Dynamical Frameworks

Progress Report

Research Objective 1:
Development of a Q3D MMF

Joon-Hee Jung and Akio Arakawa

August 2011 CMMAP Team Meeting

Ongoing work:

- Prepare a new benchmark simulation with a large domain
- Test the new Q3D MMF code using a non-trivial GCM
  (Still using an idealized setting with a domain size of a few thousands km.)
- Investigate the coupling strategy between GCM and CRM

Coupling Strategy

GCM effect on the CRM

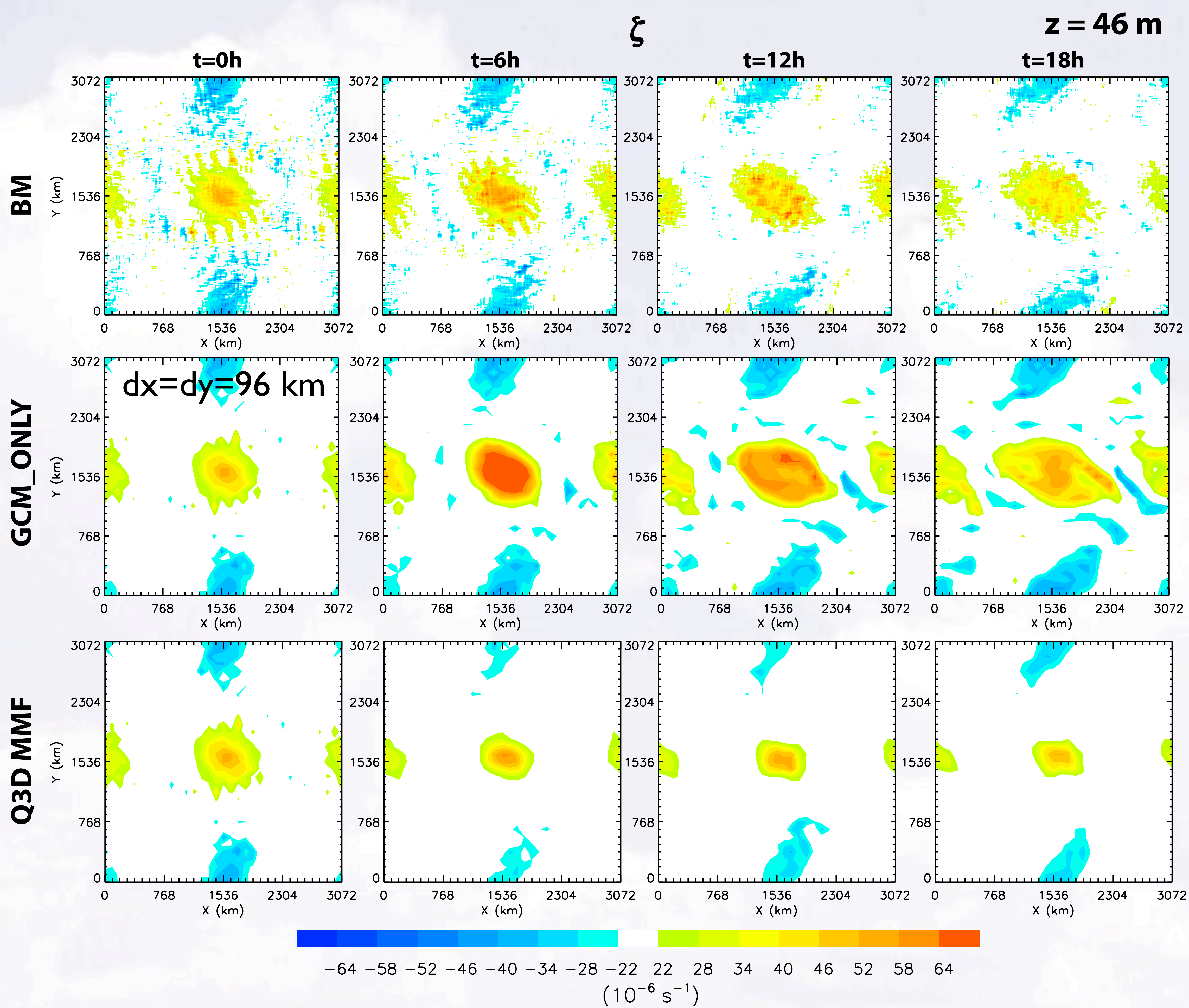
Since the Q3D CRM can partially represent large scale dynamics, it should not be forced by the GCM to avoid "double counting" in the coupled system. However, it is important that large scale fields recognized by the CRM should be sufficiently close to the GCM fields.

CRM effect on the GCM

As in the subgrid parameterization problems, the role of the CRM is to estimate the effects of eddies not resolved by the GCM. Thus, the CRM effect must be limited to the eddy effects by subtracting the non-eddy effects.

Not tested yet!

Instead, we tried a mutual relaxation through nudging.



ζ
z = 46 m
t=0h
t=6h
t=12h
t=18h
BM
GCM_ONLY
Q3D MMF
dx=dy=96 km
Y (km)
X (km)
0
768
1536
2304
3072
−64 −58 −52 −46 −40 −34 −28 −22 22 28 34 40 46 52 58 64
(10⁻⁶ s⁻¹)

THE UNIFIED PARAMETERIZATION:

