Cloud organization, cold pools and water isotopes in large eddy simulations of EUREC4A

Peter Blossey (UW) and many collaborators

Collaborators: Roel Neggers, Steef Boeing, Leif Derby, Salima Ghazayel, Ryan Eastman, Joe Galewsky, Camille Risi, Estefanía Quiñones Meléndez, Simon de Szoeke.

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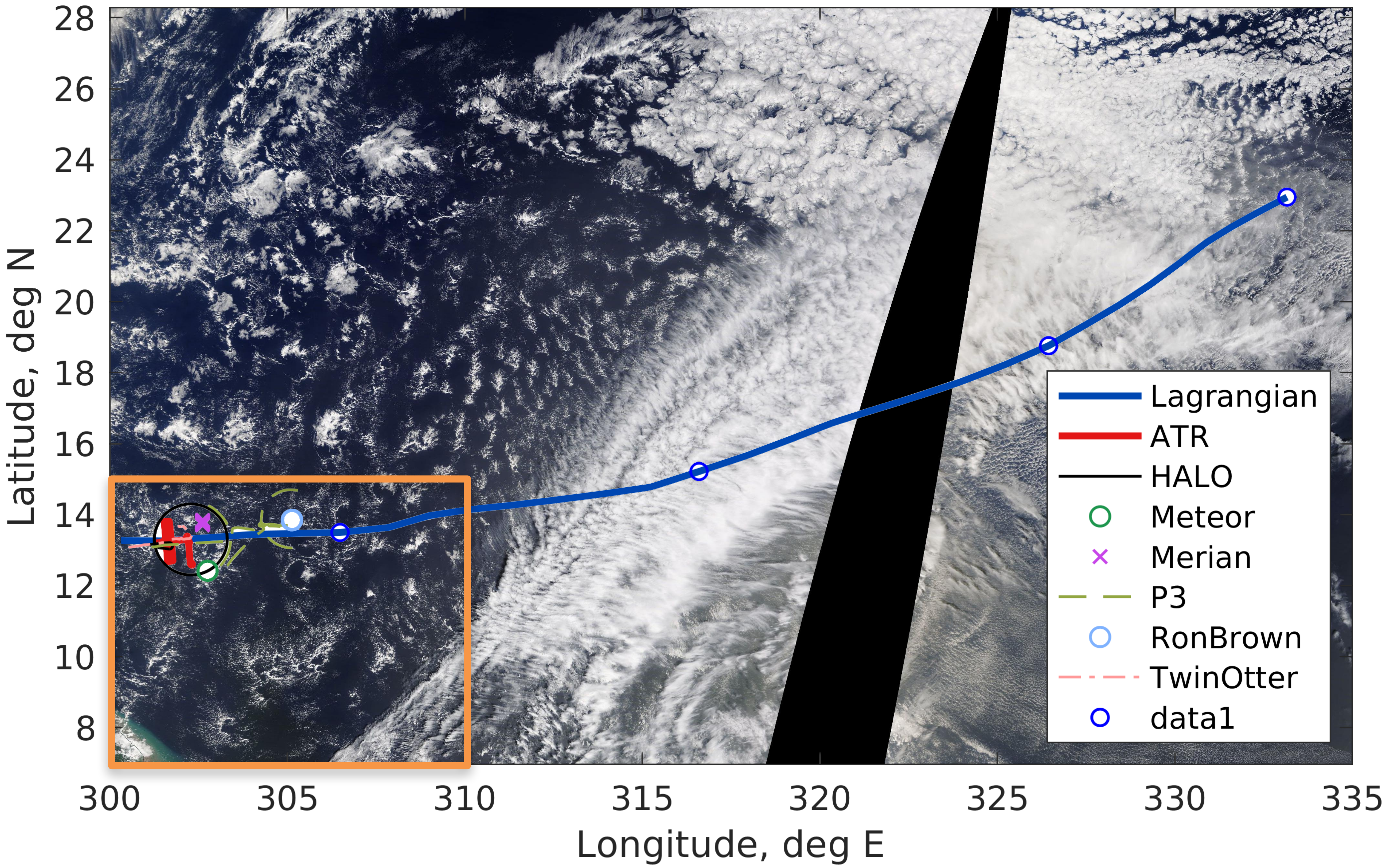
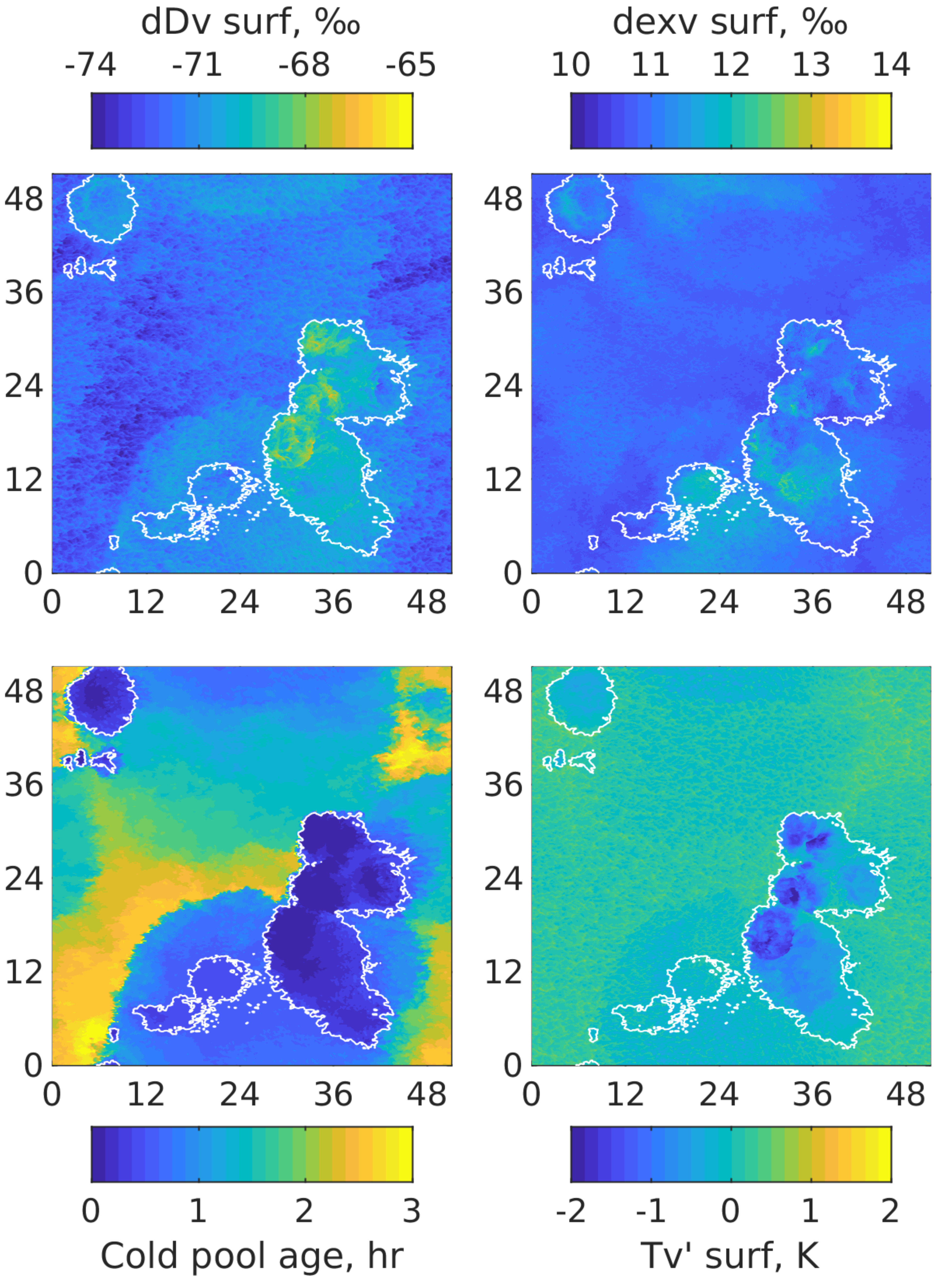
Outline

- First, develop case studies following air masses towards Barbados during EUREC4A.
- Second, simulate those case studies with water isotopes and look at isotopic signatures of cold pools.

