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NCAR CESM2.0 release of CAM-SE: A reformulation of the spectral-element dynamical core in dry-mass vertical coordinates with comprehensive treatment of condensates and energy

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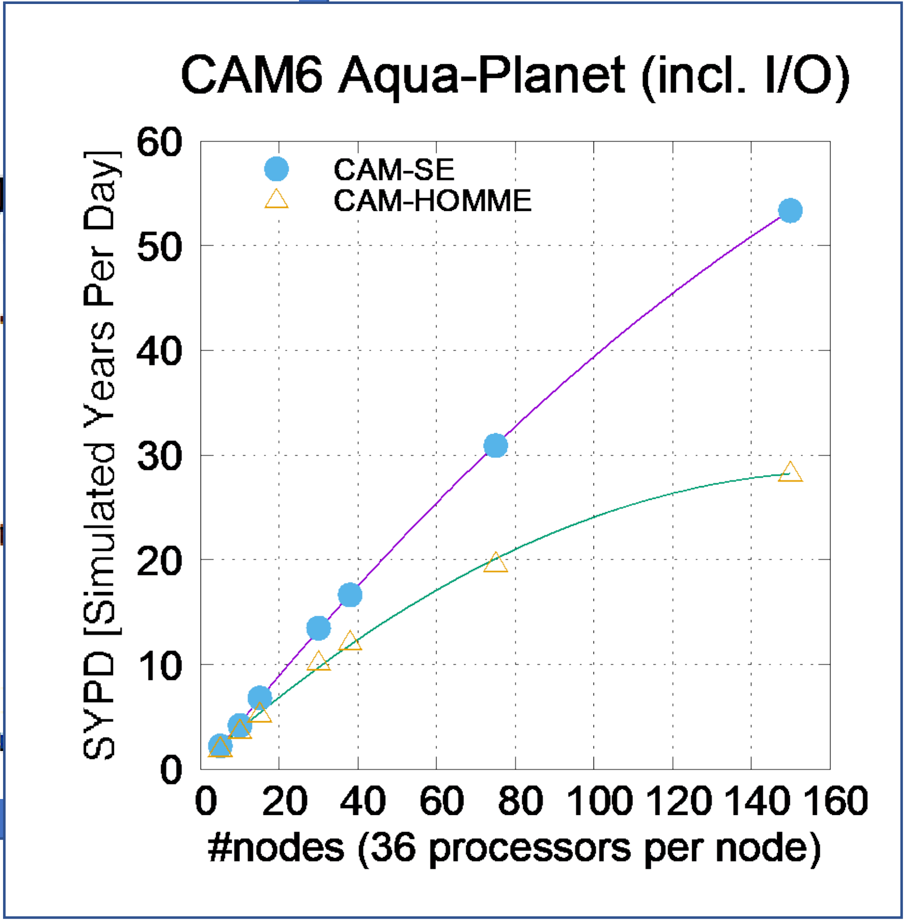

http://www.cgd.ucar.edu/cms/pel/papers/LetAl2018JAMES.pdf

Dynamical core requirements for CAM moving forward

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Community input on

Dynamical core requirements

Benchmarks to assess degree to which requirements are met

- Dycores should be tested in the same framework (in this case CESM)
- Simpler Models (Polvani, Clement, Medeiros, Simpson, Benedict, Goldhaber, Lauritzen, …) capability in CESM

		Climate	Weather	Geospace
(1)	Throughput: cost and scalability	Essential	Essential	Essential
(2)	Strong scaling	Essential	Desirable	Desirable
(3)	Efficient tracer transport	Essential	Essential	Essential
(4)	Conservation of mass (dry air, scalars)	Essential	Essential	Essential
(5)	Good tracer transport characteristics (shape-preservation, correlation, etc.)	Essential	Essential	Essential
(6)	Good conservation of total energy	Essential	Desirable	Essential
(7)	Conservation of angular momentum	Highly desirable		Essential
(8)	Dycore characteristics with topography			
(9)	Non-hydrostatics	Desirable	Essential	Highly desirable
(10)	Global mesh-refinement capability	Desirable	Essential	Essential
(11)	Regional capability		Essential	
(12)	Cartesian geometry	Desirable	Essential	
(13)	Data assimilation capability. Has to play well with DA	Desirable	Essential	Essential
(14)	Support simplified setups on the sphere	Essential	Essential	Essential
(15)	Support by developers	Essential	Essential	Essential

From initial "Singletrack" discussions

Specific for geospace modeling

		Climate	Weather	Geospace
(16)	Stable over 30 scale heights (~700km)/O(13) in pressure			Essential
(17)	Efficient 2 way 3D inline grid coupling			Essential
(18)	Species dependent mean molecular mass and specific heats			Essential
(19)	Deep atmosphere: variation of gravity, Coriolis force and geometry			Highly desirable
(20)	High top thermodynamics (prefer solving thermodynamic eqn. with T rather than theta, which is not well defined above homopause)			Essential