ITS EMPIRICAL BASIS AND FUTURE PROBLEMS

Akio Arakawa and Chien-Ming Wu

August 2011 CMMAP Team Meeting

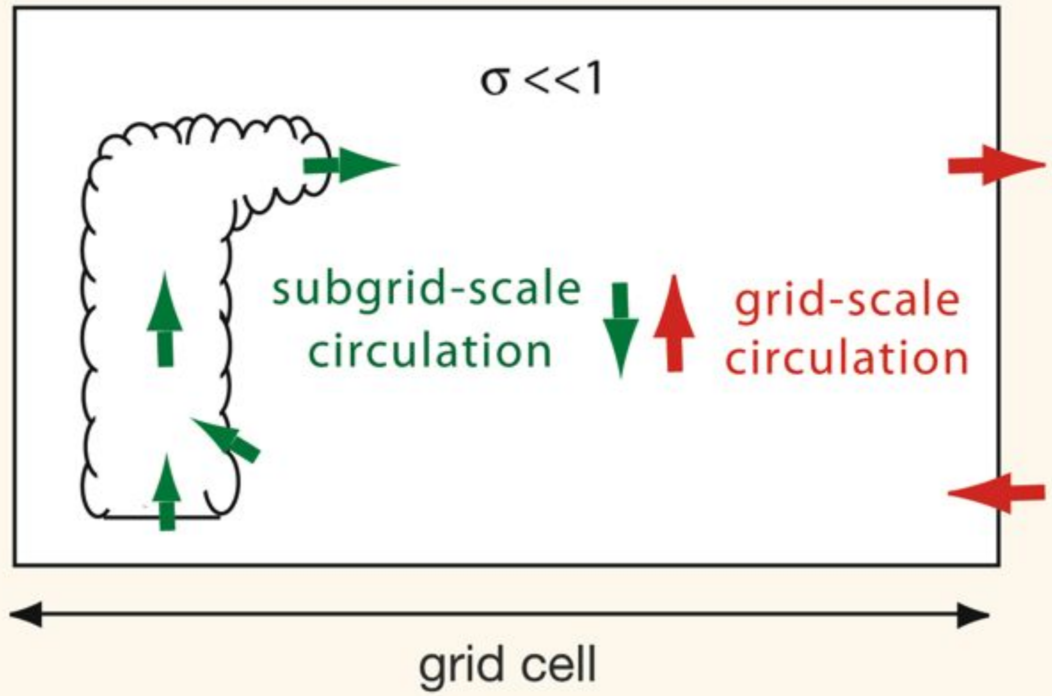
OPENING A ROUTE FOR UNIFIED PARAMETERIZATION

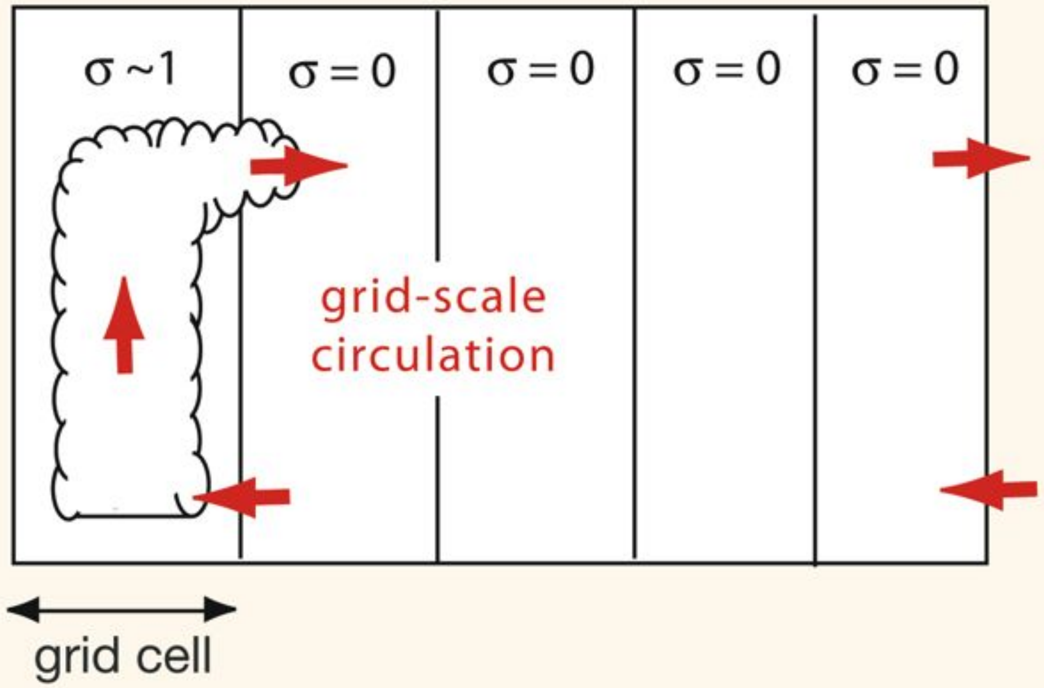
σ : the fractional area covered by *all* convective clouds

– a measure of fractional population of clouds

Conventional parameterizations assume $\sigma \ll 1$, either explicitly or implicitly.

With high resolutions, however, cloud may occupy the entire grid cell.



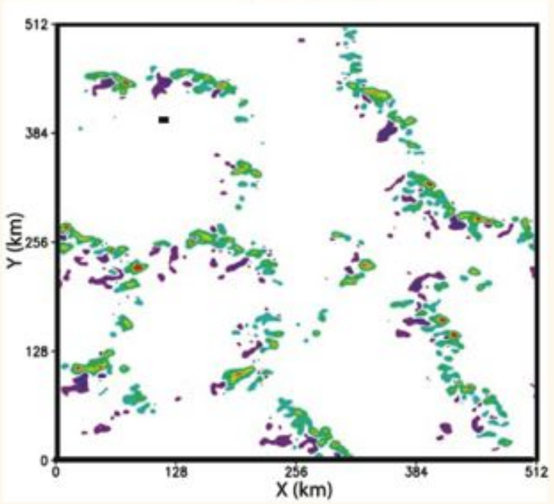


To open a route, the assumption of $\sigma \ll 1$ must be eliminated.

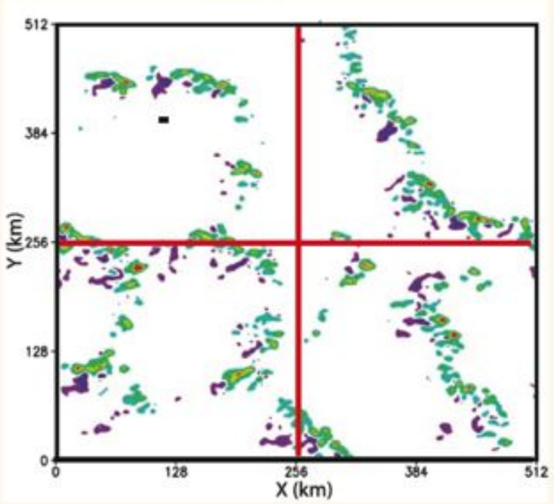
ANALYSIS OF GRID-SIZE DEPENDENT STATISTICS OF THE CRM DATA

The original domain is divided into sub-domains with the same size.

