Quasi-Lagrangian Modeling of Arctic Cloud Transitions

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1. Background & Motivation

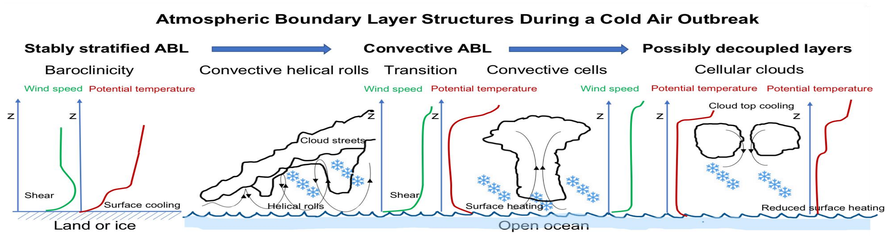


Fig. 1: *Schematic of downwind evolution of the boundary layer during a CAO*

- Arctic is experiencing a warming trend unlike any other region on Earth, with climate models underestimating the intensity of warming
- Cold-air outbreaks (CAOs) represent an important Arctic airmass transformation, when cold Arctic air flows over a warmer open ocean
- Intense surface-atmosphere exchanges ensue, leading to rapid growth of a convective boundary layer (BL) and mixed-phase clouds (MPCs) that often experience a transition in morphology downwind

2. COMBLE MIP Participants & Specification

LES Models & Leads	SCM Models & Leads
WRF: Juliano (NSF NCAR)	**CCPP**: Li & Xue (NSF NCAR)
DHARMA: Tornow & Fridlind (Columbia Univ. / NASA GISS)	**ModelE3**: Tornow & Fridlind (Columbia Univ. / NASA GISS)
SAM: Wu & Ovchinnikov (PNNL)	**E3SM**: Zhang & Zheng (PNNL)
DALES: Neggers & Chylik (Univ. Cologne)	**DALES-EDMFn**: Neggers & Chylik (Univ. Cologne)
ICON-LEM: Possner (Goethe Univ. Frankfurt)	**ICON**: Köhler (DWD)
MSU-INM: Debolskiy (LMSU)	**SL-AV**: Chechin (IAP RAS)
MIMICA: Baro Perez (Chalmers Technical Univ.)	**AOSCM**: Karalis & Svensson (Stockholm Univ.)
CM1-SDM: Chandrakar (NSF NCAR)	COMBLE MIP Page
SCALE-SDM: Gupta & Shima (Univ. of Hyogo)	
UCLALES-SALSA: Raatikainen (FMI)	

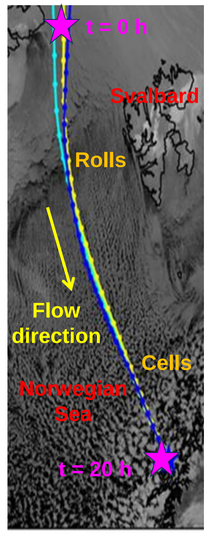
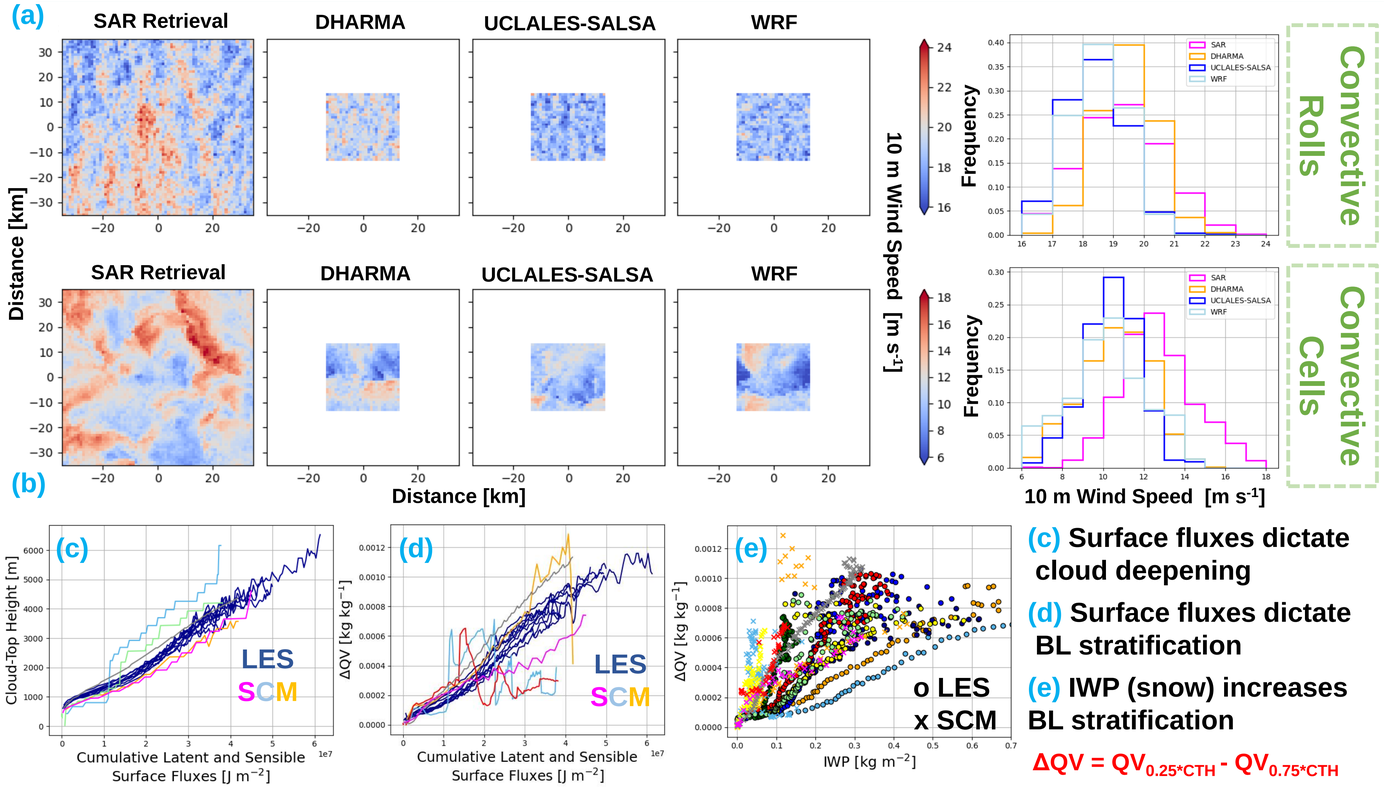


