From Sugar to Flowers:
A Transition of Shallow Cumulus Organization During ATOMIC

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1. Background

ATOMIC = The Atlantic Tradewind Ocean-Atmosphere Mesoscale Interaction Campaign

- A U.S. counterpart of the European EUREC⁴A campaign.
- Took place in January – February 2020 in the Atlantic Ocean east of Barbados.
- To understand the relationship between shallow convection and large-scale conditions in the trade wind regime.

Shallow Cumulus Organization

- Different states of shallow cumulus organization often correlate with different meteorological states.
- They can be categorized into four states: sugar, gravel, fish, and flowers (i.e., Bony et al., 2020[1]).

Objectives

- To reproduce the transition of shallow cumulus organization – from sugar to flowers – observed on February 2-3, 2020.
- To determine primary mechanisms responsible for the transition.
- To understand the relationship between the large-scale vertical velocity and the transition of the mesoscale organization.

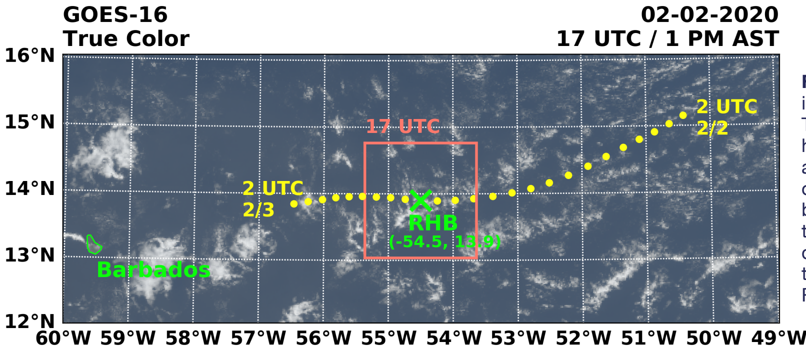
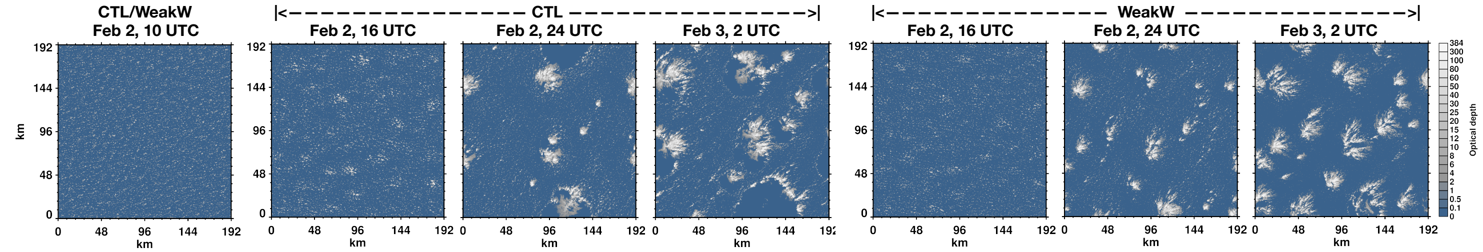


Fig. 1: A GOES-16 satellite image at 17 UTC on Feb 2. The yellow dots represent hourly coordinates of the airmass following trajectory on which the simulations are based. The red box indicates the simulation's 192×192 km² domain extent, centered at the NOAA Research Vessel Ronald H. Brown.

