Effects of Surface Energy Partitioning on Convective Organization: An observational and modeling case study in the US Southern Great Plains

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Introduction

The US Southern Great Plains is a ‘hot spot’ for land-atmosphere coupling (Koster et al. 2004). The land and convective-triggering feedback regime can be positive or negative, depending on low-level atmospheric stratification and humidity (Findell and Eltahir 2003; Williams 2019). Using all data together (without separating regimes) could result in weak/no feedback (Qiu and Williams 2020).

Then, what about land (soil moisture) and convective organization?

Introduction

Cold pools can connect surface with convective organization through:

- Cloud entrainment (Kuang and Bretherton 2005; Feng et al. 2015)
- Gust front uplift (Rotunno et al. 1988; Torri et al. 2015)
- Surface fluxes interactions (Tompkins 2001; Drager et al. 2020)

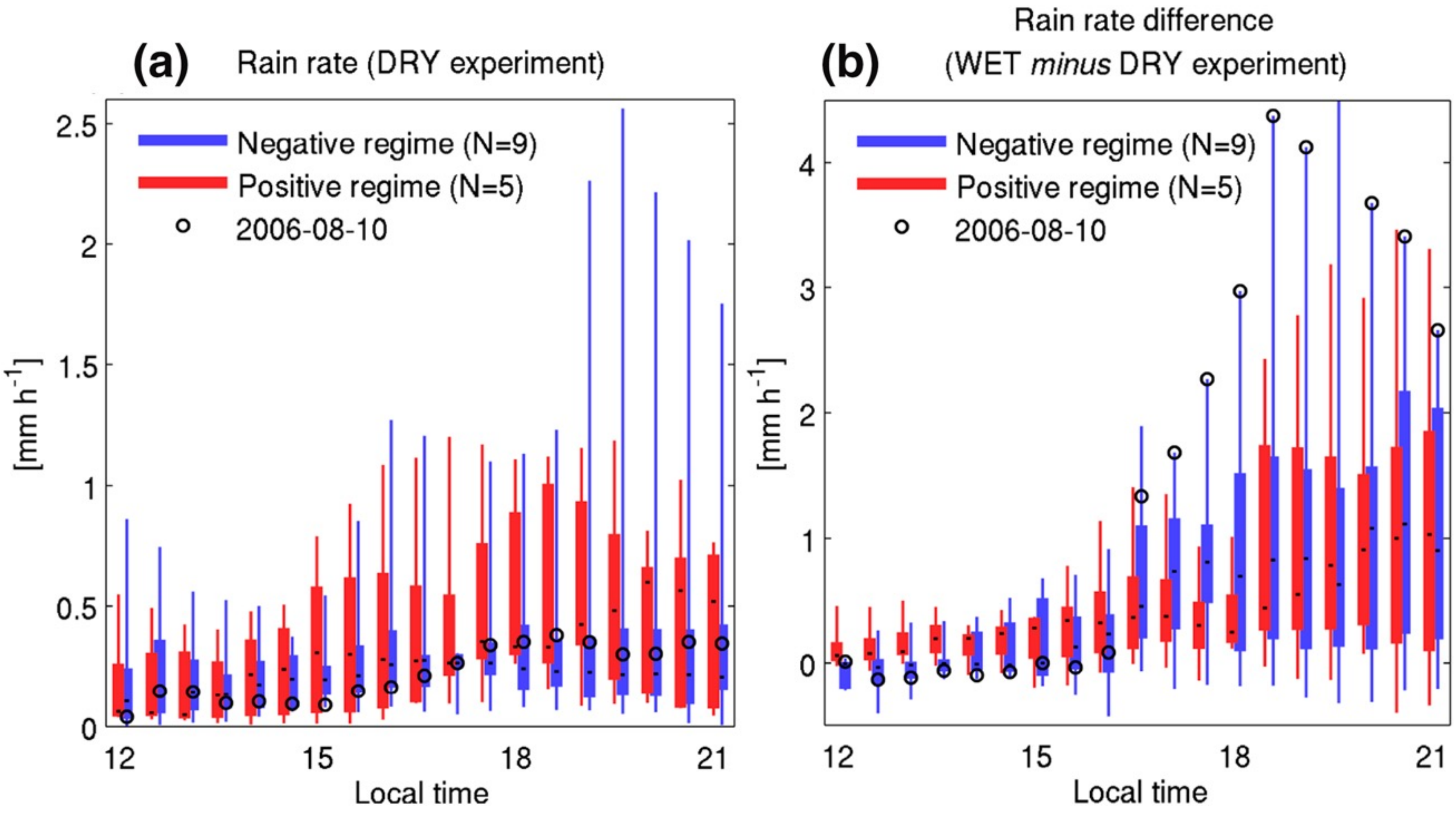
Motivation:

1. Investigate how surface energy partitioning affects the convective organization in real case experiments using a cloud resolving model.
2. Test hypothesized cold pool effects on convective organization.
3. Explore why some observed MCSs can develop and last into nighttime.

Methodology

- Weather Research and Forecasting (**WRF**, version 3.8.1) model. **DX=3 km**. Domain: 28N-42N, 105W-92W.
- Changed stomatal/soil resistance in Community Land Model Version 4 (**CLM4**). Soil moisture is perturbed (**WET or DRY**) to vary the surface energy partitioning.
- 14 locally developed MCSs near the US SGP site are chosen and simulated, with **9 in negative feedback regime** and **5 in positive feedback regime**, based on the morning low-tropospheric relative humidity and thermal stratification. The **2006-08-10** MCS case (negative feedback regime) is analyzed in detail.
- A simple cloud **entraining plume model** following Gentine et al. (2016) is used to investigate the relationship between entrainment and convective organization.
- Observation is also used for the 2006-08-10 MCS case: radar reflectivity is from **NEXRAD**; surface heat fluxes and surface wind speed are recorded by the ARM Energy Balance Bowen Ratio systems (**EBBR**) and eddy covariance instrument (**ECOR**). We also used the ARM Surface Meteorology Systems (**MET**) 1-min wind data in two sites (shown below), to be consistent with the instantaneous model output.