From initial "Singletrack" discussions

		Climate	Weather	Geospace
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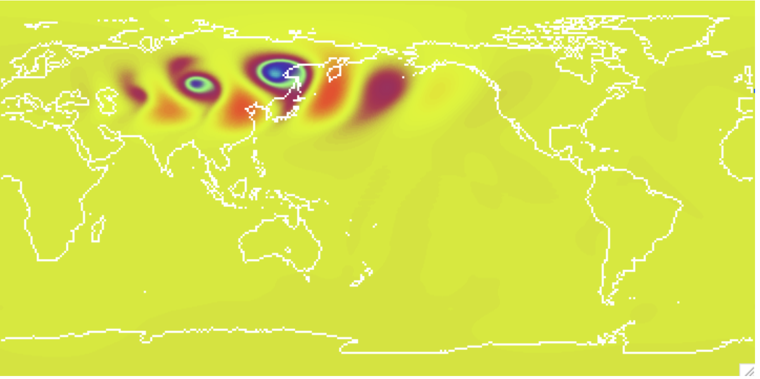
From initial "singletrack" discussions

Proposal for preliminary benchmarks to assess degree to which requirements are met

Idealized baroclinic wave
(short time-scales)



Some variant of Held-Suarez forcing
(long time-scales)

$$\frac{\partial \mathbf{v}}{\partial t} = \cdots - k_v(\sigma)\mathbf{v}$$

$$\frac{\partial T}{\partial t} = \cdots - k_T(\phi,\sigma)\left[T - T_{eq}(\phi,p)\right]$$

$$T_{eq} = \max\left\{200\text{K}, \left[315\text{K} - (\Delta T)_y \sin^2\phi - (\Delta\theta)_z \log\left(\frac{p}{p_0}\right)\cos^2\phi\right]\left(\frac{p}{p_0}\right)^{\kappa}\right\}$$

$$k_T = k_a + (k_s - k_a)\max\left(0, \frac{\sigma - \sigma_b}{1 - \sigma_b}\right)\cos^4\phi$$

$$k_v = k_f \max\left(0, \frac{\sigma - \sigma_b}{1 - \sigma_b}\right)$$

$\sigma_b = 0.7$ $\quad$ $k_f = 1 \text{ day}^{-1}$,

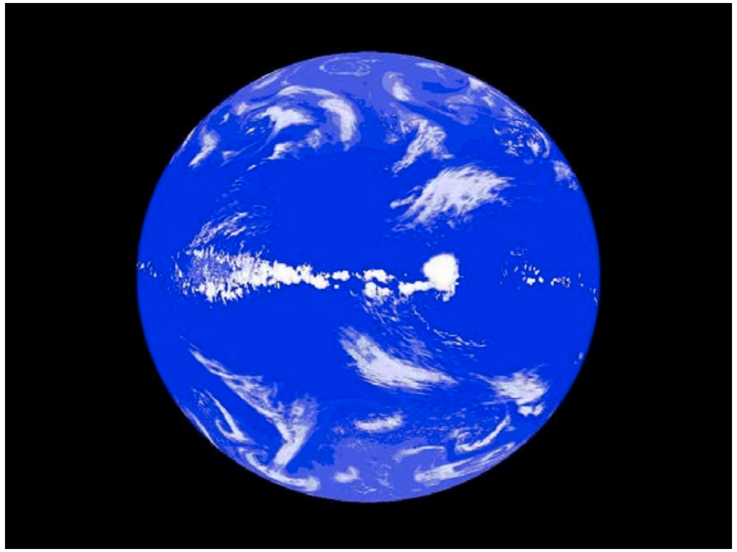
$k_a = 1/40 \text{ day}^{-1}$ $\quad$ $k_s = 1/4 \text{ day}^{-1}$

