Effects of cloud superparameterization at the land-atmosphere interface

Mike Pritchard
Assistant Professor
University of California, Irvine

Acknowledging UCI researchers:
Jian Sun, Hossein Parishani, and Gabe Kooperman
Cloud superparameterization

Latitude – 1.9° ~ 200 km

Longitude – 2.5°

CRM

32 CRM columns x 4 km = 128 km
Examples of progress using superparameterized algorithms in fixing long-standing problems linked to deep convection.

- More realistic intensity distribution of rainfall
- Missing weather patterns emerge
  - Central US mesoscale convective systems
  - The Madden-Julian Oscillation
Energy limitations are morphing supercomputers in new ways. 

*Power density / cooling demands of multi-core systems hitting a limit.*

Source: Kogge and Shalf, IEEE CISE

Courtesy of Horst Simon, LBNL
Serial CPU clock speeds are not increasing.

Source: Kogge and Shalf, IEEE CISE
Courtesy of Horst Simon, LBNL
Superparameterization is well situated to exploit new emerging forms of co-processor computing power.

- Communication bottlenecks often limit access to new forms of co-processor computing power.

- Especially for climate simulation, which involves a lot of communication.

- Superparameterization is an unusually low-communication algorithm.

- Serious potential to computationally expand the paradigm.
How can super-parameterization impact land-surface energy exchange?
Part I.

Assessment of land-atmosphere coupling in SPCAM3.5 versus CAM3.5

Sun and Pritchard, in review for JAMES
Simulations

- SPCAM v3.5 versus CAM v3.5
- 20-year AMIP simulations; SSTs prescribed.
- ~2.5 degree global resolution.
- In SPCAM, embedded cloud-resolving models with 8 CRM columns spaced 4 km apart.
Terrestrial segment.
Terrestrial coupling index (Dirmeyer 2011)

\[ I_\phi = S_{w\beta_\phi} \]

soil water variability

regression slope vs. soil water

JJA “ILH” from the Global Soil Wetness Project GSWP-2
Effect of superparameterization on “ILH” during JJA

Sun and Pritchard, in review
Several favorable regional effects.
Removal of unrealistic coupling across Northern Africa, Middle East; enhanced coupling contrast across ITCZ.

JJA  SP-CAM  CAM

Dirmeyer (2011) GSWP v2
Enhanced negative coupling over Central / Eastern China.

JJA  SP-CAM  CAM

JJA  GSWP v2  Dirmeyer (2011)
Enhanced wet season negative tropical rainforest coupling

Dirmeyer (2011) GSWP v2 Dirmeyer (2011)
Atmospheric segment.
Triggering Feedback Strength (Findell et al. 2011)

\[ TFS = \sigma_{EF} \frac{\partial \Gamma(r)}{\partial EF} \]

- Probability of afternoon rainfall occurrence
- Morning evaporative fraction variability

"TFS" from the North American Regional Reanalysis:
Superparameterization reduces the triggering feedback strength (TFS).
More realistic land-atmosphere triggering over US.

SP-CAM

CAM

NARR  Findell et al. 2011
Introducing: “PBL Feedback Strength”  
(Sun and Pritchard, in review)

\[ PFS_{PBLH} = \sigma_{EF} \cdot \frac{PBLH}{\delta EF} \]

- Mean afternoon PBL height
- Morning evaporative fraction
- Evaporative Fraction variability
$PFS_{LCL}$
In CAM, a disconnect between convective triggering versus PBL sensitivity to morning evaporative fraction.
Part II.

An unintended effect of superparameterization at the land interface revealed by ARM data.

*Pritchard et al, in prep*
Bettsian mixing diagrams following the LoCo (“local coupling”) approach of Santanello et al.

- For a given time step, plot 2m T&Q in energy space;
- Surface vector can be calculated with PBL height, $H_{sfc}$ and $LE_{sfc}$;
- Residual vector then can be derived from the T-Q trajectory and surface vector, which represent the atmospheric response including entrainment, advection, etc.
Composite mixing diagrams for models versus ARM SGP.

Climatological diurnal cycle from 15 independent realizations of JJA.
The spurious 2-m moisture cycle is not unique to SGP.
PBL-integrated energetics tell a different story than 2-m mixing diagrams, suggesting it is not a fundamental change in entrainment dynamics.

2-m state is not a robust proxy for whole-PBL model differences in LoCo mixing diagrams.
Implies problem is close to the surface.
Vertically resolved humidity tendency vs. data highlights key symptom:

- Unobserved early morning surface moistening.
- Followed by strong late morning drying.
The essence of the bias can be reproduced in short hindcast simulations, which opens the door to understanding it.

