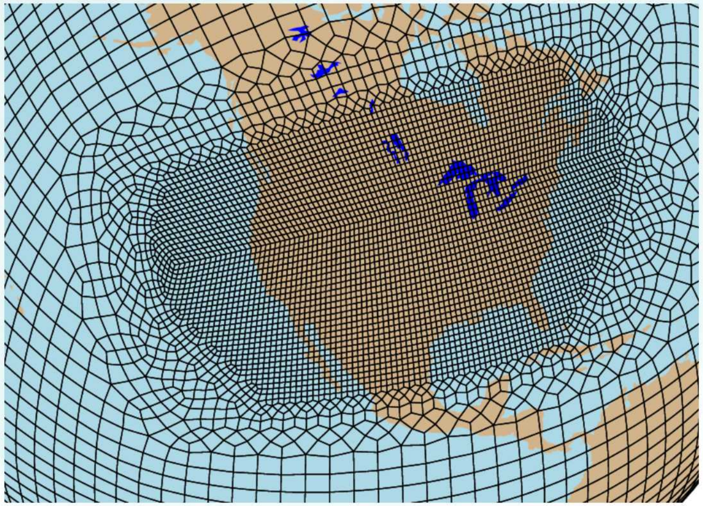
- HOMME-NH: Nonhydrostatic dycore shares (for now) the same common code-base as HOMME hydrostatic dycore.

- HOMME-NH will be ready to replace HOMME as the atmosphere dycore by E3SM v2 code freeze.

Performance: Dynamics about 1.8 times slower, transport about 3 times faster.

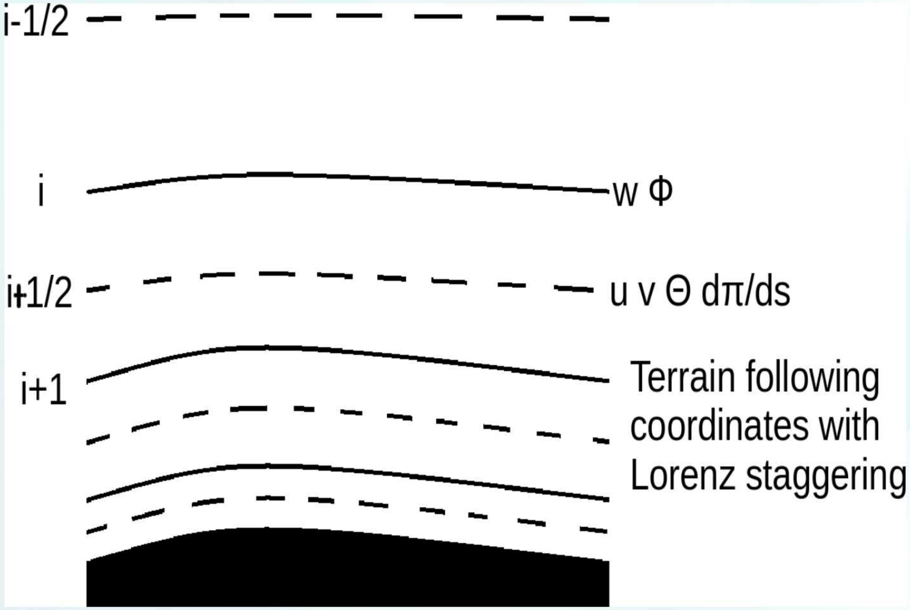
- IMEX time integration required for efficient, stable time-integration.

