Summertime Post-Cold-Frontal Marine Stratocumulus Transition Processes during ACE-ENA

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Motivation

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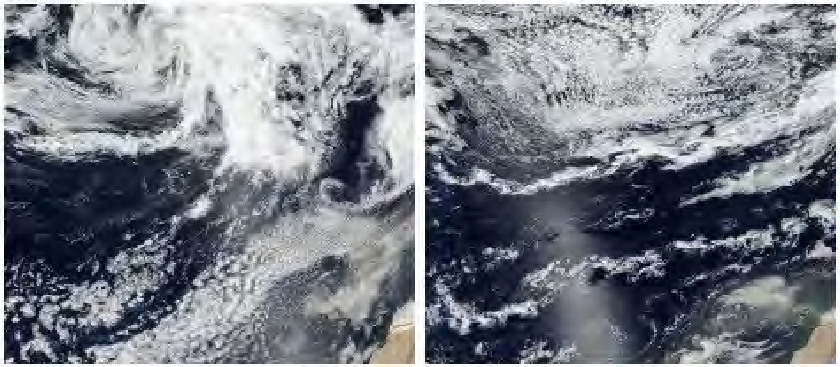
- A **deepening-warming hypothesis** describes the latitudinal transition from stratocumulus to trade-cumulus (Bretherton and Wyant, 1997) .
- Organized **mesoscale clusters** of cumuli rising into stratocumulus are a prominent feature of the ENA summertime cloud structure.
- **Cold frontal passages** are frequently observed at ENA.
- The association between these three characteristics of the stratocumulus transition region over the ENA and over the Earth's mid-latitude ocean regions, is largely unknown.
- Advances in computer power now enable simulations that (1) address the interplay between these major components of the cloud transition region over the ENA and (2) are compatible with ENA observations.
  - Large domain (resolve fronts and associated air masses)
  - Horizontal and vertical resolution sufficient to resolve mesoscale clusters

WRF Configuration and Observations



ARM-ENA Observations

- Surface meteorology station (SMET)
- Doppler Lidar (DL) data to measure the Doppler velocity in sub-cloud layer
- K-a band, Zenith-pointing Radar (KAZR) used to compute the average height-dependent cloud fraction over 30-min averaging interval
- Wind profiler: horizontal wind profile

WRF

Domain Configurations

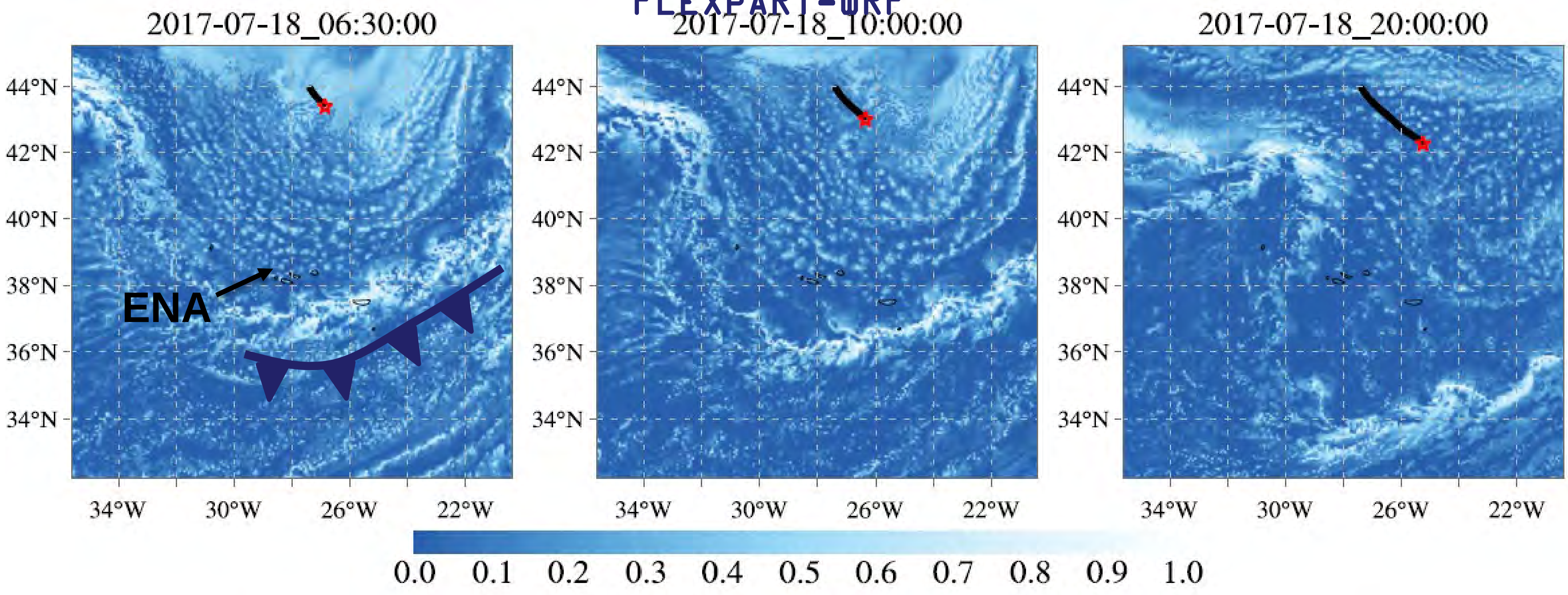
- **Two domains** centered on Graciosa Island in the Azores driven by the analysis and three-hour forecast data from NCEP GDAS/FNL 0.25 Degree Global Tropospheric Analyses and Forecast Grids GDAS/FNL (2015)
- **Horizontal Resolutions**: 4050 and 1350 m, with 750×750 and 1050×1050 horizontal grid points, respectively, 82 vertical levels with 15 m resolution near the ocean surface and an average of 70 m in the lowest 3-km
- **Two simulation cases**: 72 hours: July 17-19, 2017 (ACE-ENA golden period) and July 29-31, 2018

