Trade cumulus organization and the cloud response to aerosol in present and future climates

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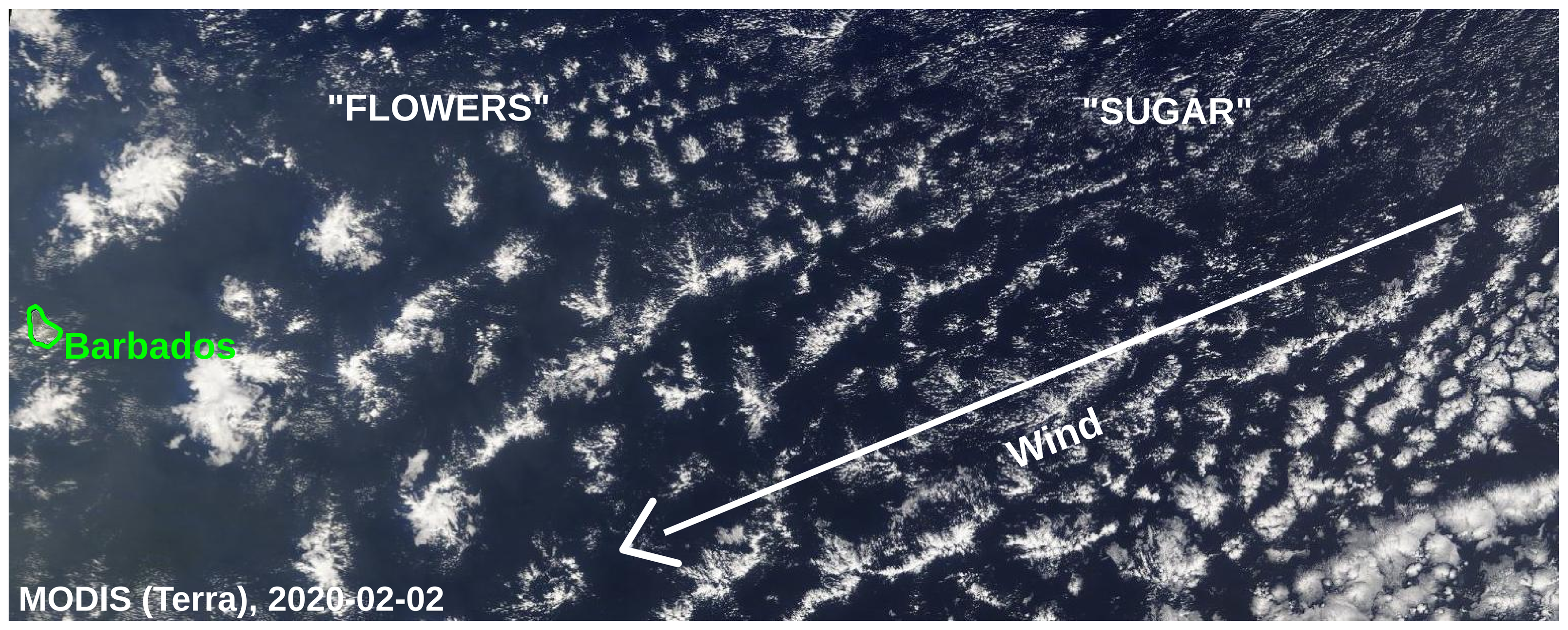
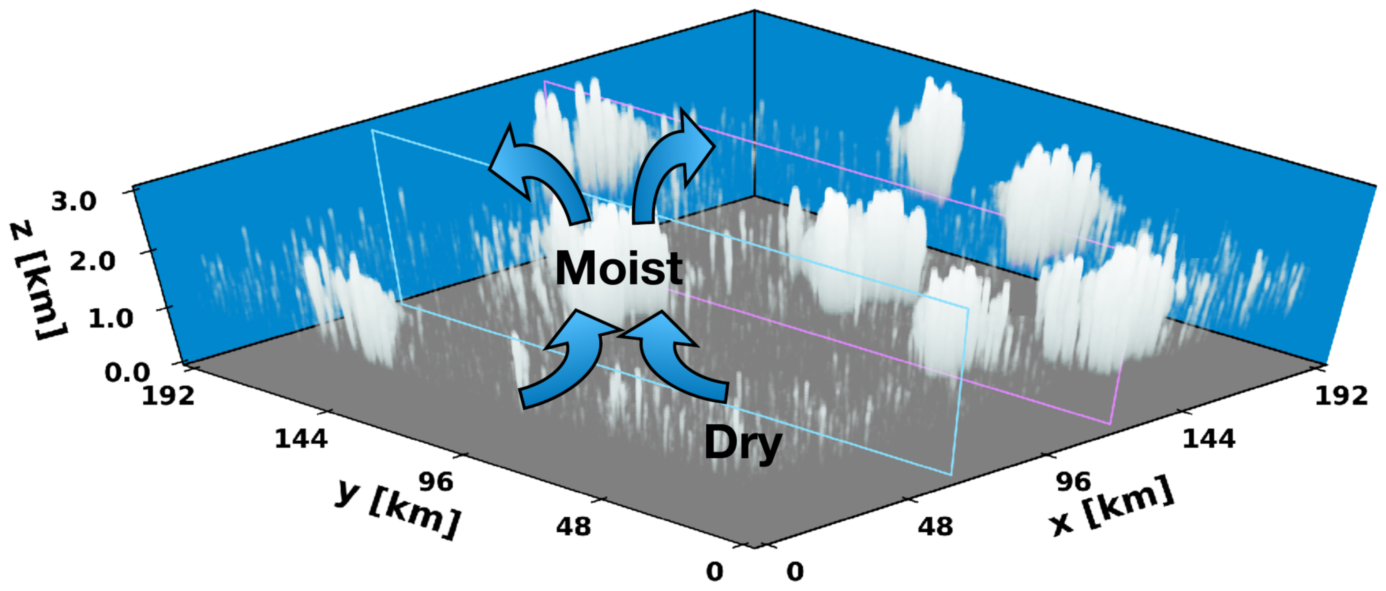
Micro2Macro: Origins of Climate Change Uncertainty Workshop, October 28 - 30, 2024

