Ultraparameterization: Using large eddy simulation for global simulation of boundary layer clouds and climate

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More info: Parishani et al. *JAMES*, to be (re)submitted 3/2017

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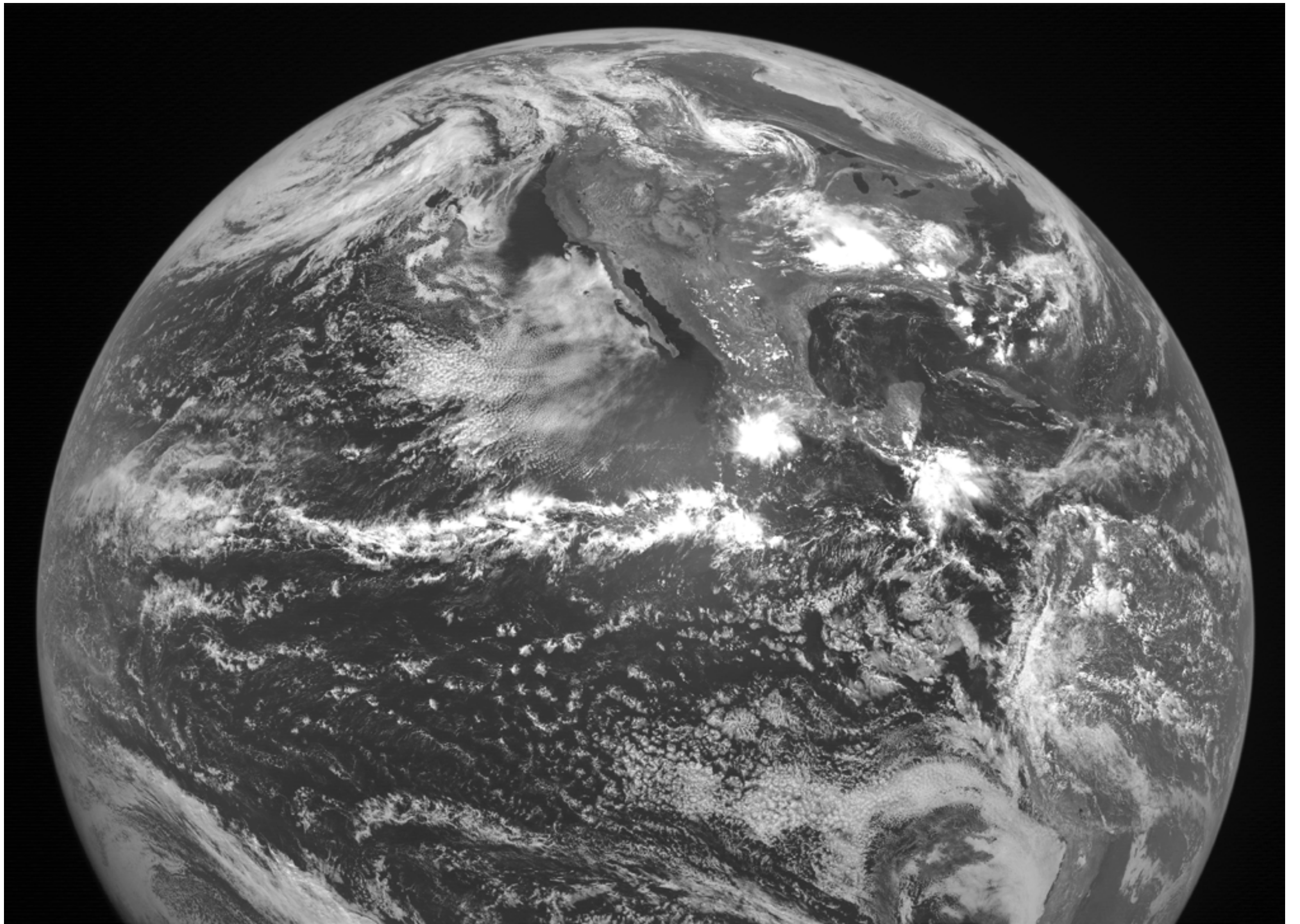
UC Irvine

The ultraparameterization team

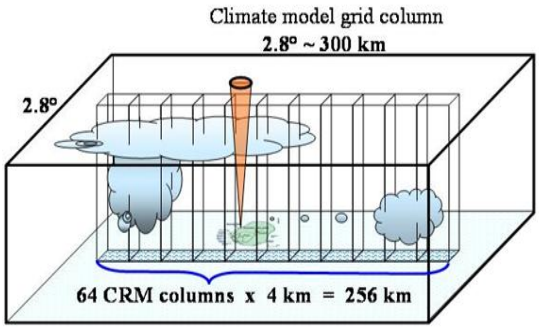
PNNL

The problem

Global LES is needed to explicitly simulate the boundary-layer clouds most important for climate sensitivity and aerosol-cloud interactions, but is too expensive for the multiyear simulations needed to do this.



Ultraparameterization (UP) –variant of superparameterization

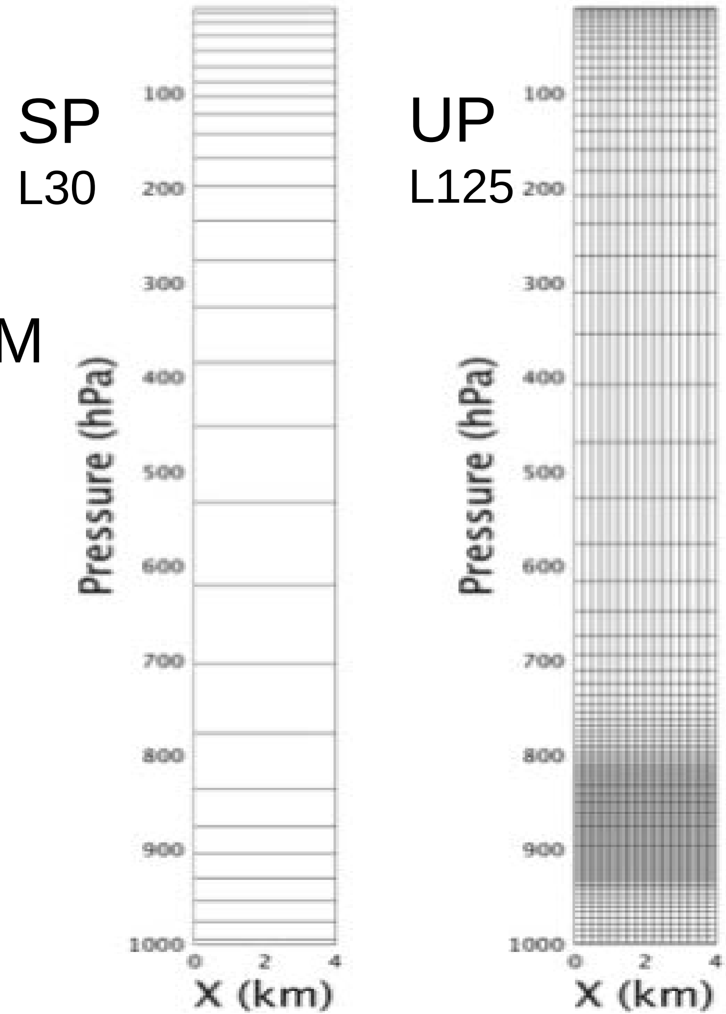


Low-cloud-resolving model in each GCM grid column (Δx = 250 m, Δz = 20 m for z=0.5-2 km, C32-L125)

Implemented in 2° SP-CAM5,
1-mom μphys, 4x mean-state accel

- Bypasses 8-200 km scales
- 200x more computations than CAM5 2°
- 5x more computations than SP
- But 10^{-6} of a similar global LES