NASA Worldview

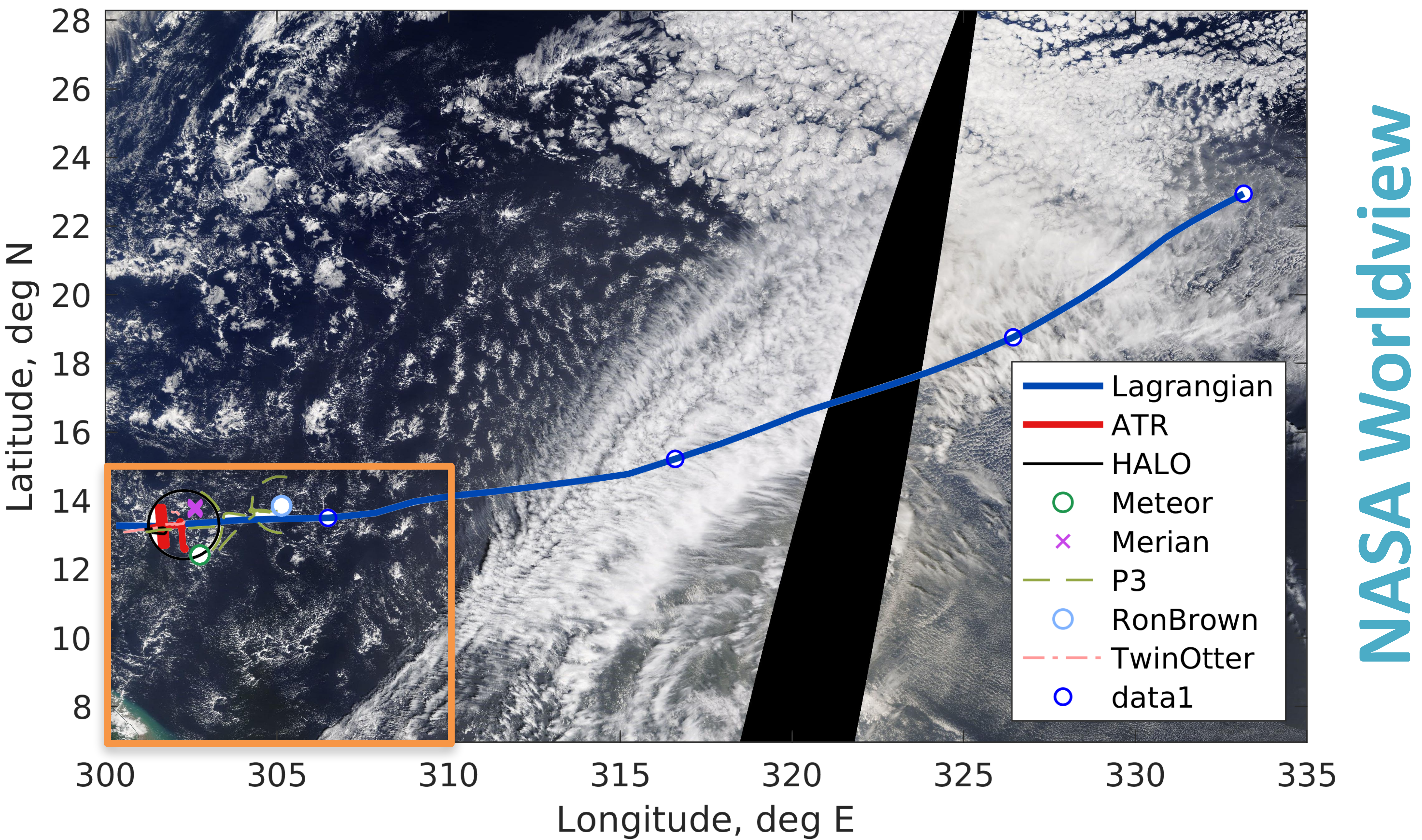




EUREC4A: Quasi-Lagrangian LES Case Studies

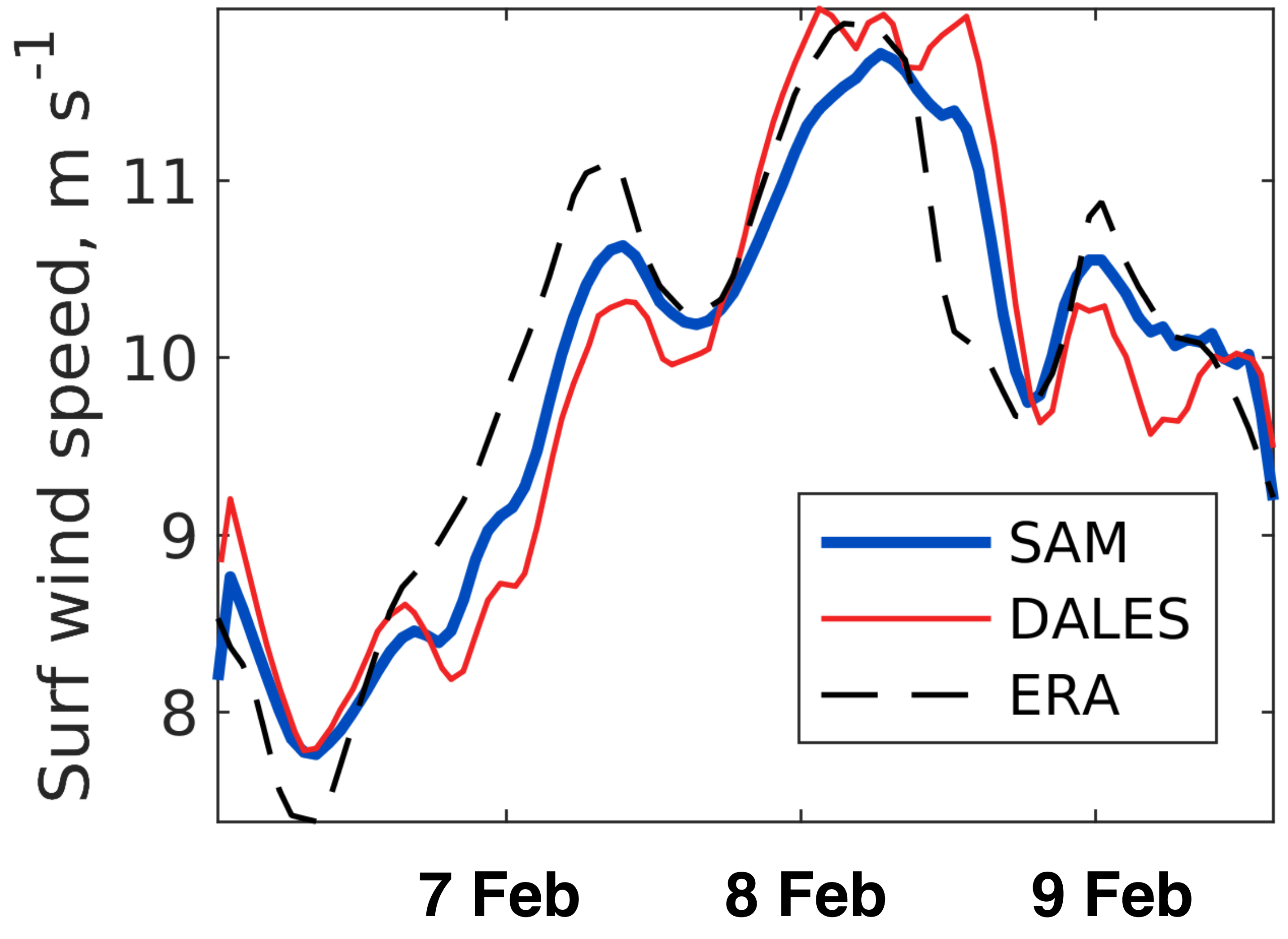
- Large eddy simulations with periodic boundary conditions in the horizontal.
- Three quasi-Lagrangian case studies so far that follow boundary layer air masses as they approach Barbados on 2 Feb, 5 Feb and 9 Feb 2020.
- Trajectories vary in meteorology and cloud organization (flowers, gravel/cold pools). May add 28 Jan and 7 Feb.

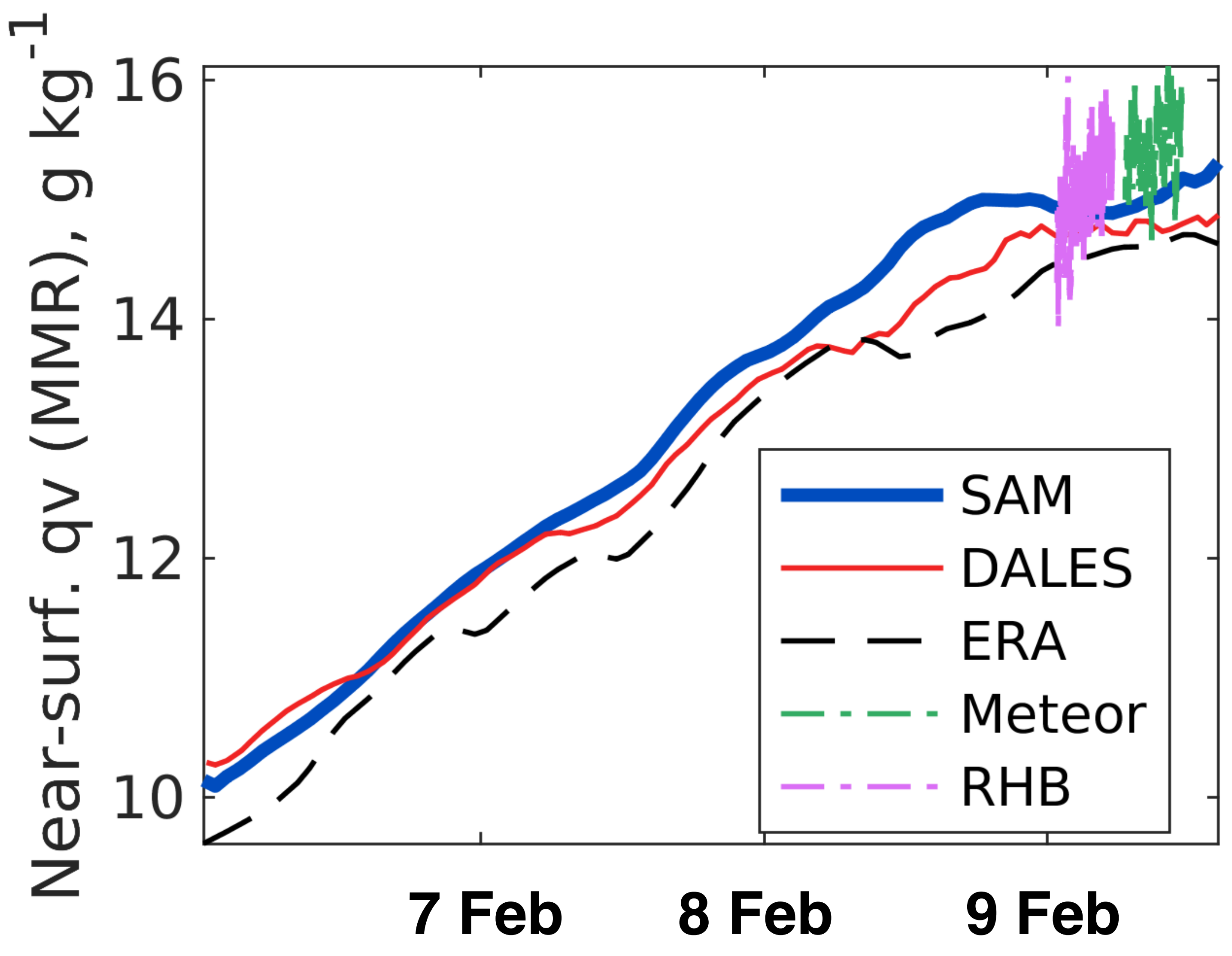
- Forcings and initial conditions from reanalysis.
- Run by groups at UW, Leeds and Cologne.
- At right (in blue), a quasi-Lagrangian trajectory that crosses the region of intense observations on 9 Feb 2020.



