The lack of Impact of Heterogeneous Surface Solar Heating on Continental Shallow Cumulus Clouds

Jake J. Gristey (Jake.J.Gristey@noaa.gov)[1,2,3] | Graham Feingold[2] | Wayne M. Angevine[1,2] | Yaosheng Chen[1,2]

[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado Boulder [2]NOAA Chemical Sciences Laboratory (CSL) [3]Laboratory for Atmospheric and Space Physics (LASP), University of Colorado Boulder

Check out my CIRES profile:

Motivation & Aim

- Ubiquitous continental shallow cumulus clouds imprint distinct patterns of solar heating on the surface below.
- All 1300+ simulations of shallow cumulus clouds provided by the LASSO activity were run with prescribed horizontally-uniform surface fluxes. *[LASSO: Large Eddy Simulation (LES) Atmospheric Radiation Measurement (ARM) Symbiotic Simulation and Observation]*
- We run LES of LASSO cases with an interactive land surface model (LSM) to investigate how dynamic, heterogeneous surface solar heating impacts cloud evolution.

Simulation of Shallow Cumulus Clouds with an Interactive Land Surface Model

- LES is run for 14 separate days during the summer of 2018[1] that each develop shallow cumulus clouds at the Southern Great Plains (SGP) Atmospheric Observatory (e.g., Fig. 1).

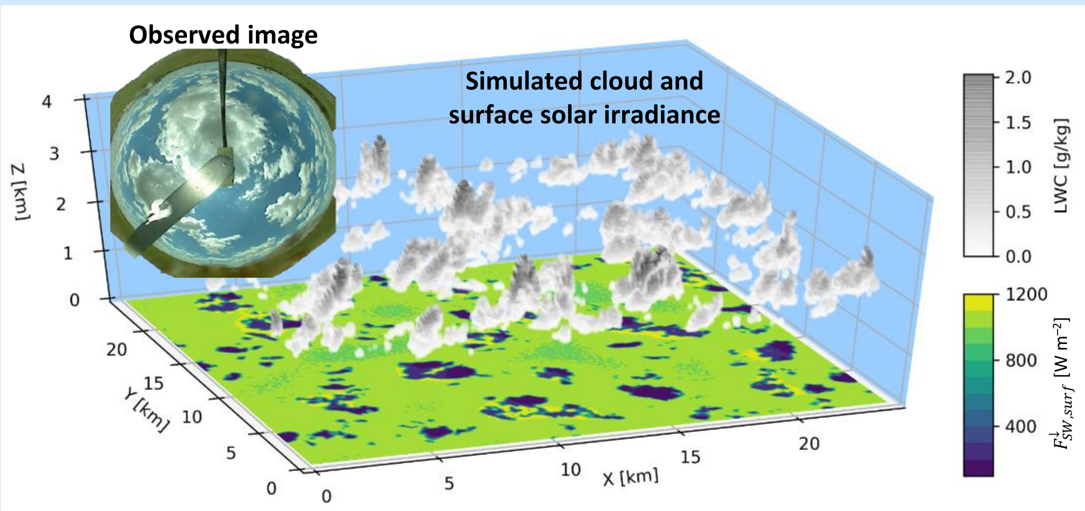


Fig. 1. Simulation of shallow cumulus clouds and associated surface solar irradiance at SGP. An observed total sky image valid at the same location and time is provided for reference in the upper left.

- An interactive LSM[2] is coupled to the LES 1D radiation scheme (RRTMG) to explicitly represent land atmosphere interactions. The LSM is initialized with surface properties observed at SGP extended facilities (Fig. 2).

