Lagrangian Large Eddy Simulation of Trade Cumulus Organization During ATOMIC

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1. Background

ATOMIC = The Atlantic Tradewind Ocean-Atmosphere Mesoscale Interaction Campaign

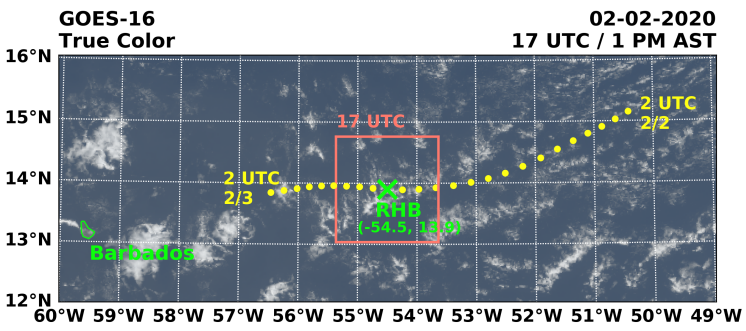
- A U.S. counterpart of the European EUREC⁴A campaign.
- Took place in January – February 2020 in the Atlantic Ocean east of Barbados.
- To understand the relationship between shallow convection and large-scale conditions in the trade wind region.

Shallow Cumulus Organization

- Different states of shallow cumulus organization often correlate with different meteorological states.
- They can be categorized into four states: Sugar, Fish, Gravel, 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.



2. Simulation Setup

- Lagrangian large-eddy simulation (LES):
  - Large-scale forcing derived from ERA5 reanalysis.
  - Trajectory following the airmass at 500 m altitude.
- 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 radiation scheme (RRTM)[4] with time-varying atmospheric profiles above domain top.
- In-situ aerosol data measured from the Ronald H. Brown ship (RHB) are used to initialize the aerosol number concentration and mineral dust. The dust properties are coupled with the RRTM radiation scheme.

References

1: Bony, S., H. Schulz, J. Vial, and B. Stevens, 2020: Sugar, gravel, fish and flowers: Dependence of mesoscale patterns of trade-wind clouds on environmental conditions. *Geophys. Res. Lett.*, **47**, e2019GL085988.
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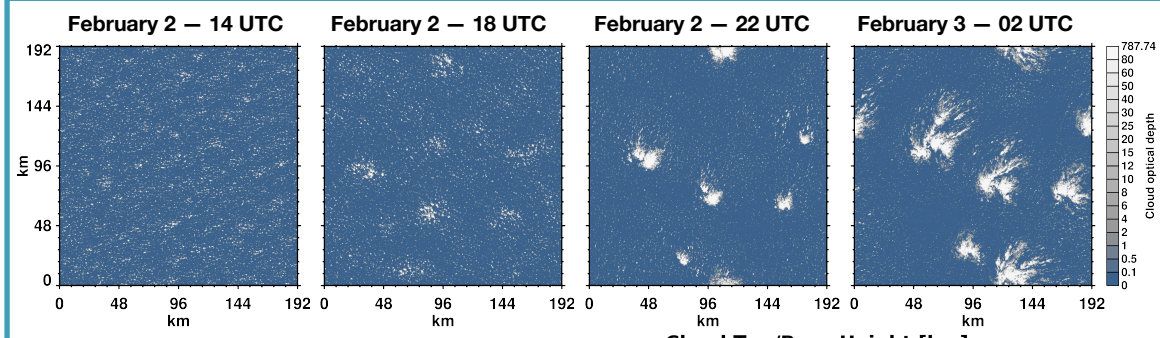
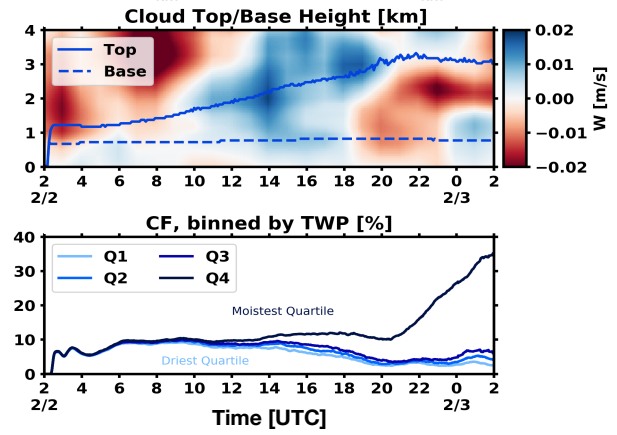
4: Mlawer, E. J., S. J. Taubman, P. D. Brown, M. J. Iacono, and S. A. Clough, 1997: Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave, *J. Geophys. Res.*, **102**(D14), 16,663-16,682.
5: Bretherton, C. S., and P. N. Blossey, 2017: Understanding mesoscale aggregation of shallow cumulus convection using large-eddy simulation. *J. Adv. Model. Earth Syst.*, **9**, 2798– 2821.