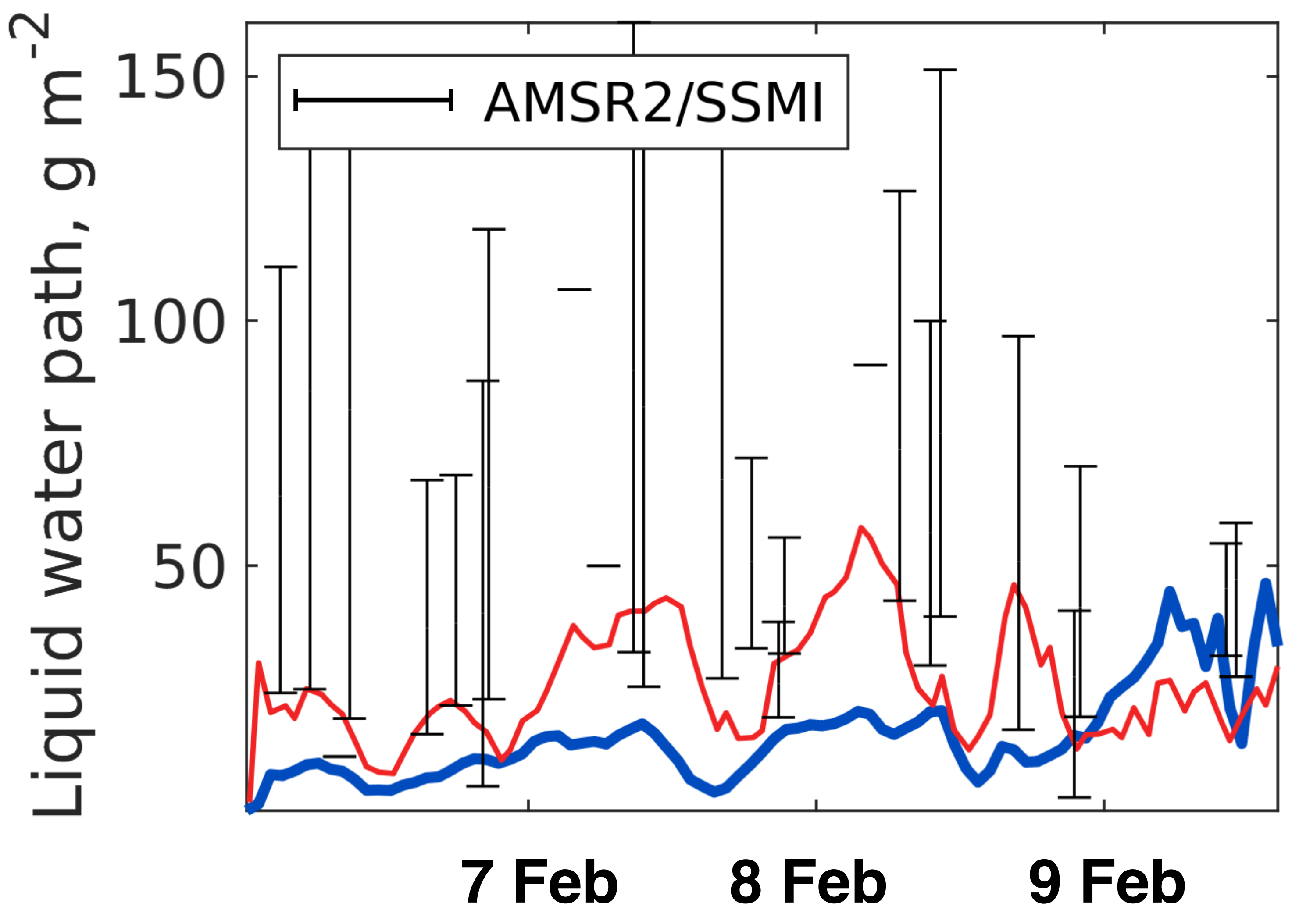
Evolution of Feb 9 Case Study

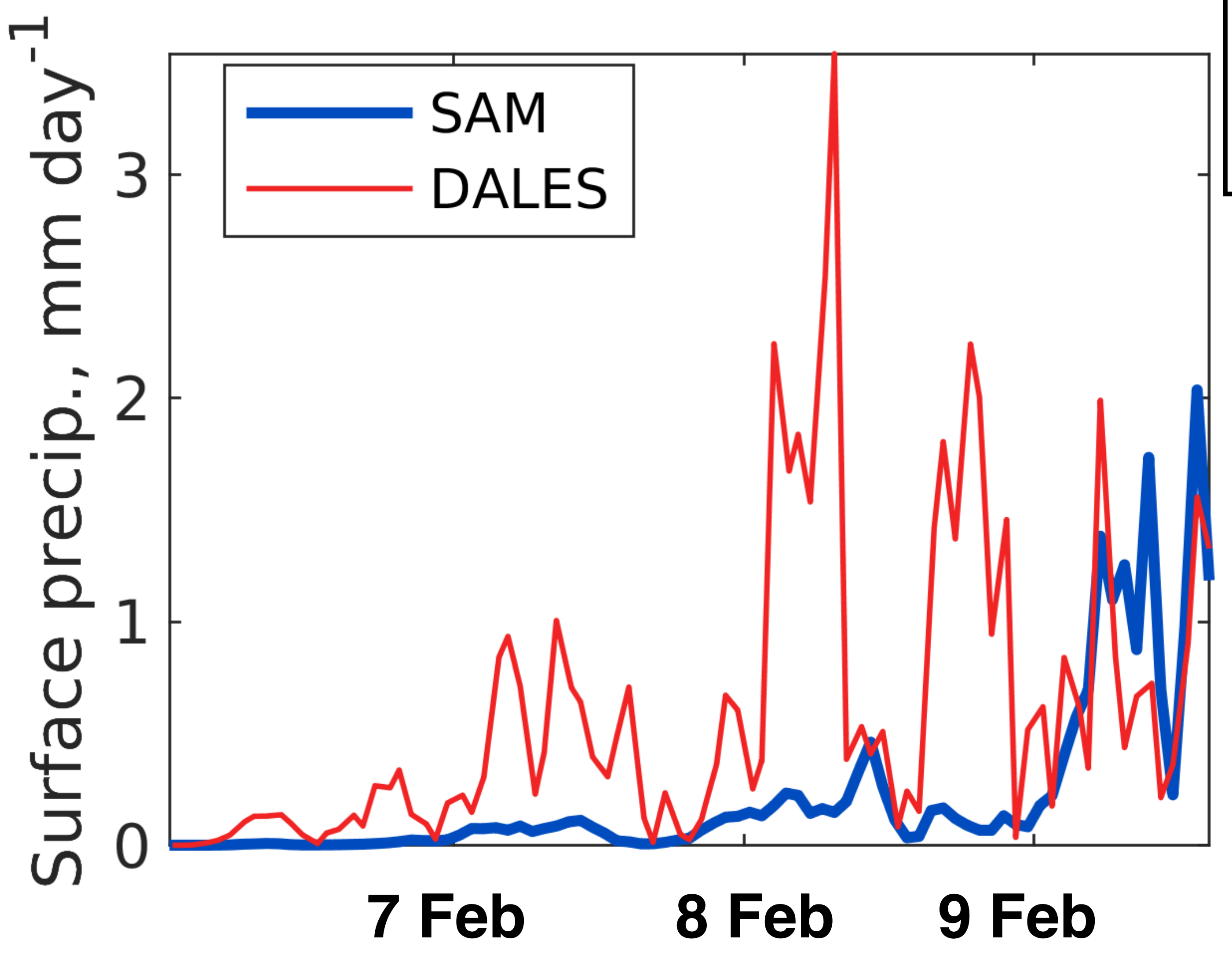
- Two LES so far: SAM and DALES (from Salima Ghazayel and Roel Neggers)
- Both track ECMWF wind speeds and subcloud layer humidity.
- Models under-predict microwave LWP and disagree on precipitation on 8 Feb
- SAM agreement with CERES is good as the trajectory approaches Barbados. High cloud affects 7 Feb.