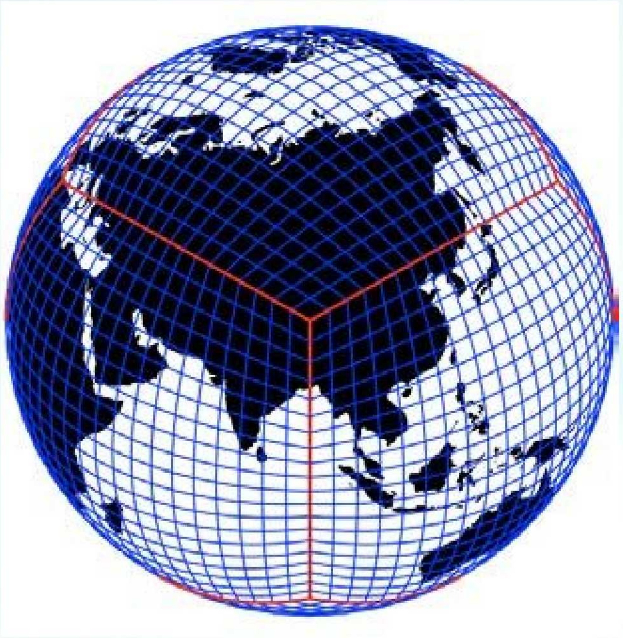
- Current work: Coupling to physics (NGD nh-atm), testing at high resolution, improving efficiency of IMEX.



Model specs

- Horizontal: 4th order Spectral elements on cubed sphere (Taylor and Fournier, 2010).
- Vertical: 2nd order SB81 with Lorenz staggering (Simmons and Burridge, 1981).
- Spatial discretization is mass and energy conserving.
- IMEX RK time integration (IMEX-KG 2-3rd order methods).
- Lagrangian vertical coordinate.
- Hyperviscosity with dissipation to hydrostatic background state.
- Can run in hydrostatic or nonhydrostatic mode.





Model formulation

- Laprise formulation (Laprise, 1992) of nh-primitive equations with some differences.
- Terrain following hydrostatic pressure as vertical coordinate.
- Virtual potential temperature formulation in terms of Gibb's potential.
- Density is hydrostatic pressure layer thickness.

$$u_t + (\nabla_\eta \times u + 2\Omega) \times u + \frac{1}{2}\nabla_\eta (u \cdot u) + \frac{\partial u}{\partial \eta} + \frac{1}{\rho}\nabla_\eta p = 0\,\eta$$

$$w_t + u \cdot \nabla_\eta w + \{\frac{\partial w}{\partial \eta} + g(1 - \mu) = 0\,\eta \text{¿} \qquad \mu = \frac{\partial p}{\partial \eta}\left(\frac{\partial \pi}{\partial \eta}\right)^{-1}$$

$$\varphi_t + u \cdot \nabla_\eta \varphi + \{\frac{\partial \phi}{\partial \eta} - gw = 0\,\eta \text{¿}$$

$$\Theta_t + \nabla_\eta \cdot (\Theta u) + \frac{\partial}{\partial \eta}(\Theta\,\eta())$$

$$\left(\frac{\partial \pi}{\partial \eta}\right)_t + \nabla_\eta \cdot \left(\frac{\partial \pi}{\partial \eta} u\right) + \frac{\partial}{\partial \eta}(\pi\,\eta())$$

