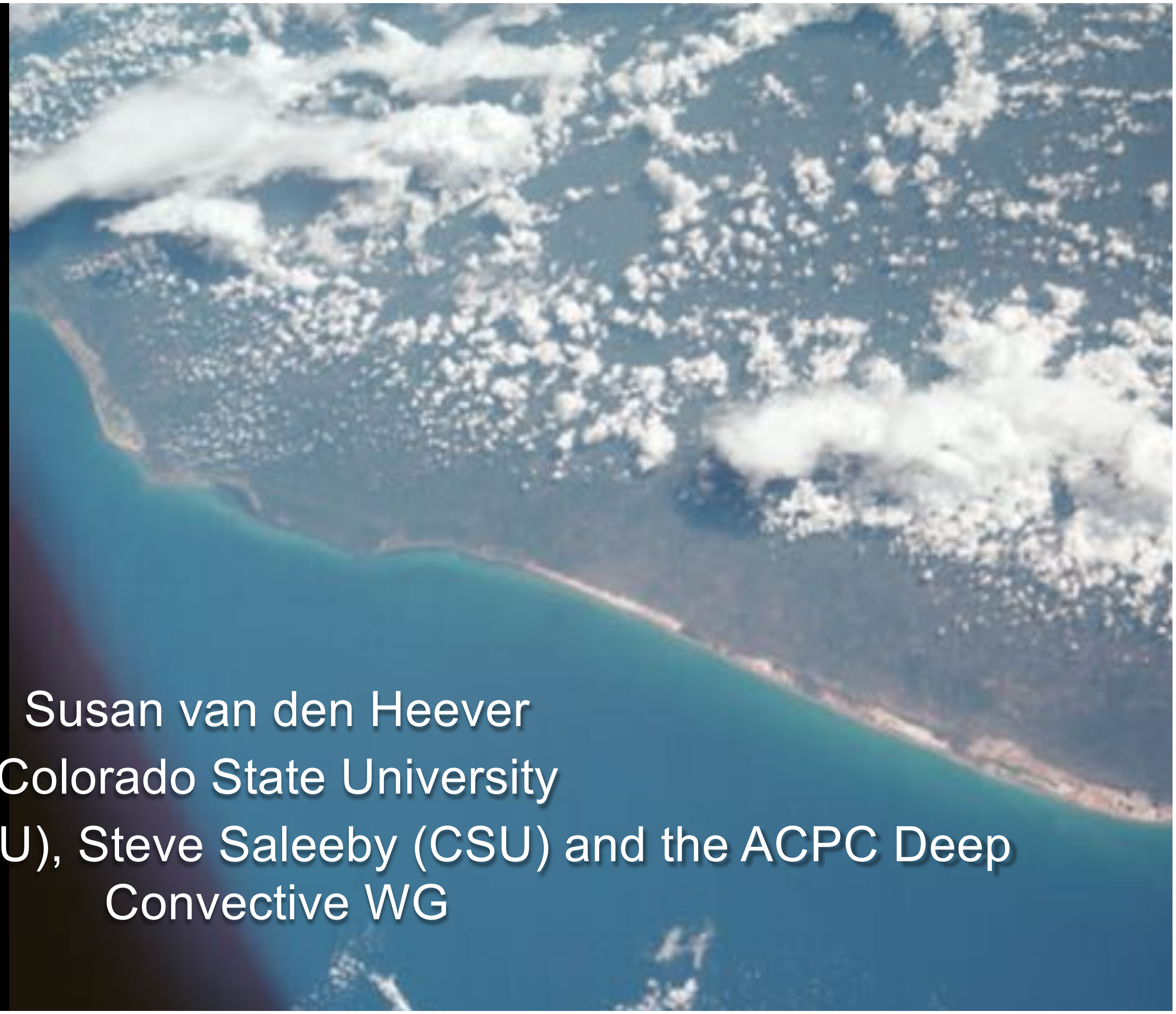
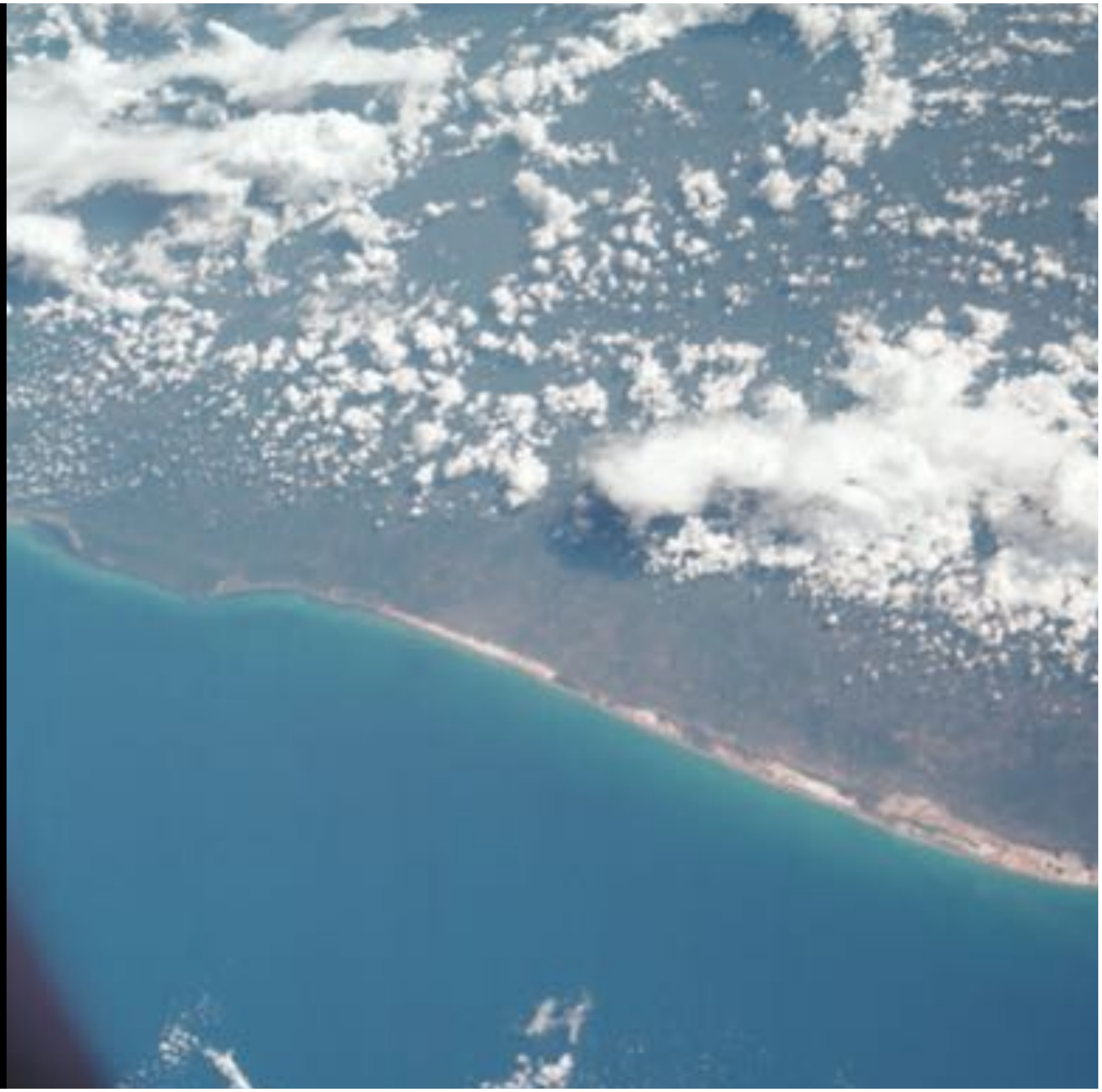
Model Data Framework for Aerosol Impacts on Deep Convection



