Towards low cloud permitting superparameterization

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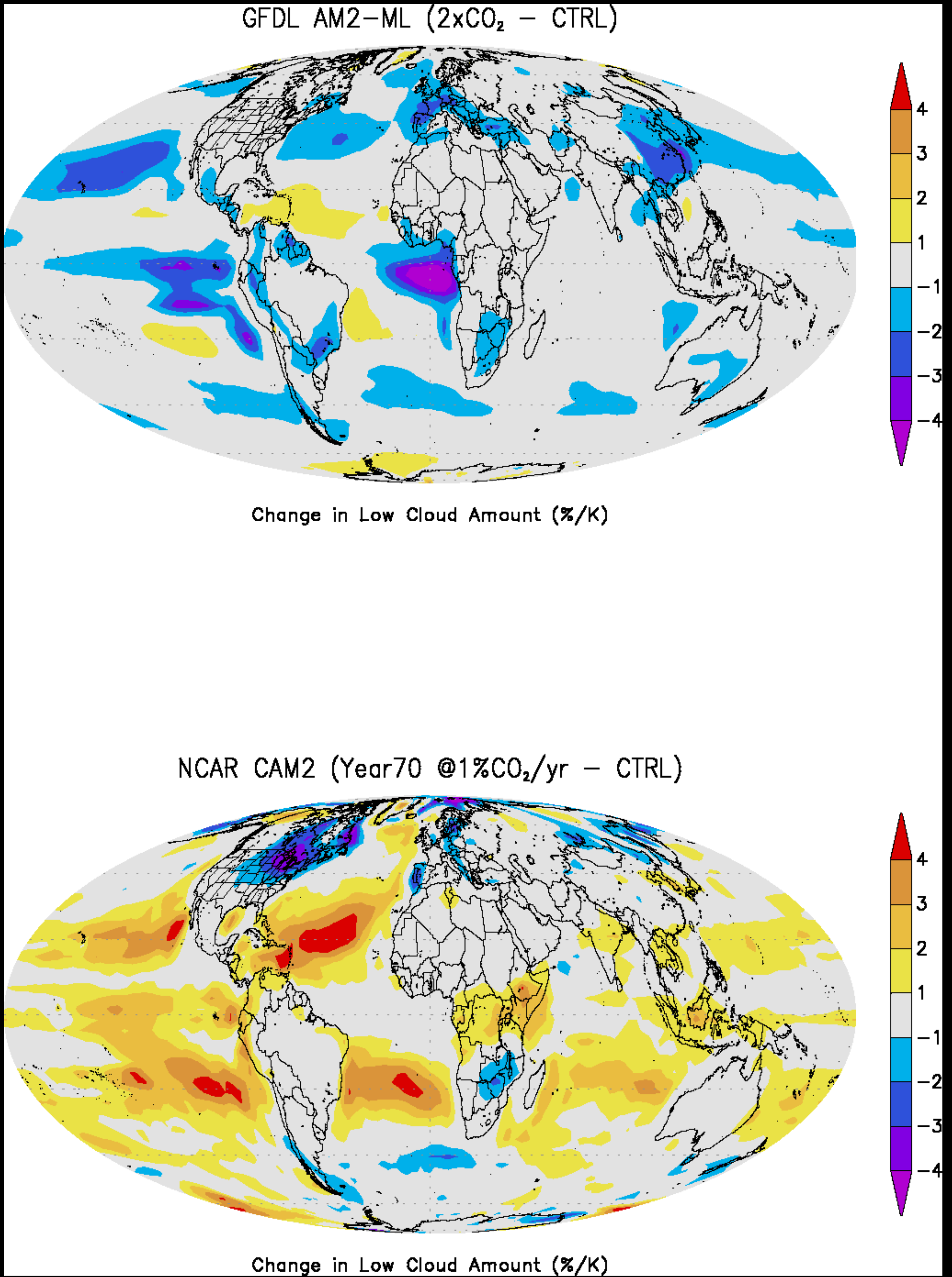
Southern California

"Uncertainty in the sign and magnitude of the cloud feedback is due primarily to continuing uncertainty in the impact of warming **on low clouds**"

— IPCC AR5, Ch. 7

Climate model predictions of low cloud feedback differ.

- With 2xCO2, low-latitude boundary layer clouds:
  - <u>Decreased</u> in GFDL AM2 (dT = 4.5K)
  - <u>Increased</u> in NCAR CAM2 (dT=1.5K)



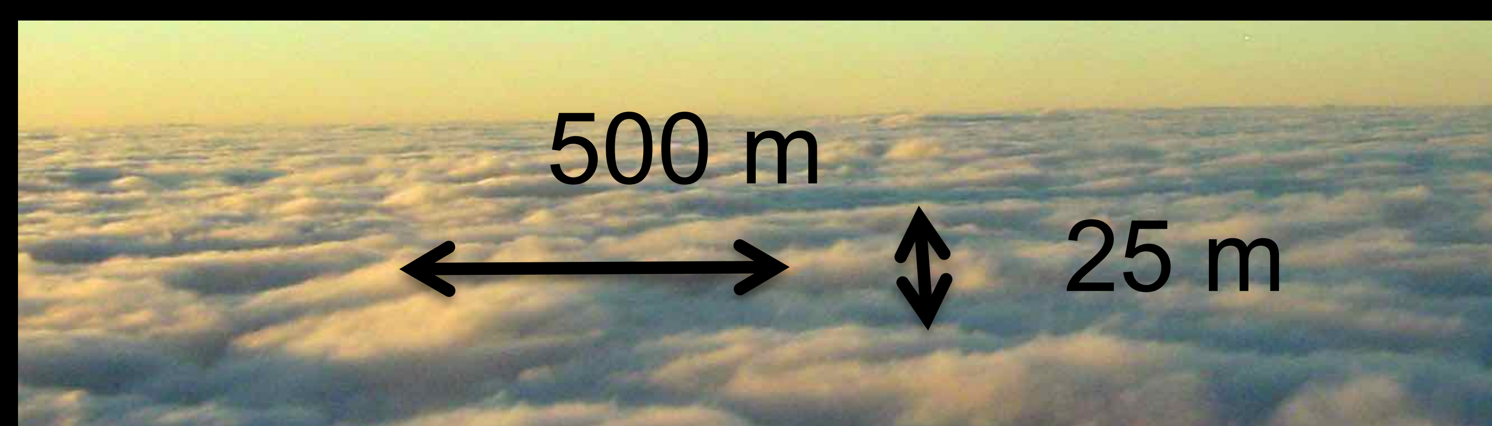
Slide credit: C. Bretherton

“Grey zones” for cloud-controlling circulations

Deep cumulus

Shallow cumulus

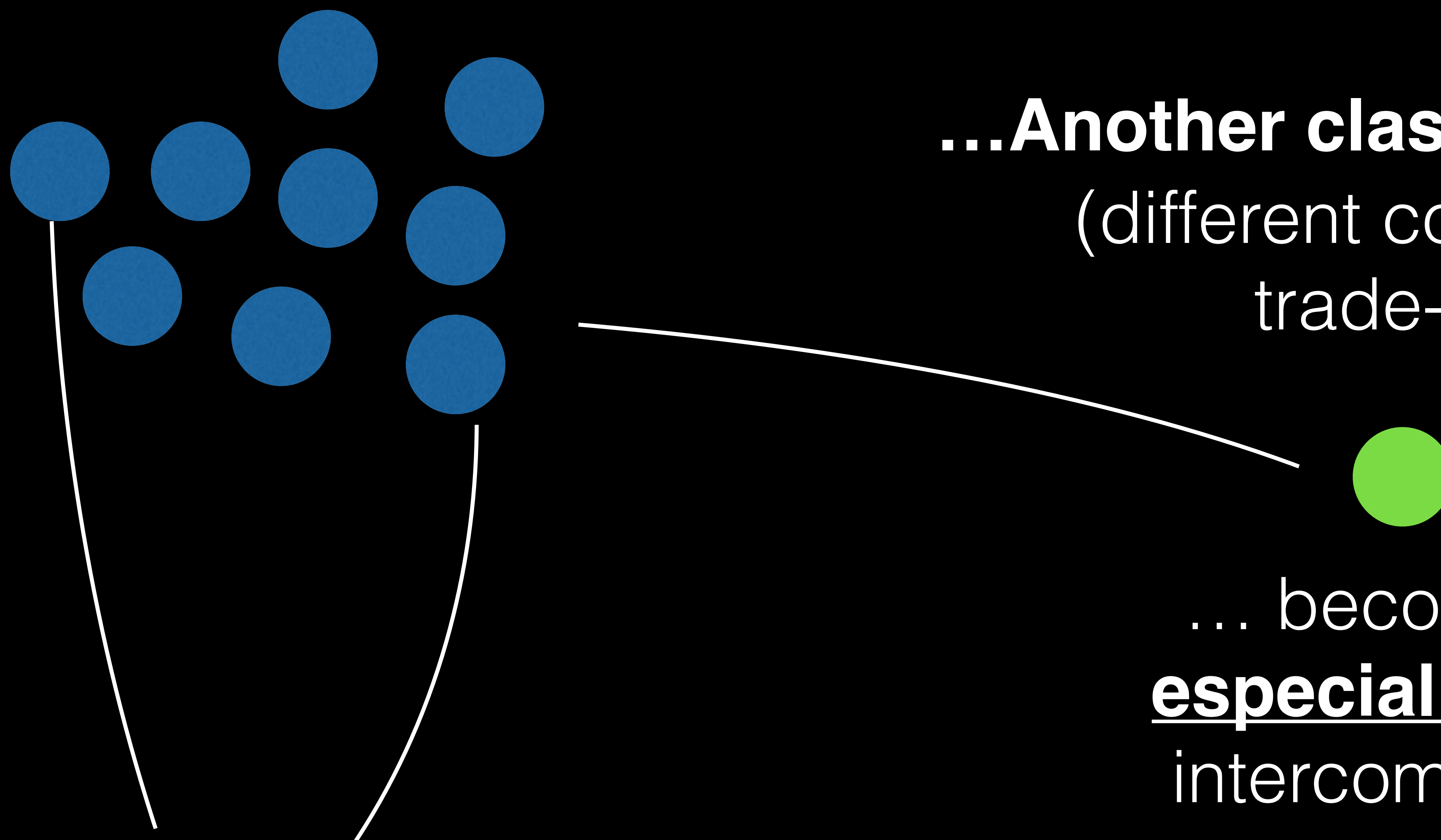
Marine stratocumulus



Slide credit: C. Bretherton

“Palette” of models with differing complexity trade-offs.

If conventional climate models…
(similar complexity tradeoffs)



…Another class of model
(different complexity trade-off)

… becomes an **especially** useful intercomparison

.. make broad range of predictions about something important (low cloud feedback)…

For **deep convective phenomena** this is why climate-duration NICAM, curl-curl & global-SAM simulations are so exciting.

MIYAMOTO ET AL.: CONVECTION IN A SUB-KM GLOBAL SIMULATION

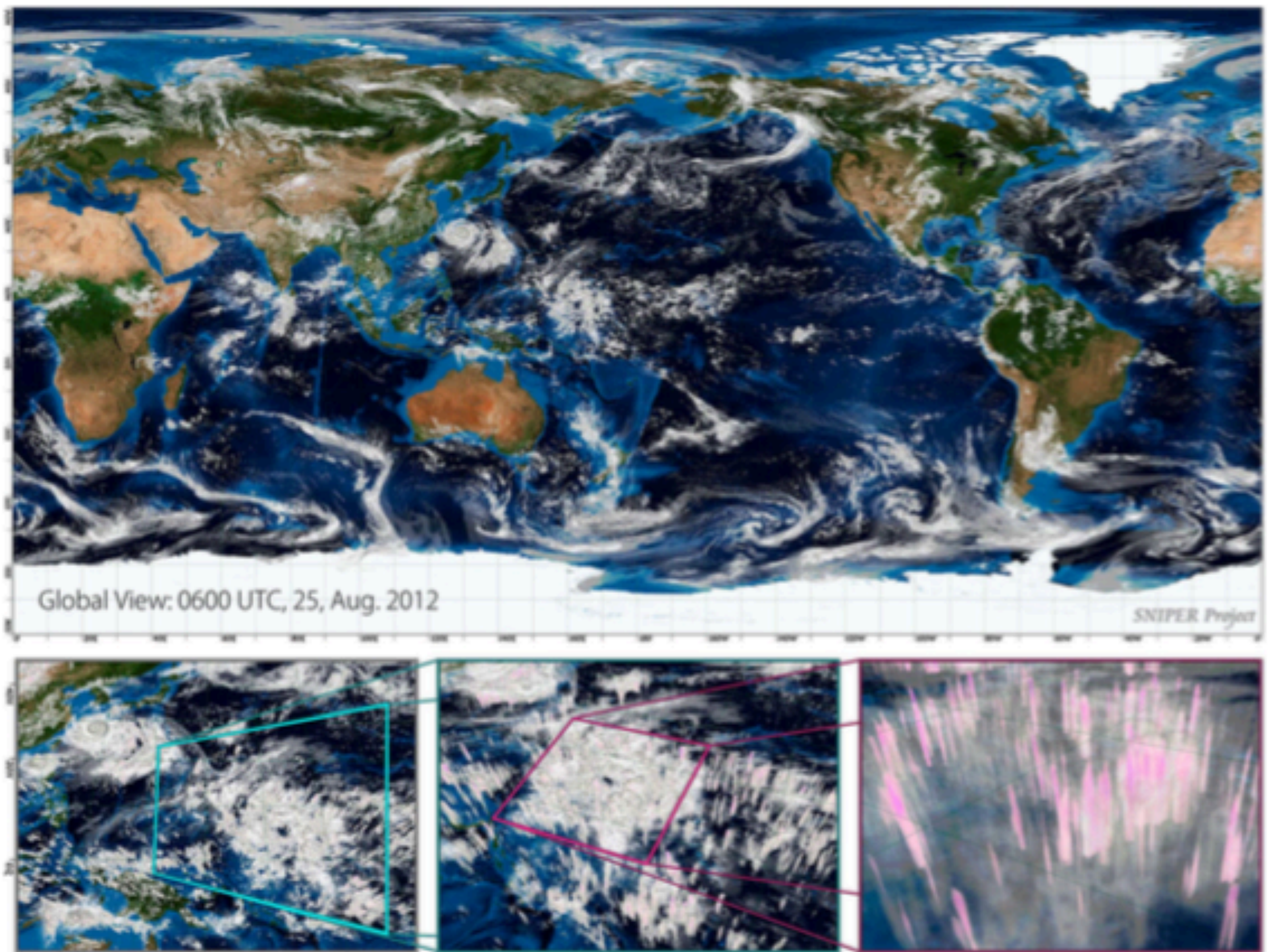


Figure 1. (top) Horizontal view of the total mixing ratio of condensed water contents in Δ0.87, (bottom left) close-up view of the northwestern Pacific, (bottom middle) a further close-up view for a cloud cluster, and (bottom right) an extreme close-up of an active convection region. The pink color indicates the hydrometeor density larger than $2\,g\,kg^{-1}$. Topography and bathymetry are Blue Marble (August) by Reto Stöckli, NASA Earth Observatory.