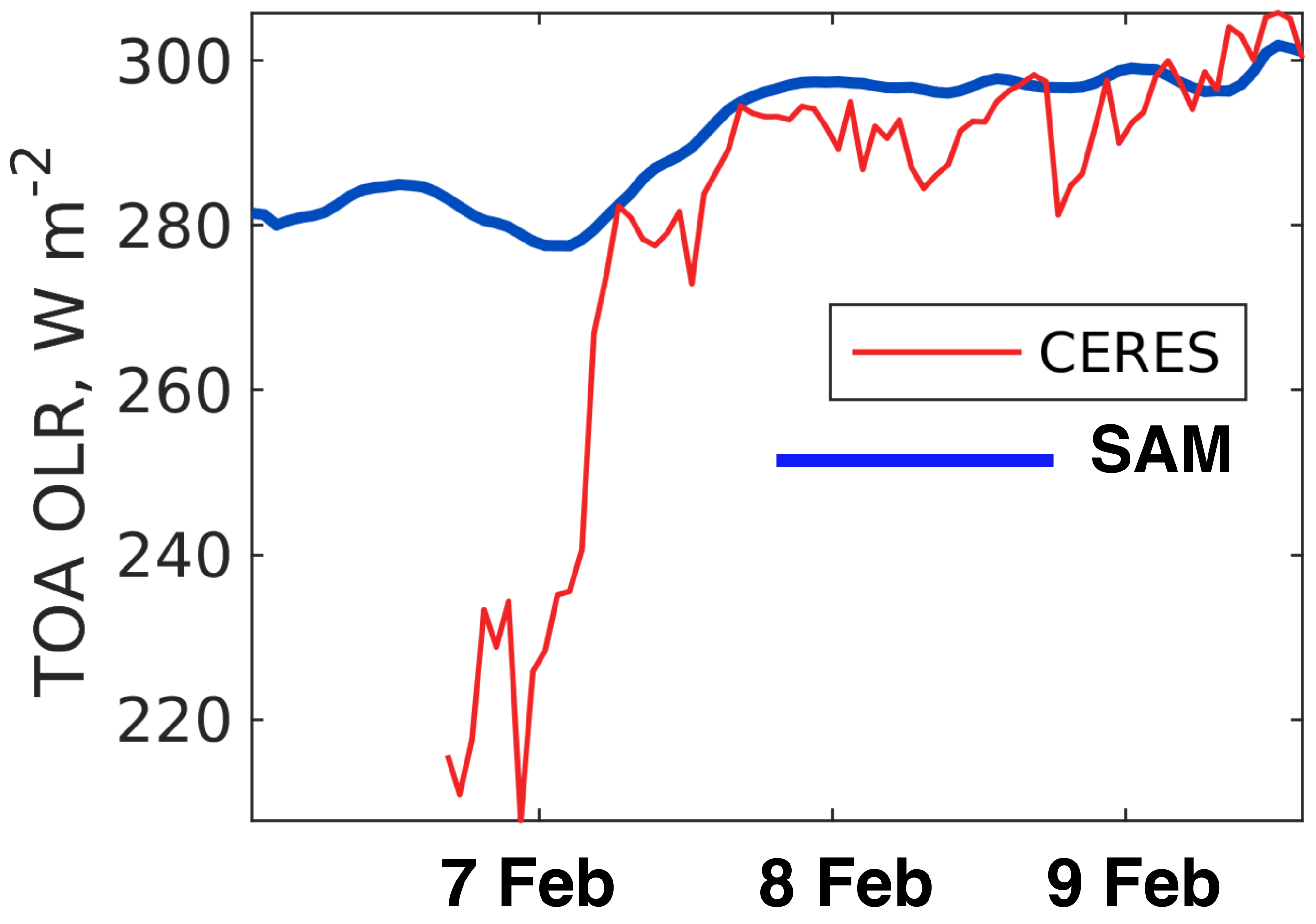




Simulation setup: Duration~3.7 days
Lx=Ly=51.2 km, Δx=Δy=100 m, Δz=40

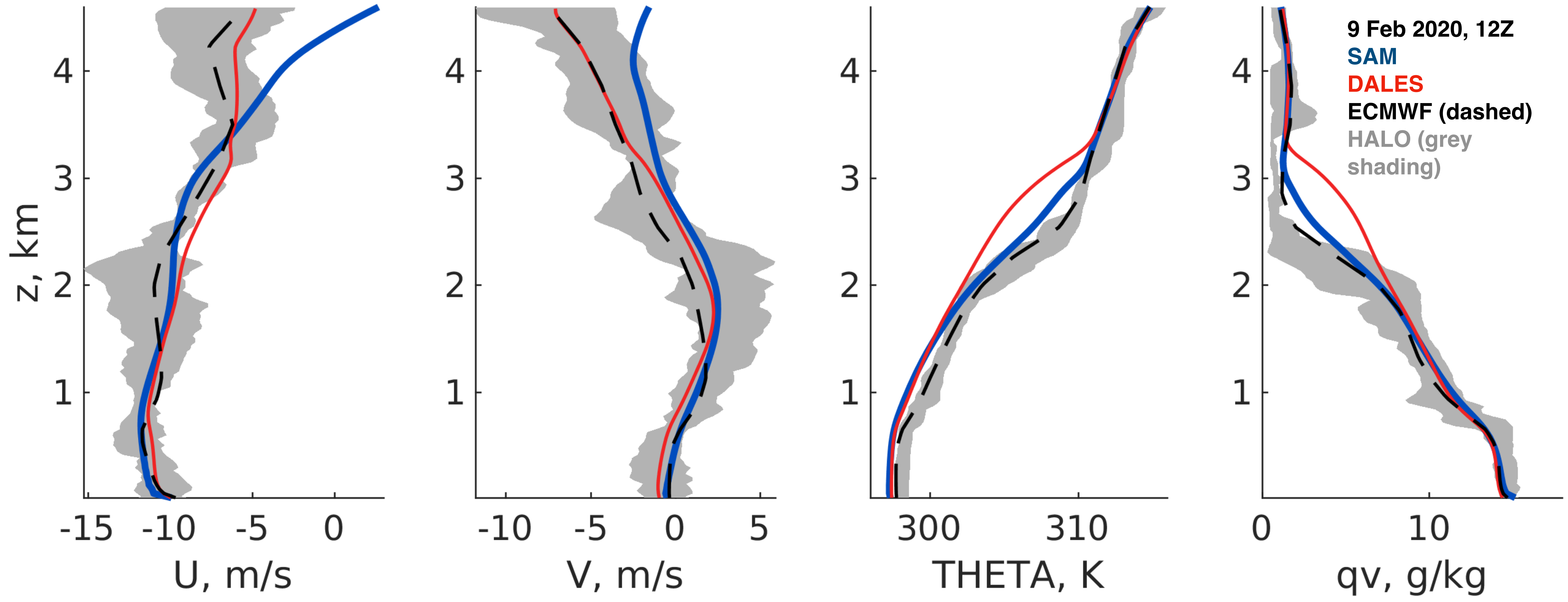






Comparison with dropsondes near Barbados

- SAM and DALES show reasonable agreement w/ HALO dropsondes (George et al, 2021) and ECMWF, though with higher trade inversions in both models and a cold bias in DALES.



Future Work

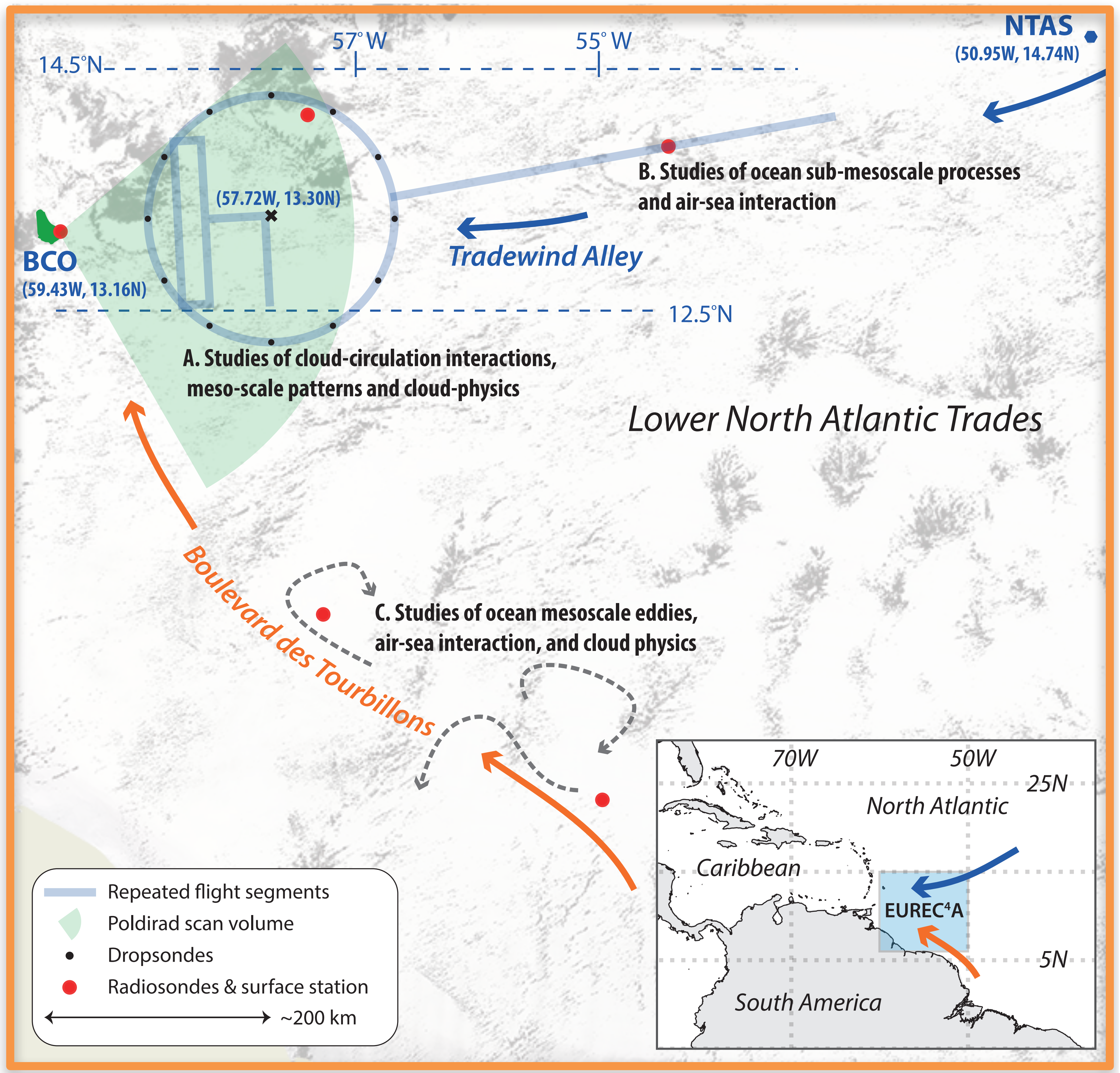
- Include new MONC simulations (from Steef Boeing and Leif Denby) in analysis.
- Look at evolution of organization in models over multiple diurnal cycles.
- Do mechanisms leading to organization differ among models or across case studies?

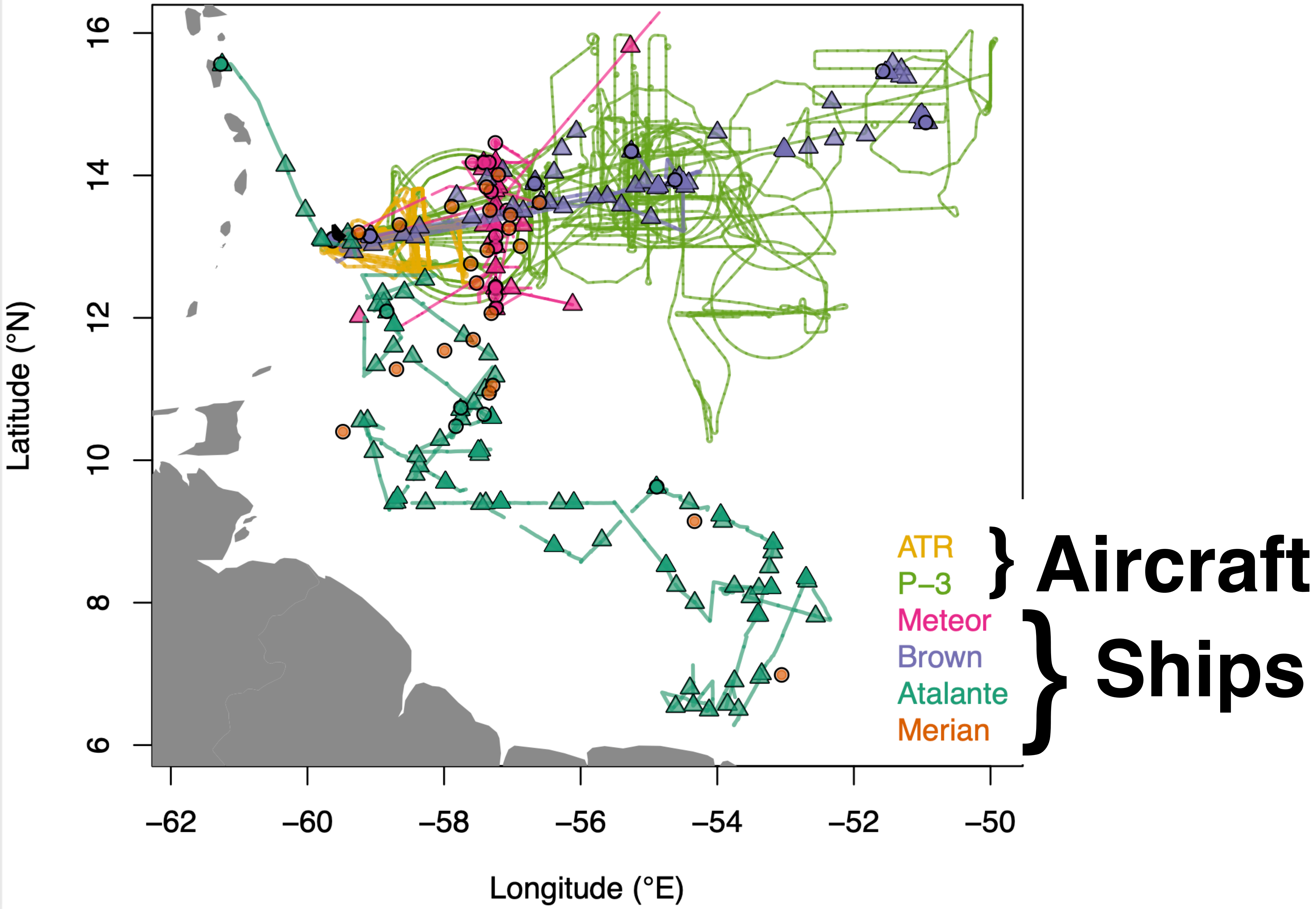
EUREC4A-iso: What can water isotopes tell us about trade wind cumulus convection?

- EUREC4A included an unusually large collection of water isotope measurements.
- Observations from 2 research aircraft, 4 ships and the Barbados Cloud Observatory.

- **Goals/questions include:**
  - What sets the isotopic composition of water vapor in the subcloud layer?
  - Are there isotopic signals associated with cloud organization and cold pools?
  - What can isotopes tell us about mixing processes in the trade cumulus boundary layer?

