Relationships Between Tropical Oceanic Convective Structure and Near-storm Environments Through the Lens of Idealized Numerical Modeling

Benjamin D. Rodenkirch[1], Angela K. Rowe[1], Rosimar Rios-Berrios[2], George H. Bryan[2]

[1]*University of Wisconsin-Madison, Department of Atmospheric and Oceanic Sciences,* [2]*NSF National Center for Atmospheric Research*

Background & Motivation

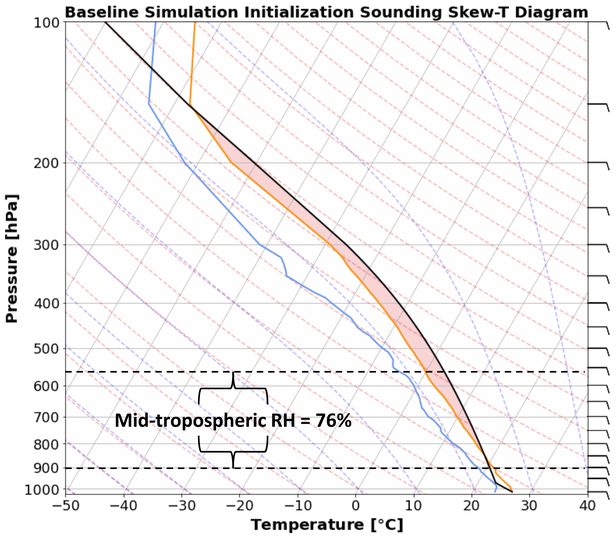
- Tropical oceanic convection (TOC) remains challenging to forecast, partly due to a lack of understanding of how local moisture and vertical wind shear conditions influence TOC structure.
- Airborne observations from the NASA CPEX (-AW, -CV) field campaign series [1] in the tropical Atlantic suggest that enhanced near-storm mid-tropospheric moisture and vertical wind shear favor larger and more intense TOC systems [2].
- The limited number of sampled convective systems during CPEX and difficulty with observations in discerning the relative importance of coexisting environmental factors necessitate supplemental means for exploring TOC relationships with local environments.
  - → **CPEX near-storm observations serve as benchmark databases for complementary idealized numerical modeling studies of TOC, where moisture and vertical wind shear impacts can be better isolated.**

→How do local environmental relative humidity (RH) and vertical wind shear influence 3-D TOC structure?

CM1 Idealized Simulations

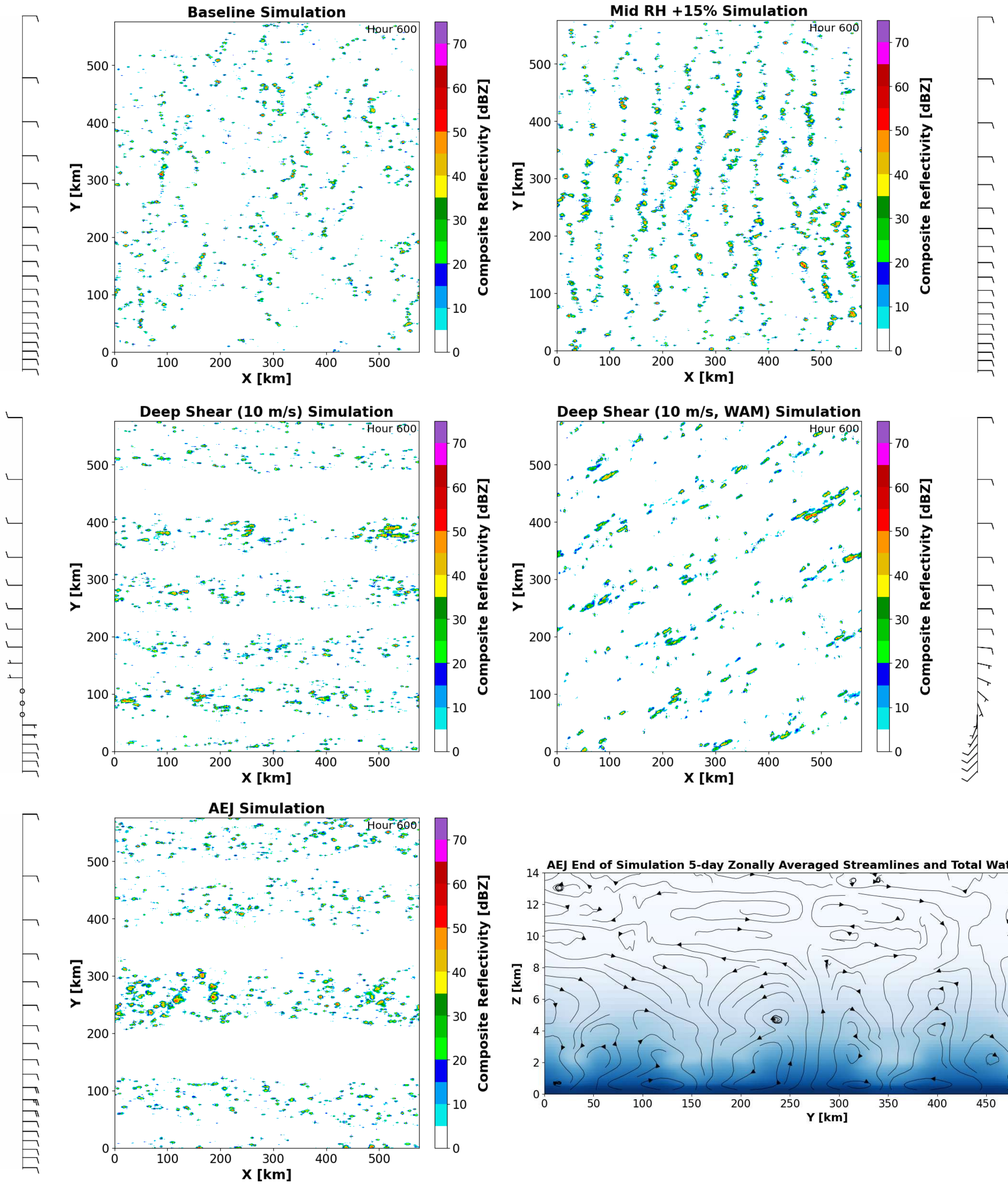
- Cloud Model 1 (CM1) [3] idealized numerical model simulations of TOC
- TOBAC algorithm for identification and spatial analysis of TOC systems
- I_{org} domain convective organization ("non-randomness") algorithm
- 30-dBZ composite reflectivity threshold used for defining individual TOC systems in TOBAC and I_{org} algorithms