Model Parameterizations

- Thompson Aerosol-aware Microphysics Scheme
- Mellor-Yamada Nakanishi and Niino Level 3 (MYNN3) Planetary Boundary Layer Scheme
- RRTMG SW and LW Radiation Schemes
- MYNN Surface Layer Scheme
- NOAH Land Surface Scheme

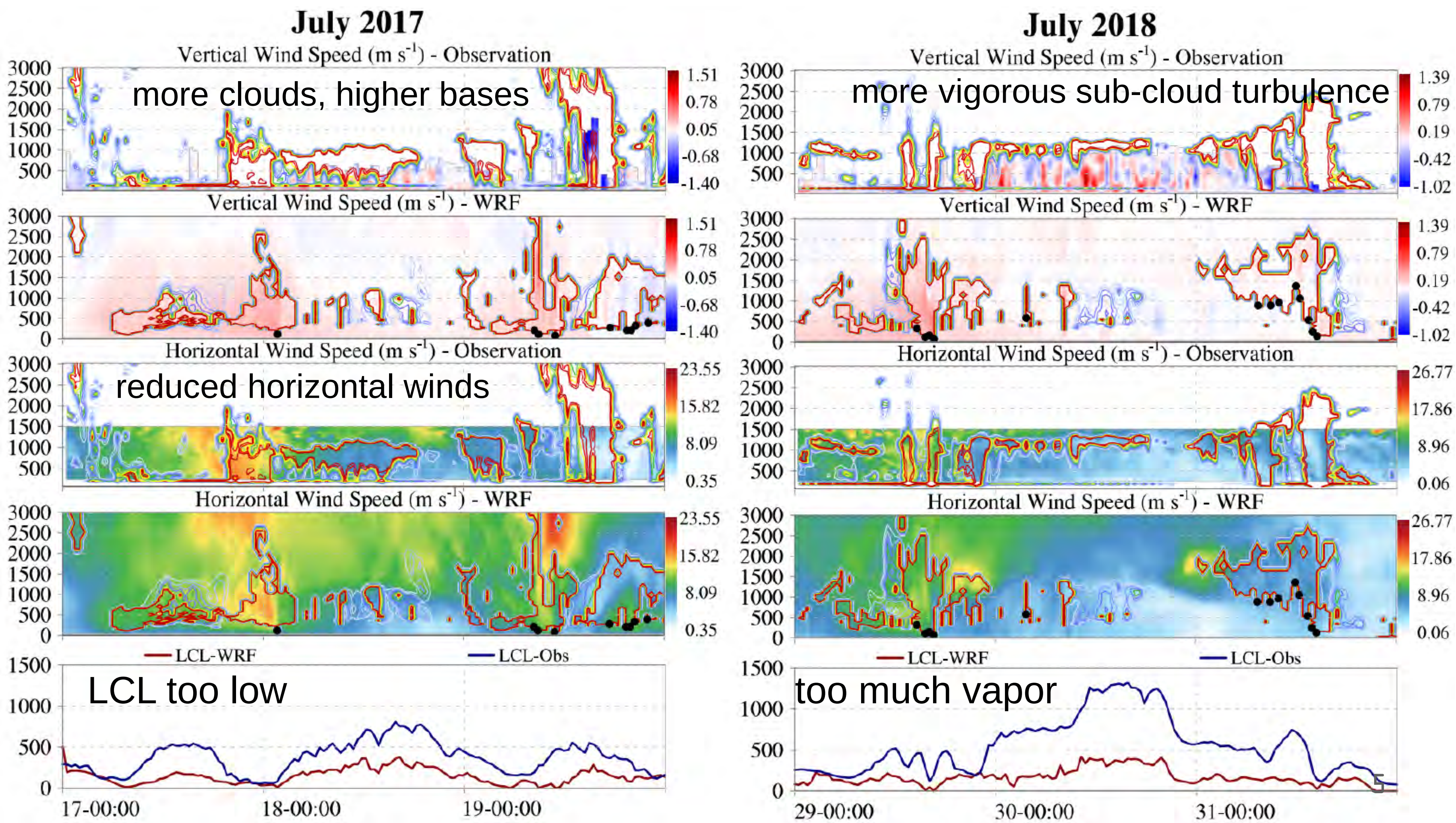
Simulated Cloud Life-Cycle: July 18, 2017

