Coupling between cloud and land surface changes aerosol-cloud interactions

TIANNING SU

ZHANQING LI

University of Maryland

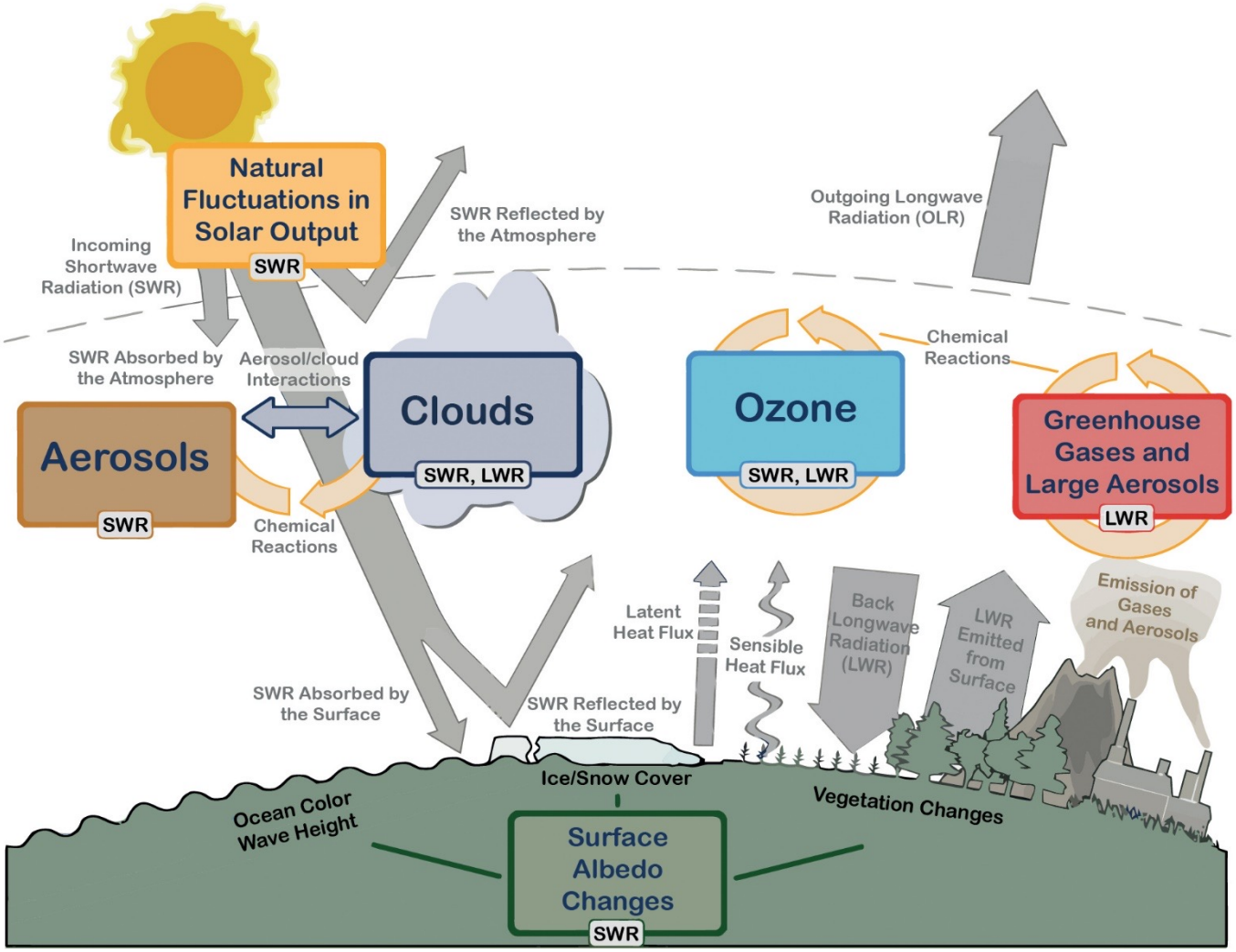
Lawrence Livermore National Laboratory

AGU 2023 Annual Meeting

Ccollaborators: Natalia Roldan; Youtong Zheng; Fangqun Yu

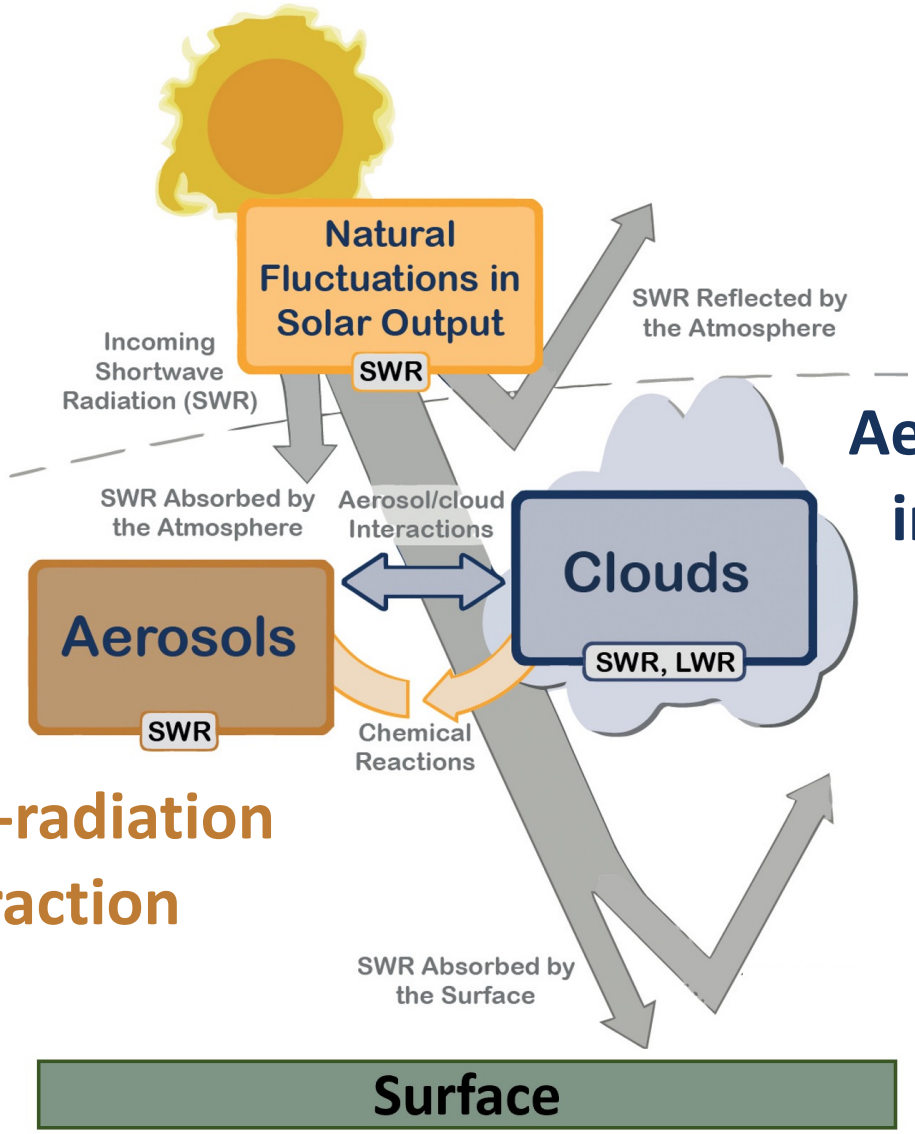
This work was performed under the auspices of the U.S. DOE by LLNL under contract DE-AC52-07NA27344. LLNL-PRES-858151