Fig. 2: *Visible satellite image with quasi-Lagrangian ("airmass-following) MIP domain trajectory, based on backward trajectory launched from COMBLE site (Andenes, Norway)*

- **Goal**: *conduct model-observation intercomparison project (MIP) to evaluate capability of LES and SCMs to reproduce quasi-Lagrangian evolution (~1000 km fetch) of Arctic MPC features under strong CAO conditions*
- **Case**: DOE ARM Cold-air Outbreaks in the Marine Boundary Layer Experiment (COMBLE); 13 March 2020 CAO; 20 h sim., beginning 2 h upwind of ice edge
- **Forcing**: initial soundings, time-varying sfc. skin temp. & geostrophic wind profile from ERA-5 along backward traj.; LW radiation; NO nudging and NO subsidence
- **Microphysics (Part I)**: **fixed droplet** (N_d = 20 cm^{-3}) & **diagnostic ice formation** → N_i = 25 L^{-1} (minimum total) where $q_c+q_r>1e^{-6}$ kg kg^{-1} and T<268.15 K (emulate immersion-mode heterogeneous ice nucleation); only other ice crystal formation mechanism active is homogeneous drop freezing
- **Obs. constraints**: ARM site w/ radiosondes, HSRL, KAZR; satellite upwind → CALIOP, MAC-LWP, SAR

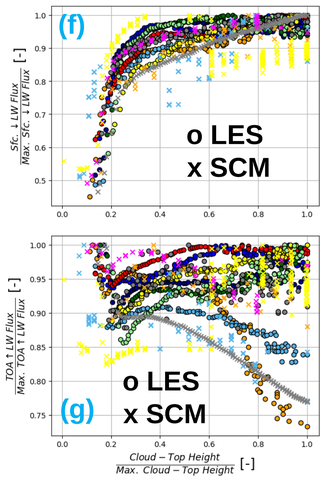
3. Results: 10 m winds (a-b); BL growth and decoupling (c-e); LW radiation (f-g)



(a) Relatively strong winds; DHARMA agrees well, UCLA & WRF underestimate

(b) Relatively weak winds; all three models underestimate

Caveats: (1) time / space offsets; (2) model domain size



(f) Cloud deepening rapidly increases ↓ LW flux at surface

(g) Range of responses in ↑ LW flux at TOA to cloud deepening

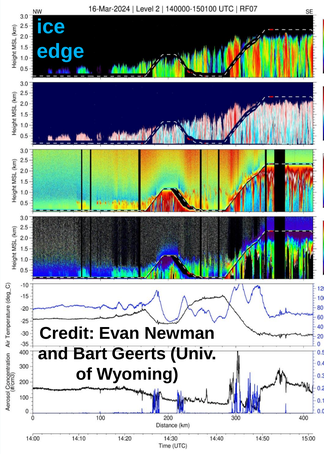
(c) Surface fluxes dictate cloud deepening

(d) Surface fluxes dictate BL stratification

(e) IWP (snow) increases BL stratification

4. CAESAR

NSF Cold Air Outbreak Experiment in the Sub-Arctic Region (CAESAR; Feb - Apr 2024) flew large suite of instruments on NSF/NCAR C-130 over Norwegian Sea. Unique payload & long-duration flights allows for new insights into CAO cloud transitions.



Aircraft captured rapid BL growth and cloud development from marginal ice zone to open ocean (RF07).

Excellent case for quasi-Lagrangian modeling approach.

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