High-resolution Coupled Mesoscale to Microscale Simulations of Mixed-Phase Convective Clouds Observed during the Cold-Air Outbreaks in the Marine Boundary Layer Experiment (COMBLE)

Branko Kosović[1],
Timothy W. Juliano[1], Lulin Xue[1], Bart Geerts[2], Christian Lackner[2], Nathaniel AbrokwahOteng[2]

1 -National Center for Atmospheric Research
2 – University of Wyoming

NCAR | RESEARCH APPLICATIONS LABORATORY

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ASR Atmospheric System Research

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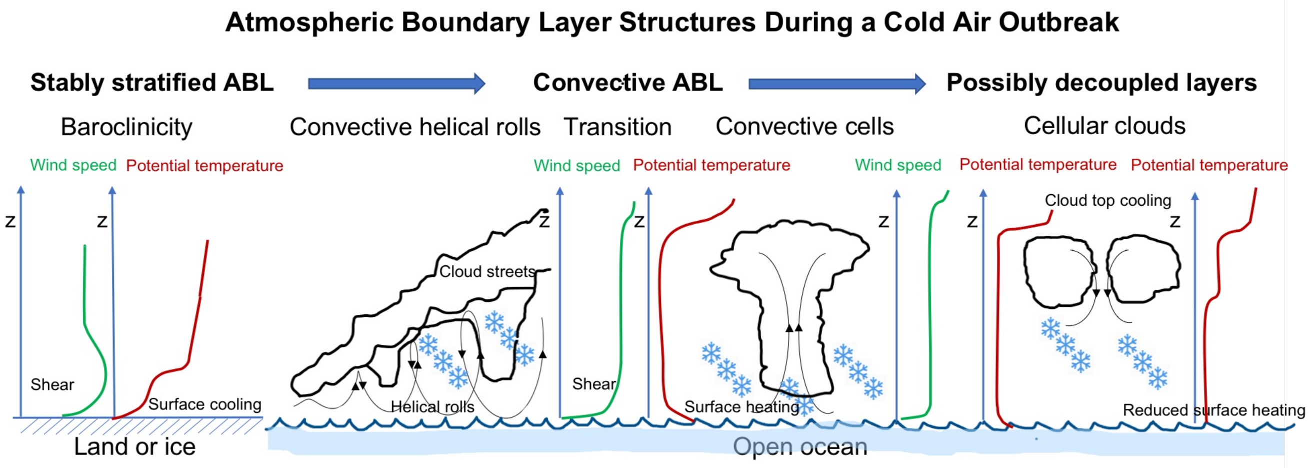
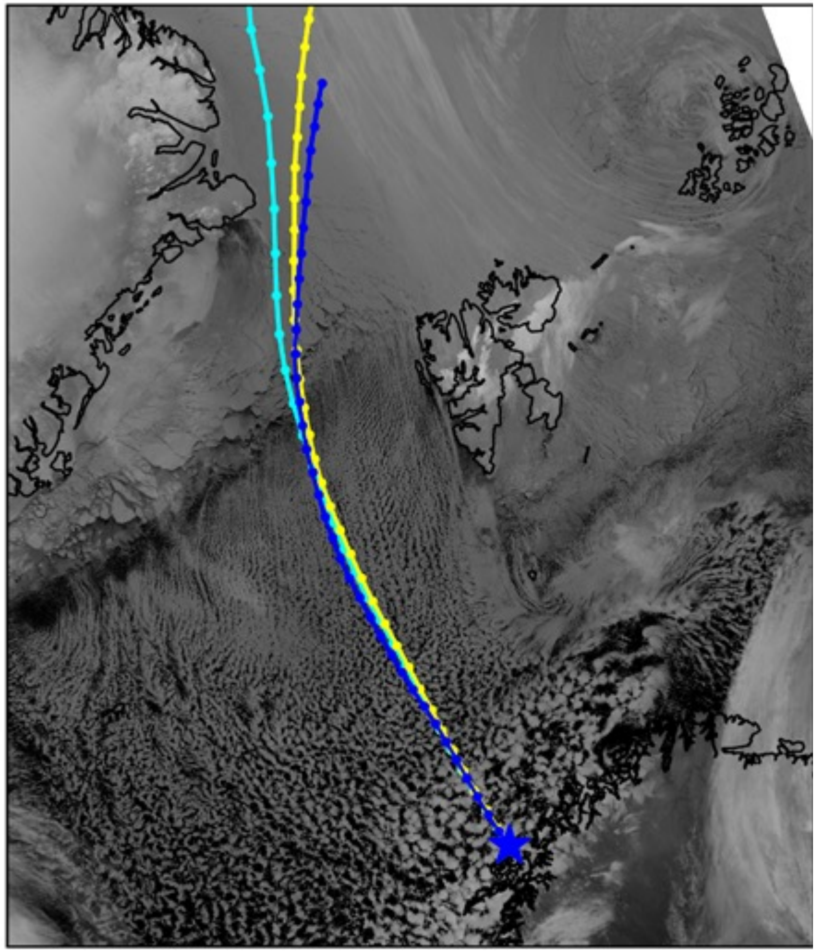
The goal of multiscale simulations was to study the evolution of a cold air outbreak with as few assumptions as possible

- How do multi-scale interactions drive the organization of mesoscale convective circulations during CAOs over open water?
- What is the role of mixed-phase cloud processes in the context of mesoscale cellular convection structure and evolution?

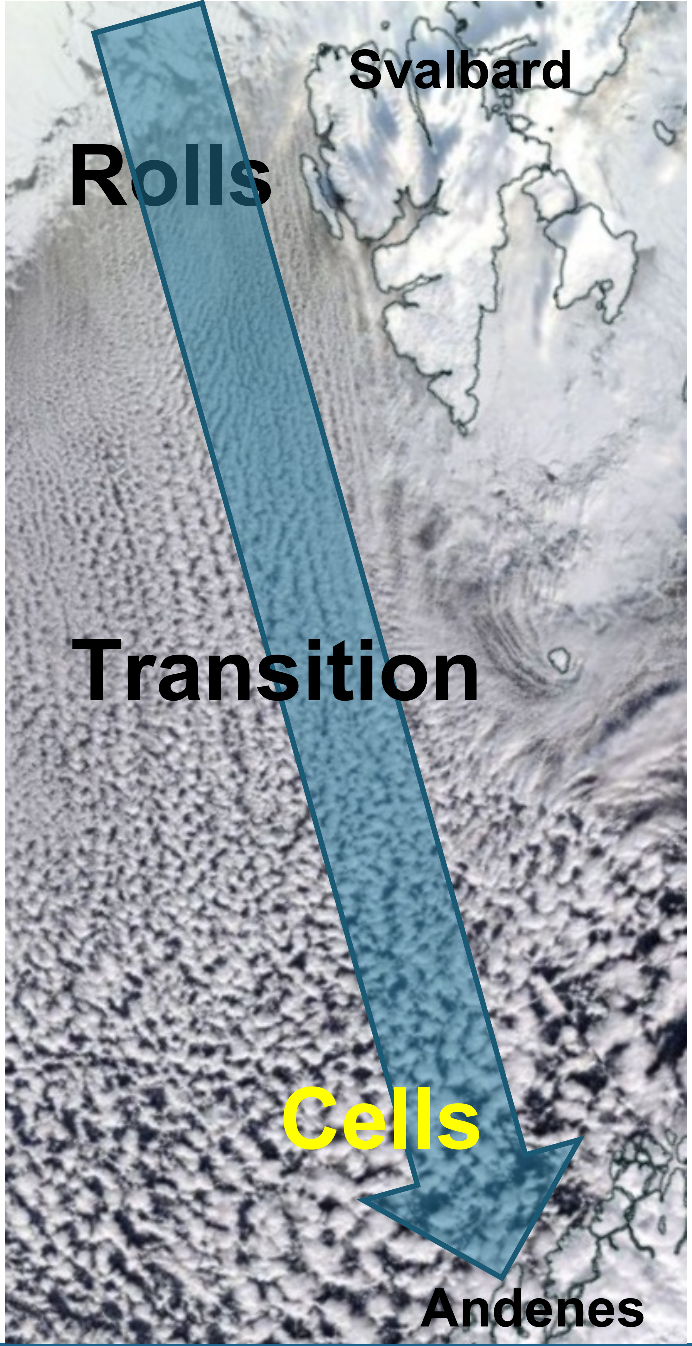


Geerts et al. (2022, BAMS)