Susan van den Heever
Colorado State University
with Mariko Oue (SBU), Steve Saleeby (CSU) and the ACPC Deep Convective WG

Outline

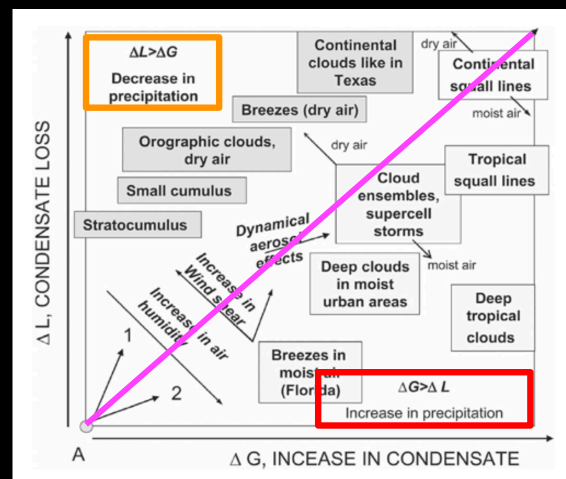
- Part 1: Model intercomparison project (MIP)
- Part 2: Ways forward in evaluating MIP results



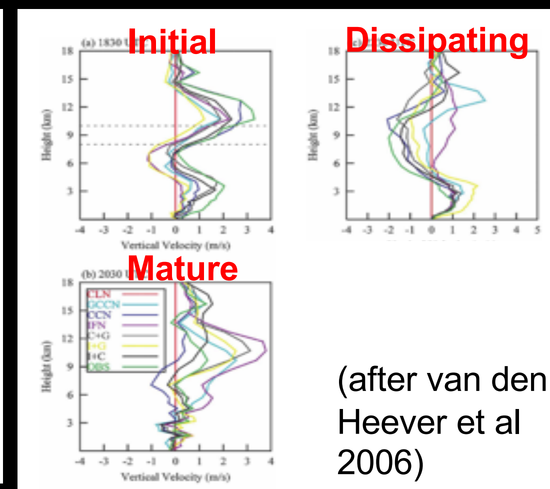
Aerosol Processes in Deep Convection

Sources of Uncertainty

1. Cloud environments
2. Cloud type
3. Cloud lifecycle
4. Isolated vs Cloud Scenes
5. Model parameterizations



(after Khain et al. 2008)



(after van den Heever et al 2006)

(after Grabowski and Morrison 2011; van den Heever et al 2011; Seifert et al. 2012)