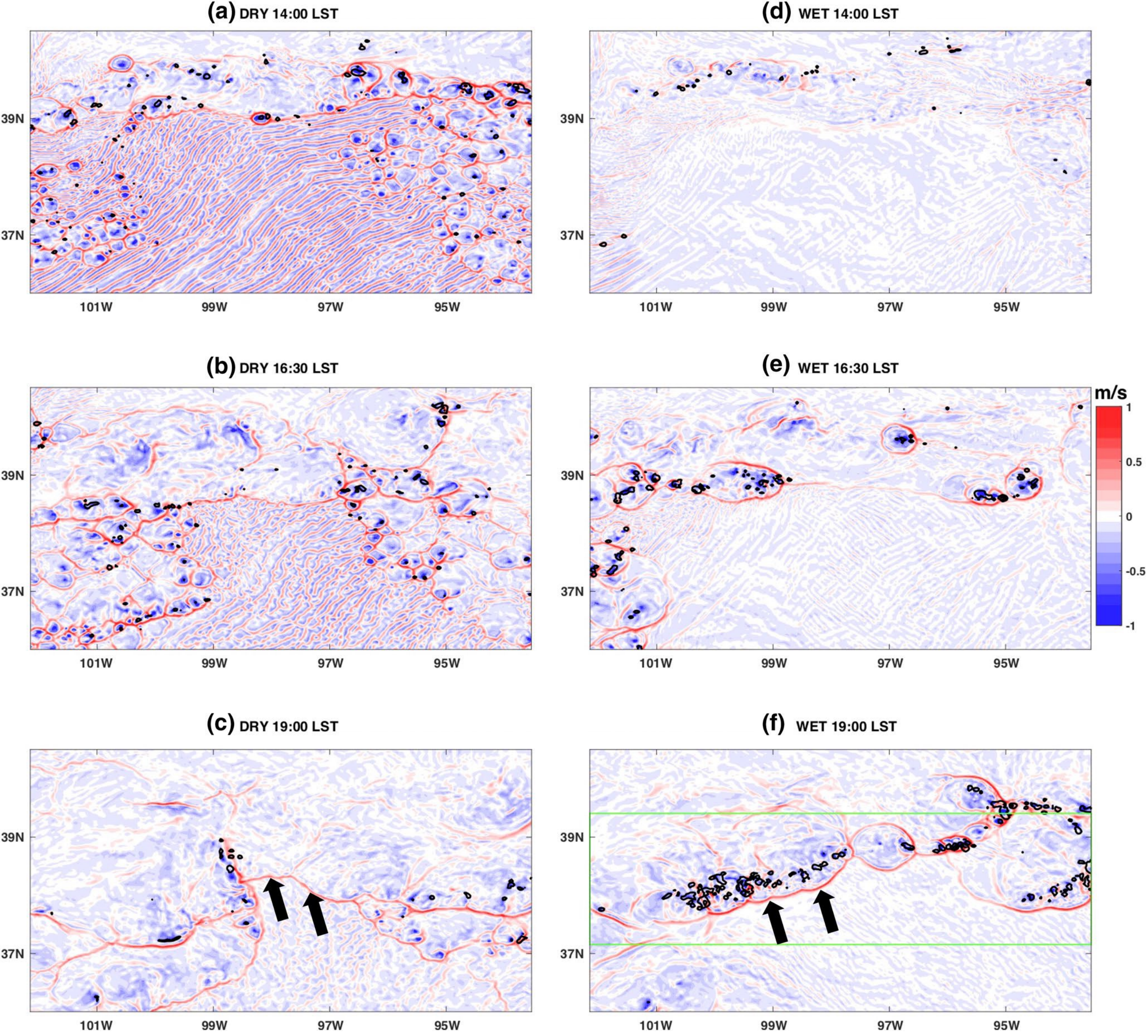
General Behavior



Before 15 LST, rain rate is larger (smaller) in WET than DRY in positive (negative) regime, consistent with convective triggering and regime relationship. However later on, larger rain rate (in most cases) occurs on a wetter surface, regardless of the feedback regimes.

