Convective self-aggregation in a mean wind

Role of thermodynamic and dynamic processes

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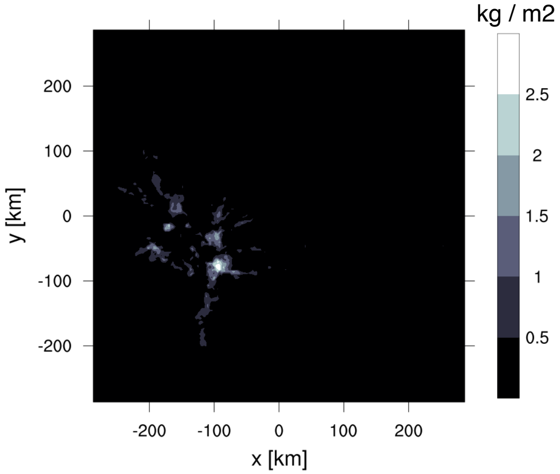
KEY POINTS

- Simulated organized convection in a mean wind using a convection-permitting model in radiative convective equilibrium
- In a mean wind, a convective cluster initially propagates, subsequently slows down and finally becomes stationary
- The surface momentum flux mainly modulates the propagation speed acting as a drag on the near-surface wind, while the surface enthalpy flux marginally contributes to the propagation speed

Motivation



Snapshot of the liquid water path in UCLA-LES in a RCE framework

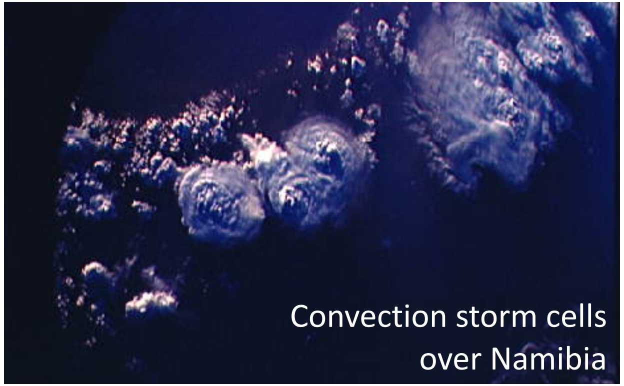


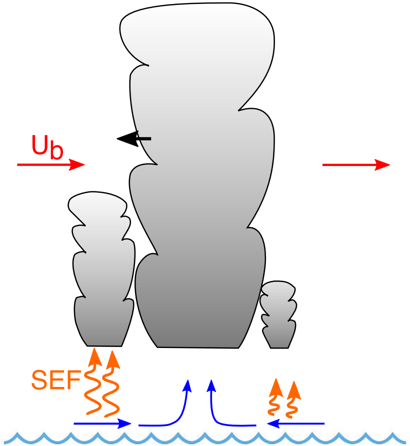
Image courtesy of the Earth Science and Remote Sensing Unit (STS005-44-1739), NASA Johnson Space Center

- Similarities between convective self-aggregation and tropical deep convection
- No large-scale background flow considered in the self-aggregation studies

*Introduce **a large-scale background flow** to a convection-permitting simulation to analyze the behavior of convective self-aggregation in the mean flow*

Hypothesis

Propagation of a convective cluster through the wind-induced surface heat exchange (WISHE) feedback (Emanuel, 1987)



Upwind side:

- *Intensified* wind through the low-level circulation in a mean wind u_b
- *Enhanced* surface enthalpy fluxes (SEF)

Downwind side:

- *Reduced wind* through the low-level circulation in a mean wind u_b
- *Suppressed* surface enthalpy fluxes (SEF)

Asymmetry of SEF → Preference of the development of convection on the **upwind** side

→ *The convective cluster would propagate upwind!*

Simulation setup

- UCLA-LES in radiative convective equilibrium
  - Δx = 3 km and a stretched vertical grid levels (Δz_{min} = 75 m)
  - on a domain size of 576x576x27 km^3
  - following Hohenegger and Stevens (2016)

- No convective parameterization
- Sub-grid fluxes with Smagorinsky model
- Homogeneous initial conditions
- Cyclic boundary conditions
- No Coriolis force, no diurnal cycle
- SST = 301 K

Research focus:
How a convective cluster behaves in a mean wind.