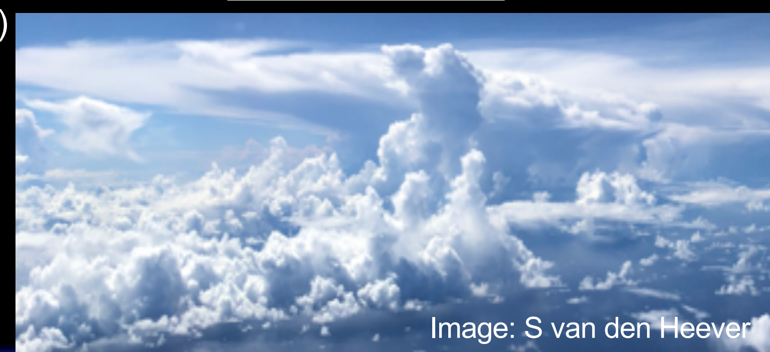


Image: S van den Heever

Model Parameterizations

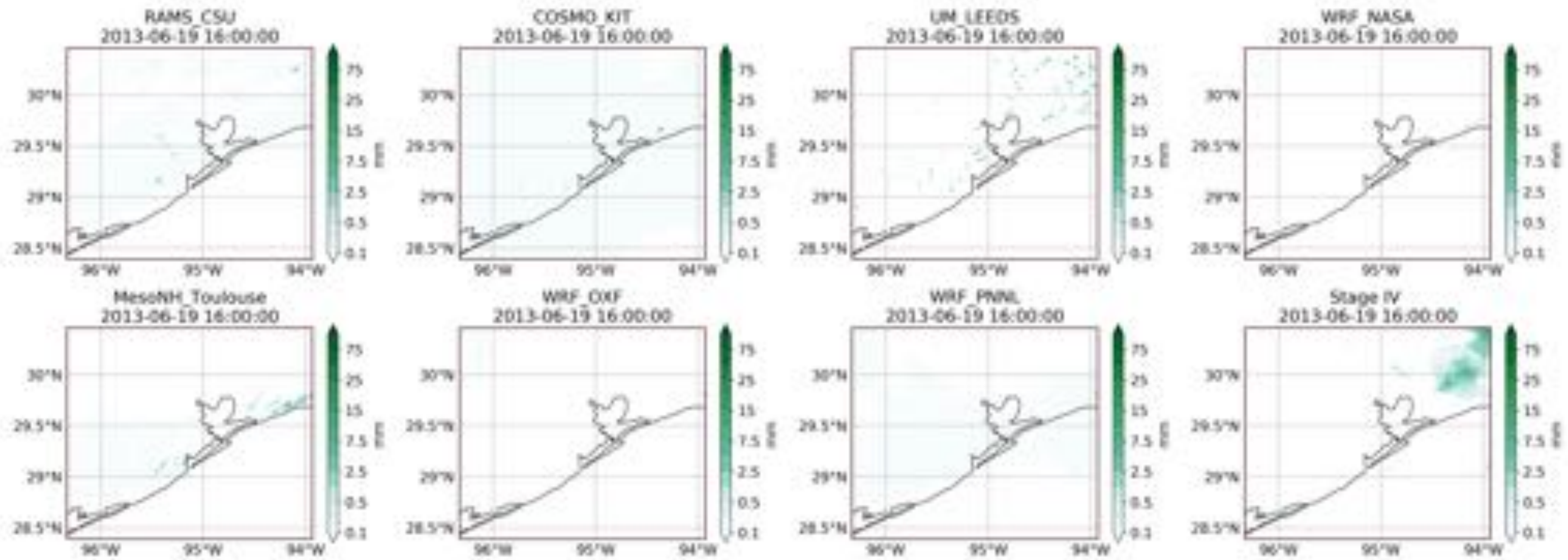
1. ACPC Model Intercomparison Project (MIP)

- First MIP of aerosol impacts on deep convective clouds (van den Heever et al. 2021; Marinescu et al. 2021)
- Formed the basis of ASR TRACER field campaign
- 7 state-of-the-art, convection permitting models (CPMs) with varying parameterizations were used to simulate the same case of deep isolated convection over Houston, TX, with varying aerosol concentrations
- Goal: to determine the range in response from state-of-the-art CRM simulated convective properties to changes in aerosol loading

Model	Abbreviation	Institution	People
Consortium for Small-scale Modeling	COSMO	Karlsruhe Institute of Technology	C. Hoose, C. Barthlott, A. Barrett
MesoNH Model	MesoNH	Meteo-France	B. Vie
Regional Atmospheric Modeling System	RAMS	Colorado State University	S. C. van den Heever, P. J. Marinescu
Unified Model	UM	University of Leeds	A. Miltenberger
NASA Unified WRF	NU-WRF	NASA Goddard Institute of Space Studies	A. Fridlind, T. Matsui
Weather Research and Forecasting (WRF) Model with Morrison Micro.	WRF-Morr	University of Oxford	P. Stier, M. Heikenfeld, B. White
WRF with HUCM BIN	WRF-SBM	Pacific Northwest National Lab.	J. Fan, J. Shpund, Y. Zhang