$(\Delta T)_y = 60\text{K}$ $\quad$ $(\Delta\theta)_z = 10\text{K}$

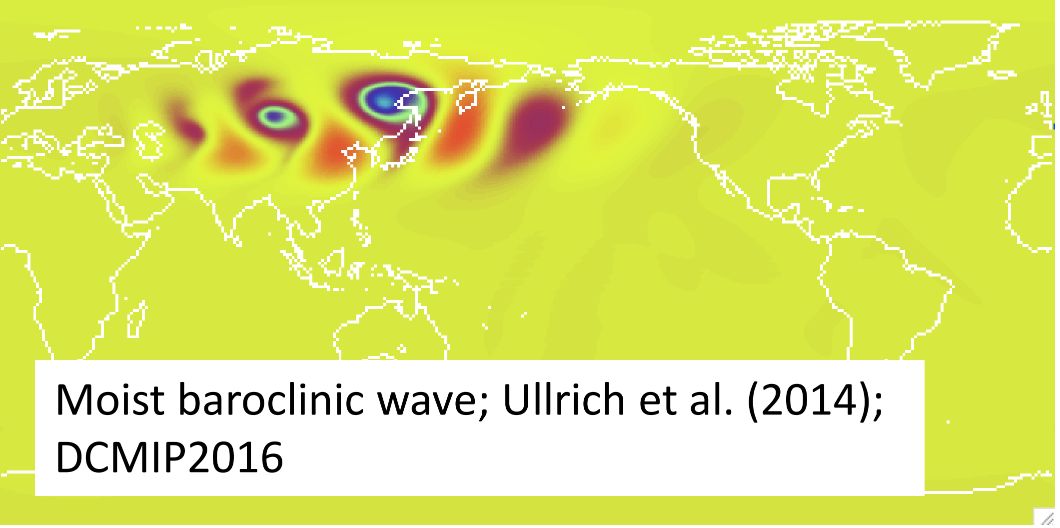
$p_0 = 1000 \text{ mb}$ $\quad$ $\kappa = \frac{R}{c_p} = \frac{2}{7}$ $\quad$ $c_p = 1004 \text{ J kg}^{-1}\text{ K}^{-1}$

$\Omega = 7.292 \times 10^{-5} \text{ s}^{-1}$ $\quad$ $g = 9.8 \text{ m s}^{-2}$ $\quad$ $a_e = 6.371 \times 10^6 \text{ m}.$

Aqua-planet
(long time-scales)



		Climate
(1)	Throughput: cost and scalability	Essential
(2)	Strong scaling	Essential
(3)	Efficient tracer transport	Essential
(4)	Conservation of mass (dry air, scalars)	Essential
(5)	Good tracer transport characteristics (shape-preservation, correlation, etc.)	Essential



Moist baroclinic wave; Ullrich et al. (2014); DCMIP2016

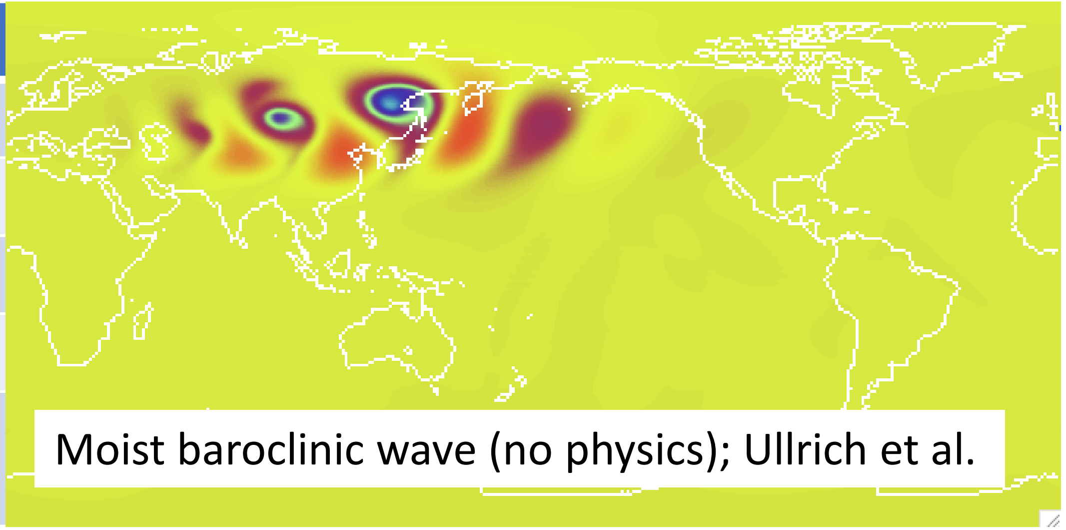
(1-3) At approximately 1^0 resolution evaluate throughput as a function of:

- number of tracers (from O(10) to O(300))
- vertical levels (from O(30) to O(200))
- number of processors (O(200) processor to O(5000) – few degrees of freedom, in the horizontal, per processor)

(4) Check for dry air mass conservation and scalar mass conservation

```
./create_newcase -compset FKESSLER (or variant thereof)
```