COMBLE Field Study
Cold Air Outbreak, March 13, 2020



Peng Wu & Tim Juliano



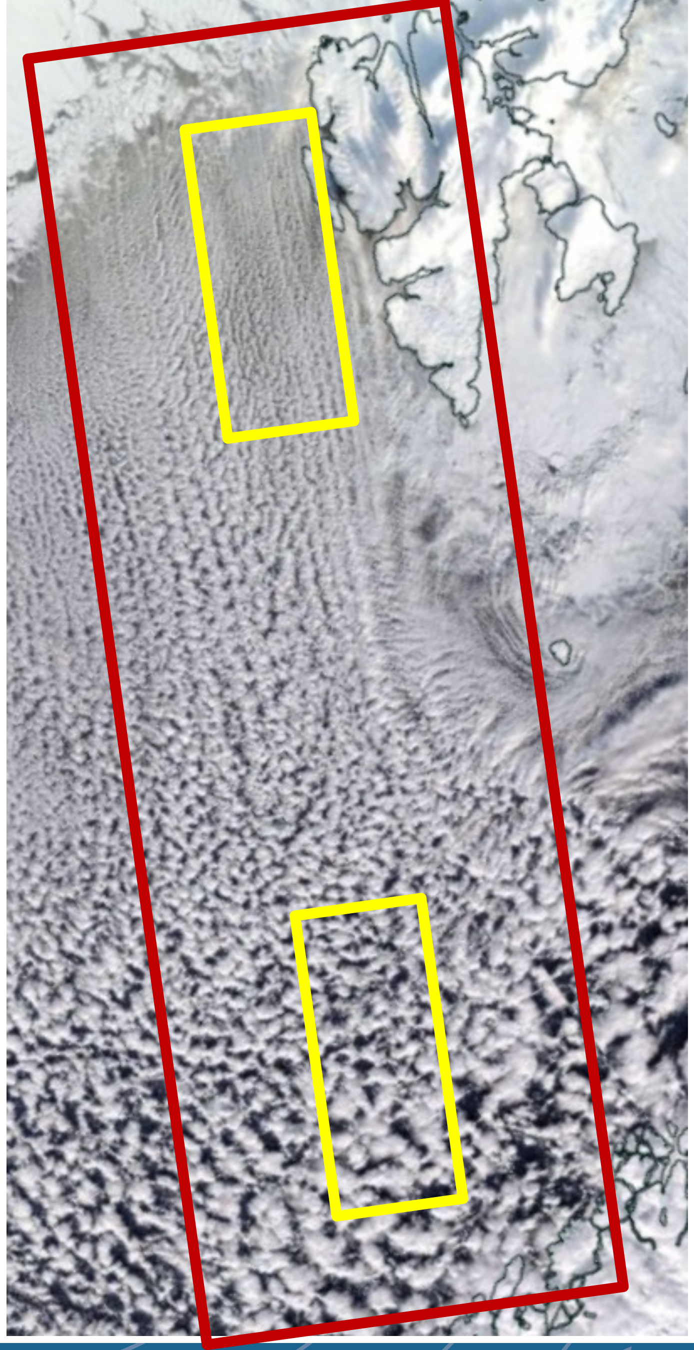
We simulate 24 hours of the cold air outbreak observed on March 13, 2020.

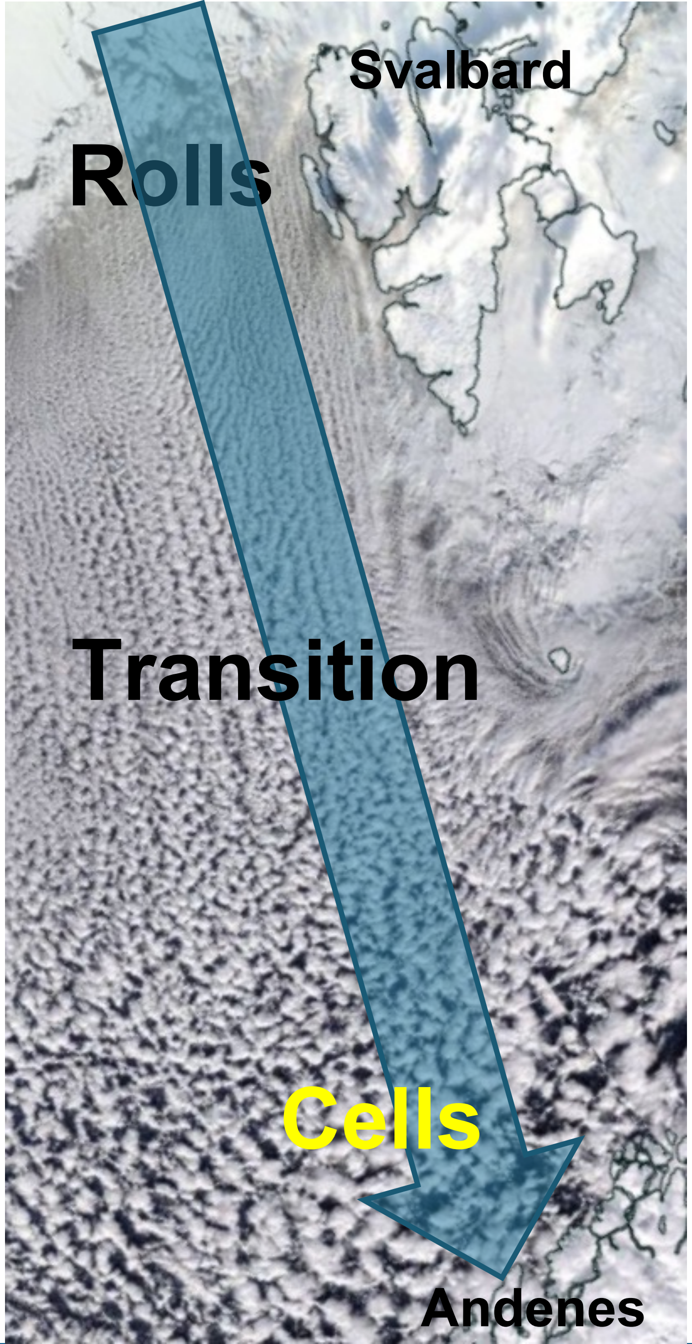
The coupled, mesoscale to microscale simulation, consisted of:

- a parent mesoscale domain - 1050 m grid cell size, and
- a nested large-eddy simulation (LES) domain - 150 m grid cell size (big yellow rectangle)
- 134 vertical levels

Within the LES domain nested were two high-resolution LES domains – grid cell size 30 m (small yellow rectangles)

Inner LES domains were introduced consecutively for 12 hours each





We simulate 24 hours of the cold air outbreak observed on March 13, 2020.

36-hour WRF mesoscale simulation covering intense CAO conditions from 12-14 March 2020

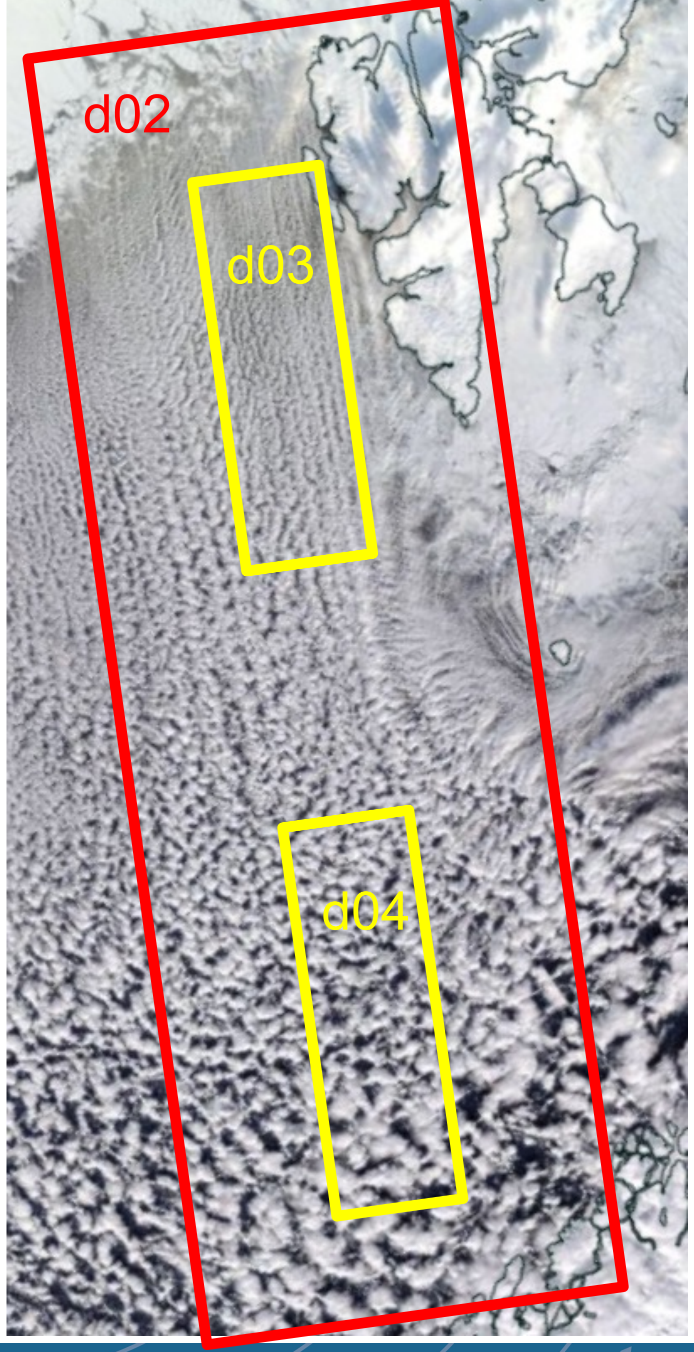
YSU PBL (d01); large-eddy simulation (LES) (d02, d03 and d04)