Surface Precipitation

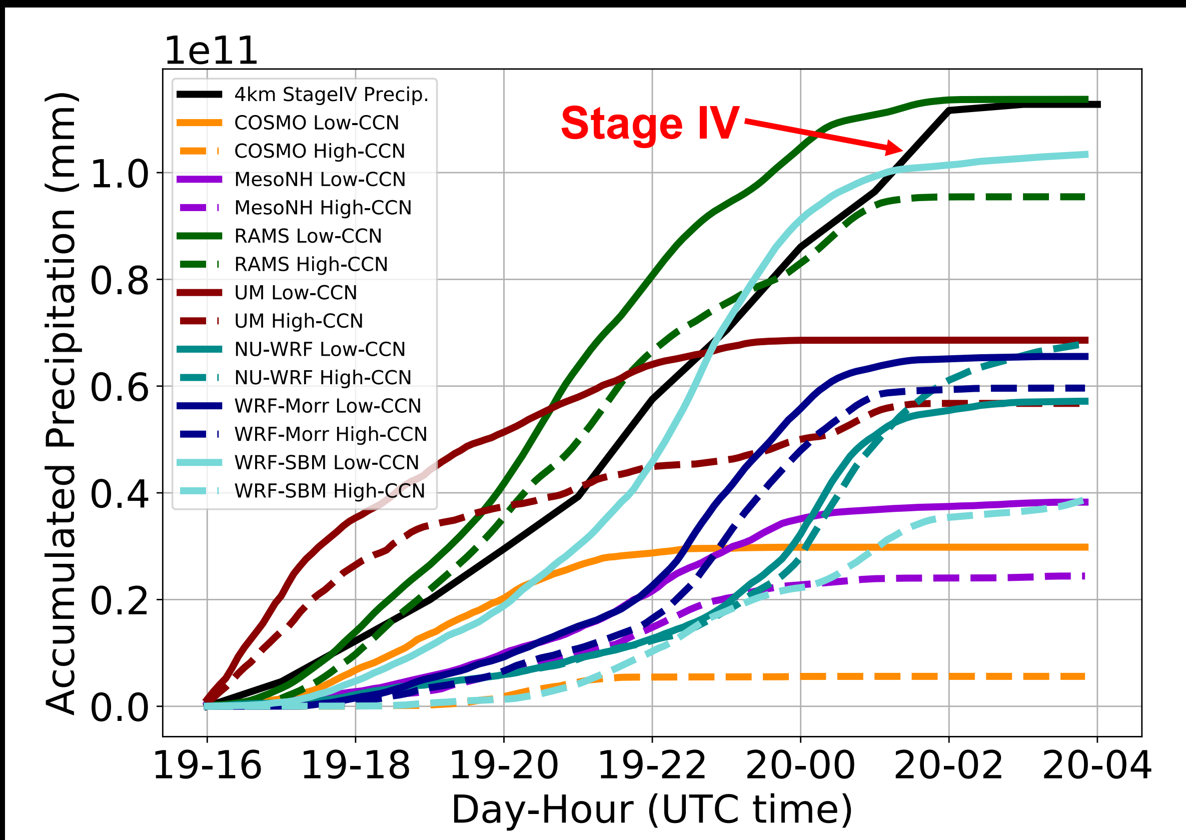
Accumulated Precipitation
(06/19/16:00 – 06/20/04:00 UTC)



Stage IV Observations

- All models produce scattered convection
- Range in the areal coverage of convection

Surface Accumulated Precipitation



(after van den Heever et al. 2021)

- Precipitation differences vary more as a function of model physics than aerosol impacts
- Most models (except two) underestimate 12 hour accumulated precipitation by more than 40%
- All of the models show a reduction in accumulated precipitation with aerosol loading

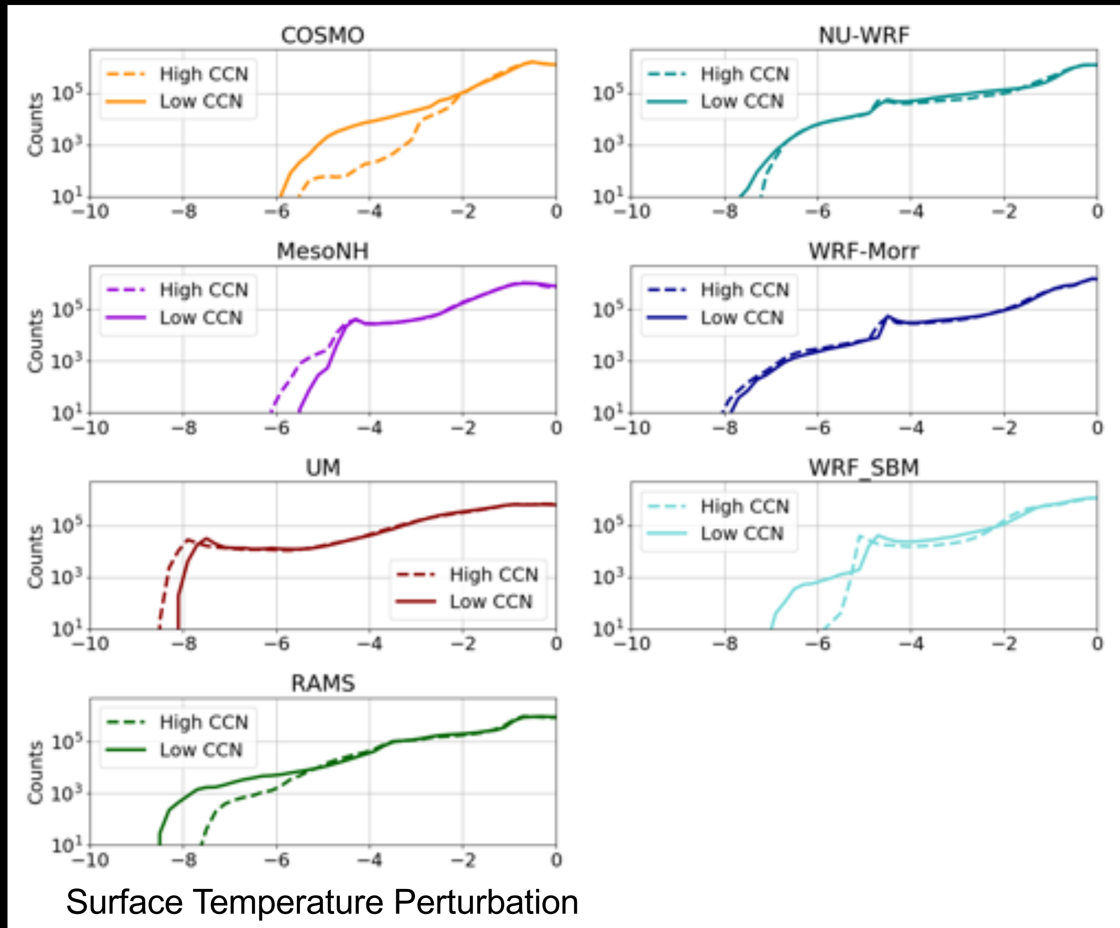
Cloud, Rain and Ice Characteristics

- With increased aerosol loading all models show:
  - Increase in cloud mass and number concentrations
  - Decrease in rain mass and number concentrations in warm phase regions
  - Increase in rain diameters
  - Increase in average anvil ice mass
- Wide range in the amount of anvil ice produced