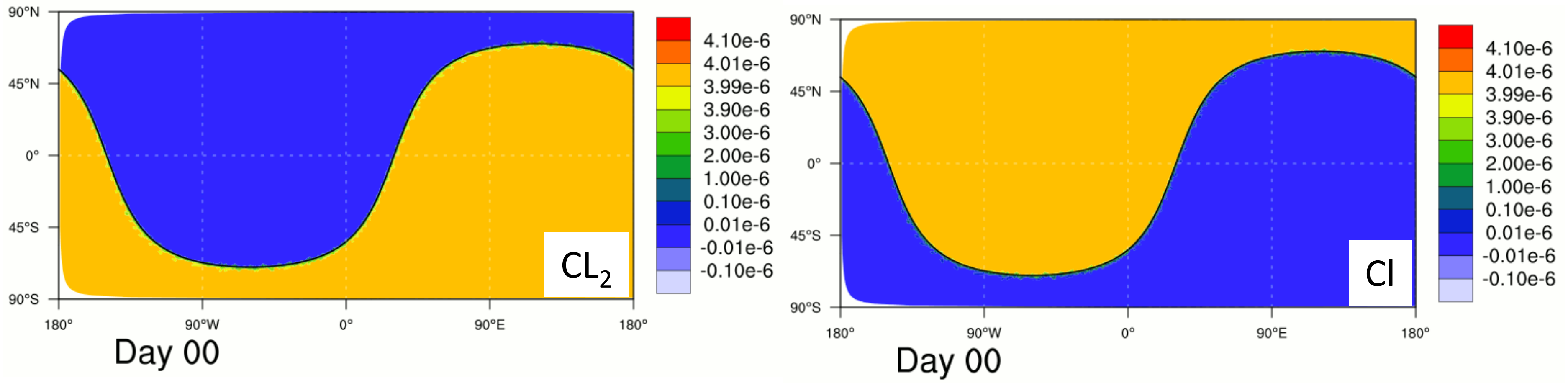
		Climate
(1)	Throughput: cost and scalability	Essential
(2)	Strong scaling	Essential
(3)	Efficient tracer transport	Essential
(4)	Conservation of mass (dry air, scalars)	Essential
(5)	Good tracer transport characteristics (shape-preservation, correlation, etc.)	Essential



(5a) **Linear correlation preservation**

Cl and Cl_2 that react with each other but always add up to a constant

(Lauritzen et al., 2015; 3D version in Lauritzen et al., 2017)



		Climate
(1)	Throughput: cost and scalability	Essential
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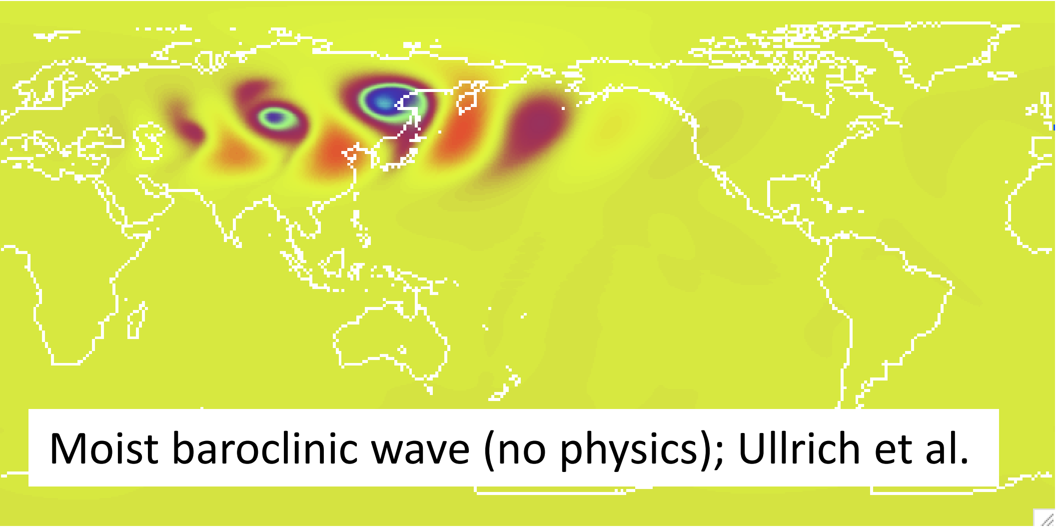
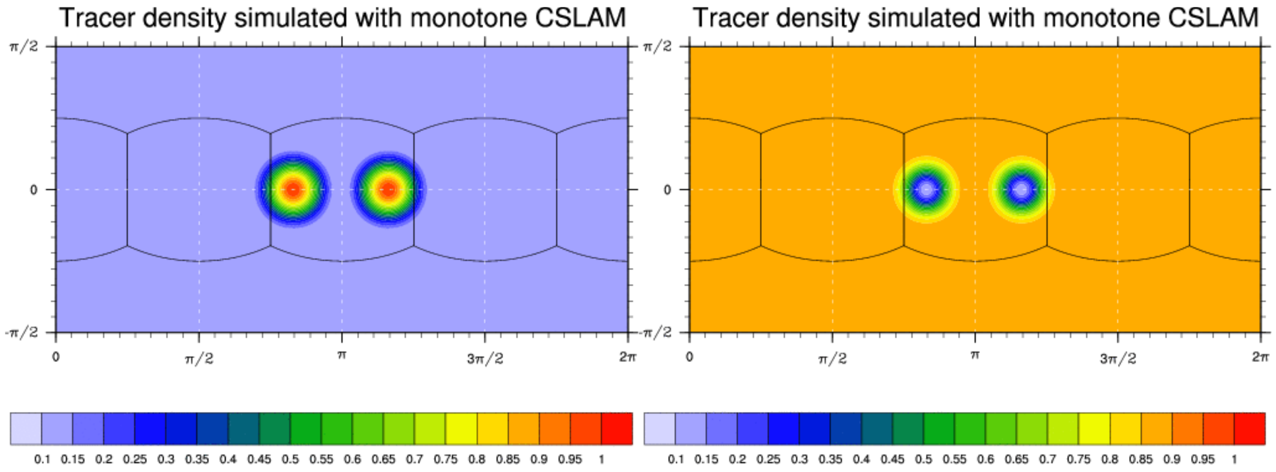