3. Results



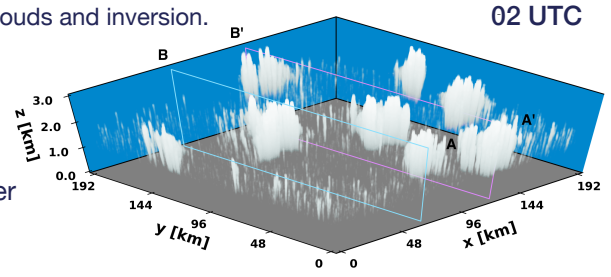
Sugar to Flowers Transition

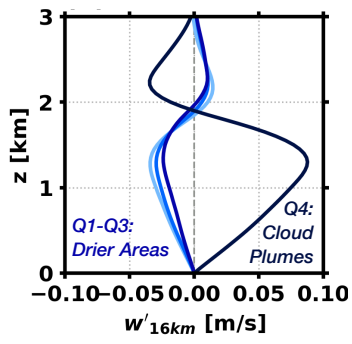
- Positive large-scale vertical wind (W) deepens the cloud layer; total water path increases during the deepening.
- Cloud fraction (CF) binned by total water path (TWP) has a wider and asymmetric distribution as the organization becomes stronger — Flowers aggregate in the moistest quartile (Q4).

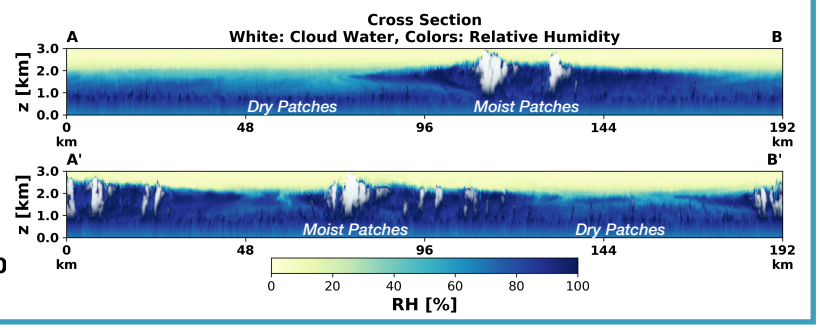


Mechanisms of Transition

- The mesoscale perturbation of W from domain mean coarse-grained to 16 km (W'_{16km}) is positive in the shallow cumulus 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 the dry patches suppresses cloud formation.
- Consistent with a previous study of other shallow cumulus cases.[5]







4. Conclusions

- A Lagrangian LES can reproduce a transition of shallow cumuli observed during ATOMIC, particularly from Sugar to Flowers.
- The mesoscale circulation leads to net moisture convergence in the moist & cloudy areas, and net moisture divergence in the dry areas.
- As the organization strengthens, the moist columns get moister and the dry columns get drier.

Future work:

- To examine processes and conditions that are important for the initial stage of organization, i.e., large-scale vertical velocity and moisture distribution.
- To explore the cloud-aerosol-radiation interaction during the transition.

Acknowledgments

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