On Cold Puddles in Cold Pools

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ASR Atmospheric System Research

The Raindrop's Journey

When first I fell onto that leaf,
My landing came as a relief.
The clouds began to fade away,
As they revealed the light of day.

Now where will I go next? I asked.
Shall I lie back, sunbathe, and bask?
If I stay put, I'll surely boil.
Perhaps I'll drip down to the soil.

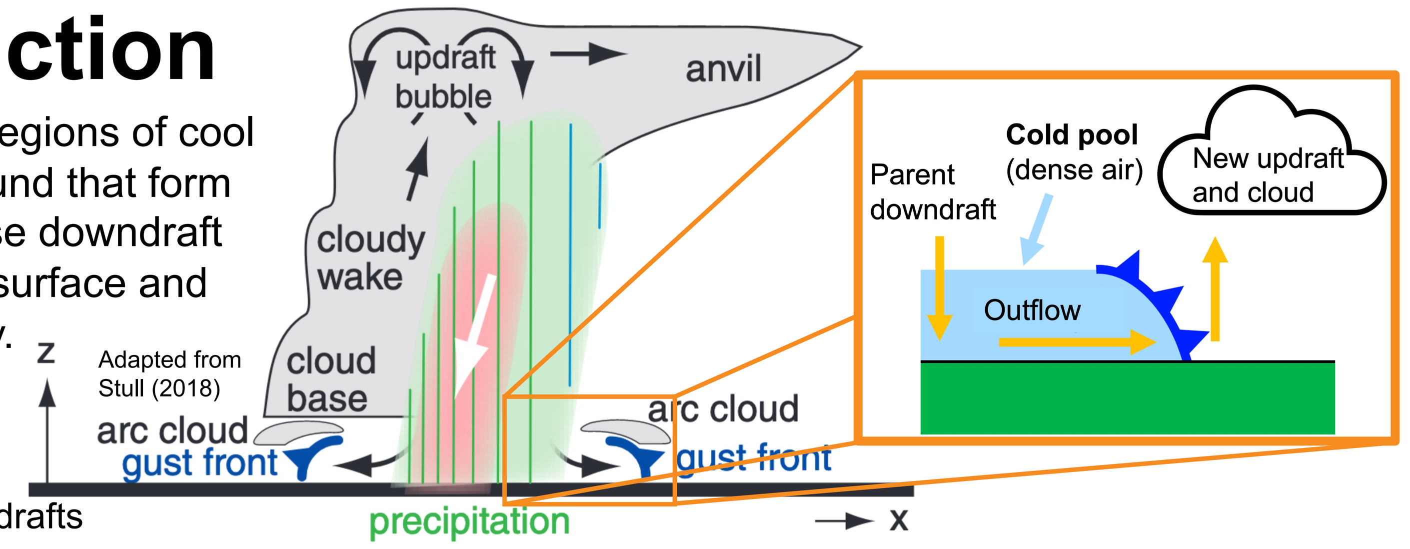
Then suddenly I understood
That soon my life would end for good:
From leaf or soil, evaporate,
Or trapped below, I'd infiltrate.

The physics meant I had no say.
Would I remain? Be blown away?
A tiny puddle, at death's door,
I feared what nature had in store.

But then I came to realize:
Well, even if I vaporize,
I'll live on in another form
And modify a future storm.

When changing phase, it is a rule,
Evaporation makes air cool.
These puddles drive stability,
And fuel cold pool vitality.

Introduction



Cold pools are regions of cool air near the ground that form when cool, dense downdraft air reaches the surface and spreads laterally.

What can cold pools do?

- Trigger new updrafts
- Suppress convection within their stable interiors
- Promote storm organization and longevity
- Alter the thermodynamic and dynamic characteristics of the boundary layer (cool air, gusty winds, etc.)
- Transport aerosol particles and trace gases
- Prolong the diurnal cycle of convection (old storms can trigger new storms that would not otherwise form)
- Modulate processes such as convective aggregation, tropical cyclogenesis, and tornadogenesis

Why are cold pools cold?

Traditional explanation:

- *Phase changes in the rain shaft, such as* ***evaporation****,* ***melting****, and* ***sublimation****, cause* ***latent cooling*** *of downdraft air.*

This study asks: ***Do rainfall-land surface interactions help to fuel cold pools?***

- *How do interactions between rainfall, land surfaces, and near-surface air affect cold pool evolution?*
- *How do these interactions depend on surface characteristics and CCN concentrations?*

What happens to rainfall after it reaches the land surface?