3.5-14 km: Tomita et al. 2005

0.9 km (for 24 hr): Miyamoto et al. 2013

The problem.

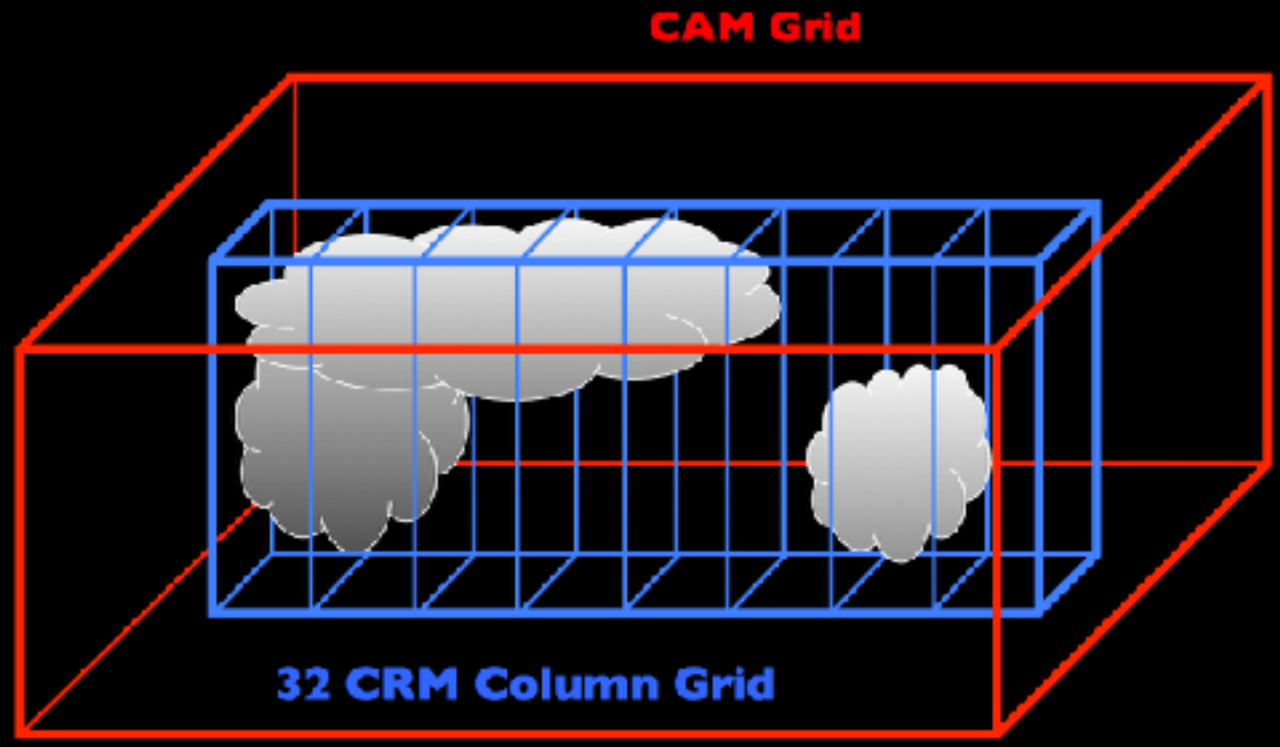
Problem:

Global LES is needed to explicitly simulate boundary layer clouds most important for climate simulation….

…. but **is <u>too expensive</u>** for the multiyear simulations needed to do this.

A possible solution - Ultraparameterization

Variant of superparameterization (SP; Grabowski, K&R 2011)



SP: 2D CRMs (typically L30-4km) are embedded in every grid column of an AGCM and prognose the cloud field and effect of moist processes such as cumulus convection in that column.

Large-scale advection, surface exchange, topography, etc. handled by AGCM.

Question:

Can low cloud physics be quasi-resolved on a global scale in a satisfying manner?

Ultraparameterization (UP)

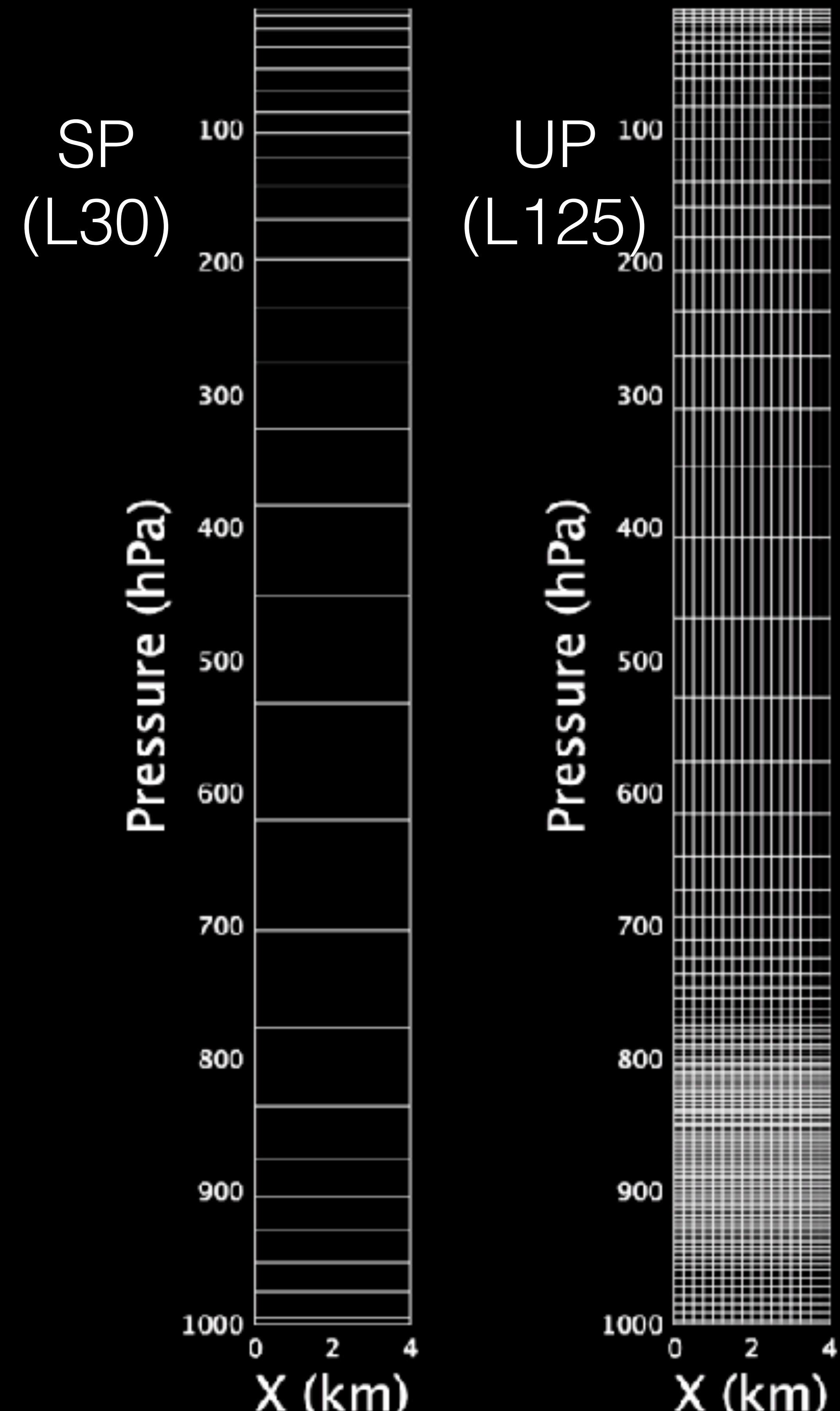
- Ultra-high resolution low-cloud-resolving model in each GCM grid column (Δx = 250 m, Δz = 20 m for z=0.5-2 km, C32-L125)

- Low clouds important for climate are explicitly simulated without SP's (or NICAM's) substantial aliasing to coarser scales

- Implemented in CAM5 GCM with 13824 columns (~2° grid), CRM: SAM Morrison μphys, diagnostic aerosol

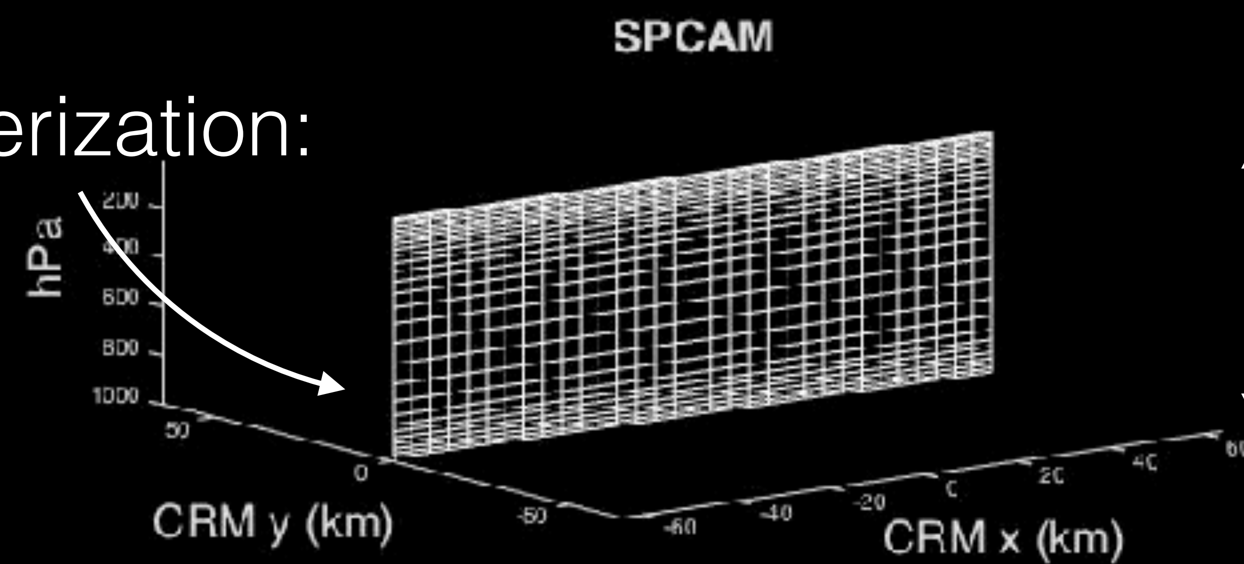
- Bypasses 2-200 km scales

  - 10^4 more computations than CAM but 10^{-6} of a similar global LES



Slide credit: C. Bretherton

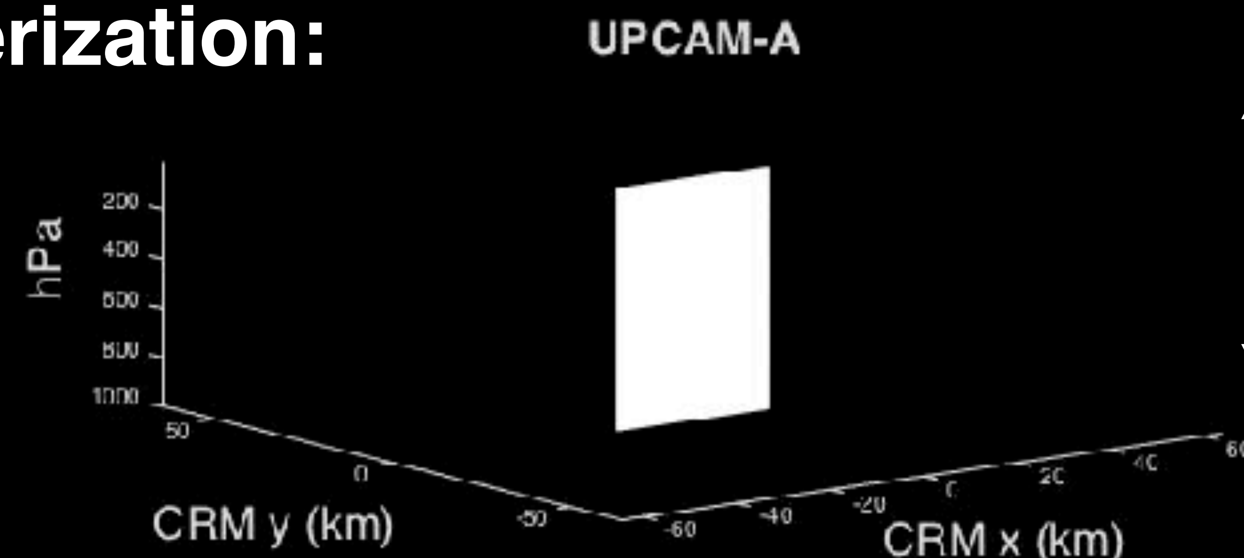
Standard superparameterization:



30 levels

dx = 4000 m

Ultraparameterization:

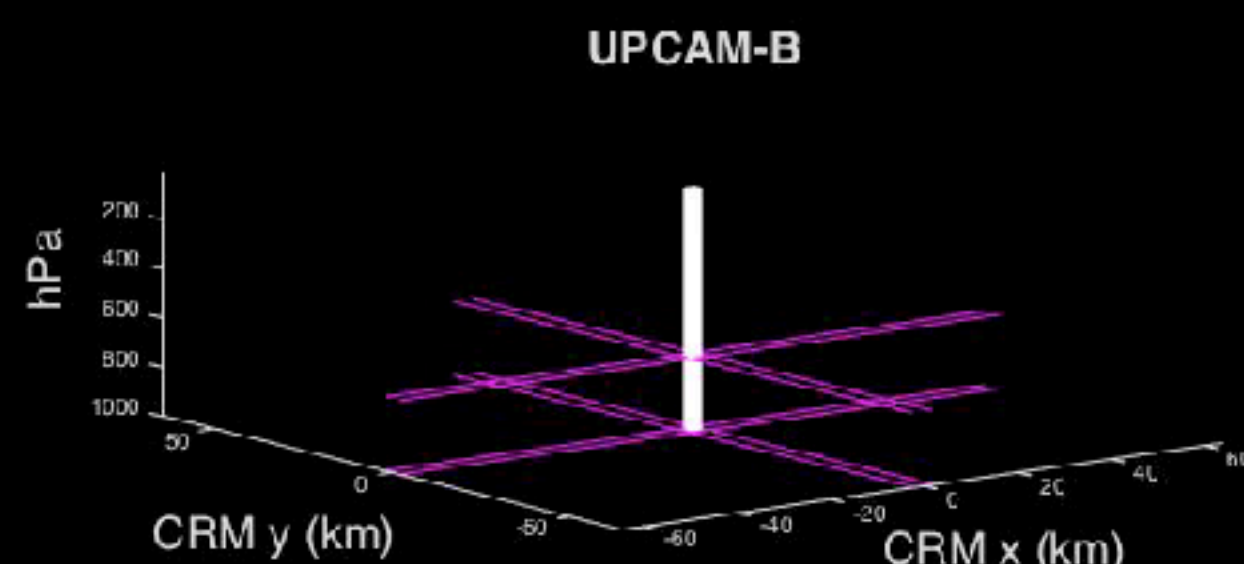


120 levels

dx = 250 m

dz —> 20 m

Candidate 1:
"One CRM
to rule them all"