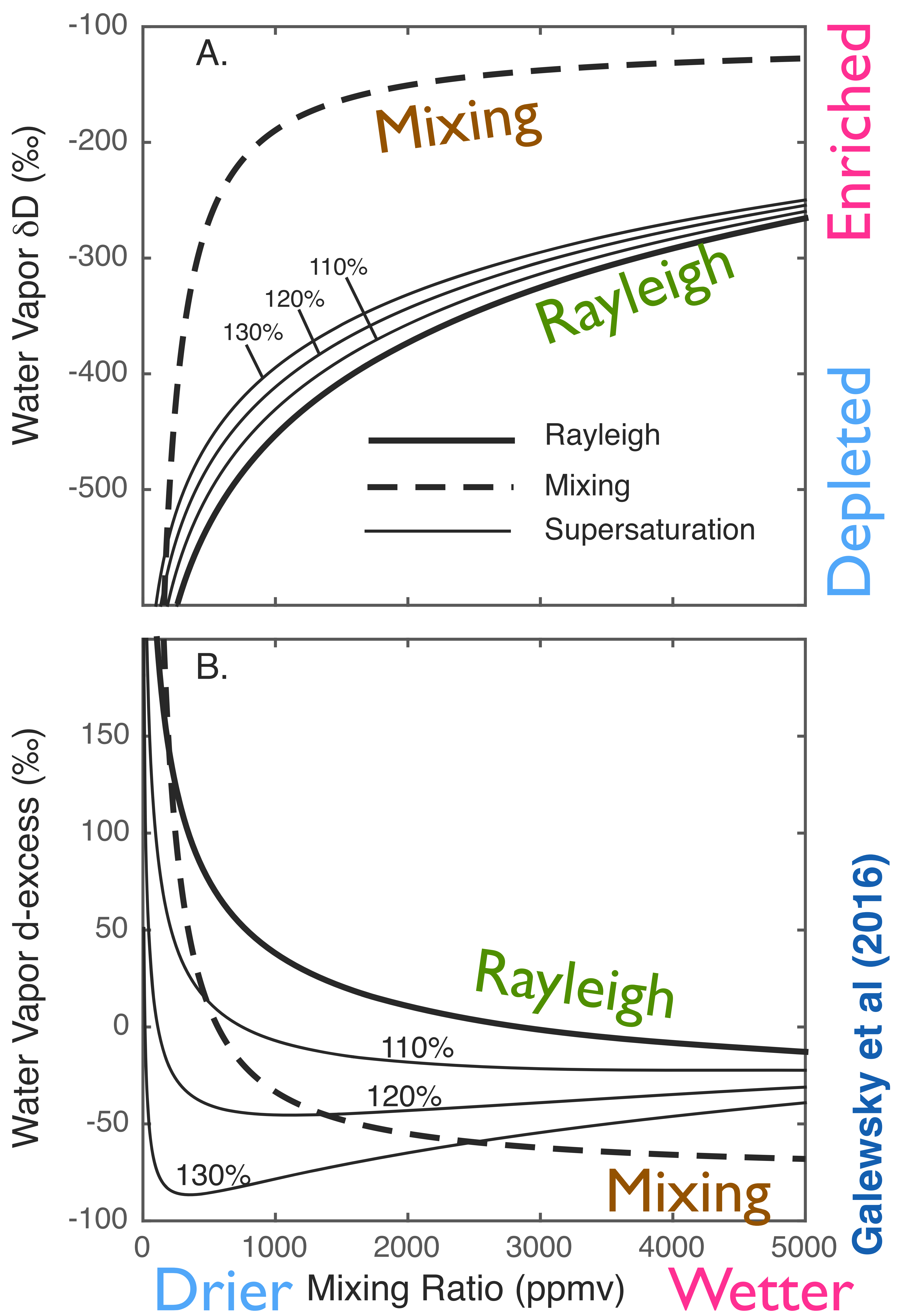
Stevens et al (2020, Submitted)





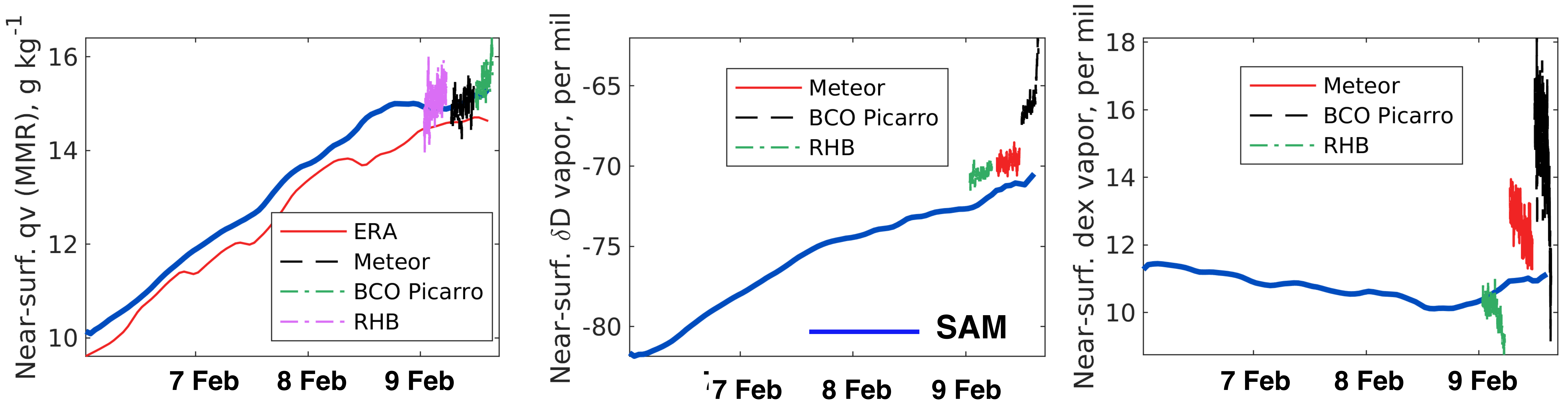
Water Isotope Basics

- Heavy water isotopes prefer condensed phase.
- Sustained condensation depletes heavy isotopes in water vapor.
- Basic isotope intuition:
  - Cooler, Drier, More Depleted
  - Warmer, Wetter, More Enriched
- Isotopic content is measured relative to a standard, e.g. $\delta D(‰) = 1000 \left(\frac{([D]/[H])^{sample}}{([D]/[H])^{SMOW}} - 1 \right)$
- Different processes can be distinguished by their paths in q-δD space, e.g. Rayleigh vs. Mixing.
- Deuterium excess ↔ non-equilibrium processes.



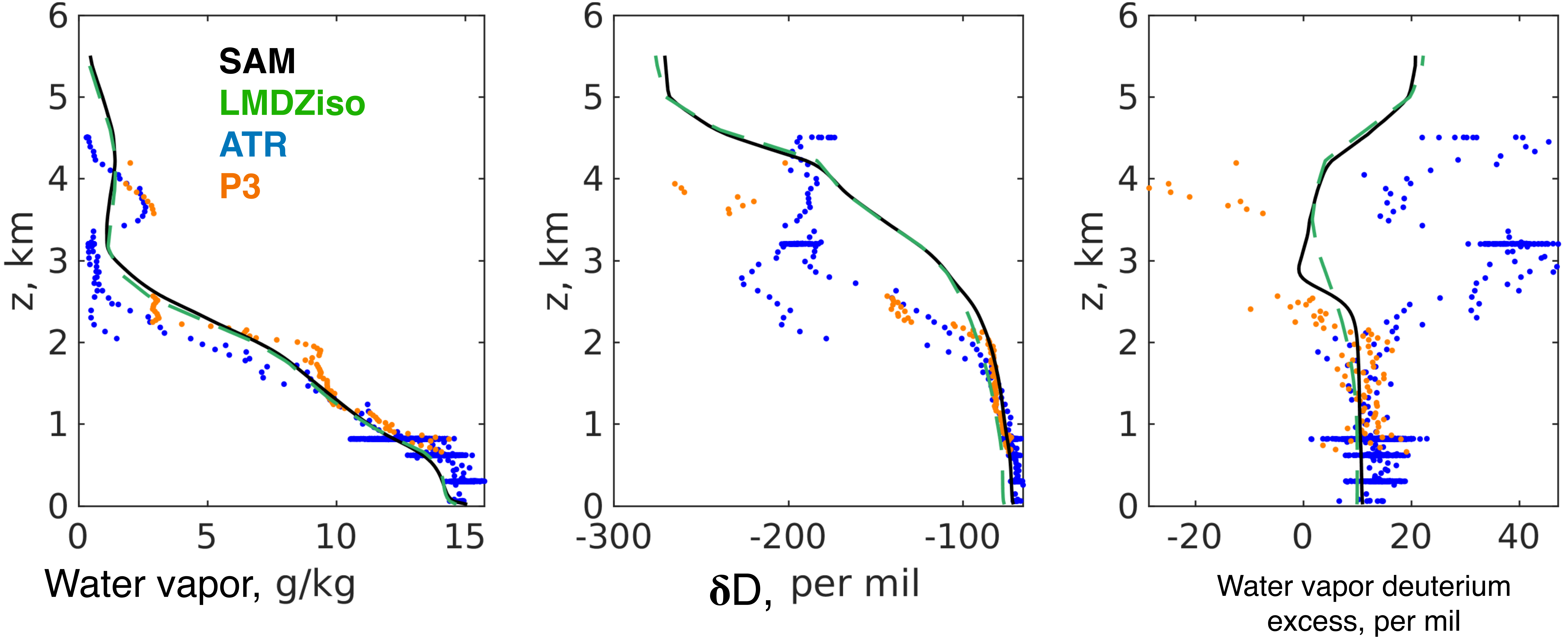
Evolution of water isotopes while traveling towards Barbados

- Isotope initial and boundary conditions come from an isotope-enabled GCM (LMDZiso) nudged to reanalysis.
- Ocean isotopic composition from observations during the campaign.
- Simulations with isotope-enabled SAM using Thompson microphysics.
- Given spread in observations, near-surface isotopic composition is reasonable.