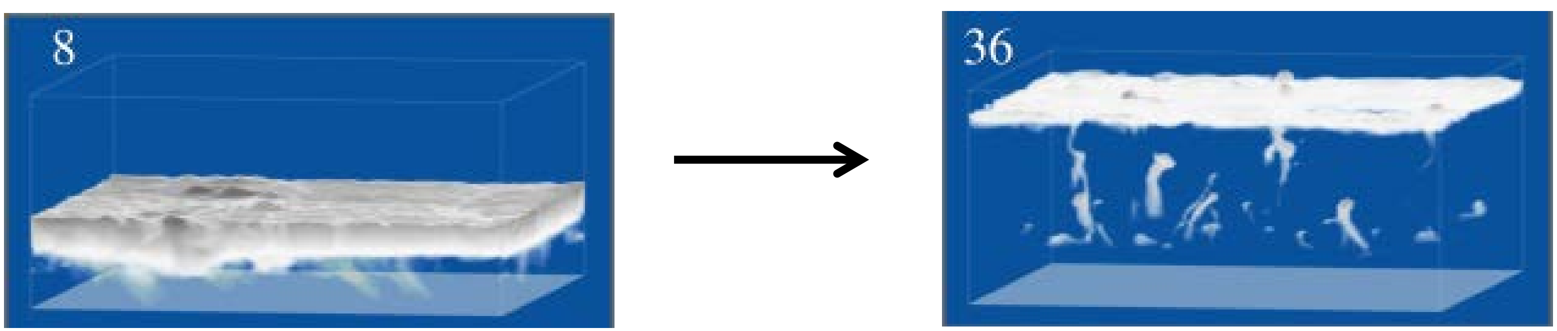
See also: Marchand & Ackerman 2010:SP1 km-L52



Parishani et al. 2016;
see also Grabowski 2016

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



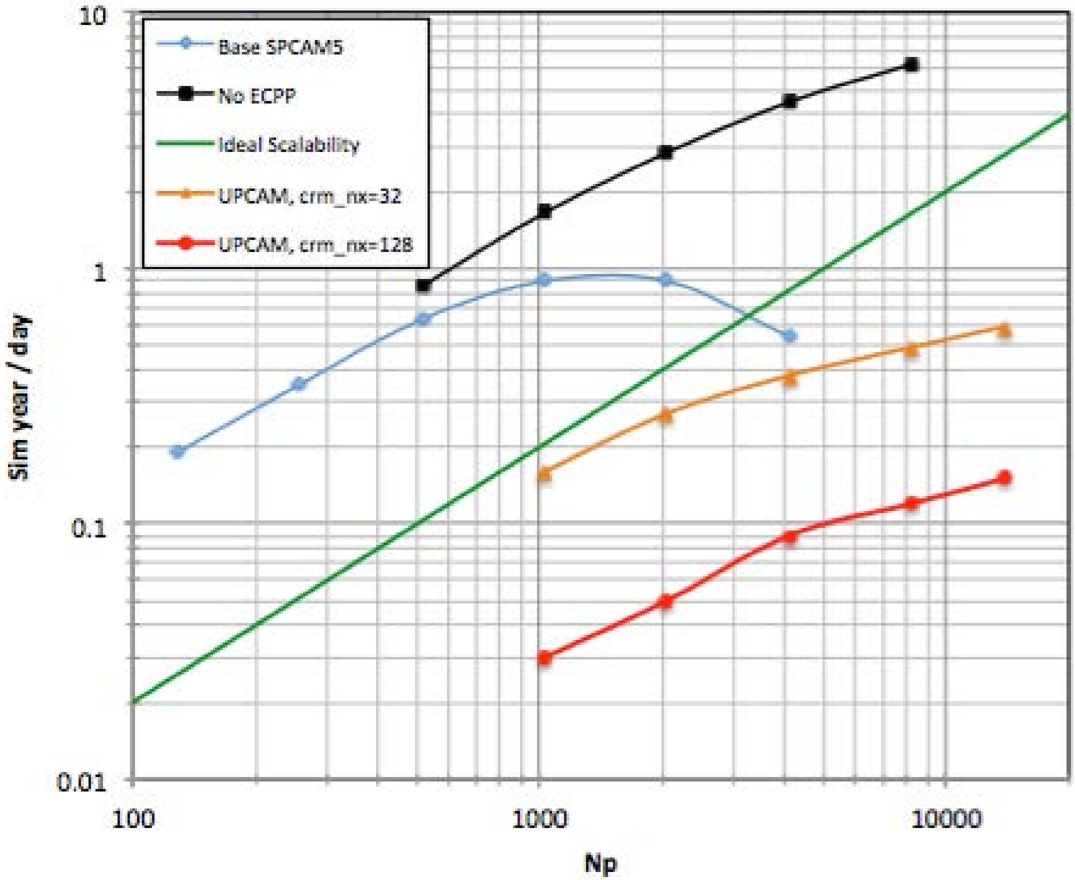
UP development and testing

Questions:

1. Does the UP ‘large-scale, turbulence-scale’ approach help simulate challenging boundary-layer clouds?
2. Can UP be run long enough (>1 yr) for climate applications?

UP is highly parallelizable

CRMs exchange info thru GCM every 10 mins ≈ 500 timesteps
Current limit: 1 CRM per core ➔ 0.45 sim years/day on Edison.