Forward Lagrangian Trajectories: FLEXPART-WRF



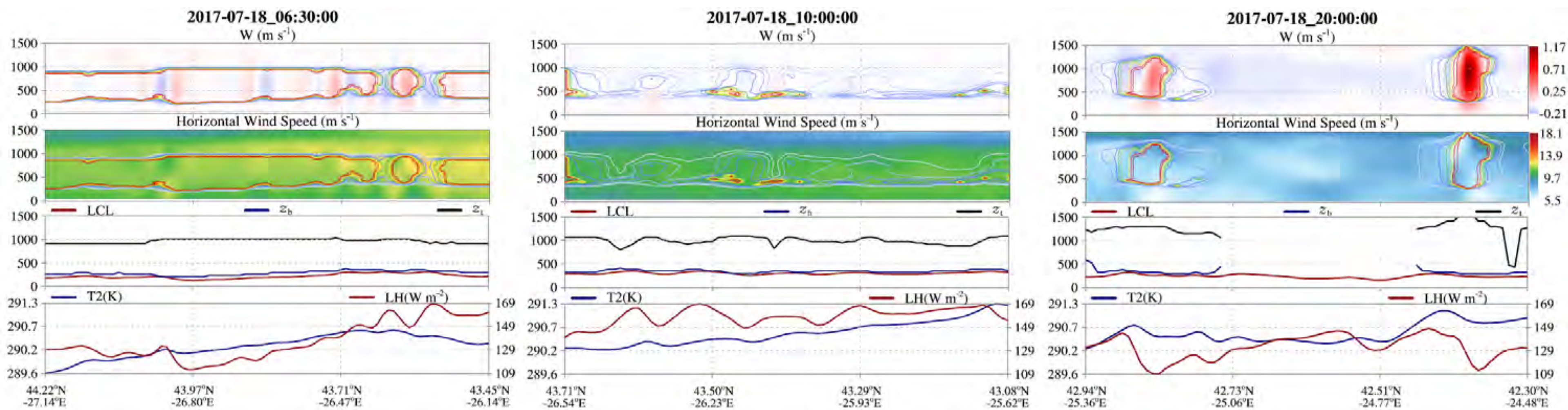
Low Cloud Coverage

ENA observations and WRF simulations



Simulated Cloud Life-Cycle: July 18, 2017

Vertical Cross-sections aligned with Lagrangian trajectories

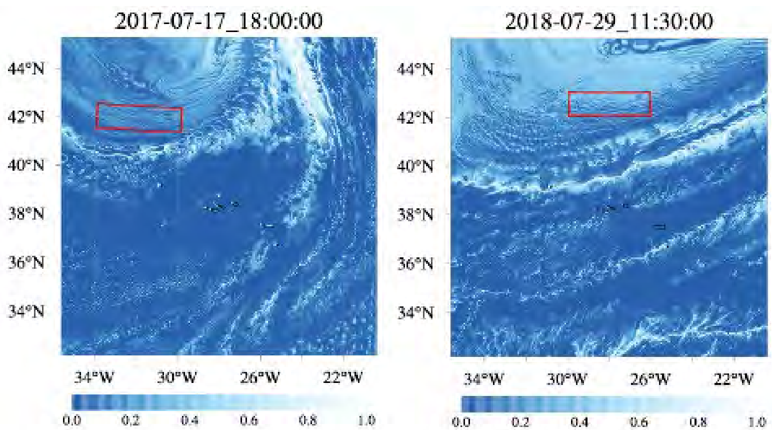


- solid deck begins to break up
- enhanced vertical velocities
- increase in temp and latent heat