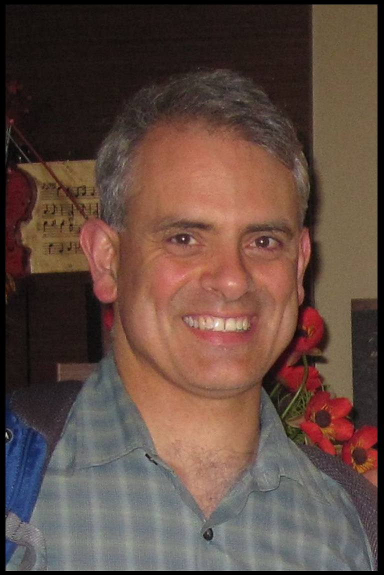
Candidate 2:
micro-LES

Stoney Brook

UC Irvine

The ultraparameterization team

UW



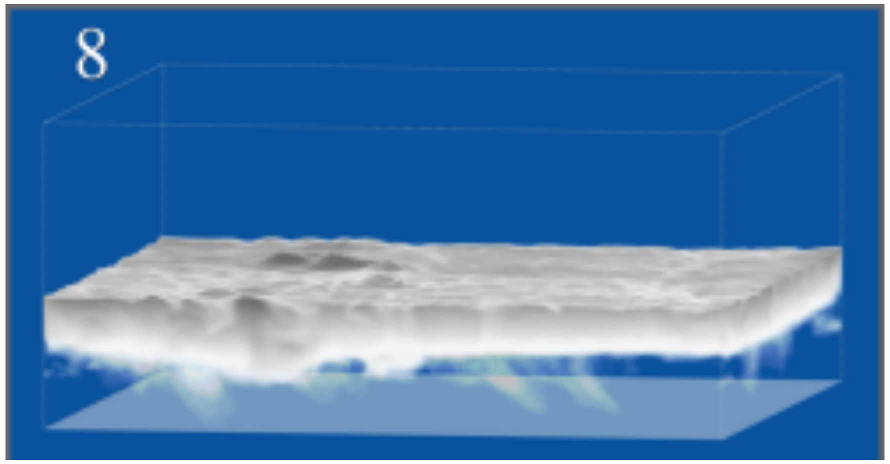
PNNL

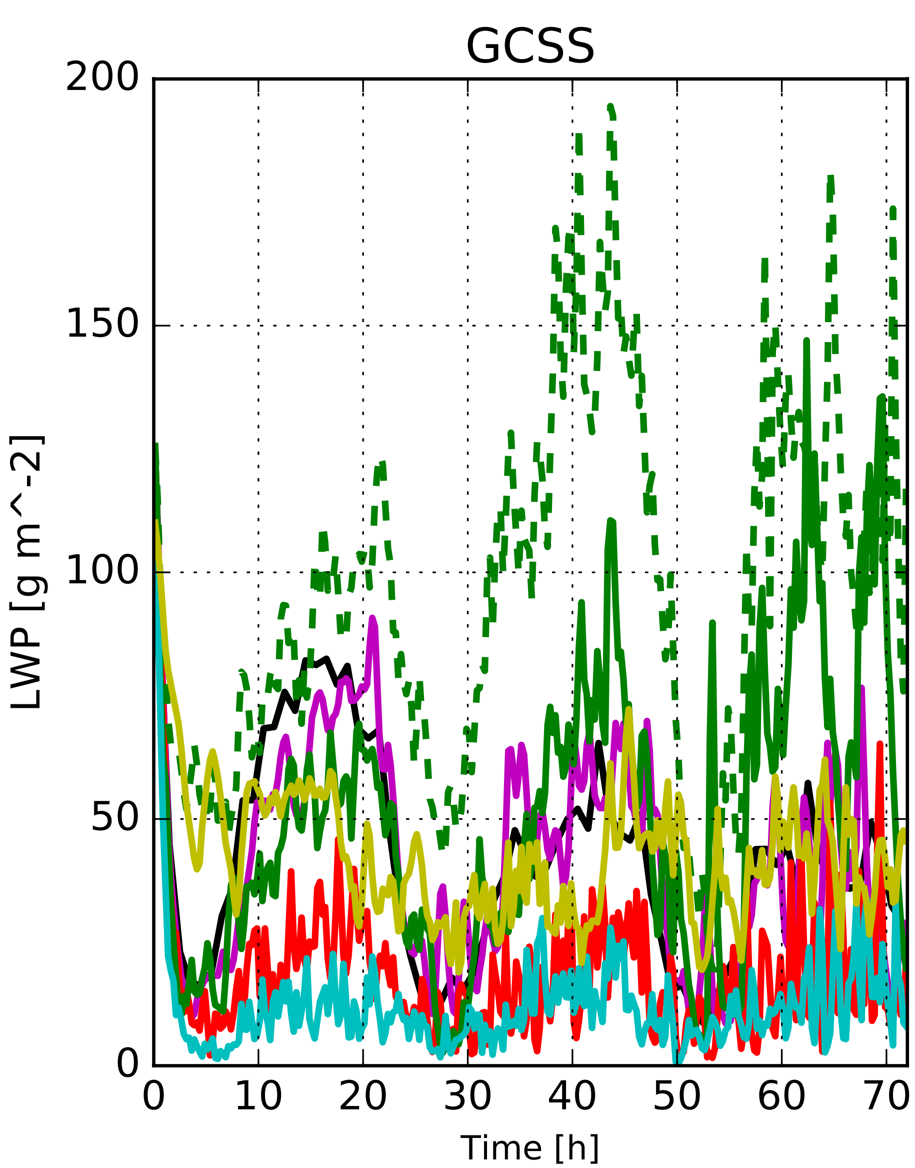
How did we choose our UP grid?

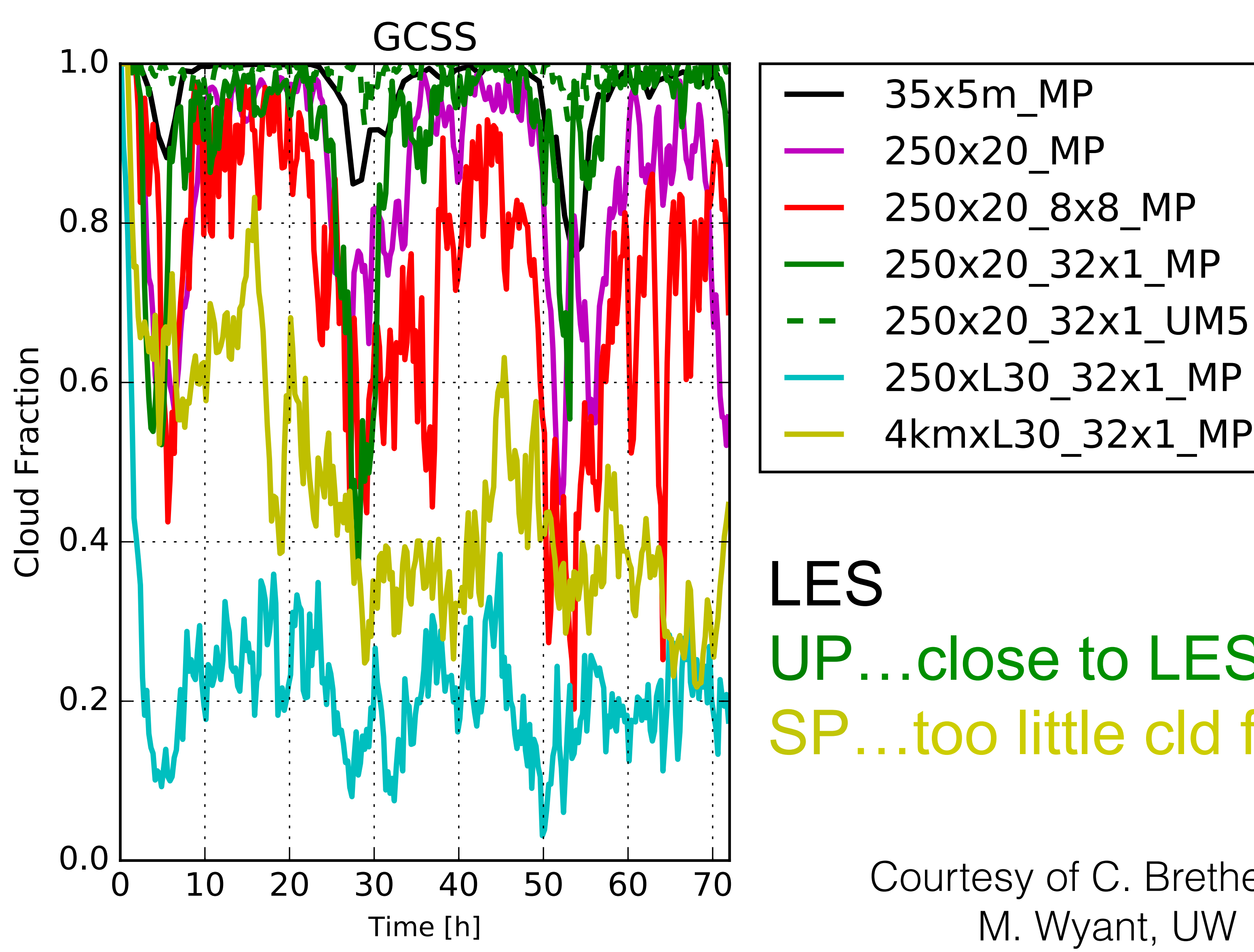
- Past experience in the boundary-layer cloud literature
- LES grid sensitivity tests using Sc, Cu, and transition cases
- Δz = 20 m from 500-2000 m where Sc inversions common
- Δz = 1 km in upper trop suffices for deep convection
- Δz coarsened near surface to promote resolved eddy ventilation of the lowest model level where surface fluxes are deposited

Slide credit: C. Bretherton

LES sensitivity tests: GASS composite Sc-Cu transition case







LES

UP…close to LES

SP…too little cld frac

Courtesy of C. Bretherton,
M. Wyant, UW

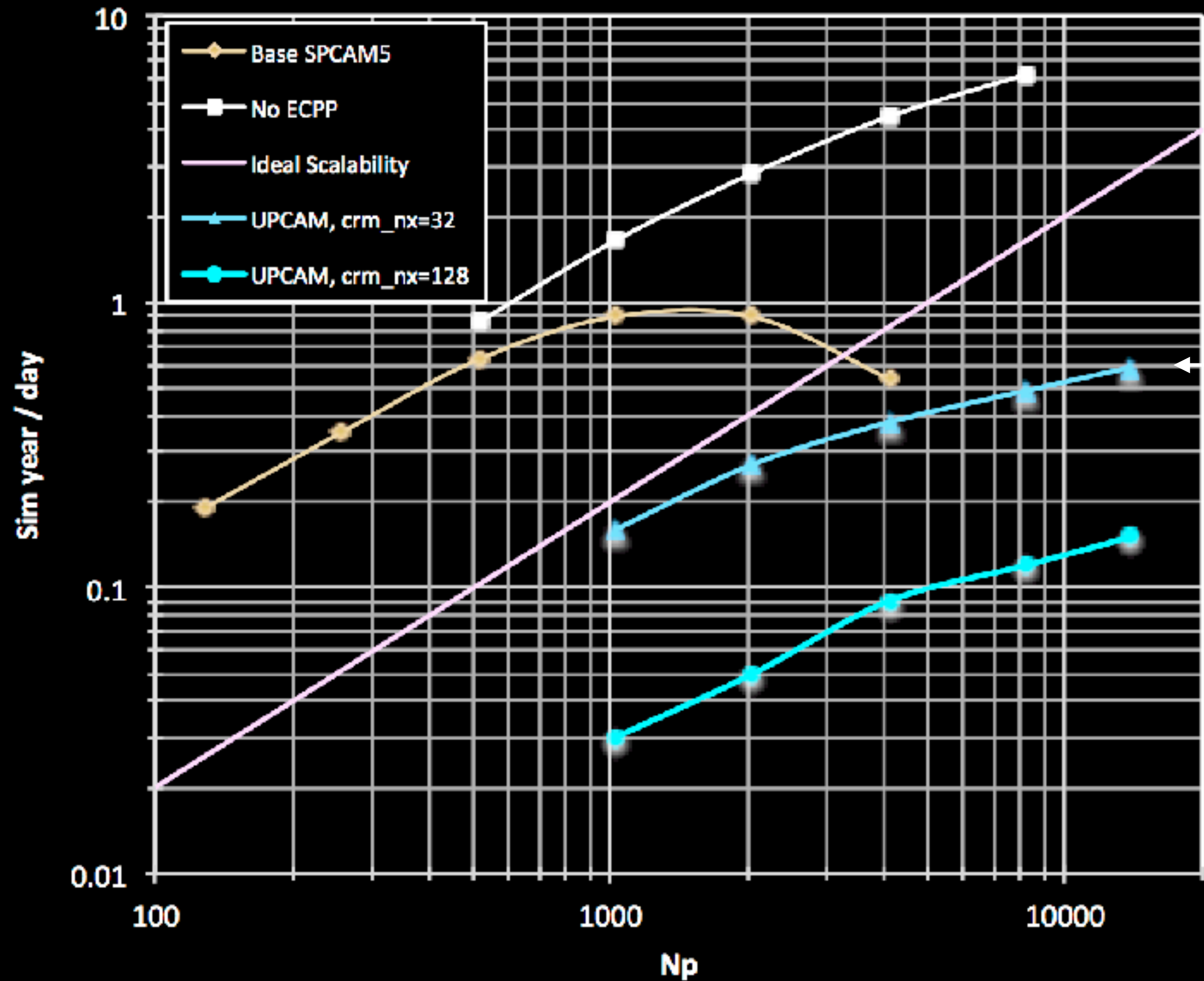
Question:

Can low cloud physics be quasi-resolved on a global scale in a satisfying manner?

LES tests in an unusual "grey zone" suggest perhaps at 250-m x 20-m.

Can the computational expense of adding this much resolution be managed?

UP is highly parallelizable.



