The Boundary Layer and Cloud Field Associated with Marine Cold Air Outbreaks (MCAOs) In the COMBLE Observations and the E3SM SCREAM Simulations

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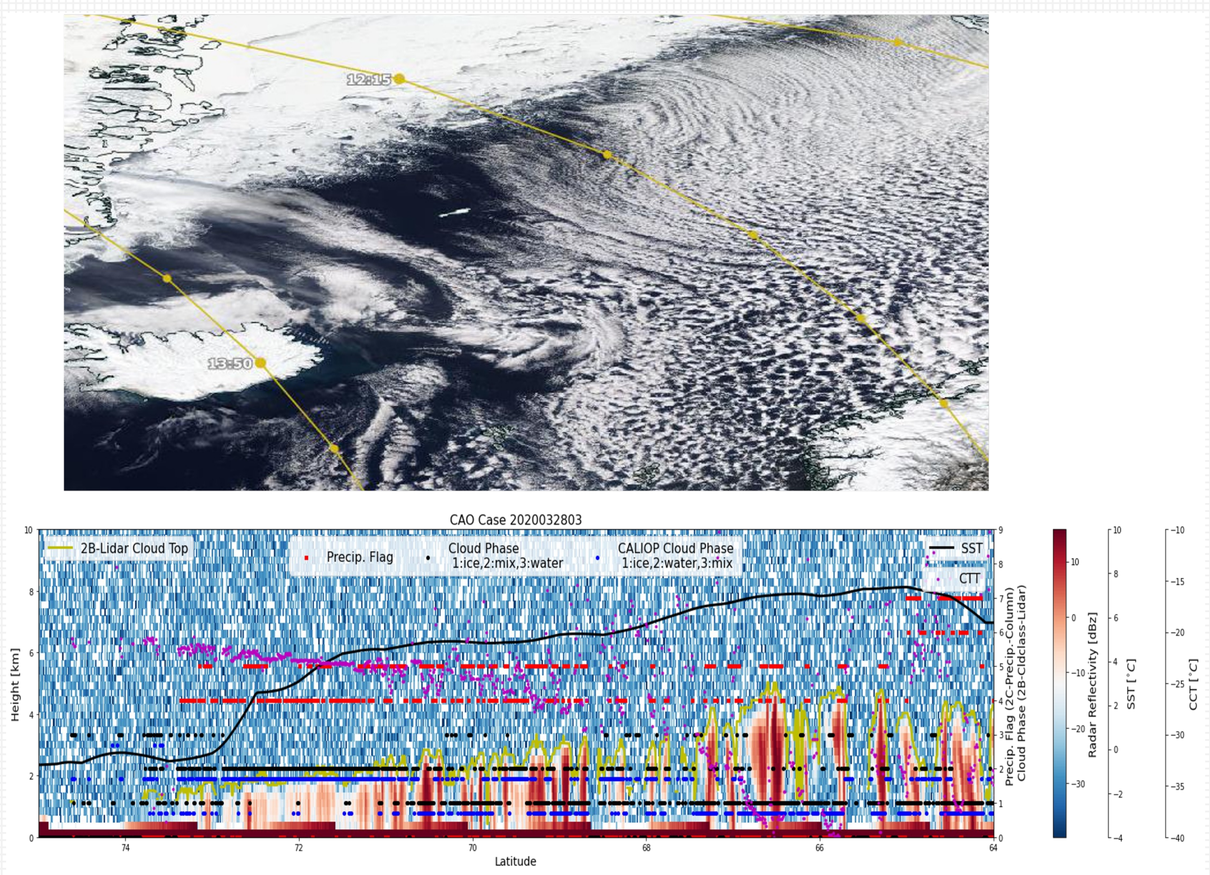
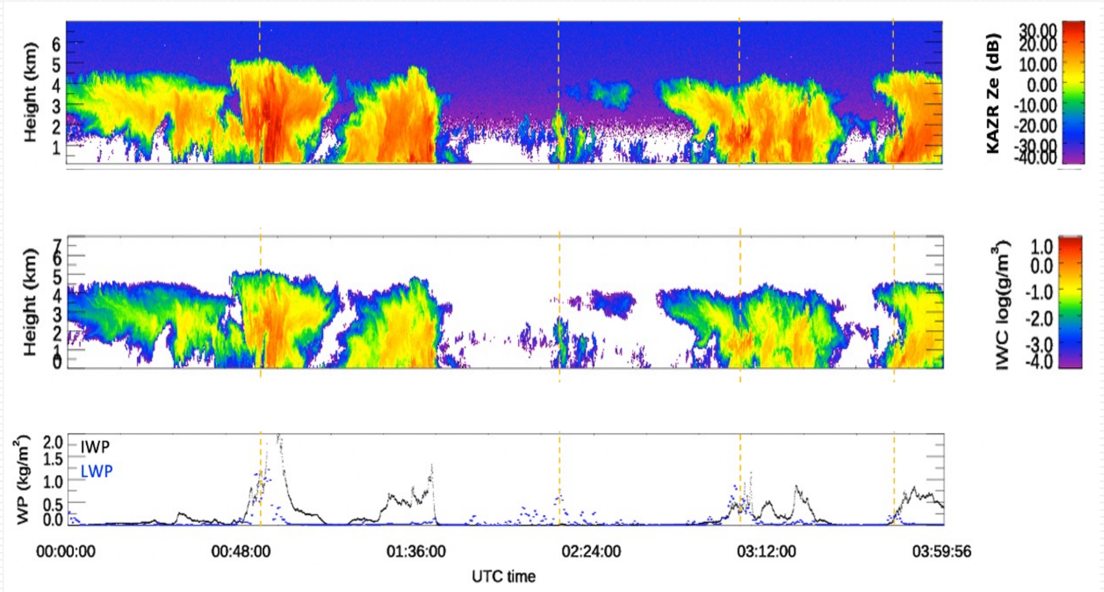
Introduction