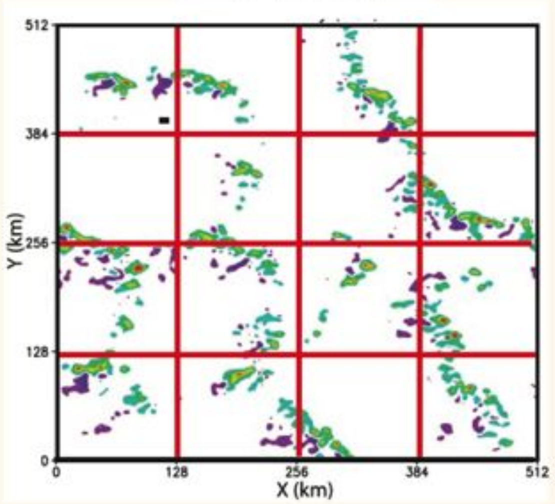
512 km



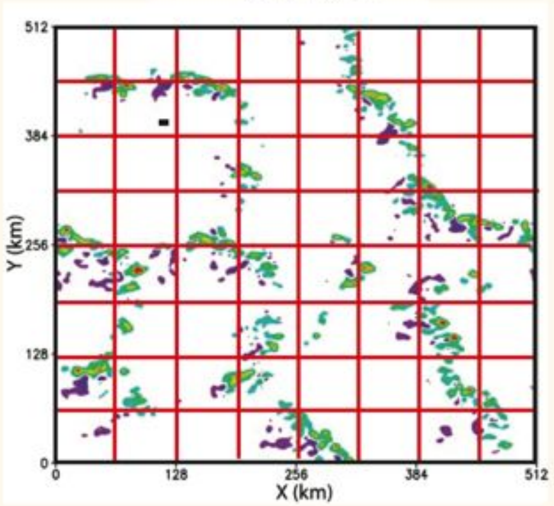
256 km



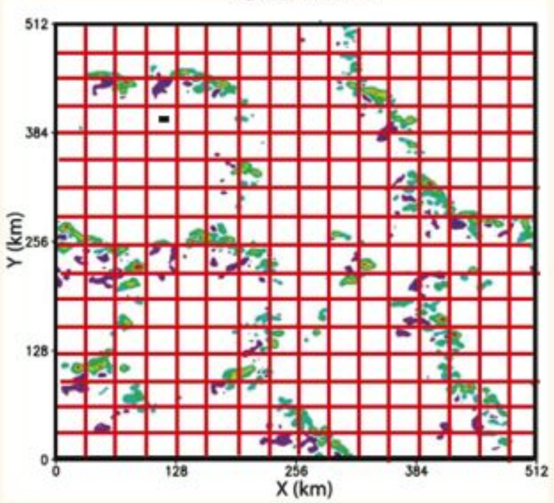
128 km



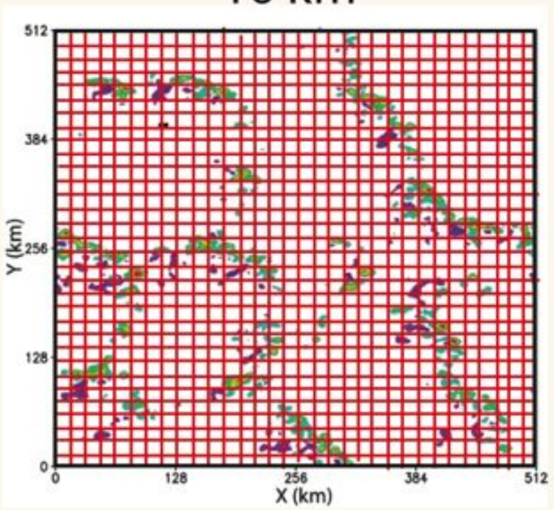
64 km



32 km



16 km

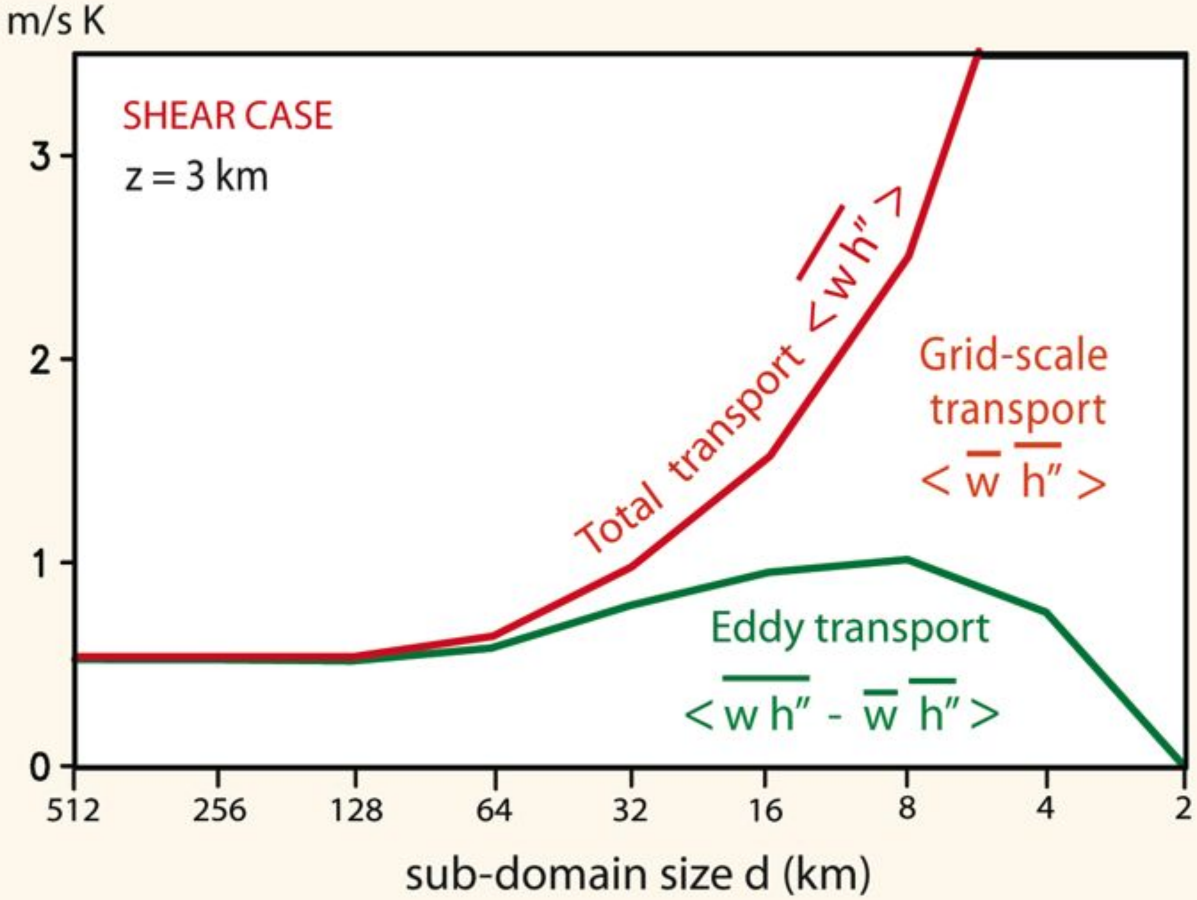


8 km 4 km 2 km

These sub-domains are assumed to represent grid cells of a GCM.

RESOLUTION DEPENDENCE OF

ENSEMBLE-MEAN VERTICAL TRANSPORT OF MOIST STATIC ENERGY



h″ : Deviation of h from its reference value

$\overline{(\ )}$: Average over all CRM grid points in the sub-domain

< > : Ensemble average over all cloud-containing sub-domains

In the mesoscale range, the eddy transport is only a fraction of the total transport.