Thompson-Eidhammer scale-aware microphysics

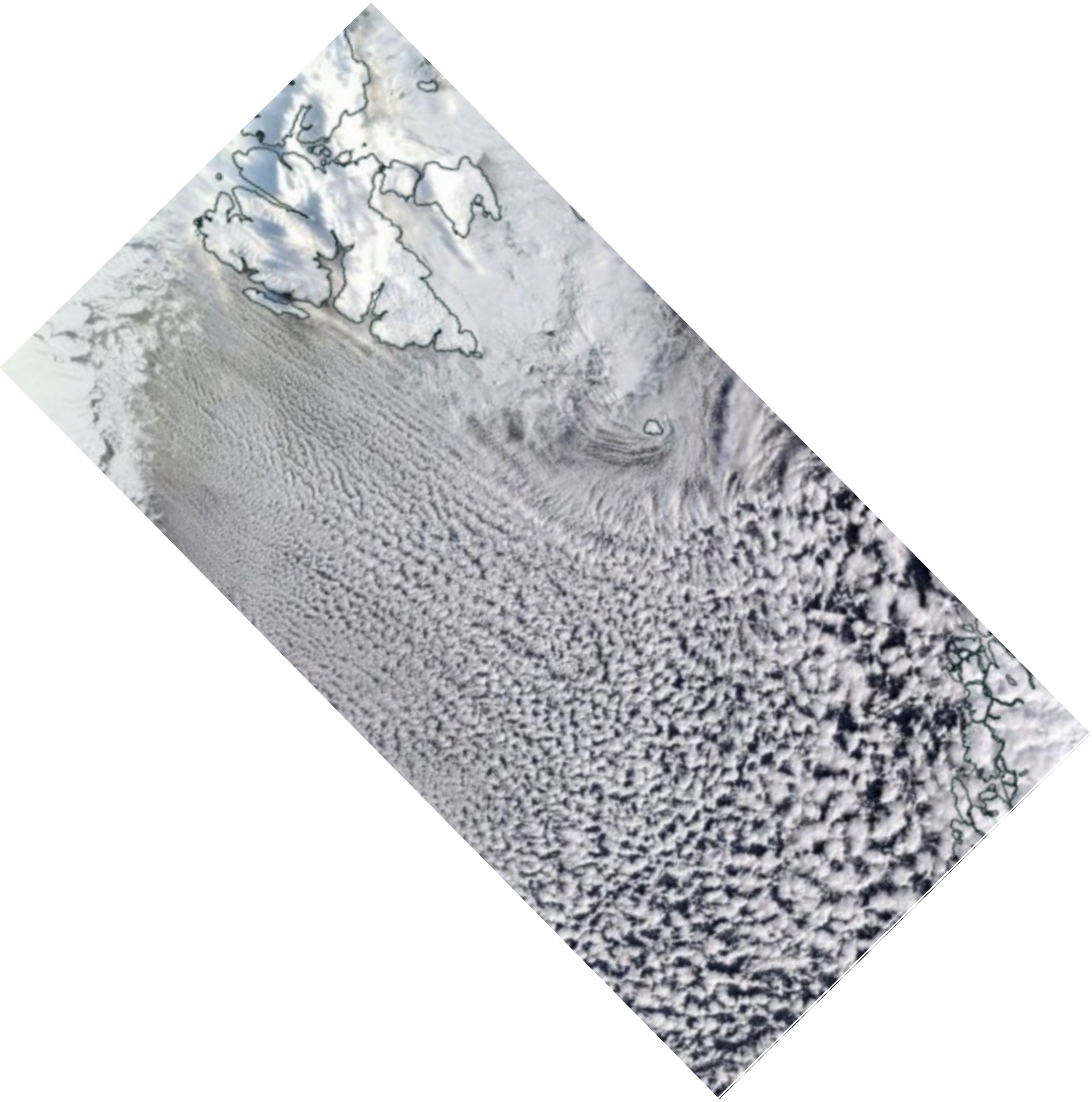
Outputs every 5 min

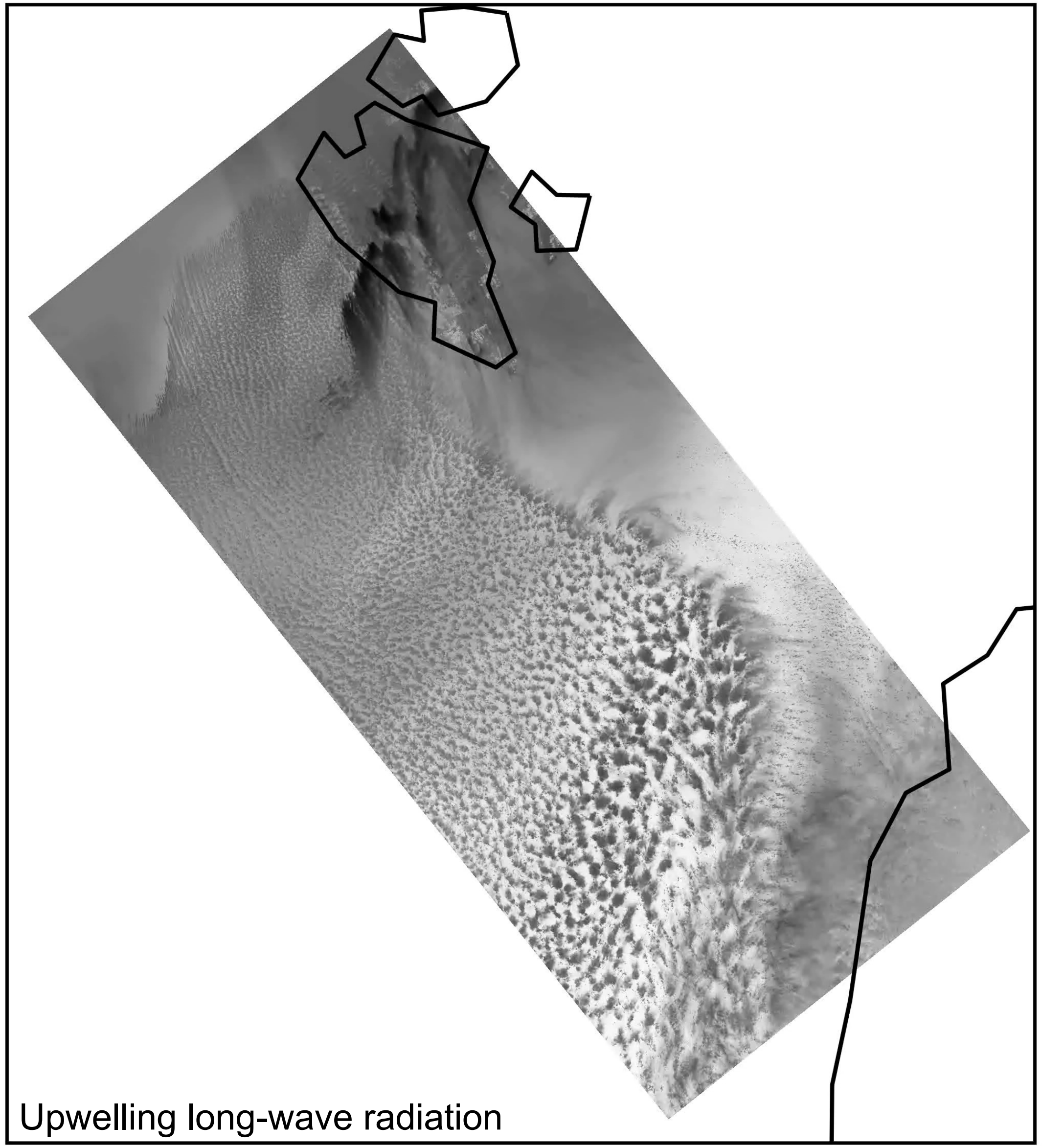
Virtual towers at Andenes (AMF1) for evaluation w/ COMBLE measurements

Key instruments: Ka-Band zenith radar (KAZR), microwave radiom. (MWR), & micropulse lidar (MPL)