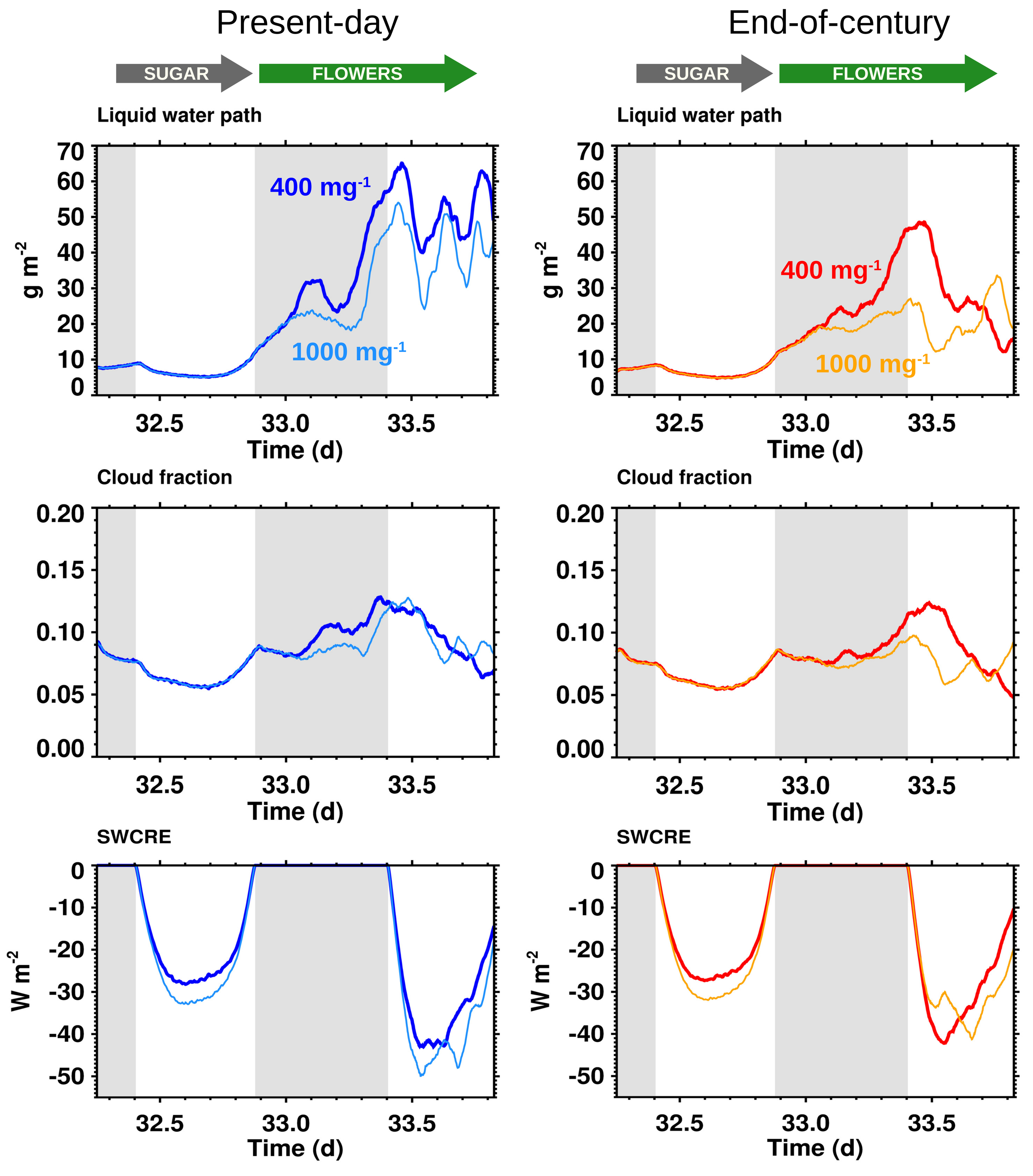


- Trade cumulus clouds in the Caribbean appear in four states of organization: "Sugar", "Gravel", "Fish", and "Flowers" (Stevens et al., 2020).
- The "Sugar" cloud state can transition into the "Flower" cloud state.