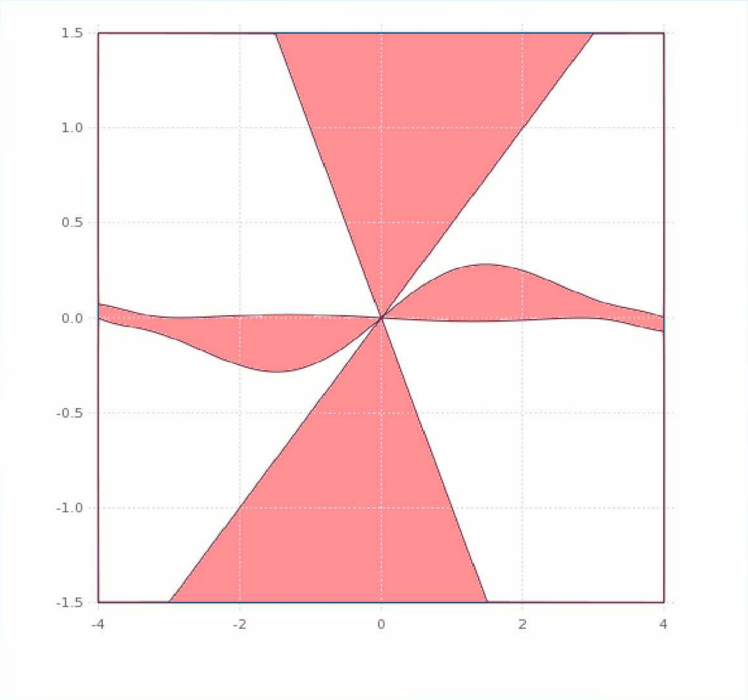
IMEX time integration 1 of 2

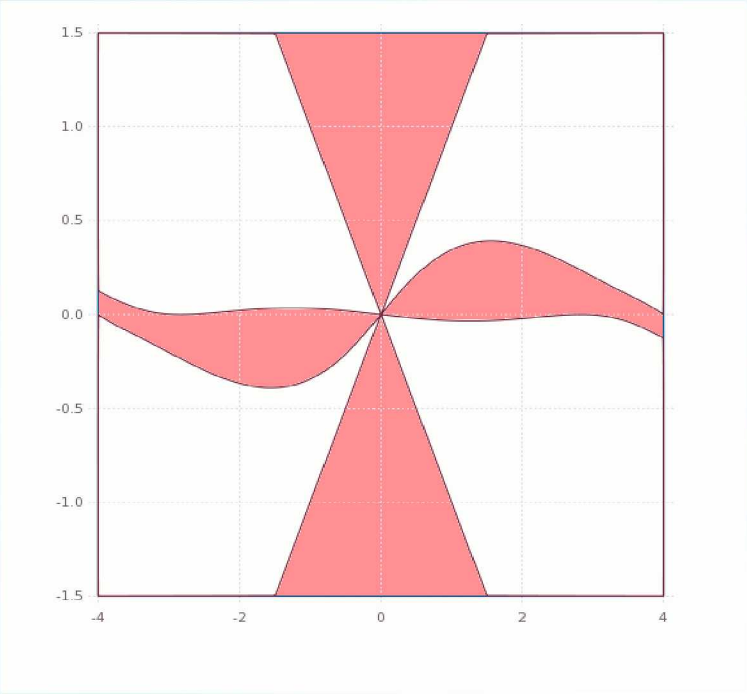
- Horizontally explicit vertically implicit (HEVI) splitting.

- SUNDIALS-ARKODE interface allows fast testing of a variety of methods (see Gardner et all 2018 and Vogl et al 2018).

- Goal: methods running hydrostatic time-steps at nonhydrostatic resolutions.

- Careful derivation of methods with good coupled stability regions is key to large step size.





Left: IMEX-KG254a (375s at 1 degree horiz. res.). Right: IMEX-KG254b (300s at 1 degree horiz. res.).

IMEX time integration 2 of 2

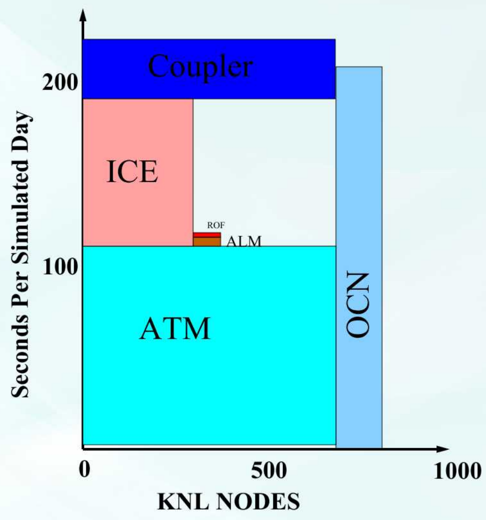
Method	Explicit stages	Implicit stages	H-dt	NH-dt	Score
KGU35 (explicit)	5	N/A	375	<1	1.0
IMEX-KG232	3	2	175	175	0.78
IMEX-KG242	4	2	275	225	0.75
IMEX-KG243	4	3	275	275	0.92
IMEX-KG252	5	2	375	275	0.73
IMEX-KG253	5	3	375	325	0.87
IMEX-KG254a	5	4	375	300	0.80
IMEX-KG254b	5	4	375	375	1.0
IMEX-KG343a	4	3	250	250	0.83
IMEX-KG354a	5	4	375	300	0.80