Main drivers of climate change



IPCC, 2013

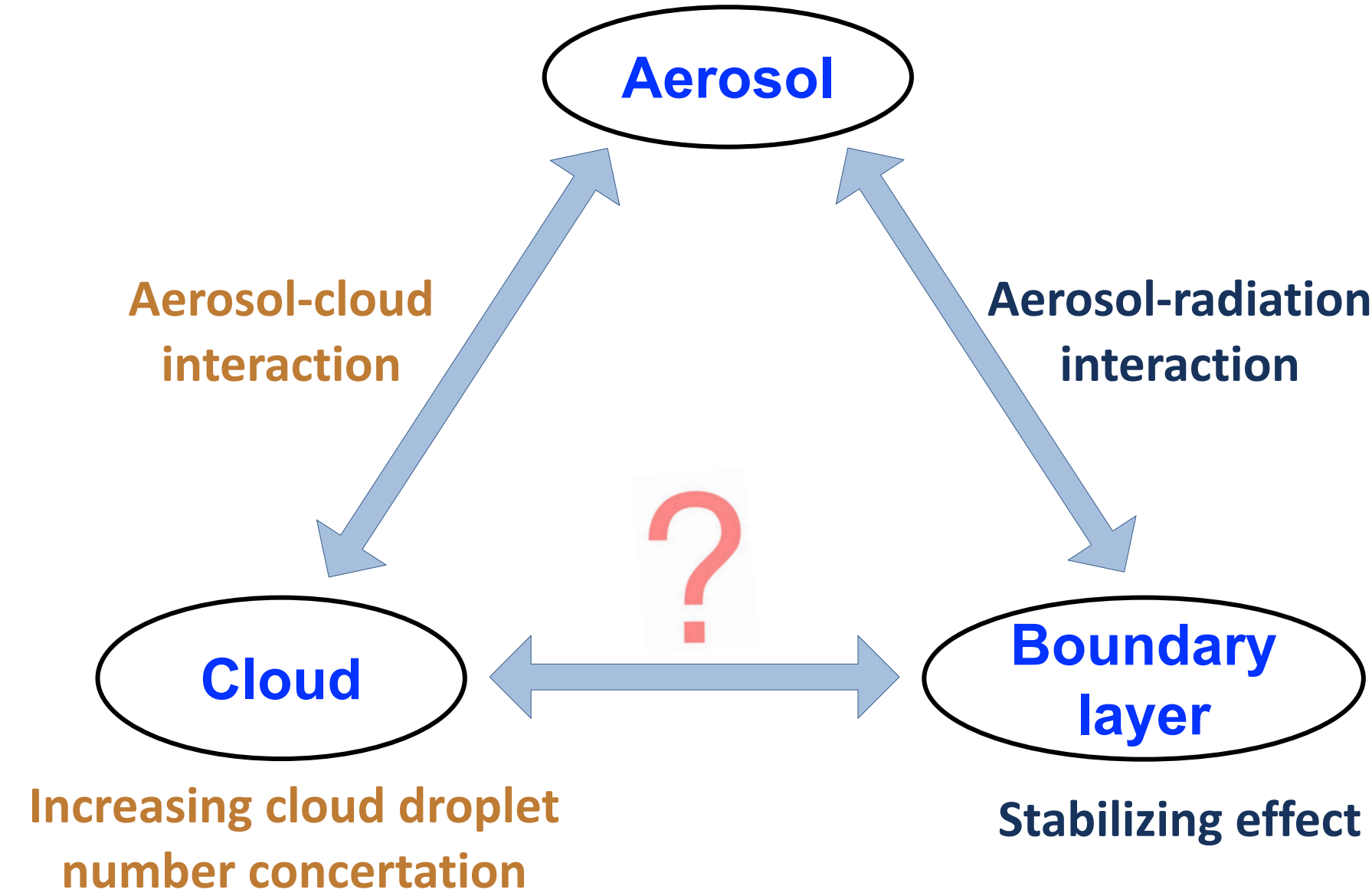
Aerosol radiative forcing

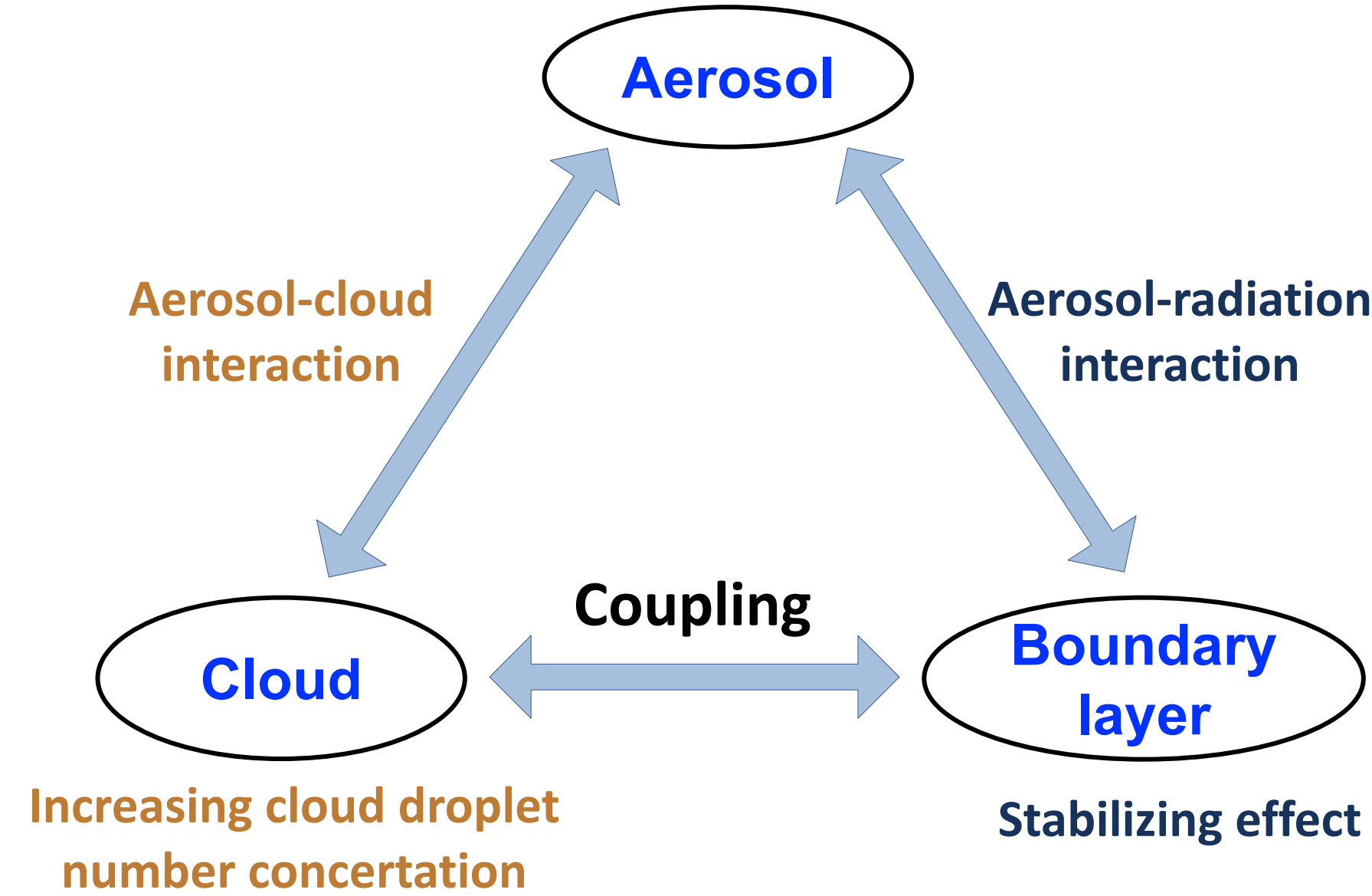


Aerosol-cloud interaction

Aerosol-radiation interaction

IPCC, 2013


Aerosol
Aerosol-cloud interaction
Aerosol-radiation interaction
?
Cloud
Boundary layer
Increasing cloud droplet number concertation
Stabilizing effect

