Effects of cloud superparameterization at the land-atmosphere interface

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1. Motivation, questions and strategy

Explicit convection can modify physics of land-atmosphere interaction (Hohenegger et al. 2009). Yet the consequences of using cloud superparameterization (SP) for simulating the land/atmosphere interface in climate models have not been deeply explored.

We have recently found that SP modifies the rainfall Triggering Feedback Strength (TFS; Findell et al. 2011) over North America and that SP amplifies the global Bowen ratio and its rate of increase under climate change simulations. **Understanding why requires process level analysis on the diurnal timescale of flux partitioning / PBL feedback**.

Questions: How does SP modify diurnal PBL energetics of the mean summer day? Does SP modify the sensitivity of PBL energetics to land surface conditions?

Strategy: Apply a Bettsian mixing diagram approach under the LoCo philosophy of Santanello et al. (2009). Compare climatologies of the mean summer day in SPCAM vs. CAM simulations globally & against ARM Best-estimate data at SGP.

Models: SPCAM3.5 and CAM3.5; semi-Lagrangian T42 exterior resolution; default 32-column / 4km interior resolution for its cloud resolving models; analysis of 15-year simulations. **Data:** ARM SGP Best-Estimate and MERGESONDE products.

2. SP adds curvature to LoCo 2-m mixing diagrams

Systematic effect observed over multiple land surfaces -- a stronger moistening/drying diurnal cycle in SPCAM than in CAM.

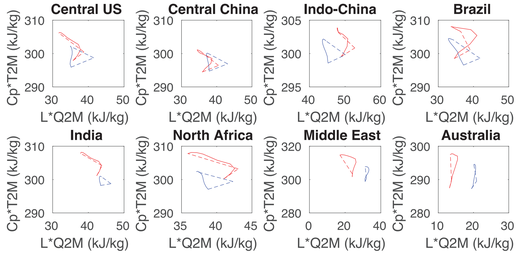

Fig. 1: LoCo mixing diagrams for JJA mean summer day for (red) SPCAM vs. (blue) CAM.

3. Details at ARM SGP imply SP alters atmospheric resonse vector.

SP introduces a desirous but exaggerated counterclockwise rotation of the 2-m atmospheric response vector in the q-T plane, from a morning heating- to afternoon drying-dominated regime.

Relative to ARM data, the diurnal moisture cycle is too extreme in SP, and an unrealistic "atmospheric response" of early morning moistening occurs.

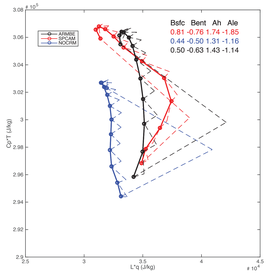

Fig. 2a: Hourly decompositon of LoCo mixing diagram from 2-meter T and Q at ARM SGP site in models and data.

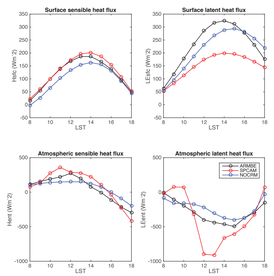

Fig. 2b: Diurnal cycle of each component in the surface and 2-m atmospheric response vectors shown at left.

4. ..But actual bulk PBL energetics are insensitive to SP, 2-m state in LoCo is not a robust proxy for bulk PBL.

To ease comparison with data, the LoCo framework uses 2-meter conditions as a proxy for the bulk PBL.

But explicitly integrating PBL conditions tells a different story. Comparing Figs. 1 & 3, the bulk PBL does not exhibit the systematic sensitivity to SP seen in Fig. 1, implying it is mostly a near-surface effect.

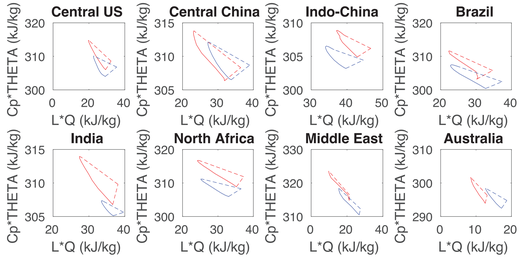

Fig. 3: As in Fig. 1 but using explicitly integrated PBL mean heat and moisture.

5. Robust effects of SP on near-surface PBL diurnal dynamics.

A Striking effects of SP mostly confined to the surface; enhanced heat & moisture contrast between lowest and overlying model levels.

B SP introduces observed late morning surface-amplified drying, but rate is 2X too strong.

C SP introduces unobserved early morning near-surface moistening -- latent heat fluxes vertically "trapped" to only moisten the lowest model level during the early morning?