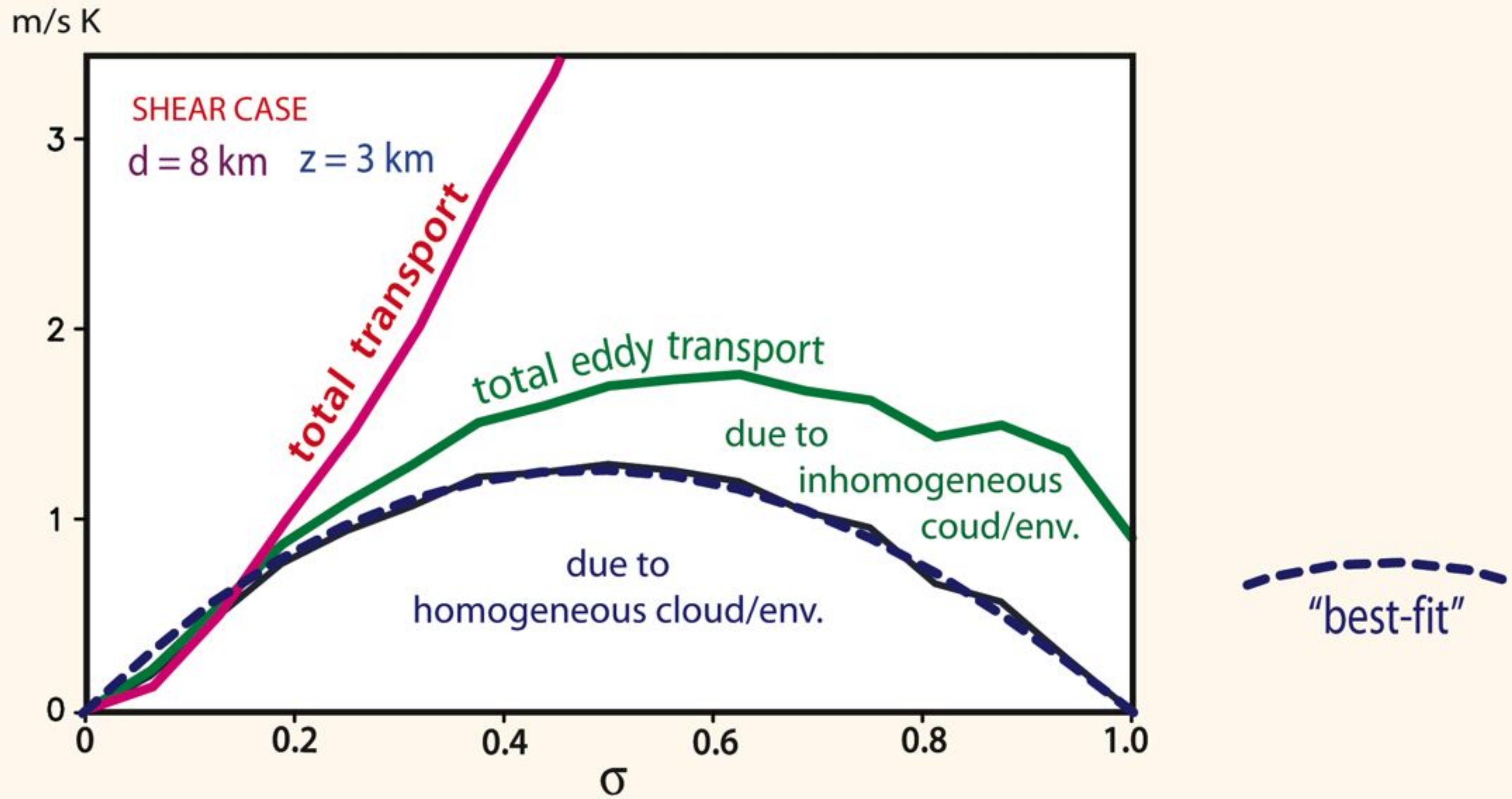
σ–DEPENDENCE OF

ENSEMBLE-MEAN VERTICAL TRANSPORT OF MOIST STATIC ENERGY

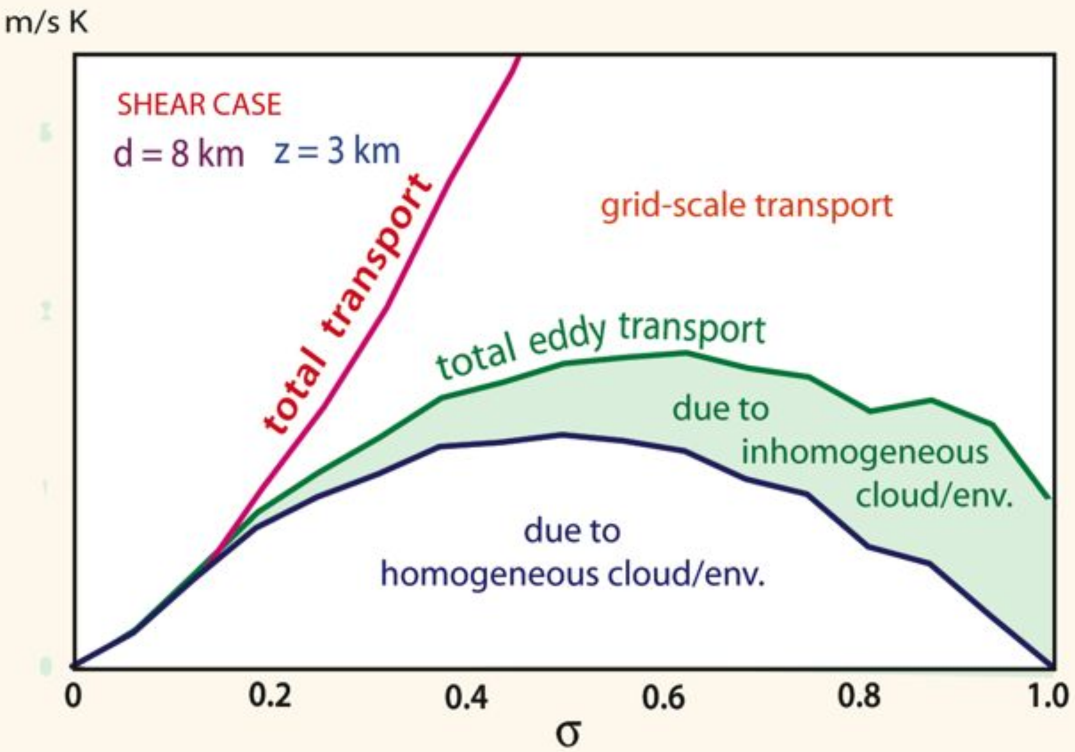
For homogeneous cloud/env.: $\overline{wh}-\overline{w}\,\overline{h}=\frac{\sigma}{1-\sigma}(w_c-\overline{w})(h_c-\overline{h})$ (1)

From the convergence requirement: $(w_c-\overline{w})(h_c-\overline{h})=(1-\sigma)^2\left(w_c{}^*-\overline{w}\right)\left(h_c{}^*-\overline{h}\right)$ (2)

From (1) and (2), $\overline{wh}-\overline{w}\,\overline{h}=\sigma(1-\sigma)\left(w_c{}^*-\overline{w}\right)\left(h_c{}^*-\overline{h}\right)$ (3)



FUTURE PROBLEMS - EDDY TRANSPORTS FOR LARGE σ



The effect of convective downdrafts

As far as the 3 km level is concerned, the eddy transport due to inhomogeneous "environment" is negligible.

The analysis should be extended to lower levels including the sub-cloud layer.

The effects of multiple cloud types, cloud organization, and internal structure of clouds

The relative importance of these effects should be assessed.

When the resolution is high and σ is large, however, these effects are small compared to grid-scale transports.

Unification with parameterization of stratiform clouds

Large σ can appear even with low-resolutions when stratiform clouds dominate.
Then unification with stratiform-cloud parameterization becomes an issue
– geometrical representation, closure based on non-buoyancy, ...

Implicit-Explicit Multistep Methods for Fast-Wave Slow-Wave Problems

Peter Blossey & Dale Durran

10 August 2011

Fast waves require small timesteps, unless you ...

- choose governing equations that prohibit fast waves (anelasitc, unified framework, etc.)
- split fast waves from rest of physics, so that they alone are integrated on small timesteps. (As in WRF)
- treat them implicitly. (ECMWF, Met Office, ...)

First and third options require the solution of a global (usually linear) system at each timestep.

In this talk, we are focused on the third option.

Fast waves: sound (and sometimes gravity) waves.
Slow waves: advection (and sometimes gravity) waves.

Desired Properties of Alternate Schemes

Implicit schemes:

- *A*-stability (numerical approximations to

$$\frac{du}{dt} = \eta u$$

  satisfy $|A| \equiv |q^{n+1}/q^{n}| \leq 1$ if $\Re\{\eta\} \leq 0$)
  (But *A*-stable scheme can be no better than 2nd-order.)
- Damps high frequencies ($|A|$ becomes small as $\Im\{\eta\}\Delta t \to \pm\infty$).

Desired Properties of Alternate Schemes

Explicit schemes:

- Good stability for purely oscillatory phenomena (i.e. larger CFL limit).
- Able to handle both oscillatory and damping phenomena.

A family of implicit-explicit Adams methods

Building on Frank et al. 1997, consider a family of implicit Adams schemes (A-stable for $c \geq 0$):

$$\frac{\mathbf{q}^{n+1} - \mathbf{q}^n}{\Delta t} = \frac{1}{2}\left[\mathbf{L}\mathbf{q}^{n+1} + \mathbf{L}\mathbf{q}^n\right] + \frac{c}{2}\left[\mathbf{L}\mathbf{q}^{n+1} - 2\mathbf{L}\mathbf{q}^n + \mathbf{L}\mathbf{q}^{n-1}\right]$$

Trapezoidal is $c = 0$.

Similarly, consider a family of three-step explicit Adams schemes:

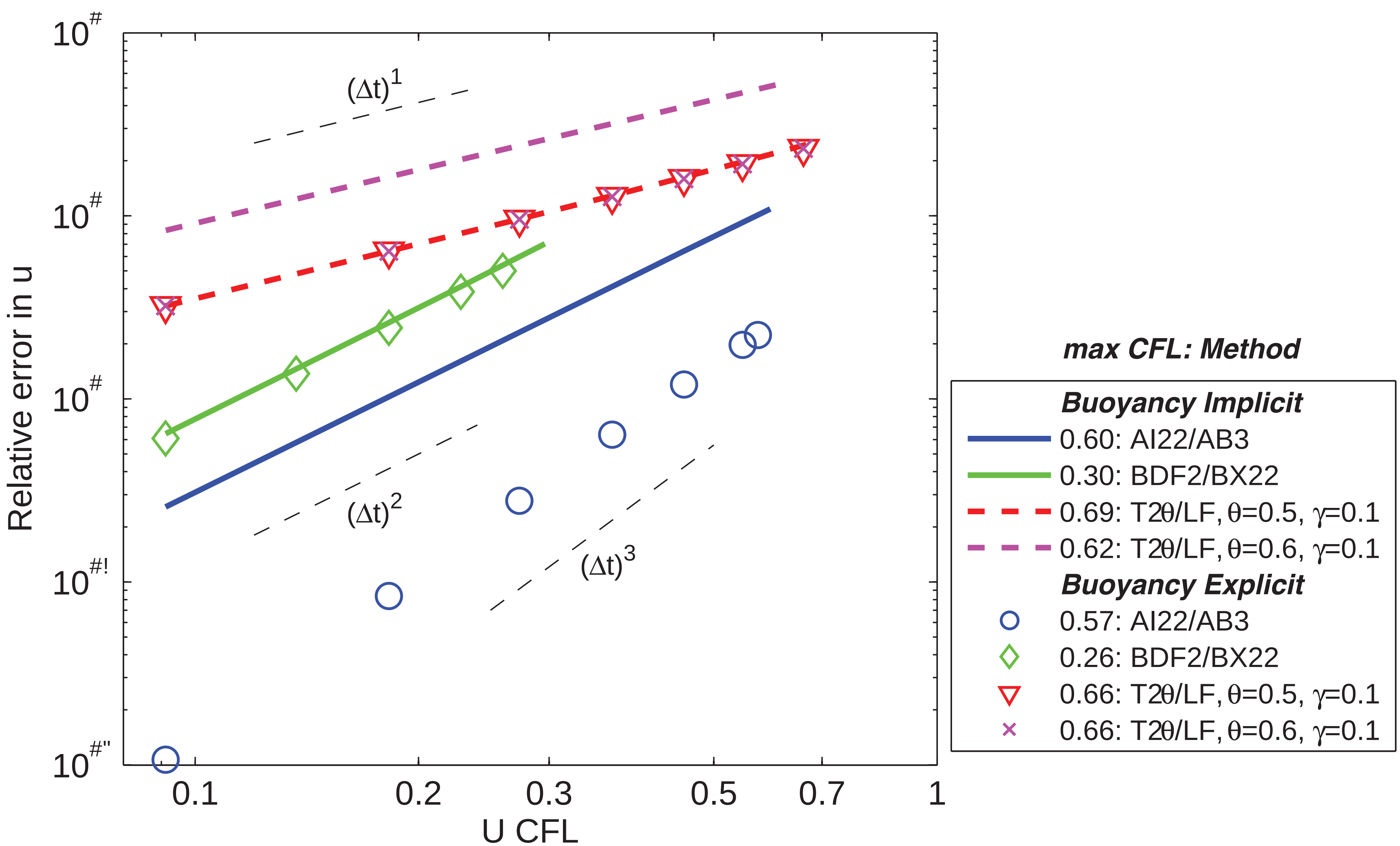
$$\frac{\mathbf{q}^{n+1} - \mathbf{q}^n}{\Delta t} = \frac{3}{2}\mathbf{f}(\mathbf{q}^n) - \frac{1}{2}\mathbf{f}\left(\mathbf{q}^{n-1}\right) + \frac{b}{2}\left[\mathbf{f}(\mathbf{q}^n) - 2\mathbf{f}\left(\mathbf{q}^{n-1}\right) + \mathbf{f}\left(\mathbf{q}^{n-2}\right)\right]$$

$b = 0$ gives 2nd order Adams-Bashforth, $b = 5/6$ gives AB3.

We seek combinations of b and c which yield good stability for fast wave-slow wave problems.

Improvement at almost no CPU cost

14% reduction in maximum Δt for AI22/AB3 relative to Asselin-filtered leapfrog scheme



A Progress Report and More on the Unified System

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Eleventh CMMAP Team Meeting, 9-11 August 2011, Fort Collins, CO
Dynamical Framework Working Group

Unified System

Arakawa and Konor (2009, *MWR*)

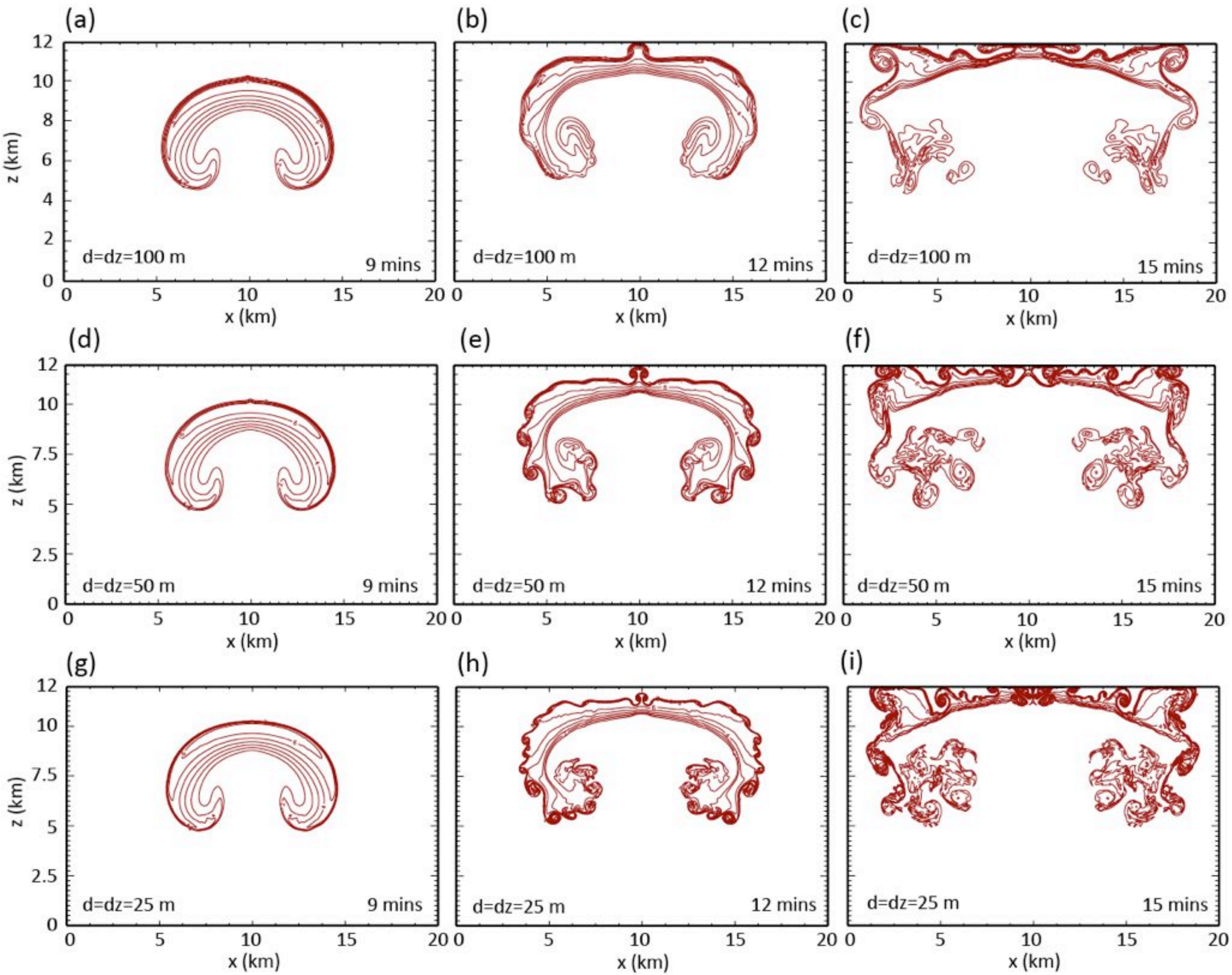
A nonhydrostatic system applicable to wide range of atmospheric scales of motion

- Filters vertically propagating acoustic waves while allowing elasticity due to thermal expansion
- Does not require a basic or mean state
- Does not introduce any approximation to the momentum and thermodynamic equations
- Introduces a minor approximation to the continuity equation
- Conserves energy