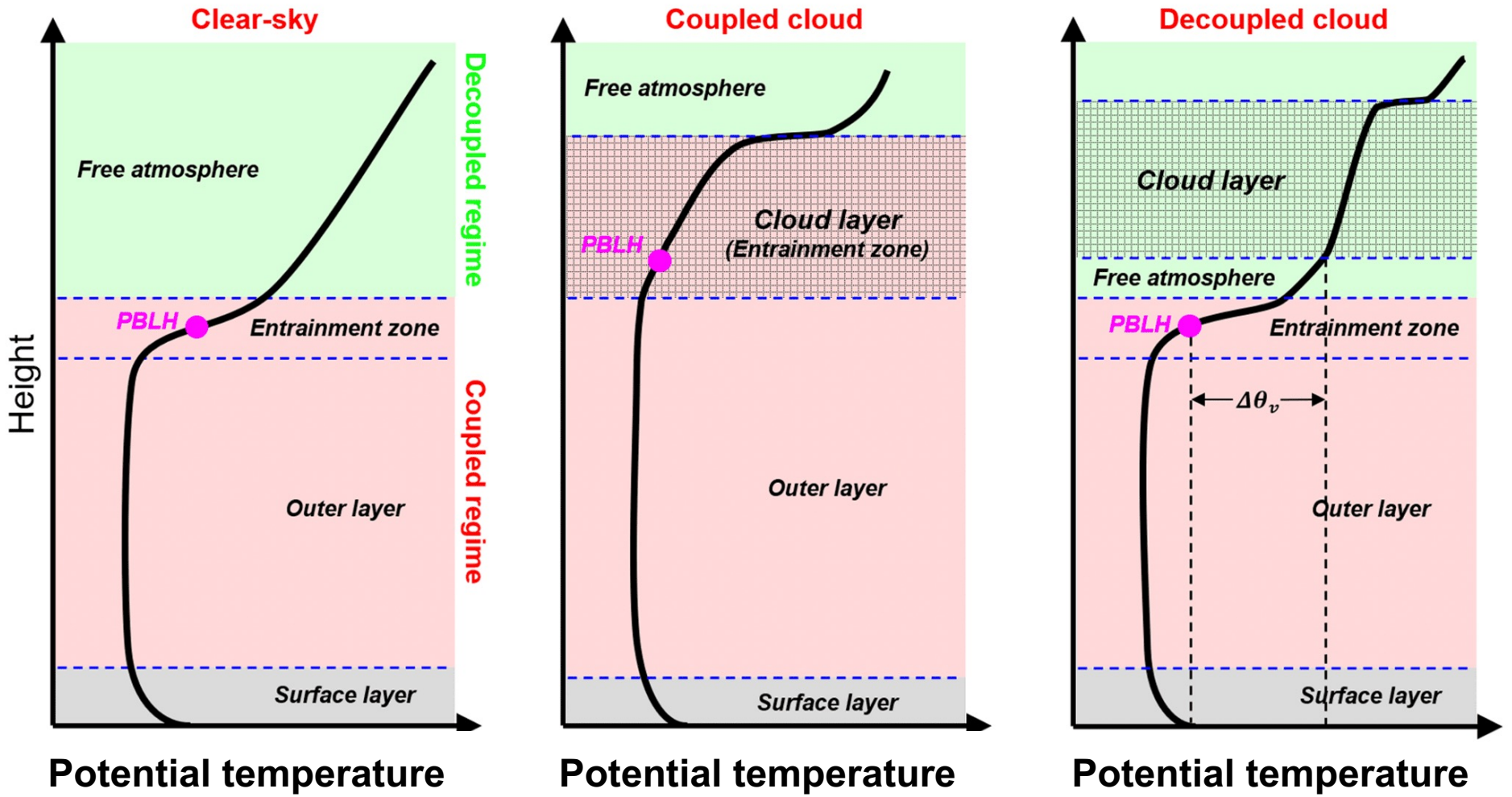

Aerosol
Aerosol-cloud interaction
Aerosol-radiation interaction
Coupling
Cloud
Boundary layer
Increasing cloud droplet number concertation
Stabilizing effect

ARM observations

Southern Great Plains (SGP):

https://www.arm.gov/capabilities/instruments

Linkage between surface, PBL, and cloud



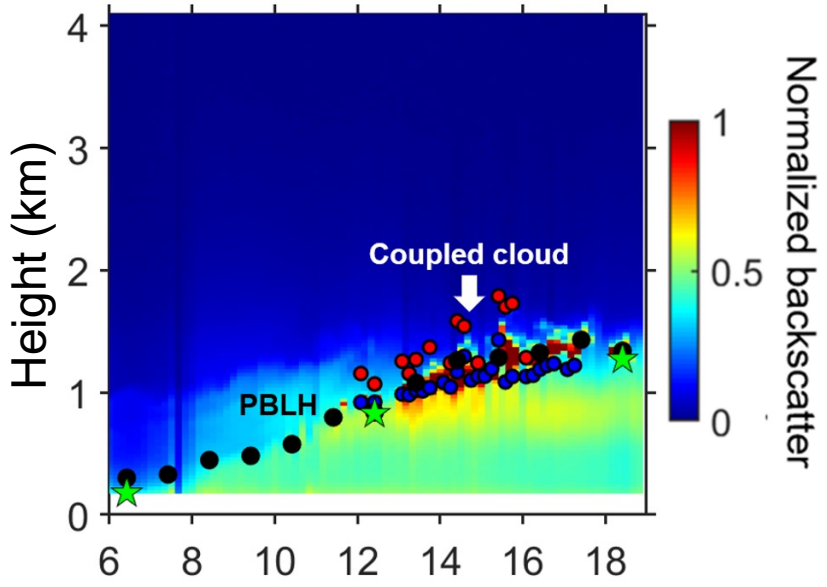
Cloud-PBL coupling is equivalent to cloud-land coupling over land