The Sugar-to-Flower transition proceeds by a positive feedback between circulation and moisture accumulation on the mesoscale (Narenpitak et al. 2021, Bretherton and Blossey 2017).

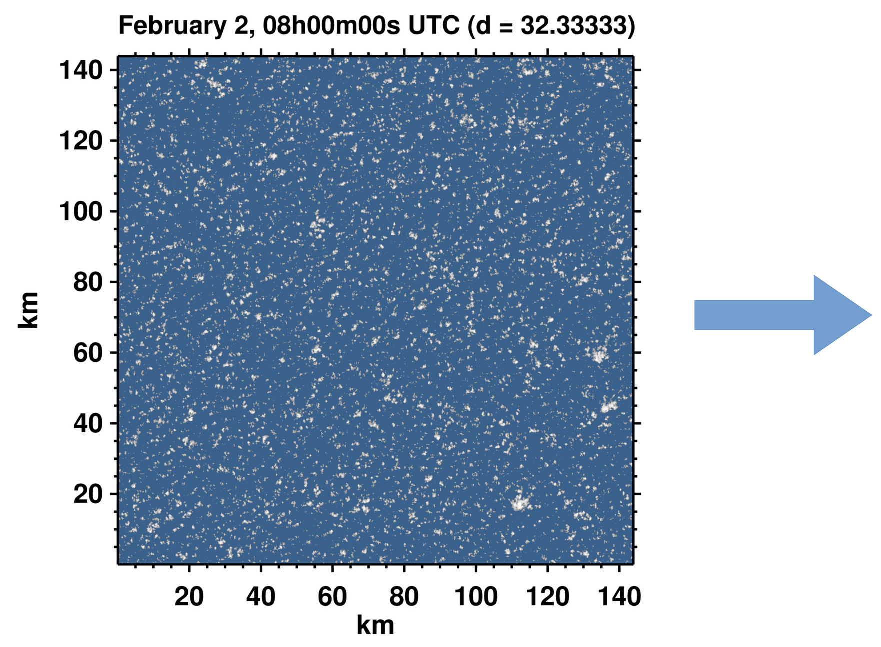
Mesoscale organization modulates the cloud response to aerosol