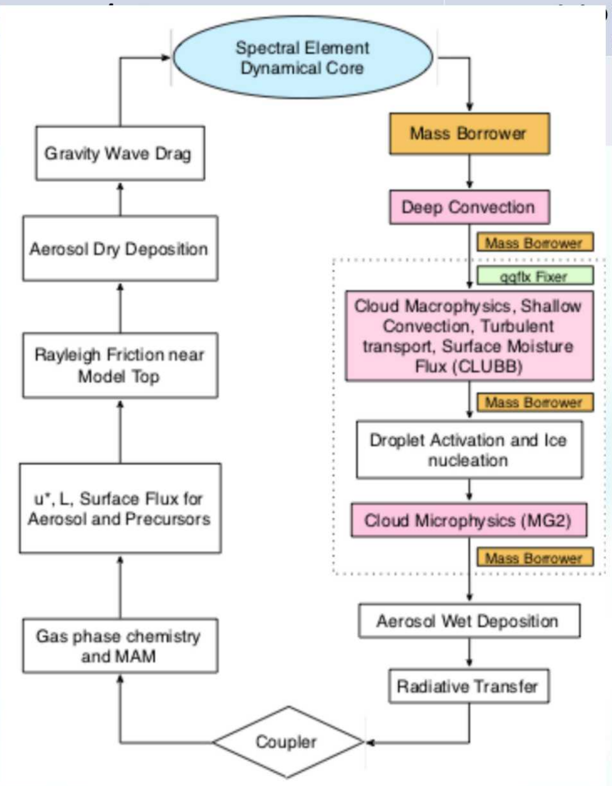
Caption: H-dt is hydrostatic time-step, NH-dt is nonhydrostatic time-step. Scores depend on number of explicit stages (implicit stages relatively cheap in HEVI). Methods derived and analyzed in (Steyer et. al. 2018).

Performance

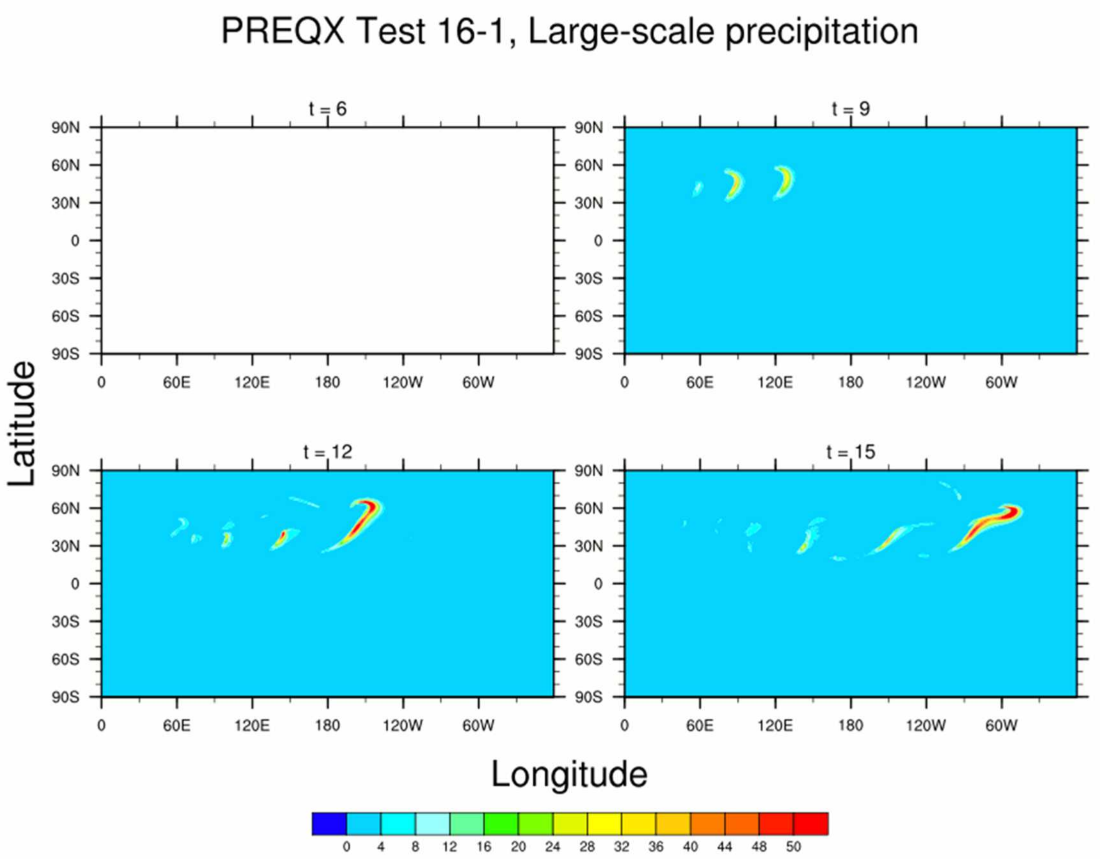
- HOMME-NH (stand-alone nh-dynamics) is about 1.8 times more expensive than HOMME (h-dynamics).
- Physics (52%) is spread over dozens of parameterizations.
- Dycore (transport + dynamics, 48% total) has the most work per lines of code and is usually our first porting/acceleration target.