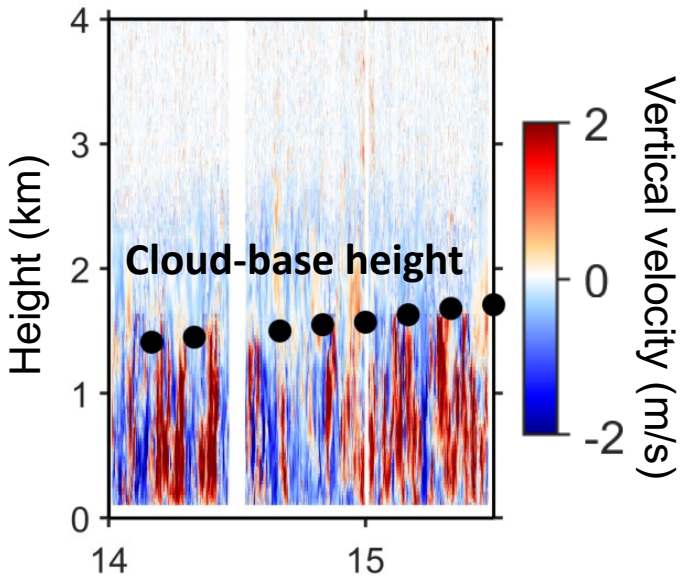
Su et al., 2022, ACP

Retrievals of cloud-land coupling

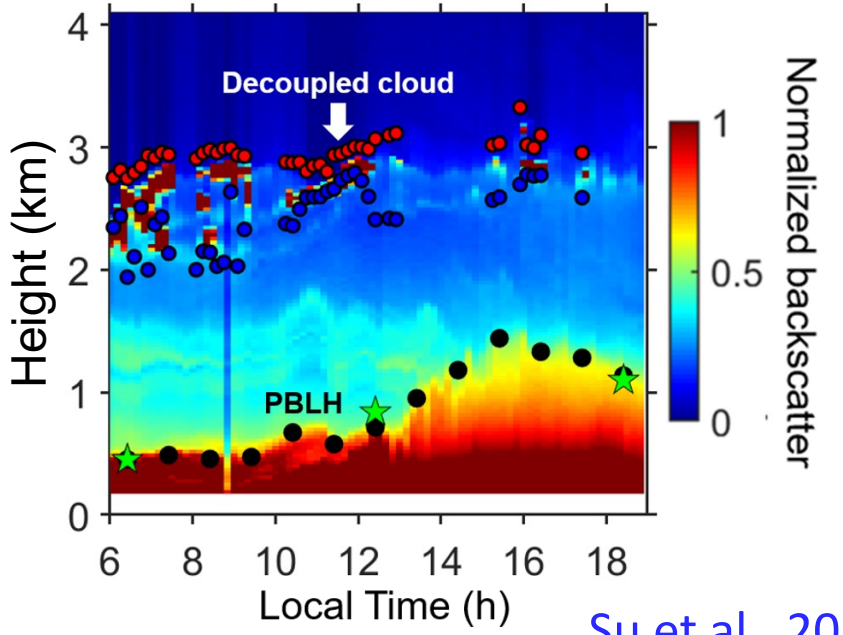
Dynamic evidence from Doppler lidar

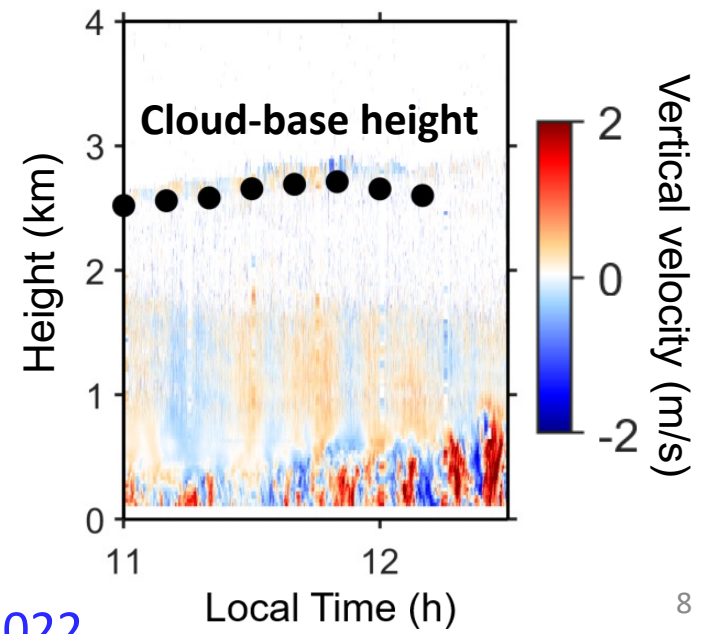
Coupled





Decoupled





Su et al., 2020, 2022

Highlight in DOE ARM Annual Report

Cloud-Land Coupling Examined at Southern Great Plains Observatory

Cloud-Land Coupling Examined at Southern Great Plains Observatory

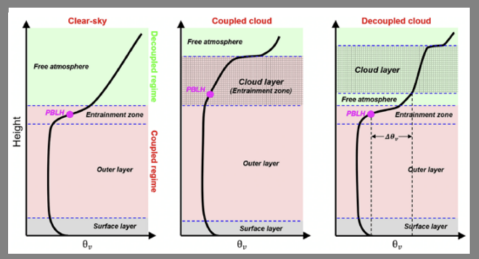
Connections between the surface and clouds are important for understanding how clouds develop. Most previous work on these connections has centered on oceans rather than land. Data from ARM's Southern Great Plains atmospheric observatory allowed researchers to study the coupling between clouds and land.

In research published by *Atmospheric Chemistry and Physics* in January 2022, scientists simultaneously measured the planetary boundary-layer height and coupled states under cloudy conditions. A lidar-based method developed by the researchers relies on the planetary boundary-layer height, lifted condensation level (the altitude at which a moist but unsaturated air parcel becomes saturated), and cloud base height to identify cloud coupling.

As coupled and decoupled clouds have distinct features, the new method offers an advanced tool to separately investigate them. Researchers generated a 20-year climatology by using the method.

Reference

Su T, Y Zheng, and Z Li. 2022. "Methodology to determine the coupling of continental clouds with surface and boundary layer height under cloudy conditions from lidar and meteorological data." *Atmospheric Chemistry and Physics* 22(2):1453-1466, https://doi.org/10.5194/acp-22-1453-2022.



Analyzing data from the MOSAiC expedition, scientists noted a difference in ice-nucleating particle concentration scales between different temperatures. Error bars represent standard deviation. (*Copyrighted image from the journal.***)**

One of nine studies highlighted in the Annual Report

How does the coupling process affect aerosol-cloud interactions?

Estimation of aerosol-cloud interaction

f: cloud fraction	N_d: cloud droplet number concentration
S: income solar radiation	**α: proxy for aerosol amount**

$$RF_{aci} = f_{liq} A(f, \tau_c) \frac{1}{3} \frac{d\ In\ N_d}{d\ In\ \alpha} [In\ \alpha - In\ (\alpha - \alpha^{ant})] S$$

Quaas et al., 2008

Liquid water cloud fraction

Responses of N_d to aerosol

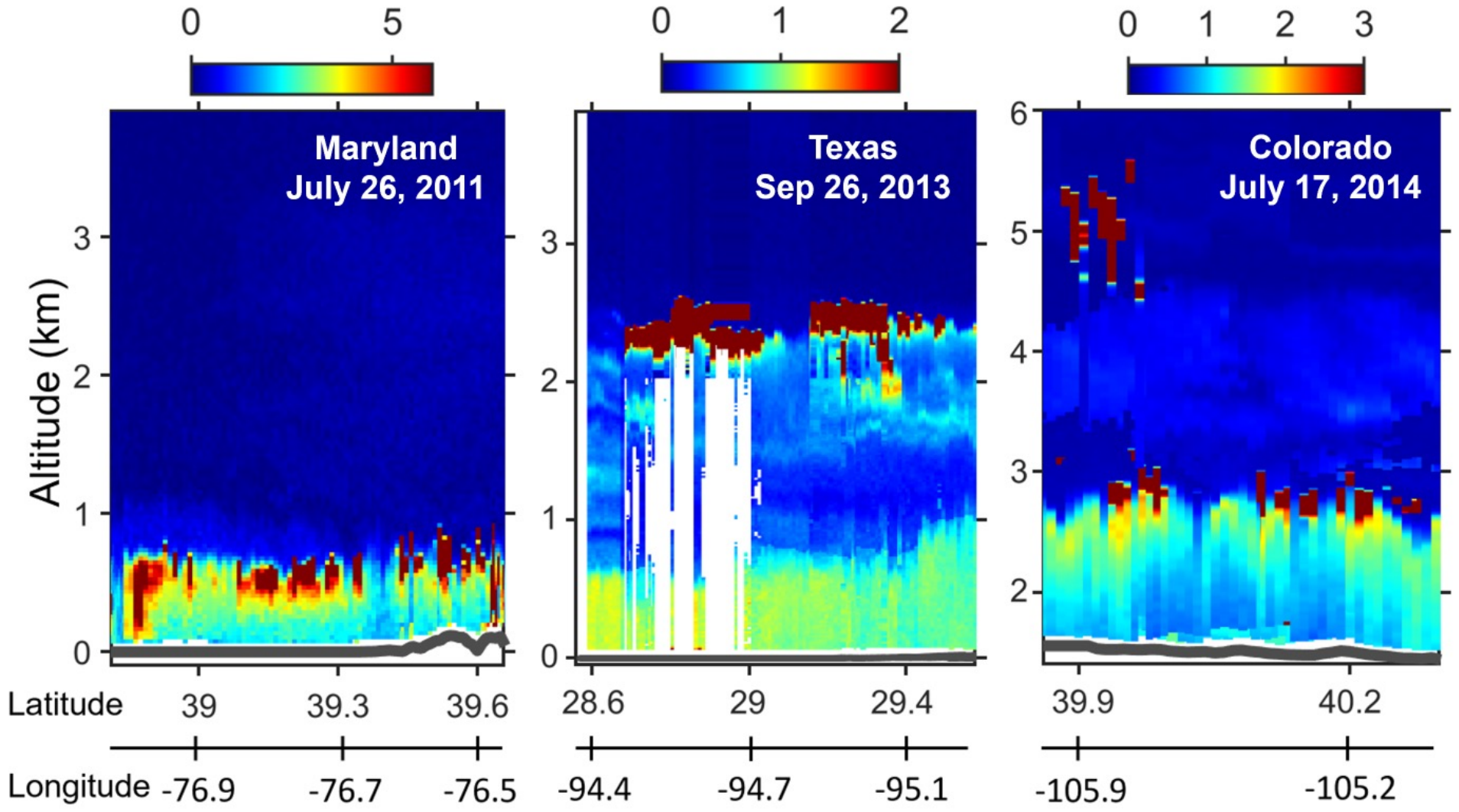
Natural aerosol amount

Can aerosol proxy represent aerosols near clouds?