Global convection-permitting models (GCPM) at kilometer-scale grid spacing explicitly resolve deep convective systems and major mountain ranges. Yet the remaining sub-grid processes in GCPMs, e.g., turbulent mixing and cloud microphysical processes, cause significant discrepancies in the simulation of low clouds among GCPMs.

The DOE E3SM project is developing a GCPM called the Simple Cloud-Resolving E3SM Atmosphere Model (SCREAM). This study aims to evaluate the boundary layer cloud transition associated with marine cold-air outbreaks (MCAO) in a SCREAMv0 simulation based on the DOE Atmospheric Radiation Measurement (ARM) ground-based observations and satellite retrievals.



MODIS image around the Norwegian Sea for the observed MCAO event on March 28, 2020 (top). The CALIOP and CloudSat retrievals along the yellow path (bottom). The color contour: CloudSat radar reflectivity. The yellow and solid black line: the cloud top and sea surface temperature. The red and black dots: the precipitation flag and cloud phase. The blue dots: the CALIOP cloud top phase retrieval. The magenta dots: the CALIOP cloud top temperature retrieval.



ARM ground-based observation of radar reflectivity, cloud ice water content, and LWP/IWP at the AMF1 site (69.3°N,16.1°E) during a MCAO event from the COMBLE field campaign.