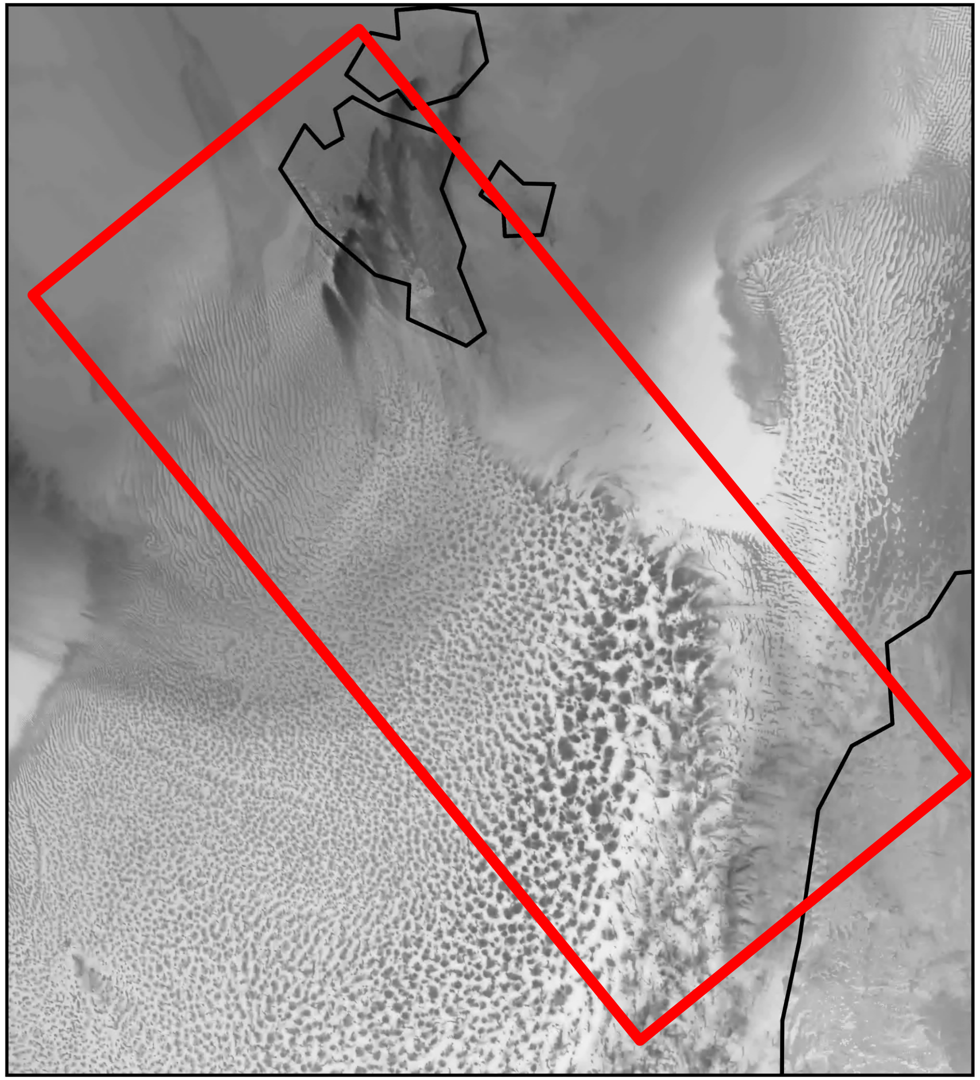
The outer LES domain spans the entire length of the cold air outbreak



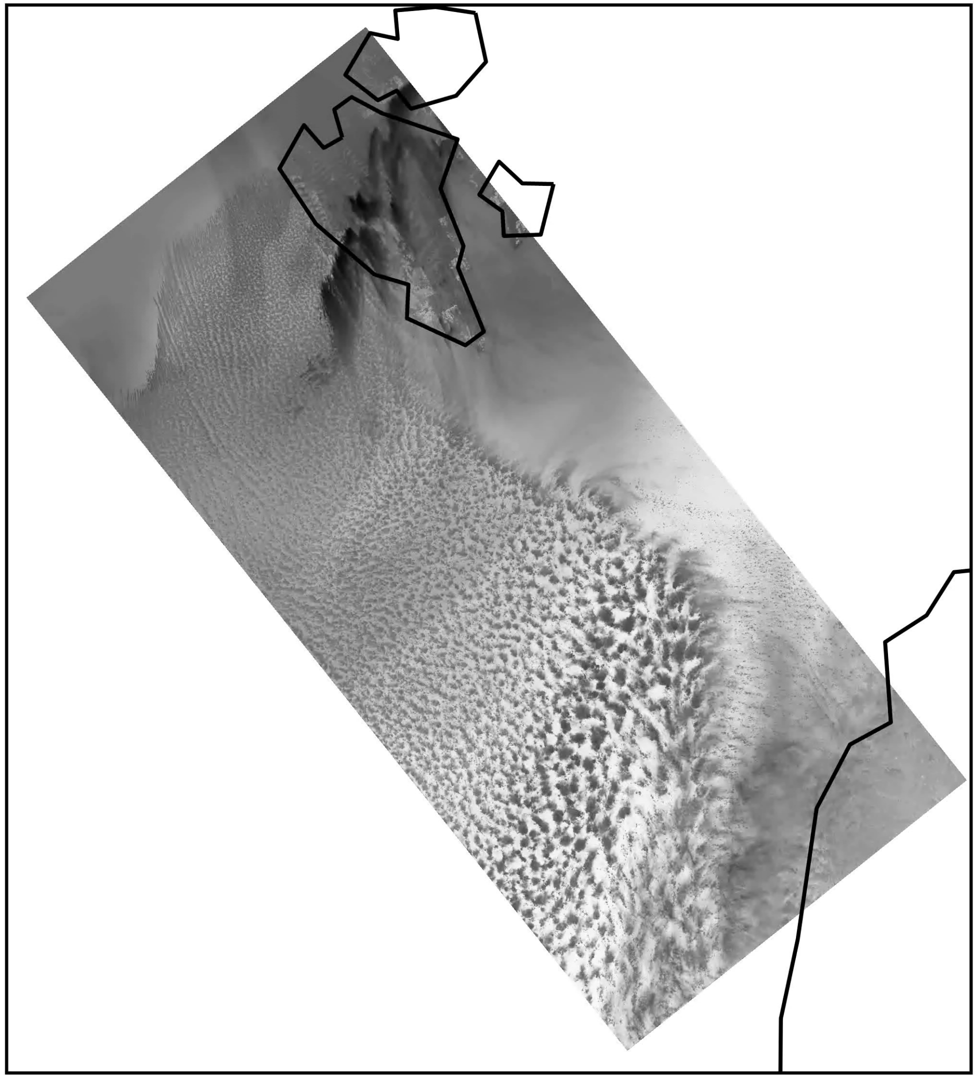


LES is needed to resolve well convective structures

Mesoscale Simulation - 1 km grid cell size

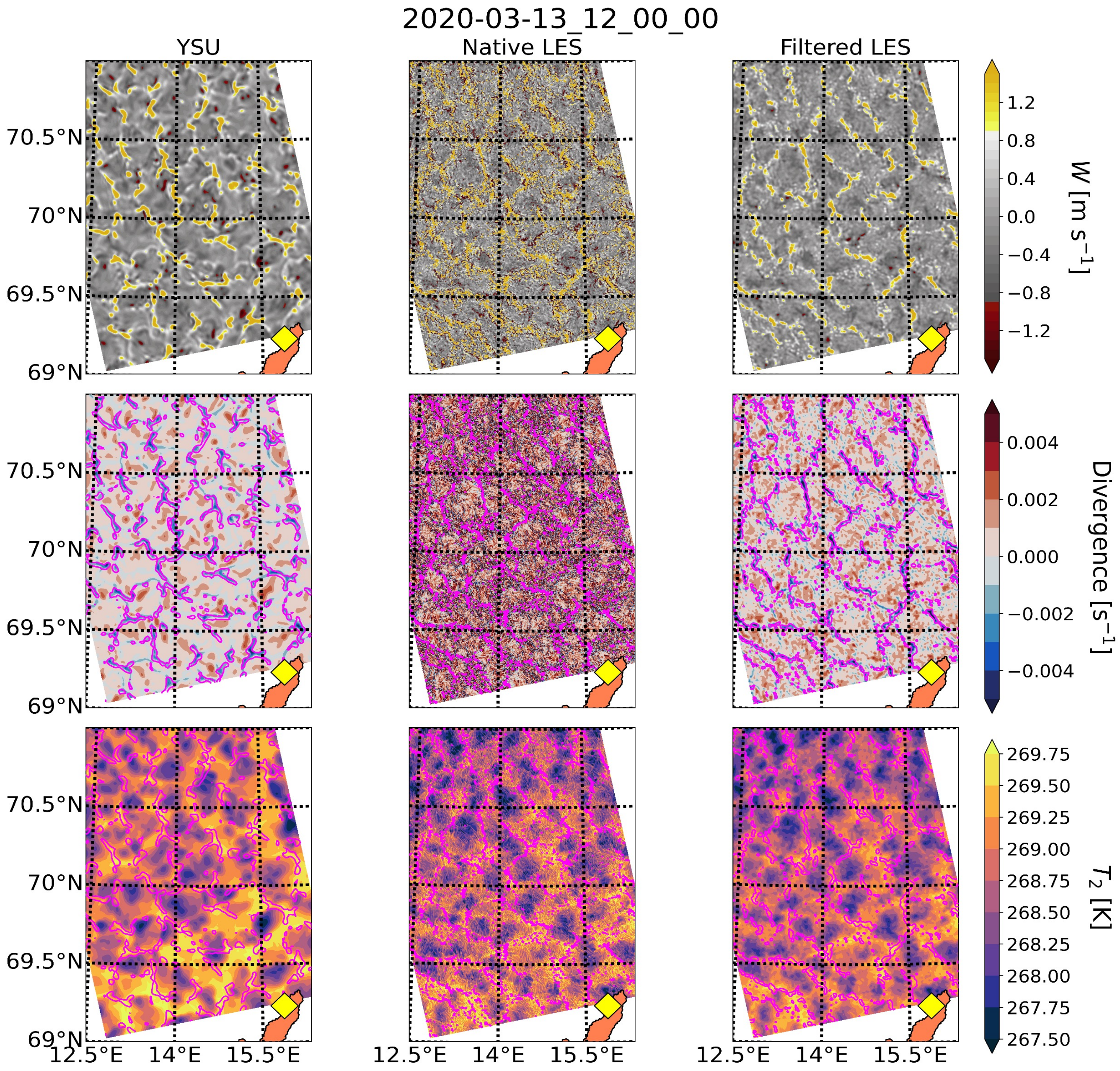


LES – 150 m grid cell size



We filtered LES to mesoscale resolution to assess how well are convective structures resolved in mesoscale simulations