Dai et al., 2021

2006-08-10 case



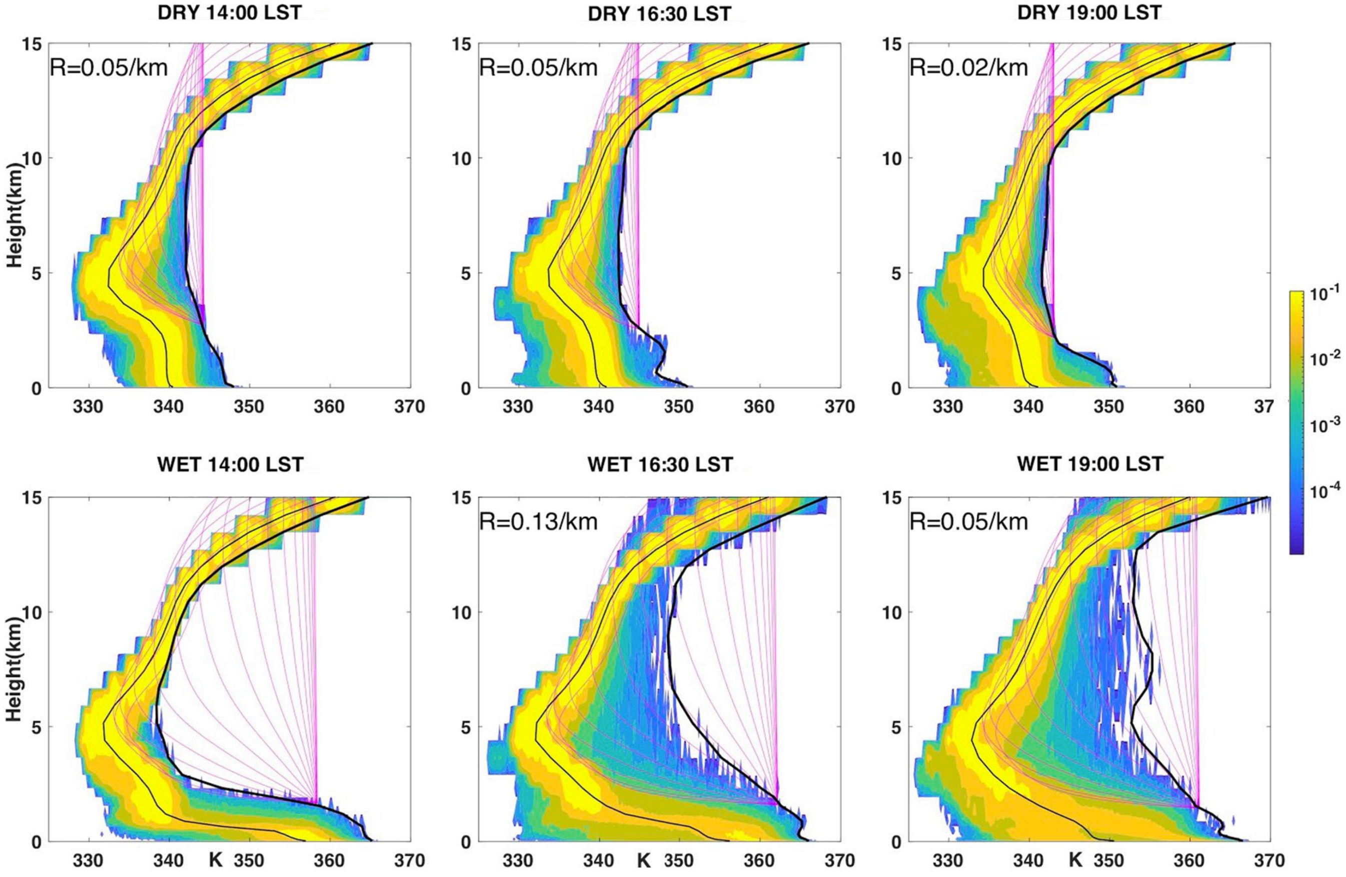
Shading: W at z=200m
Contour: W=2m/s at z=6km

- Deep convection is either at the center of the cold pool, or at the edge of the colliding gust fronts.
- DRY has much higher sensible heat flux than WET, creating turbulent horizontal rolls.
- **Convection is triggered earlier in DRY, but is better organized in WET later on.**

Dai et al., 2021

PDF of moist static energy (MSE)