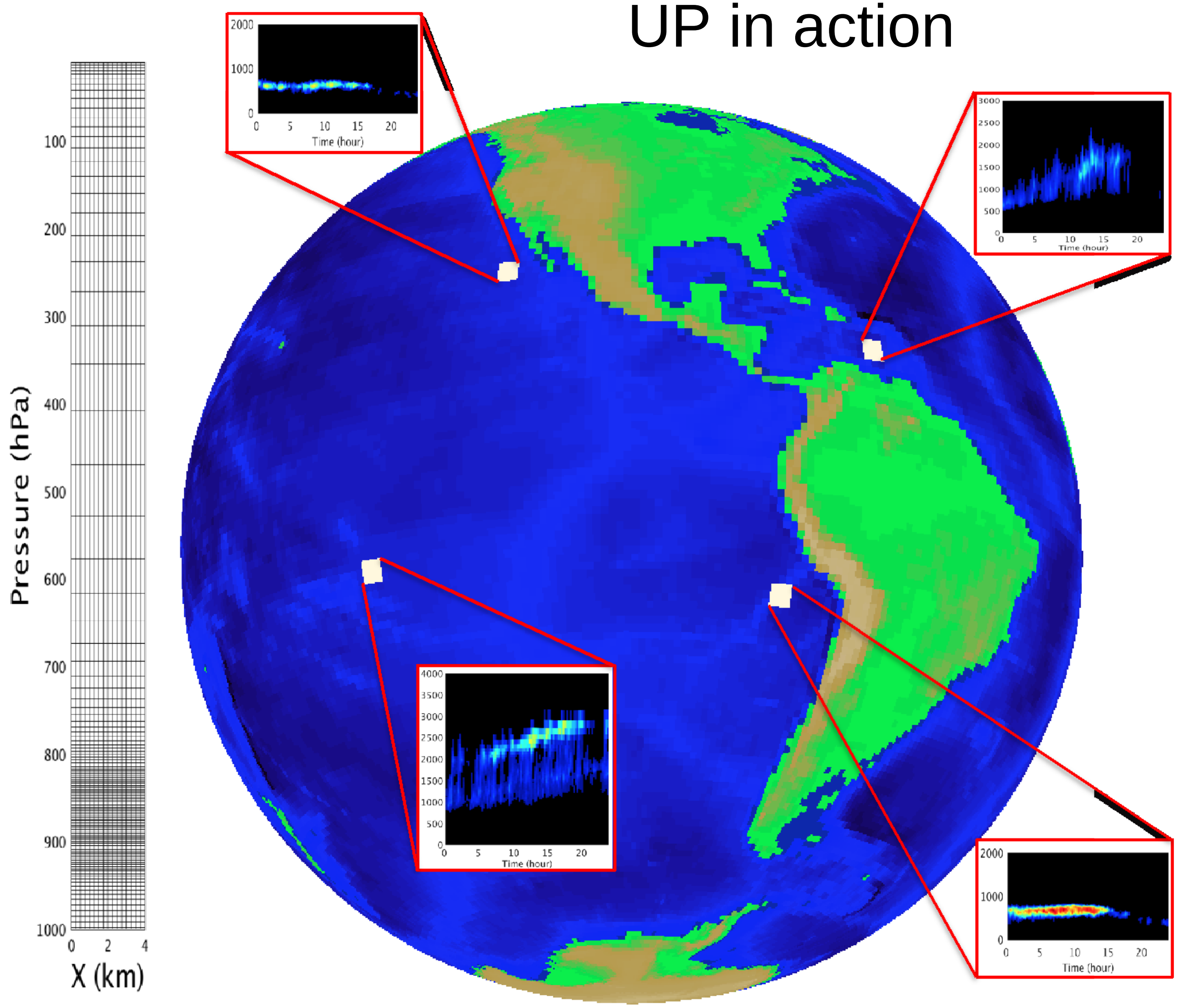


Speed-up from mean-state acceleration is on top of this.
Climate applications are (somewhat) computationally feasible

Testing UP

- Want a computationally affordable UP testing protocol
- Clouds evolve quickly in response to meteorology.
- Initialize with ECMWF YOTC analysis
- Turbulence and clouds spin up in a few hours, so compare 12-36 hour hindcasts with collocated cloud-relevant satellite observations (gridded daily CERES-SYN RSW, OLR, microwave LWP, C3M cloud profiles)
  - long enough to spin up low clouds
  - short enough to keep large-scale circulation accurate
- 10 hindcasts initialized 12Z every 3rd day in Oct 2008
- Error statistics: Global bias and spatial RMSE vs. obs.

UP in action



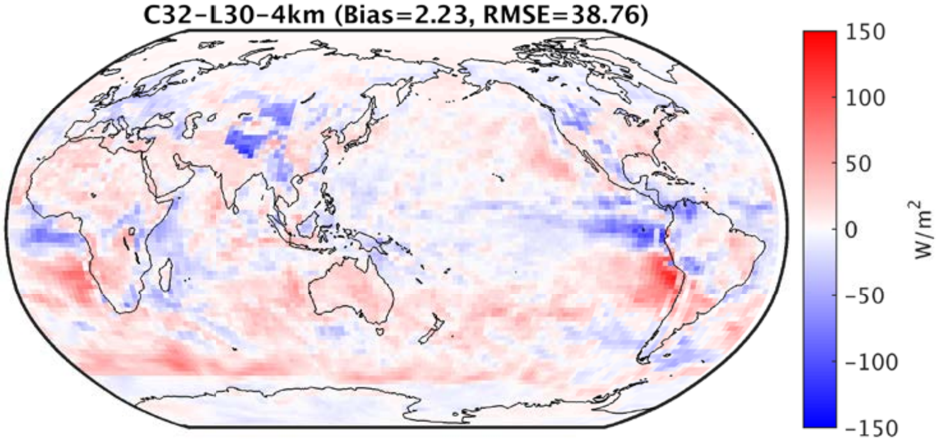
Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
0 2 4
X (km)
2000
1000
0
0 5 10 15 20
Time (hour)
3000
2500
2000
1500
1000
500
0
0 5 10 15 20
Time (hour)
4000
3500
3000
2500
2000
1500
1000
500
0
0 5 10 15 20
Time (hour)
2000
1000
0
0 5 10 15 20
Time (hour)

ASR vs. obs

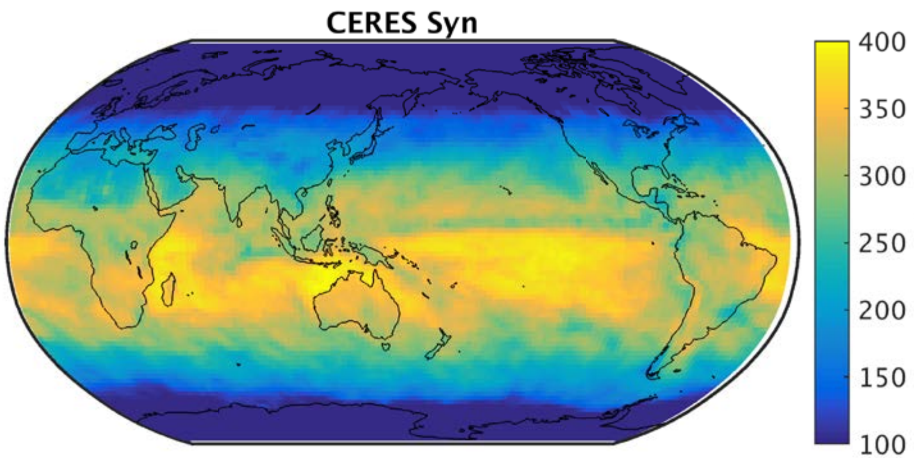
12-36 hr 10-hindcast mean

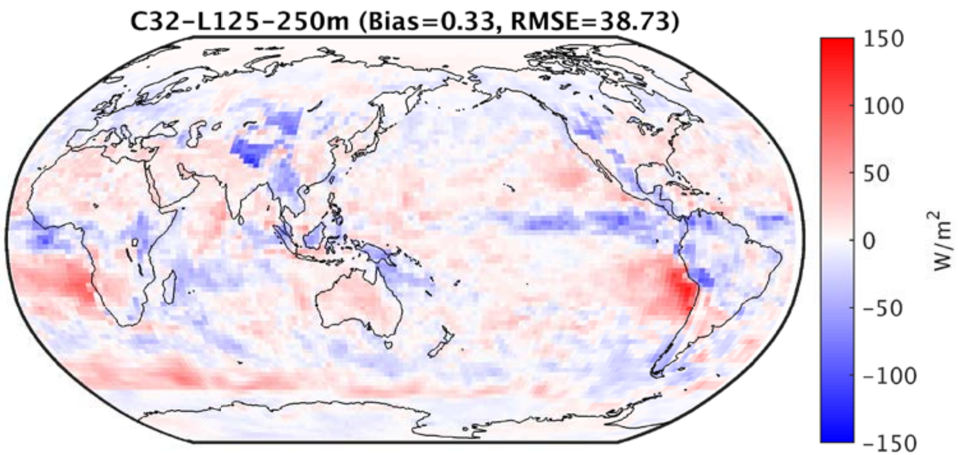
- UP biases similar to SP, both have too little subtropical Sc, too much ITCZ cloud
- UP slightly improves extratropical cloud

