Towards explicit low clouds in global climate models using Ultra-Parameterized CAM5
Impact of the resolution in the grey zone

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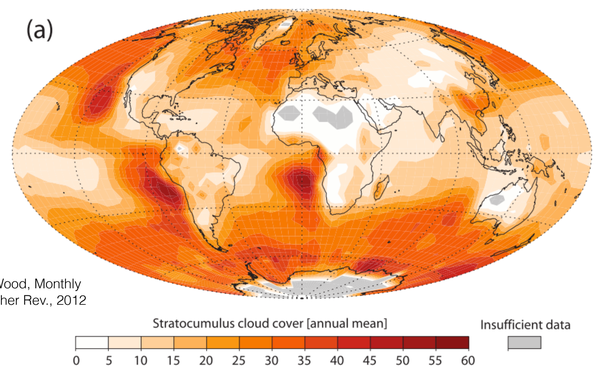
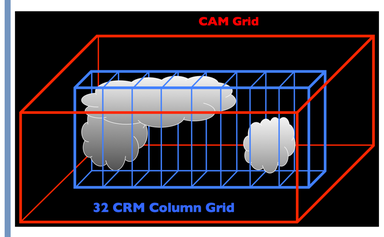
Motivation

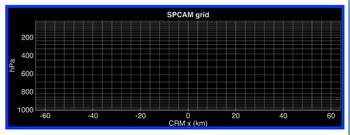
Low clouds play a key role in regulating the global radiation budget:



Simulating shallow clouds is a long standing problem: "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

Super-parameterization is a scalable multi-scale modeling approach to improve subgrid cloud processes by replacing statistical cloud parameterization with high-resolution CRMs in GCMs.





30 levels, 4km horizontal resolution

The problem is regular SP cannot capture the low clouds. Shallow clouds require an even higher resolution grid. Why?

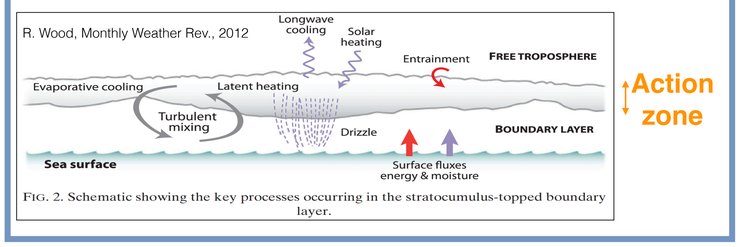
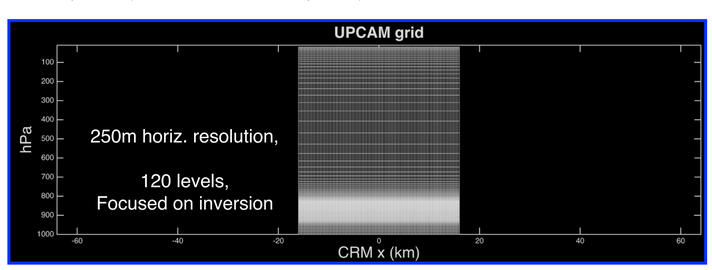


FIG. 2. Schematic showing the key processes occurring in the stratocumulus-topped boundary layer.

Approach: Ultra-parameterization

- Build on SPCAM (available infrastructure).
- Introduce a high resolution CRM grid: 120 levels with 250m horizontal resolution.
- Requires 10x refinement of time step dt.
- Overall **O(200x)** more computational cost.
- Developed strategies to make this huge overhead affordable on todays computers (not discussed in this poster).



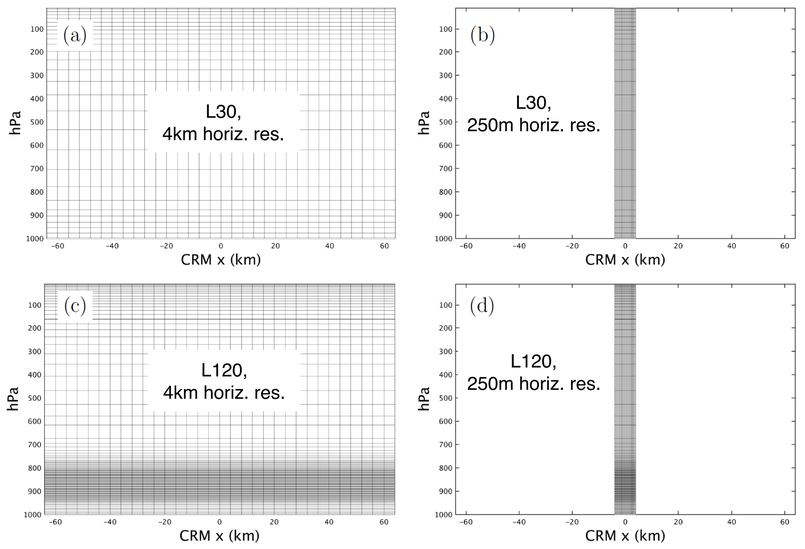
Offline LES tests (not shown) using DYCOMS case show this CRM resolution (despite being coarse by LES standards) can capture reasonable LWP in offline simulations.