(5-day 6/20/1997 hindcast, all land grid points 20S-60N)
What causes the spurious moisture bump?

H1: Insufficient CRM resolution
Motivation:
Known artifacts of coarse cloud resolving resolution.
WRF-LES convergence tests of continental PBL development at a

LES (50-m dx)  CRM (1 km dx)

Insufficient dx linked to familiar surface-amplified morning bias

Figures from Jason Simon, Civil Engineering, Berkeley — AGU 2015 poster.
What causes the spurious moisture bump?

H1: Insufficient CRM resolution

Expect: Radically higher CRM resolution removes the bump.
Standard superparameterization grid structure

SPCAM grid

128 km

dx ~ 4 km

30 levels
"Ultraparameterization"

UPCAM grid

dx ~ 250 m
dz ~ 20 m

120 levels

(Now affordable for 5-day hindcasts)
Insensitivity to cloud-resolving resolution.
What causes the spurious moisture bump?

H1: Insufficient CRM resolution

X
Clue: bump is associated with surface flux magnitude.
What causes the spurious moisture bump?

H1: Insufficient CRM resolution

X

Sensitive to surface flux screening

H2: Something is wrong with the way surface fluxes are transmitted to the CRM

X
Context.

Standard CAM boundary layer parameterization:

Step 1:
Apply surface fluxes to lowest model layer

Step 2:
Apply countergradient terms from turbulent diffusion parameterization to spread fluxes vertically.
In the context of the greater integration circuit.

- Fluxes from land model
- Conventional boundary layer diffusion parameterization
- Moist convection parameterization
- Hydrostatic dynamics
- Net physics tendency
In the context of the greater integration circuit.
When superparameterization is used…

…cloud resolving models replace PBL and moist convection parameterizations.

…surface fluxes felt by CRM via retained initial perturbation on lowest model layer in BL scheme.

This would be fine **except that**…
**Problem:** Dynamics is called in between PBL and superparameterization in SPCAM.

- Conventional boundary layer diffusion parameterization
- Fluxes from land model
- Hydrostatic dynamics
- Net physics tendency

**Underlying problem:** Hydrostatic dycore feels undesirable tendency.

Consistent with a near-surface symptom output.
Potential fix: Wait to apply surface fluxes.

Ensures dycore receives a complete physics tendency

The spurious bump disappears
Consistent with expectation, bump disappears.
What causes the spurious moisture bump?

H1: Insufficient CRM resolution

X

Unintended order of flux / dynamic adjustment operations found

Correcting it removes the moisture bump symptom

H2: Something is wrong with the way surface fluxes are transmitted to the CRM

✔
Underlying problem in SPCAM:
Hydrostatic dycore feels undesirable tendency.

Fluxes from land model

Net physics tendency

New Question:
How has this limited the potential of previous SPCAM simulations?

Conventional boundary layer diffusion parameterization

How does correcting the problem impact
Supermonsoons?
The Great Red Spot?
The MJO?
The daily cycle of rainfall?
Promising changes in coastal low cloud fraction
Stay tuned!
Meanwhile, ARM data & CAPT hindcasts point to value of vertical resolution and issues of chronic daytime overentrainment.

**Humidity evolution, June 1997 hindcast @ SGP**

**CAM**

**SPCAM 8x1**

**UltraCAM 8x8 (hi-res helps)**

**MERGESONDE DATA**

Local solar time
Summary.
Favorable effects of super parameterization on land-atmosphere coupling.

- **Terrestrial segment:**
  - Reduced N. African, Middle-East positive JJA coupling; enhanced cross-ITCZ contrast; enhanced E. China JJA negative coupling; enhanced DJF rainforest negative coupling.

- **Atmospheric segment:**
  - Probability of afternoon rainfall less sensitive to surface state in inappropriate regions.
  - Synchrony emerges across rainfall triggering, PBL height and LCL sensitivities to surface wetness.
ARM data is proving quite useful for improving superparameterized climate models.

- Mixing diagram analysis at the SGP site turned up a spurious near-surface moisture cycle in SPCAM.

- Symptom of underlying issue in how surface fluxes are transmitted to its cloud resolving models.

- Inadvertently exposes the dynamical core to an incompletely adjusted subgrid physics tendency.

- This may have limited the potential of all previous SPCAM simulations.
Thanks.