2. Simulation Setup

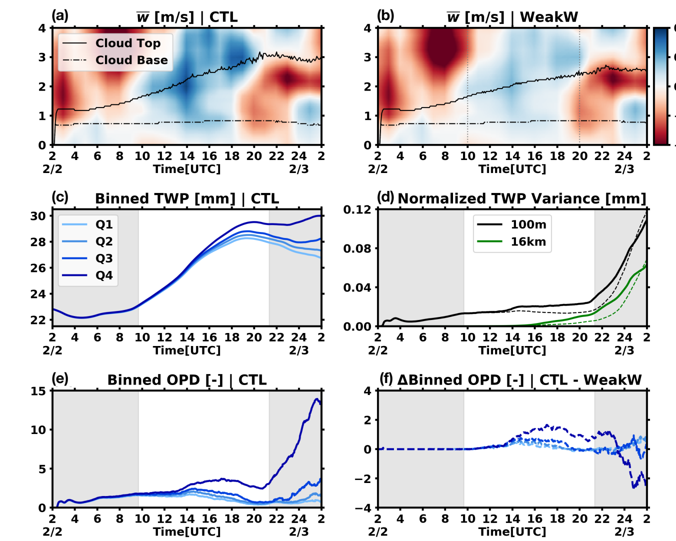
- **Lagrangian large-eddy simulations (LES)**:
  - Large-scale forcing derived from ERA5 reanalysis, with trajectory following airmass at 500 m altitude.
  - Aside from the control simulation (*CTL*), an additional simulation called ***WeakW*** is run with weaker large-scale vertical velocity when the cloud layer was deepening (Fig. 3a-b).
- **Using the System for Atmospheric Modeling (SAM)**[2]:
  - Resolution: $\Delta x = \Delta y = 100$ m $\Delta t = 2$ s
    $\Delta z = 50$ m increasing geometrically from 4 km to 8 km.
  - Domain size: $L_x = L_y = 192$ km $L_z = 8$ km with ERA5 forcing up to TOA.
  - Bulk two-moment bin-emulating microphysics scheme.[3]
  - Rapid radiative transfer model for global climate model applications (RRTMG) radiation scheme[4] with time-varying atmospheric profiles above domain top.
- **In-situ aerosol data measured from the NOAA Research Vessel Ronald H. Brown (RHB)** are used to initialize the aerosol number concentration and mineral dust. The sea salt aerosols are coupled with the microphysics scheme. The dust properties are coupled with the RRTMG radiation scheme.

3. Results

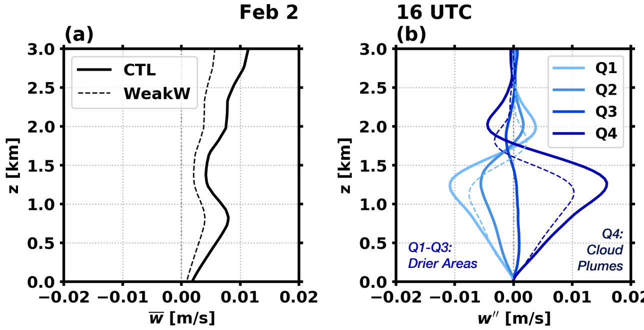


Sugar to Flowers Transition

- Positive large-scale vertical wind ($\overline{w}$) deepens the cloud layer; total water path (TWP) increases during the deepening (Fig. 3a-b).
- TWP binned into quartiles has a wider and asymmetric distribution as the organization becomes stronger (Fig. 3c).
- The TWP variance is also a proxy for organization (Fig. 3d).
- Total (cloud+rain) optical depth (OPD) binned by TWP is largest in the moistest quartile (Q4) in which flowers aggregate. (Fig. 3e)
- During the time with stronger upward vertical motion, *CTL* has higher optical depth than ***WeakW*** in all quartiles — with the greatest difference in Q4 (Fig. 3f).



(Top) **Fig. 2:** Snapshots of total optical depth from *CTL* and *WeakW*.
(Right) **Fig. 3:** Time series of large-scale vertical velocity, total water path (TWP) binned into quartiles, normalized TWP variances, total optical depth (OPD) binned by TWP, and the difference in binned OPD between *CTL* and *WeakW*.
(Bottom) **Fig. 4:** Vertical profiles of the domain-mean vertical velocity and the mesoscale perturbation coarse-grained to 16-km tiles at 16 UTC on Feb 2.



Mechanisms of Transition

- The mesoscale perturbation of W from domain mean (w'') is positive in the cloud plumes and negative in the inversion aloft (Q4):
  - ➡ Ascending air in the cloud plumes supports shallow convection.
  - ➡ *Net* convergence of moisture in the moist patches:
    - Moisture convergence in and below the cloud plumes.
    - Moisture divergence in the stratiform clouds and inversion.
- The sign is reversed in the drier quartiles (Q1-Q3).
  - ➡ Descending air in drier patches suppresses cloud formation.
- Consistent with a previous study of other shallow cumulus cases.[5]
- Stronger W" in *CTL* drives stronger *net* moisture convergence

4. Conclusions

- Lagrangian LES can reproduce the transition of shallow cumulus organization from sugar to flowers observed on February 2-3, 2020 during ATOMIC.
- While the large-scale upward vertical wind deepens the cloud layer, the mesoscale wind leads to net moisture convergence in the moist and cloudy areas. This renders moist areas moister, assisting cloud organization.
- Stronger large-scale upward motion strengthens the mesoscale circulation and accelerates the transition process.

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