→ Simulation is run for **26 days** until convection is self-aggregated.

After day 26 ..

Impose a mean wind

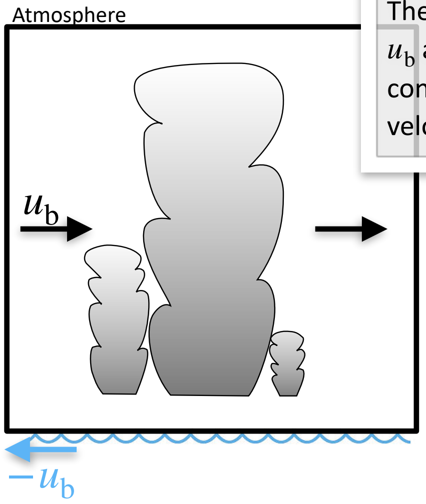
- A mean wind u_b is imposed through the surface flux calculation to minimize the vertical shear

Momentum flux $F_\mathrm{m} = \rho\,(\overline{w'u'}^2 + \overline{w'v'}^2)^{\frac{1}{2}}|_\mathrm{sfc}$

Surface enthalpy flux $\mathrm{SEF} = \rho\,(c_p\,\overline{w'\theta'} + l_\mathrm{v}\,\overline{w'q'})|_\mathrm{sfc}$

$$\overline{w'u'}^2 + \overline{w'v'}^2 = \boldsymbol{u}_*^2$$
$$\overline{w'\theta'} = -\,\boldsymbol{u}_*\theta_*$$
$$\overline{w'q'} = -\,\boldsymbol{u}_*q_*$$

The modeled flow u feels u_b as if u is on a moving conveyor belt with a velocity of $-u_\mathrm{b}$



The turbulence scale of velocity $\boldsymbol{u}_*$ is proportional to the near-surface horizontal velocity u_h.