SP - obs



UP - obs





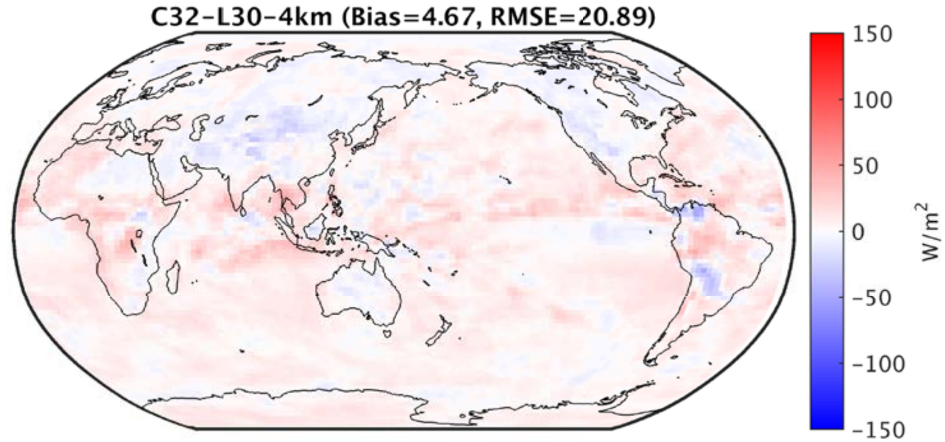
Parishani et al. 2017

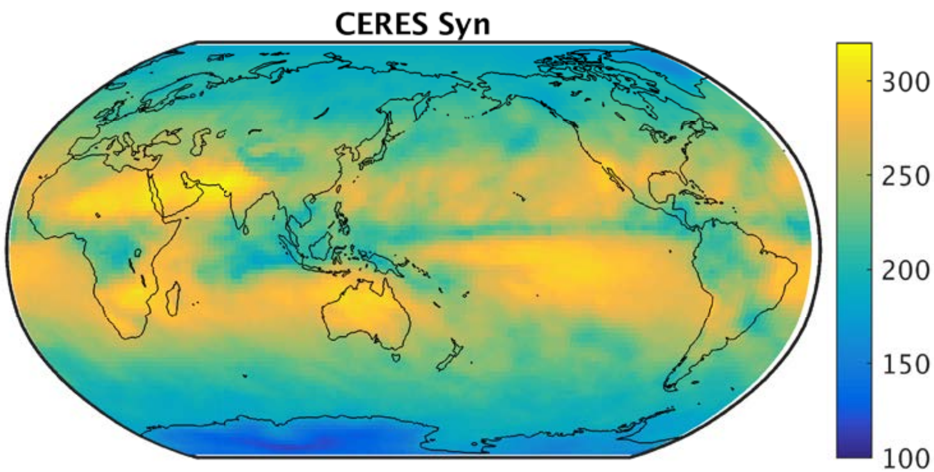
OLR vs. obs

12-36 hr 10-hindcast mean

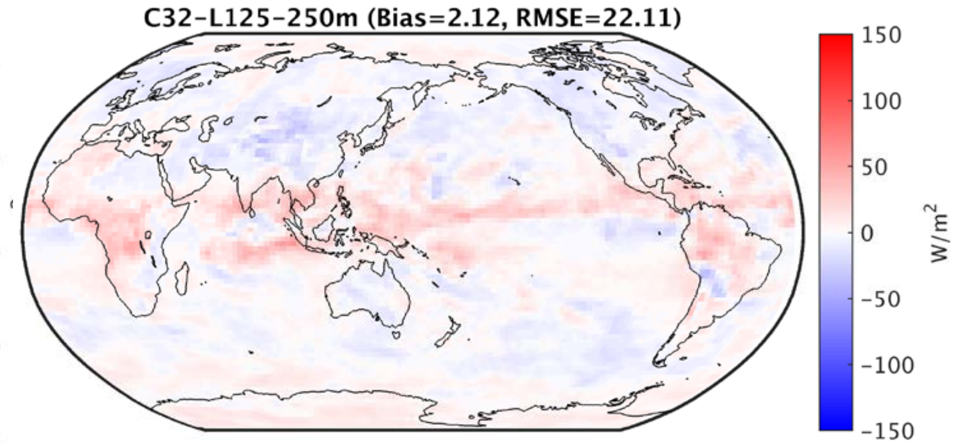
UP similar to SP despite 8 km wide domain that is too small for cumulonimbus cloud systems

SP - obs





UP - obs

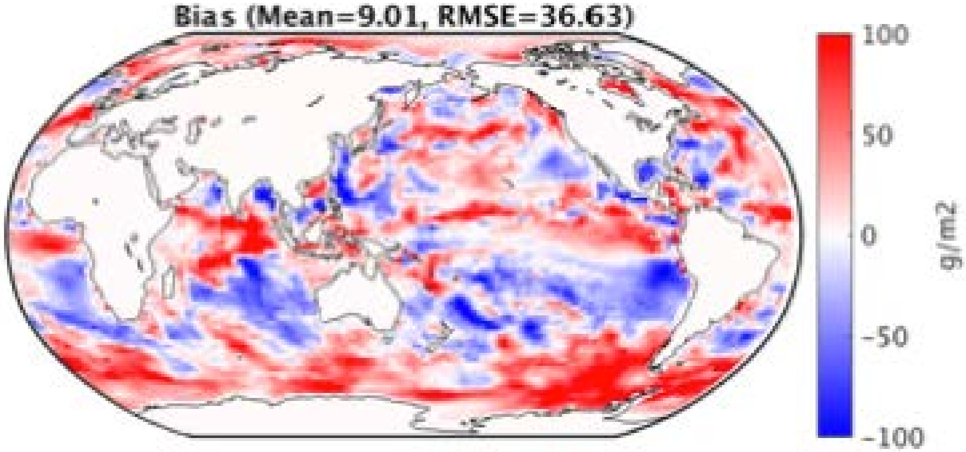


Parishani et al. 2017

Liquid water path: 10-hindcast stats

UP also has similar LWP errors to SP

SP - obs



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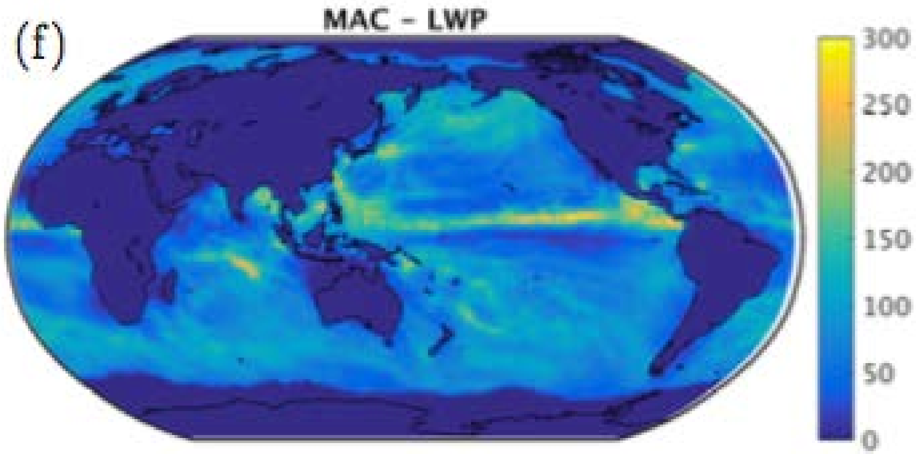