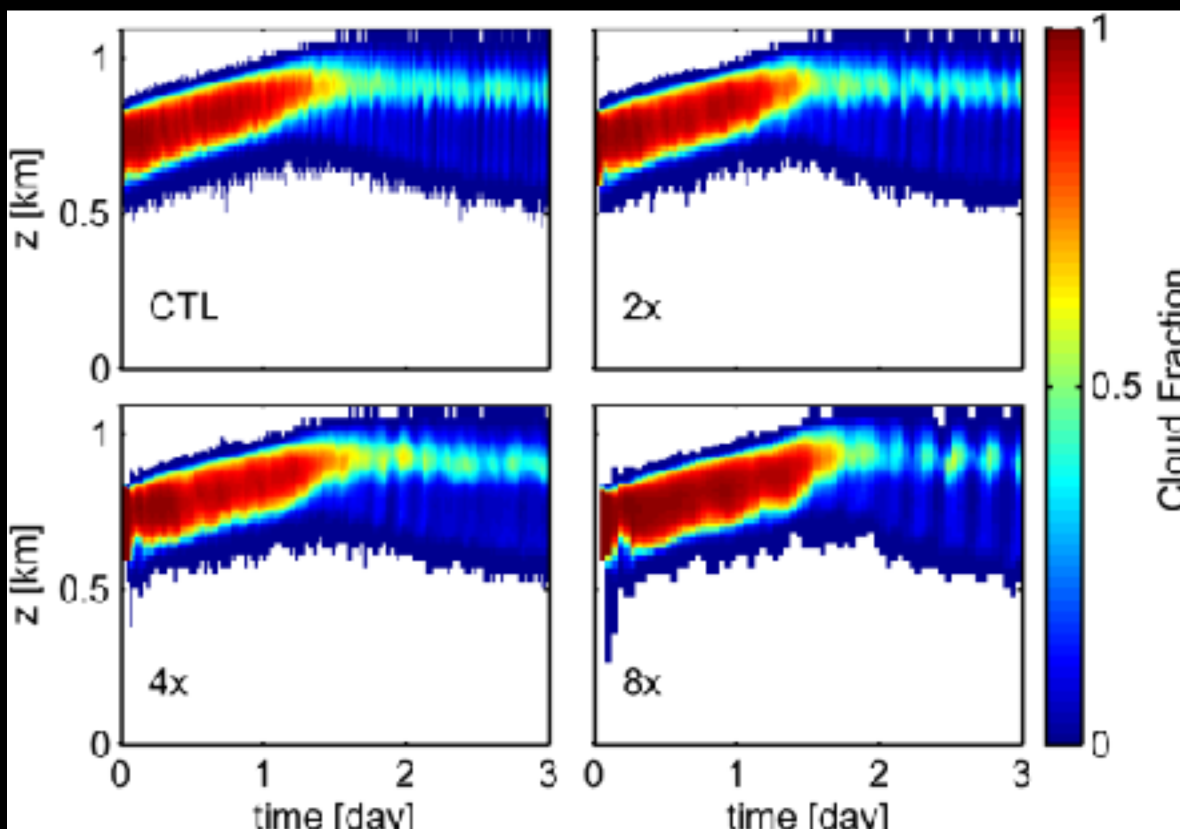
Current limit:
1 CRM per core
—> 0.4 sim-years/day on Edison

Climate applications are (somewhat) feasible

Parishani et al., in review for *JAMES*

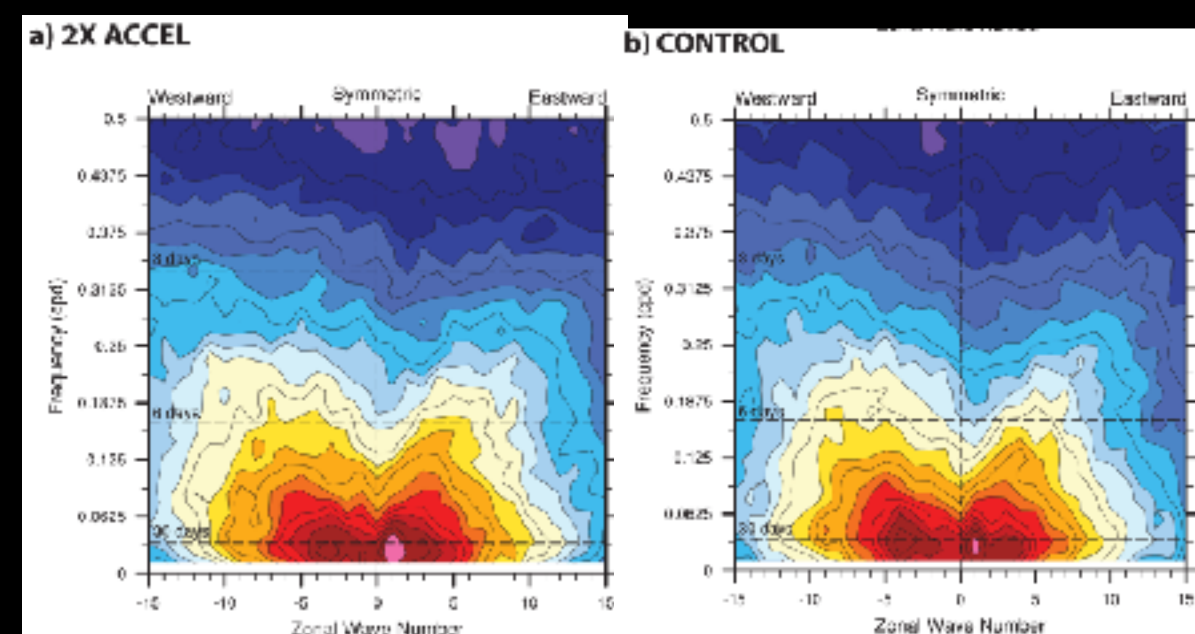
A new acceleration technique yields <u>4X model speedup</u> with little impact on cloud condensate for a range of cases.

Stratocumulus LES at a fraction of cost…



… same mean state cloud evolution.

Superparameterization at half the cost:



… same equatorial wave spectrum.

Jones, Bretherton and Pritchard, JAMES (2015)

Question:

Can low cloud physics be quasi-resolved on a global scale in a satisfying manner?

LES tests in an unusual "grey zone" suggest perhaps at 250-m x 20-m.

Can the computational expense of adding this much resolution be managed?

A new LES acceleration algorithm cuts costs by 4X

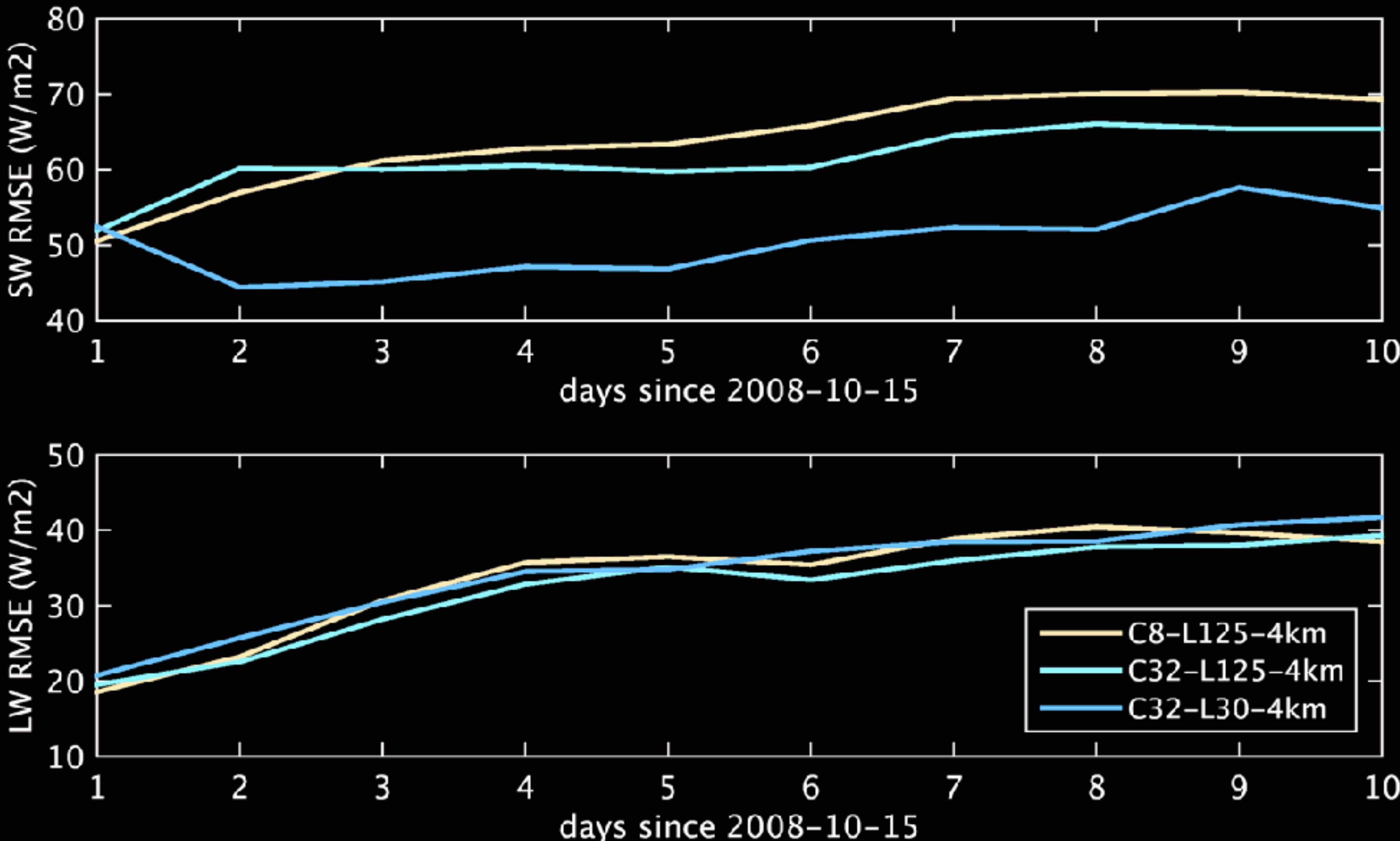
Scalability gains boost SPCAM's computational limit by > 4X

Yes. Short pilot tests with "ultraparameterization" now possible.

Strategy for testing UP

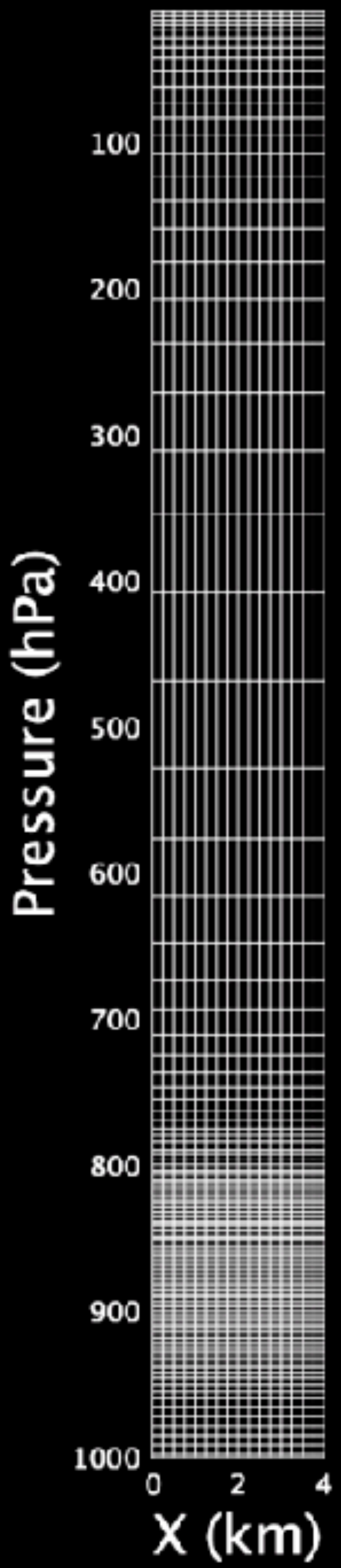
- Want a computationally affordable UP testing protocol
- Clouds evolve quickly in response to meteorology.
- Initialize with global weather analysis
- Turbulence and clouds spin up in a few hours, so compare 12-36 hour hindcasts with collocated cloud-relevant satellite observations
- Long enough to spin up low clouds
- Short enough to keep large-scale circulation accurate

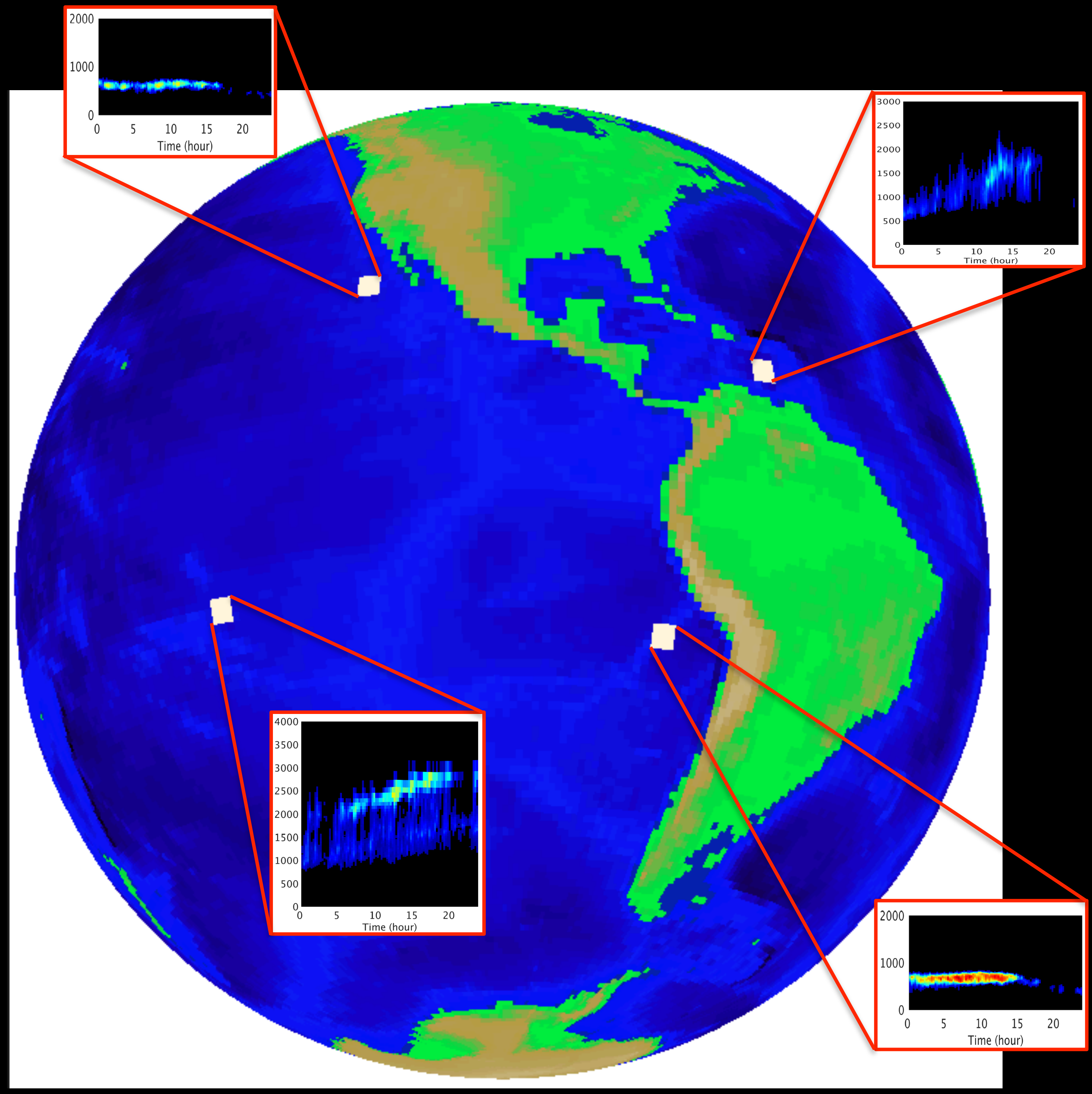
Low cloud errors develop fast.
Day 1: all of shortwave and 50% of longwave errors.



