An Idealized Parameter Study of Instability Maxima on the Cool Side of Airmass Boundaries

Jason M. Keeler[1], Adam L. Houston[2], and Christian H. Boyer[1]*

[1] Dept. of Earth and Atmospheric Sciences, Central Michigan University; [2] Dept. of Earth and Atmospheric Sciences, University of Nebraska-Lincoln. *Current affiliation: Lynker at NOAA/NCEP/NWS/EMC

COLLEGE OF SCIENCE & ENGINEERING CENTRAL MICHIGAN UNIVERSITY

1. Background

- The cool side of airmass boundaries can, paradoxically, be characterized by higher near-surface θ_e and associated CAPE.
- These airmasses are referred to as Mesoscale Airmasses with High Theta-E (MAHTE; Hanft and Houston 2018) and have been shown to influence thunderstorm severity (Gilmore and Wicker 2002).
- In the continental United States, individual ASOS sites observe an average of 2.5 MAHTEs per year, corresponding to sfc-CAPE increases of 728 ± 523 J kg^{-1} (Kropiewnicki et al. 2023).

2. Hypotheses

- MAHTE development occurs through processes related to the local rate of change of entropy:

$$\frac{\partial s}{\partial t} = F_a + F_p + F_i + F_q + F_T$$

Advection

Precipitation evaporation into unsaturated air

Insolation

Surface latent and sensible heat flux

- An idealized parameter study of MAHTE development is needed to understand these processes.

3. Idealized Simulation Method

- CM1 v21.1 simulations were run on a 20×200×18 km domain (S-N, W-E, vertical), with water in the western 50 km and irrigated cropland and pasture elsewhere.
- Simulations were initialized at 10 UTC (6 am LT) and run for 12 hours, with radiation consistent with Holland, Michigan, USA.
- Horizontal grid spacing was 100 m with vertical level spacing of 50 m (below 2 km), stretching to 500 m at and above 7.5 km AGL.
- Lateral boundary conditions were periodic for N and S boundaries, and open radiative with eddy recycling for W and E.
- Sea-breeze fronts (SBFs) developed in a broad parameter space, varying water temperature (Lake Michigan 25th, 50th, 75th, and 90th percentiles for mid June, July, and August), cross-shore wind component (-5, -2.5, and 0 m s^{-1}), and radiative forcing corresponding to the water temperature date (Boyer et al. 2024).
- Supplemental simulations presented herein focused on varying moisture content above the boundary layer and further cooling the water to the 10th percentile to examine the influence on MAHTE development and characteristics.

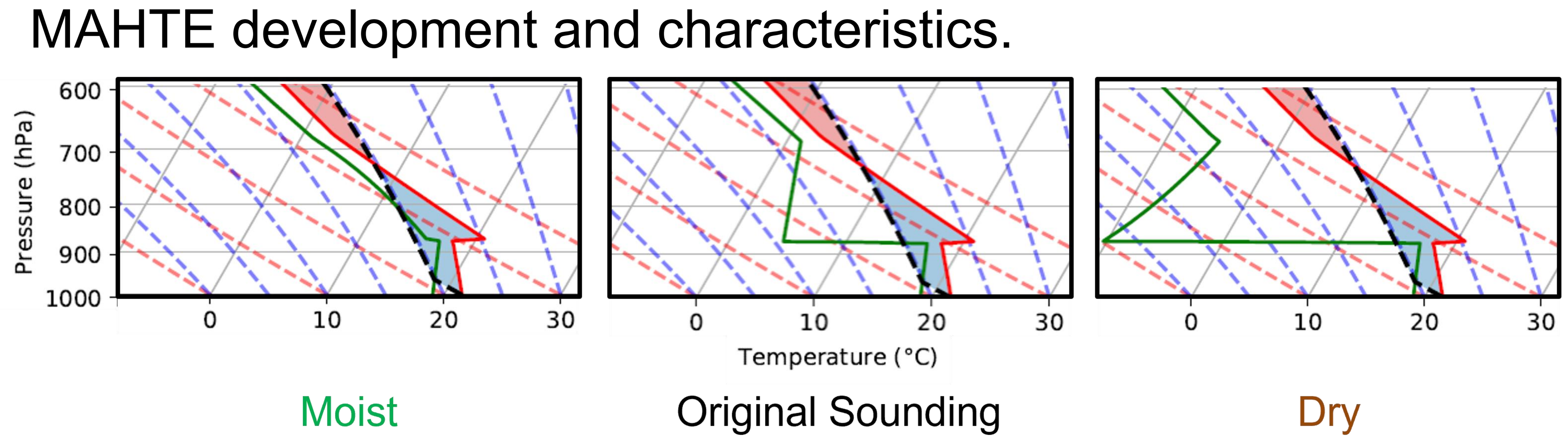

Fig. 1. Base-state soundings with a dashed line for the surface parcel path, CIN (blue shading) and CAPE (red shading). The original sounding from Boyer and Keeler (2024) is included in the center, and soundings with increased or decreased moisture content above the boundary layer are included on the left and right, respectively.