Frozen MSE = $C_p * T + g * z + L_v * q_v - L_f * q_i$

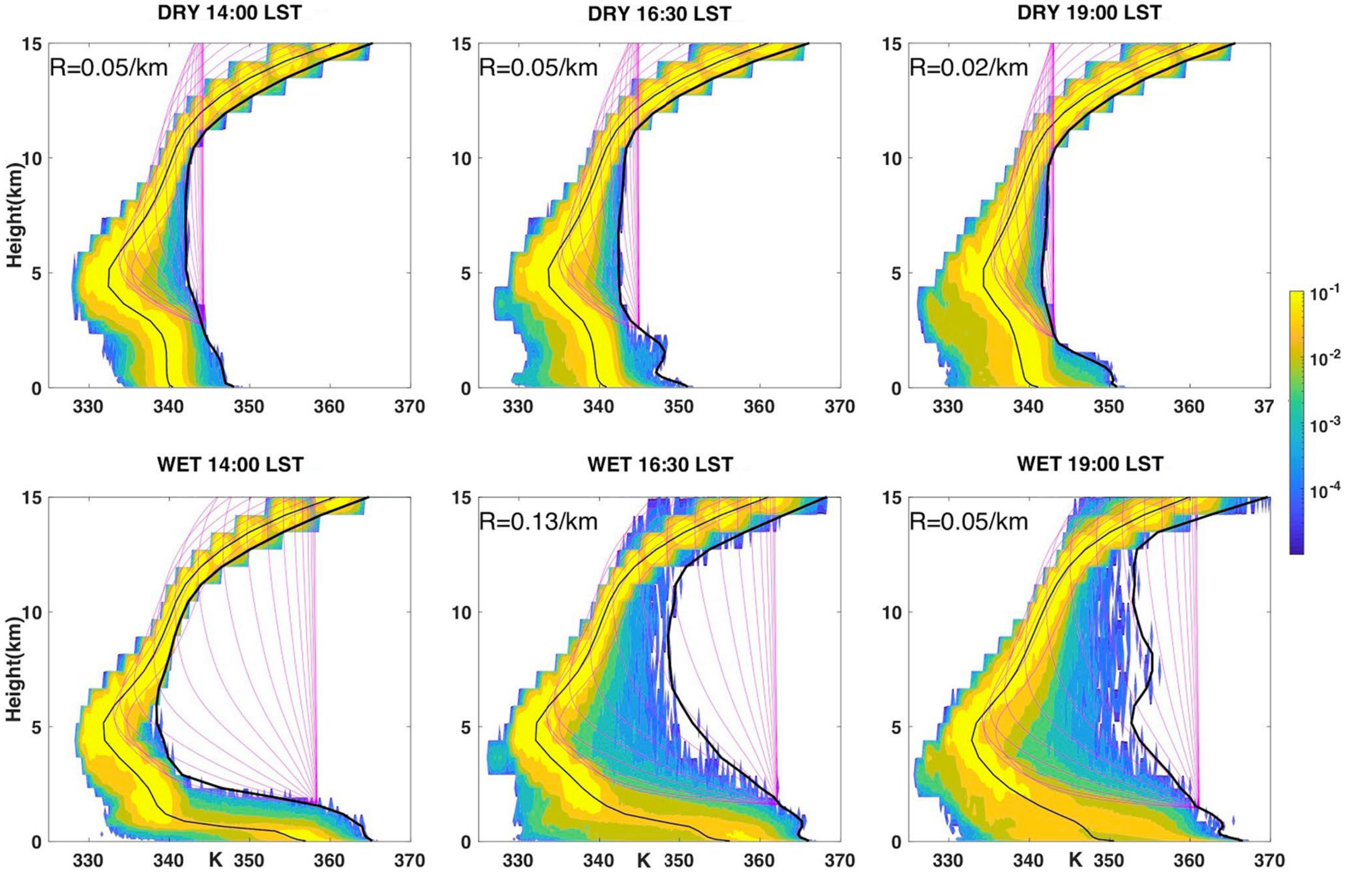


- ❖ Much larger PBL MSE, but shallower PBL height in WET than DRY
- ❖ Larger MSE also partly due to reduced upward longwave radiation, and reduced downward ground heat flux, a result of cooler surface in WET
- ❖ CAPE in WET: ~4000 J/kg, compared to <1000 J/kg in DRY

Dai et al., 2021

Entraining plume model

$$\frac{\partial MSE}{\partial z} = R\left(\overline{MSE} - MSE\right)$$



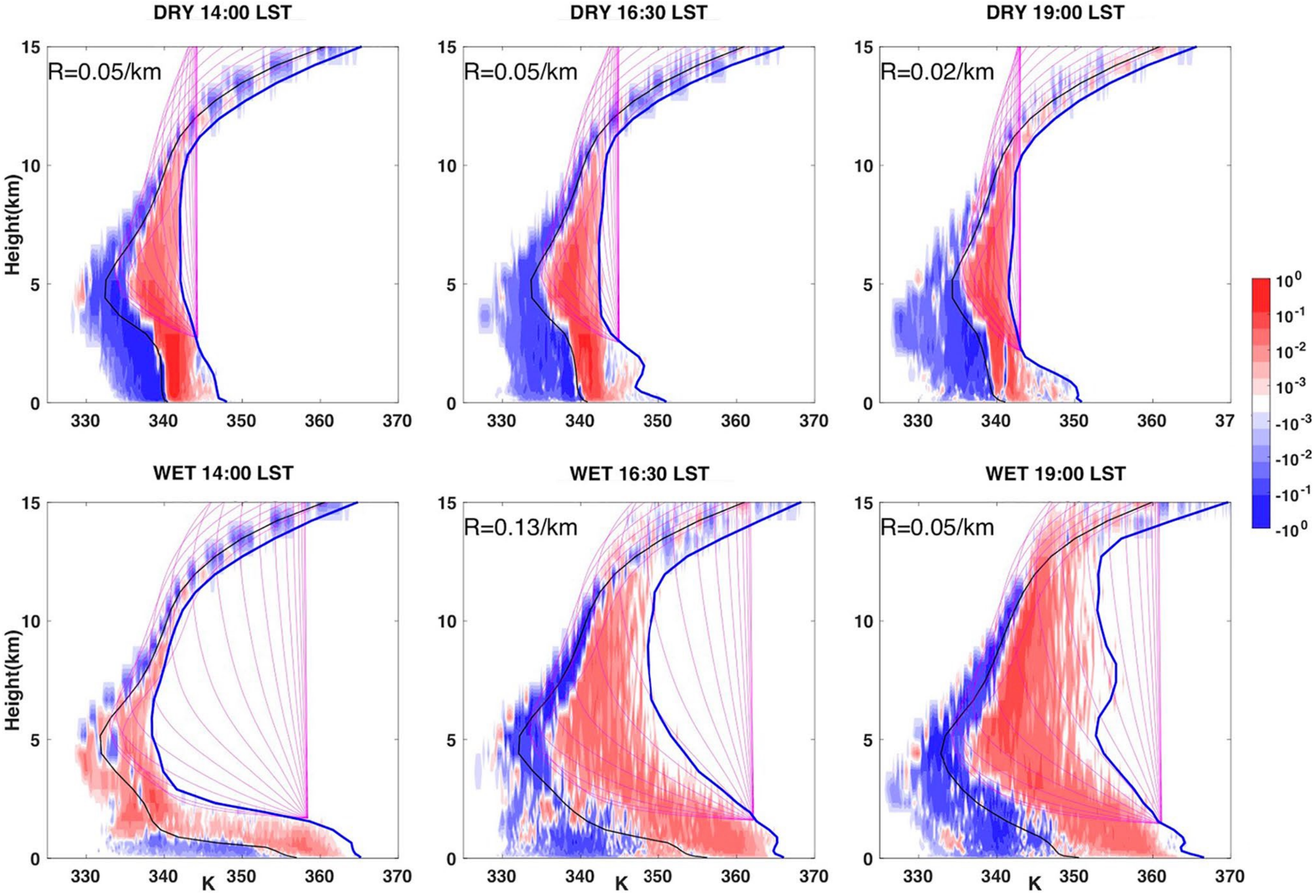
- ❖ Parcel starts with much lower MSE in DRY, reflecting much deeper and more entraining PBL.