Parishani et al., in review for *JAMES*

Results - UP in action.





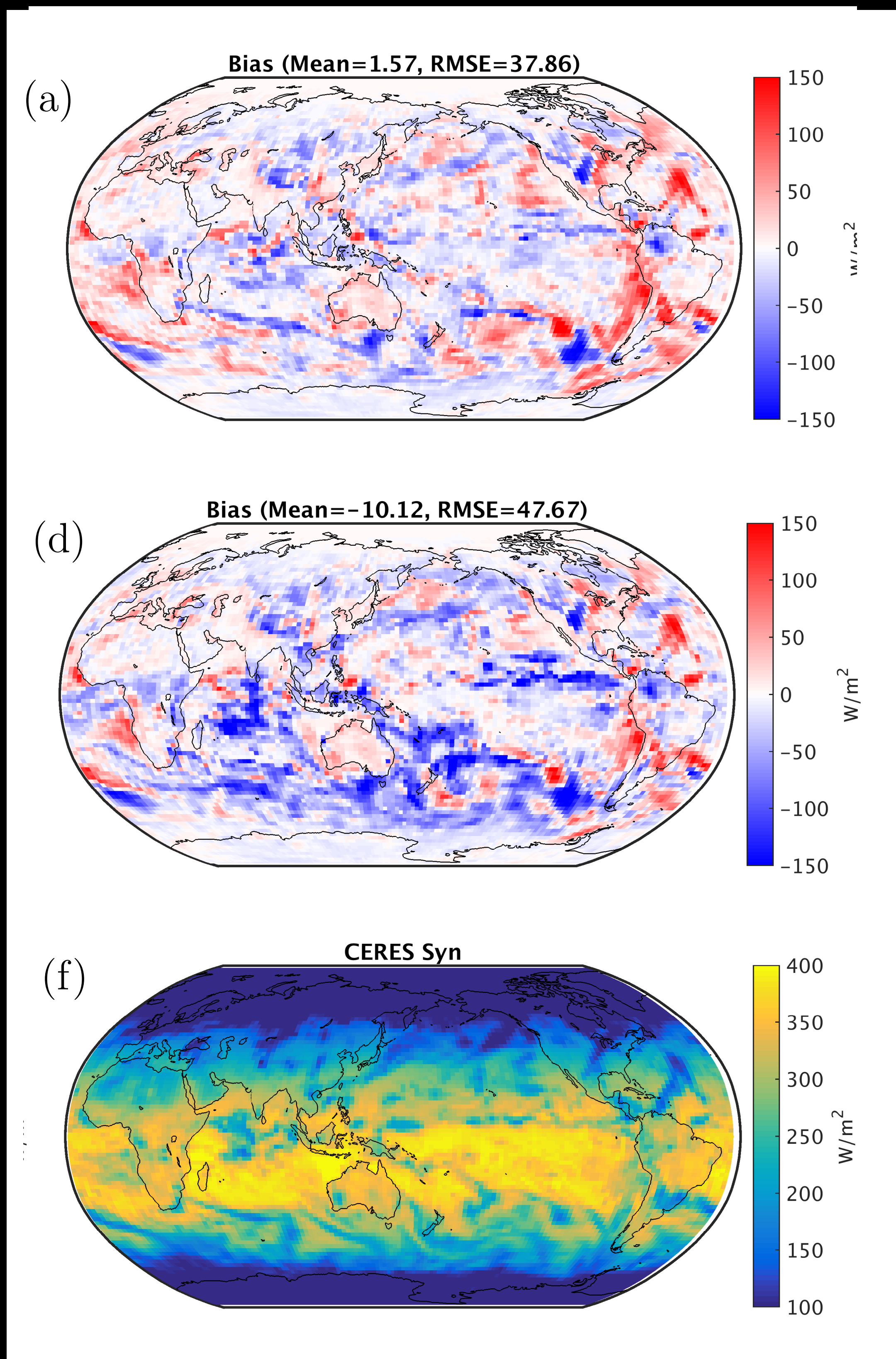
ASR vs. Oct. 15 2008

12-36 hours hindcast from 12 UTC 10/14 vs. CERES-SYN satellite obs.

SP bias

UP bias

OBS



- UP has larger errors and brighter midlatitude clouds.
- But is competitive with SP.

Parishani et al., in review for *JAMES*

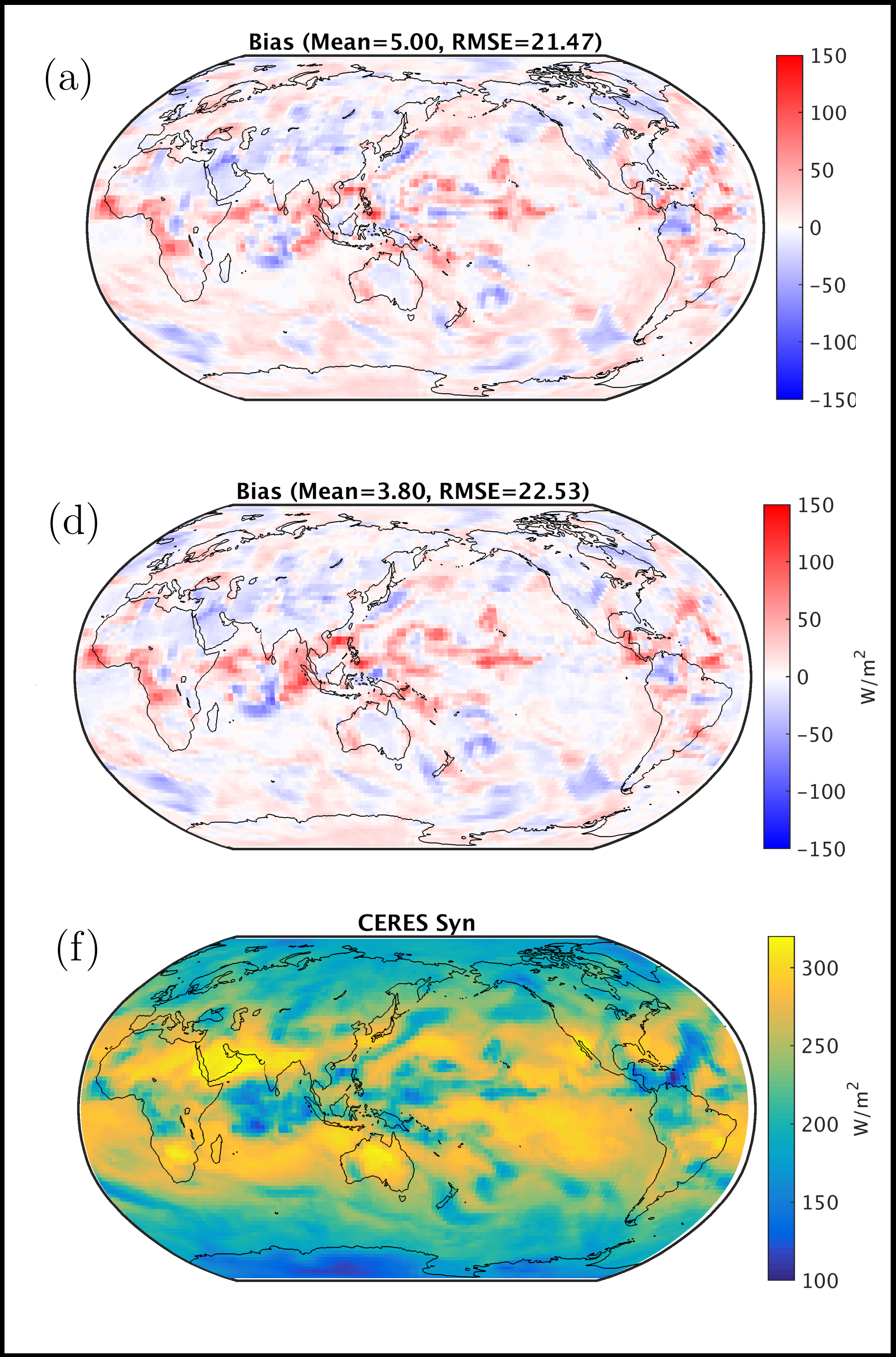
OLR vs. Oct. 15 2008

12-36 hours hindcast from 12 UTC 10/14 vs. CERES-SYN satellite obs.

SP bias

UP bias

OBS

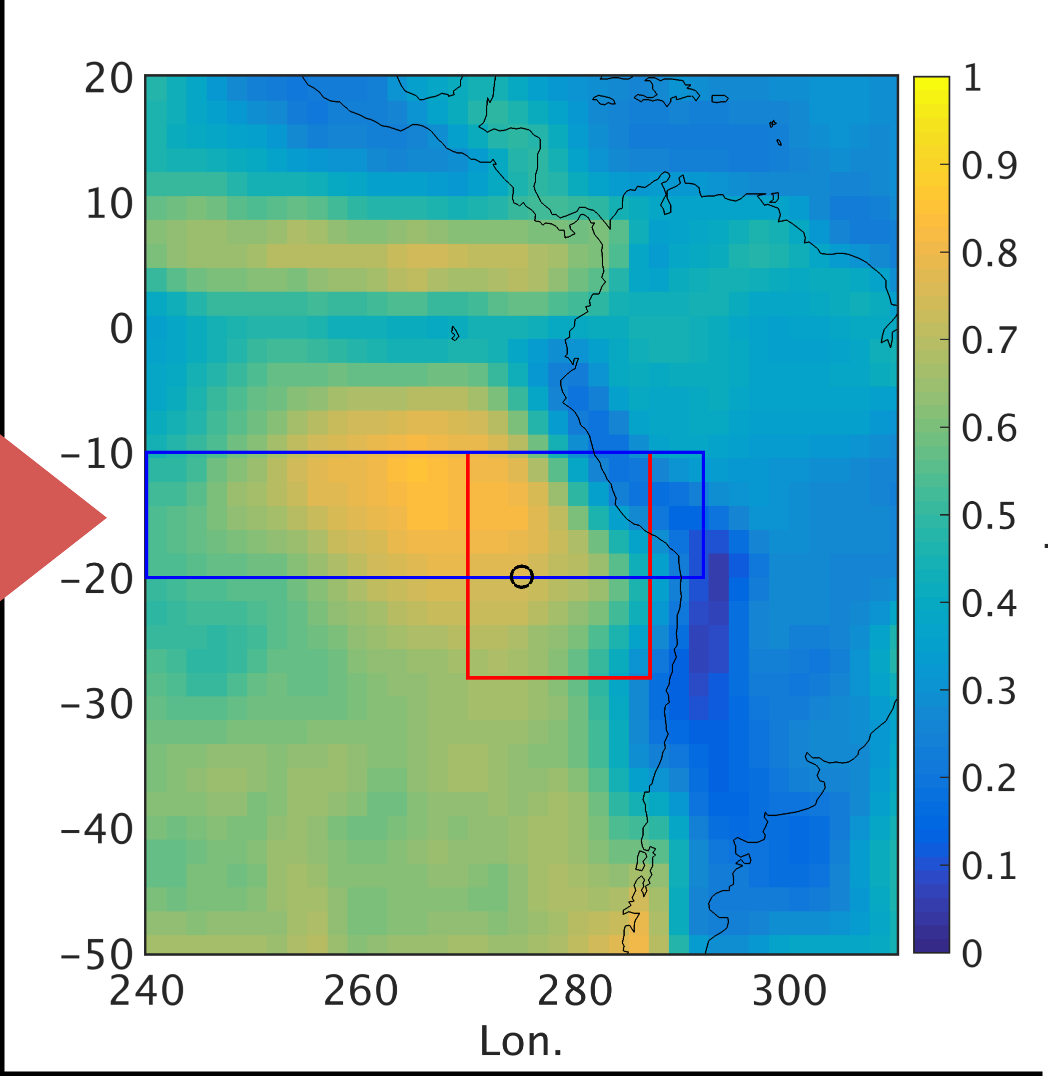


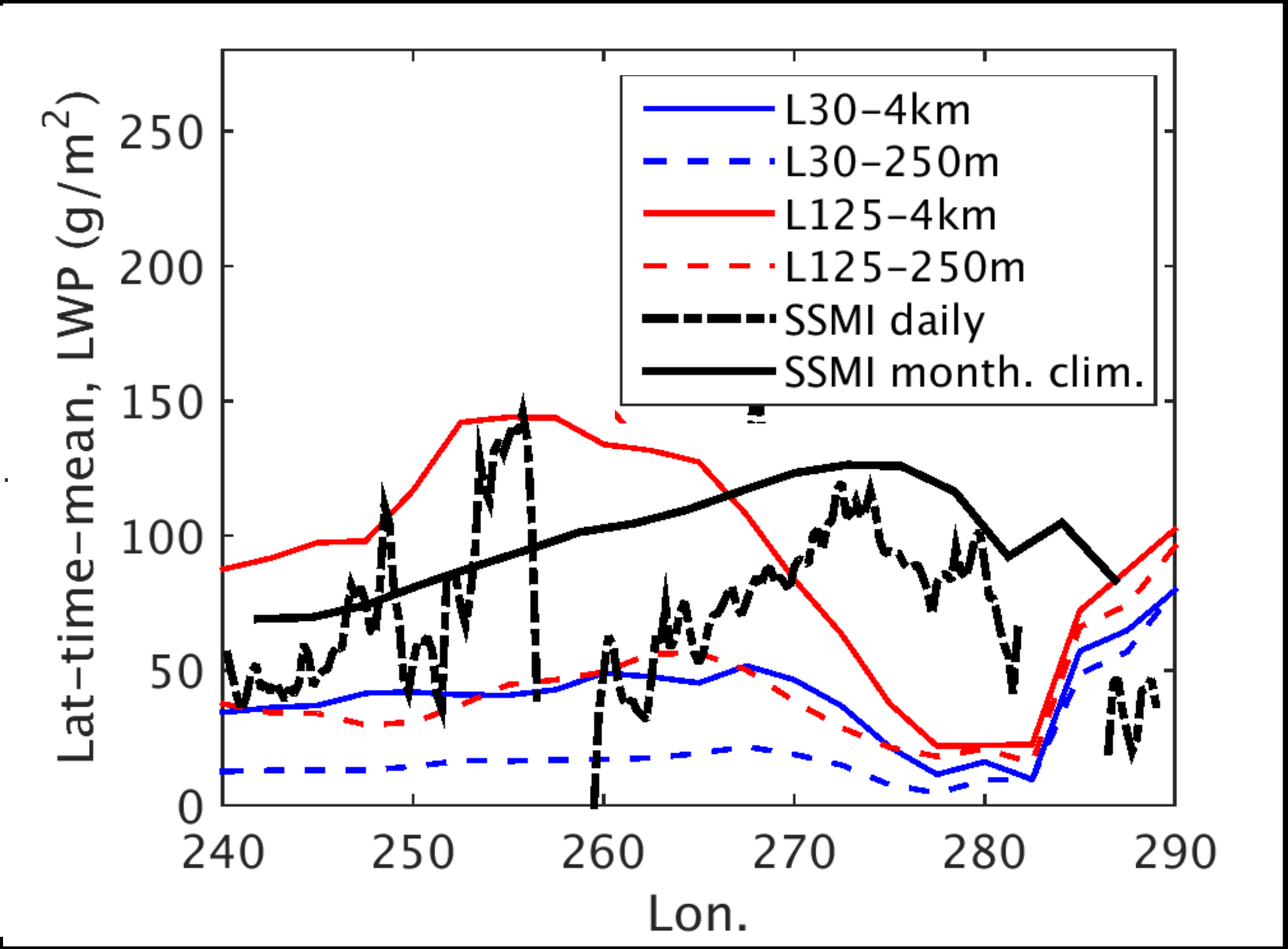
- UP similar to SP
- Despite domain far too small for cumulonimbus systems.