Cold Pool Intensities

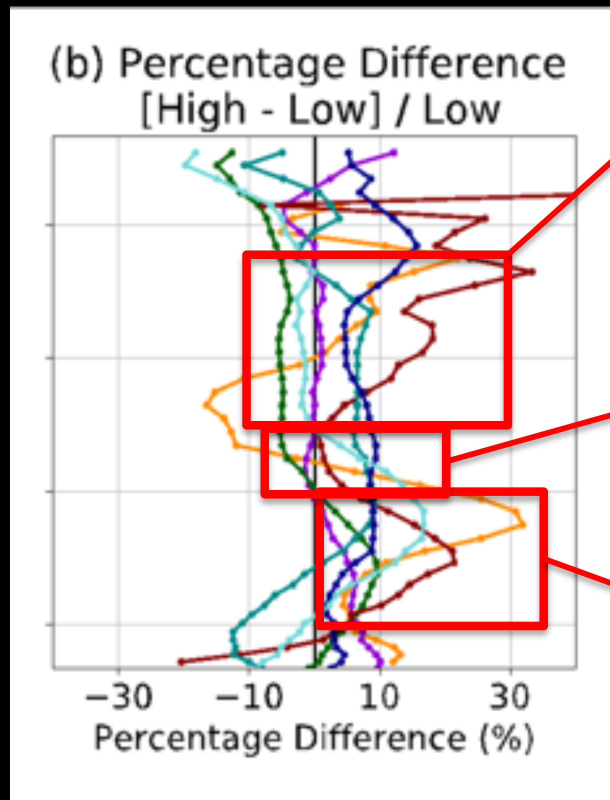
- Four models (COSMO, NU-WRF, RAMS, WRF-SBM,) show weaker(warmer) cold pools in high aerosol cases, while the rest show colder cold pools
- This is despite weaker downdrafts and larger rain mean diameters in most cases which should produce warmer cold pools
- Aspects such as model treatments of sedimentation as well as land surface processes may impact this result

(after van den Heever et al. 2021)



Deep Convective Vertical Velocity

- In High-CCN simulations, more condensation onto more, smaller drops, which increases latent heating, thermal buoyancy, and *w* between 3 and 5 km
- In high-CCN simulations, drier mid-level updrafts from enhanced condensation in the region below, which causes the waning response between 5 and 7 km
- Above 7 km, both weaker and stronger updrafts in High-CCN simulation → VPPG appears to play an important role



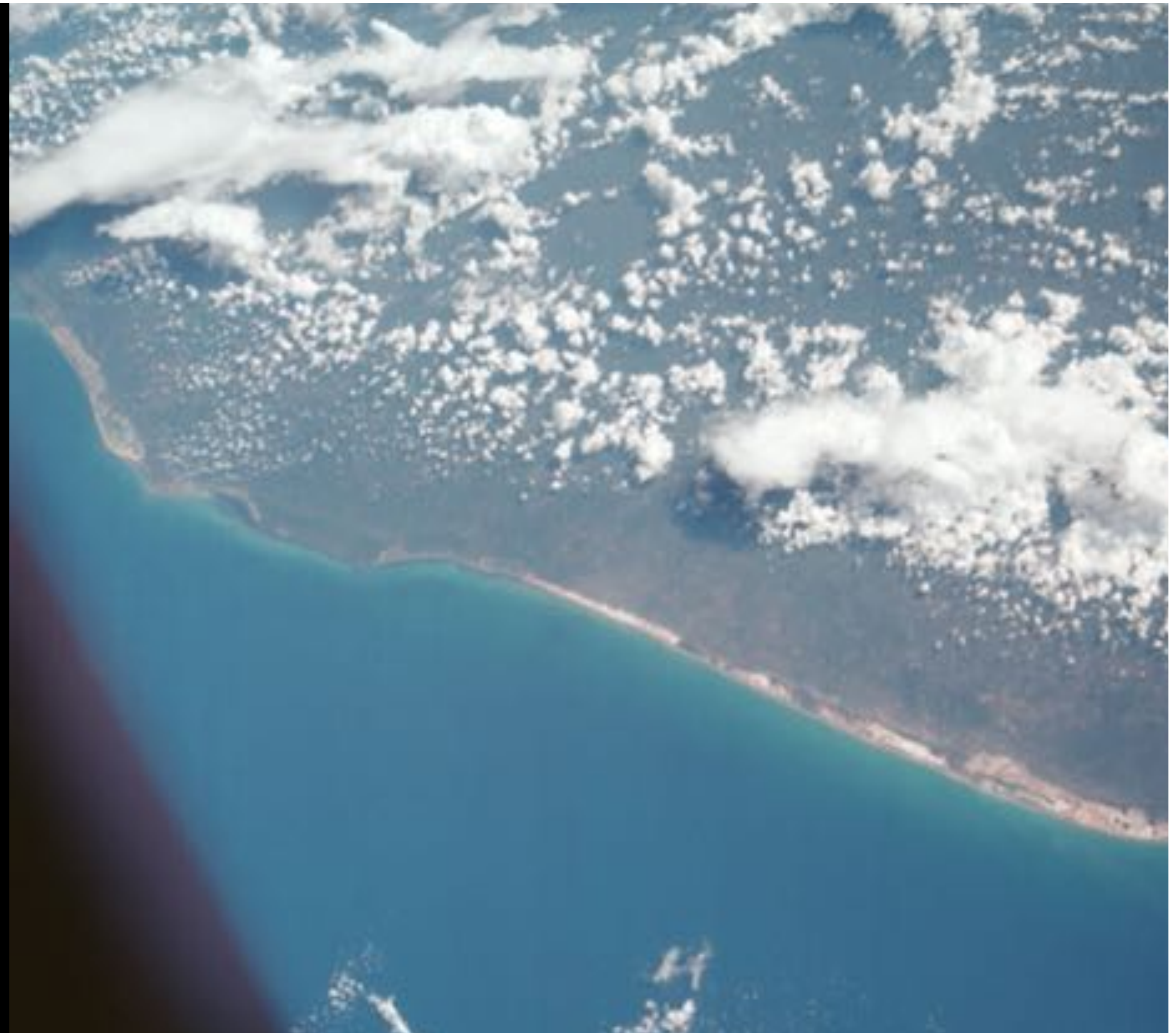
(after Marinescu et al. 2021)

