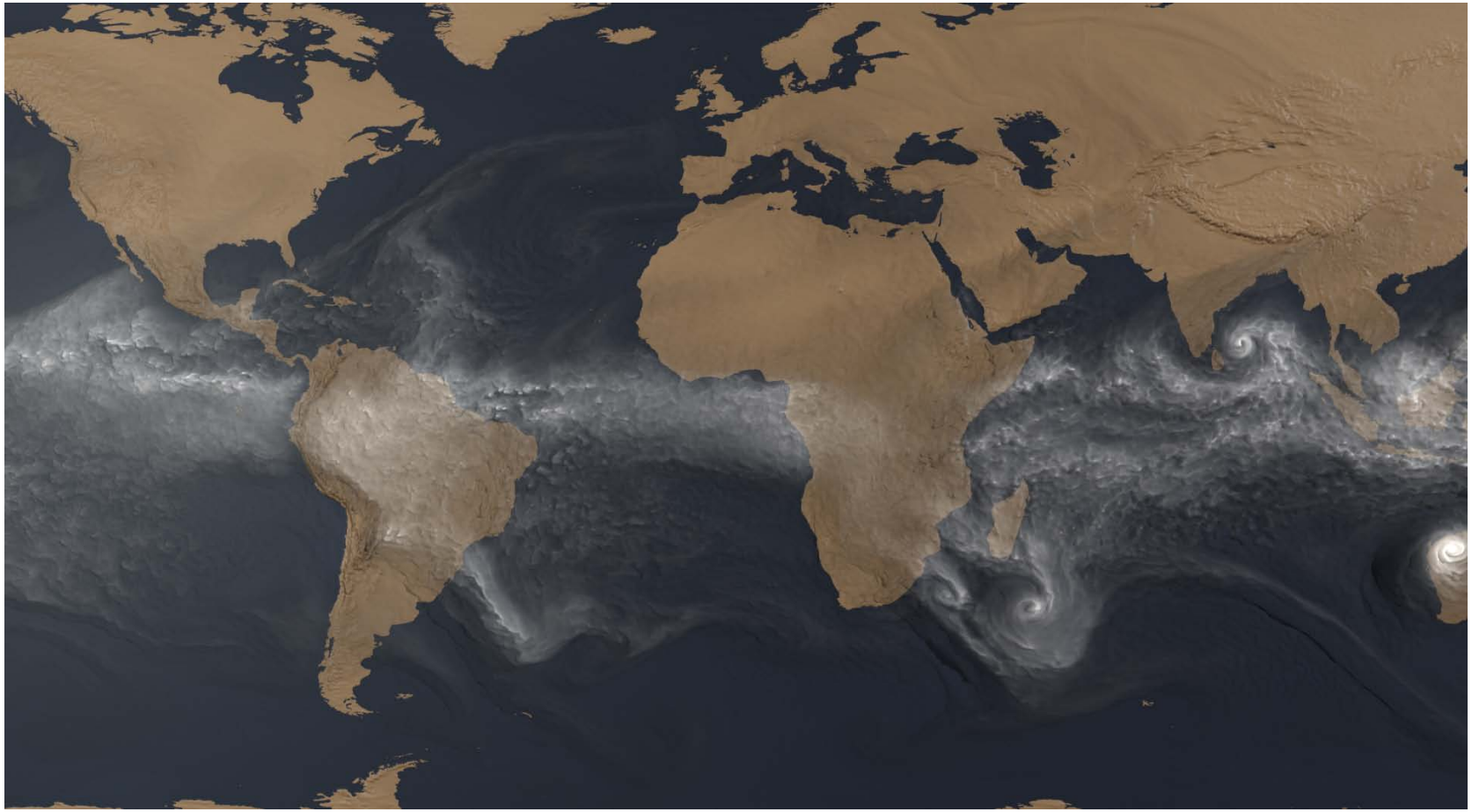
Implicit time-stepping methods within the CAM-SE dycore.

When are they a ‘win’ ?