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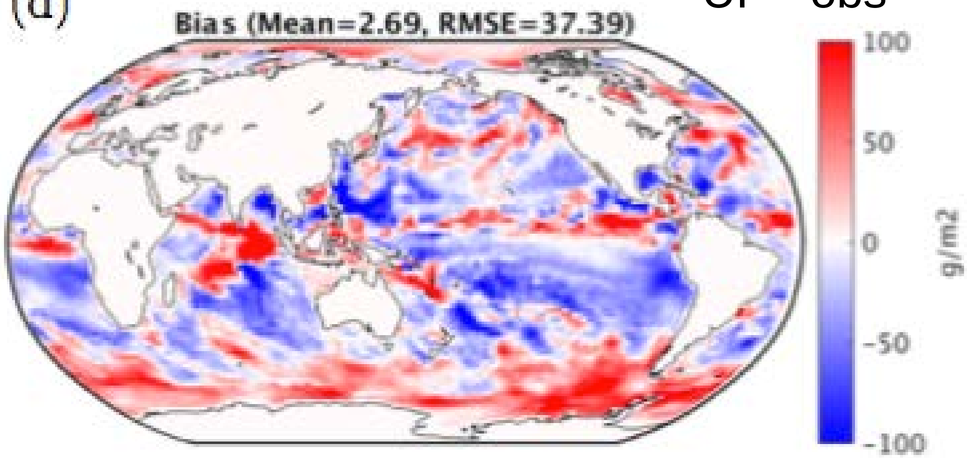
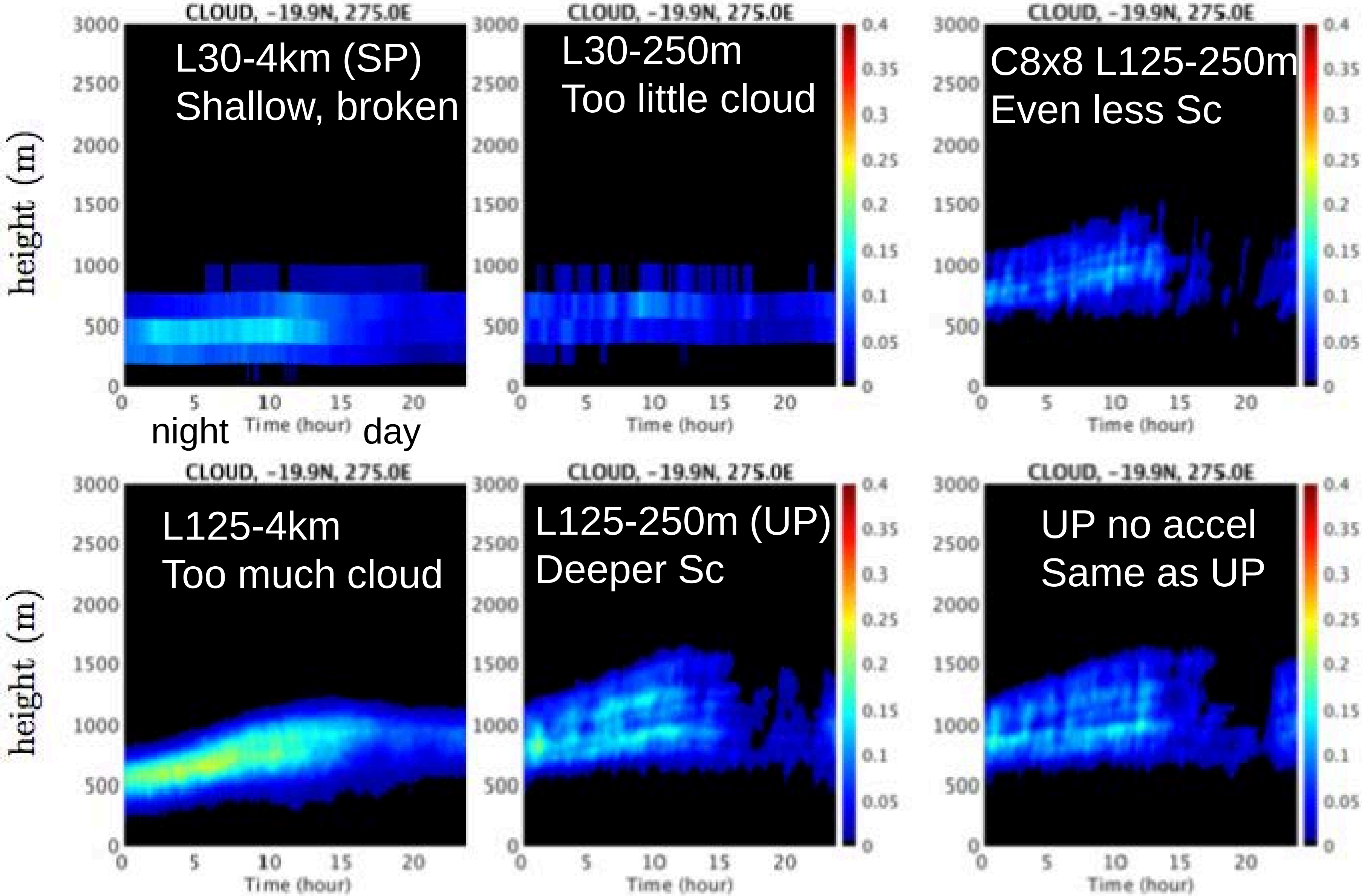
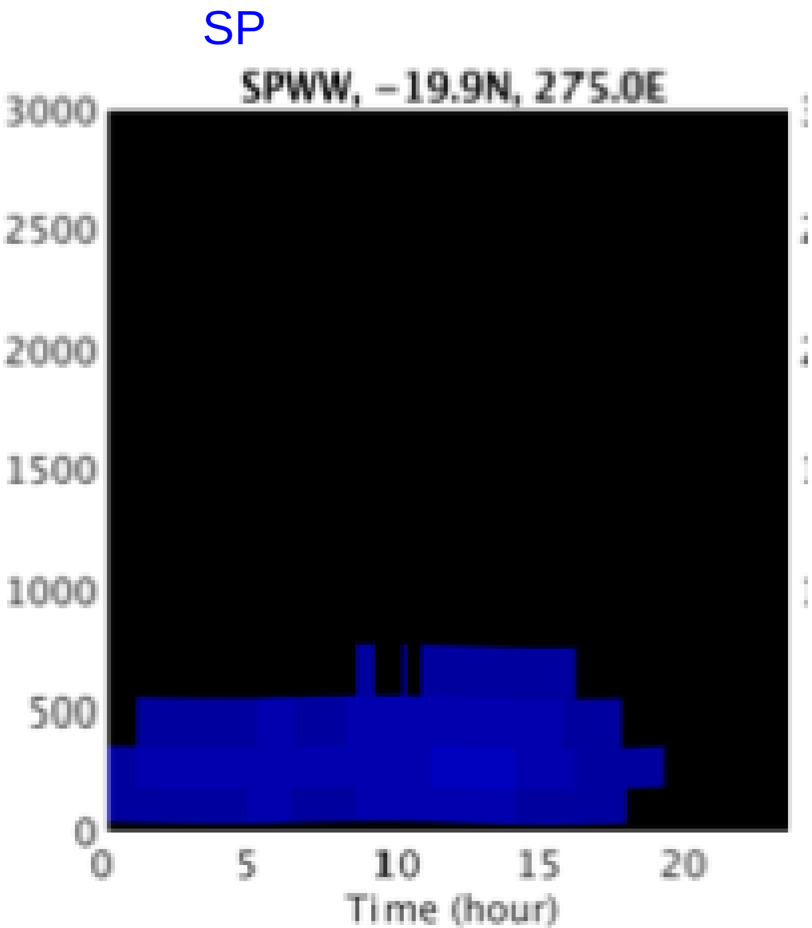
UP - obs