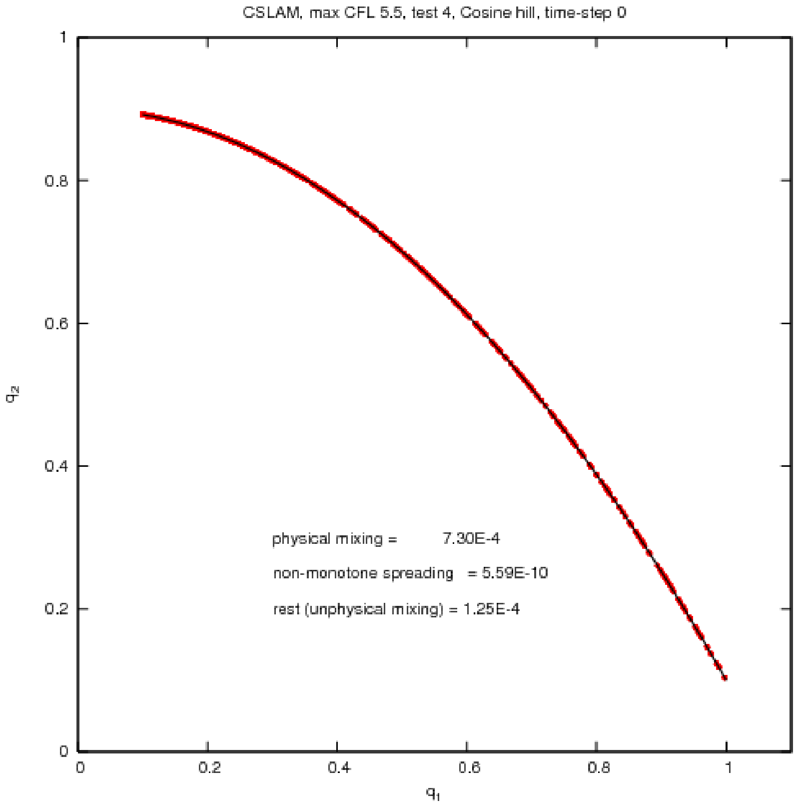
Moist baroclinic wave (no physics); Ullrich et al.

(5b) Non-linear correlation preservation

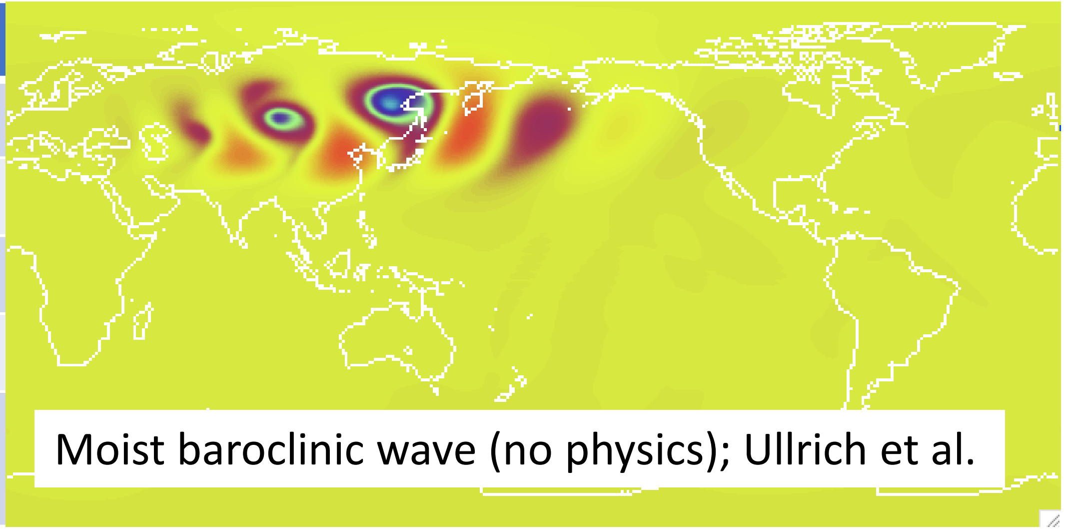
Two inert and passive distributions

(Lauritzen and Thuburn, 2010 -> need to extend to 3D!)