Summary

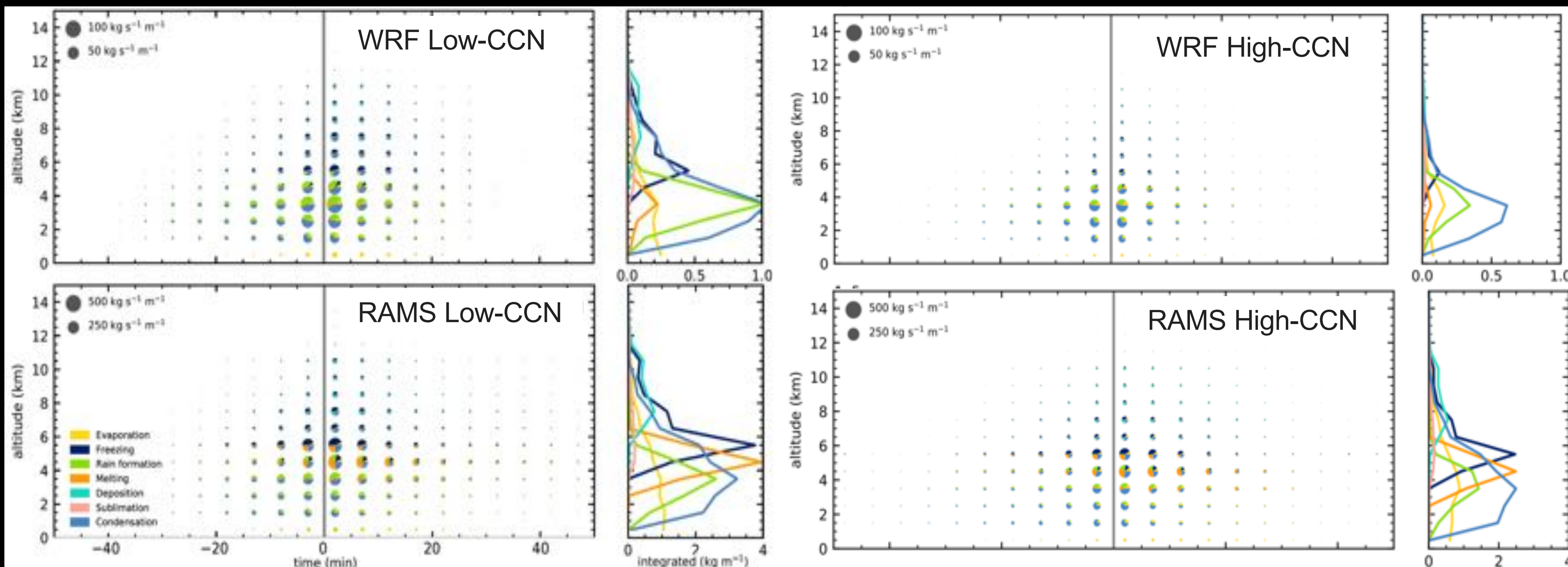
- 7 state of the art CRMs
- All models → produce scattered convection around Houston
- **Encouraging similarities** – with enhanced aerosol loading most models show:
  - Decreased accumulated precipitation
  - Increased cloud mass and number concentrations, decreased rain mass and number concentrations, increased raindrop diameters; increase in total anvil ice mass
  - Weaker downdraft velocities and increased updraft velocities in warm rain region
  - Longer-lived and / or greater anvil extents
- **Important differences**
  - **Precipitation:** vary more as a function of model physics than aerosol impacts
  - **Anvils**: wide range in anvil ice mass amounts → cloud radiative forcing implications
  - **Updrafts**: mixed response in mixed through ice phase regions (above 4km AGL)
  - **Cold Pools**: 4/7 show warmer / weaker cold pools – in spite of the fact that all models show weaker downdrafts and most have larger raindrop diameters → storm longevity and CI

2. Ways forward in MIP Evaluation

- What is the most appropriate way to evaluate the MIP results?
- What ways can the models be used to assist in field campaign observational strategies and/or explain the processes observed?