Data and methods

- **SCREAMv0 simulation**

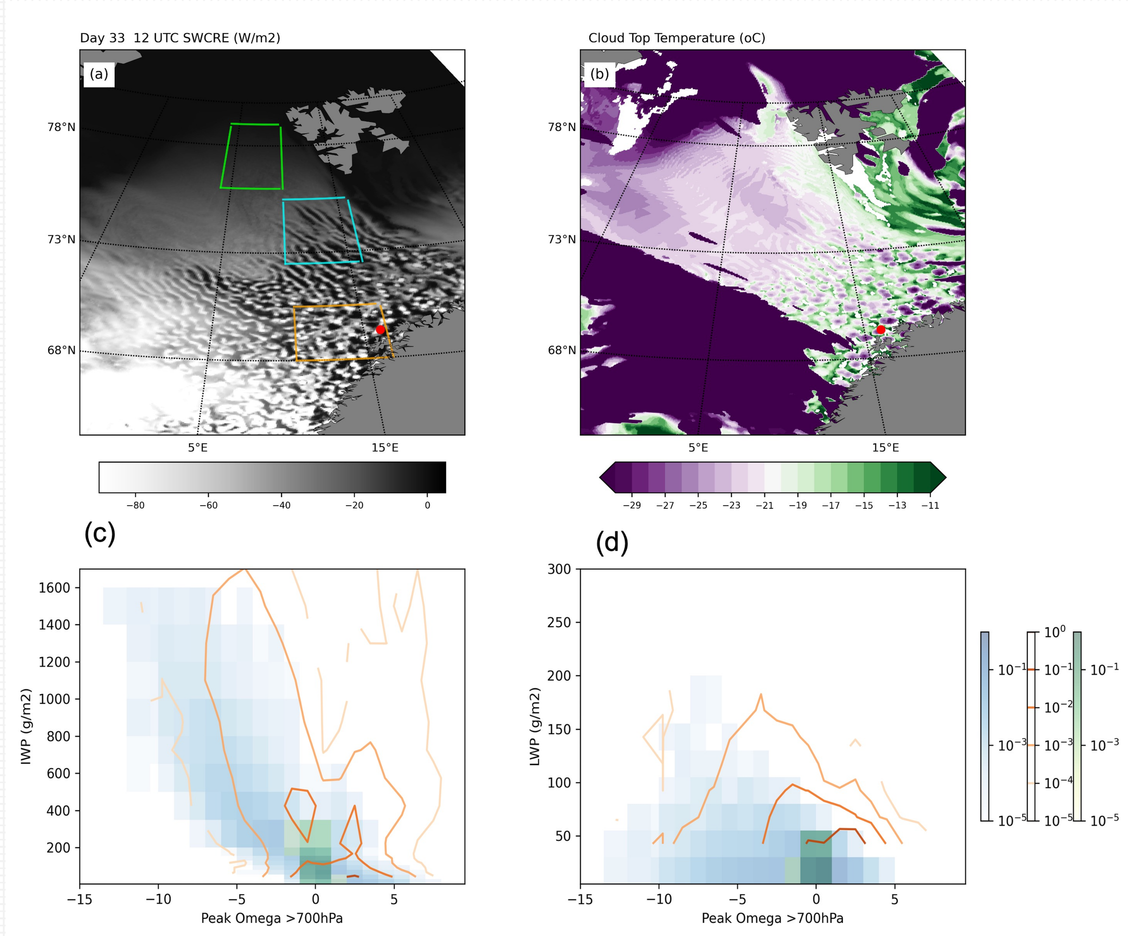
The E3SM SCREAM has 128 vertical model layers and globally uniform 3.25 km horizontal grid spacing.

This study analyzes the 40-day DYAMOND2 simulation (Jan 20 - Mar 1, 2020) reported by Caldwell *et al.* (2021). Only one intense MCAO event was simulated in the Nordic Seas on Day 33 of this simulation.

- **Observations**

The DOE ARM Cold-Air Outbreaks in the Marine Boundary Layer Experiment (COMBLE) conducted comprehensive ground-based observations within the Arctic Circle on the island of Andøya, just off the Scandinavian mainland, between 1 December 2019 and 31 May 2020 (Geerts *et al.,* 2022). The observed MCAO event on 28 March 2020 shows the highest similarity with the SCREAMv0 simulated MCAO case.

MODIS, CloudSat, and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) sampled this region around 12:15 UTC (~13:00 local time) on 28 March 2020.