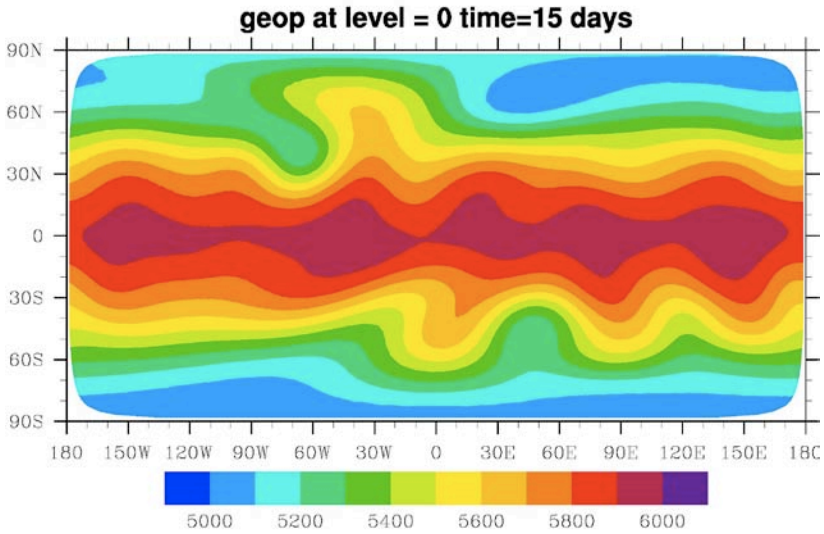
Kate Evans, ORNL, presenter
R. Archibald, ORNL
A. Lott, LLNL
J. Ribbeck, UTK
M. Taylor, SNL
C. Woodward, LLNL
P. Worley, ORNL

Goal: global or local CAM4-SE 1/8 degree (14km) spatial resolution

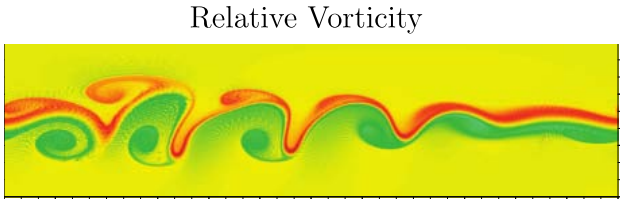


Right now, ¼ CAM5-SE on 27.7K processors runs at ~1.5 SYPD
We need 5 SYPD coupled to perform long stable simulations

Shallow water: mimics separation of scales as in with the primitive equations



TC5



1200 s

SJ1

SW implicit TC5: timings for 1 day, 48 procs

Spatial Resolution: ne=30, np4 (classic 1 degree resolution setup used in CAM)

Integration	Time Step (s)	Sim Time (s)	Nonlin its*	Lin/Nlin its*
Explicit RK	180	12	N/A	N/A
Implicit BDF2	1800	16	1	30
BDF2 precon	1200	43	1	3