Glossary

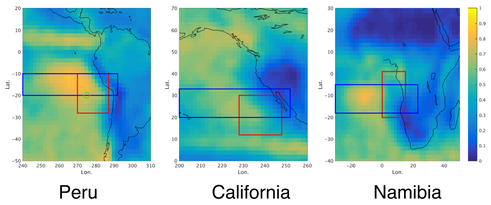
CRM: cloud resolving model
GCM: general circulation model
SW: shortwave radiation
SST: sea surface temperature
SPCAM: Super-parameterized Community Atmosphere Model
LWP: liquid water path

Experiment Design

Using SP and UPCAM, we study the systematic effects of the CRM horizontal and vertical resolution on low clouds. Our "square" experiment is designed using these 4 grids for CRM:

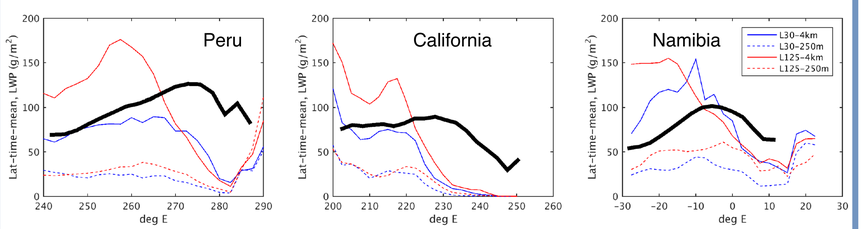


1-day AMIP style global simulations
Start date: 2008/10/15.
Prescribed SST and aerosols.
Target three shallow cloud regions.

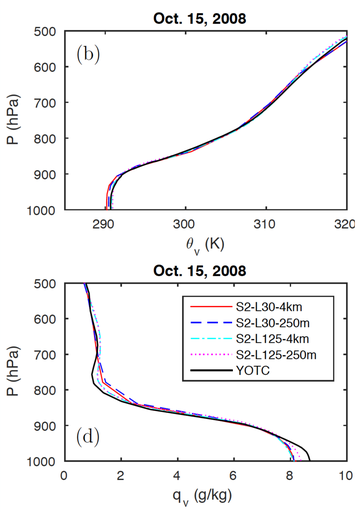


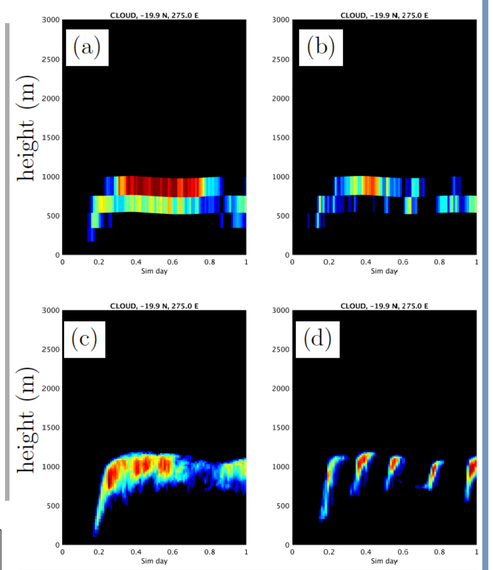
Results

High horizontal resolution causes a significant drop in cloud water / LWP over all low cloud regions.



Why is this happening?



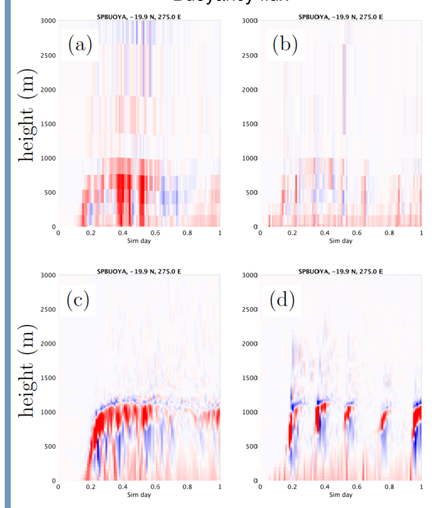


- The thermodynamic profiles (potential temp. and specific humidity) are realistic in all experiments.
- L125 better captures the temperature and humidity at inversion.
- Model slightly drier close to surface independent of the resolution.

