**Evaluating Marine Boundary Layer Dynamics During Arctic Cold-Air Outbreaks: Insights from CLASS Model Simulations**

**Introduction**

The dynamics of the marine boundary layer during Arctic cold-air outbreaks are pivotal for the comprehension of polar meteorological phenomena and the advancement of climate prediction models (Murray-Watson and Gryspeerdt, 2023). The study utilizes insights from the Cold-Air Outbreaks in the Marine Boundary Layer Experiment (COMBLE) campaign, which was carried out from December 2019 to June 2020(Geerts *et al.*, 2022). Through the application of the CLASS model, the research simulates the progression of air masses originating from the Arctic ice edge, with the aim to clarify the transformation of boundary layer properties. The report investigates the effects of surface heat flux variations on the formation of clouds and the evolution of the boundary layer, providing a detailed analysis rooted in the empirical data procured during the COMBLE campaign.A satellite image of the arctic

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Figure : MODIS visible image and radar reflectivity mosaic (with coverage over/near Scandinavia only) at 1130 UTC 13 Mar 2020. Lagrangian evolution of cells from ice edge to Andenes over 20 hrs.

Ice edge

Andeness

**Objectives**

The simulation aims to accurately mimic the behavior of the Arctic boundary layer during cold air outbreaks, as observed in the COMBLE campaign, by employing the CLASS model. Incorporating 30ECOR data for surface and latent heat fluxes, the simulation(Sullivan *et al.*, 1997) meticulously investigates the impact of these fluxes on the properties of the boundary layer and the mechanisms of cloud formation. This methodical approach ensures that the CLASS model scenarios closely emulate the actual Arctic conditions recorded during the COMBLE initiative, thus enhancing the reliability of climate model projections for polar meteorological events.

**Data Acquisition**

Data were obtained from the Eddy Correlation Flux Measurement System (30ECOR) as part of the ARM Mobile Facility during COMBLE(Sullivan *et al.*, 1997), capturing surface heat fluxes and latent heat fluxes at high temporal resolution. These measurements provided the 'maximum' and 'mean' values of the fluxes, which served as critical inputs for the CLASS model simulations, enabling a detailed exploration of the boundary layer's sensitivity to these key fluxes.

**Model Implementation**

The CLASS model was employed to emulate the complex evolution of the marine boundary layer post-transition from the Arctic ice edge. Incorporating fixed 'maximum' and 'mean' flux values from the COMBLE data, the model was run under various scenarios with and without cloud cover to track the Lagrangian evolution of air parcels for up to 24 hours. The use of the CLASS model allowed for the detailed investigation of changes in boundary layer height, potential temperature, specific humidity, wind patterns, and cloud dynamics.

**Results and Analysis**

The CLASS model's analysis of the Arctic marine boundary layer underscores the significant influence of surface heat fluxes and cloud dynamics on atmospheric conditions. In scenarios devoid of clouds, both 'high' and 'mean' surface flux conditions lead to a rise in specific humidity, indicative of increased moisture due to surface heating. Contrarily, the presence of clouds triggers a reduction in specific humidity across these scenarios, suggesting that the cooling effect of clouds results in drier boundary layer conditions. A notable increase in the boundary layer height and temperature is observed in 'high values - (no clouds)' scenarios, highlighting the impact of active surface heating. Clouds, however, exert a moderating effect on these parameters, introducing stability to the boundary layer's development. This stabilizing role of clouds is further evidenced by the wind speed analysis, which shows heightened turbulence and momentum transfer in the absence of clouds, suggesting a more dynamic and convective boundary layer. The transient nature of cloud development within the boundary layer is a pivotal finding from the CLASS model simulations. While there is an initial increase in cloud core and total cloud fractions under both 'high' and 'mean' surface flux conditions, these clouds prove to be short-lived. Cloud cores diminish rapidly, completely disappearing after 6 hours for 'high values' and before 10 hours for 'mean values'. The total cloud cover follows a similar fleeting existence, underscoring the challenges in maintaining sustained cloudiness within the boundary layer. Mass flux patterns, indicative of vertical movements within the boundary layer, initially mirror the increases seen in cloud fractions, pointing to an early stage of active vertical mixing. However, this vertical flux diminishes swiftly, aligning with the clear-sky scenario levels and illustrating the short duration of enhanced vertical transport.

**Conclusion**

Despite the CLASS model's simplicity, it has successfully mimicked air-mass transformations from the Arctic ice edge by integrating sensible and latent heat fluxes from the 30ECOR dataset of the COMBLE field campaign. While direct comparisons with observational data were not conducted, the application of actual flux values from the COMBLE dataset in the model underscores its effectiveness in simulating the boundary layer's response to cold-air outbreaks. The resulting insights into the interactions between cloud cover and boundary layer attributes such as humidity, temperature, and convective activity highlight the model's value. These findings enhance our understanding of Arctic meteorological phenomena and provide a solid framework for further research, potentially leading to improvements in climate modeling and forecasting for polar regions.

**Reference:**

Brümmer, B. (1996) ‘Boundary-layer modification in wintertime cold-air outbreaks from the Arctic sea ice’, *Boundary-Layer Meteorology*, 80(1–2), pp. 109–125. Available at: https://doi.org/10.1007/BF00119014.

Geerts, B. *et al.* (2022) ‘The COMBLE Campaign: A Study of Marine Boundary Layer Clouds in Arctic Cold-Air Outbreaks’, *Bulletin of the American Meteorological Society*, 103(5), pp. E1371–E1389. Available at: https://doi.org/10.1175/BAMS-D-21-0044.1.

Sullivan, R. *et al.* (1997) ‘Eddy Correlation Flux Measurement System’. Atmospheric Radiation Measurement (ARM) Archive, Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (US); ARM Data Center, Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (United States). Available at: https://doi.org/10.5439/1025039.

**FIGURES:**

A graph with colored lines

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Figure :Boundary Layer Height Evolution Over Time: High (Blue for no clouds, Red for clouds) versus Mean (Cyan for clouds, Green for no clouds) Conditions

A graph of different values

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Figure :Specific Humidity Trends Over Time: High (Blue for no clouds, Red for clouds) versus Mean (Cyan for clouds, Green for no clouds) Conditions.

Figure :Temporal Variation of Mixed-Layer Potential Temperature: High (Blue for no clouds, Red for clouds) versus Mean (Cyan for clouds, Green for no clouds) Conditions.

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Figure 5:U-Wind Speed Changes Over Time: High (Blue for no clouds, Red for clouds) versus Mean (Cyan for clouds, Green for no clouds) Conditions.

Figure 6:V-Wind Speed Variations Over Time: High (Blue for no clouds, Red for clouds) versus Mean (Cyan for clouds, Green for no clouds) Conditions.

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Figure 8:Cloud Core Fraction Dynamics Over Time: High (Blue for no clouds, Red for clouds) versus Mean (Cyan for clouds, Green for no clouds) Conditions.

Figure 7:Total Cloud Fraction Evolution Over Time: High (Blue for no clouds, Red for clouds) versus Mean (Cyan for clouds, Green for no clouds) Conditions.

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Figure 9:Mass Flux Variability Over Time: High (Blue for no clouds, Red for clouds) versus Mean (Cyan for clouds, Green for no clouds) Conditions.