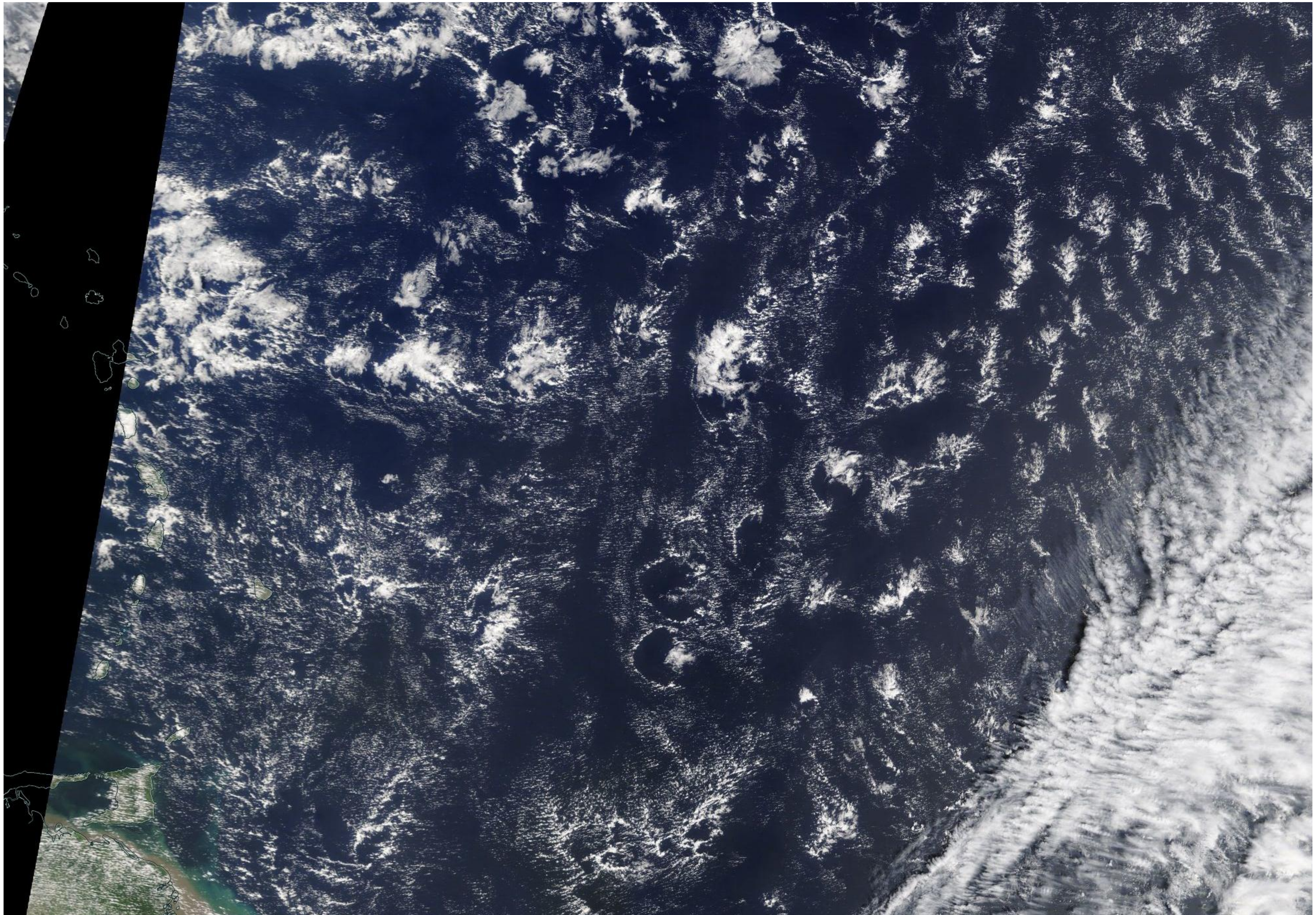


Comparison of isotopes w/aircraft near Barbados

- Profiles of water vapor isotopic composition in SAM-iso have modest biases in the MBL with respect to in situ aircraft observations from the ATR and P3 aircraft, but larger spread above the MBL where SAM is nudged to the LMDZiso GCM.
- SAM's δD within the MBL agrees better with aircraft observations than LMDZiso.

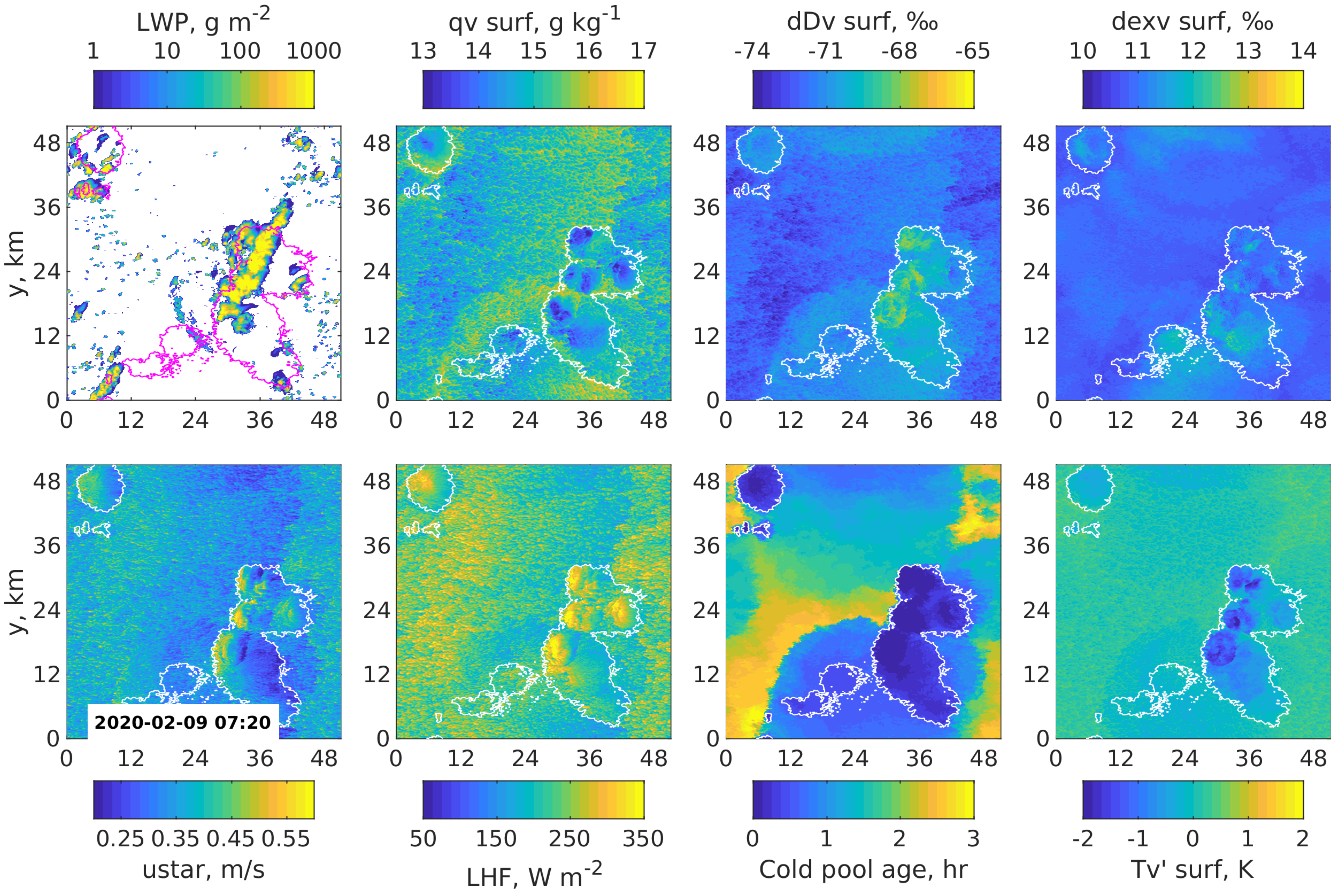


Cold Pools On Feb 9th (NASA Terra)



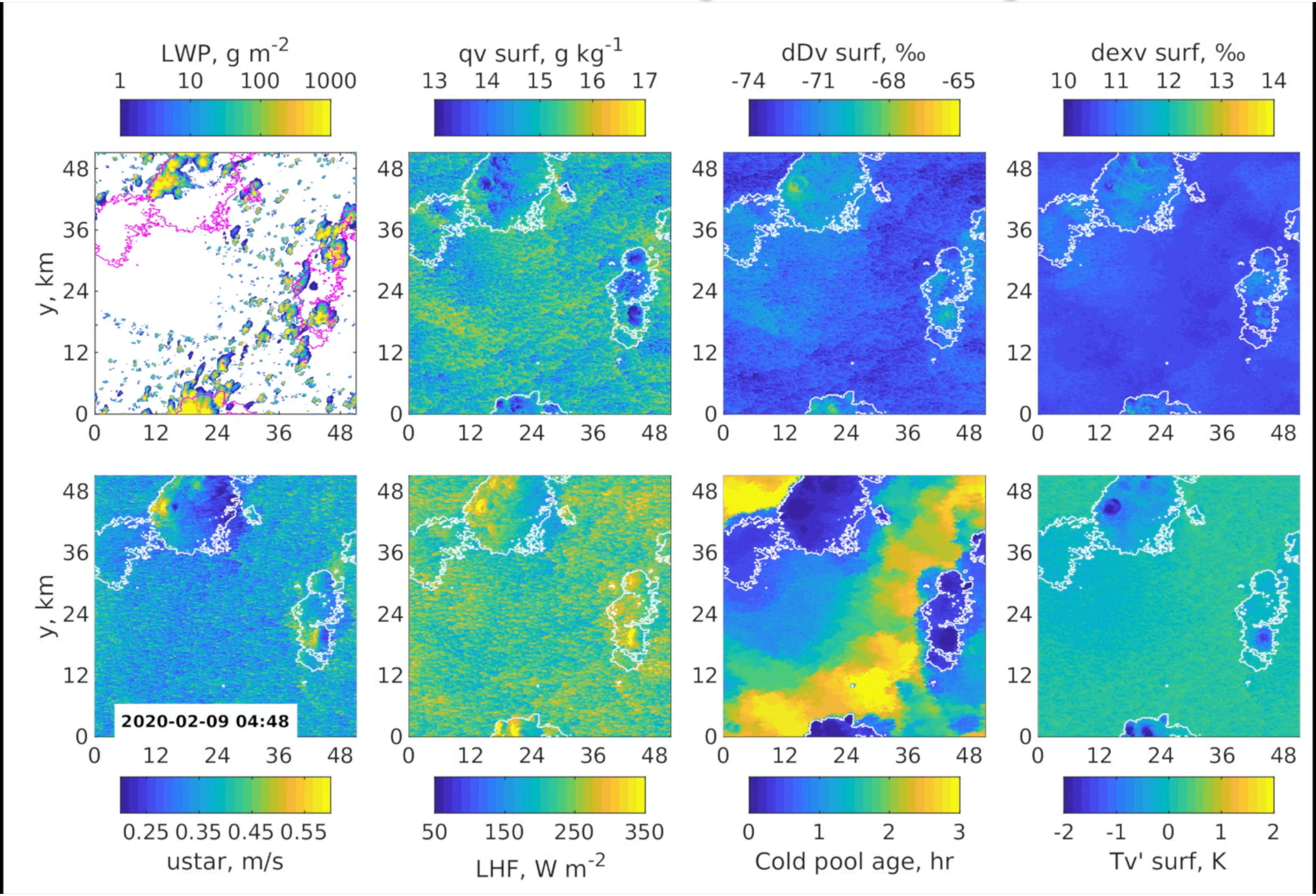
NASA Worldview (Terra)

Cold Pools On Feb 9th (Simulated)



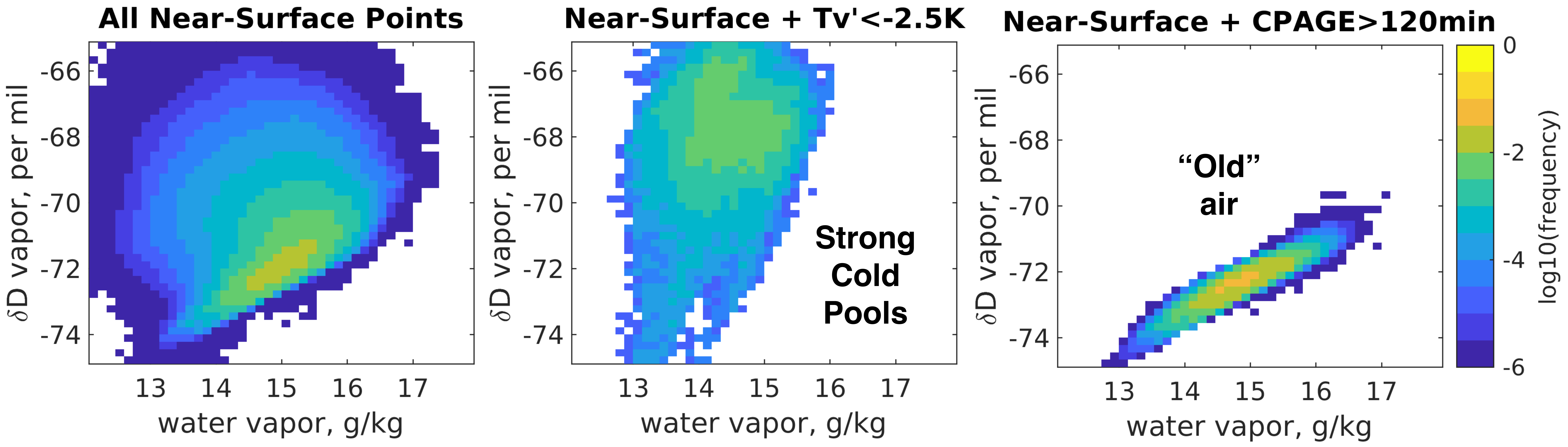
Cold pool age (based on tracer): Time since air was negatively buoyant with more than 0.1 g/kg of rain.