		Climate
(1)	Throughput: cost and scalability	Essential
(2)	Strong scaling	Essential
(3)	Efficient tracer transport	Essential
(4)	Conservation of mass (dry air, scalars)	Essential
(5)	Good tracer transport characteristics (shape-preservation, correlation, etc.)	Essential

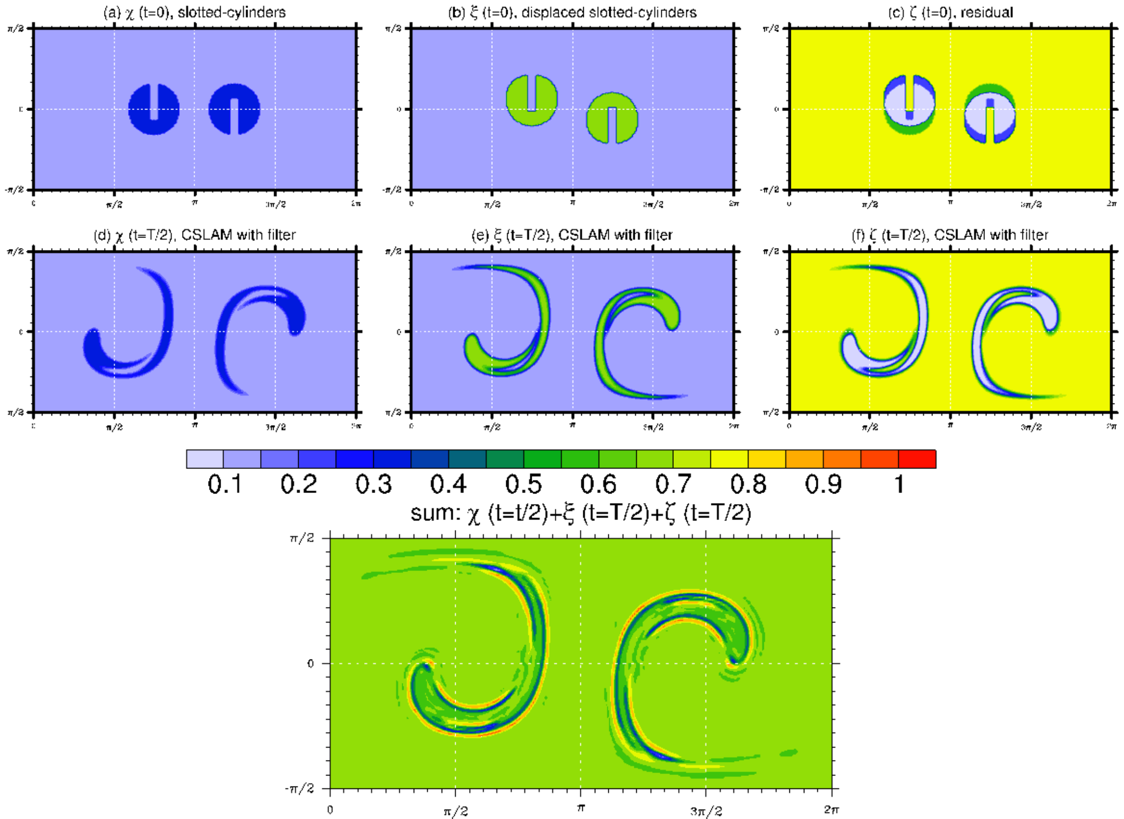


Moist baroclinic wave (no physics); Ullrich et al.

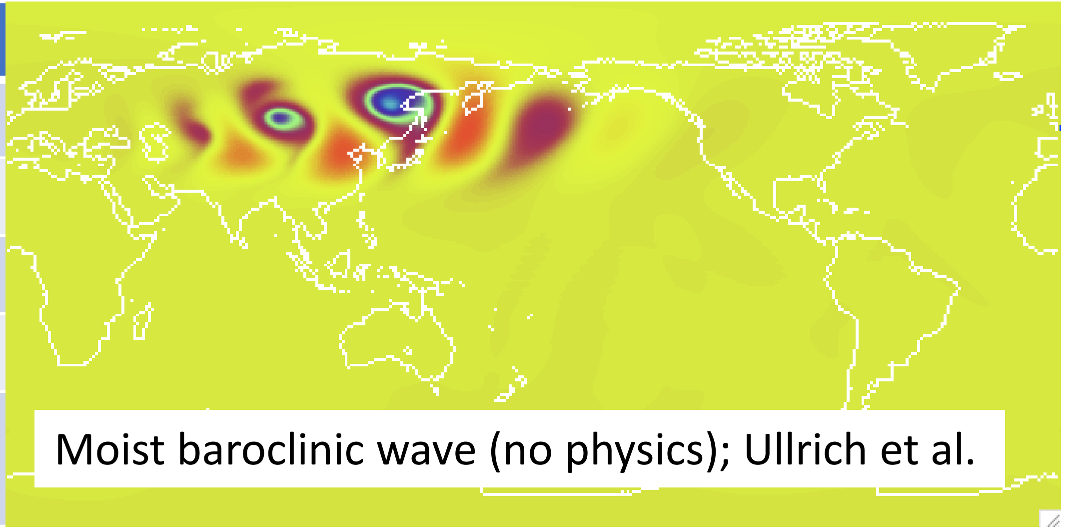
(5c) **Conserving family of species**

3 distributions that add up to a constant

(Lauritzen and Thuburn, 2010 -> need to extend to 3D!)