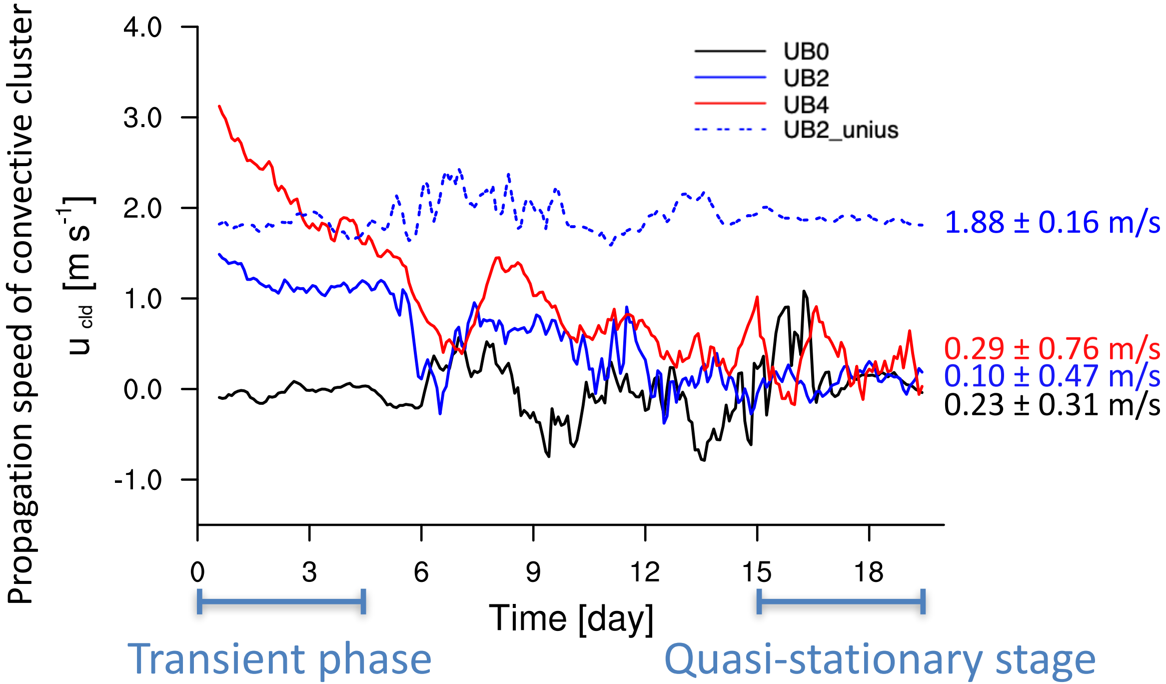
$$u_h = \sqrt{(u+u_b)^2 + v^2}$$

Experiment	$u_\mathrm{b}\,[m\ s^{-1}]$
UB0	0
UB2	2
UB4	4
UB2_unius	2

Each experiment is run for 20 days.

UB2_unius:
u_* = 0.09 m/s in F_m (not in SEF!)

How does a convective cluster propagate in the mean wind?



- Transient phase:

$$u_{\mathrm{cld}} < u_{\mathrm{b}}$$

→ Convection propagates upwind!

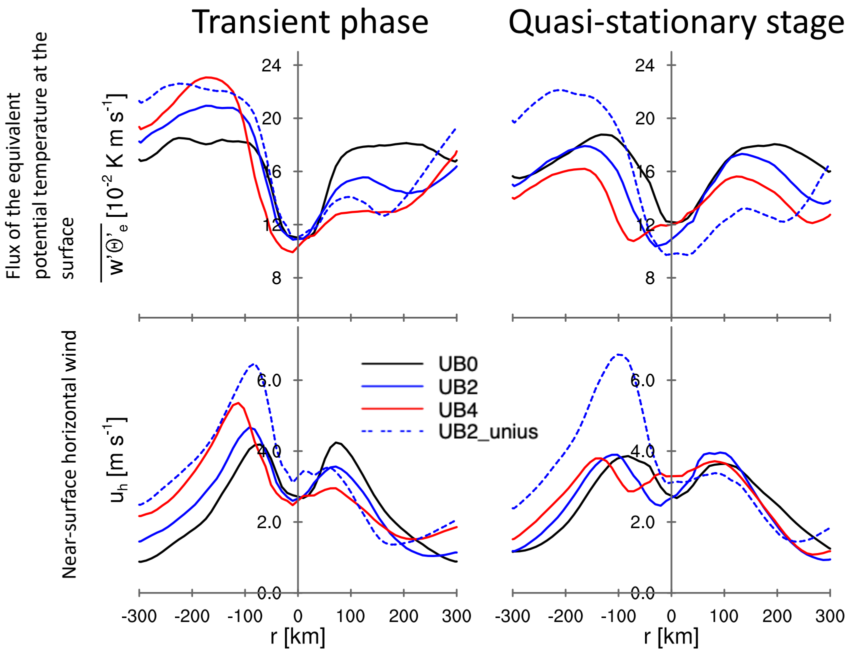
- Quasi-stationary stage:

$$u_{\mathrm{cld}} = 0 \text{ m/s}$$

Why does propagation speed arrive at 0 m/s regardless of the mean wind speed???

*Note that here day 0 indicates the time when the mean wind begins to be imposed.

Thermodynamic response to the mean wind



r=0, center of a convective cluster
r<0, upwind side
r>0, downwind side

*Note that $\overline{w'\theta_e'}$ is a indicator of SEF

$$\overline{w'\theta_e'} \approx \left[\overline{w'\theta'} + \frac{l}{c_p}\left(\frac{p_0}{p}\right)^{\frac{R_{c_p}}{c_p}}\overline{w'q'}\right]$$

- **Asymmetry** w.r.t. the center of the convective cluster in the transient phase
- Asymmetry in $\overline{w'\theta_e'}$ agrees with the hypothesis.
- Same spatial distribution in u_h but not in Δq or $\Delta\theta$

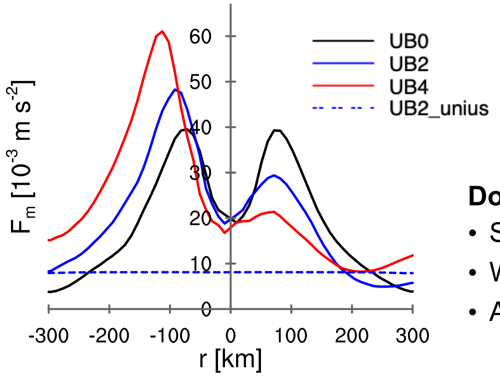
- **Symmetry** in the quasi-stationary stage
- How do the asymmetries become symmetric?
- Why is a convective cluster NOT advected in a mean wind, instead stationary?