- ❖ Smaller entrainment rate (R) in DRY than WET, suggesting the colliding cold pools help triggering convection in the early stage.

- ❖ R also decreases with time in WET at later stage, confirming the wider cold pool--the less R.

Dai et al., 2021

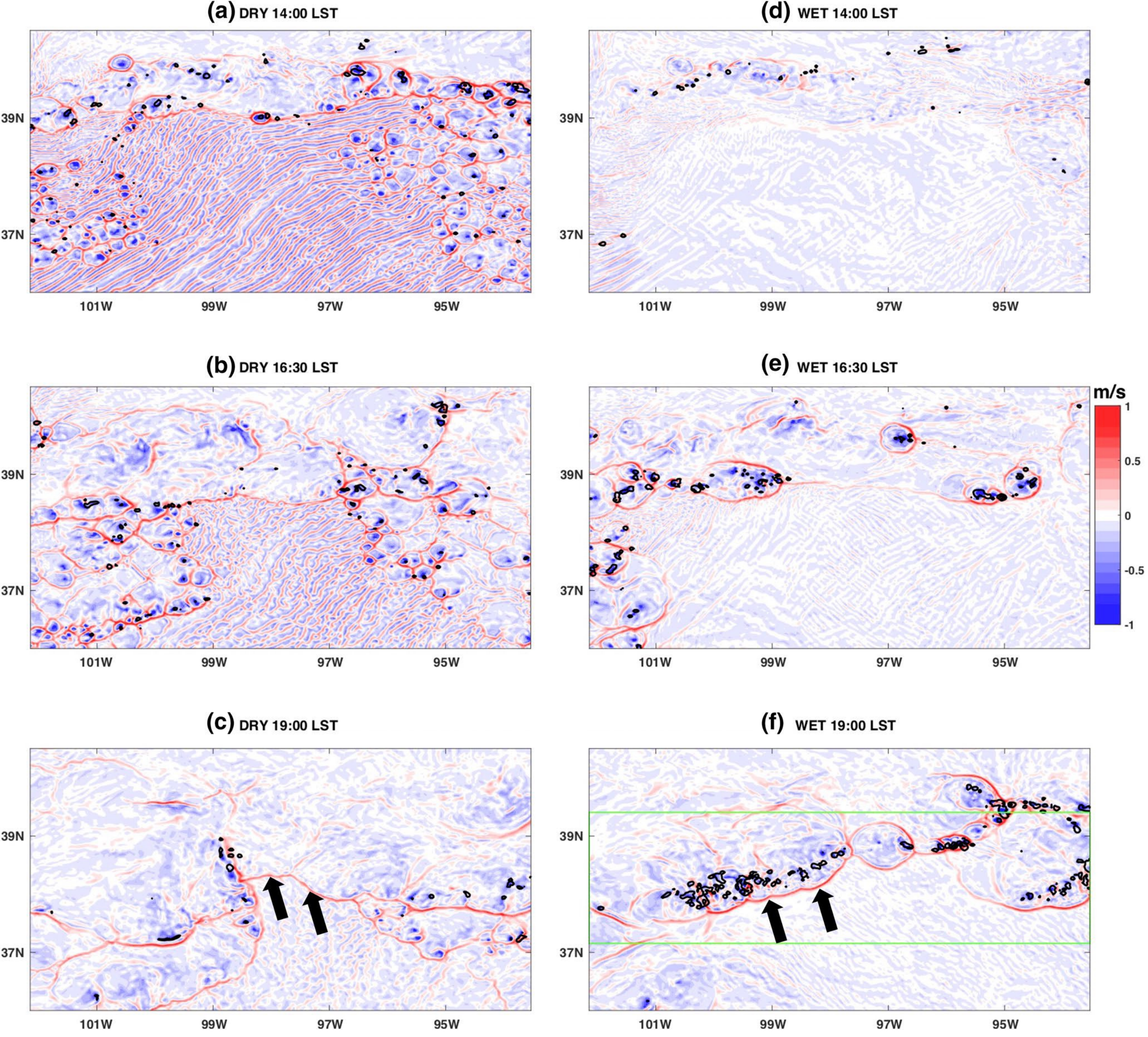
Vertical mass flux



Strong downward mass flux (cold pool activity) correlated with small R

Dai et al., 2021

2006-08-10 case



Shading: W at z=200m
Contour: W=2m/s at z=6km

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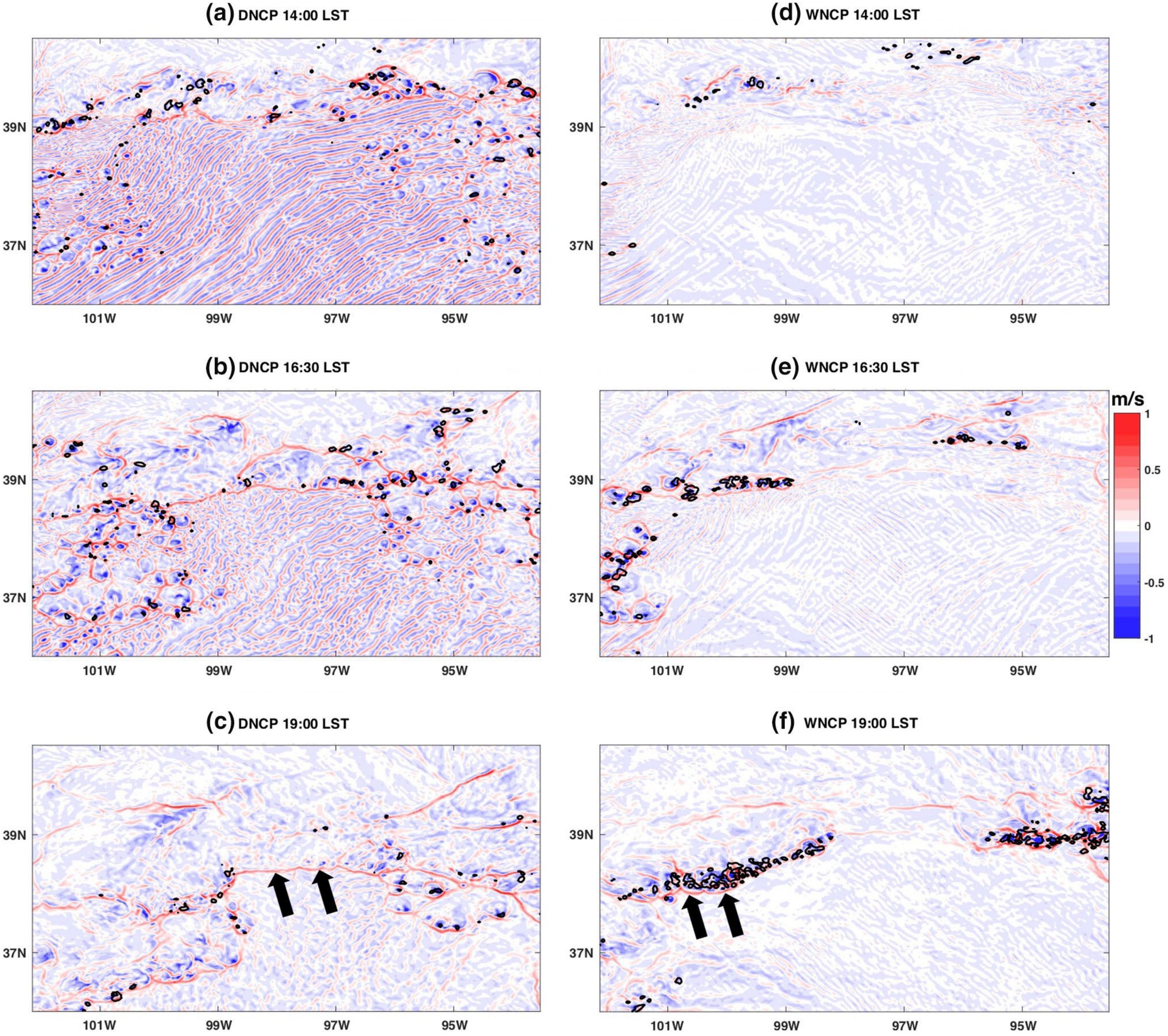
Dai et al., 2021

