The impact of surface heterogeneities and land–atmosphere interactions on shallow clouds over ARM SGP site

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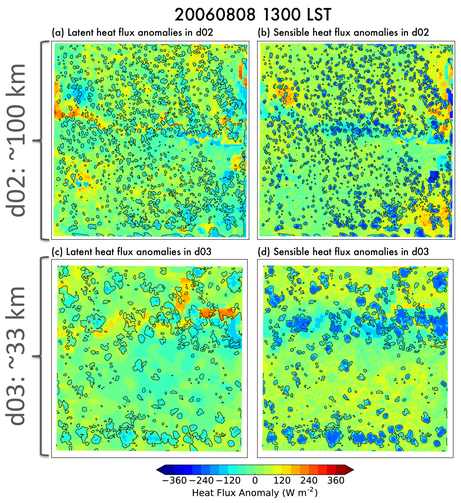
Motivation

How much do subgrid-scale land-atmosphere interactions affect the simulation of grid-mean cloud cover and liquid water content of shallow clouds in regions like central U.S. and Amazon in climate models?

Approach

- We performed **nested WRF LESs** of summertime shallow convection over ARM SGP with interactive land surface (Noah model) and realistic initial/boundary conditions. (**CONTROL**)
- A 3-nest setup is used. The two inner domains (d02 and d03) are LES domains and comparable in size to typical climate model grid boxes.



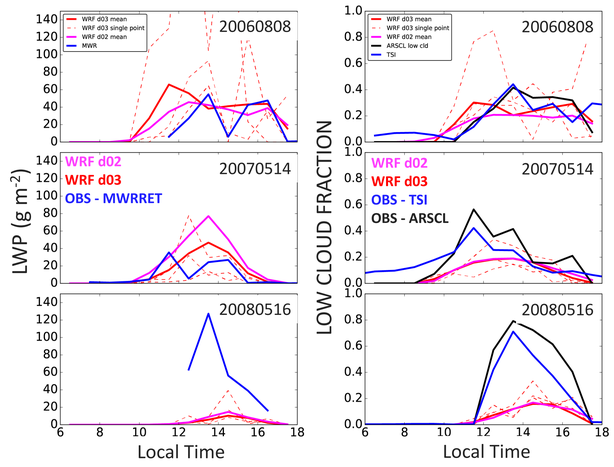
Simulated surface latent (left) and sensible (right) heat flux heterogeneities in the two inner LES domains (dx=300 and 100 m).

Note the cloud shading effect (black contours for cloud LWP=10 g m^{-2})

- A set of experiments were performed where we artificially **smooth out (by averaging) heterogeneities in surface incoming long and short-wave radiation (AVE_SFC_RAD) or latent and sensible heat fluxes (AVE_SFC_HEAT)** in the LES domain.
- These averaging experiments were then compared to CONTROL and to "transparent clouds" experiments **(TRANSPARENT_CLD) where cloud radiative effects are completely turned off.**

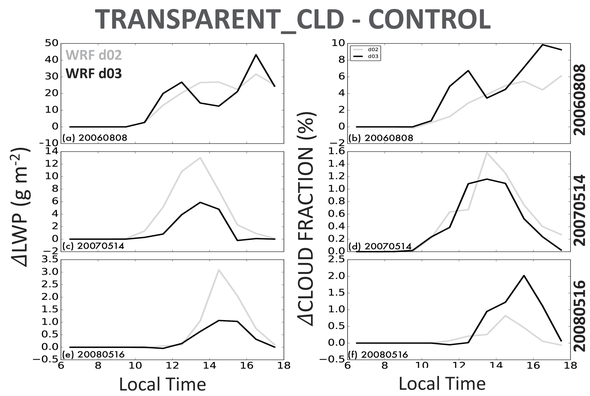
Control simulations

- Three cases are examined:
  Aug 8, 2006, BR=~1.68, ~3 m/s sfc wind;
  May 14, 2007, BR=~0.45, >10 m/s sfc wind;
  May 16, 2008, BR=~0.61, 3–5 m/s sfc wind.