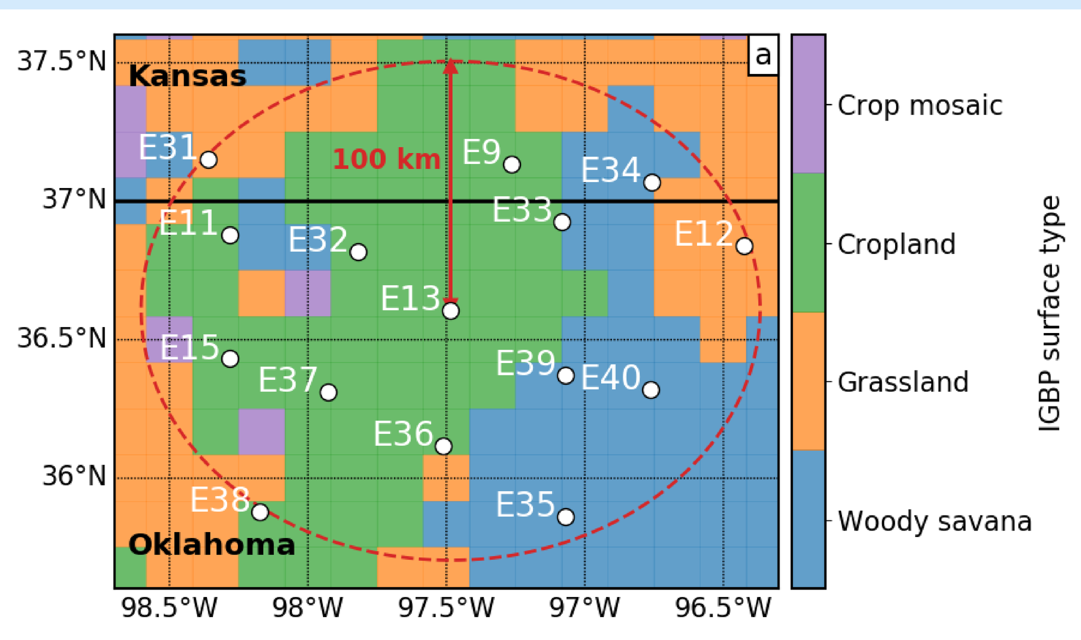


Fig. 2. Map of SGP extended facilities where soil profile data are used. Colors show the International Geosphere-Biosphere Programme (IGBP) surface classification.

Summary

1. Surface solar heating patterns created by shallow cumulus clouds generate dynamic and heterogeneous surface fluxes that large eddy simulations often neglect.
2. A new set of large eddy simulations of shallow cumulus clouds in the Southern Great Plains are run with an interactive land surface model.
3. **In stark contrast to recent published results based on simulations with 3D radiative transfer, we find that dynamic heterogeneities in surface fluxes have limited impact on cloud evolution.**

Case Study of the Impact of an Interactive Land Surface on Cloud Evolution

- Cloud shading modulates the LSM-predicted surface fluxes (Fig. 3).