		Climate
(1)	Throughput: cost and scalability	Essential
(2)	Strong scaling	Essential
(3)	Efficient tracer transport	Essential
(4)	Conservation of mass (dry air, scalars)	Essential
(5)	Good tracer transport characteristics (shape-preservation, correlation, etc.)	Essential

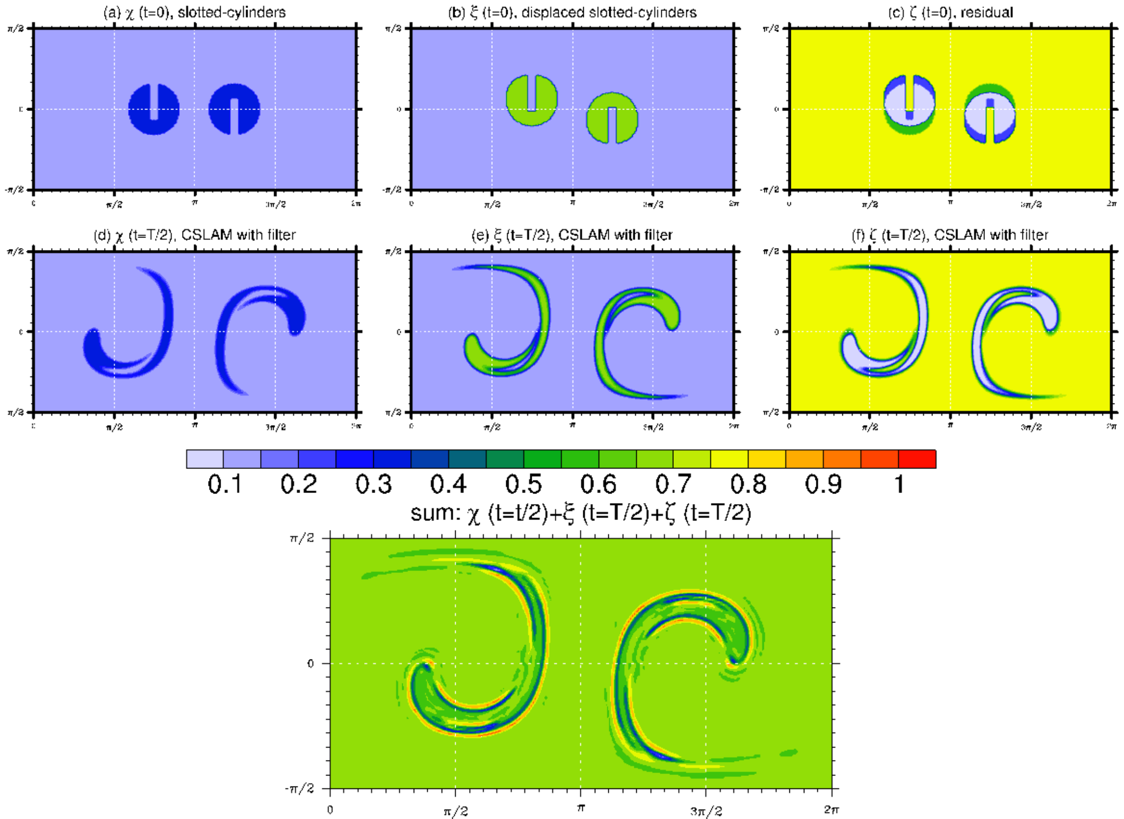


Moist baroclinic wave (no physics); Ullrich et al.

(5d) **Gradient preservation & shape-preservation**

Filament diagnostic: A measure of how well a transport scheme preserves gradients

(Lauritzen et al., 2012)



		Climate	Weather	Geospace
(1)	Throughput: cost and scalability	Essential	Essential	Essential
(2)	Strong scaling	Essential	Desirable	Desirable
(3)	Efficient tracer transport	Essential	Essential	Essential
(4)	Conservation of mass (dry air, scalars)	Essential	Essential	Essential
(5)	Good tracer transport characteristics (shape-preservation, correlation, etc.)	Essential	Essential	Essential