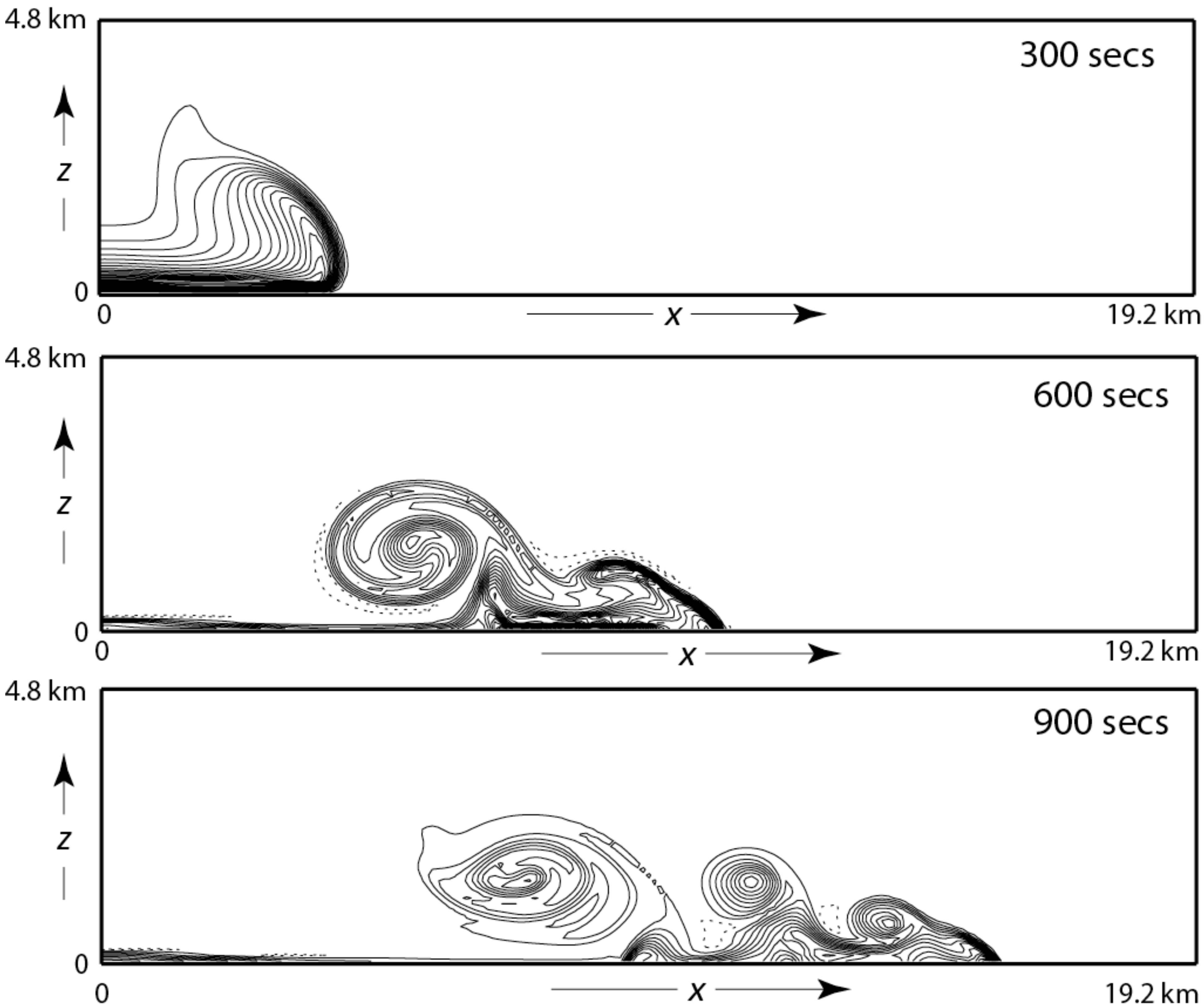
Progress

- A dynamical core based on the unified system has been developed
- A paper describing the dynamical core and presenting the results has beed submitted for publication to JAMES.
- Development of a global dynamical core based on the unified system is nearly completed

Warm bubble tests [Suggested by Mendez-Nunez and Carroll, 1993]

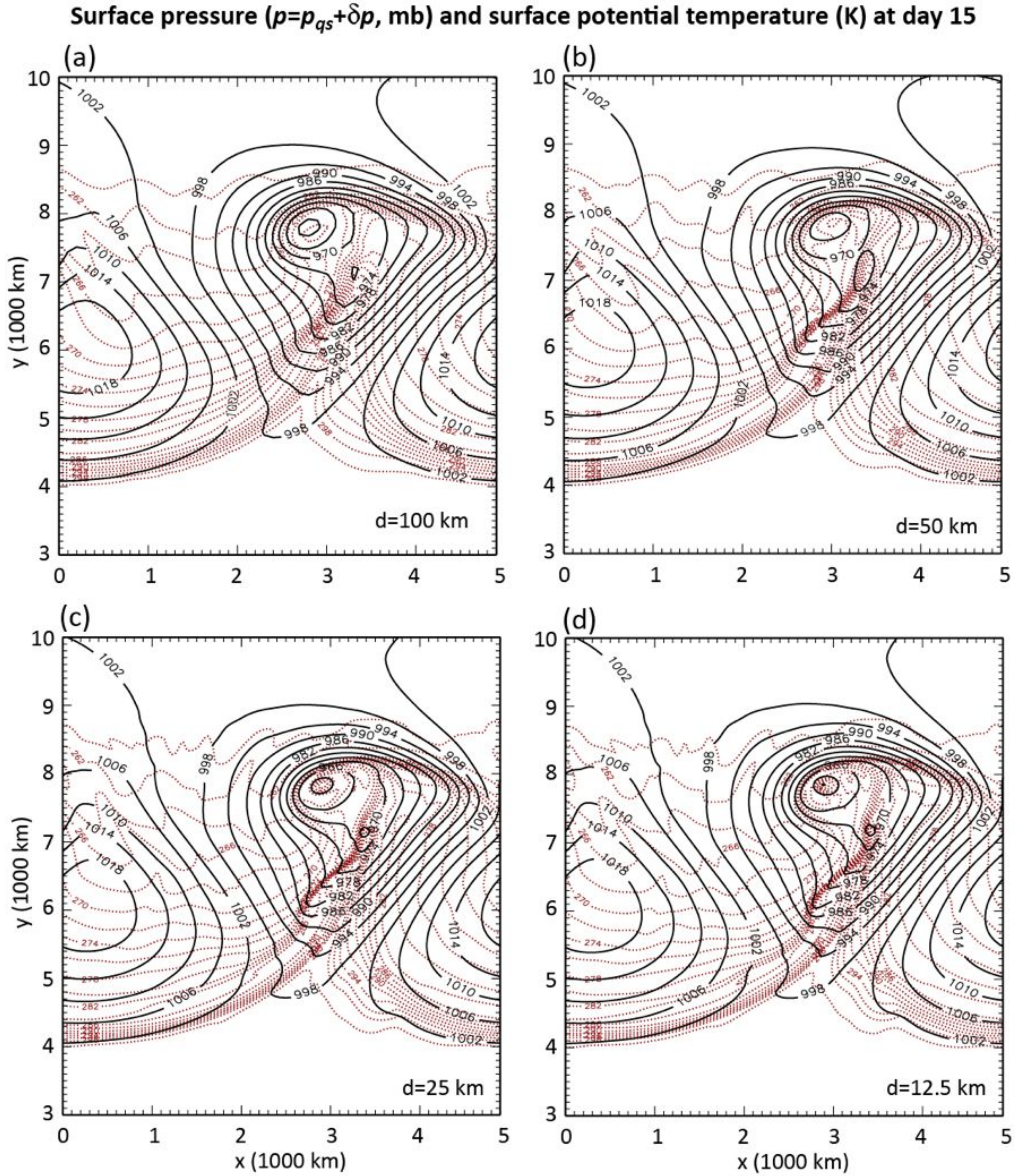


Cold bubble tests [Suggested by Straka et al., 1993]



Idealized extratropical cyclogenesis simulations

Surface fields at Day 15



A Vorticity-Divergence Dynamical Core based on the Nonhydrostatic Unified System of Equations on the Icosahedral Geodesic Grid