Parishani et al., in review for *JAMES*

Liquid water path along a Peruvian Sc zonal transect.

UP (L125-250m) vs. SP (L30-4km) results from 12-36 hour hindcast.





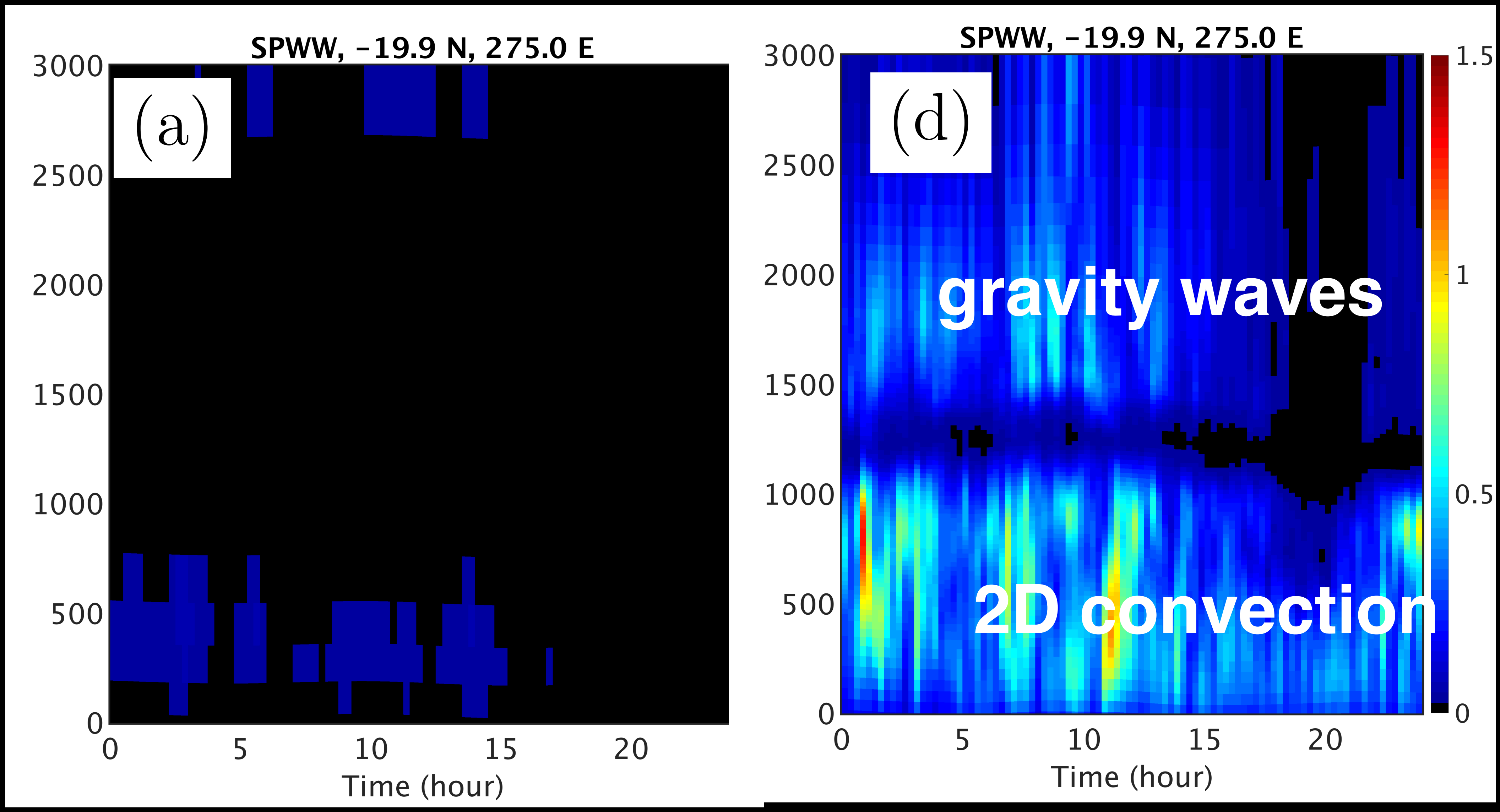
Surprisingly little difference between SP (—) vs. UP (- -)

Parishani et al., in review for *JAMES*

UP improves PBL turbulence.

UP (L125-250m) vs. SP (L30-4km) hindcast results near Peru

SP: **UP:**



SP updrafts too weak

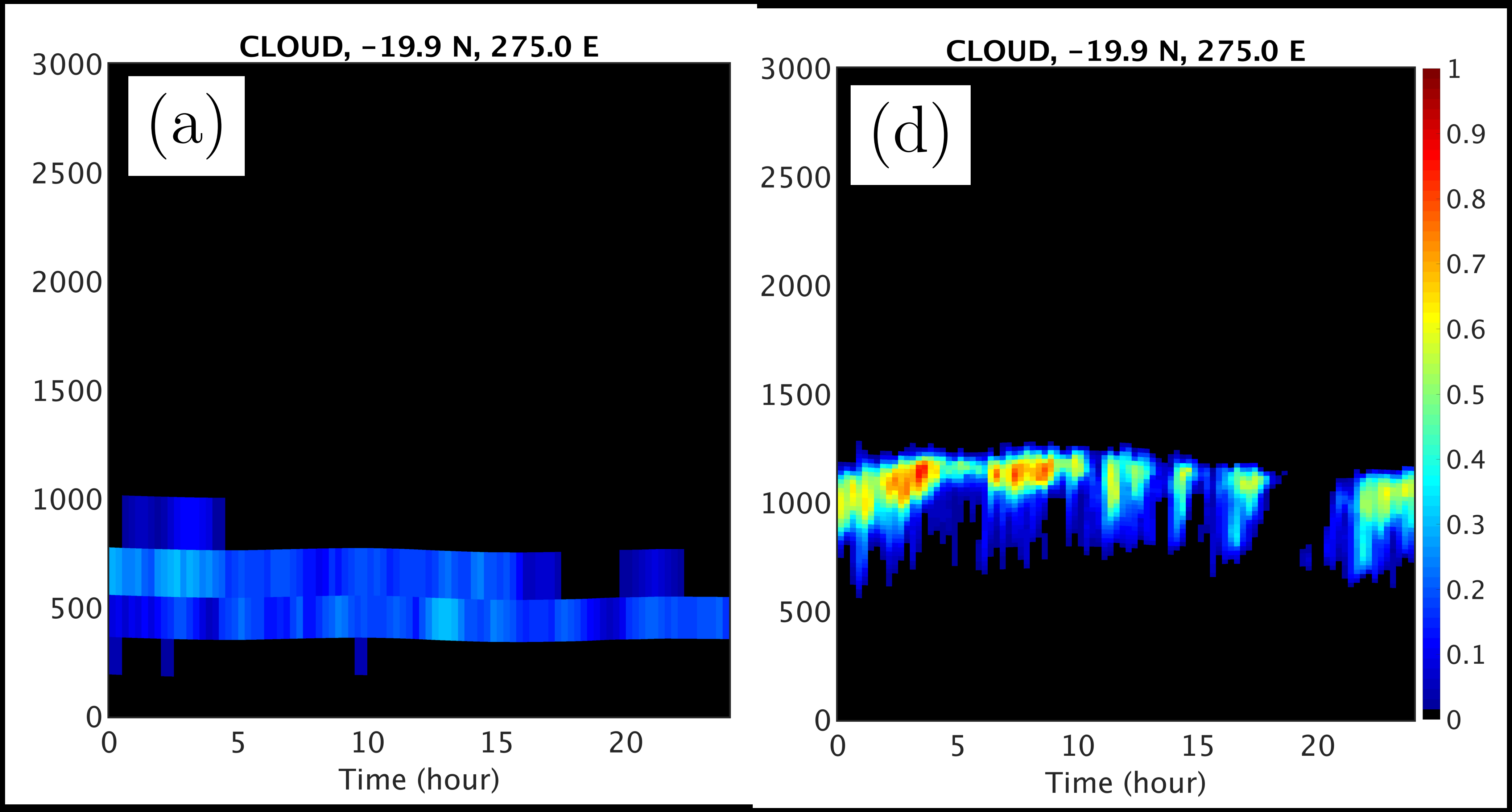
UP updrafts even a bit too strong.

Parishani et al., in review for *JAMES*

UP improves cloud vertical structure

UP (L125-250m) vs. SP (L30-4km) against satellite data (C3M)

SP: **UP:**

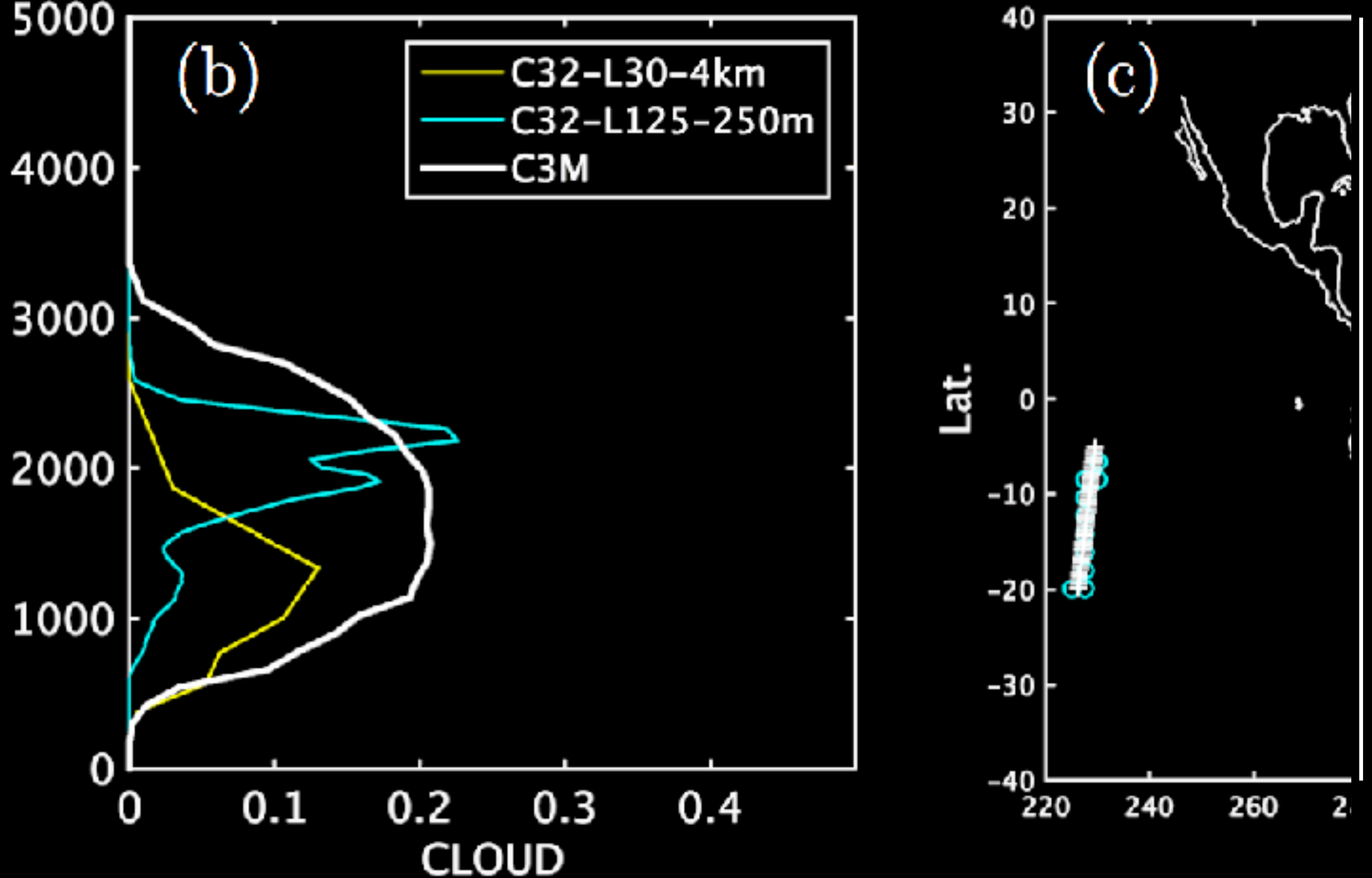


UP clouds have correct vertical structure…

Parishani et al., in review for *JAMES*

UP improves cloud vertical structure

UP (L125-250m) vs. SP (L30-4km) against satellite data (C3M)

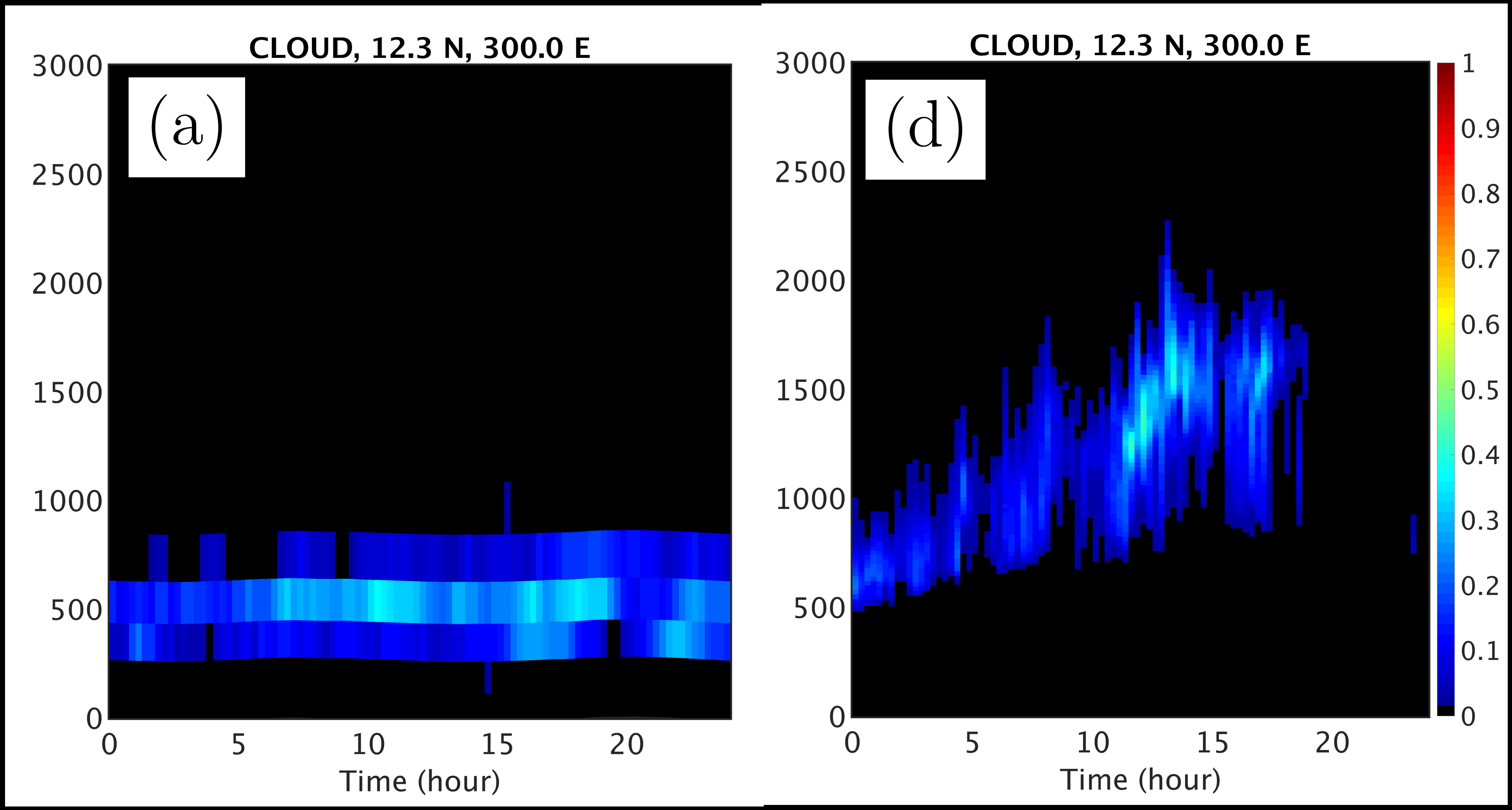


… UP cloud height validates better against co-located satellite constraints.