SW implicit TC6: timings for 1 day, 60 procs

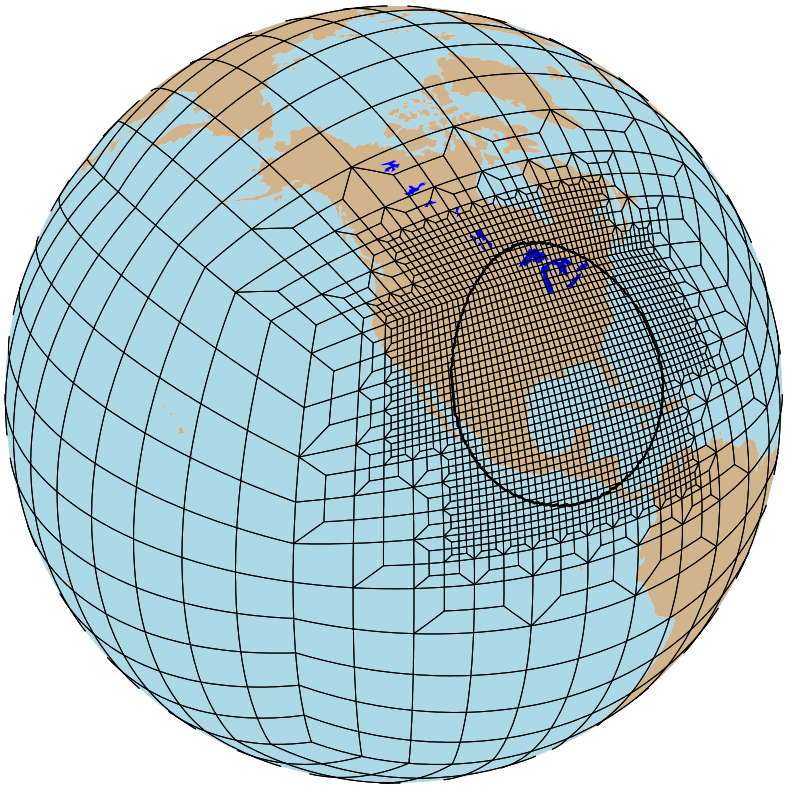
Spatial Resolution: ne=15, np8 (higher spatial order, matches reg test case)

Integration	Time Step (s)	Sim Time (s)	Nonlin its*	Lin/Nlin its*
Explicit RK	40	16	N/A	N/A
Implicit BDF2	1800	24	4	24
BDF2 precon	1800		2	2.5

*The number of iterations and timing is strongly dependent on the choice of tolerance

OAK RIDGE National Laboratory

Regional refinement using an implicit solver



- **TC5 Mountain test case**
- **2 cases with refinement over mountain region**