Ross Heikes, C.S. Konor and D. Randall

Dept. of Atmospheric Science
Colorado State University

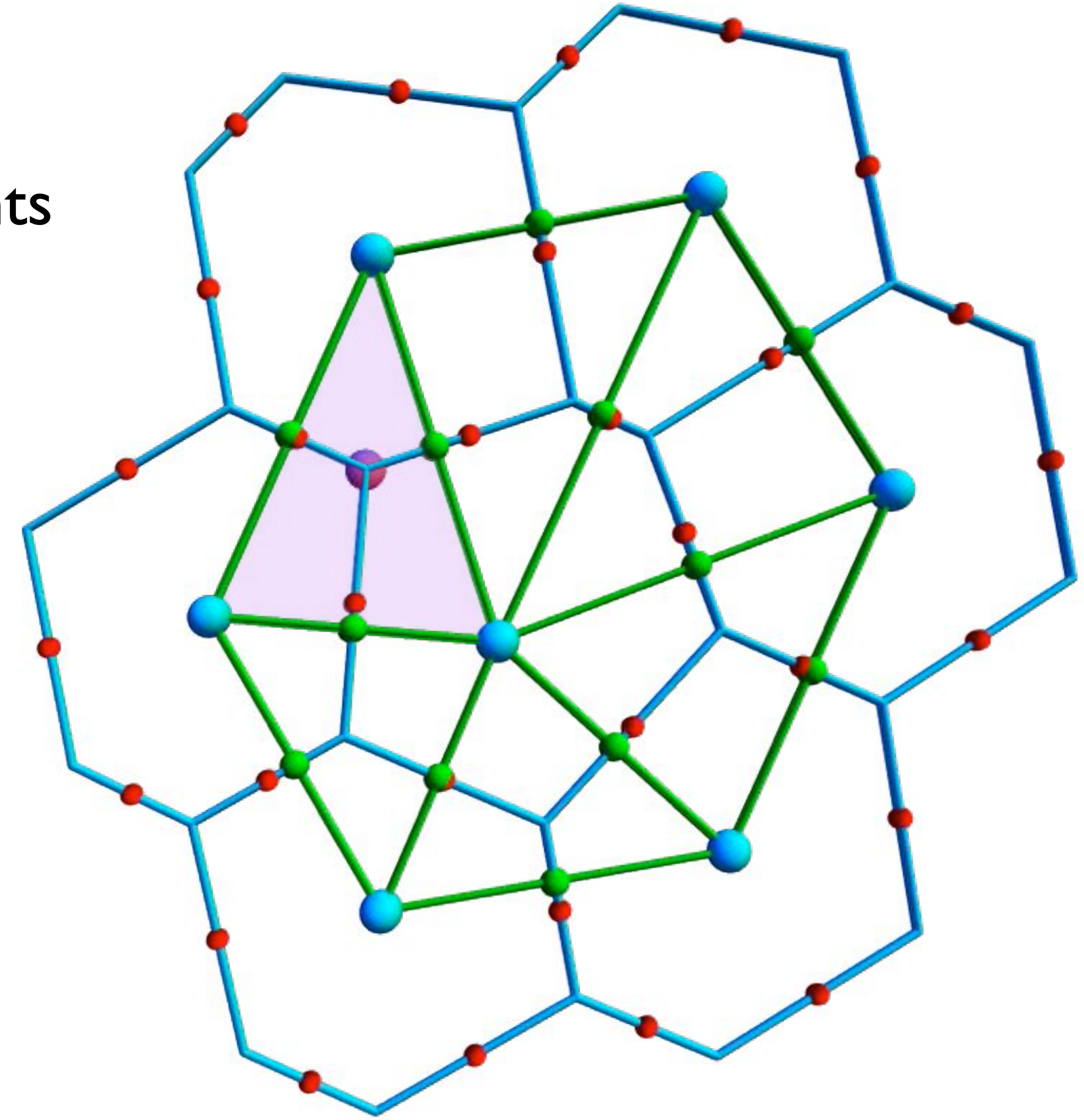
Office of Science
SciDAC
Scientific Discovery through Advanced Computing
CMMAP
Reach for the sky.

Grid Optimization Algorithm

- The ***Voronoi Corner*** (purple dot) is defined as the point equidistant from surrounding grid points (blue dots).

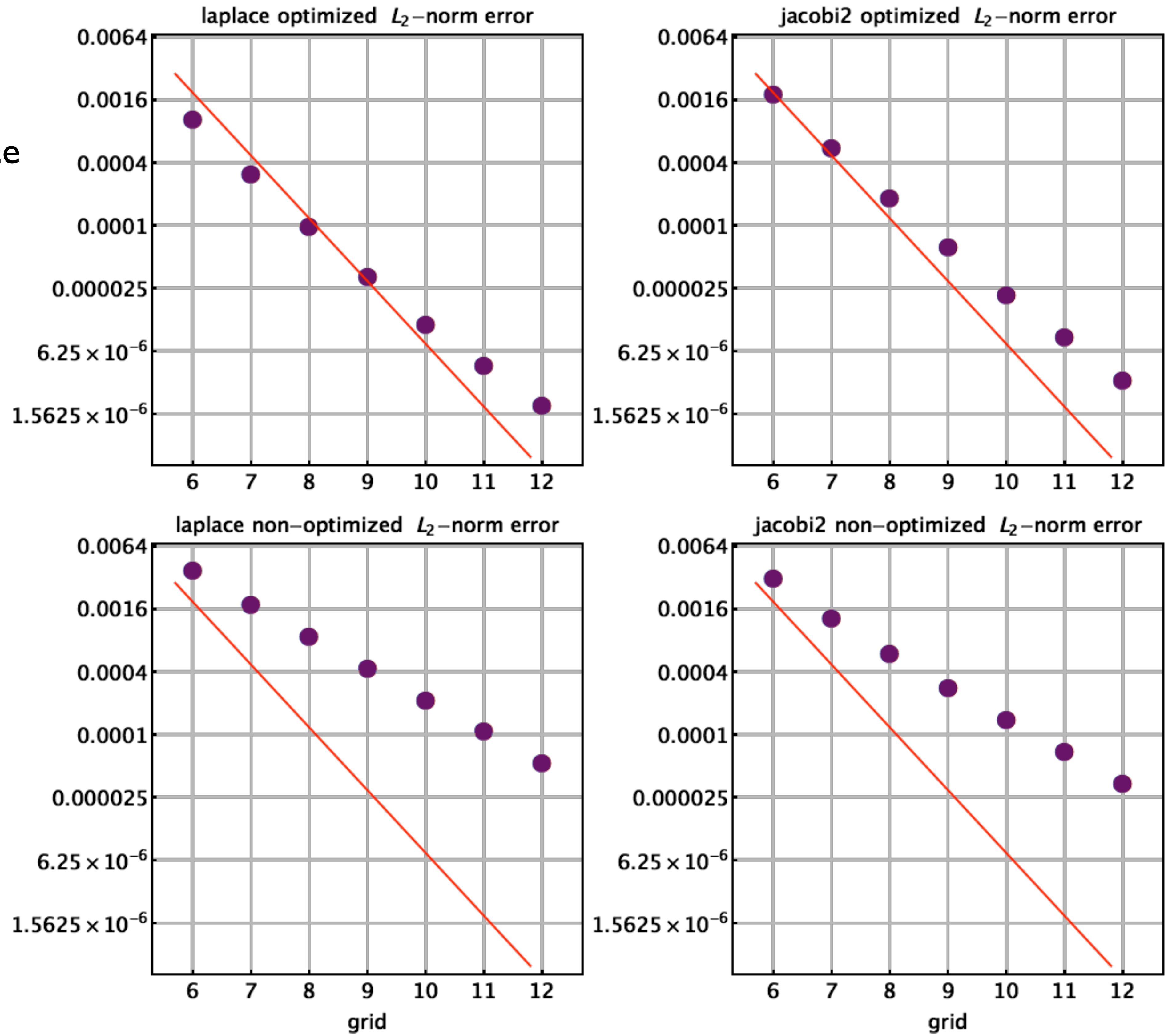
- There is a flaw with the Voronoi grid -- a line connecting grid points does not bisect the cell wall.

