# LES acceleration for cloud-resolving and superparameterized simulations

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# The vision

- We are burning lots of CPU cycles doing long LES, CRM and SP-CAM simulations in which the mean atmospheric state is evolving on periods of hours or days even though the turbulent motions are churning the air in minutes.
- CMMAP summer 2013 meeting coffee break chat:
  Is there a way to exploit this timescale separation to accelerate the simulations and reduce compute cost without degrading them?
- A simple acceleration approach turns out to work surprisingly well!

# Theory

- The idea: Artificially accelerate the slow rate of horizontal mean-state evolution, but not the turbulent eddies (whose numerical CFL stability already limits the CRM timestep.)
- The math: In each time step, magnify the mean-state tendencies of moist-conserved variables $q_t = q_n + q_r$ and $s_l$ by an **acceleration factor** $a > 1$:

$$\frac{d\phi}{dt} = F(\phi,t) \quad \rightarrow \quad \frac{d\phi'}{dt} = F'(\phi,t) \text{ and } \frac{d\overline{\phi}}{dt} = a\overline{F}(\phi,t)$$

or:

$$\frac{d\phi}{dt} = F(\phi,t) + \underbrace{(a-1)\overline{F}(\phi,t)}_{\text{extra accel tendency}}$$

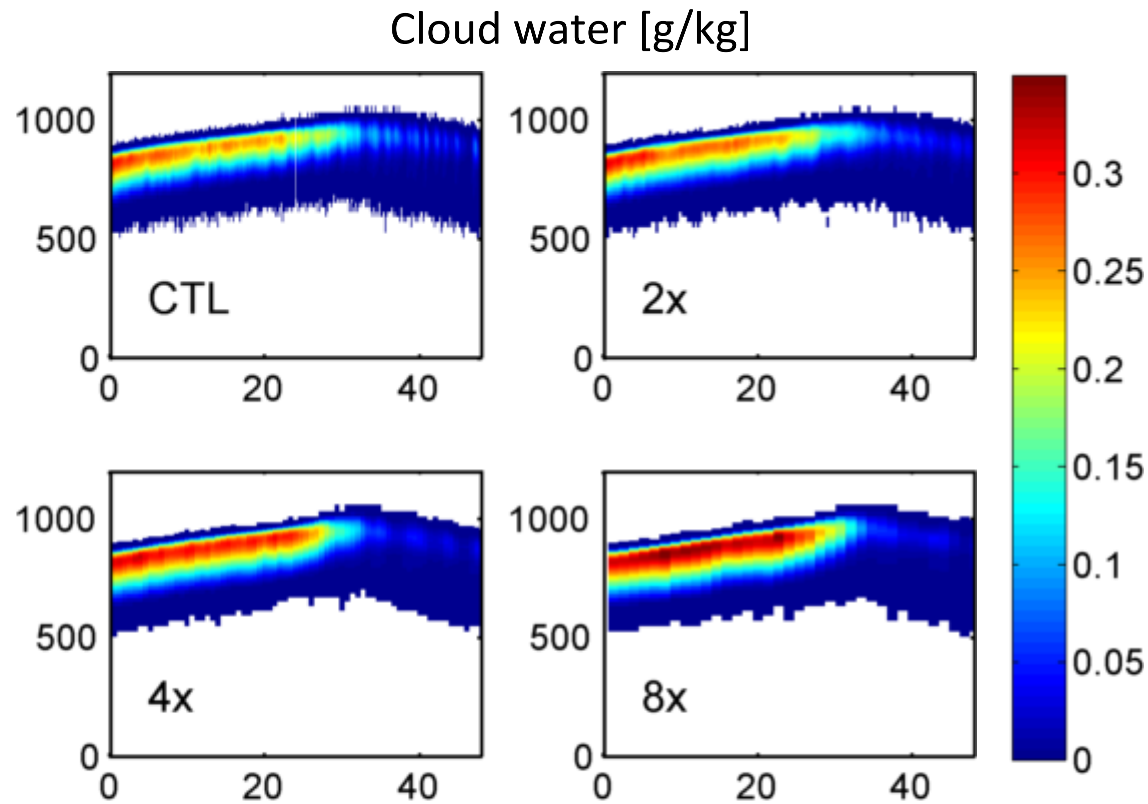
If CRM-mean velocities are not being nudged, the acceleration should also be applied to the momentum eqns.