EAM Component	% time
Transport	0.35*(1/3)
Dynamics	0.13*(1.8)
Ph	)

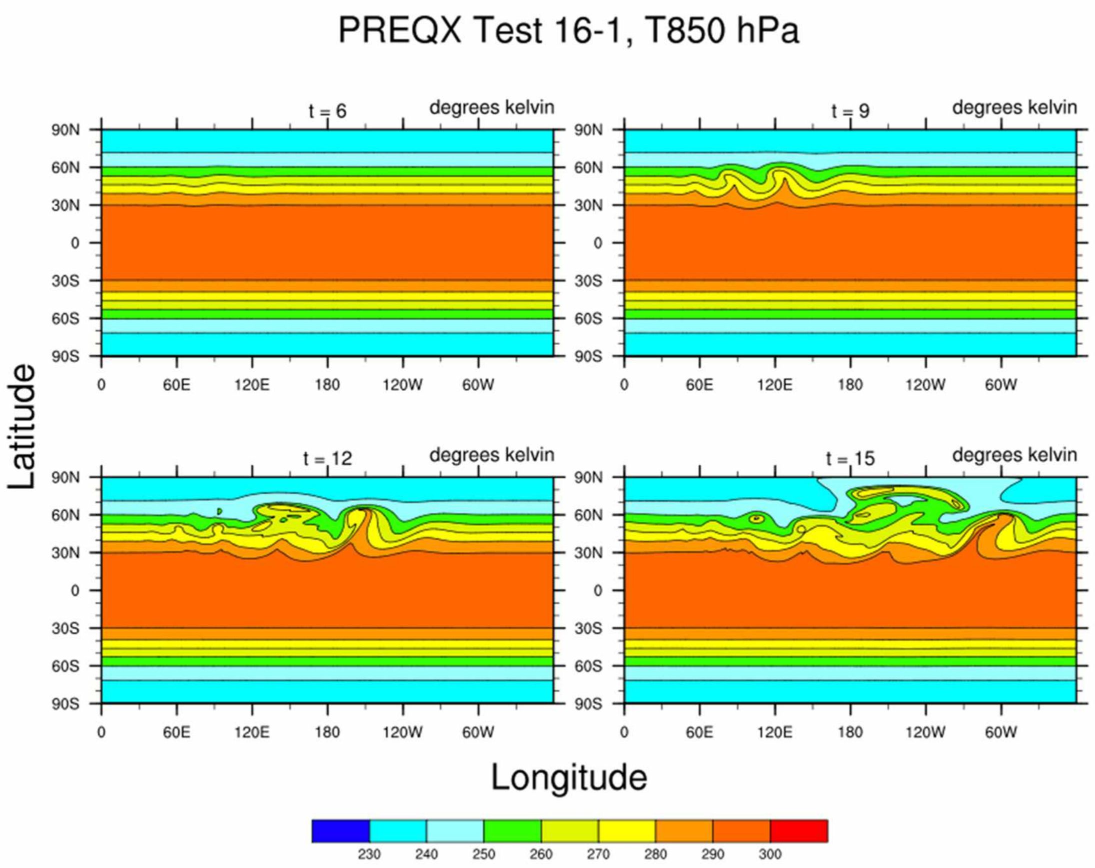




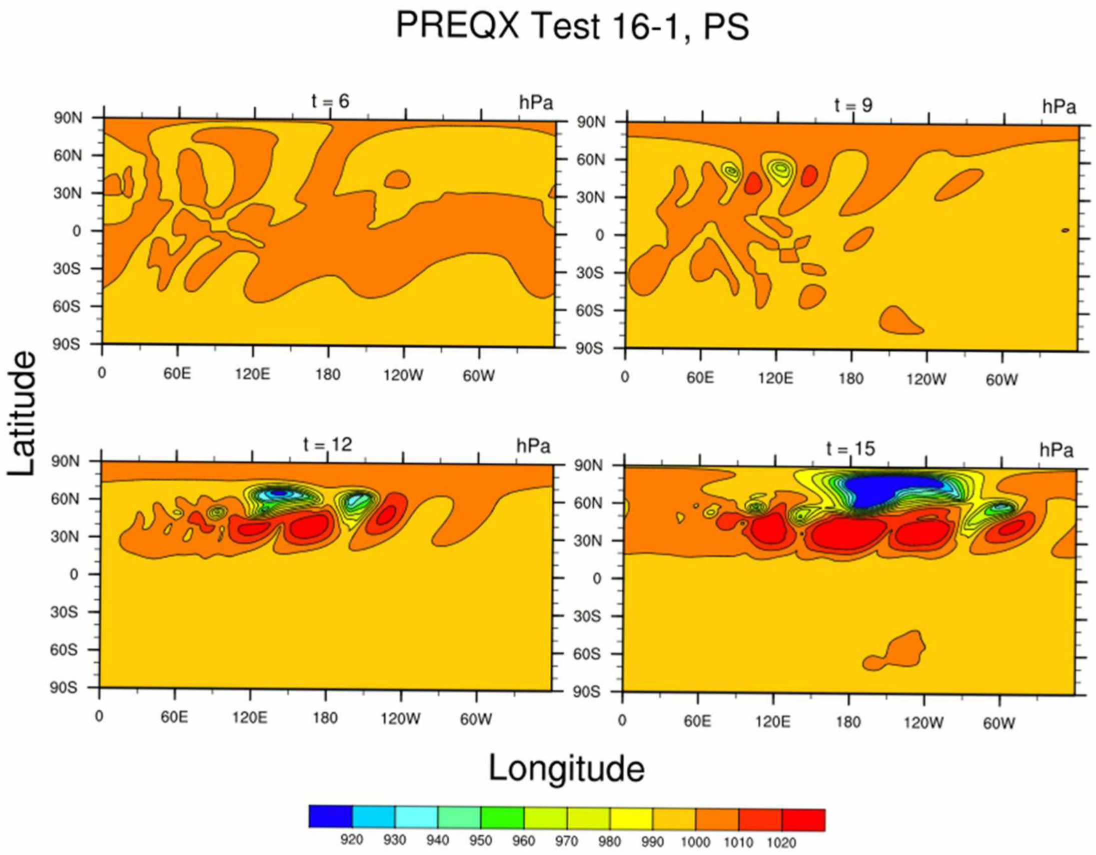
Results 1 of 3



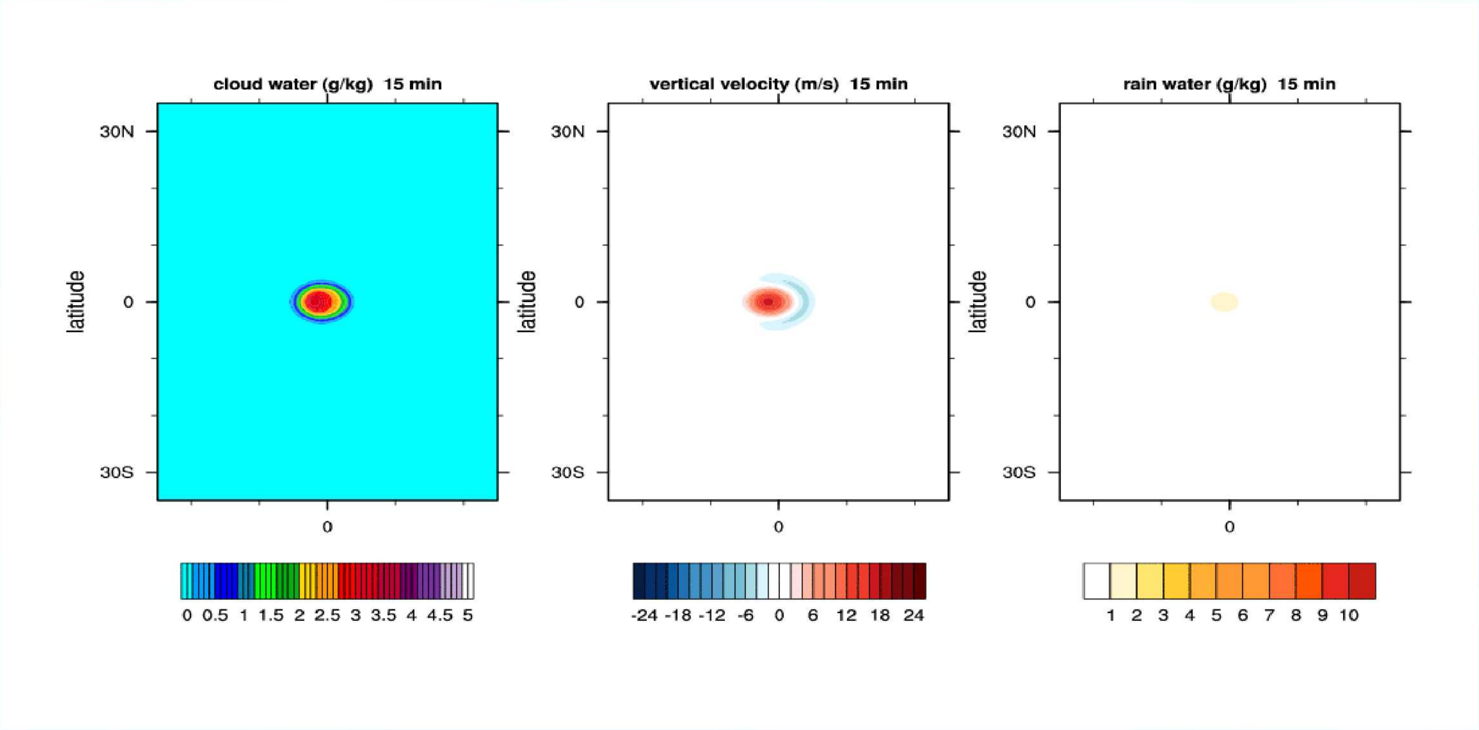
Results 2 of 3



Results 3 of 3



DCMIP2016 Supercell thunderstorm (500m resolution)



- Klemp et al., JAMES 2015, small planet (120x) test case with good correspondence to flat plane regional model results.
- Warm-rain Kessler-type physics.
- Single updraft with strong precip forms in the first 30min, starts to split by 60min, propagates away from the equator for 2h.
- Strong convective cell, rotating updrafts, moist unstable convection
- Resolution independent physical viscosity (so should converge under mesh refinement).

THANKS!

QUESTIONS?

References.

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