- Horizontal slices show that dynamics and thermodynamics are closely linked
- Cell cores are defined by low-level horizontal convergence and strong column updrafts
- Low-level divergence is tied to cold pools that develop from sublimation of falling snow and graupel
- Compared to filtered LES, YSU produces cells that have wider updraft cores, weaker low-level convergence, and warmer near-surface air in convergent regions



We used wavelet transform to analyze the structure of open cells

- Allows one to analyze dominant modes of variability over time by transforming 1-D time series into 2-D time-frequency space
- Wavelet transform preferred over other spectral techniques (e.g., windowed Fourier transform) when predetermined scaling may not be appropriate due to wide range of dominant spatial scales
- Morlet wavelet function with nondimensional frequency of 6
- Continuous wavelet transform

The wavelet scale is varied and translated along the localized time index to reveal amplitude of a feature versus space as well as change in amplitude with time

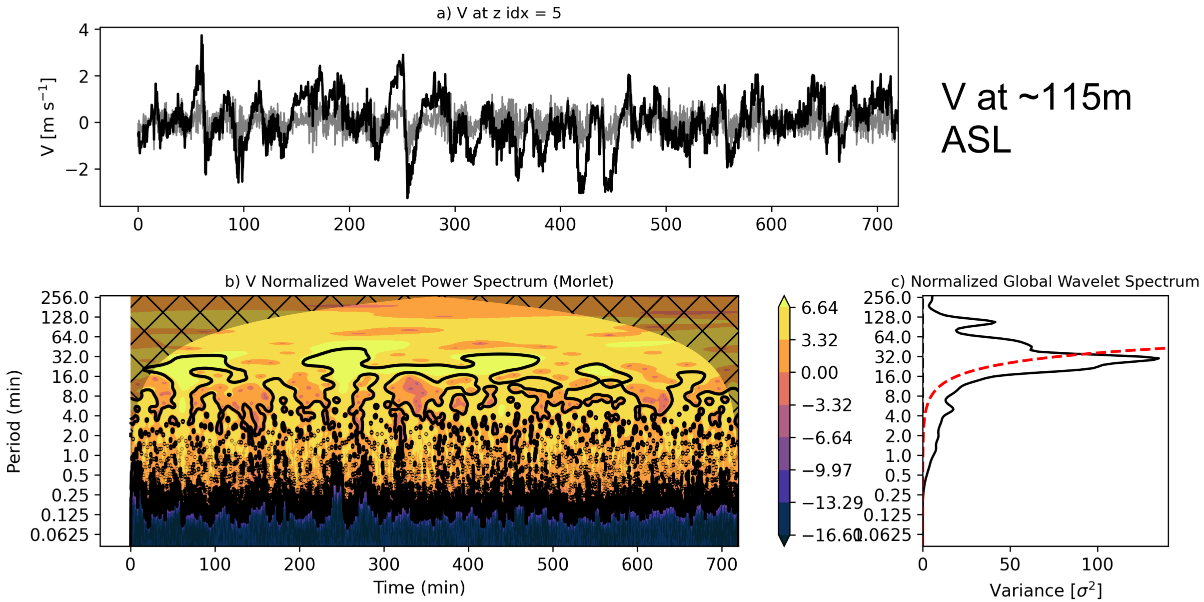
$$W_n(s) = \sum_{n'=0}^{N-1} x_{n'} \psi^* \left[\frac{(n' - n)\delta t}{s} \right]$$

wavelet function; localized time index; time spacing; sample; time series; wavelet scale

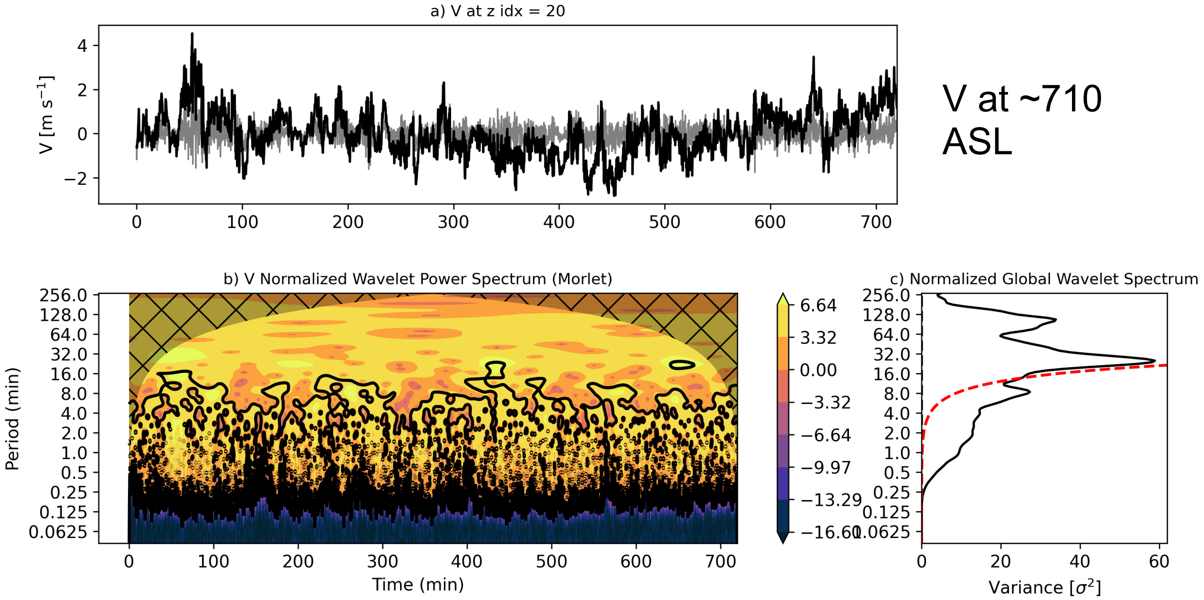
In reality, this is done in Fourier space to be more computationally efficient

Informative review by Torrence and Compo (1998, *BAMS*); we used PyCWT python package

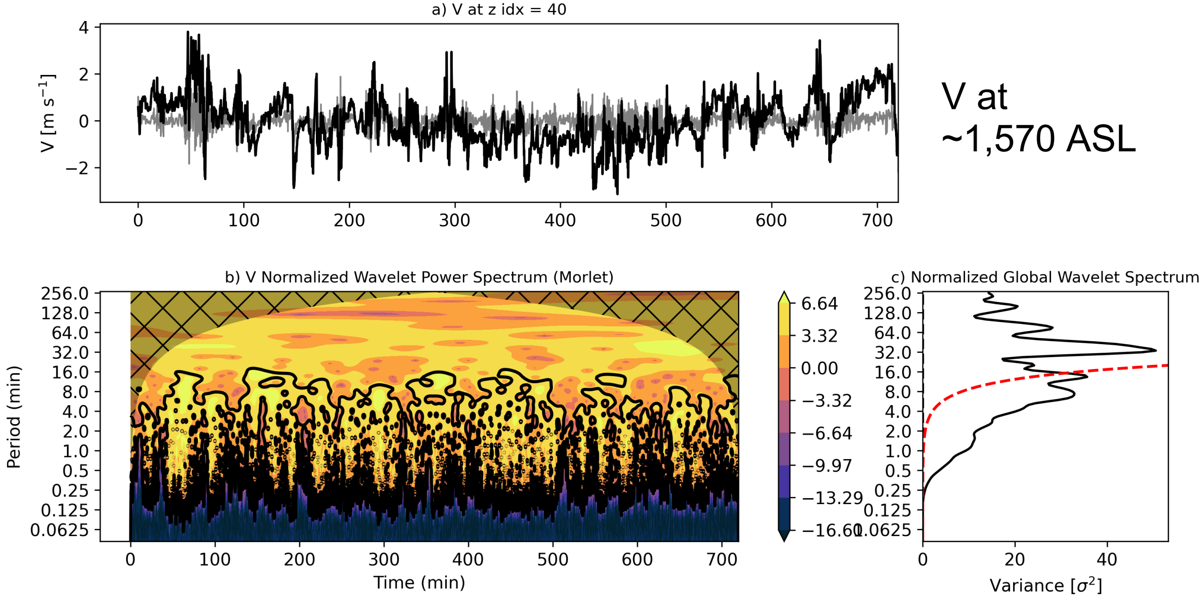
Near the surface V velocity has significant energy at low frequencies