Computational cost reduced by factor $a$.

# A simple example

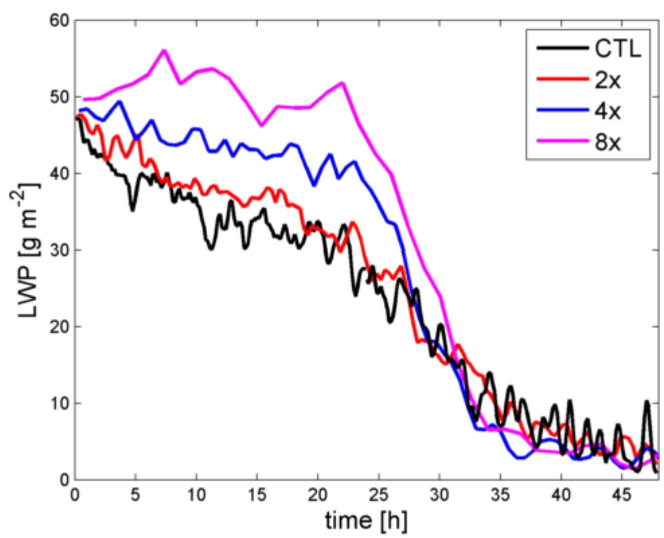
DYCOMS RF01 case

- well-mixed nocturnal Sc
- no drizzle
- SAM6.7
- Standard resolution
- 48 hr simulation




*a* = 2x nearly identical to CTL

Slightly more LWP but similar evolution and numerical stability for 4x, 8x accel.

