Cloud-topped boundary layers in climate

...and climate models

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Marine boundary layer archetypes

Subtropical Stratocumulus

Trade-wind Cumulus

Stevens et al. 2006

Stevens et al. 2007
Observed top-of-atmosphere cloud radiative effects

Net CRE [W m$^{-2}$]

SW CRE [W m$^{-2}$]

LW CRE [W m$^{-2}$]

CERES EBAF v4

AVG: -17.82

AVG: -45.80

AVG: 27.98

Loeb et al. 2018
months when $|\text{SWCRE}| > 5 \times |\text{LWCRE}|$
Observed top-of-atmosphere cloud radiative effects, impact of BL clouds

Clouds under large-scale subsidence

tropical trade-wind clouds

tropical stratocumulus
Boundary layer clouds in CESM2
Model Physics:

- Parameterized deep convection (Zhang-McFarlane)
- Unified shallow convection – turbulence – cloud macrophysics (CLUBB)
- 2-moment microphysics (Morrison-Gettelman v2)
- 4-mode aerosol model with 18 predicted aerosol tracers (MAM4, Liu et al.)
Simulated top-of-atmosphere cloud radiative effects

Net CRE [W m$^{-2}$]

SW CRE [W m$^{-2}$]

LW CRE [W m$^{-2}$]
CERES EBAF & ERAI

CRE

cloud area

CESM2

CRE

cloud area

$\omega_{500}$ [hPa d$^{-1}$]

LTS [K]
Climate models have errors in BL clouds: “too few, too bright”
Climate models’ vertical structure

Medeiros & Nuijens 2016
Simulated Sc-to-Cu Transition

Cloud Fraction

Satellite-based product

Cloud Liquid
Cloud feedbacks are very uncertain in climate models

Vial et al. 2013
Boundary layer clouds are a major contribution to Earth’s energy balance

- They are low, mostly liquid, and highly reflective
- Tropical/subtropical stratocumulus and shallow cumulus are about 25% of the total TOA cloud effect
- Broader trades cover MUCH more area, account for 2x more TOA cloud effect than stratocumulus decks

Early evaluation of CESM2

- Broad spatial patterns of cloud cover are pretty well captured
- Still exhibits compensating errors between cloud cover and optical properties
- Biases in thermodynamic structure and circulation complicate evaluation

Climate models more generally

- Similar issues as CESM2: compensating errors, poor vertical structure
- At least partially responsible for uncertainty in cloud feedbacks