Cold Pools On Feb 9th (Simulated)



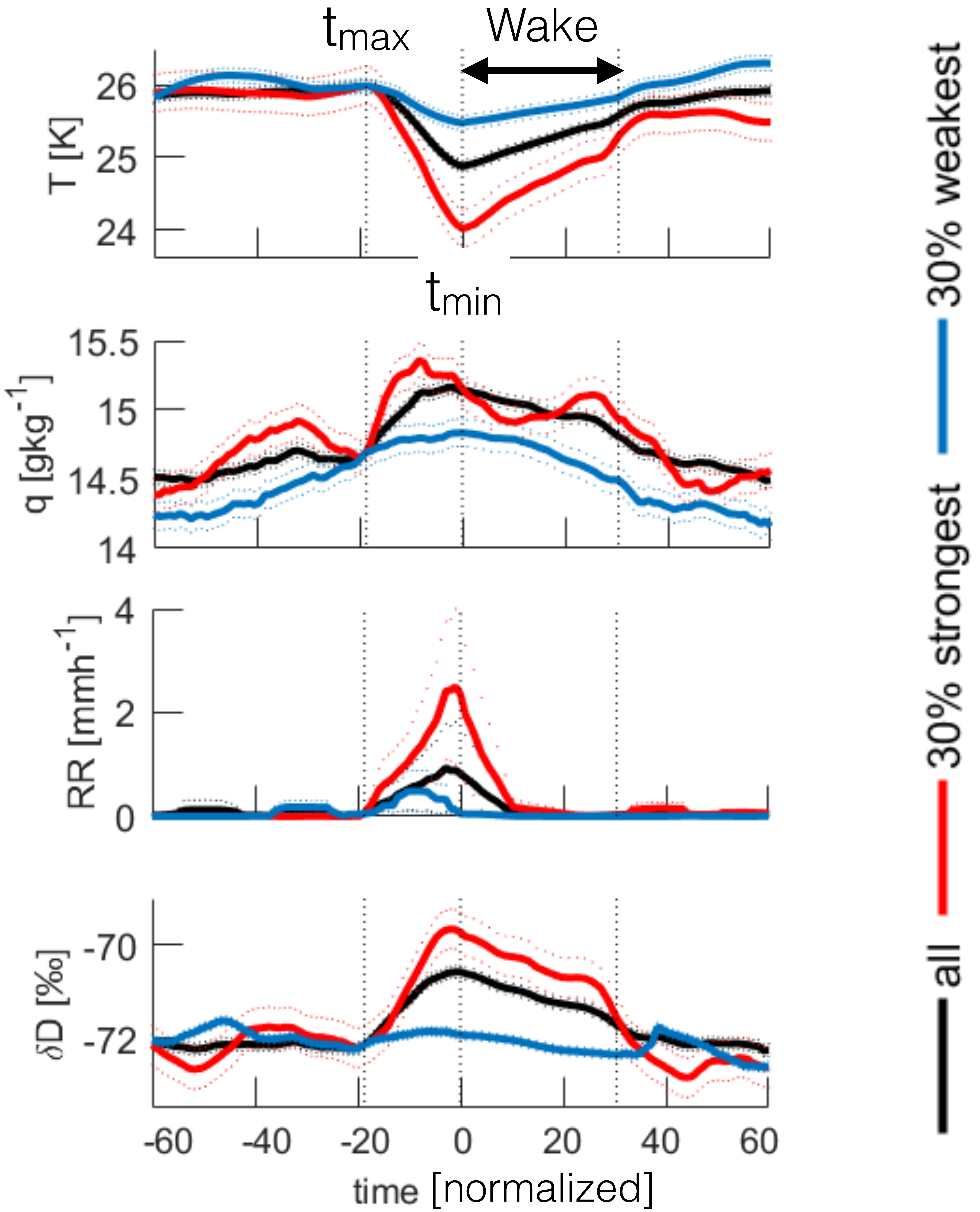
Cold Pools On Feb 9th

- The simulations show decreased water vapor, increased δD and more variable deuterium excess in cold pools.
- Joint distributions of water vapor and its isotopic content (δD) are nearly distinct between strong cold pools and "older" air.



Cold Pools in Observations

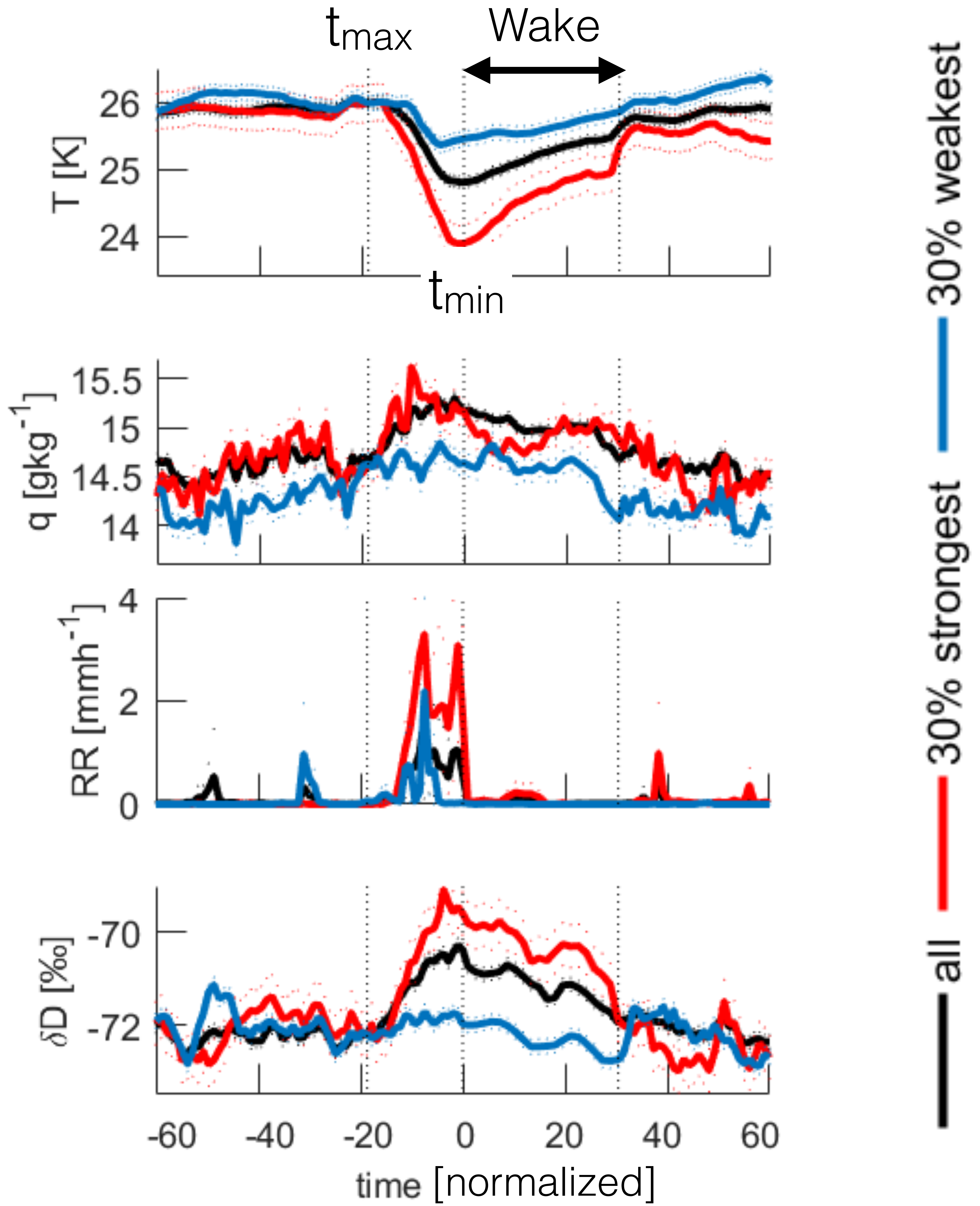
- Cold pool composite based on data from R/V Ron Brown.
- Follows identification method in Vogel et al (2021)
- Small sample size (~20)
- Clear signal of more enriched vapor (δD↑) in stronger cold pools.
- δD anomaly more connected to rainfall than increased LHF (not shown).
- Deuterium excess signal uncertain.



Courtesy of Estefanía Quiñones Meléndez (Oregon State Univ.)

Cold Pools in Observations

- Unfiltered timeseries emphasize role of rain during passage of cold pool front and coincident peak in δD.