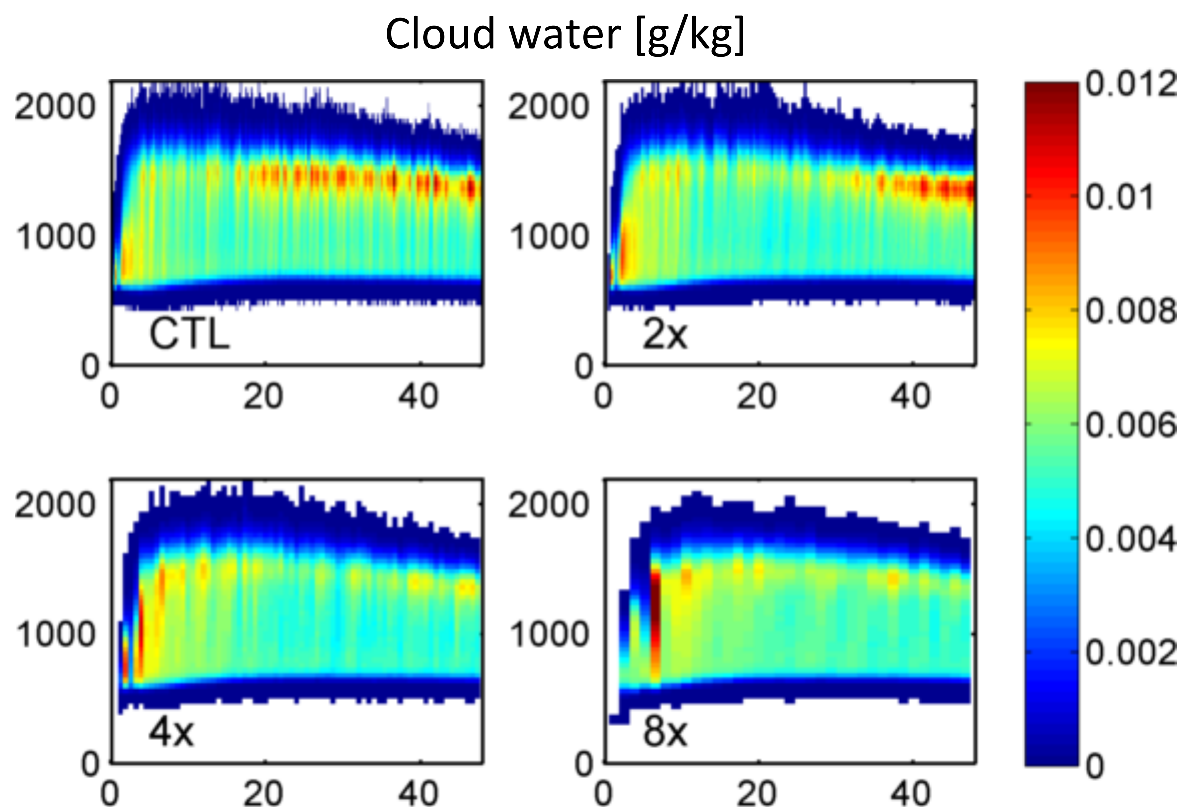


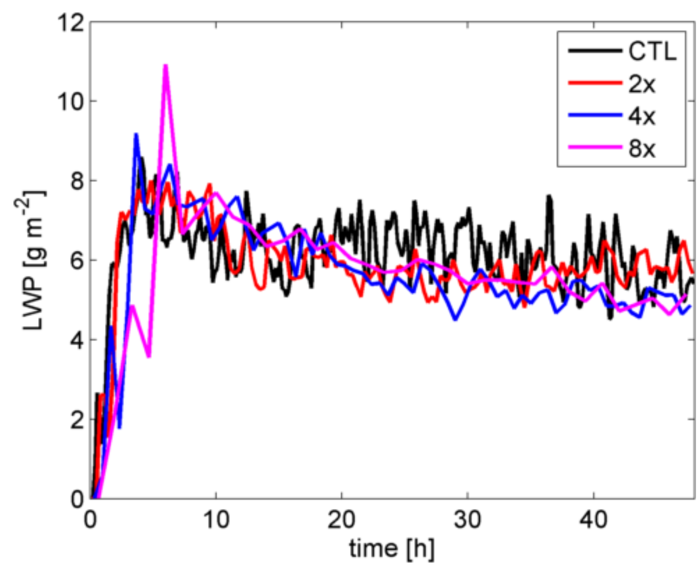

Encouraging!

# BOMEX example

- Shallow Cu