Goal: to assess microphysical process rates as a function of lifecycle, cloud type, thermodynamic environment, aerosol environment and model framework



Microphysical process rates for a composite of tracked deep convective clouds aligned around the timing of maximum latent heat release for WRF and RAMS for Low- and High-CCN conditions (after Heikenfeld et al. 2021)

Our Approach

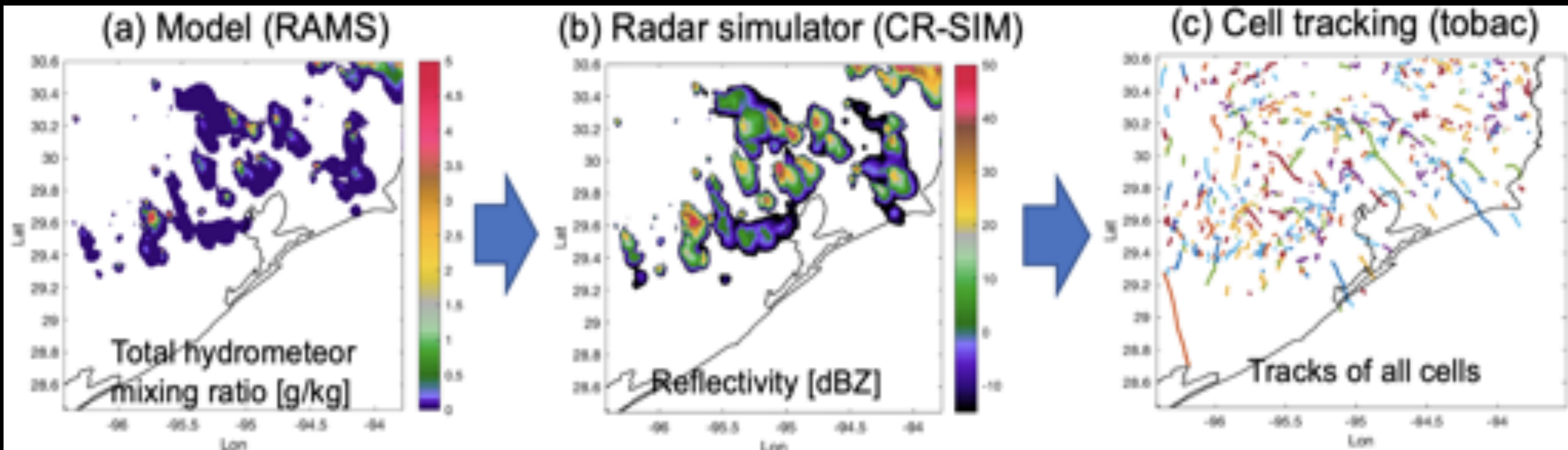
Approach

- Use instrument simulators to ensure apples-to-apples comparisons and assessing appropriate campaign strategies
- Track (lifecycle) large numbers of individual clouds (cloud type) under multiple thermodynamic and aerosol environments (environments) in both observational and modeling (model parameterizations) datasets
- Assess isolated and regional responses to aerosol loading in both observations and models

Uncertainties

1. Cloud environments
2. Cloud type
3. Cloud lifecycle
4. Isolated vs Cloud Scenes
5. Model parameterizations

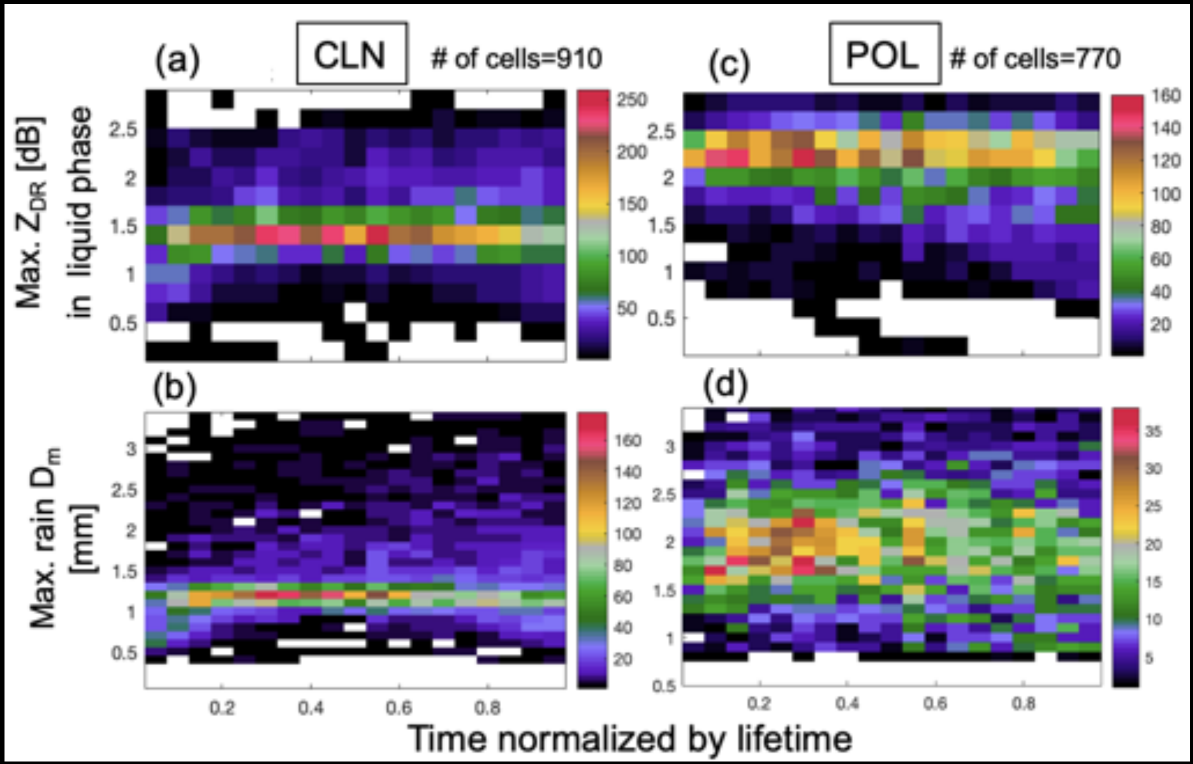
Instrument Simulators and Cell Tracking



(a) A snapshot of the RAMS-simulated total hydrometeor field, (b) CR-SIM-simulated radar reflectivity field (Oue et al 2020), and (c) tracks of convective cells detected using tobac (Heikenfeld et al 2019).