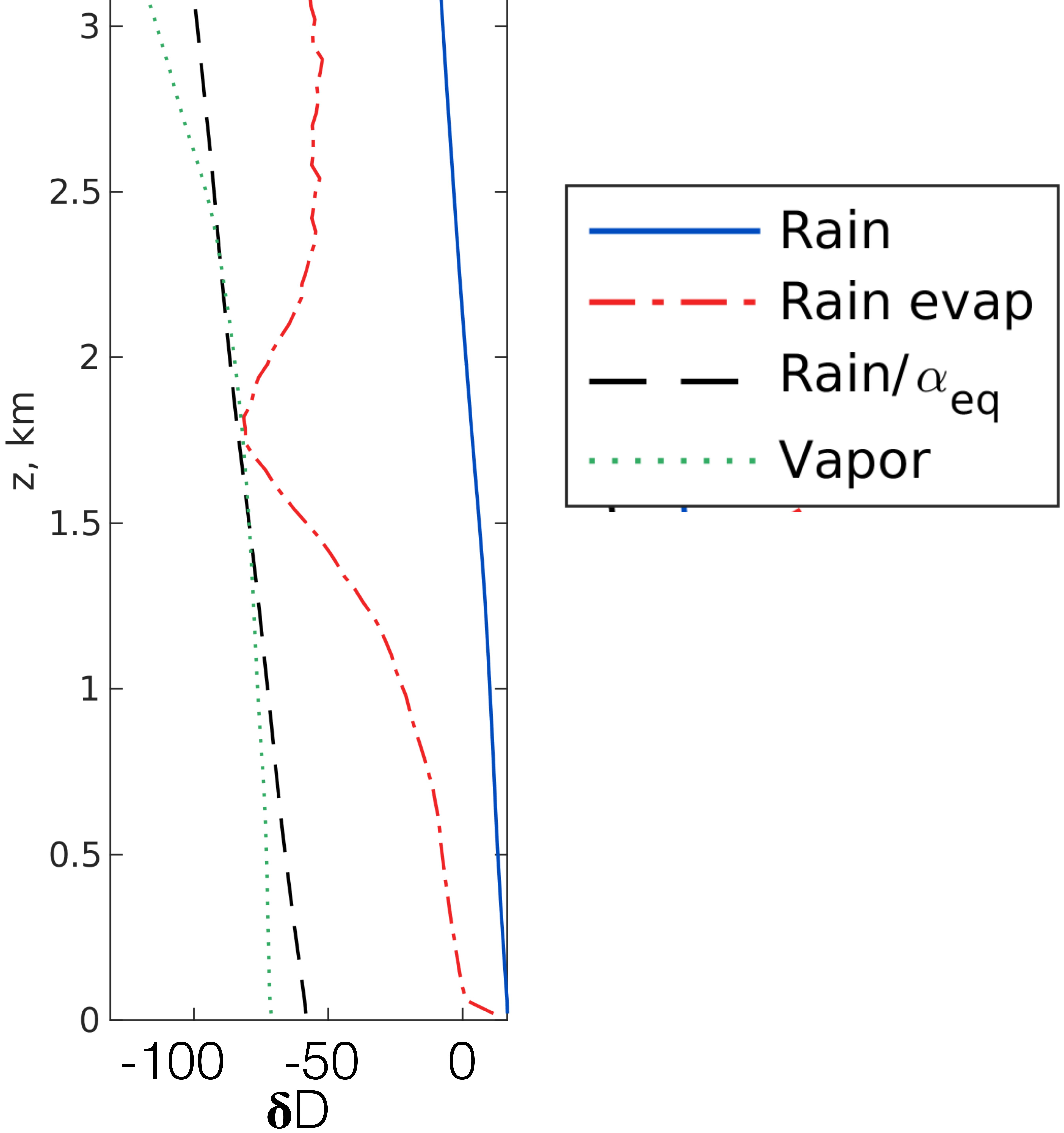


Courtesy of Estefanía Quiñones Meléndez (Oregon State Univ.)

Simulated water vapor δD tendency due to rain evaporation

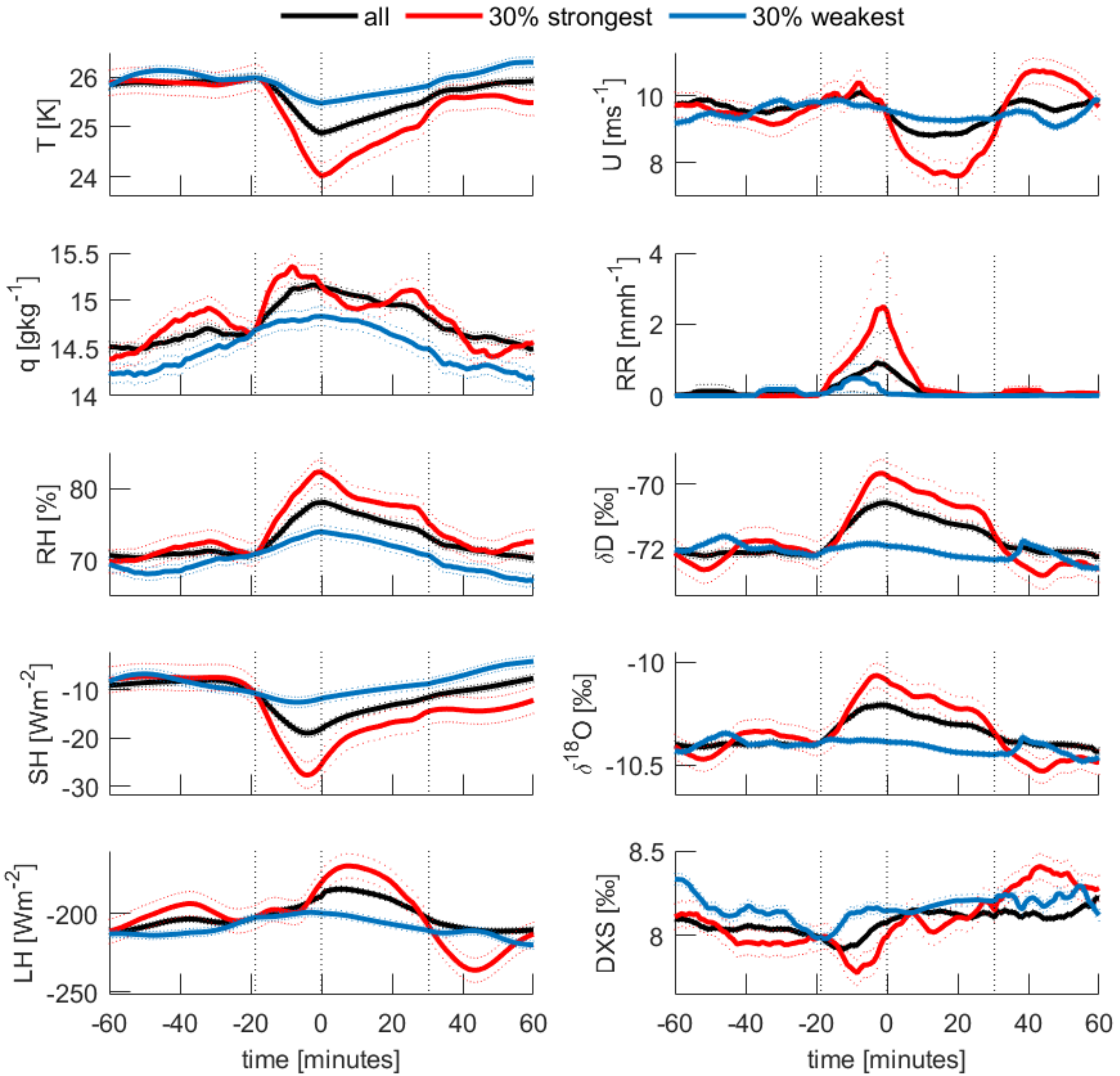
- What is the isotopic composition of vapor produced by rain evaporation?

- In the subcloud layer, vapor produced by rain evaporation is much richer than vapor in equilibrium with rain (black dashed line) and close to that of rain itself in the subcloud layer.



Looking forward, we would like to…

- Understand drivers of organization better and whether those drivers differ among models,
- Connect the isotopic signal at the surface to the rain evolution (e.g., fraction of rain evaporated),
- And run with finer grid spacing to better resolve rain shafts. (Would this impact cold pool signals in our simulations?)



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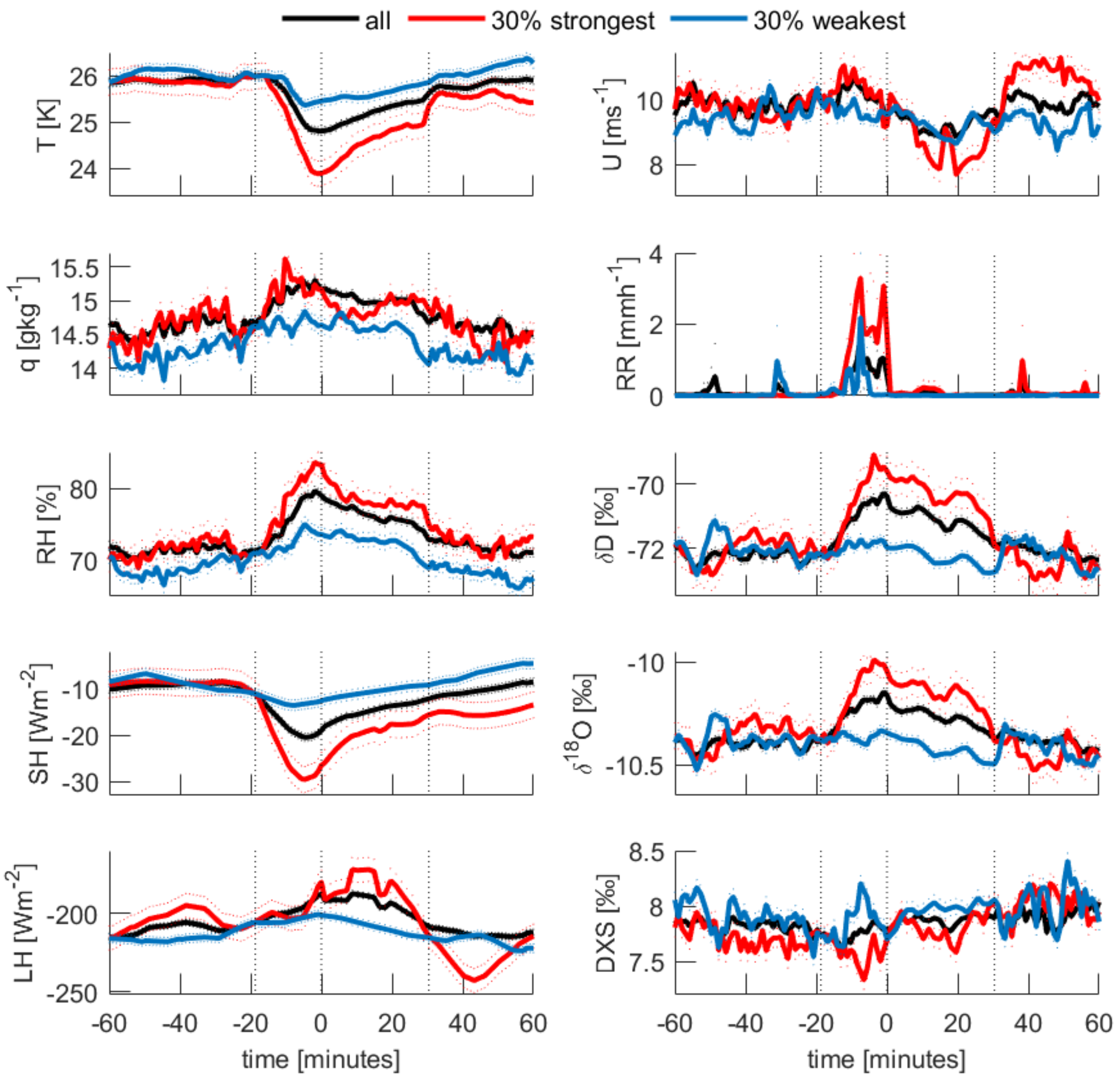

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