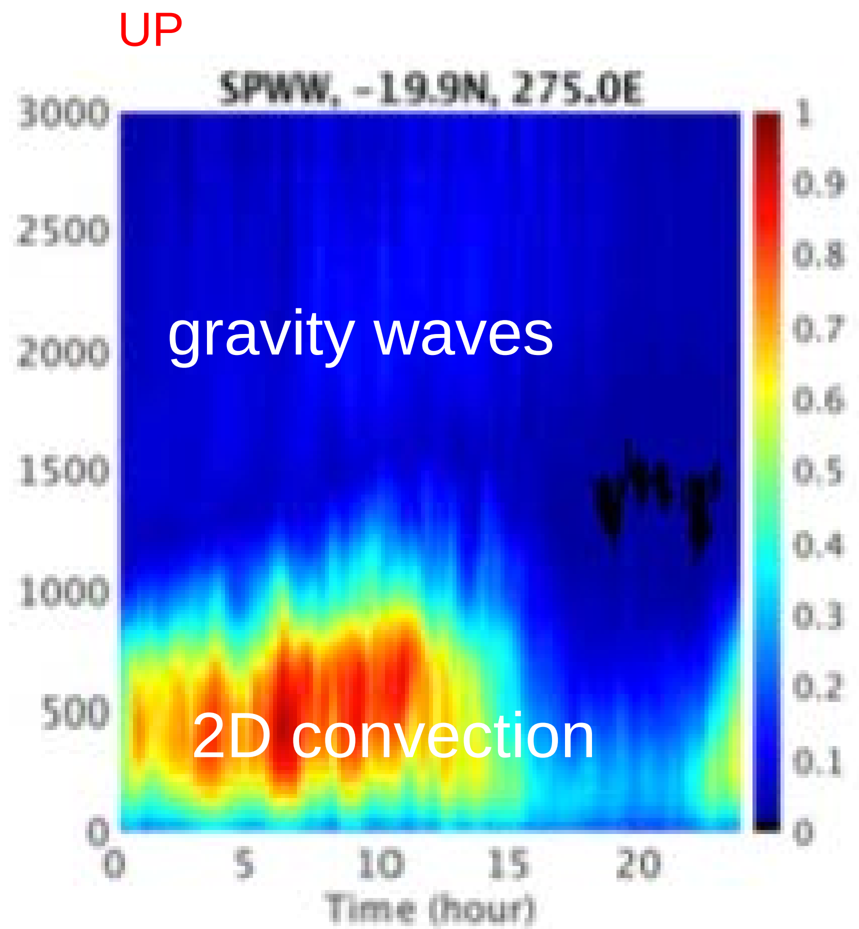
Cloud vertical structure: SE Pac Sc gridpoint



UP improves PBL turbulence

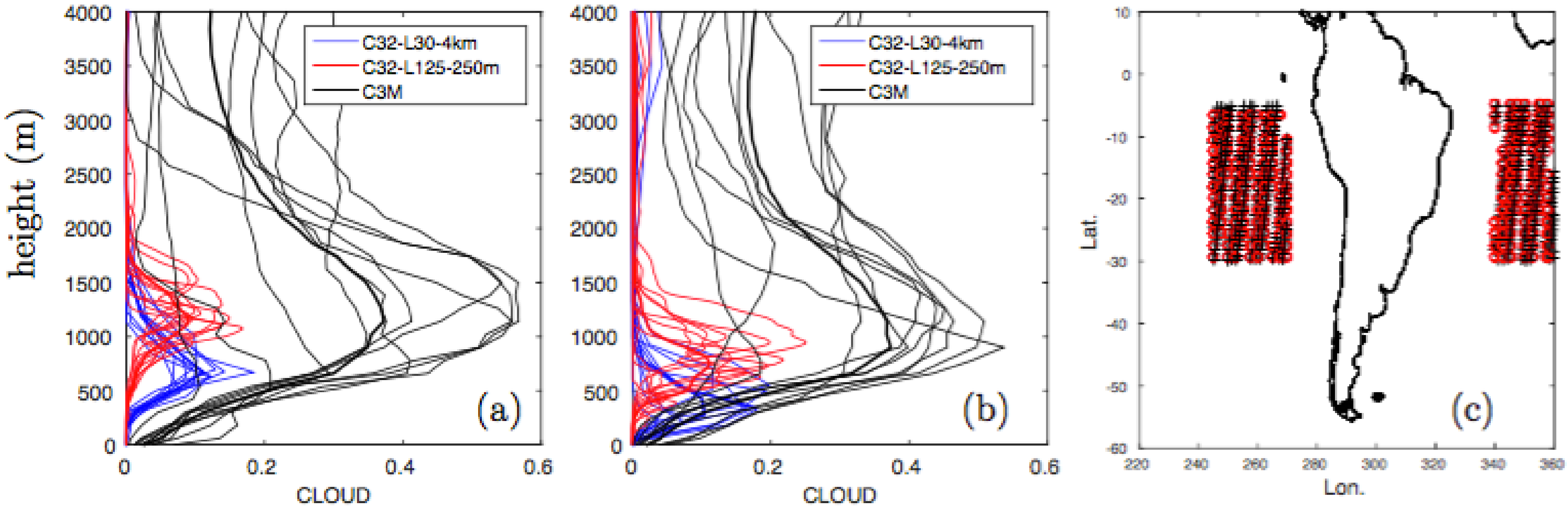


SP updrafts too weak



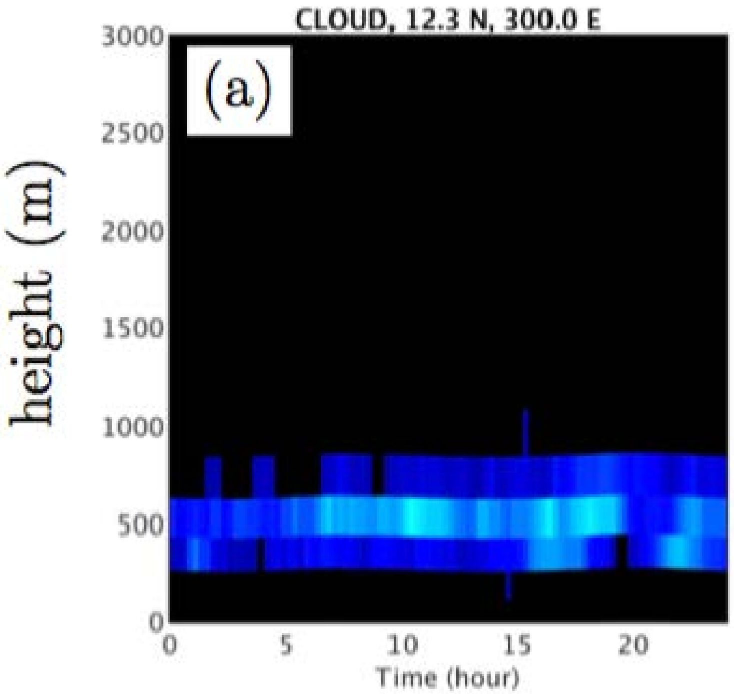
Realistic diurnal cycle of turbulence
UP updrafts even a bit too strong