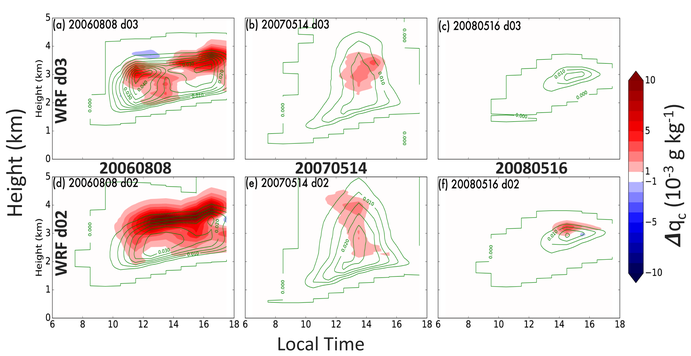
The simulation of May 16, 2008 case underestimates cloud cover and LWP but the simulated vertical extent and duration of shallow clouds are realistic (not shown).

Responses in TRANSPARENT_CLD

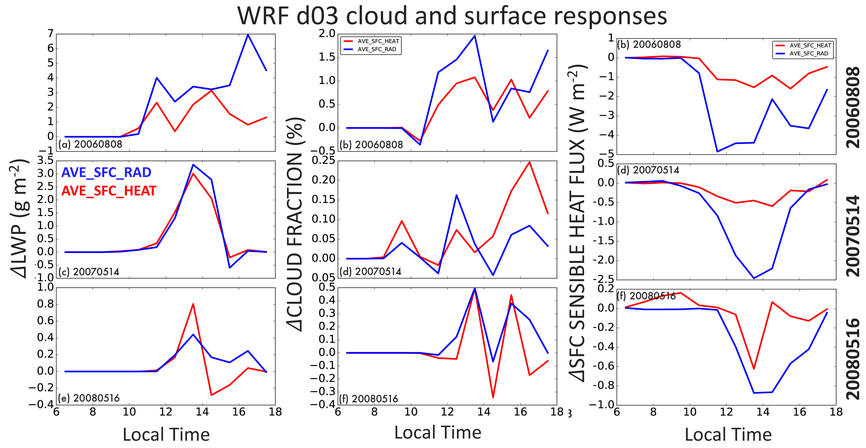


Making shallow clouds transparent removes all the cloud shadows at the surface, increases the mean surface heat fluxes and invigorates shallow convection.

Responses in the averaging experiments

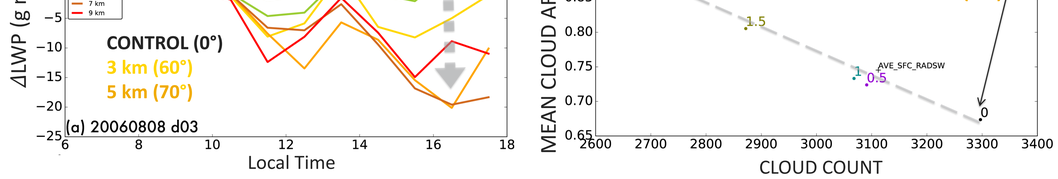


AVE_SFC_RAD – CONTROL shows consistent increase in cloud water content in almost all cases.



- Responses in AVE_SFC_HEAT and AVE_SFC_RAD are comparable in magnitude, suggesting the dominance of cloud shading-induced heterogeneities in our cases. But responses in AVE_SFC_HEAT and AVE_SFC_RAD are smaller than those in TRANSPARENT_CLD.
- Negative mean surface heat flux responses suggest that negative feedbacks through domain-scale land-atmosphere coupling can constrain the impact of land–atmosphere interactions at smaller scales.

Sensitivity to solar incidence angle



We mimic the condition of non-zero solar incidence angle by horizontally shifting downward solar radiation at the surface by a certain distance. The response in AVE_SFC_RAD (SW only) changes sign as solar incidence angle increases.

With non-zero solar incidence angles, cloud shadows at the surface are shifted away from directly under the clouds. This favors more vigorous cloud-scale circulation and increases cloud size and cloud water content.

Summary

- Cloud shadows at the surface have a clear impact on the strength of shallow convection and shallow cloud water content under realistic winds and surface conditions. This impact depends sensitively on the solar incidence angle.
- For a climate model grid box, subgrid-scale heterogeneities induced by cloud shadows can be as important as those due to more static features in land use/cover or soil temperature/moisture for the simulation of grid mean shallow cloud properties.

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