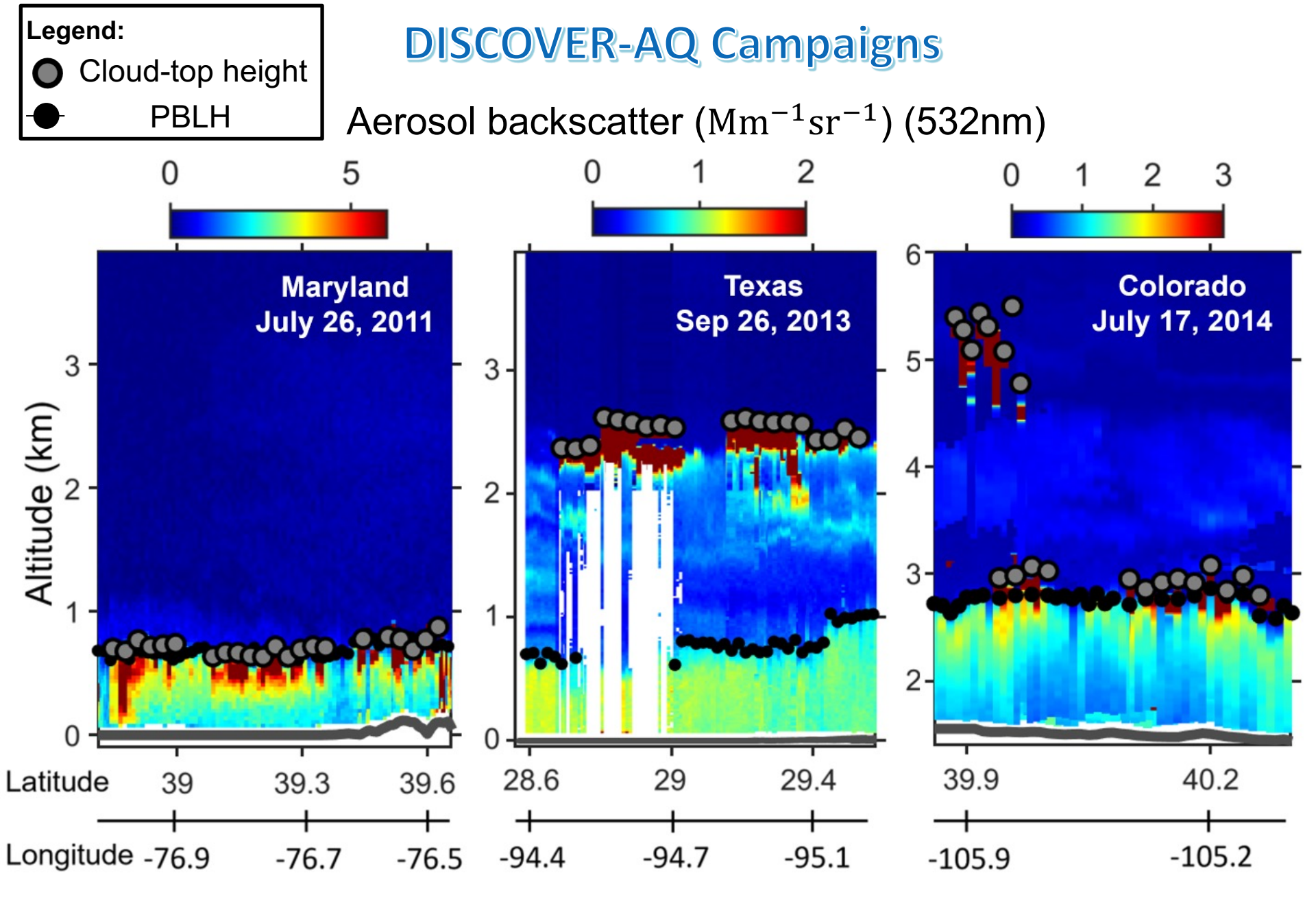
Cloud-land coupling can answer this question