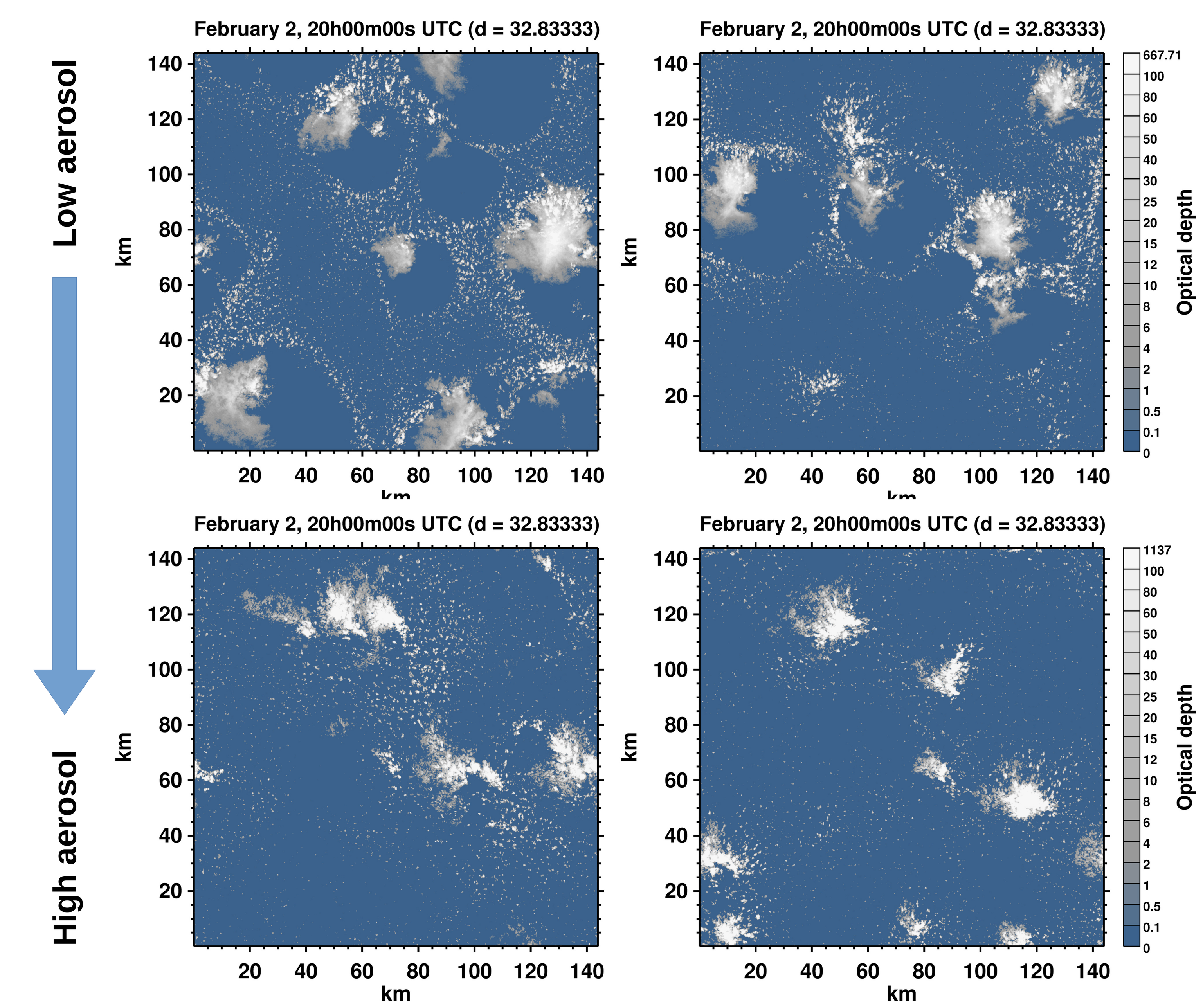


- In the Sugar cloud state, liquid water path and cloud fraction are insensitive to aerosol in both PD and EC conditions. The Twomey effect renders the clouds brighter.
- In the Flower cloud state, higher aerosol reduces liquid water path, and less prominently, cloud fraction.
- The response to aerosol appears less systematic in EC conditions. This may be due to an insufficient number of Flower clouds in the domain, rendering the signal statistically not representative.

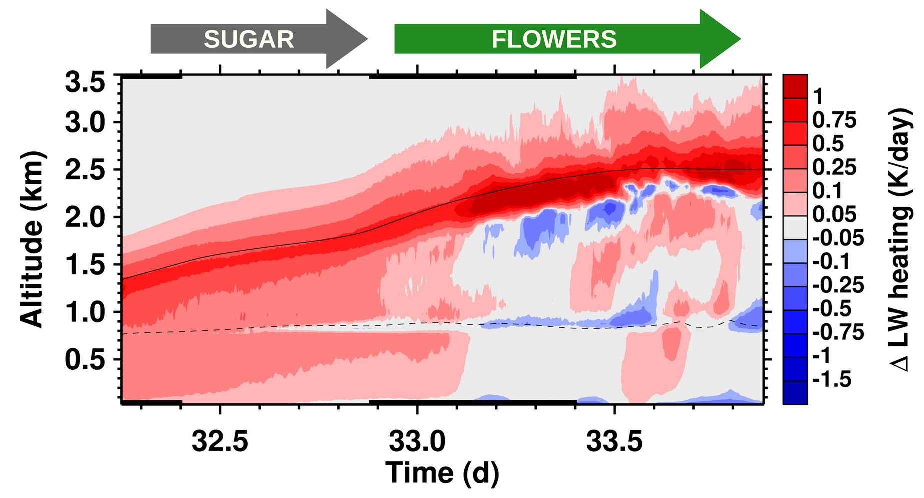
Large eddy simulations

Large eddy simulations driven with ERA5 meteorology (February 2, 2020) produce a present-day Sugar-to-Flower transition. Applying the change in temperature, water vapor, wind speed, subsidence, and sea surface temperature from present-day (PD, 2016-2025) to end-of-century (EC, 2090-2099) under the RCP8.5 scenario from an ensemble of CMIP5 CESM1(WACCM) simulations to the ERA5 forcing allows simulating the effect of climate change. A low (400 # mg^{-1}) and a high (1000 # mg^{-1}) initial aerosol concentration in the boundary layer is used to test the cloud response to aerosol number. The 400 # mg^{-1} aerosol size distribution consists of sea salt and was constructed (Narenpitak et al. 2021) from observations (Quinn et al., 2020) for the simulated period.