- Nonprecipitating

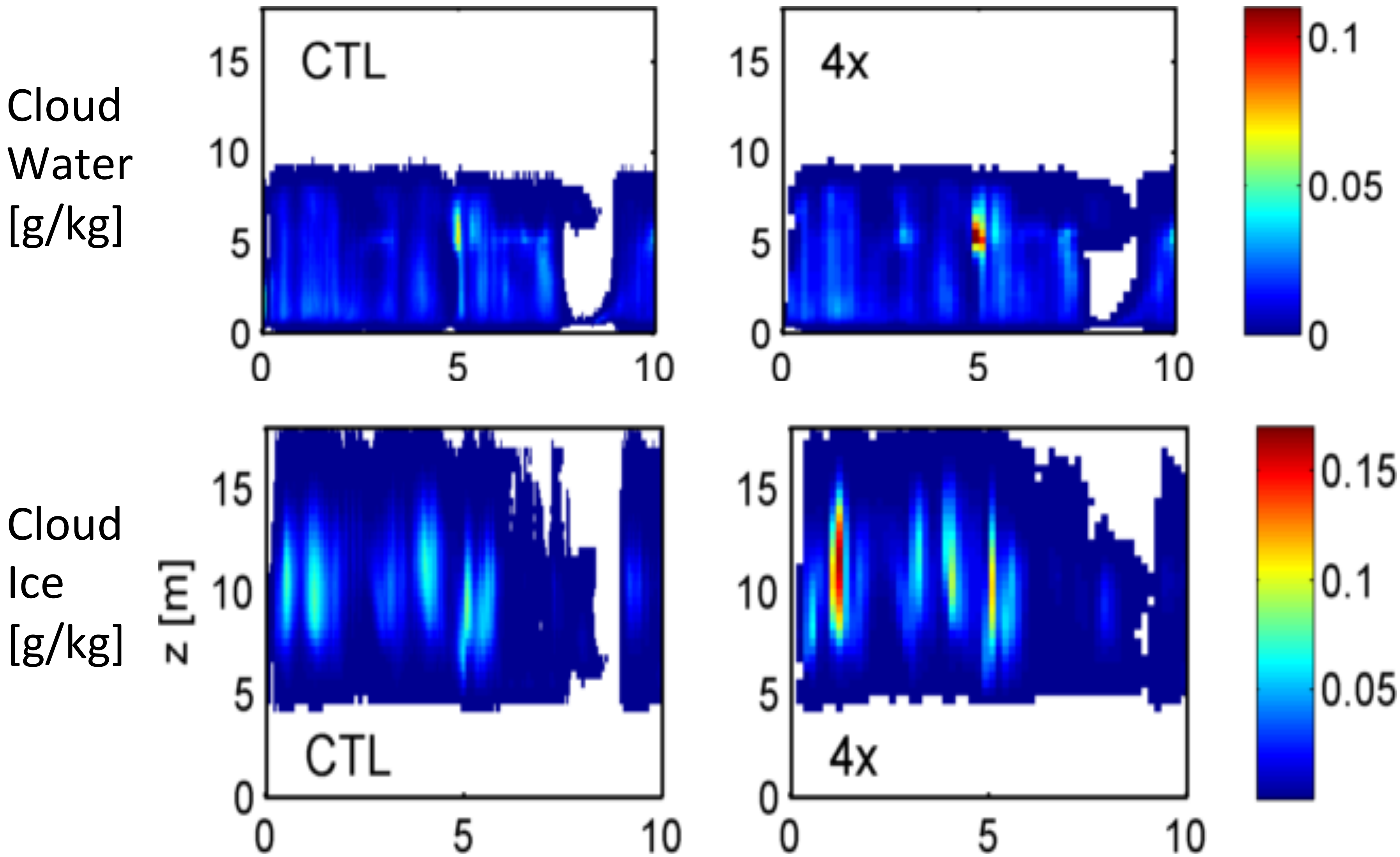
Again, remarkably good results even with *a* = 8x speedup!