Rain Characteristics

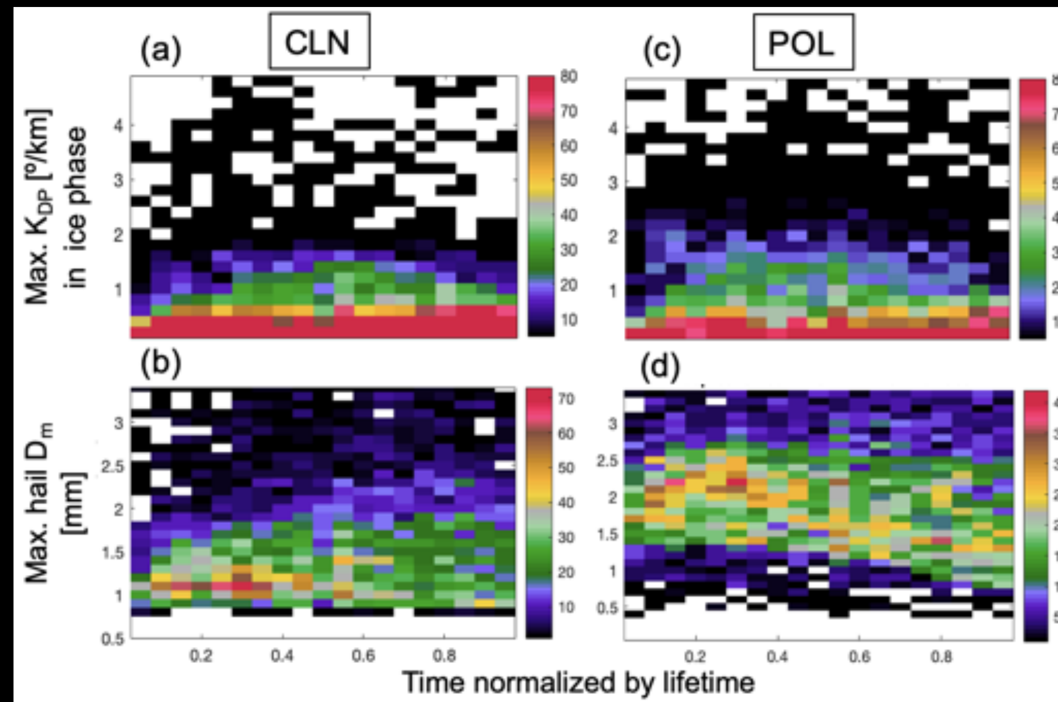
- Relationship between Z_{DR} (differential reflectivity) in liquid phase and rain Dm (mass-weighted mean diameter) as a function of lifetime.
- Generally the POL case produces ~0.8 dB larger Z_{DR} than that from the CLN case, while the POL case produces approximately 1 mm larger Dm for rain.
- Z_{DR} values can represent the raindrop size distribution.



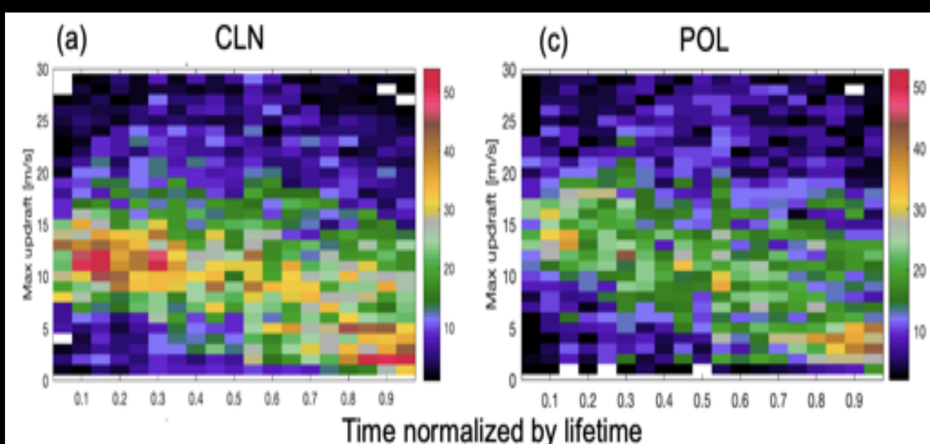
(a, c) Maximum Z_{DR} (differential reflectivity) in liquid phase and (b, d) rain Dm (mass-weighted mean diameter) values from each convective cell as a function of lifetime normalized by the length of lifetime for CLN case (a, b) and POL case (c, d). Color represents frequency of occurrence.

Hail Characteristics

- POL case produces slightly larger K_{DP} than that from the CLN case, while the POL case produces ~1 mm larger Dm for hail.



Top right: (a, c) Maximum K_{DP} in ice phase and (b, d) hail Dm (mass-weighted mean diameter) values from each convective cell as a function of lifetime normalized by the length of lifetime for CLN case (a, b) and POL case (c, d). Color represents frequency of occurrence. Bottom left: Maximum updraft velocities for the clean and polluted cases.



Approach to Address MIP Uncertainties

- Select clean and polluted TRACER case studies
- Using instrument simulators to ensure apples-to-apples comparisons
- Use tracking algorithms to track (lifecycle) large numbers of individual clouds (cloud type) under multiple environments (environments) in both observational and multiple modeling frameworks (model parameterizations)
- Assess isolated and regional responses to aerosol loading in both observations and models

See posters (Poster session 3) and a combined talk by Steve Saleeby and Mariko Oue in the session on “Improving understanding of deep convection life cycle with novel measurement and modeling approaches” on Wednesday