(5e) **Age-of-air (longer time-scales)**

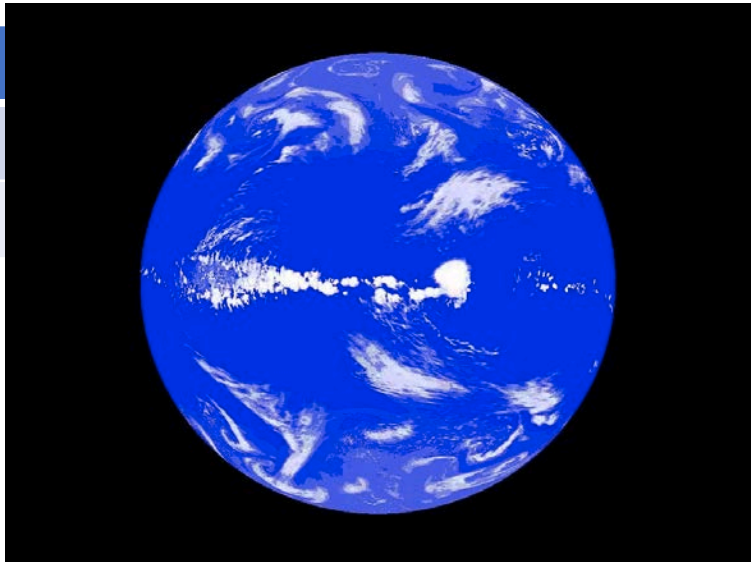
Polvani-Kushner (= variant of Held-Suarez with more realistic stratosphere) forcing with “clock tracer”

(Gerber and Gupta, NYU)

(4) Trends in mass-conservation over long time-scales

```
./create_newcase -compset FHS94 (modified)
```

		Climate	Weather
(6)	Good conservation of total energy	Essential	Desirable
(7)	Conservation of angular momentum	Highly desirable	



(4) Check for dry air mass conservation and scalar mass conservation

(6) **Derive what total energy the continuous equations of motion (on which dycore is based) conserve.**

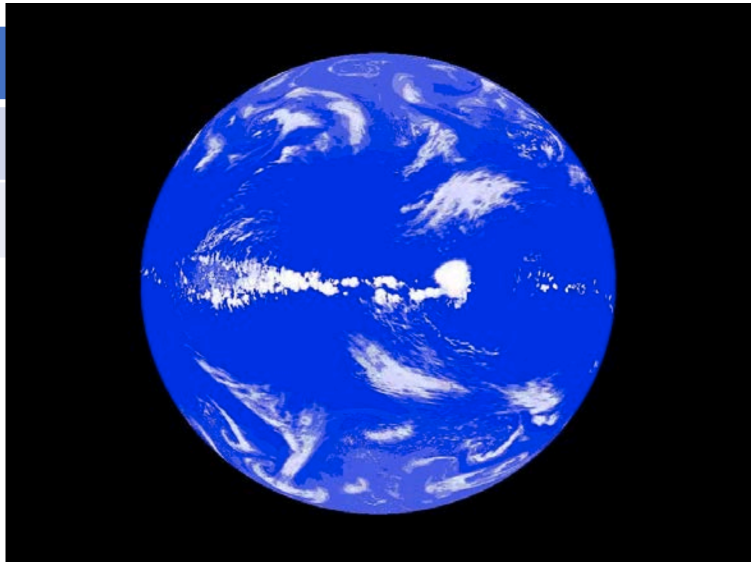
Total energy dissipation of the dynamical core should be assessed with moist physics (simplest setup is probably Aqua-planet) at (?) ~1^0 horizontal resolution

-> Diagnostics already exist in CAM physics layer

-> A detailed analysis of the energy conservation properties of different aspects of the dynamical core is of interest (currently diagnostics only in CAM-SE)

```
./create_newcase -compset QPC6 (or QPC4 or QPC5)
```

		Climate	Weather
(6)	Good conservation of total energy	Essential	Desirable
(7)	Conservation of angular momentum	Highly desirable	



(6) **Derive what axial angular momentum the continuous equations of motion (on which dycore is based) conserve (in the absence of mountain torque).**

Total axial angular momentum conservation can be tested with Aqua-planet or Held-Suarez (at (?) $\sim 1^0$ horizontal resolution).

Spurious torque from the dynamical core should << torque from parameterizations

-> Diagnostics already exist in CAM (in physics layer)

		Climate	Weather	Geospace
(8)	Dycore characteristics with topography			

(8) To my knowledge: **No "real-word" topography test in the literature!**

Topography smoothing and the dynamical core are closely related. It is, in general, desirable to have rougher topography. However, rough topography can trigger grid-scale noise from dynamical core.

Held-Suarez (or similar) forcing with real-world topography smoothed at different predefined scales (using the NCAR topography generation software; Lauritzen and Bacmeister):

-> all dycores "will see" the same topography and we can get an idea of the dynamical cores response to topographic forcing (e.g., magnitude and structure of vertical velocity)

-> add tracers to assess ("spurious") vertical transports over orography

ANY OTHER IDEAS?