- The algorithm positions all grid points so that red points are coincident with green points (or at least it does the best it can)



RMS errors of finite-difference Laplacian and Jacobian

- With a very smooth analytic test function show the convergence properties of the optimized and non-optimized grids
- The RMS error measures the overall goodness of the grid
- The red line shows idealized 2nd-order convergence

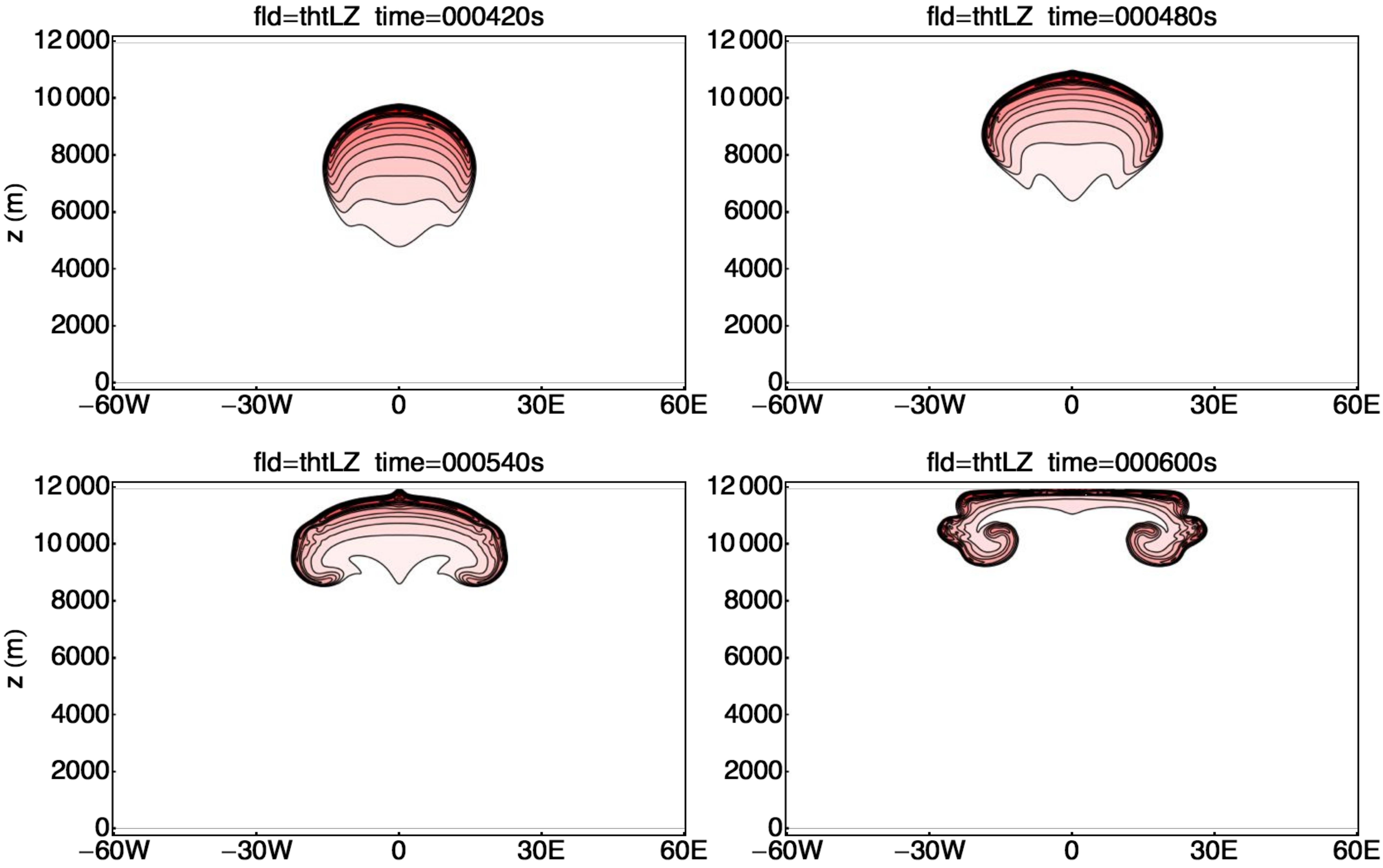


Scaling test of 3D-multigrid on Jaguar XT5

- The **NCCS Cray XT5** with 244,256 cores.
  Each compute node contains two hex-core AMD Opteron processors, 16GB memory, and a SeaStar 2+ router.
- 20 V-cycles
- 128 layers

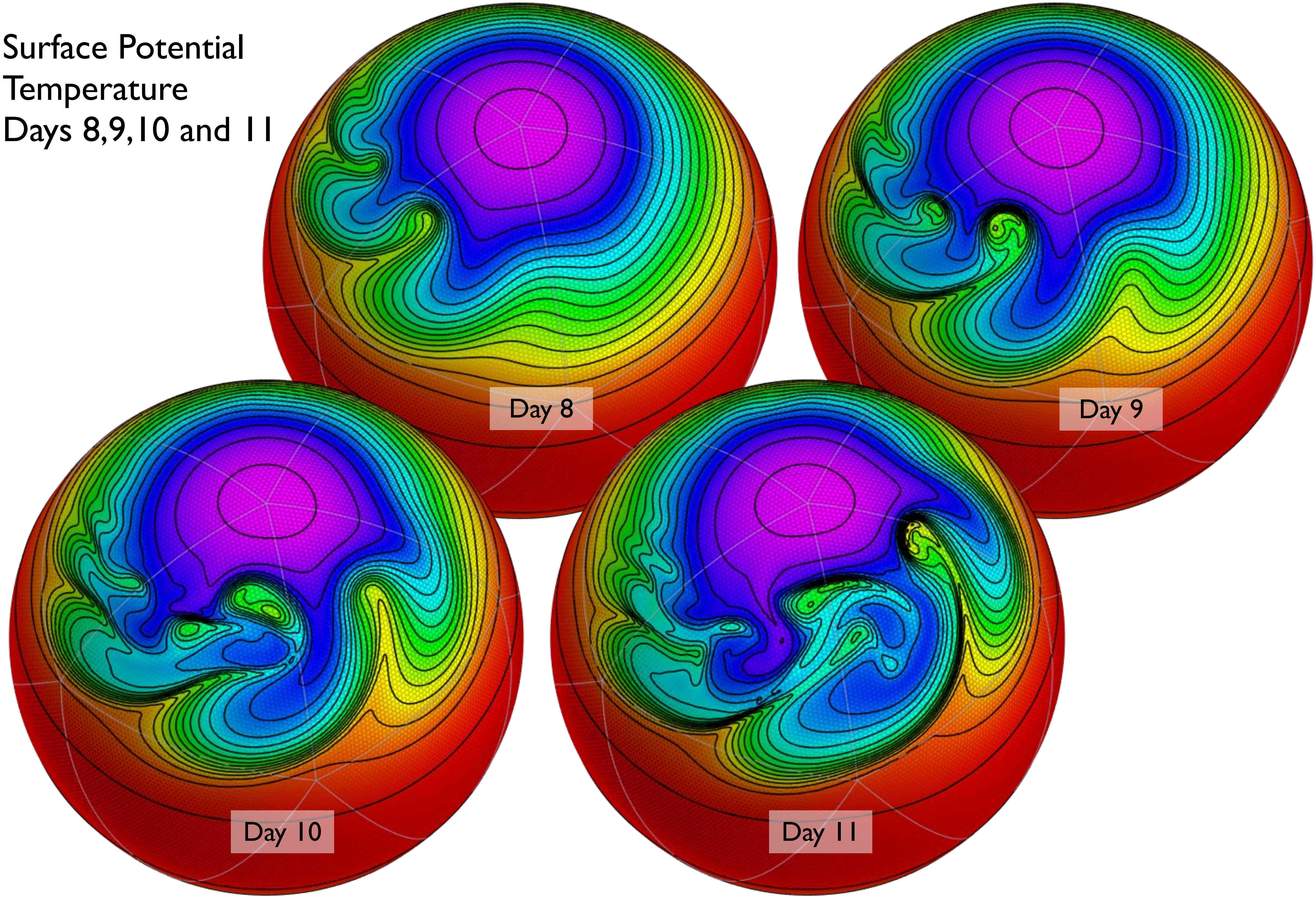
Time (s) 128 vertical layers 20 V-cycles		Number of cores				
		5120	10240	20480	40960	81920
Grid resolution. Number of cells. (Grid point spacing)	41,943,042 (3.909km)	16.867	8.971	5.590	4.004	
	167,772,162 (1.955km)	62.527	33.978	18.057	8.746	5.066
	671,088,642 (0.977km)	insufficient memory per core	insufficient memory per core	62.717	32.006	17.166

Warm Bubble Test



Extratropical cyclone

- Surface Potential Temperature
- Days 8,9,10 and 11



progress, conclusions and future work

- The grid optimization stuff is finally laid to rest.
- A vorticity-divergence model based on the nonhydrostatic unified system of equations on the icosahedral grid has been developed and tested.
- Addition of physics