  - **2 levels ~2 degree refined to ~1 degree**
  - **8 levels: ~2.5 degree refined to ~1/3 degree**
- **More stringent CFL restriction**
- **Hyperviscosity is still under development**

OAK RIDGE National Laboratory

1 degree refined to 1/2 degree: 1 day, 60 procs

Integration	Time Step (s)	Sim Time (s)	~Nonlin its*	~Lin/Nlin its*
Explicit RK	60	14	N/A	N/A
Implicit*	1800**	24	3	30
Implicit w/ pre	1800	6m5s	2	3

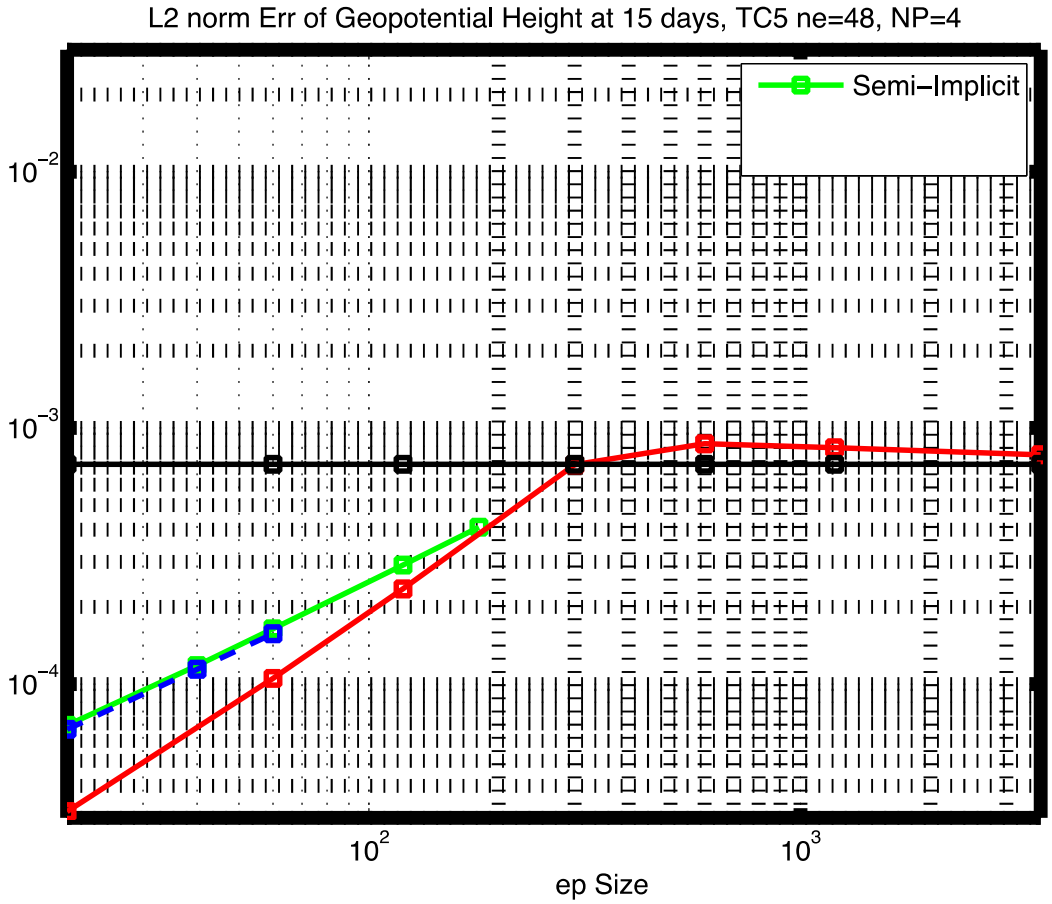
~2.5 degree refined to 0.3 degree: 1 day, 64 procs