Airborne lidar data

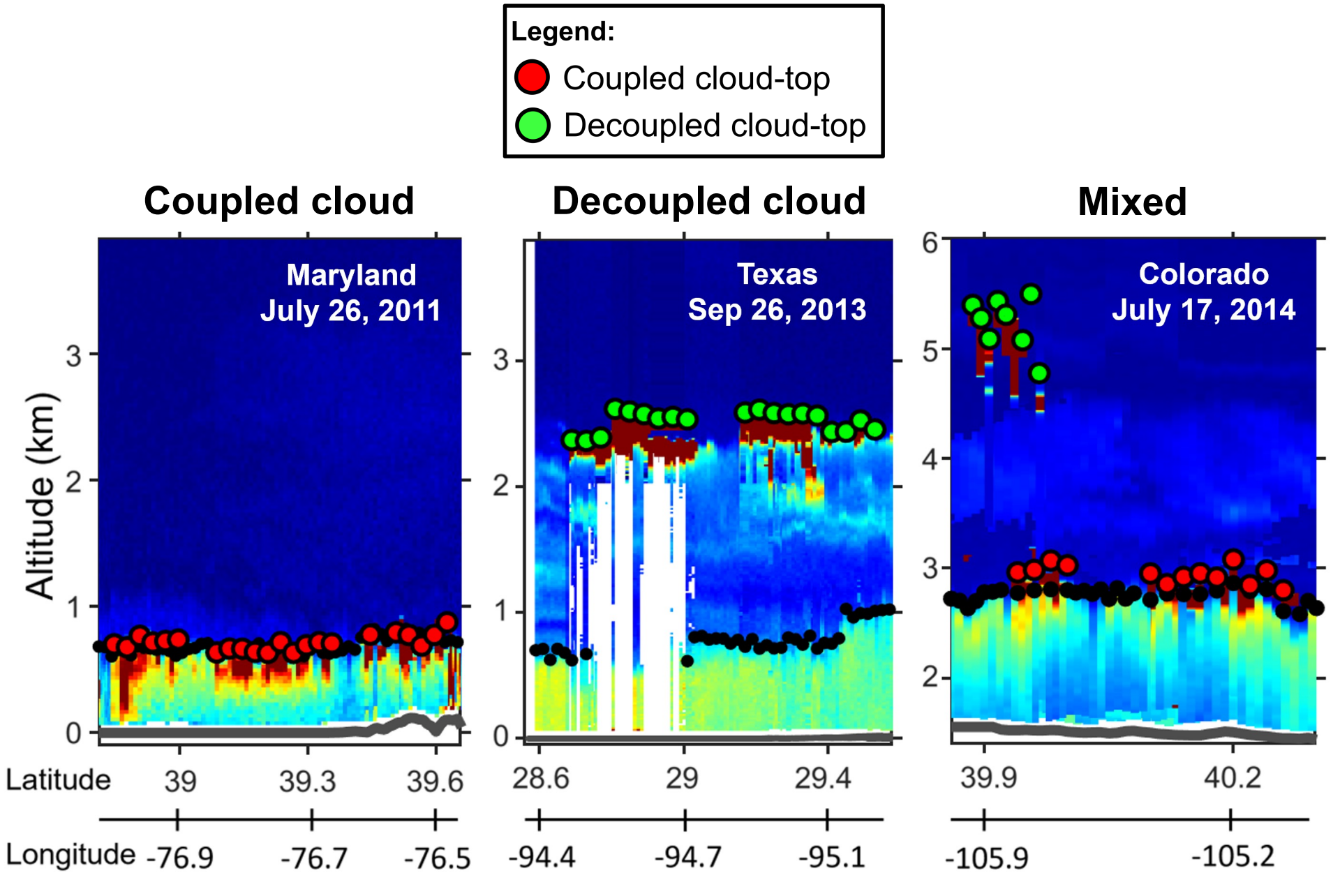
DISCOVER-AQ Campaigns



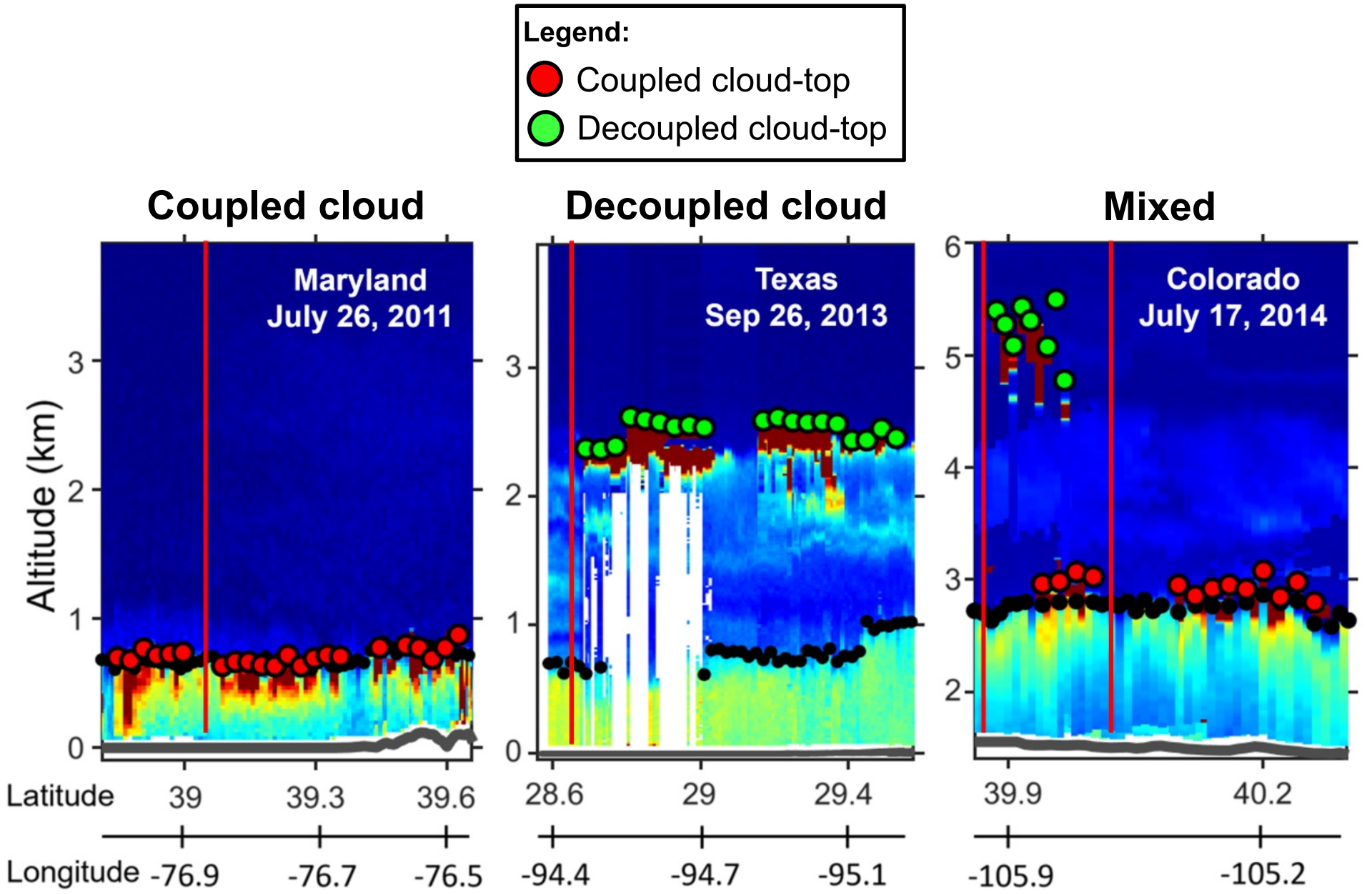
Airborne lidar data



Airborne lidar data

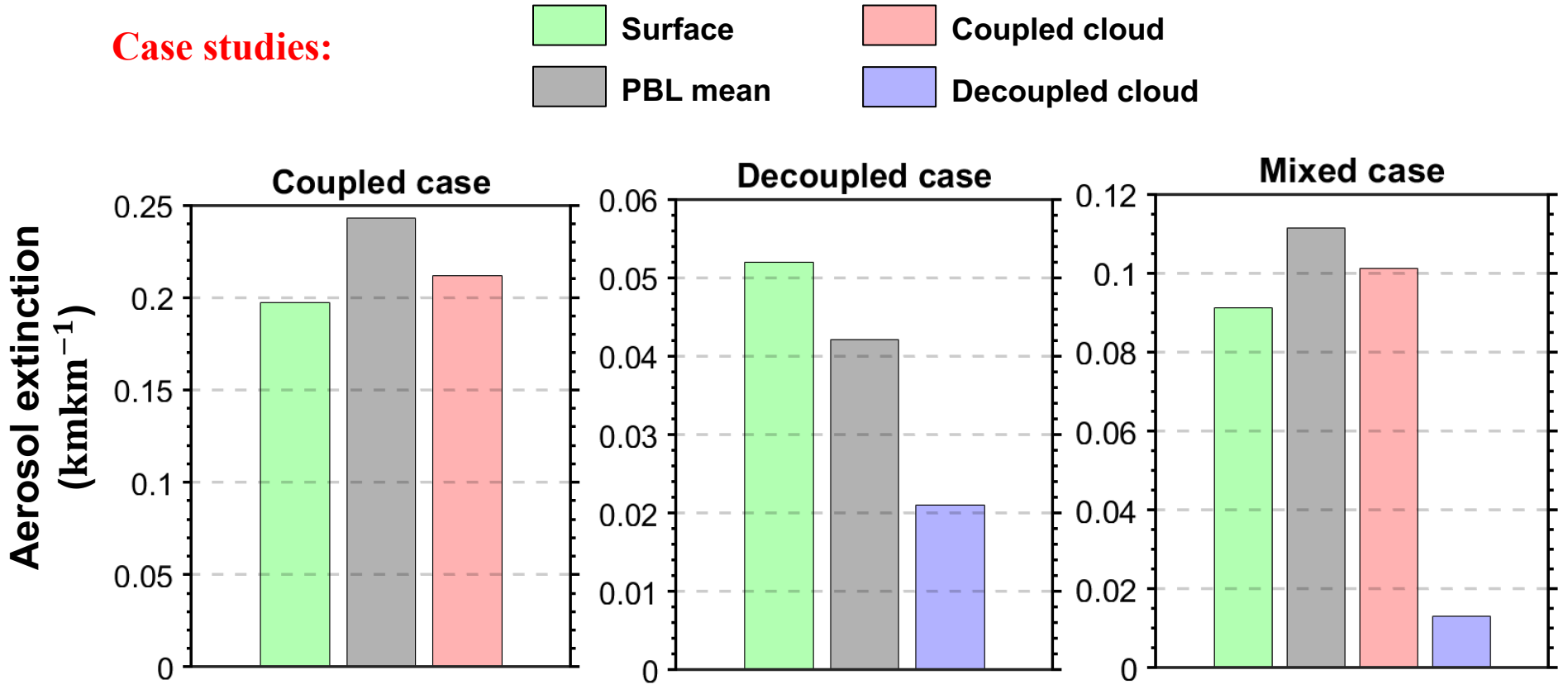


Airborne lidar data

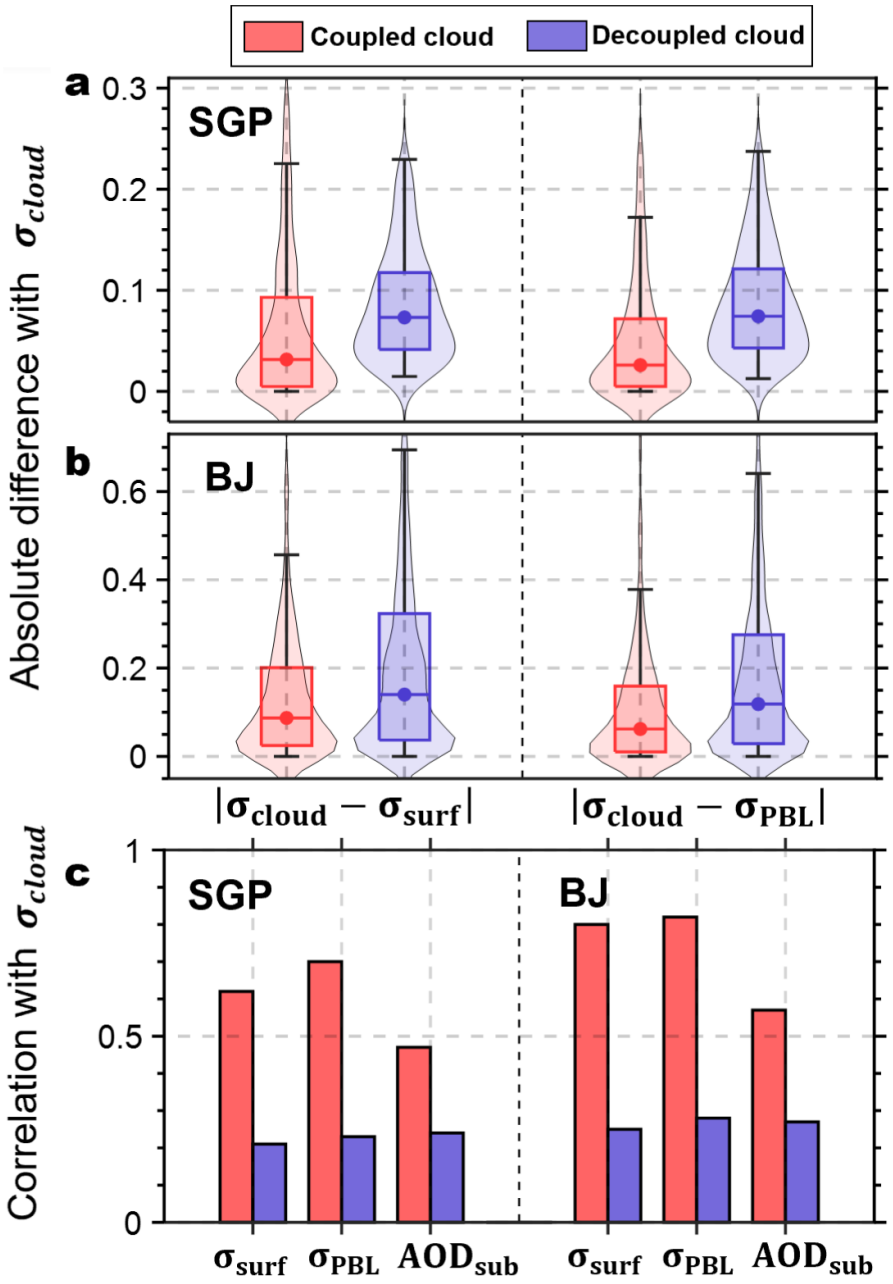


Airborne lidar data