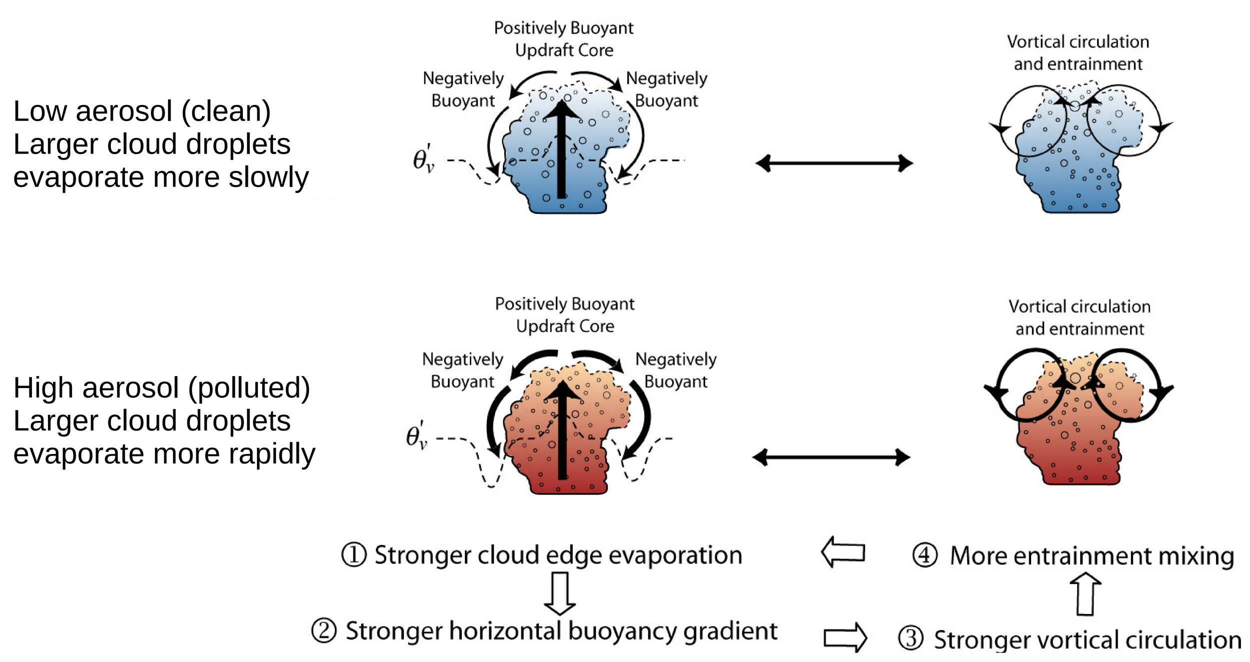


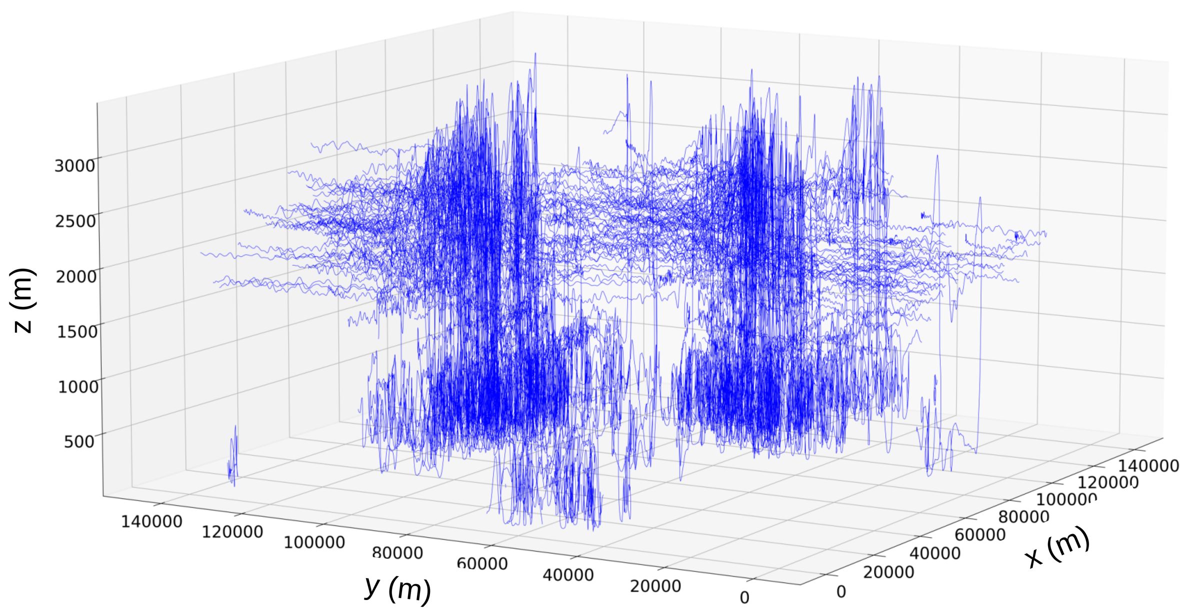
Response to climate change



- Stronger down-welling long-wave radiation at higher greenhouse gas levels causes additional warming at the inversion. This stabilizes the boundary layer, and weakens the mesoscale circulation and the associated moisture accumulation. The result is a reduction of the cloud radiative effect in the Flower cloud state from present-day to end-of-century conditions (Kazil et al., 2024).
- Higher aerosol suppresses precipitation and the formation of cold pools.

Liquid water response to aerosol in PD and EC conditions: subsiding shells

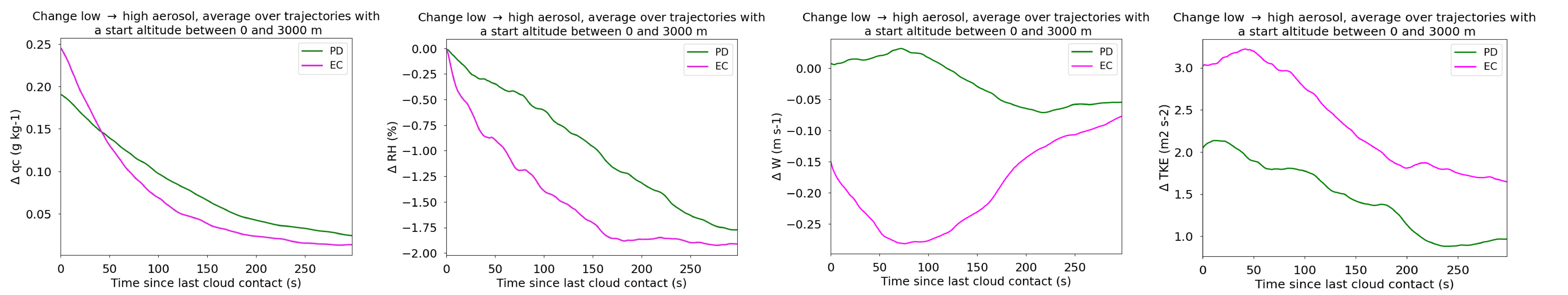




Higher aerosol results in smaller cloud droplets, which evaporate more quickly along trade cumulus edges. The associated latent cooling strengthens subsiding shells, turbulence, cloud edge mixing, and cloud drop evaporation. This is a microphysical-dynamical feedback that enhances cloud edge evaporation (Small, Chuang, Feingold, and Jiang, 2009).

We track air parcel trajectories in the Flower cloud state and analyze their properties as a function of time since last cloud contact. This plot shows trajectories that at any point produce a liquid water content of ≥ 3 g kg^{-1}.

Difference (Δ) high - low aerosol in PD and EC along air parcel trajectories in the "Flower" cloud state



Higher aerosol in EC: faster evaporation of cloud water, lower relative humidity, stronger downdrafts, and higher turbulence along trajectories that have just emerged from a cloud.

Conclusions

- **In large eddy simulations, we find that mesoscale organization modulates the response of trade cumulus clouds to aerosol,**
- **A microphysics-dynamics feedback causes faster evaporation of cloud water in the organized "Flower" cloud state in response to higher aerosol in EC (end-of-century) conditions, compared to PD (present-day) conditions.**

Work in progress – further analysis will be conducted to substantiate the findings!