- stratocumulus beneath passive convection
- complex structure
- weak convection
- large fluctuations in latent heat

- deeper PBL
- organized convective clusters
- widely scattered

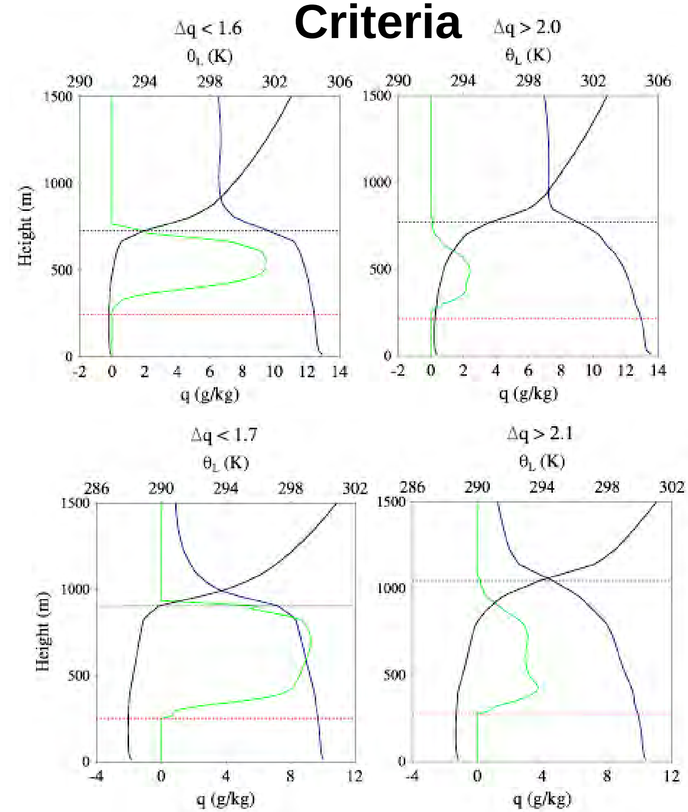
Decoupling Diagnostics



$$\Delta q = q_{\mathrm{bot}} - q_{\mathrm{top}}$$

Mean of total water mixing ratio over the lower and upper 25% of the boundary layer below the inversion