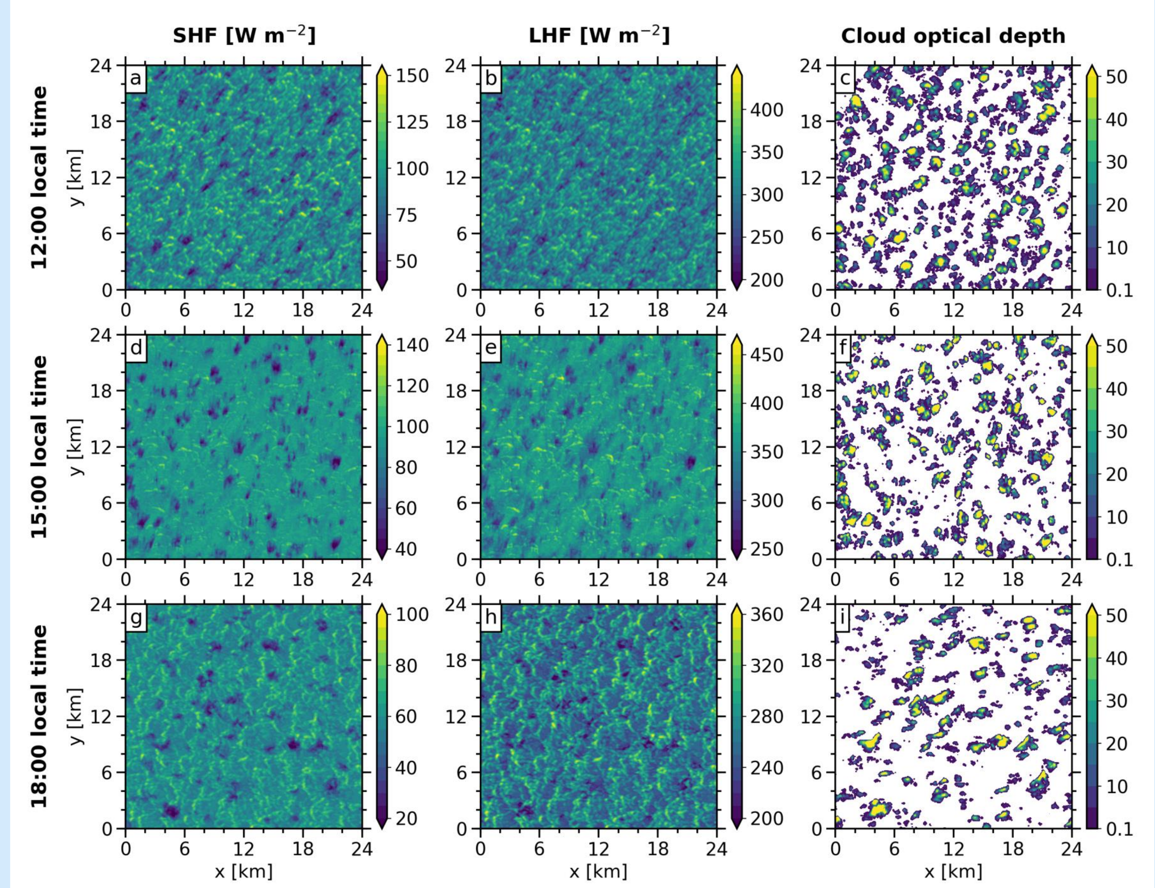


Fig. 3. Simulated fields of (**a**, **d** and **g**) sensible heat flux (SHF), (**b**, **e** and **h**) latent heat flux (LHF), and (**c**, **f** and **i**) visible cloud optical depth at (**a**, **b** and **c**) 1200 CDT, (**d**, **e** and **f**) 1500 CDT, and (**g**, **h** and **i**) 1800 CDT on 22 May 2018 at the SGP site.

- The substantial structure in surface fluxes has very little impact on the evolution of the cloud field, as shown by comparing simulations with interactive and homogenized surface fluxes (Fig. 4 & 5).

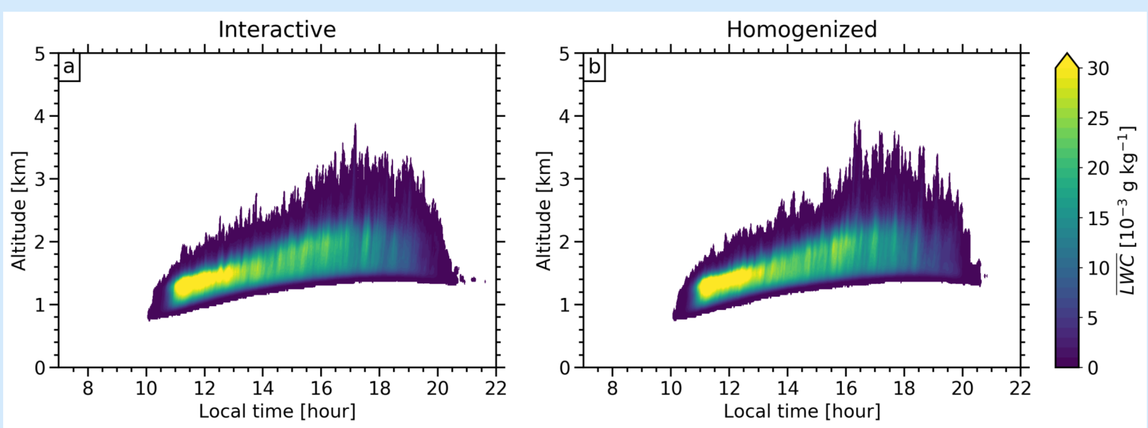


Fig. 4. Diurnal evolution of horizontally-averaged cloud liquid water content ($\overline{LWC}$) for simulations with (**a**) interactive surface fluxes and (**b**) homogenized surface fluxes on 22 May 2018 at the SGP site.