Role of the surface momentum flux F_m acting as a drag

Upwind side:

- Enhanced F_m
- Strong drag on u_h
- Decrease in u_h

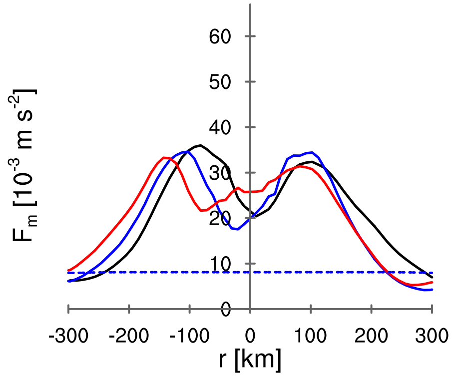
Transient phase



Downwind side:

- Suppressed F_m
- Weak drag on u_h
- Attaining u_h

Quasi-stationary stage



→ the near-surface horizontal wind u_h has the comparable maximum on the upwind and downwind sides.
Symmetrized!

→ Symmetry in u_h results in the surface turbulent fluxes (F_m, SEF) in the quasi-stationary stage

Does the momentum flux dominantly modulate the near-surface wind?

UB2_unius

- Experiment to suppress the dynamic feedback modulating the interaction between the surface momentum flux F_{m} and the near-surface horizontal wind u_{h}

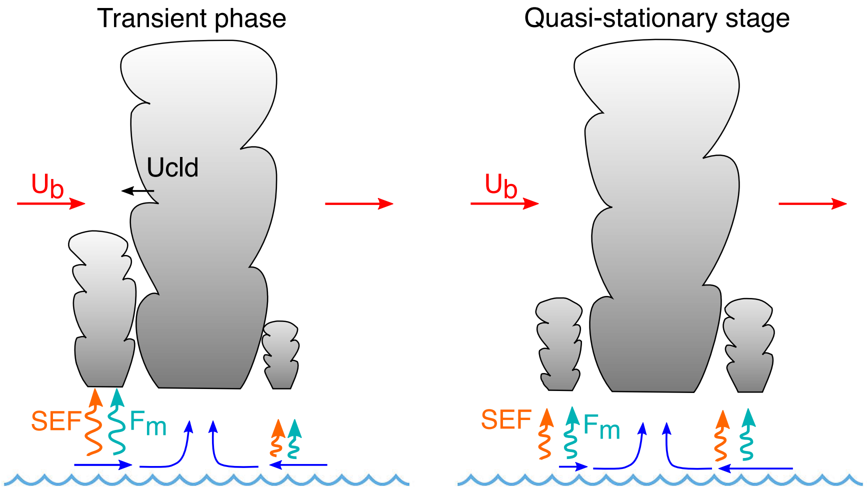
- Propagation speed: u_{cld} = 1.88 m/s
  - smaller than the mean wind speed u_{b}= 2 m/s
  - convective cluster indeed propagates upwind

- Asymmetry of the thermodynamic flux $\overline{w'\theta_{\mathrm{e}}'}$ in the transient phase and the quasi-stationary stage

***Yes**, the thermodynamic response to the mean wind contributes to the propagation speed to a small extend.*

Conclusion

- In a mean wind, the convective cluster propagates upwind, slows down, and eventually becomes stationary.
- The dynamic response to the mean wind dominates the propagation as the surface momentum flux acts as a drag on the near-surface wind, which consequently feeds back moderating surface turbulent fluxes.
- The thermodynamic feedback, through WISHE, is very weak and is regulated by the dynamic feedback.



References

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