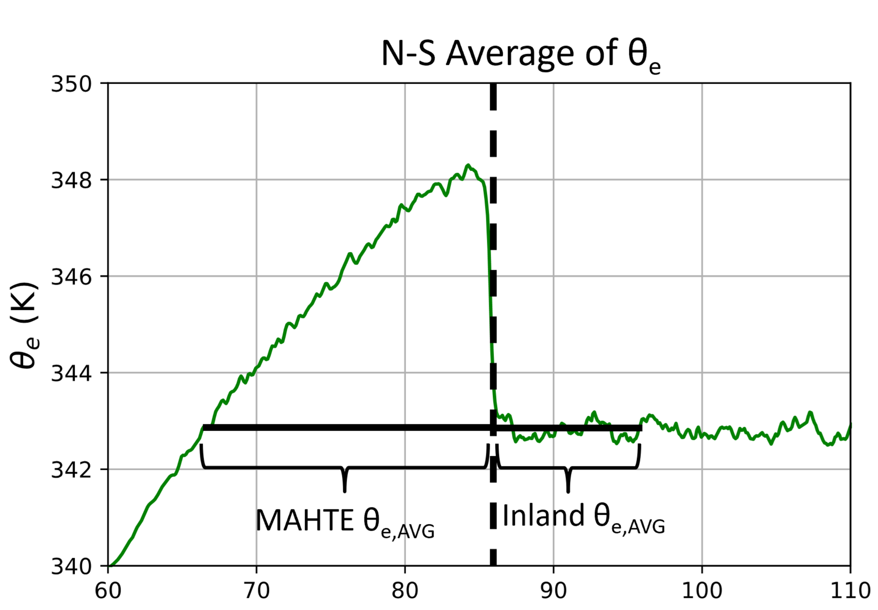

Fig. 2. Meridionally-averaged θ_e (green line) in the vicinity of a simulated SBF (dashed black line). The leading 10 km of the ambient environment, i.e., the area over which the inland average θ_e was computed, and horizontal extent of the MAHTE are indicated using labeled brackets.

4. Results

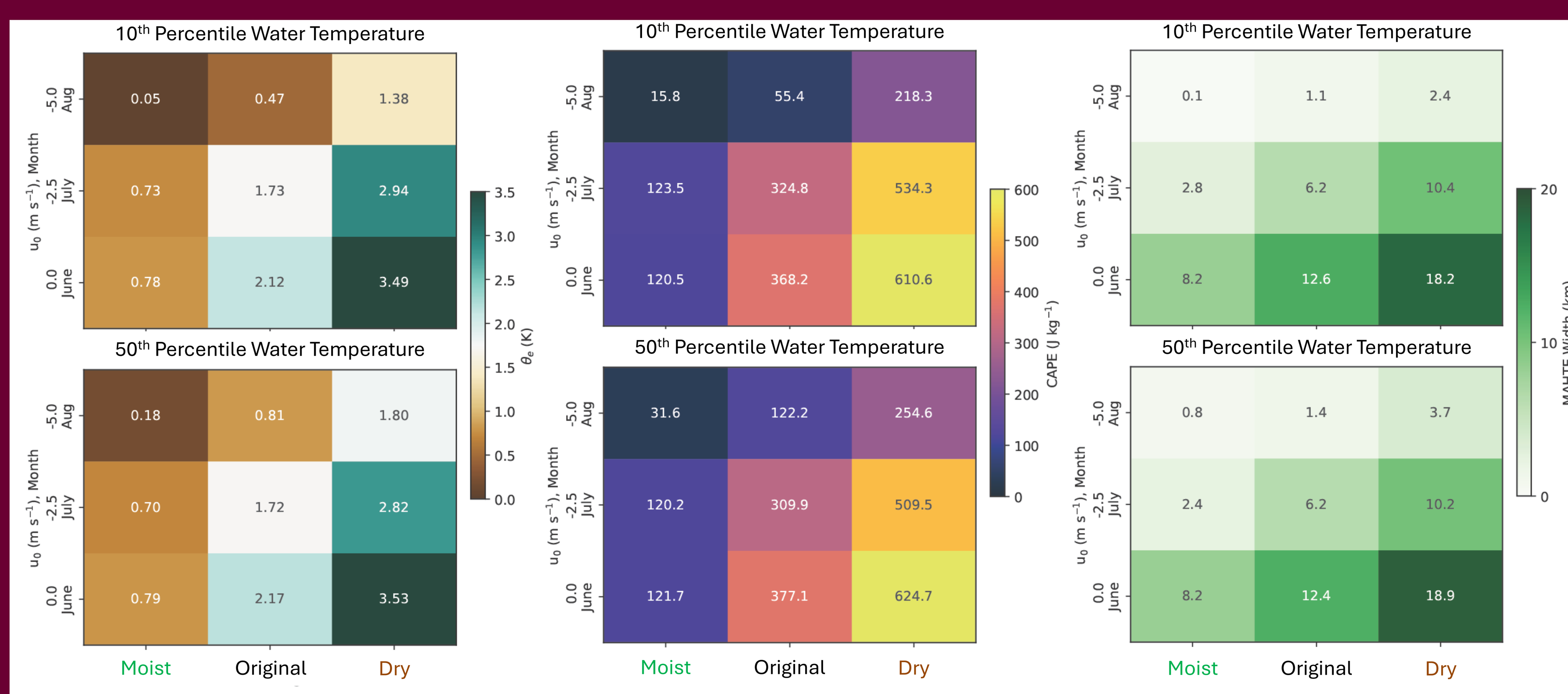

Fig. 3. Heatmaps of the mean θ_e perturbation and mean surface-based CAPE perturbation within simulated MAHTEs (left and center columns) and MAHTE width (right column) at the model output time preceding earliest convection initiation in any one of these simulations.