- Interception by vegetation
- Shedding and stemflow (plants → soil)
- Contributes to soil moisture
- Surface water
- Runoff

Consequences:

- Cools and moistens the near-surface air:
  - Alters the partitioning of surface fluxes, promoting latent heat fluxes at the expense of sensible heat fluxes
  - Increased evaporation (of moister soil and vegetation-intercepted rain)
  - Increased transpiration (reduced heat stress, increased soil moisture)
- Reduces surface temperature through direct cooling (cold rainwater)
- May also cause surface warming if soil moistening lowers the soil albedo

Mechanism-Denial Experiments

NOTE: As used here, "puddles" refers to *all* rainfall-land surface interactions.

Regional Atmospheric Modeling System (RAMS) simulation design:

- **Domain:** 50 km × 50 km (horizontal) × ~26 km (vertical); 11 soil levels; no Coriolis; no topography; periodic lateral boundaries
- **Grid spacing:** 125 m (horizontal); 40 m stretched to 250 m (vertical)
- **Initial conditions:** Sounding from Grant and van den Heever (2014, see right); pseudorandom small thermal perturbations in lowest 500 m
- **Surface:** Land Ecosystem-Atmosphere Feedback model, version 3 (LEAF-3)
- **Microphysics:** RAMS two-moment bin-emulating bulk microphysics, 8 hydrometeor classes
- **Radiation:** Harrington (1997) two-stream scheme; insolation: 3.0°N latitude on 1 July
- **Diffusion:** Modified Smagorinsky (1963) scheme
- **Aerosol:** Sulfates; advected and diffused with no sources or sinks; microphysically active but radiatively inactive; DeMott (2010) ice nucleation; initial aerosol profiles decrease exponentially with altitude (scale height = 7000 m)

Sensitivity tests:

- **Surface: Rainforest (default) or Desert**
  - Rainforest: broadleaf evergreen tree, sandy clay loam soil initialized at 75% of saturation
  - Desert: bare soil, initialized at 25% of saturation
- **Initial surface CCN number concentrations:**
  - 200/mg (default), 400/mg, 800/mg, 1600/mg, and 3200/mg
- **Restart time (see diagram in upper-right corner):**
  - 1200 LT (default), 1330 LT, 1500 LT, and 1630 LT

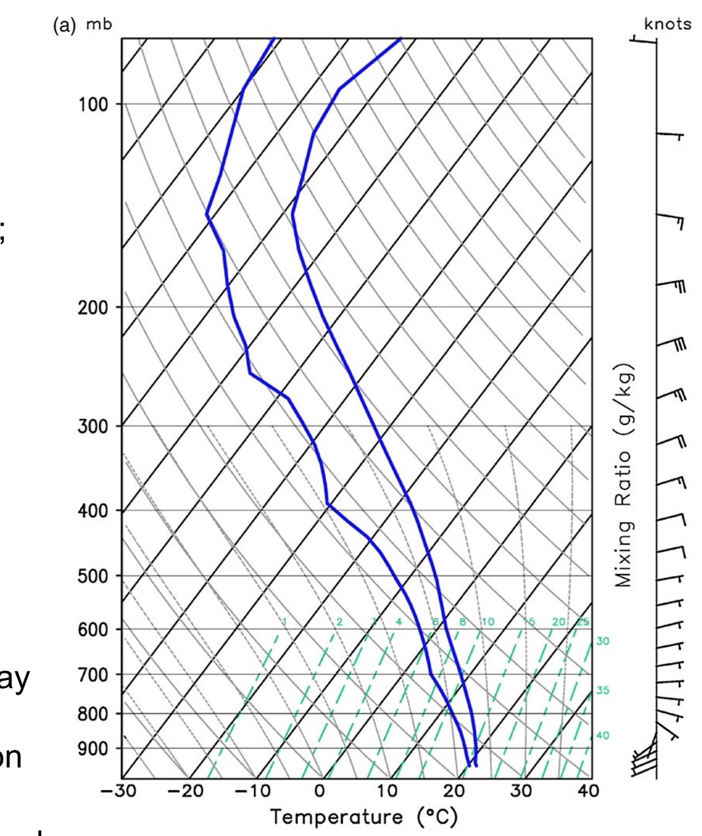
0700 LT (start) → 1200 LT (restart) → 1800 LT (end)

Spin-up with "puddles" disabled: Uses a modified version of LEAF-3, in which the land surface model ignores surface precipitation

NO PUDDLES: Continue the original simulation

NEUTRAL PUDDLES: Turn on puddles but ignore raindrop internal energy in LEAF-3

PUDDLES: Turn on puddles (revert to the standard version of LEAF-3)



Skew-T from Grant and van den Heever (2014, JGR-Atmos). The sounding is based on ECMWF YOTC analyses in June, July, and August of 2008 and 2009 (dry season in Cameroon's rainforest region in equatorial Africa).