D In SP, early morning sensible heating is trapped in the lowest model level leading to exaggerated near-surface heating rates.

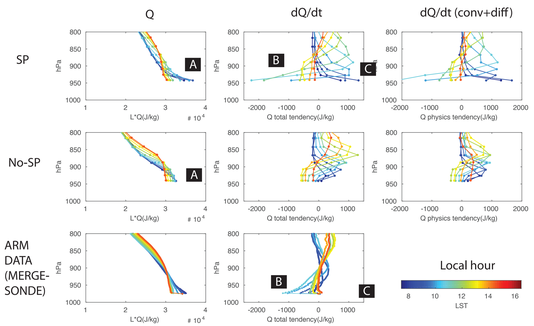

Fig. 4: Mean diurnal cycle at SGP of (left) PBL moisture, (center) its tendency and (right) the tendency due to moist convection plus vertical diffusion.

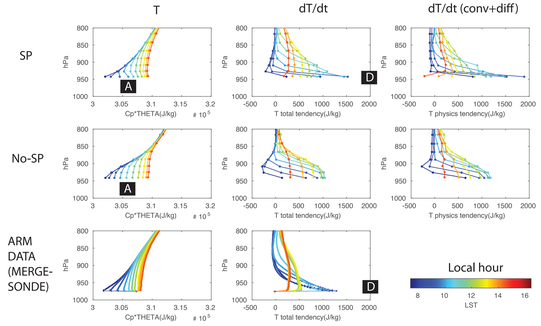

Fig. 5: As in Fig. 4 but for the PBL heat content at SGP.

6. SP doesn't modify PBL sensivity to land surface moisture.

Explicit convection has the capacity to alter land-atmosphere feedback under certain meteorological regimes due to exotic entrainment feedbacks affecting PBL dynamics.

However, this does not lead to major emergent effects distinguishing the SPCAM. The sensitivity of bulk PBL diurnal energetics to land surface evaporative fraction in SPCAM mostly resembles that in CAM.

One regional effect of SP over the Central US is reducing the mean PBL moisture sensitivity to EF.

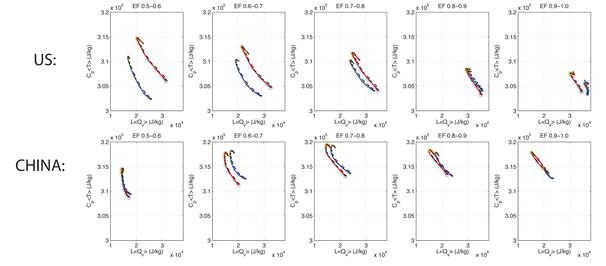

Fig. 6: Explicitly integrated PBL-mean mixing diagrams in (red) SPCAM and (blue) CAM binned by evaporative fraction EF for grid points at (top) Central US and (bottom) Central China.

7. Take-home points

- We discover cloud superparameterization (SP) does not systematically modify bulk diurnal PBL energetics nor the atmospheric segment of land-atmosphere coupling as measured by the EF-sensitivity of diurnal PBL energetics.
  - Although one regional effect is to reduce the mean PBL moisture sensitivity to EF over the Central US.
- We discover new effects of SP on near-surface diurnal variability in the PBL over most land surfaces:
  - SP strongly amplifies diurnal heating and especially moistening in the model layer immediately adjacent to the land surface. The lowest model level's state properties are less tightly coupled to overlying model levels than in the conventionally parameterized CAM.
  - Trapping of early morning surface fluxes in the lowest model layer of the cloud resolving models occurs.
  - Compared to ARM data, the early morning moistening in SPCAM is unrealistic but the emergence of late morning surface-amplified drying is an improvement on the conventional CAM, albeit too exaggerated.
- Regarding the Lo-Co model intercomparison methodology of Santanello et al. (2009):
  - Caution is advised in interpreting 2-m T and q as a proxy for PBL-integrated energetics.
  - Unfolding hourly time resolution in the surface/atmosphere decomposition method can be helpful; for us it helped fingerprint origins of an important near-surface effect of superparameterization on the PBL state.

References:

Findell et al. (2011), Probability of afternoon precipitation in eastern United States and Mexico enhanced. *Nature Geoscience*, 4, 434-439.

Hohenegger et al. (2009),The soil moisture–precipitation feedback in simulations with explicit and parameterized convection. J. Clim. 22 (19), 5003–5020.

Santanello et al. (2009), A modeling and observational framework for diagnosing local land-atmosphere coupling on diurnal time scales, *J. HydroM.*, 10, 577-599.

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