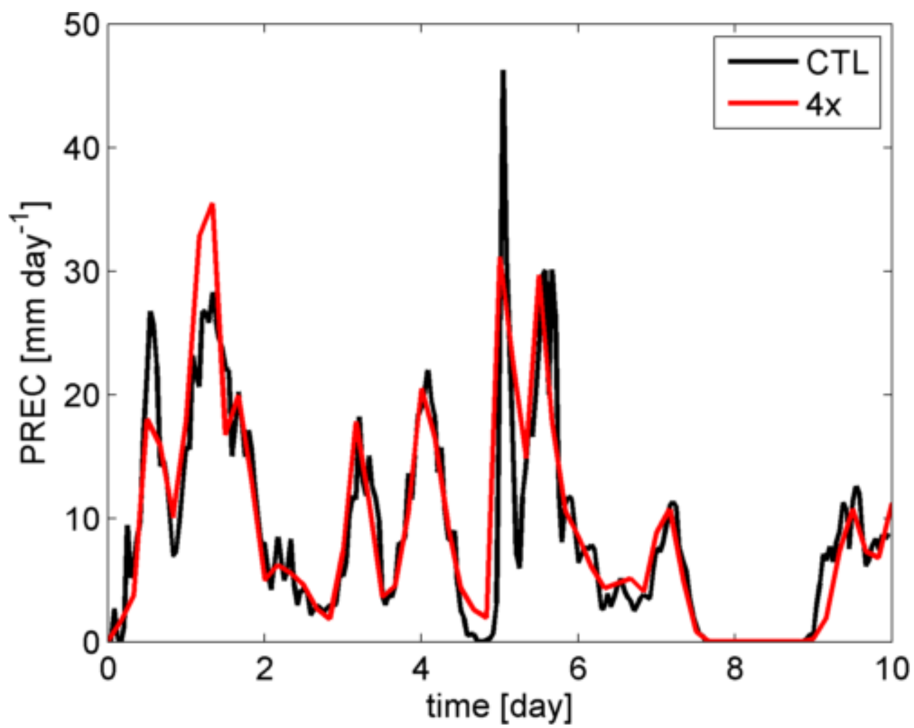
# KWAJEX deep convection

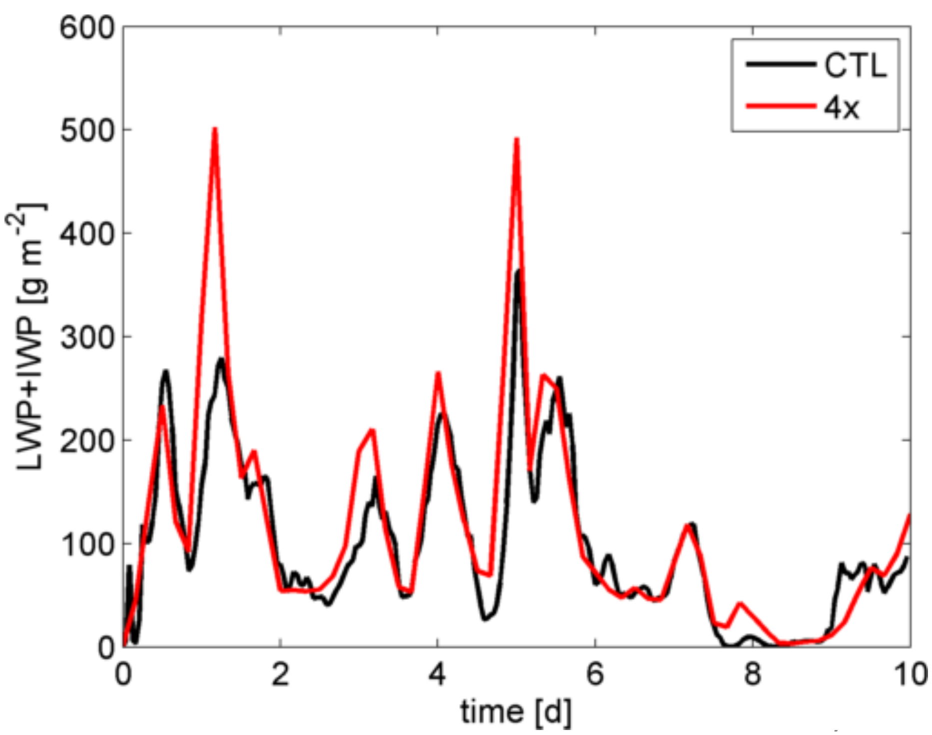
- Tropical deep convection, Time-dependent forcing, 10 days shown
- 4x accelerated run similar but more spiky (episodic cloud ice)



# Refinements needed for deep convection

- Rain and snow are not accelerated (else CFL fallspeed instability)
- Any negative $q_t$ at a grid point is set to zero.
- Bulk statistics are then well preserved under 4x acceleration