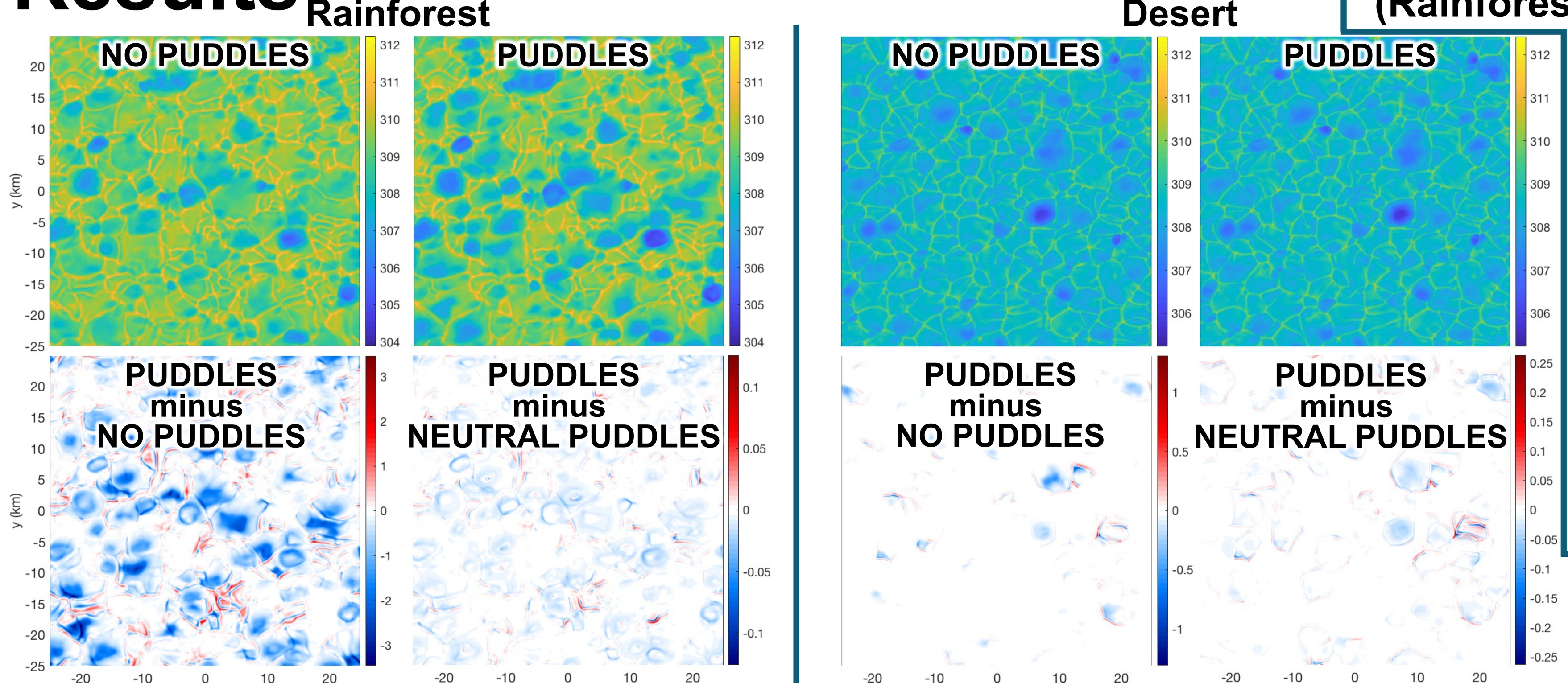
The "restart time" (default: 1200 LT) occurs after clouds have already begun to form and precipitate.