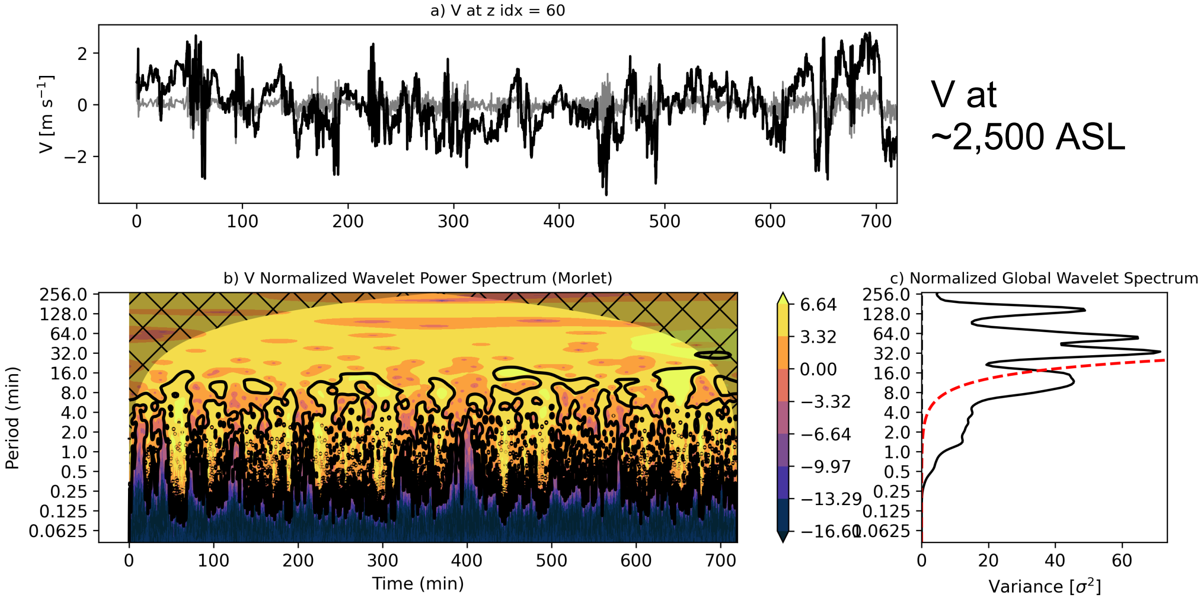
V at ~115m ASL



V at ~710 ASL

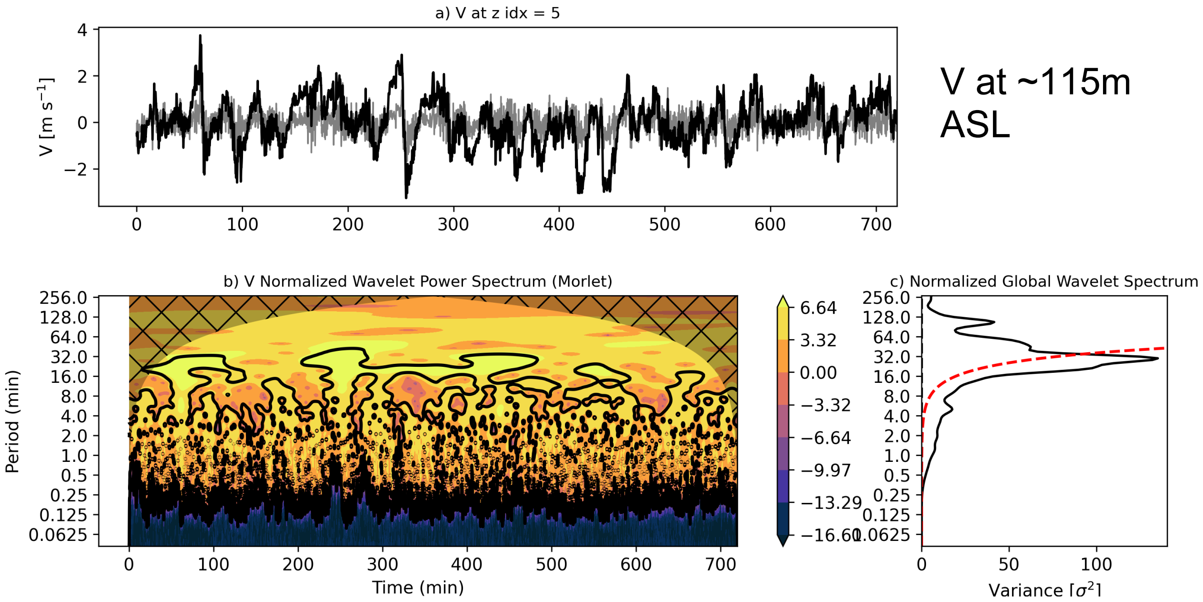


V at ~1,570 ASL

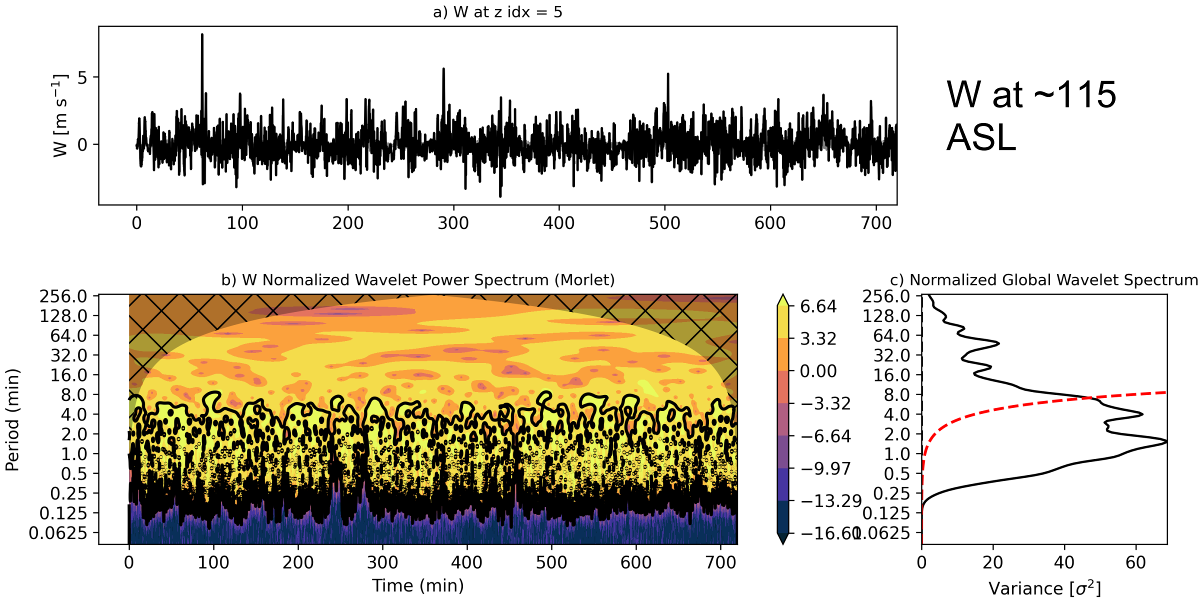


V at ~2,500 ASL

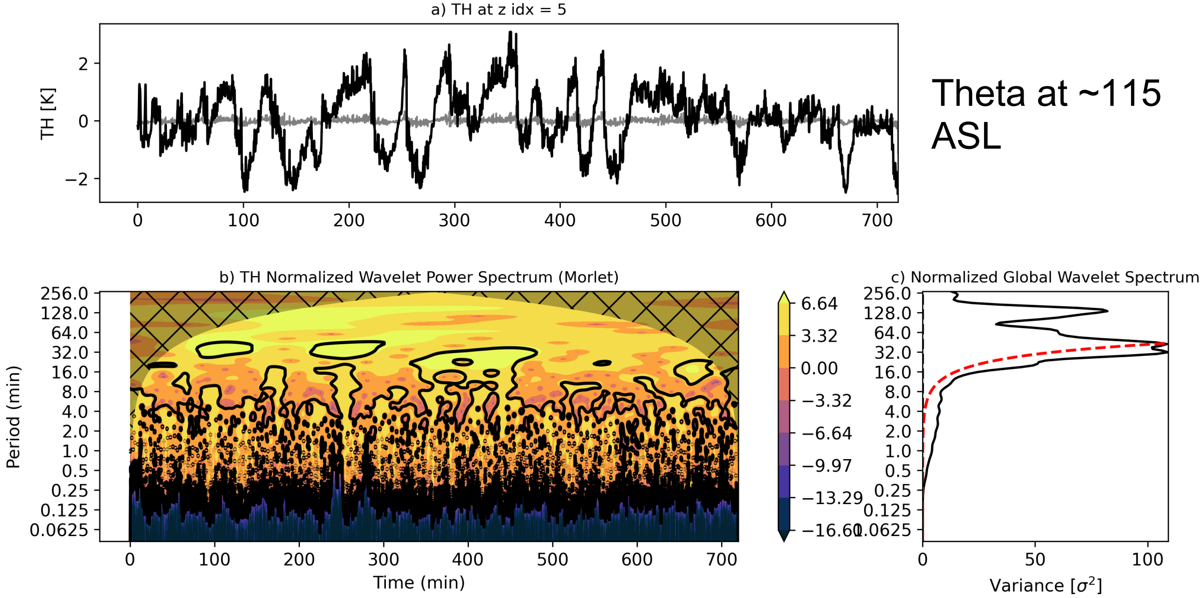
Significant variance at low frequencies for V and θ is related to cold pools