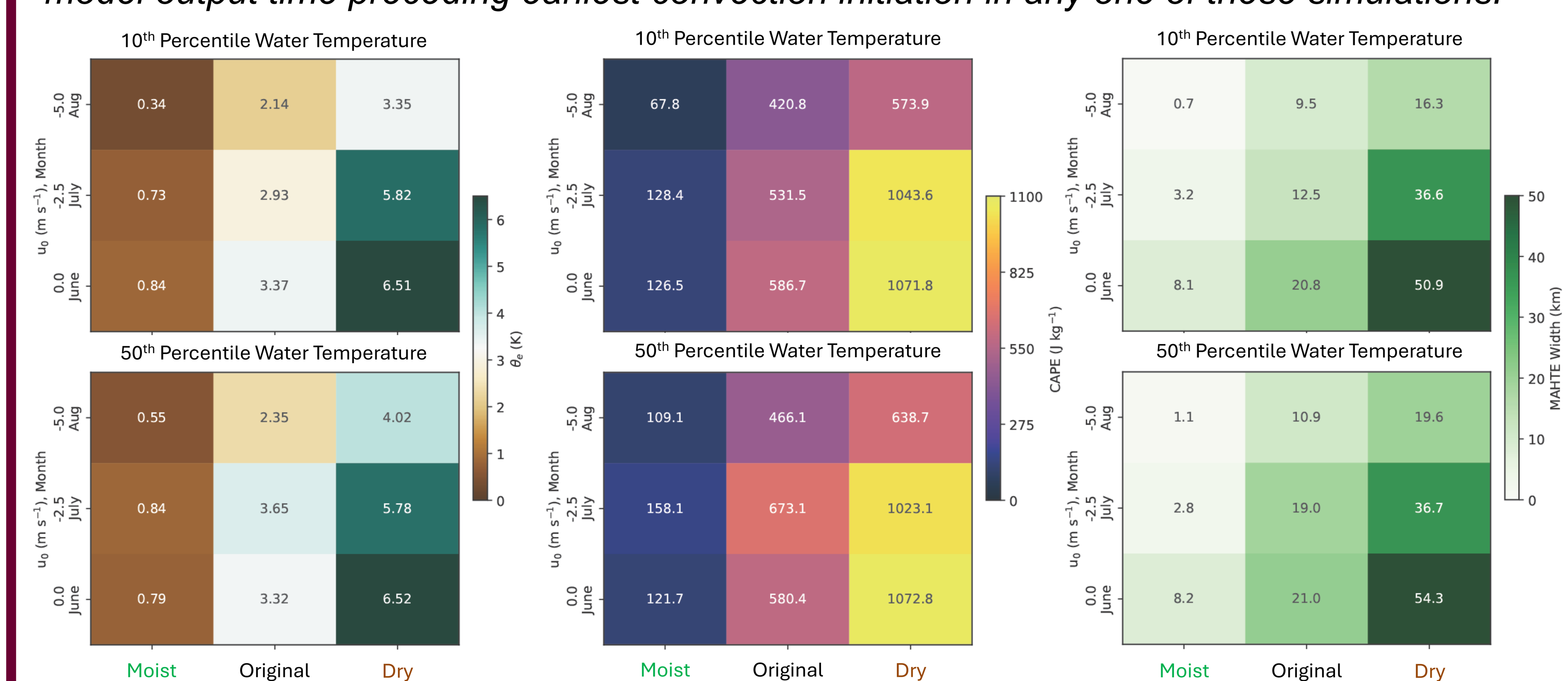

Fig. 4. Same as Fig. 3, except for the model output time preceding convection initiation (CI) in the individual simulations. Note that the color scales are different than in Figure 3.

- Preceding the earliest CI in any simulation (Fig. 3):

  Moisture Profile: MAHTEs were wider with higher θ_e and CAPE for the dry sounding, relative to the original and moist soundings.

  Month: MAHTEs were more pronounced in June, relative to July and August, though differences were less pronounced.

  Water Temperature: Differences were minimal, with warmer water supporting slightly more pronounced MAHTEs.

- Preceding the earliest CI in *individual* simulations (Fig. 4):

  Delayed CI for simulations with the dry input sounding provided more time for MAHTEs to develop and resulted in more pronounced differences in θ_e, CAPE, and MAHTE width.

- Ongoing research: MAHTE development in continental regions.

Acknowledgements and References

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