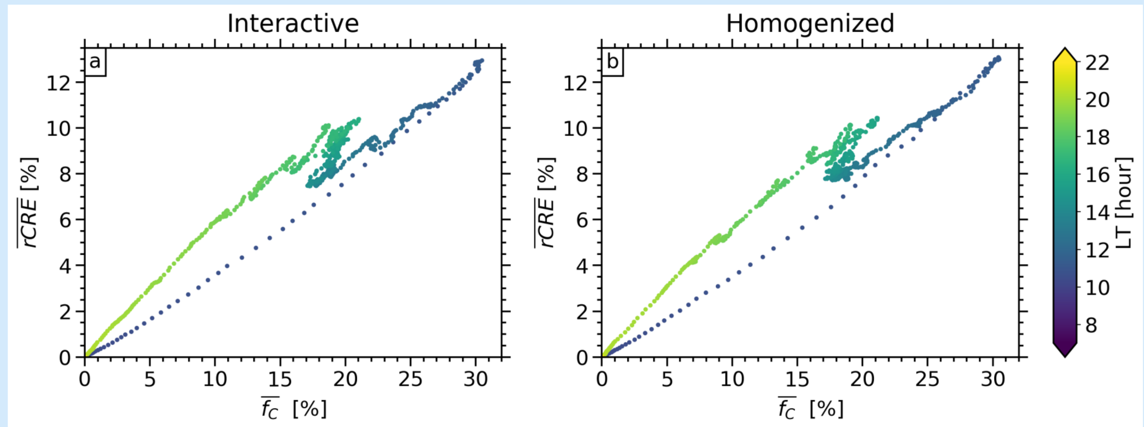
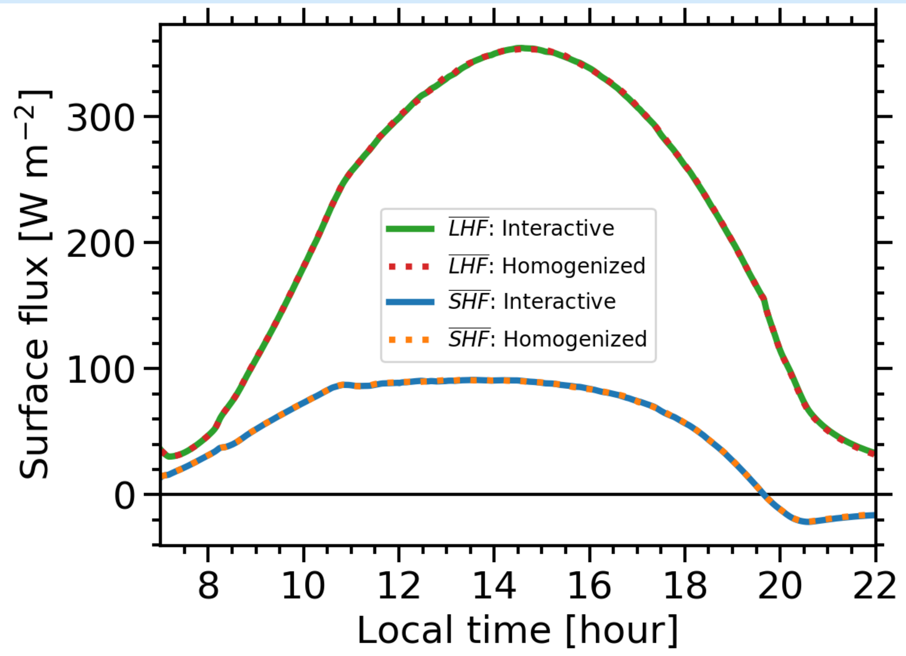


Fig. 5. Diurnal evolution of the relationship between domain-mean cloud fraction ($\overline{f_c}$) and relative cloud radiative effect ($\overline{rCRE}$) for simulations with (**a**) interactive surface fluxes and (**b**) homogenized surface fluxes on 22 May 2018 at the SGP site .

- The LES domain-mean surface fluxes from simulations with interactive and homogenized surface fluxes track each other almost perfectly (Fig. 6). This is not enforced; one might have hypothesized that the cloud fields evolve differently and modulate the domain-averaged surface fluxes differently, but this does not happen

Fig. 6. Diurnal evolution of domain-mean latent heat flux ($\overline{LHF}$) and sensible heat flux ($\overline{SHF}$) for simulations with fully interactive and homogenized surface fluxes on 22 May 2018 at the SGP site.