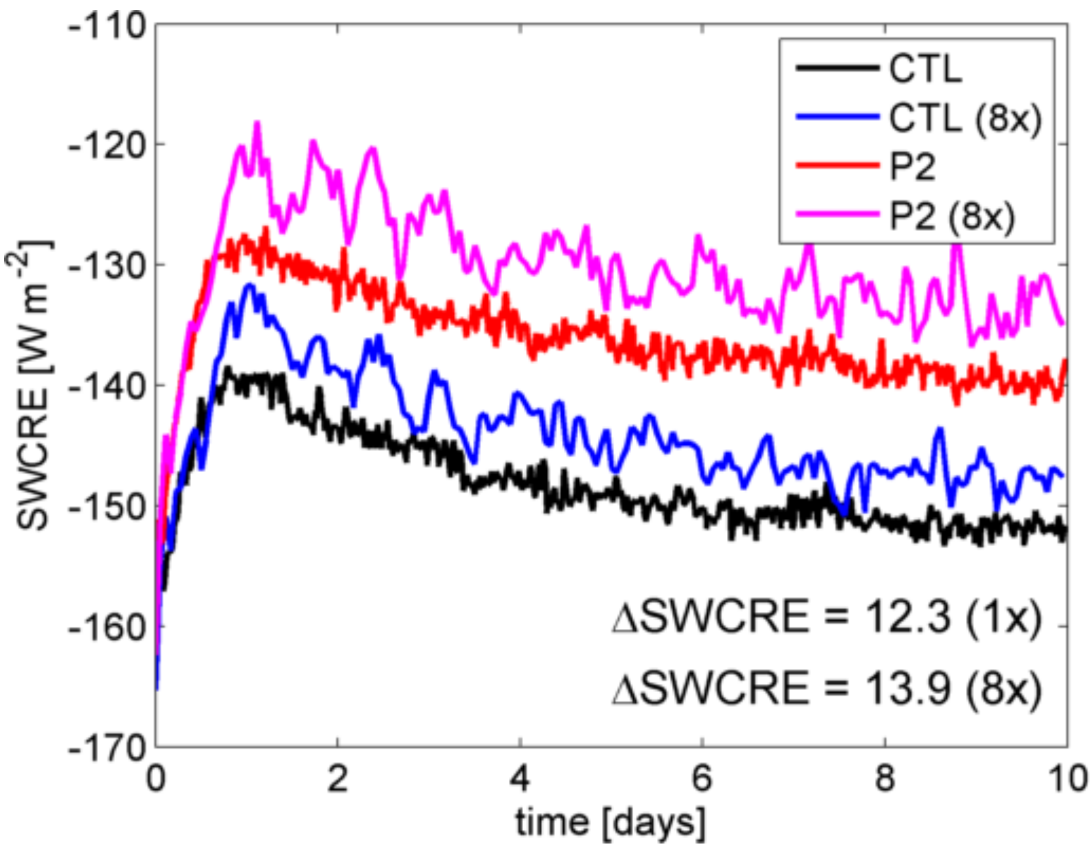


# Application to cloud feedbacks

Case: CGILS S12 location (well-mixed Sc; Blossey et al 2013 *JAMES*)

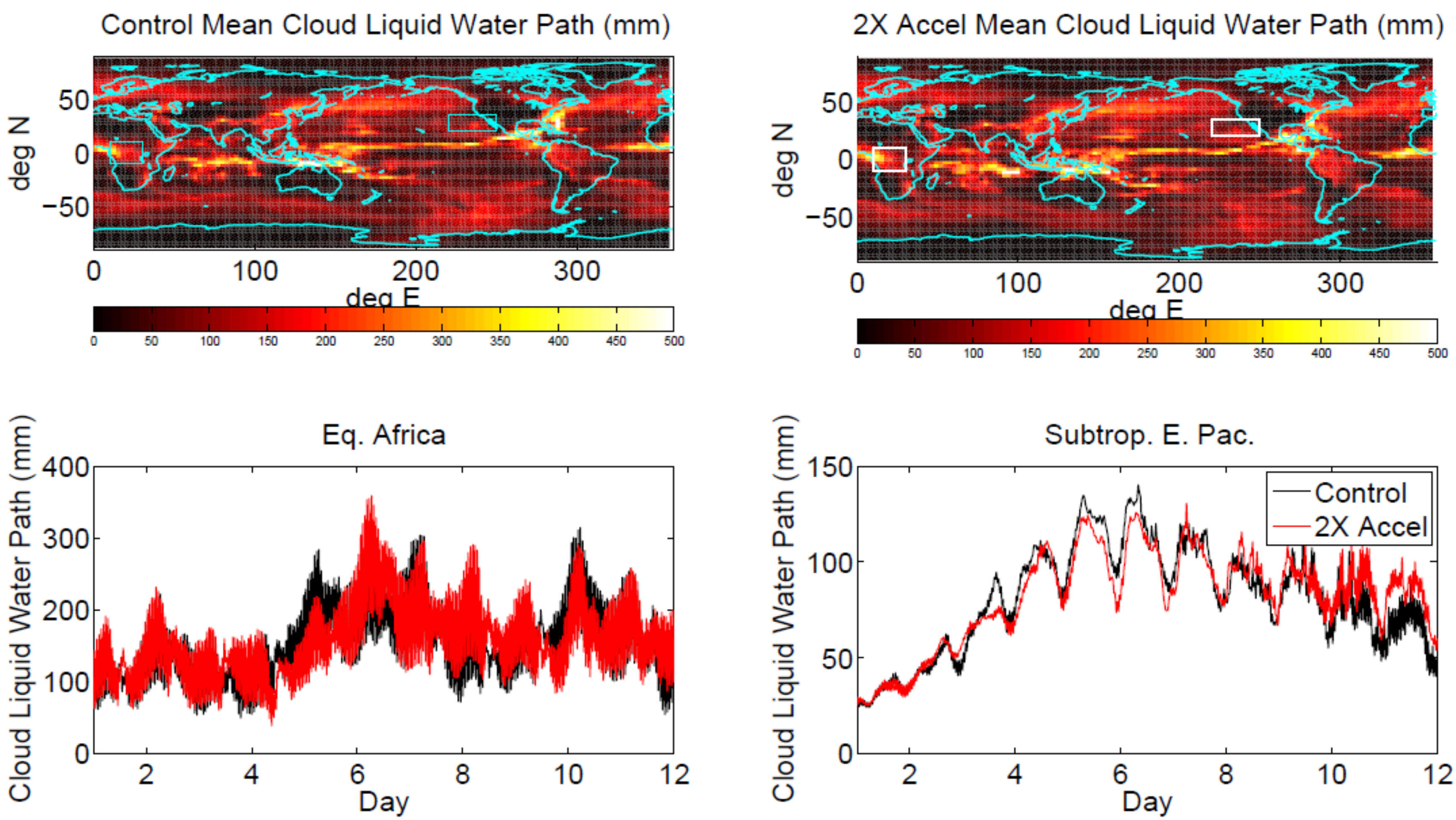
- CTL: Current-day climate, fixed SST
- P2: 2K local SST increase; free-troposphere moist-adiabatically warmed by 2K remote boundary-layer warming