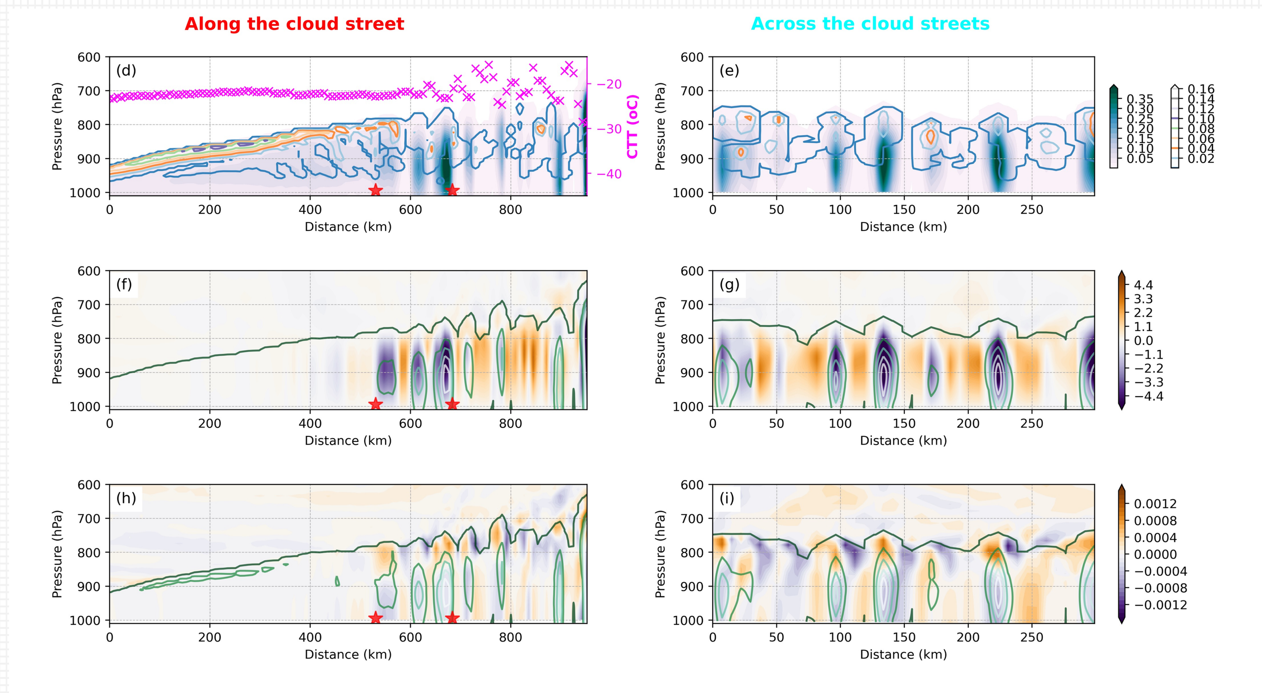


Instantaneous snapshots of the (a) SWCRE and (b) cloud top temperature. The histograms of the model resolved updraft vs. (c) IWP and (d) LWP in three areas on Day 33 as shown in (a). Green shaded bins demark the solid stratocumulus region within the green box. Blue shaded bins are for the cloud streets within the blue box. The contours are for the scatter cumulus within the brown box. The AMF1 site is shown with a red dot.