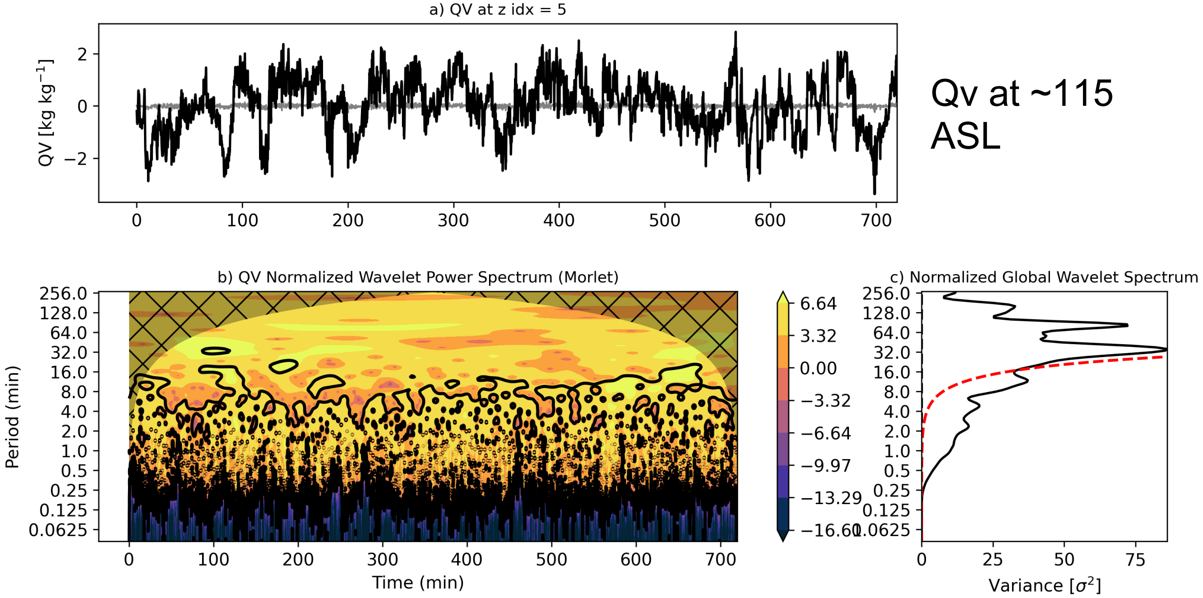
V at ~115m ASL



W at ~115 ASL

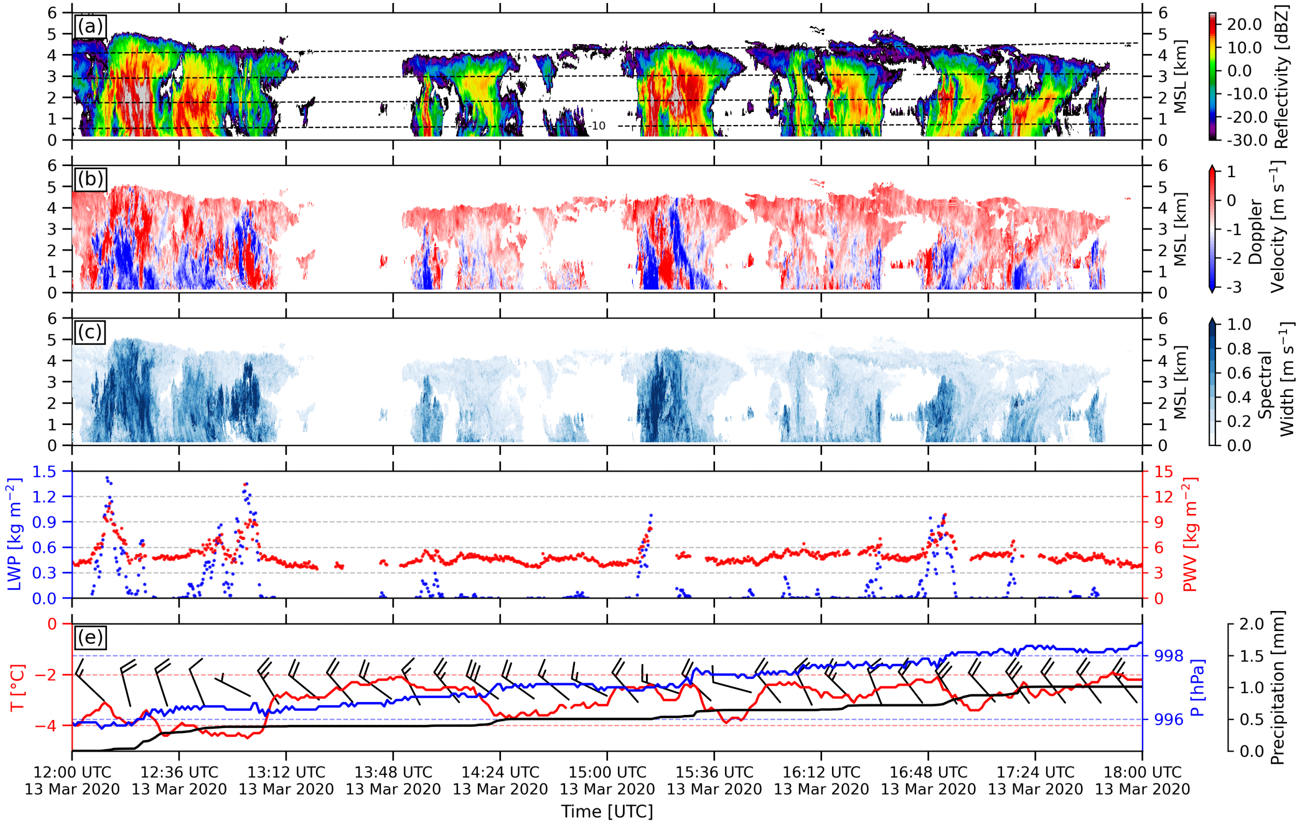


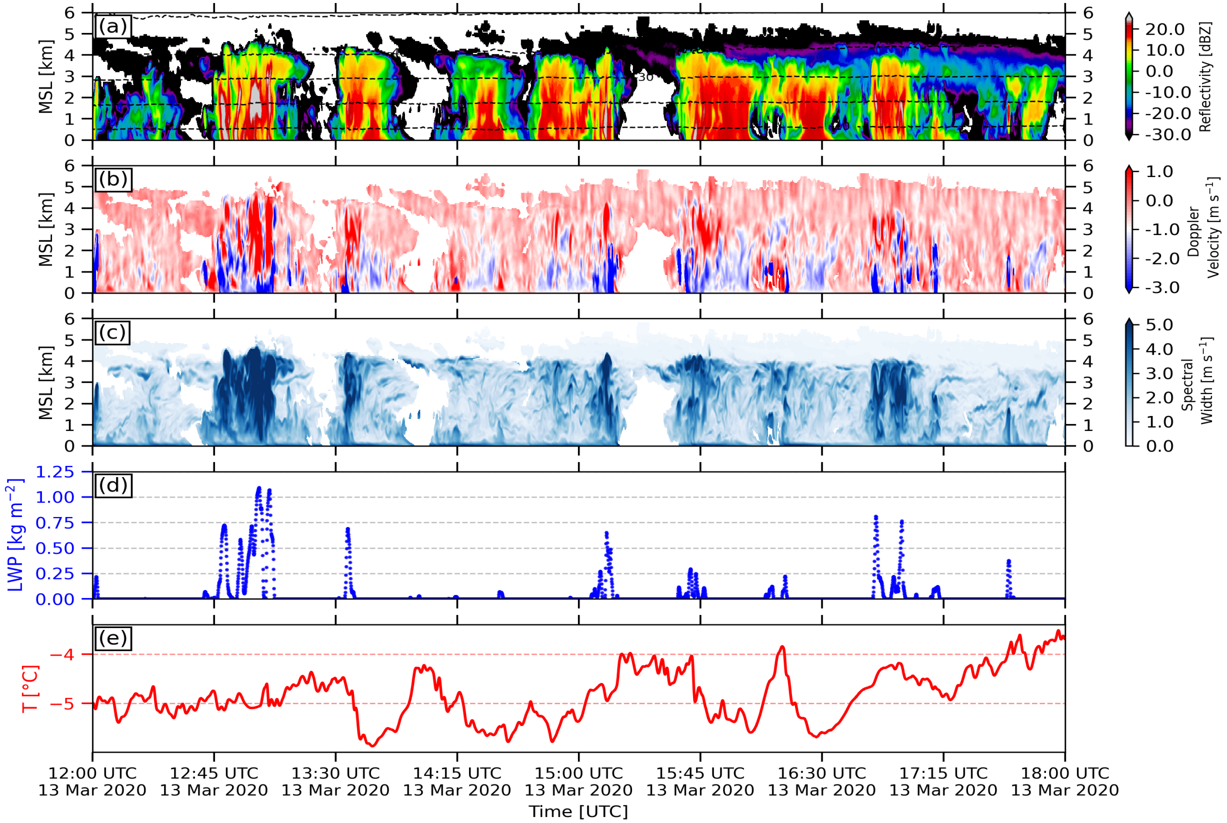
Theta at ~115 ASL



Qv at ~115 ASL

We compared LES results with observations at Andenes by processing LES output using CR-SIM