Integration	Time Step (s)	Sim Time (s)	~Nonlin its*	~Lin/Nlin its*
Explicit RK	30	28***	N/A	N/A
Implicit BDF2	1800	26***	3	27
Implicit w/ pre	1800	3m45s	2	3

*explicit needs hyperviscosity activated, while implicit does not
**in the refined cases, ts=1800 was most efficient
***highly variable run time over the past week, all we know is # are prob similar

OAK RIDGE National Laboratory

Previous work validated the method for accuracy with uniform cases



Refined case 2 (ne10-80) after 1 day: L2 norm=4.3e-4

Fully implicit method applied to the primitive equations of CAM-SE: full dynamical core

The pluses

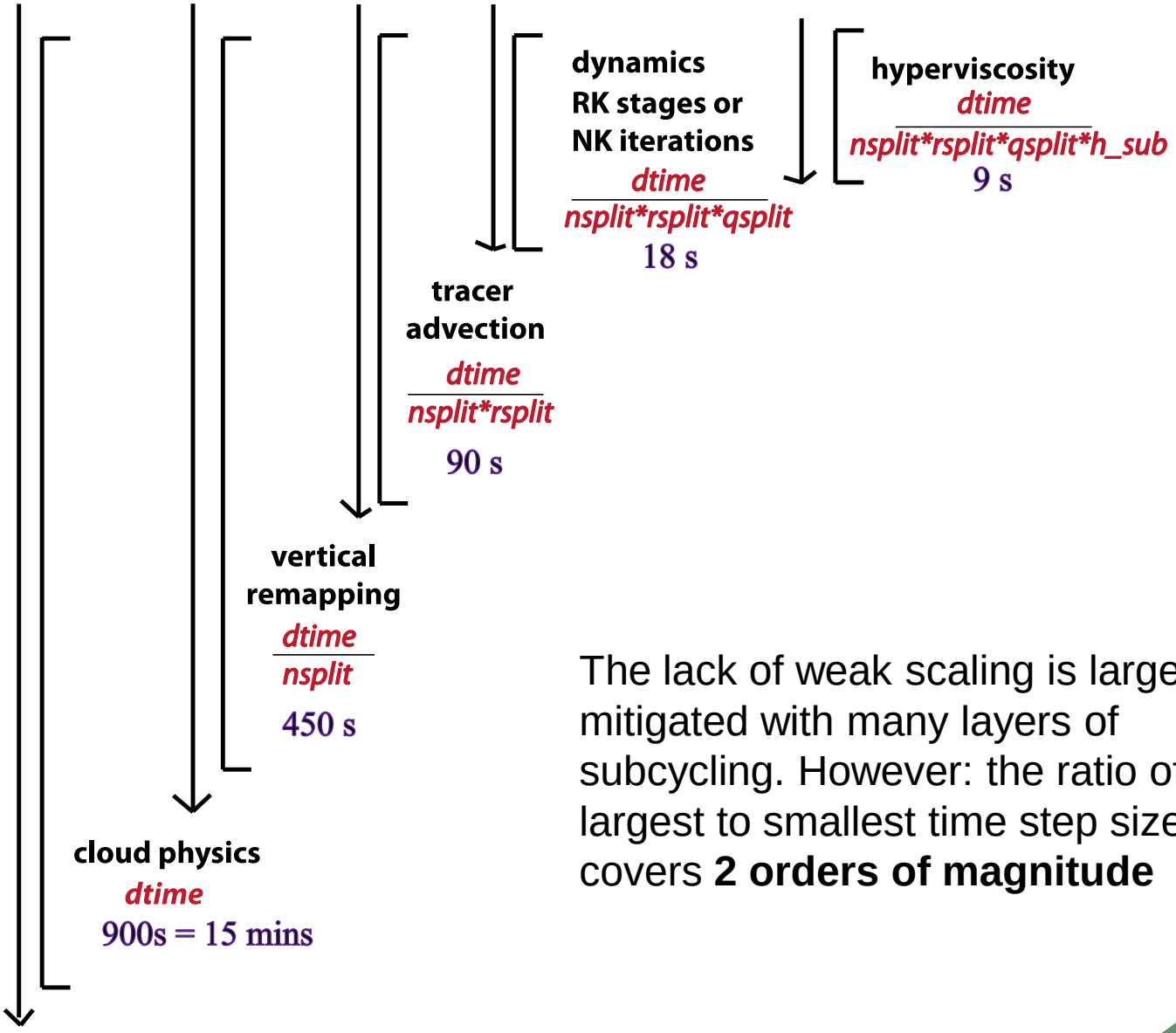
- **Uses same C++ solver template as 2D and other CESM components. Change runtime xml file to optimize solver**
- **Primitive equation code was in better form for creating residual evaluation**

The minuses

- **Much more code, with more layers, to dive into**
- **Working on the trunk: higher coding standard**
- **Testing takes longer, since problems are larger**

OAK RIDGE National Laboratory

Anatomy of a Time Step: ¼° CAM-SE dycore



The lack of weak scaling is largely mitigated with many layers of subcycling. However: the ratio of the largest to smallest time step size covers **2 orders of magnitude**

OAK RIDGE National Laboratory

3D Test Case: baroclinic instability '2d' (from Jablonowski and Williamson '06)

- **9 days: Short enough to perform many runs for convergence studies and analysis**
- **Dry adiabatic idealized baroclinic wave in the Northern Hemisphere**
- **No physical parameterizations included**
- **Refer to Taylor et al. (2007) SciDAC proceedings for CAM-SE using explicit leapfrog time integration scheme**
- **Goal: remove dynamics subcycling, then the hyperviscosity subcycling.**
- **May want to remove tracer subcycling but keep an eye on mass conservation**

OAK RIDGE National Laboratory

Status of fully implicit in 3D

- **Dynamics solve of T, u, v, ps_v now solved implicitly with a first order method**
- **Not yet optimized using new data structure layout in SW, not yet using a preconditioner**

Method	Time Step	qsplit	hypervis	N	N/L
Explicit RK	150s	4	2	N/A	N/A
Implicit BE	150s	4	2	3	3.99
Implicit BE	600s	1	8	3	14.9
Implicit BE	1200s	1	16	3	32.6

~2 degree (ne15 np4) 128 processors

OAK RIDGE National Laboratory

Next steps: fastest simulations without crashing or going off course

Sochi, Russia, training run
Courtesy: New York Times

OAK RIDGE National Laboratory