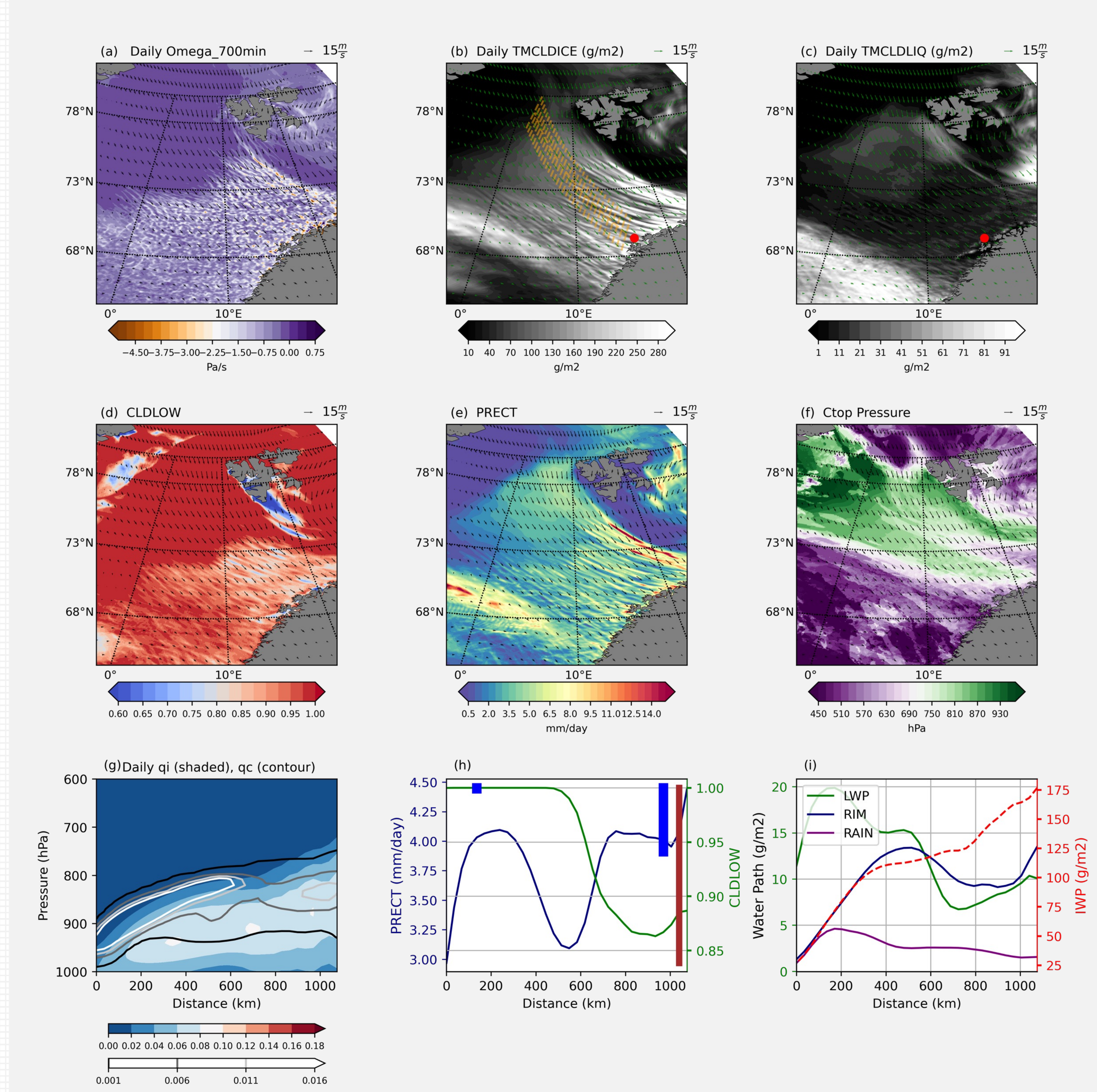
Summary and Future work

- E3SM SCREAMv0 well captures mesoscale cloud variabilities during cold air outbreak events.
- SCREAMv0 captures the transition of the cloud and PBL properties based on satellite and ARM observations.
- The cloud water is mainly ice phase in regions with cloud streets and scattered cumulus clouds; the ice water path (IWP) is strongly linked to the model resolved updrafts.
- We will study the underline mechanisms with Doubly Periodic mode of SCREAM.

Results



Vertical cross-section of (d,e) cloud ice condensation (shaded), cloud liquid condensation (contour), and cloud top temperature (magenta symbols); (f,g) resolved omega vertical velocity; and (h,i) horizontal divergence. The beginning and end of a cloud street are marked with red stars.



(a-f) Daily maps of the model variables on Day 33. (g) The vertical cross-section of the averaged cloud waters along the orange band in (b). (h) The averaged surface precipitation, low-level cloud cover, and (i) the vertically integrated cloud and precipitation waters. The blue bars in (h) are the MODIS retrieved cloud cover, while the brown bar shows the range of the observed cloud cover at the ARM site (the red dot in b).

References

Caldwell, P. M., Terai, C. R., Hillman, B., Keen, N. D., Bogenschutz, P., Lin, W., et al. (2021). Convection-permitting simulations with the E3SM global atmosphere model. *JAMES*, 13, e2021MS002544.

Geerts, B., Giangrande, S. E., McFarquhar, G. M., Xue, L., *et al.* (2022). The COMBLE Campaign: A Study of Marine Boundary Layer Clouds in Arctic Cold-Air Outbreaks, *BAMS*, *103*(5), E1371-E1389.

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