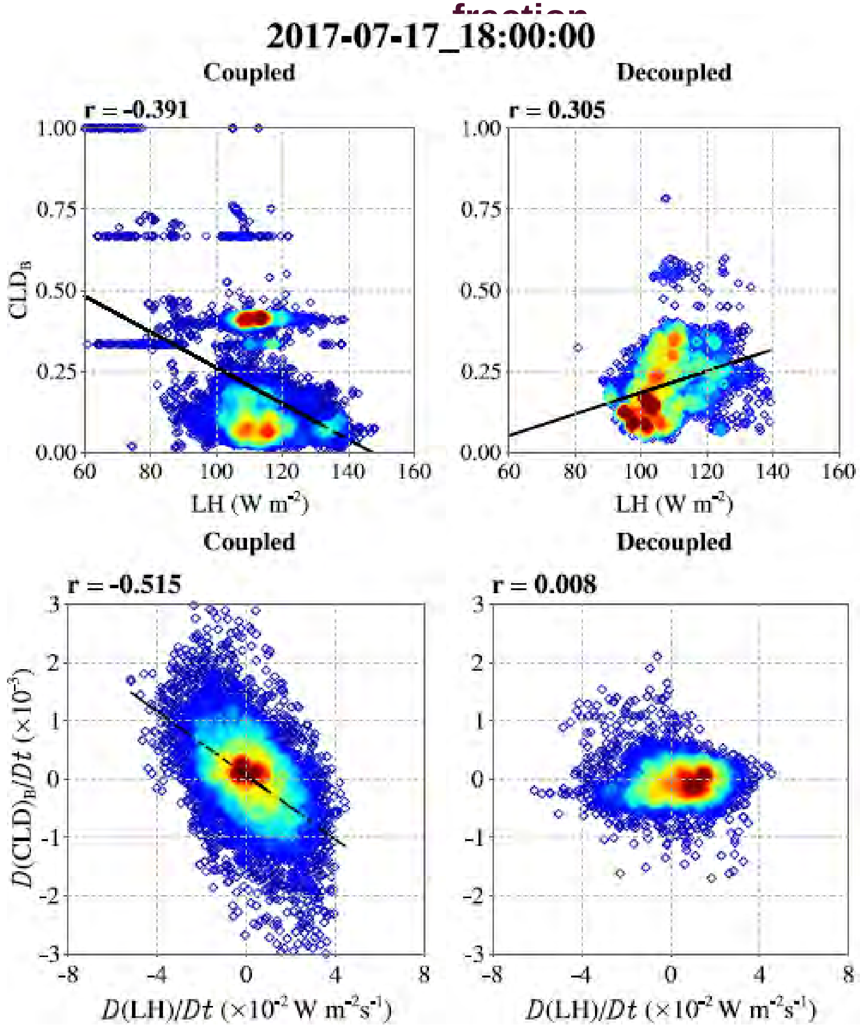
Jones Decoupling Criteria



C. Jones, C. Bretherton, and D. Leon. Coupled vs. decoupled boundary layers in
vocals-rex. Atmospheric Chemistry and Physics, 11(14):7143–7153, 2011.

Cloud-base Processes

Correlations between Latent Heat (LH) and cloud-base cloud fraction



LH directly beneath cloud base

Lagrangian derivative of the LH

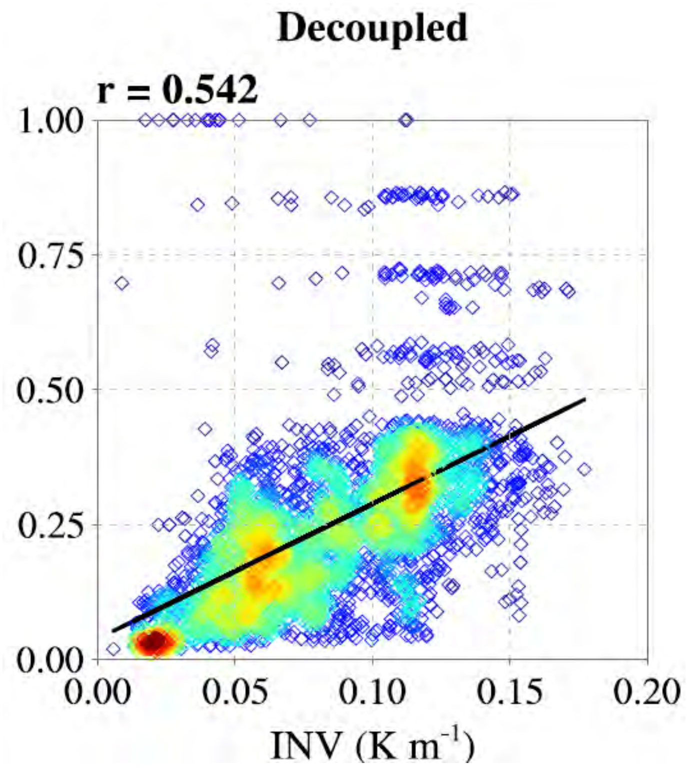
Transition from solid to broken cloud:

- Coupled
  - ✓ partially modulated by LH (especially Lagrangian)
- Decoupled
  - ✓ partially modulated by LH immediately beneath cloud base

Cloud-top Processes

A New Measure of Inversion Strength Designed for use in Large Scale Models

$$\mathrm{INV} = \frac{d}{dz}(\theta_{es} - \theta_e)$$



- Cloud-top processes exerted minimal influence on transition process
- Cloud-top entrainment instabilities were effective only when MBL was decoupled

Conclusions

- Simulated summertime post-cold frontal stratocumulus transition is consistent with the deepening and warming hypothesis proposed by Bretherton and Wyant (1997)
- Development of cumuli and the initiation of the transition to broken structure is correlated with the Lagrangian derivative of surface LH
- Cloud-top entrainment instability appears to operate effectively only after the MBL is decoupled.
- Model-ENA observation comparisons suggest that WRF simulated sub-cloud large eddies using this combination of parameterizations are not vigorous enough.

- Kazemi-Rad, M., and M. A. Miller, 2020: Summertime Post-Cold-Frontal Marine Stratocumulus Transition Processes over the Eastern North Atlantic. *J. Atmos. Sci.*, **77**, 2011–2037, https://doi.org/10.1175/JAS-D-19-0167.1