No cold pool: switching off evaporation

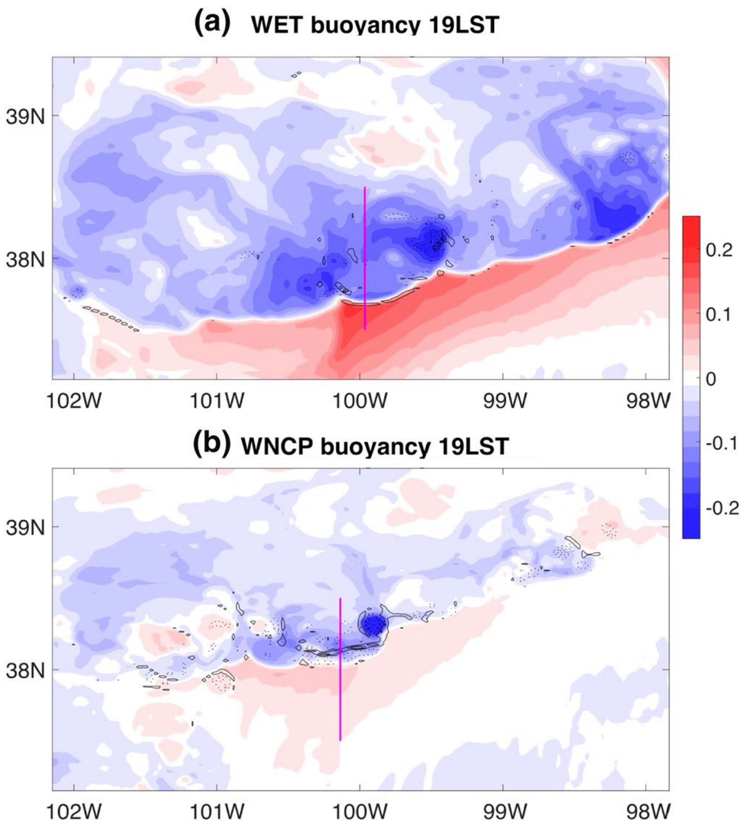


Surprisingly

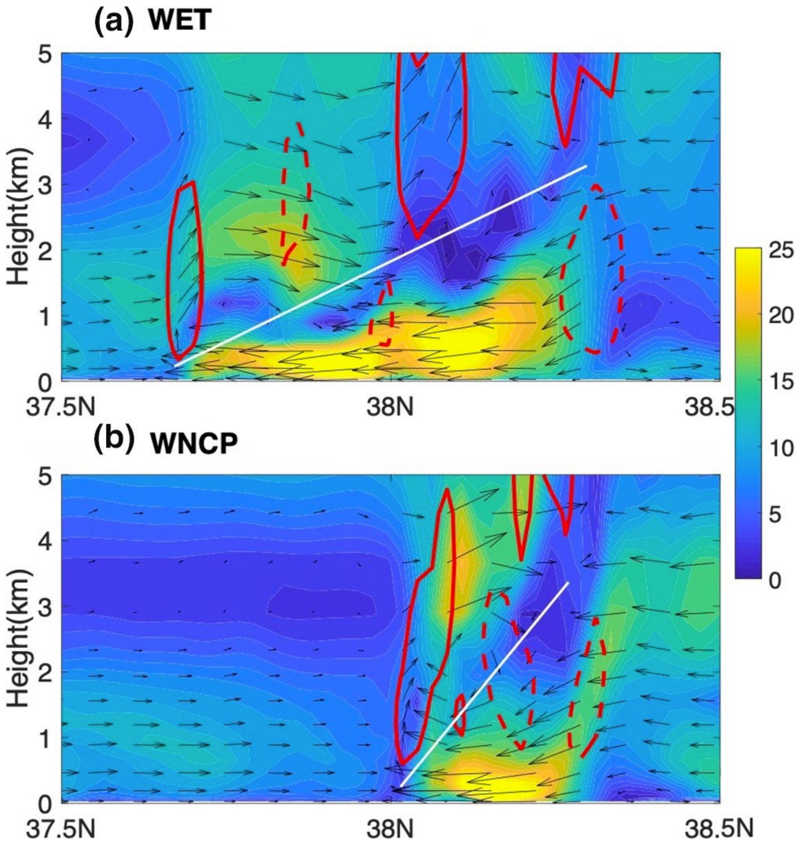
- ❖ Gust fronts still exist, except that horizontal propagation is weaker.
- ❖ Convective organization is even slightly better

Dai et al., 2021

2006-08-10 case



Buoyancy



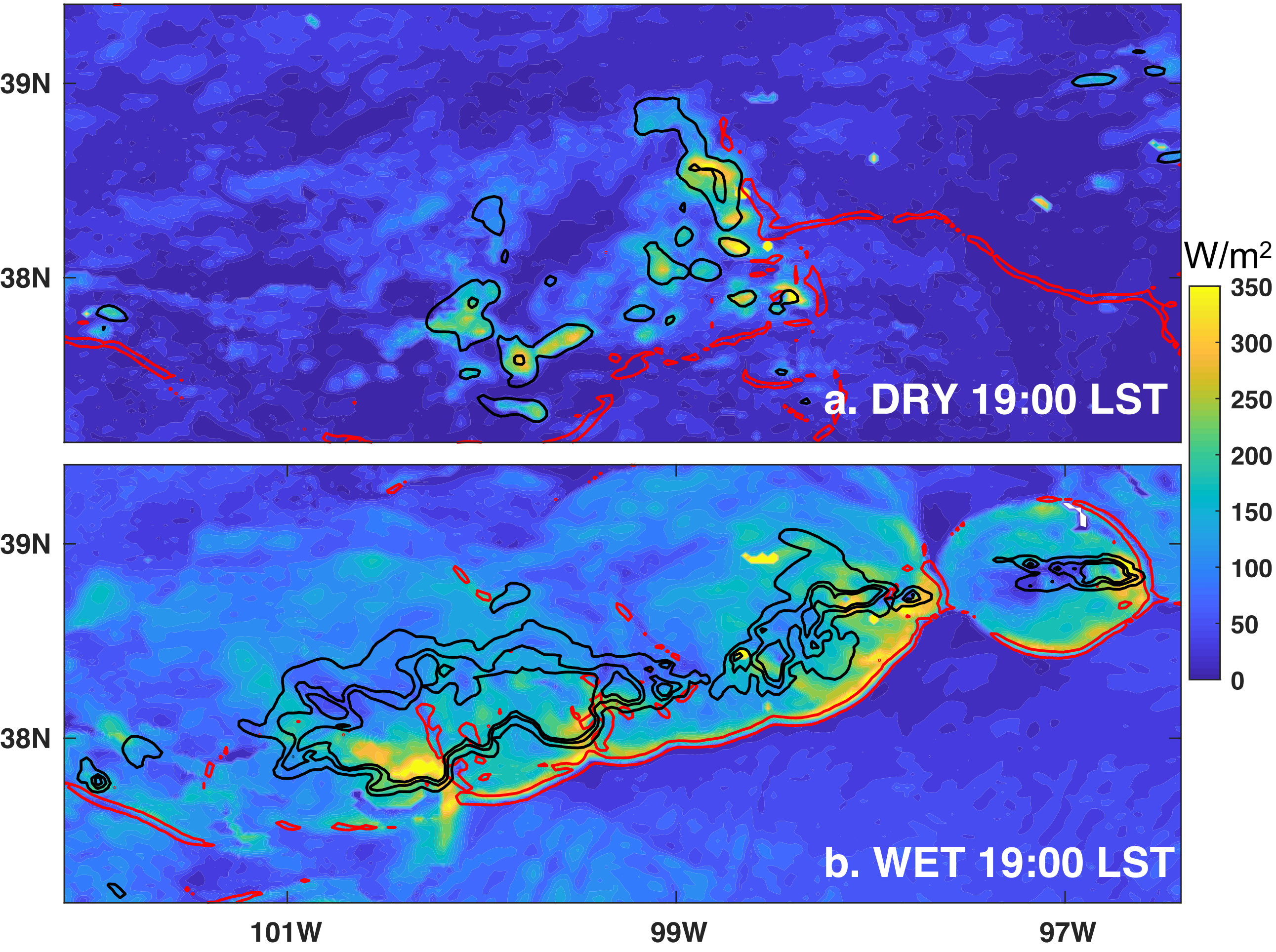
Shading: horizontal wind speed

Red contours: ±2 m/s

When density current in the cold pool is too strong, convection at the gust front is tilted upshear and weaker. This effect exists in the well-know RWK theory of squall lines (Rotunno et al. 1988), but not in current cold pool parameterizations, where gust-front lifting power is proportional to the integrated negative buoyancy.