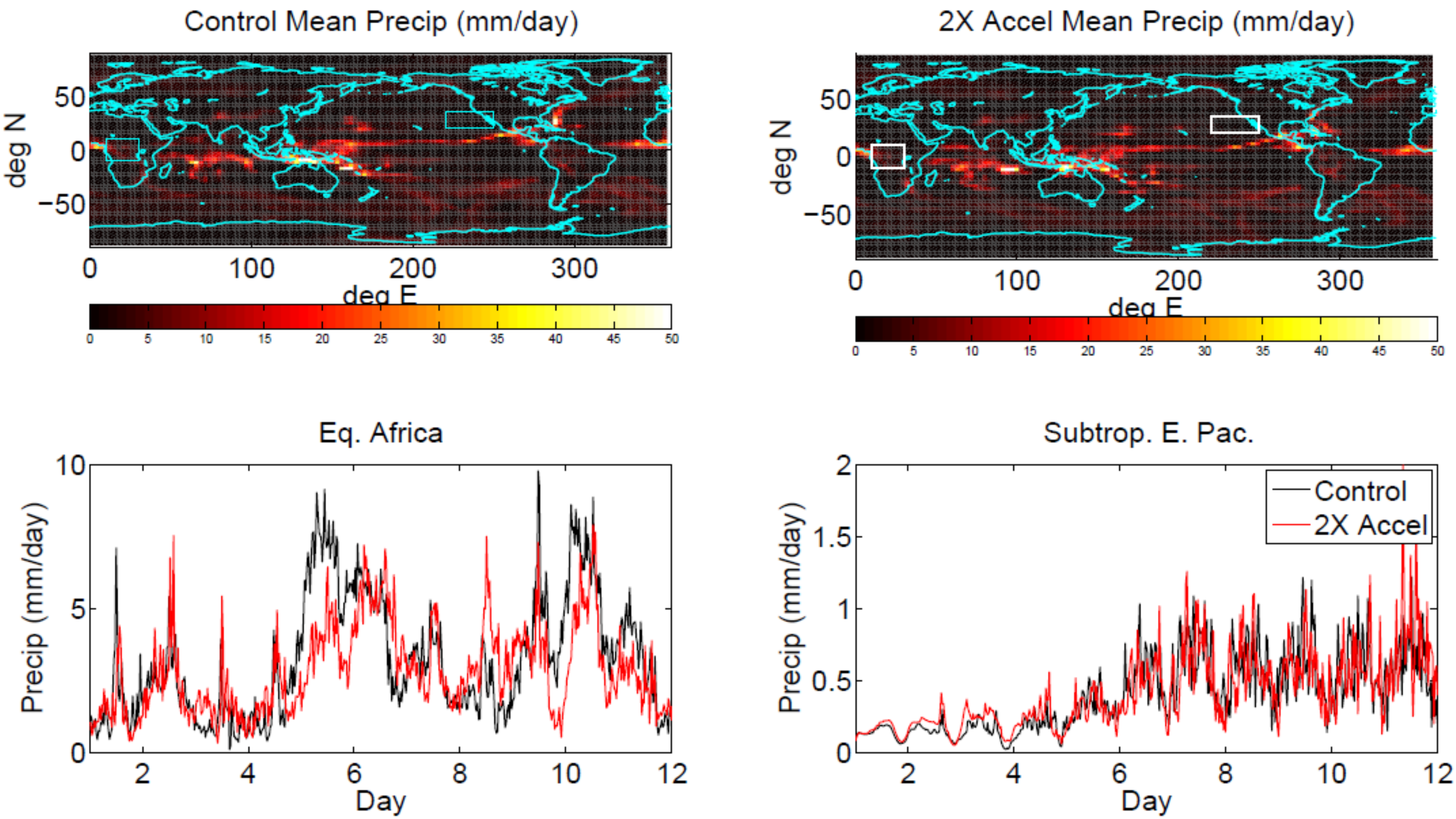

8x speedup with negligible change in cloud response!