UP gives better shallow Cu structure too.

UP vs. SP near Barbados trade Cu observatory.

SP: UP:



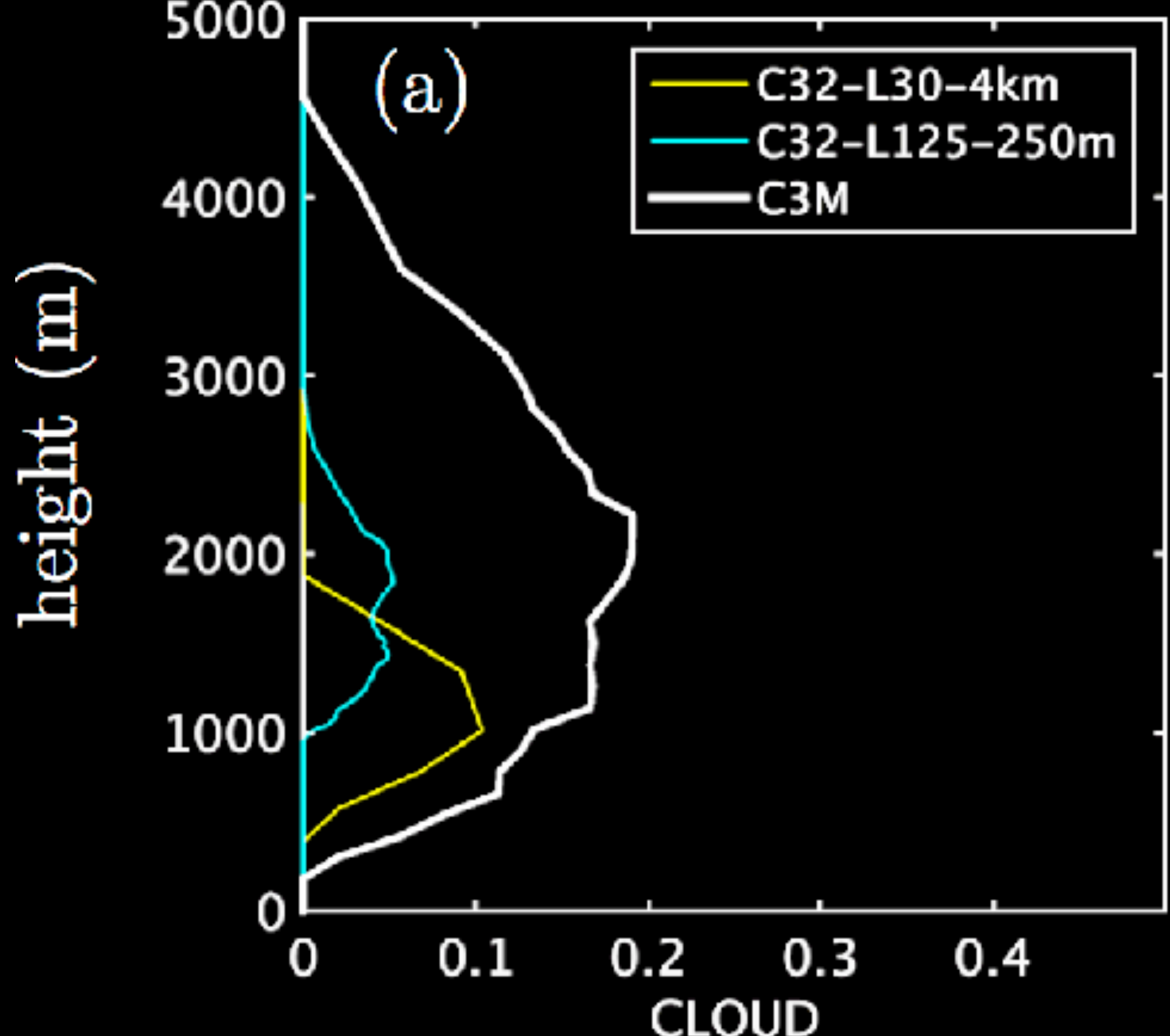
SP cumuli low, shallow

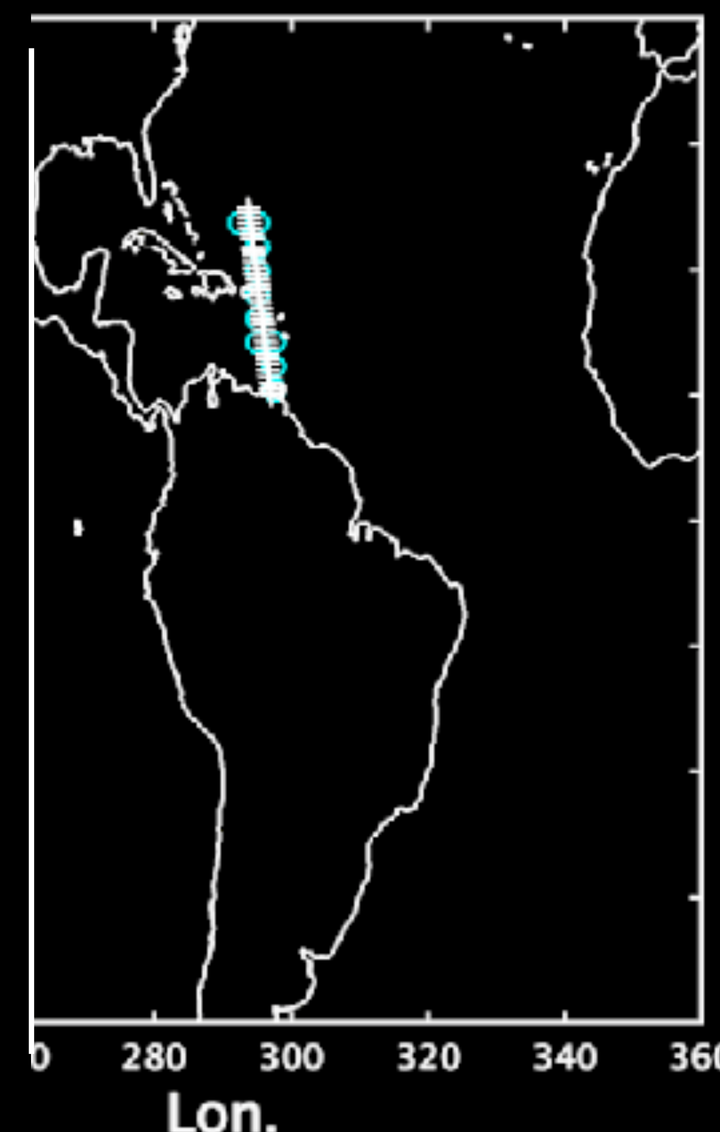
UP cumuli realistically deep (but cloud base too high)

Parishani et al., in review for *JAMES*

UP gives better shallow Cu structure too.

UP (L125-250m) vs. SP (L30-4km) against satellite data (C3M)





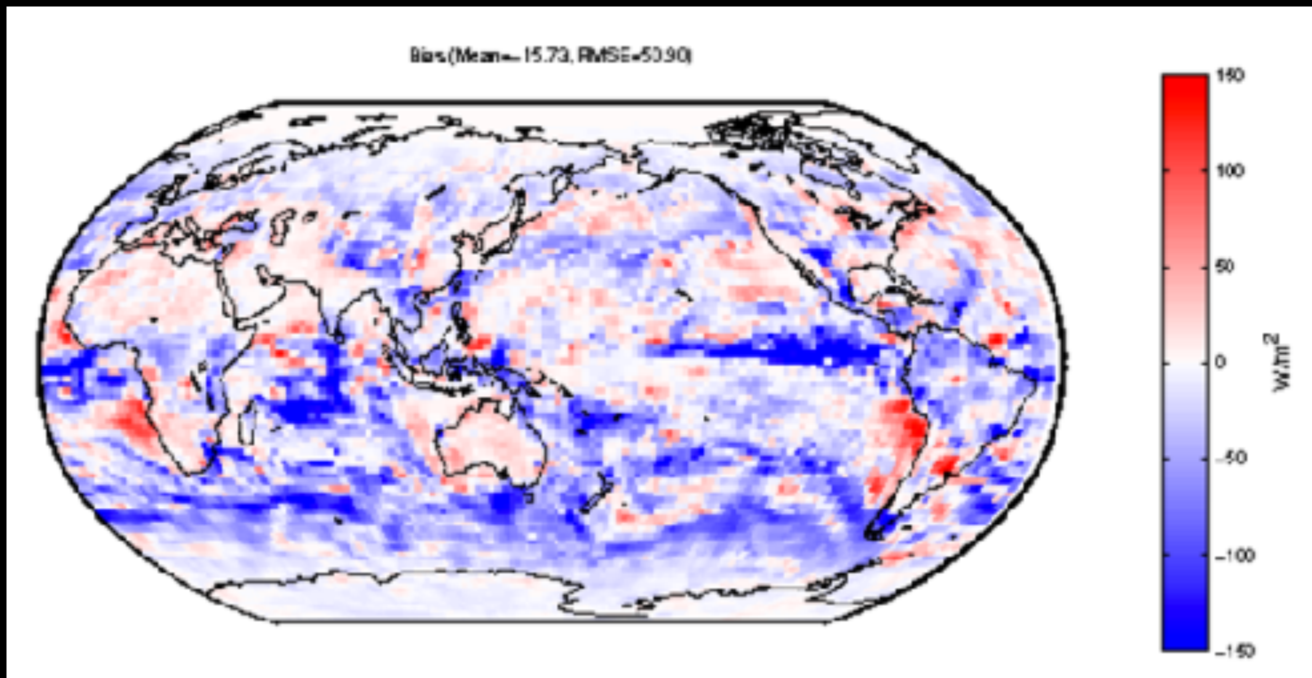
Parishani et al., in review for *JAMES*

Interesting technical issues.

- In LES, we often translate the CRM grid at a typical mean flow speed to reduce Courant number and increase accuracy.
- With ‘grey zone’ resolution, CRM and UP are surprisingly sensitive to this, with a translated grid increasing turbulent updraft speeds and entrainment.
- Small 3D (vs. 2D) domains and a more sophisticated advection scheme don’t provide expected payoffs for UP.
- Substantial issues with ‘pulsy’ turbulence and convection in very small CRM domains.
- UP activates many more cloud droplets for the same aerosol loading as does SP due to strong updrafts.
- Despite issues, we plan to use UP to look at SST+4K low cloud feedbacks and compare with SP.