Dai et al., 2021

Surface latent heat flux (LH)



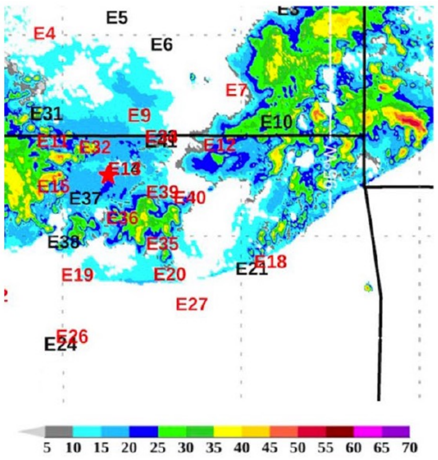
Shading: LH
Red contour: W=0.5 m/s at z=200m
Black contours: rain rate of 1, 5, 10 mm/h

Large LH in WET occurs at the location of gust fronts, not large rain rate.

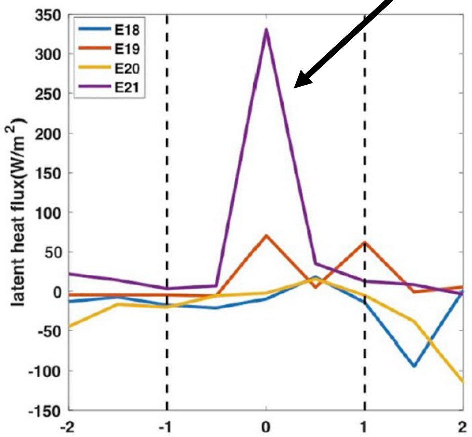
Dai et al., 2021

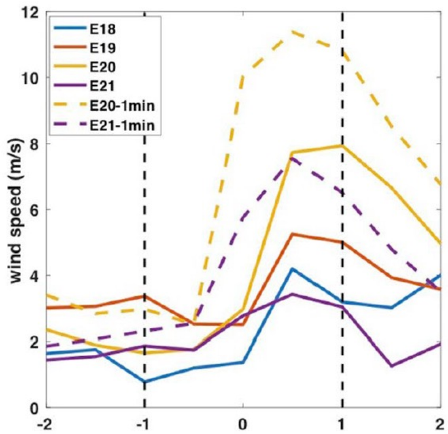
Surface latent heat flux (LH)

Observation

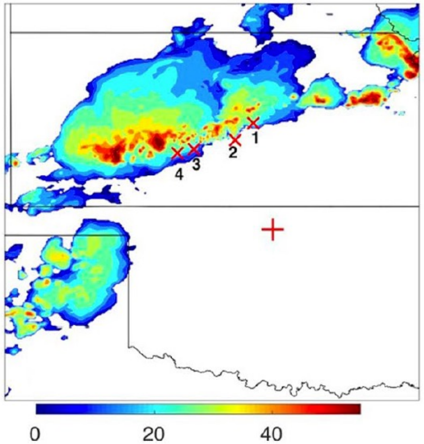


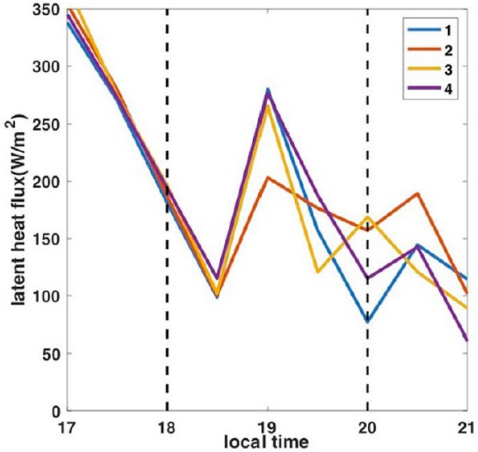
E21, a forest site!

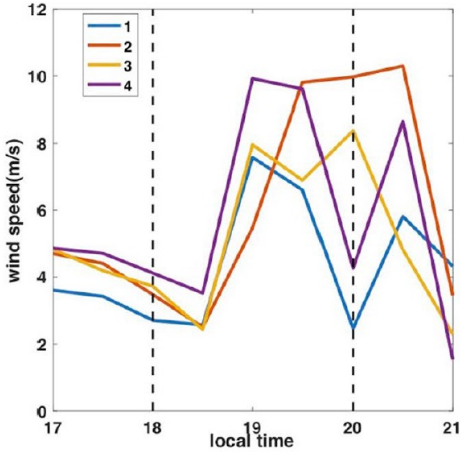




Model







Reflectivity

LH

Wind speed

Dai et al., 2021

Summary and Discussion

- Wet soil can lead to better organized convection than dry, constituting a positive rainfall feedback, despite earlier triggering over dry.

- Enhanced surface latent heat flux along gust fronts was found in both models and observations, that indicates interaction between land surface and convection.

- Cold pools can diminish or contribute to feedback; their effects vary with convective lifecycle stage and are not captured in parameterizations. The slantwise gust front updraft should be considered to counter the effect of negative buoyancy, which is the only important feature in current cold pool parameterization. Dynamical effect: land-shear interaction

Acknowledgments

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