KAZR retrievals highlight the life cycle of open cellular clouds, from developing to mature to dissipating

Stronger vertical motions and enhanced turbulence tightly coupled to pockets of liquid water production in mature cells

WRF-LES in general captures well the cellular cloud characteristics, except for an overestimation of cloud fraction (esp. at cloud top) https://arm-development.github.io/comble-mip/README.html#visualization-tools

ARM

COMBLE Model-Observation Intercomparison Project Cookbook

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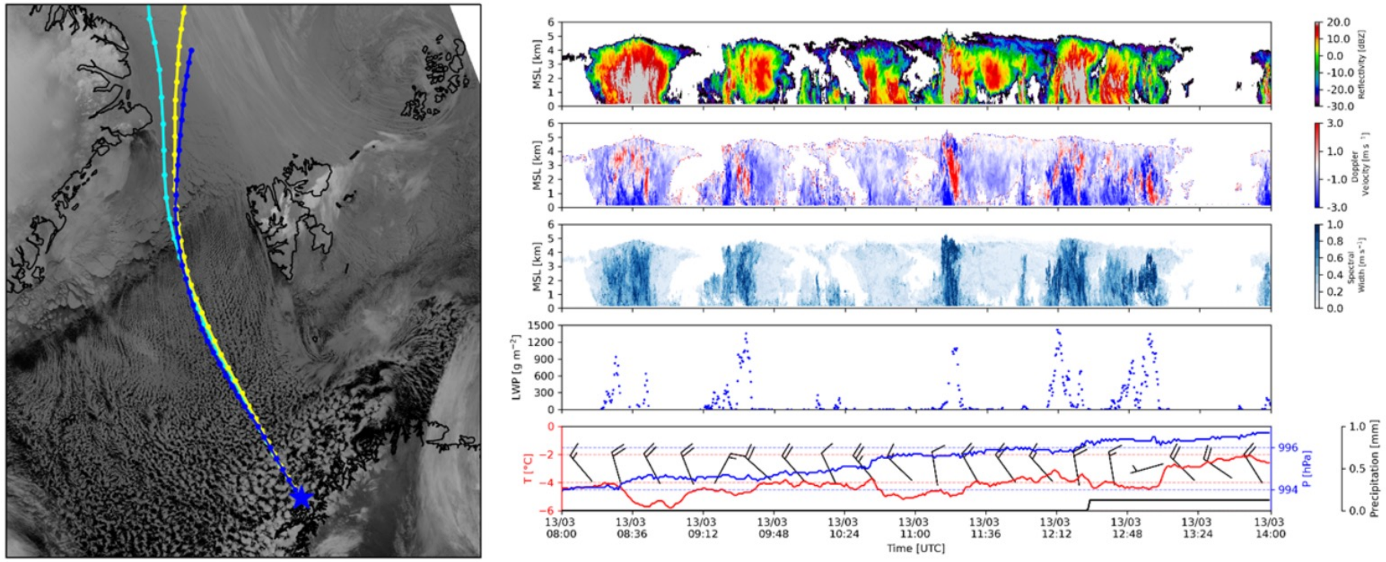
13 March COMBLE CAO Case



Authors

Tim Juliano, Florian Tornow, and Ann Fridlind – Intercomparison development and definition
Abigail Williams, Lynn Russell, Yijia Sun, Caniel Knopf – Aerosol analysis
Max Grover, Scott Collis, Kyle Dumas, Monica Ihli – Infrastructure development

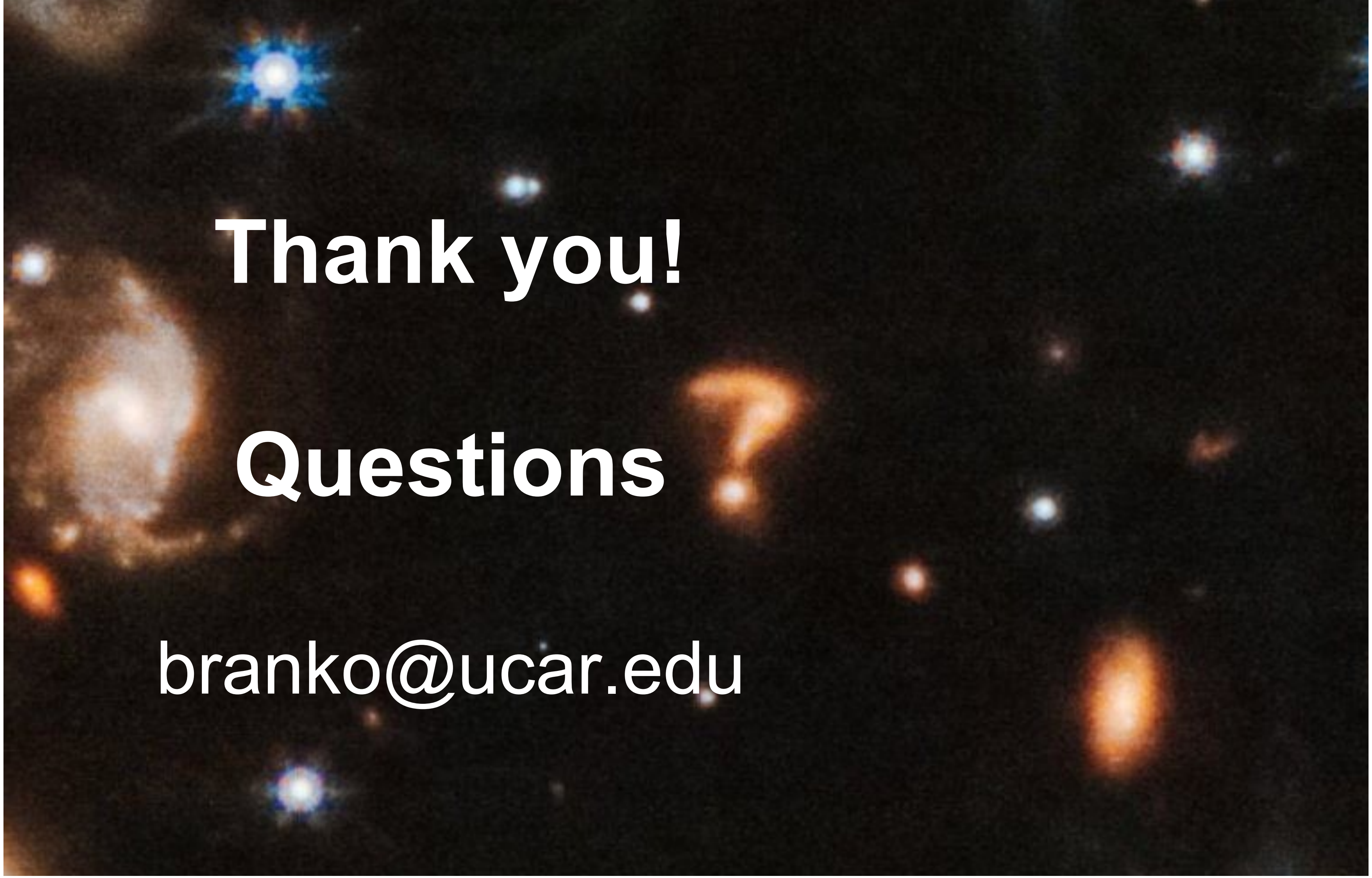
Contact: Tim Juliano: tjuliano (at) ucar.edu OR Florian Tornow: ft2544 (at) Columbia.edu https://arm-development.github.io/comble-mip/timeline.html

Timeline

Attention

Ready to make your model outputs accessible to other MIP participants? Please refer to this page to learn how to upload your model outputs to the repository.

Stage	Product	Due Date
Phase I	- SCM/small-domain LES, liquid-only - SCM/small-domain LES with ice - Large domain LES with ice	Nov. 15, 2023 Nov. 15, 2023 Feb. 1, 2024
Phase II	- SCM/small-domain LES, liquid-only - SCM/small-domain LES with ice - Large domain LES with ice	Nov. 15, 2023 Nov. 15, 2023 Feb. 1, 2024



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