- Results for this case study have been reproduced for all 14 simulated days and the **findings are robust across all cases**[3].

Simulated vs. Observed Surface Fluxes

- The LSM-predicted surface fluxes show some differences to observations but are generally within the range of observations (Fig. 7).

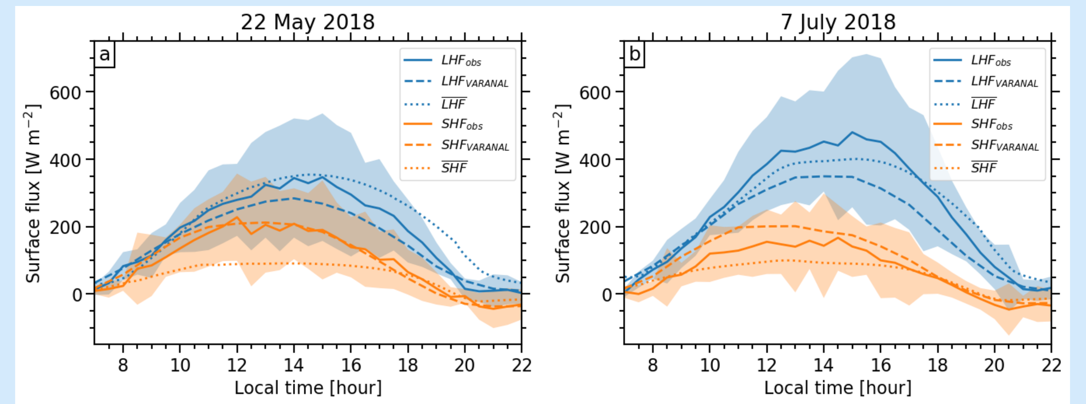


Fig. 7. Diurnal evolution of domain-mean latent heat flux ($\overline{LHF}$) and sensible heat flux ($\overline{SHF}$) for (**a**) the case study day (one of the worst cases), and (**b**) 7 July (one of the better cases). Values are shown for the LSM (dash) and for observations across SGP extended facilities (solid: mean, shading: ±2 standard deviations). Observations are from the best-estimate of the energy balance Bowen ratio and bulk aerodynamic calculations (BAEBBR) value added product.

- Consistency with observations is not strictly required for this model-based study, but this result provides reassurance that LSM-predicted surface fluxes are somewhat realistic.

Future Work

- So far, the LSM is only coupled to the 1D radiation scheme in the LES. Ultimately, we plan to couple the LSM to a new 3D radiation scheme.
- In order to include 3D radiation in a computationally-efficient manner, a 3D radiative transfer emulator for implementation into LES is under development[4].
- The 3D radiation setup will enable us to check if recently reported changes in cloud evolution[5,6] occur for LASSO cases, and will provide better understanding of why the 1D radiation setup reported here shows little difference in cloud evolution.

References

1. Gristey et al., *JGR*, 2022: Influence of aerosol embedded in shallow cumulus cloud fields on the surface solar irradiance. https://doi.org/10.1029/2022JD036822
2. Lee and Khairoutdinov, *JAMES*, 2015: A Simplified Land Model (SLM) for use in cloud-resolving models: Formulation and evaluation. https://doi.org/10.1002/2014MS000419
3. Gristey et al., *in prep.*: Large Eddy Simulation of Shallow Cumulus Clouds in the Southern Great Plains with an Interactive Land Surface Model.
4. Yang et al., *in prep.*: Machine Learning Emulation of 3D Shortwave Radiative Transfer for Shallow Cumulus Cloud Fields.
5. Veerman et al., *JAMES*, 2020: Three-Dimensional Radiative Effects By Shallow Cumulus Clouds on Dynamic Heterogeneities Over a Vegetated Surface. https://doi.org/10.1029/2019MS001990
6. Veerman et al., *GRL*, 2022: A Case Study of Cumulus Convection Over Land in Cloud-Resolving Simulations With a Coupled Ray Tracer. https://doi.org/10.1029/2022GL100808