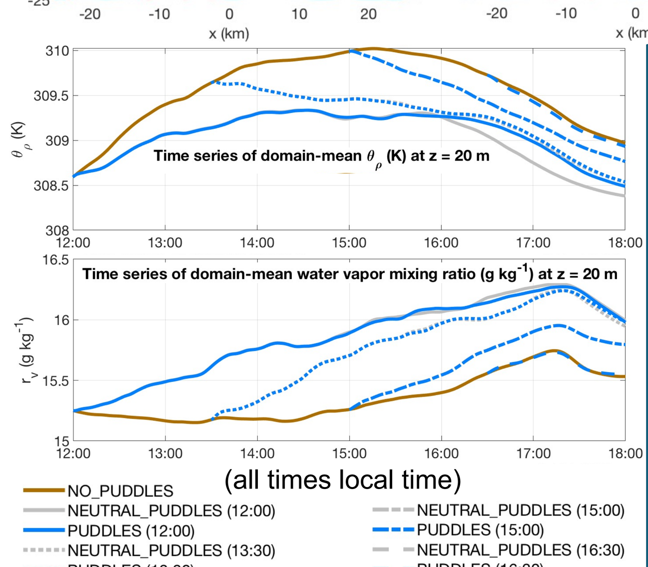
At the restart time, the existing simulation branches into three "parallel universes" in which rainfall-land surface interactions either remain disabled or are abruptly reenabled.

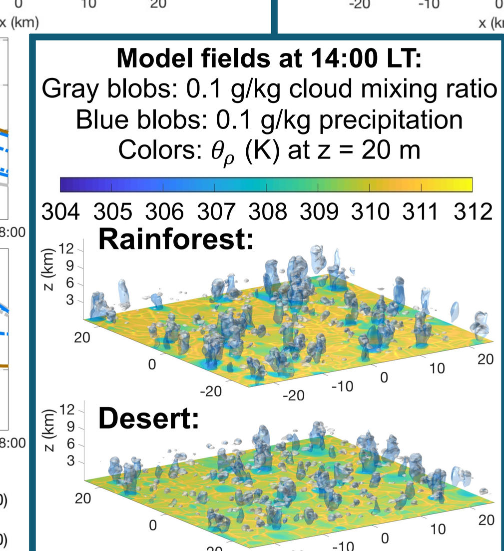
The differences that gradually emerge between these "parallel universes" (particularly within the first ~90 minutes) **reveal the impact of rainfall-land surface interactions on cloud and cold pool evolution.**

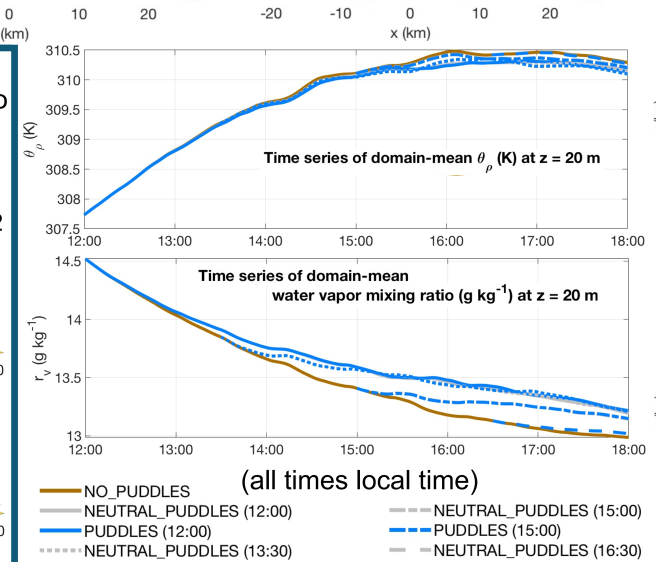
Results

θ_ρ (K) at z = 20 m at 12:45 LT (45 min after restart)