- **Baseline simulation setup**:
  - 25-day runtime
  - 576-km x 576-km square domain
  - 1-km horizontal resolution
  - Stretched vertical grid (resolution range: 0.1-km to 0.5-km)
  - Doubly periodic boundary conditions
  - Morrison double-moment microphysics scheme
  - Uniform SST: 29 °C
  - **Initial wind profile**: uniform 5 m/s easterly winds
  - **Initial thermodynamic profile**: mean convective inflow environment captured by CPEX dropsondes



Domain-wide Horizontal Convective Structure Comparisons

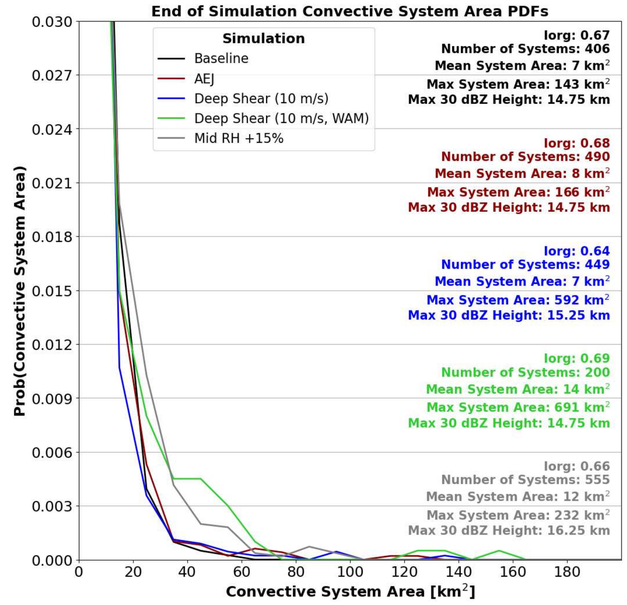
- **CM1 sensitivity simulations:**
  - **Mid RH +15%**: RH is increased by ~15% in the mid-troposphere (PBL top (900 mb) – freezing level (~570 mb))
  - **Deep Shear (10 m/s)**: 5 m/s easterlies in the PBL (below 900 mb) linearly transition to 5 m/s westerlies above 400 mb
  - **Deep Shear (10 m/s, WAM)**: 5 m/s southwesterlies (mimicking West African monsoon (WAM) flow) in the PBL linearly transition to 5 m/s easterlies above 400 mb
  - **AEJ**: a 13 m/s Gaussian mid-level (800 – 500 mb) easterly jet mimics an African Easterly Jet (AEJ)



- TOC systems collectively organize into banded structures by the end of each sensitivity simulation
  - **Mid RH +15% simulation**: narrower TOC "streets" oriented perpendicular to the background easterly winds
  - **Wind shear simulations**: broader TOC bands oriented parallel to the wind shear vector
    - Exhibit horizontal convective roll-like flow patterns below 10 km
    - Deep layer shear simulations produce greater number of TOC bands compared to the AEJ simulation

Individual Convective Structure Comparisons

- Compared to the baseline simulation:
  - **Mid RH +15%**: larger, deeper, and more numerous TOC systems
  - **Wind shear simulations**: larger, though not necessarily deeper nor more numerous, TOC systems
- TOC systems are largest and most organized for the **Deep Shear (10 m/s, WAM)** simulation
- TOC system area, particularly larger values (>120 km^2), is most influenced by deep layer shear
- TOC system depth (i.e., intensity) is most influenced by mid-tropospheric RH



Conclusions & Future Work

Idealized RH and wind shear sensitivity simulations of TOC show:

- ✓ **Bands of clustered TOC form with enhanced mid-tropospheric RH, along with enhanced mid- and deep-tropospheric wind shear**
- ✓ **Larger TOC systems are associated with greater RH and wind shear**
  - ✓ **Results similar to NASA CPEX field campaign series studies**
- ✓ **TOC system area is most impacted by deep layer wind shear, while TOC system depth is most impacted by mid-tropospheric RH**

Future work:

- ❑ Investigating physical mechanisms for the simulated banded clustering of TOC systems, as well as the absence of larger MCSs in simulations
- ❑ Sensitivity simulations covarying RH and wind shear in different layers

Acknowledgements

This research was supported by NASA Award 80NSSC20K0894, as well as the NSF NCAR ASP GVP Fellowship program. We would also like to acknowledge high-performance computing support from the Derecho system (doi: 10.5065/qx9a-pg09) provided by NSF NCAR.

[1] Nowottnick et al., 2024: doi: 10.1175/BAMS-D-23-0201.1
[2] Rodenkirch and Rowe, 2024: doi: 10.1029/2023JD039632
[3] Bryan and Fritsch, 2002: doi: 10.1175/1520-0493(2002)130<2917:ABSFMN>2.0.CO;2

Contact Email: brodenkirch@wisc.edu