UP's ASR bias can be "fixed" using 1-moment microphysics

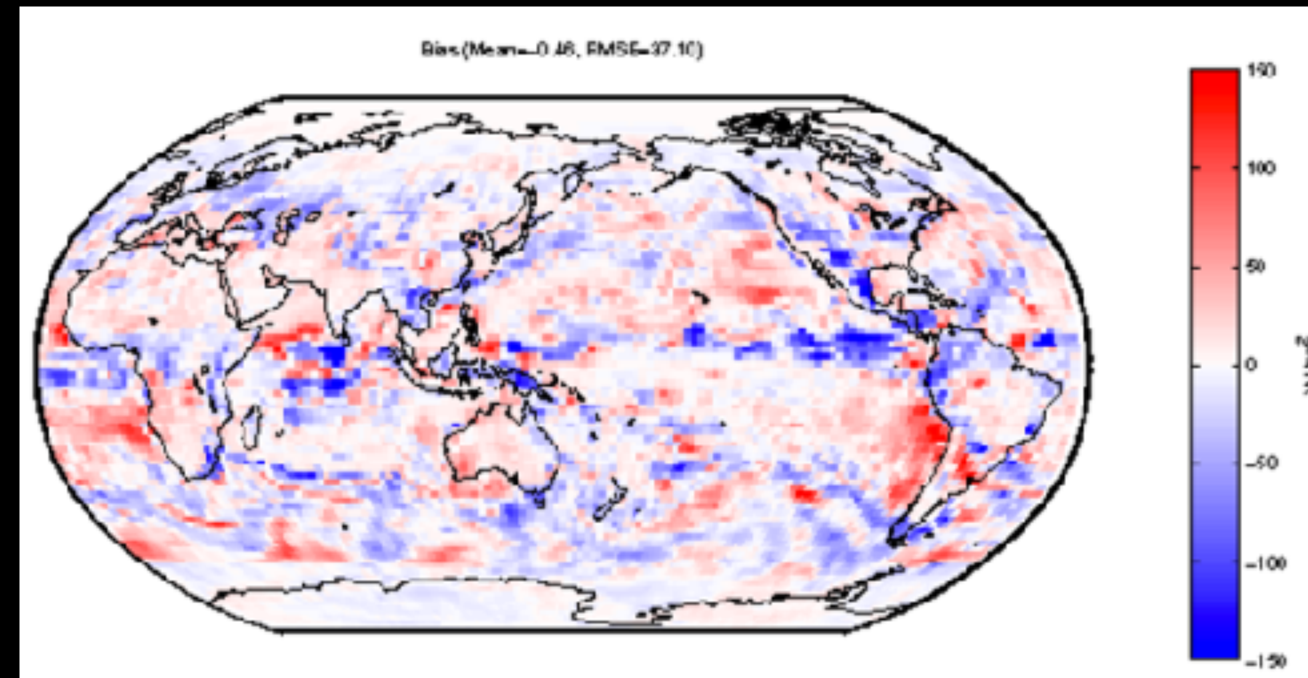
L125 - M2005



C32_r4_MPD_32x1CRM250m_1mrad_36h_L125_20081014_12Z_1008

Morrison 2-moment w.
nucleation of specified CCN

L125 - SAM1mom



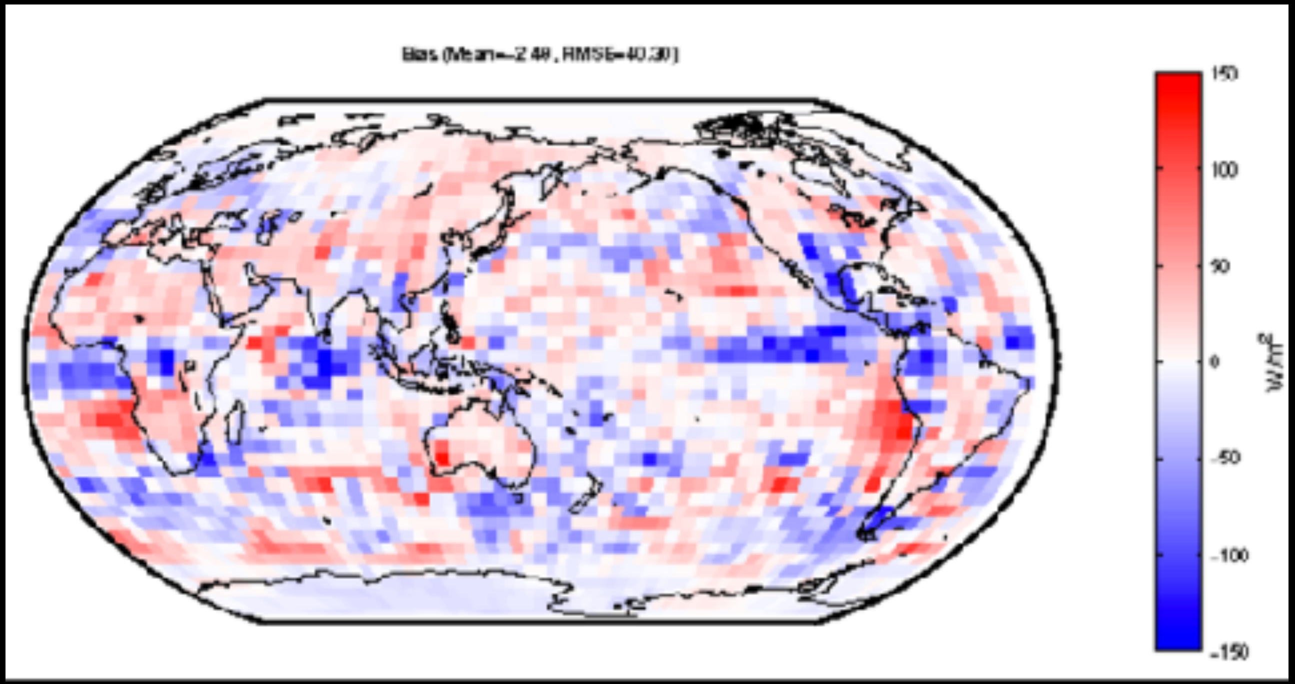
sam1m2deg_FV_r1_32x1CRM250m_10mrad_1d_YTC_nZM_L125_20081014_12h_1024

1-moment, fixed r_{eff}.
Kessler autoconv

no midlat bias!
25% reduced RMSE
…but aerosol-unaware

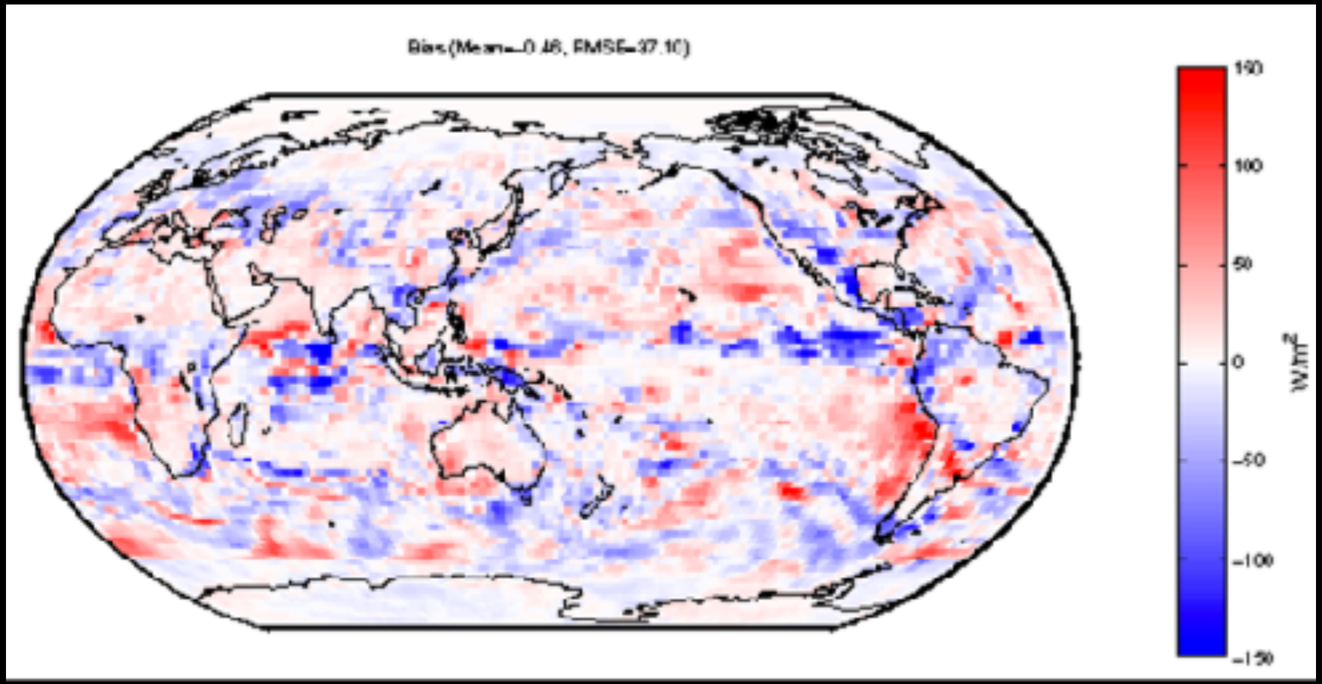
Coarsening exterior resolution from 2-deg to 4 degree does not affect UP's ability to simulate low clouds.

4x5 - L125 - SAM1mom



sam1mom4x5_FV_r14_32x1CRM250m4x_10mrad_36h_L125_20081014_12Z_1024

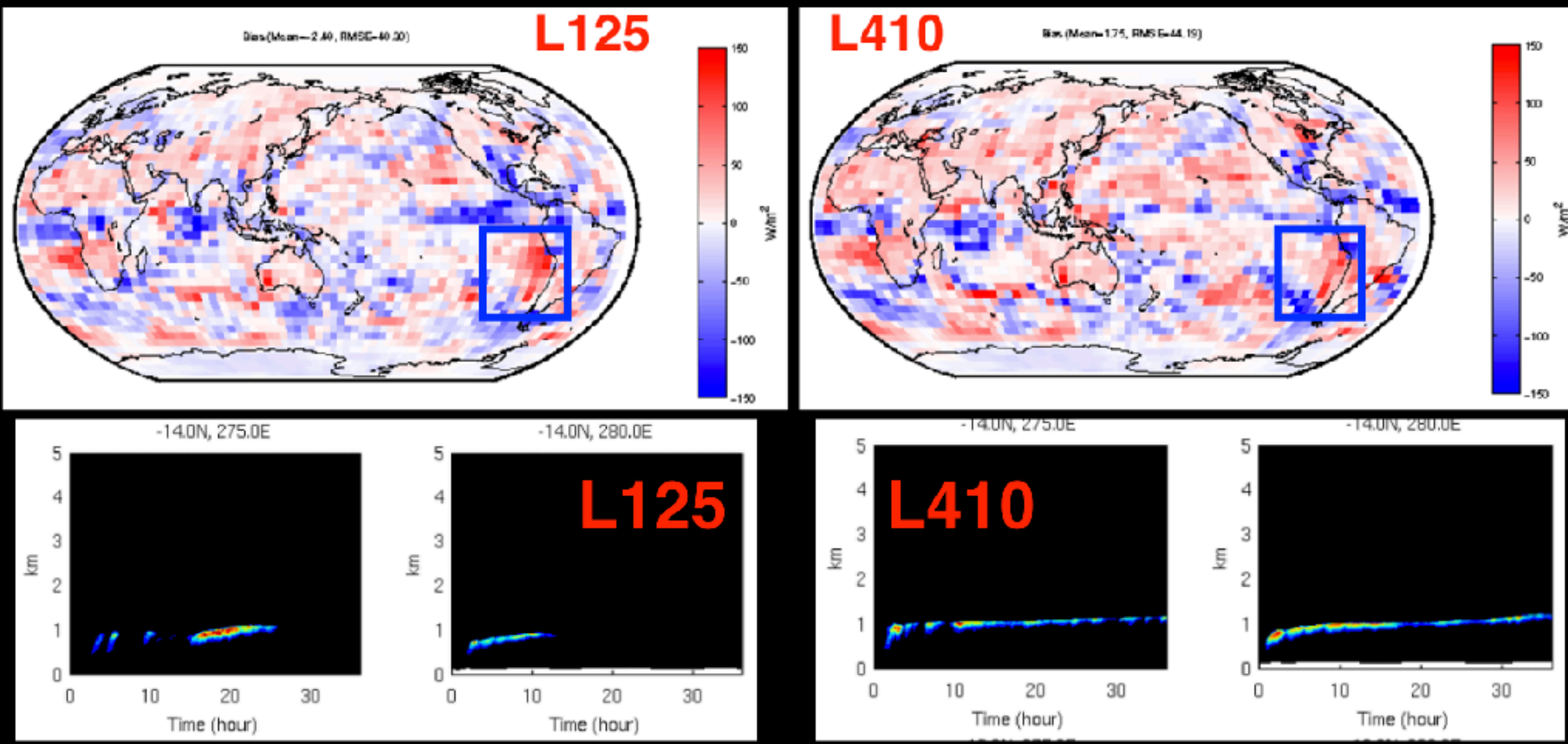
1.9x2.5 - L125 - SAM1mom



sam1m2deg_FV_r1_32x1CRM250m_10mrad_1d_YTC_nZM_L125_20081014_12h_1024

- Reduces computational expense by 4x.
- Opens room for even more vertical resolution.

Eightfold increase of vertical resolution from 20-m to ~ 3-m near inversion (410 levels) improves the burstiness & overentrainment.



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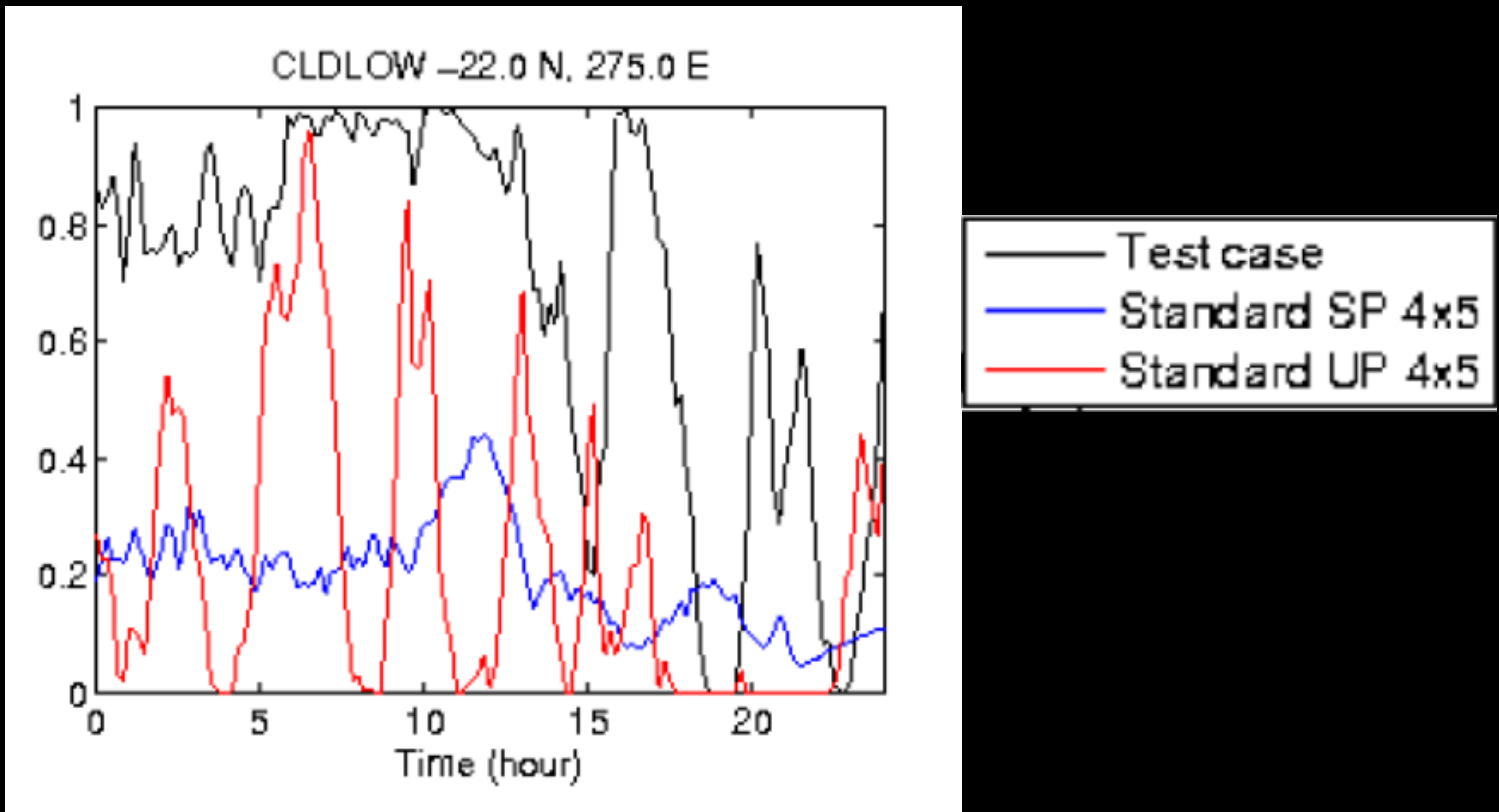

Summary & outlook.

- Successful and computationally feasible implementation of ultraparameterization gives reasonable global cloud distribution
- Better vertical structure of boundary-layer clouds than SP
- Better contrast between cumulus and stratocu than SP
- Highly parallelizable
- Can save 4x computation using mean-state acceleration
- Still a work in progress, but runs of a year are practical; we plan control, perturbed-SST and perturbed-CO2 simulations in 2017


Thanks.