# Application to superparameterization (Mike Pritchard)

- Superparameterization is a stringent test of this approach, because the embedded CRM is subjected to a wide range of forcings across a wide range of spatial and temporal scales.

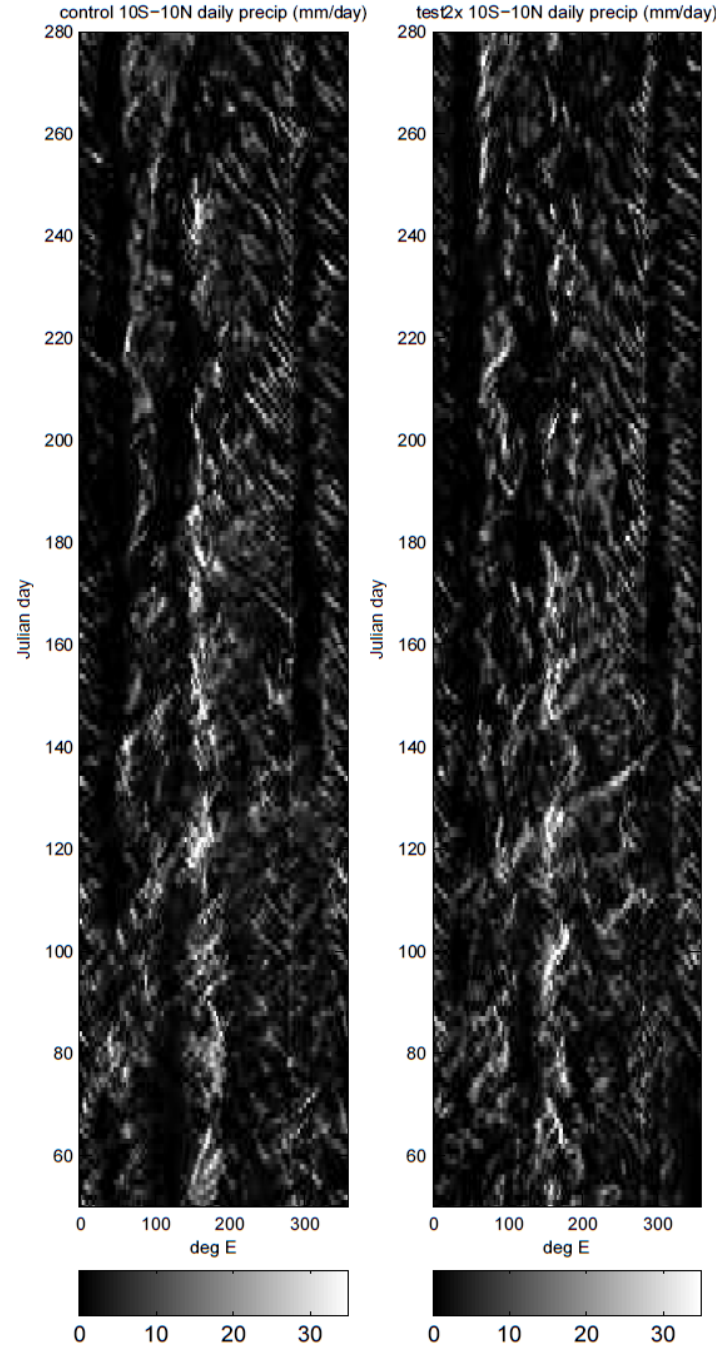


# 2x acceleration also preserves the SP precipitation field



# Successful 1 year test of 2x accelerated SP

Longitude-time Hovmueller of 10S-10N mean precip



# Conclusions

- Acceleration is a robust method for speeding up CRM and SP simulations in which the turbulent circulations and clouds are evolving faster than the CRM horizontal mean state.
- Depending on the problem, 2x to 8x or more speedup can be achieved without serious degradation of the solution.
- Mike and I, together with Marat and collaborators at PNNL, are using this as part of a proposed strategy for 'ultraparameterization': the use of small CRMs with very high vertical resolution to allow superparameterization to better simulate boundary layer clouds and their response to climate. HOC and other CRM improvements, GPU acceleration, and improved SP performance with $10^4$ or more processors are other components of this strategy.