UP realistically lifts PBL cloud compared to SP

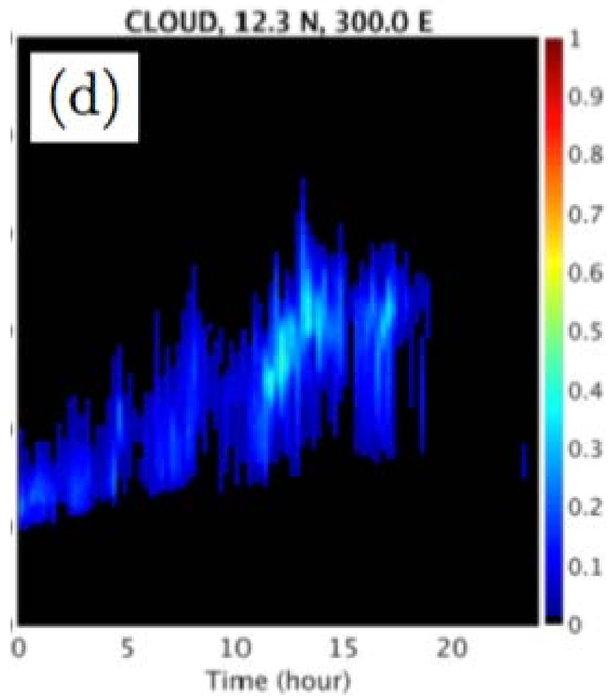


UP gives better shallow Cu structure too

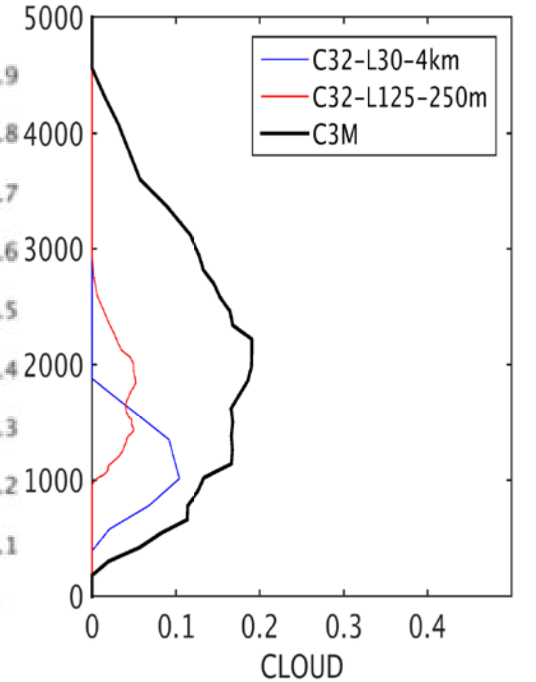
SP 10/15



UP 10/15

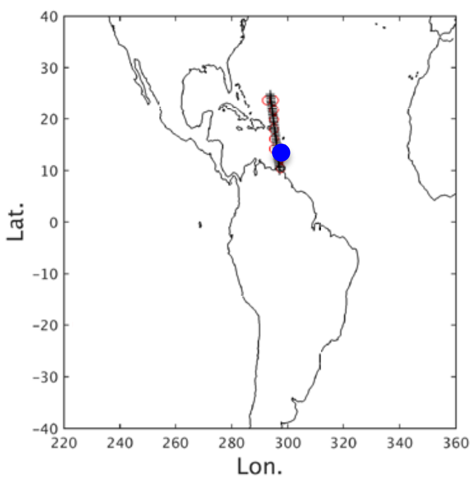


vs. C3M SEP swaths

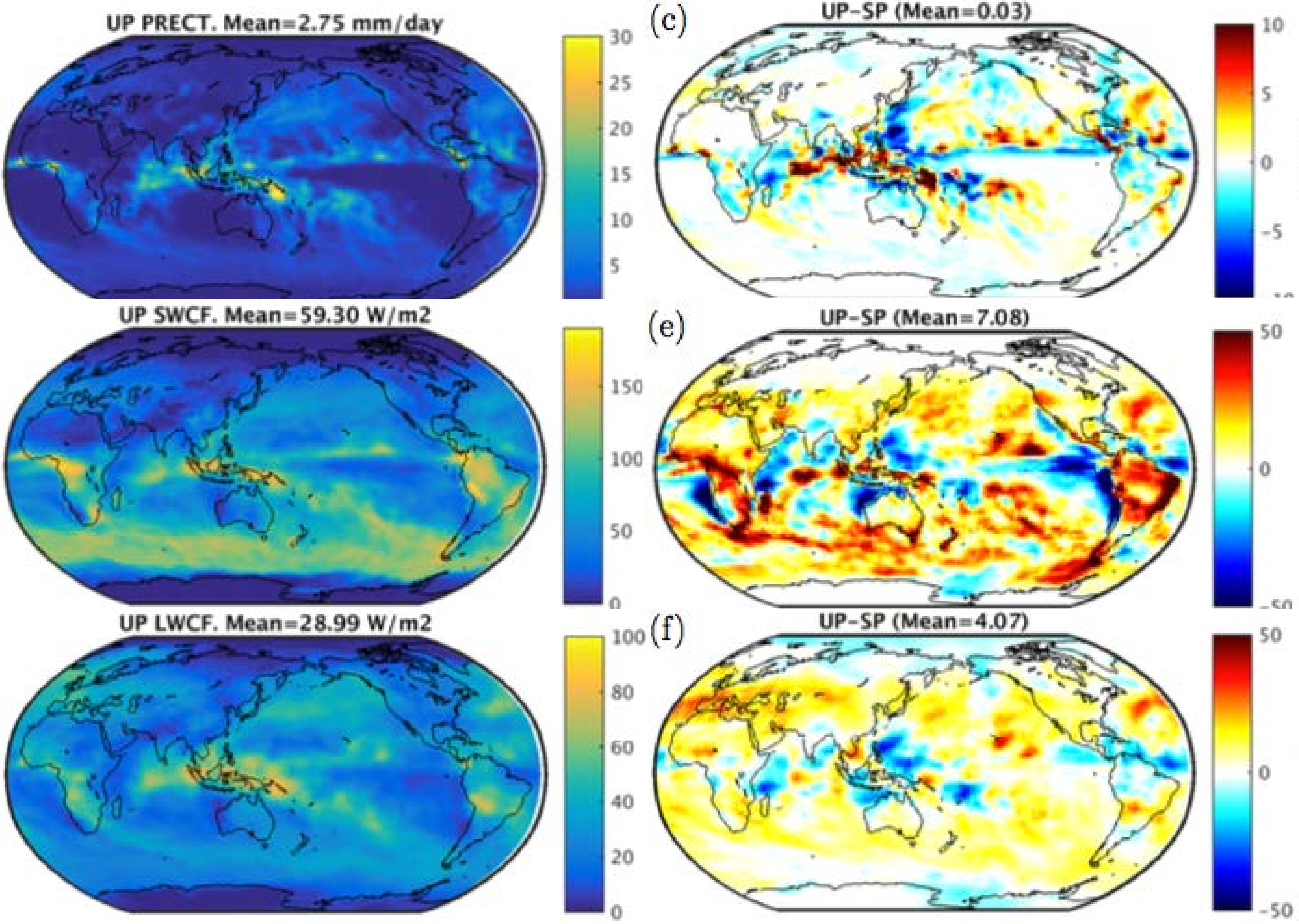


SP cumuli low and shallow

UP cumuli realistically deep

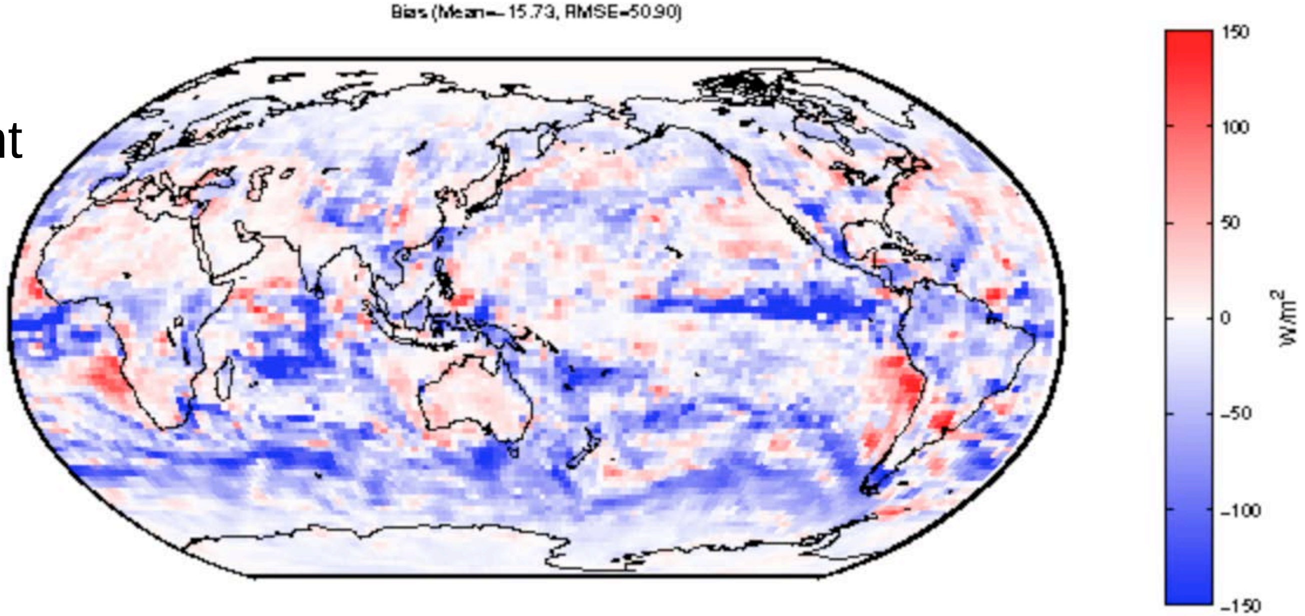


A 90-day UP simulation stays on planet Earth



UP adventures with aerosol-aware microphysics

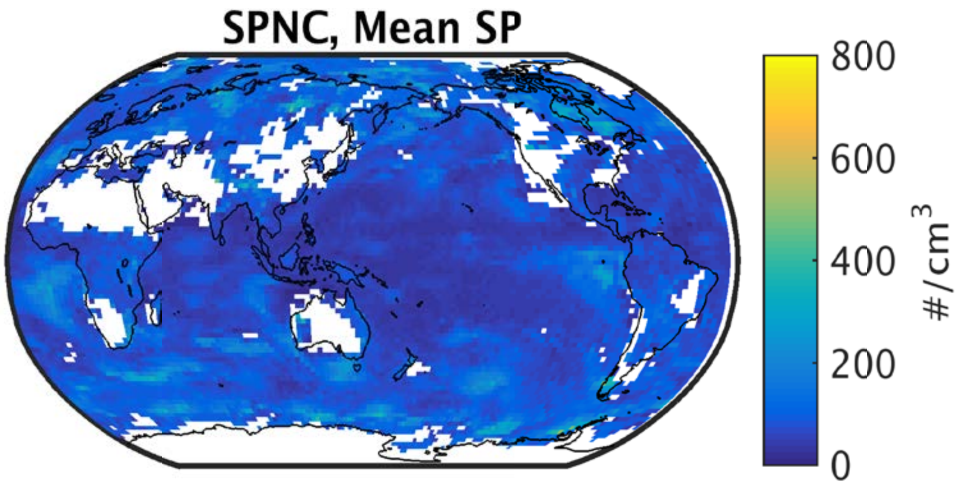
Morrison 2-moment w. nucleation of CAM5 specified aerosol

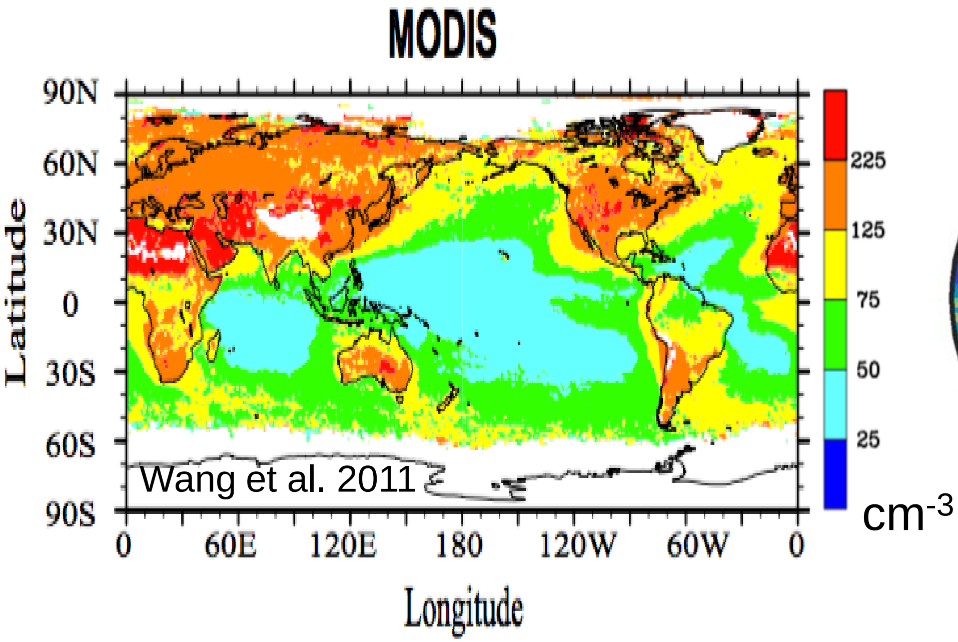


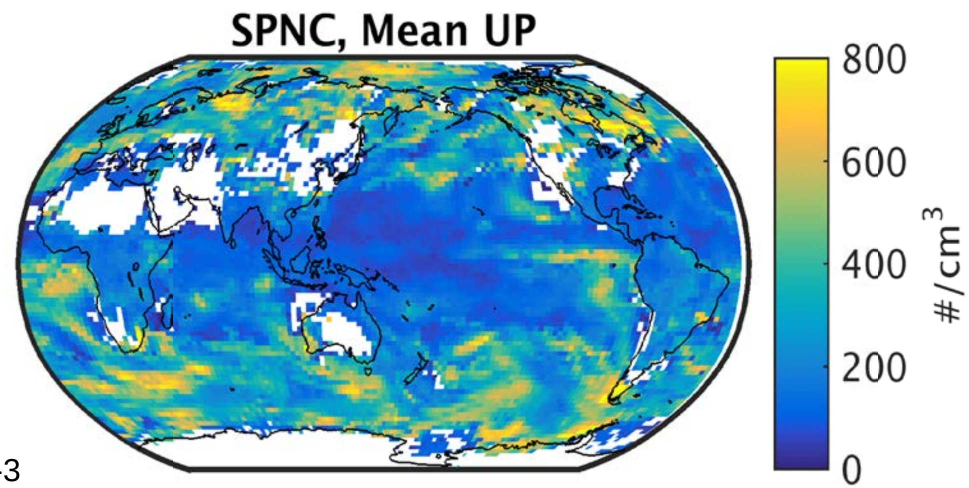
12-36 hr SWCRE bias, Oct. 15 2008 hindcast shows a strong bright bias in Southern Ocean cloud

Cloud droplet nucleation in Morrison 2-mom UP version

- UP-2mom greatly overestimates cloud droplet conc compared to SP, MODIS obs, esp. in midlats.
- This creates the strong Southern Ocean bright bias







Outlook

- Computationally feasible ultraparameterization implementation gives good global cloud and radiation distribution.
- Better vertical structure of boundary-layer clouds than SP, but doesn't maintain enough coastal stratocumulus.
- We plan year-long control, +4K SST, perturbed-CO_2 simulations in 2017 with 1-moment microphys (cloud feedback).
- Need to revisit aerosol overactivation with 2-moment microphys to make UP usable for simulating cloud-aerosol interaction.