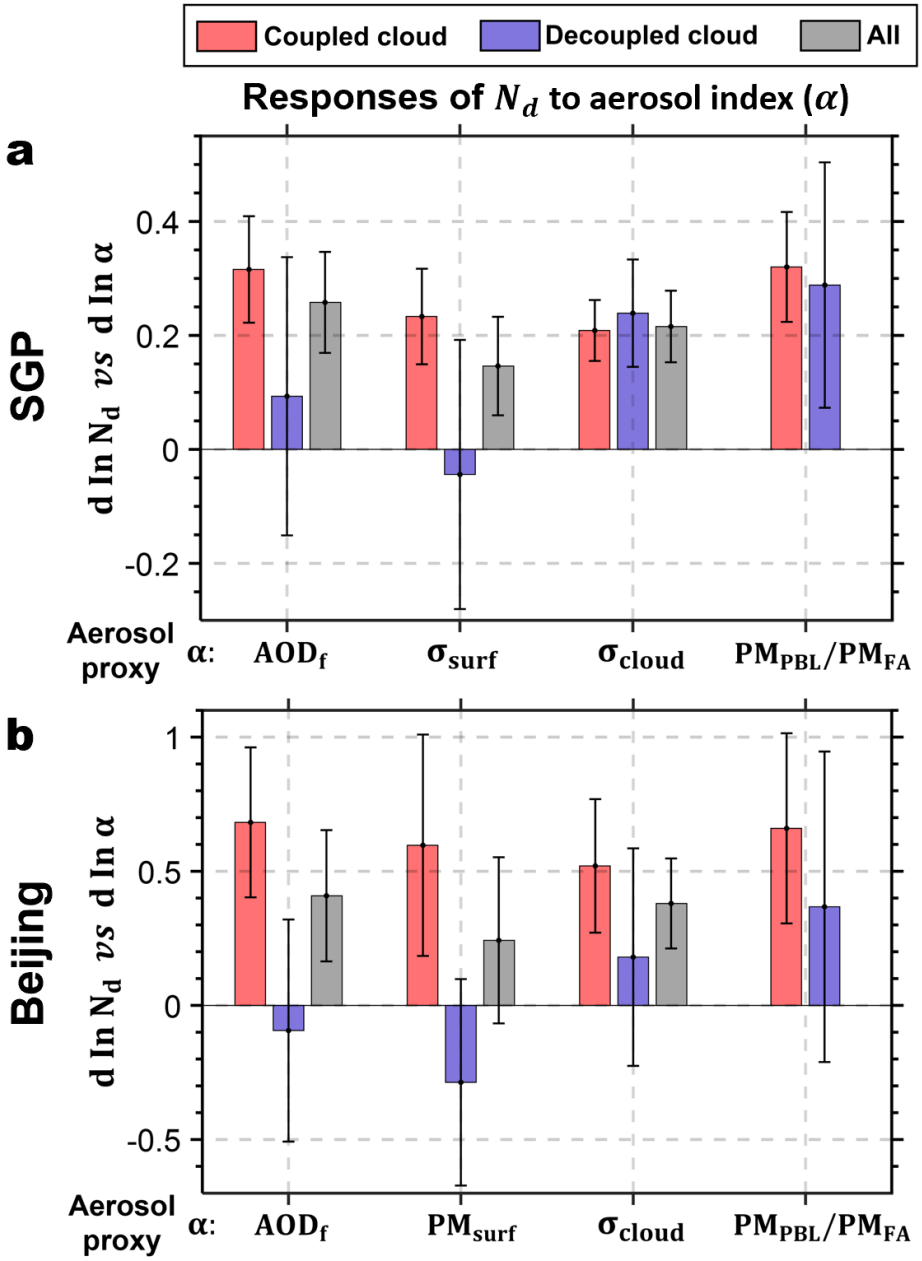
Case studies:



Cloud-land coupling affects aerosol distributions

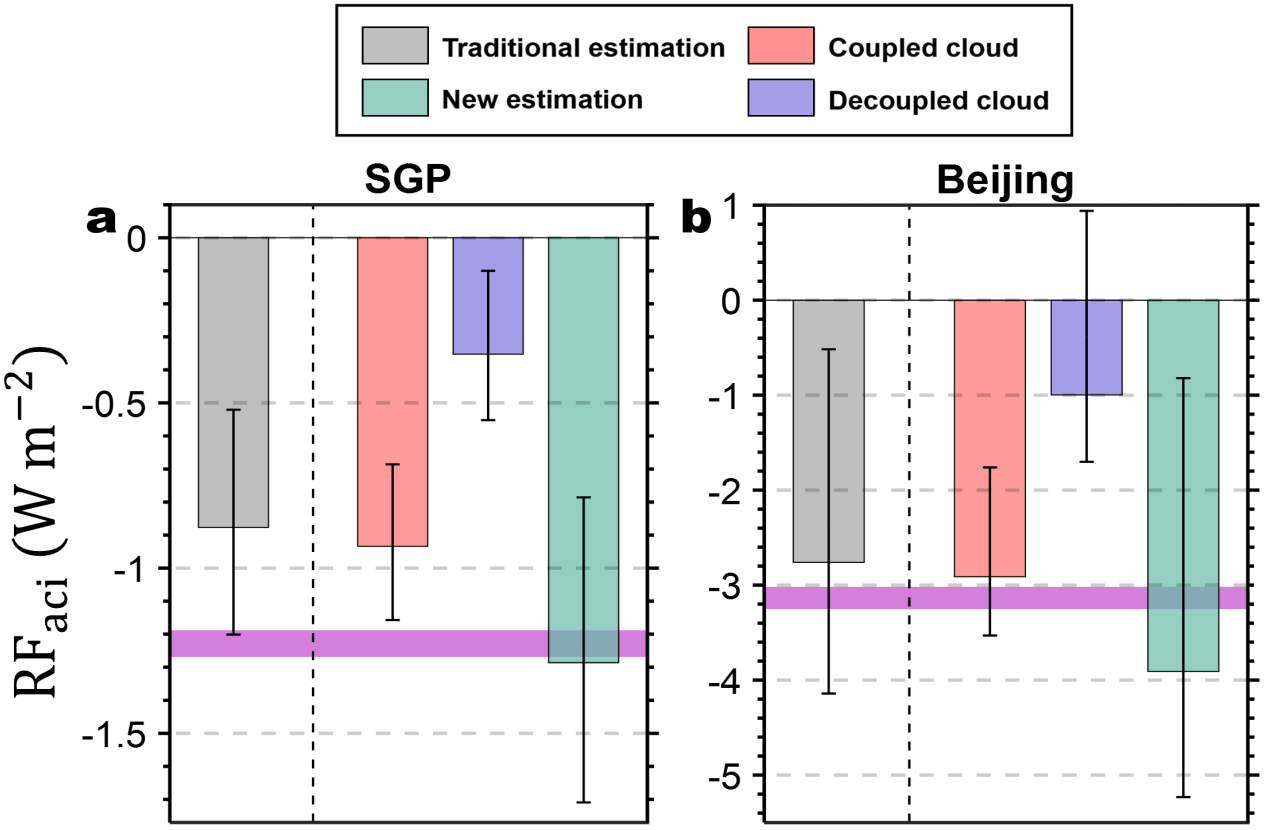


Cloud coupling changes responses of clouds to aerosol



Constraining aerosol indirect radiative effects by accounting for cloud-land coupling

Aerosol first indirect effect (PD-PI)