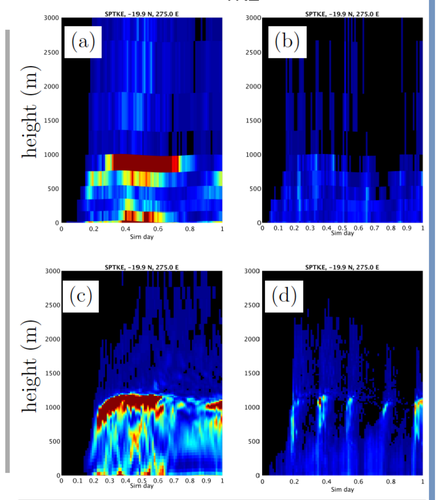
- At high res. (panel d): Boundary layer top and cloud liquid are oscillatory, with accelerated inversion rise indicative of a chronically over-entraining BL.
- Combination of high vertical resolution and low horizontal resolution is capable of representing the low clouds realistically.

Results

Buoyancy flux



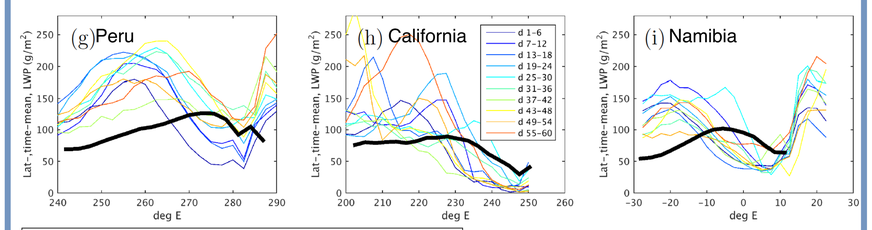
TKE



- Surface flux anomaly is unlikely to be driving the shallow cloud biases (not shown).
- Higher resolution capture more satisfying vertically decoupled boundary layer. Standard SP produces an unrealistically well mixed MBL.

- High horizontal resolution causes a significant drop in the resolved TKE.
- Shift in TKE to subgrid scale. Difficult to quantify *a priori* because the turbulence scales fall in the "grey zone".

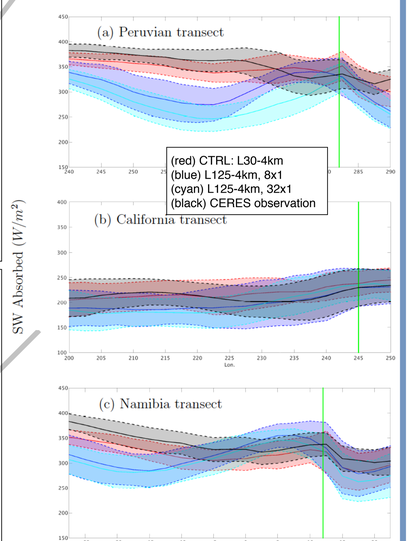
Extended Simulations



2-month sims: Oct. 15 to Dec. 14, 2008 with 4km horizontal resolution.

- L120-4km setup captures a realistic LWP over the Sc region, however the clouds are still not dense enough.
- High vertical res. brings a positive LWP bias in the bright trade region, i.e. overproduction of Cu clouds suggesting UP would be best used in tandem with other CRM strategies in non-Sc zones.

- The high vertical resolution, combined with coarse horizontal resolution captures the shortwave absorbed off the coast of the low cloud regions. However …
- High vertical resolution amplifies the model radiative bias in trade cumulus region (more intense bright trade bias).
- Most striking effects of high resolution can be seen equivalently in 8x1 and 32x1 domains, allowing efficient sensitivity testing in a "micro-CRM" setup.



Take home message

1. **Increase in vertical and horizontal resolution of CRM produces a a mixture of desired and unindented effects for low clouds, therefore …**
2. **Combination of high vertical resolution and low horizontal resolution is suggested as a potential strategy for explicit simulation of low clouds in multi scale GCMs that hedges against unintended effects.**
3. **A high CRM horizontal resolution leads to cloud top over-entrainment and hence dissipation of low clouds.**
4. **Causes of over-entrainment at high horizontal resolution is unknown. Sensitivity tests show this issue is independent of surface flux feedbacks, GCM viscosity, SGS schemes, dycore formulation, and GCM horizontal resolution (not shown). An unintended GCM/CRM interaction may be to blame.**
5. **Unsurprisingly, a small domain with LES-scale resolution underperforms for bright trade region and deep convection; High resolution SP for low clouds will only work if posed in combination with multiple CRMs where others are tuned for deeper cloud regimes.**
6. **More details: Parishani et al., Towards low cloud-permitting cloud super-parameterization, will be submitted to JAMES, 2016.**