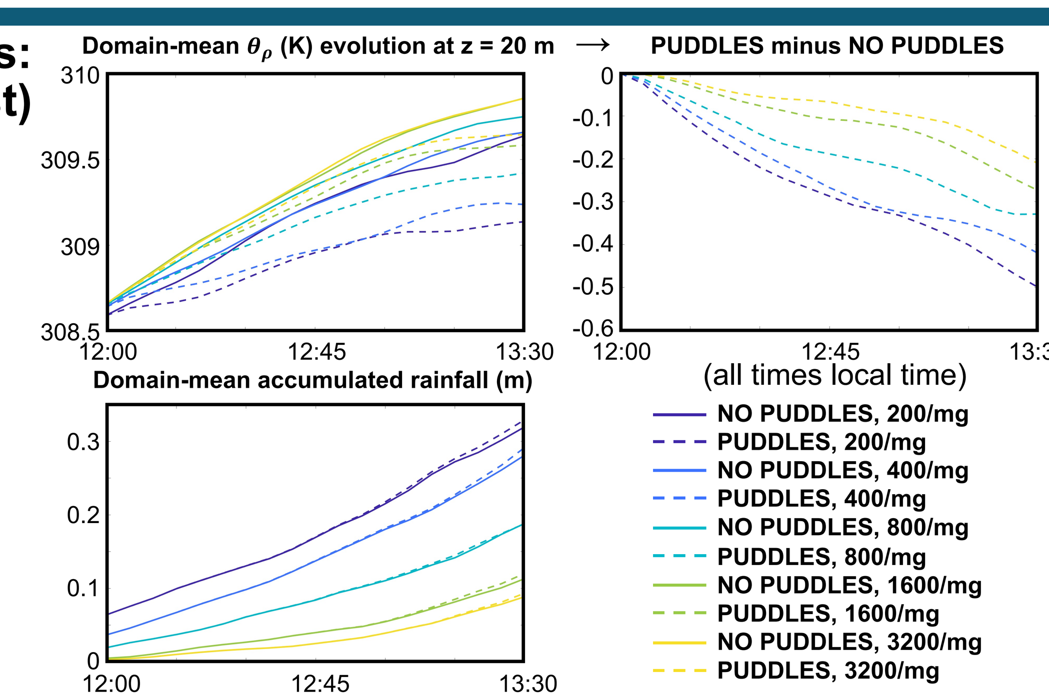




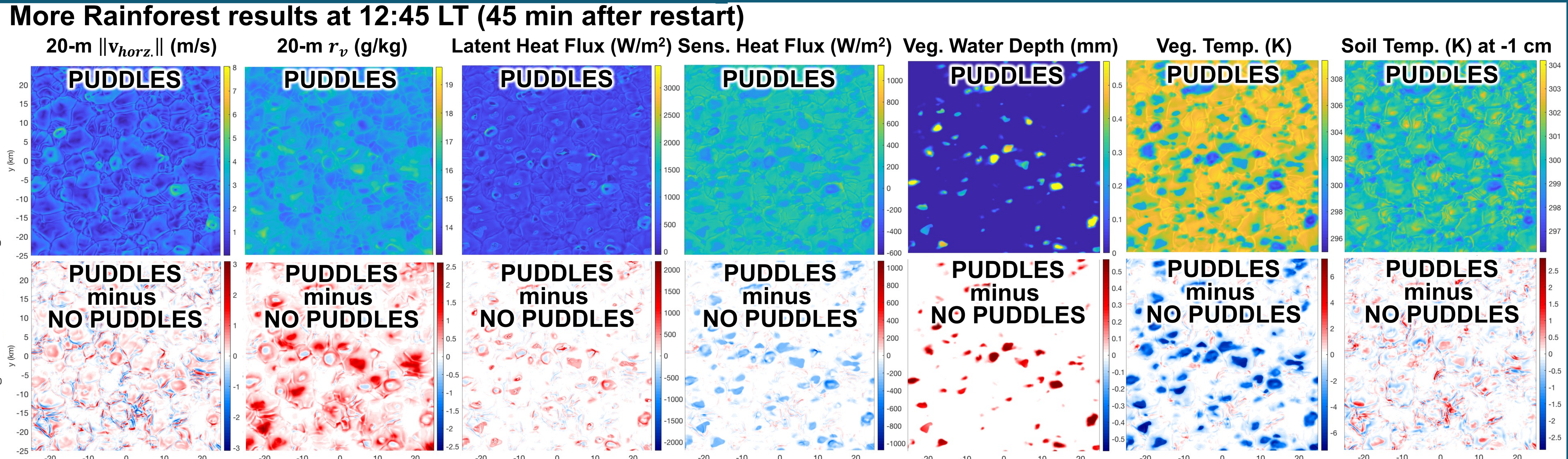




CCN results: (Rainforest)



More Rainforest results at 12:45 LT (45 min after restart)



Conclusions

Intercepted precipitation can invigorate cold pools and prolong the cold pool dissipation process over land. This effect is particularly important over vegetated surfaces.

As CCN concentration increases, precipitation decreases (during the early afternoon, at least), resulting in less puddle-based cold pool invigoration (in a domain-mean sense, at least).

Next questions:

- Sensitivity to the initial sounding? Other land cover types? Case-study simulations?
- What happens when aerosol is radiatively active?
- Do we see puddle-based cold pool invigoration in observations? How can we measure this?

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