Radiation data: CERES/MODIS

Natural aerosol fraction: MACv2

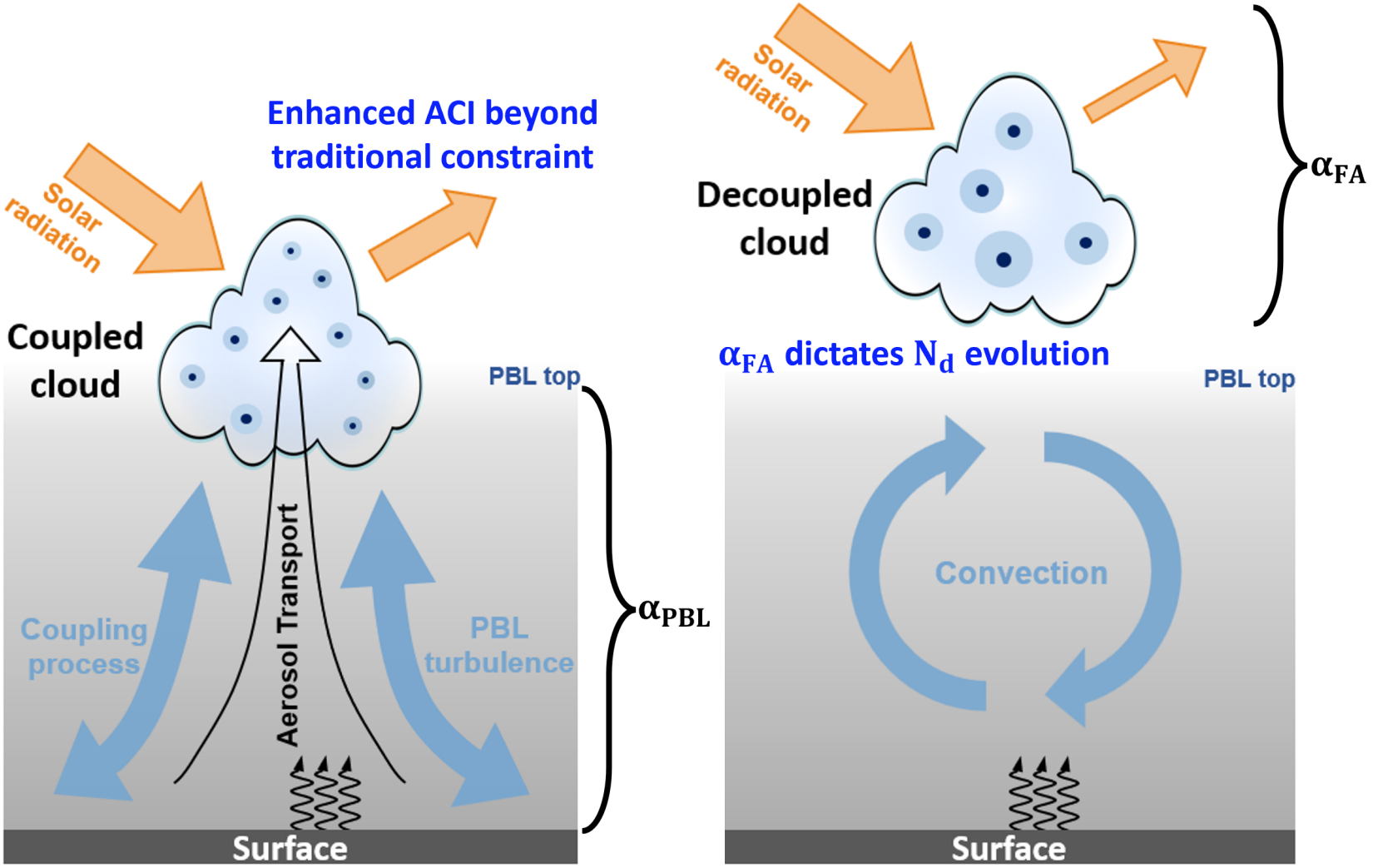
Cloud optical properties: MFRSR

Aerosols : AOS/Lidar

Cloud boundary and coupling: Lidar

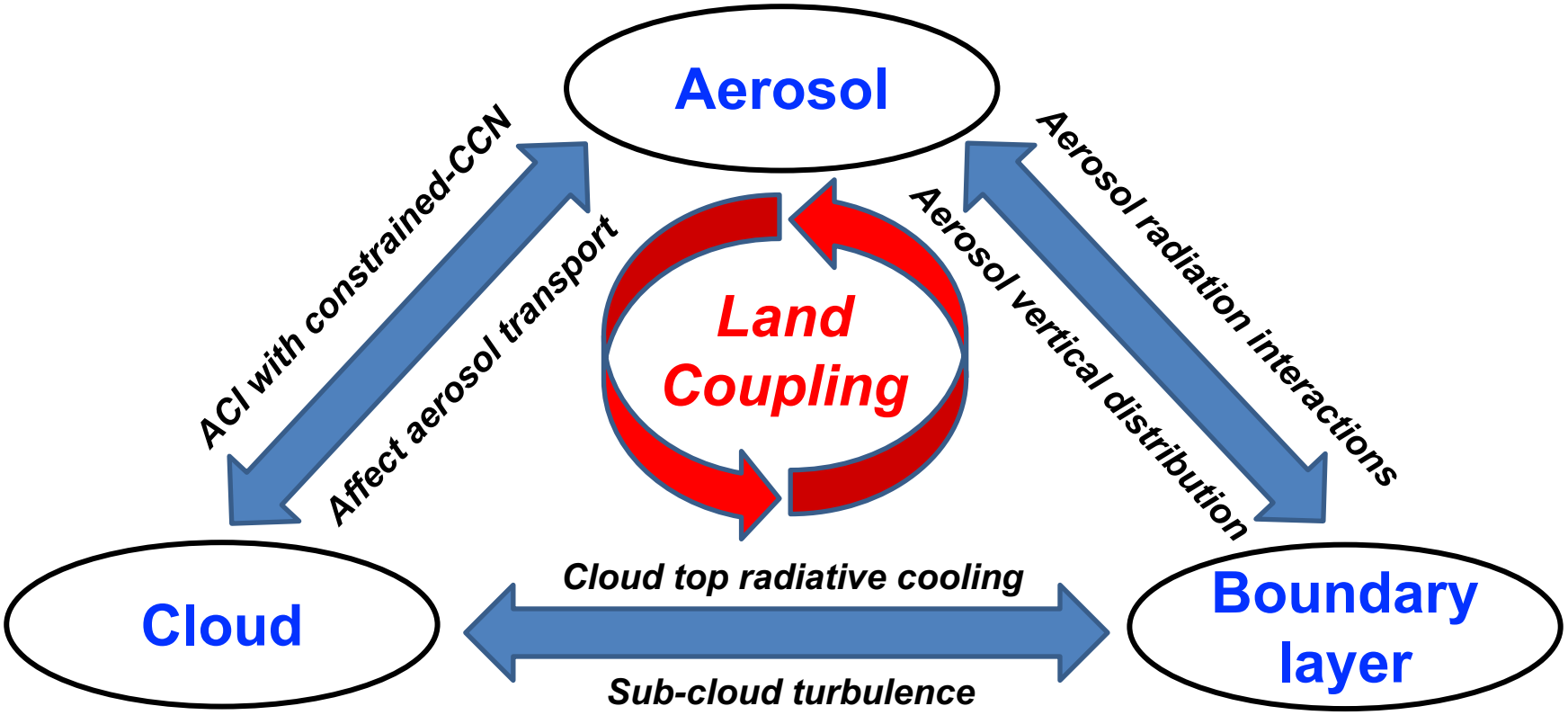
Model: GEOS-Chem run by Dr. F. Yu

The neglect of cloud coupling results in an underestimation of aerosol-cloud interaction



Su et al. under review.

Summary


Aerosol
ACI with constrained-CCN
Affect aerosol transport
Land Coupling
Aerosol vertical distribution
Aerosol radiation interactions
Cloud
Cloud top radiative cooling
Sub-cloud turbulence
Boundary layer

References

Su, T., Zheng, Y., & Li, Z. (2022). Methodology to determine the coupling of continental clouds with surface and boundary layer height under cloudy conditions from lidar and meteorological data. Atmospheric Chemistry and Physics, 22(2), 1453–1466. https://doi.org/10.5194/acp-22-1453-2022

Su, T., & Li, Z. (2024). Decoding the dialogue between clouds and land. Eos, 105. https://doi.org/10.1029/2024EO240072

Su, T., Li, Z., & Kahn, R. (2020). A new method to retrieve the diurnal variability of planetary boundary layer height from lidar under different thermodynamic stability conditions. Remote Sensing of Environment, 237, 111519. https://doi.org/10.1016/j.rse.2019.111519

Su, T., Li, Z., Roldán, N., Luan, Q., Yu, F. (2024). Constraining Effects of Aerosol-Cloud Interaction by Accounting for Coupling between Cloud and Land Surface, Science Advances, 2024 (Under Review)

Boucher, O., et al. (2013), Clouds and aerosols, in Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 571–657, Cambridge Univ. Press, Cambridge, U. K.