Components of the Arctic Inversion Dual Mixed-Layer Boundary-Layer Paradigm at MOSAiC and their Relationship to Synoptic Conditions

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ASR Atmospheric System Research

Project/Poster Objectives

Through observations and modeling, the project will evaluate, develop, and further our understanding of a proposed Arctic Inversion (AI) conceptual model of the lower troposphere over Arctic ice-covered regions, particularly the sea ice. Poster will present work accomplished over the past year providing statistics of lower-troposphere structures and examples of observed processes.

Arctic Inversion Dual-Mixed Layer Structural Paradigm

Key structural features

Arctic Inversion (AI) – General, large-scale inversion that forms over Arctic, ice/snow-covered regions. AI top is interface with the free troposphere. Structural features occur within the AI as air moves over ice/snow. Separation of AI from ABL is the unique aspect of this paradigm.

Atmospheric boundary layer (ABL) – the locally-formed atmosphere-surface boundary layer. It may be stable or consist of a temperature inversion, or a surface-forced surface mixed layer (SML).

Cloud mixed layer (CML) – upside-down convection driven by cloud-top radiative cooling of clouds within the AI. It forms a mixed layer totally independent of surface characteristics, and may couple with ABL.

Low-level jets (LLJs) – synoptically or inertially forced local wind maxima occurring under either clear or cloudy conditions. LLJs may force local vertical mixing

Arctic Inversion Dual-Mixed Layer Conceptual Model

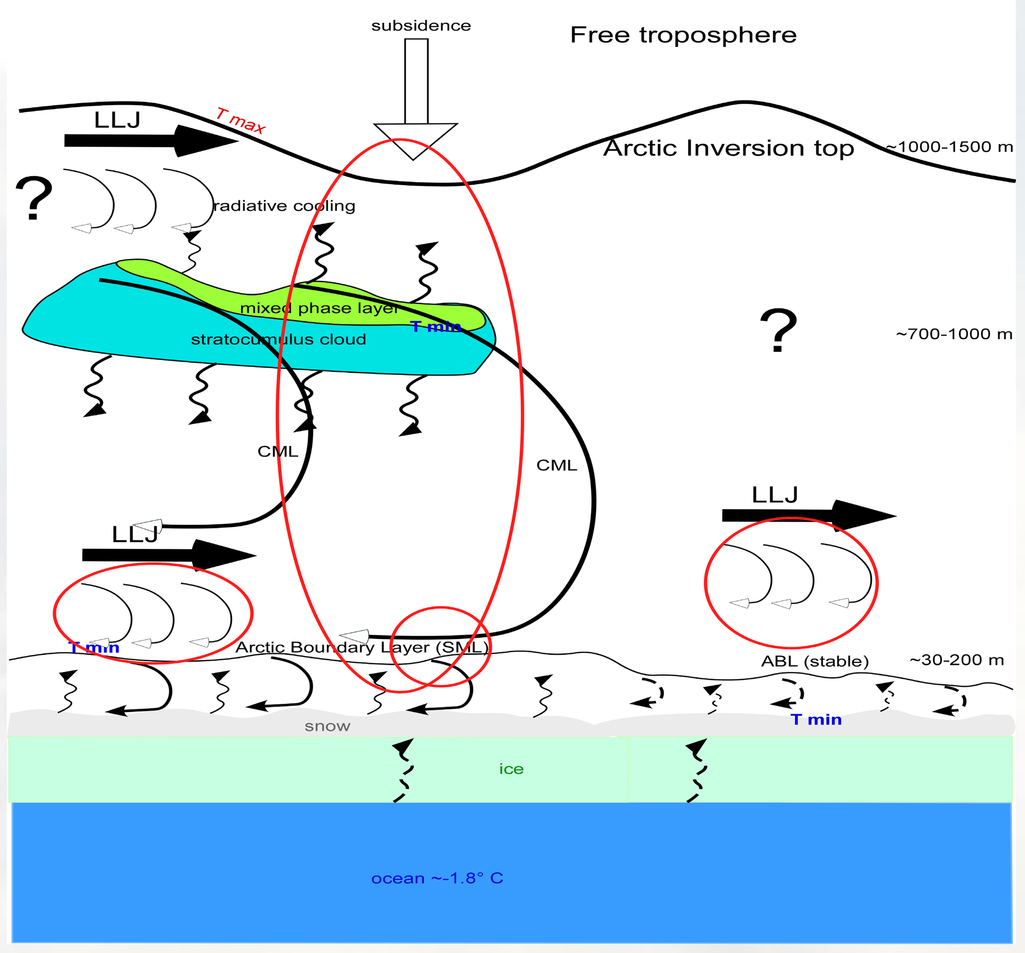


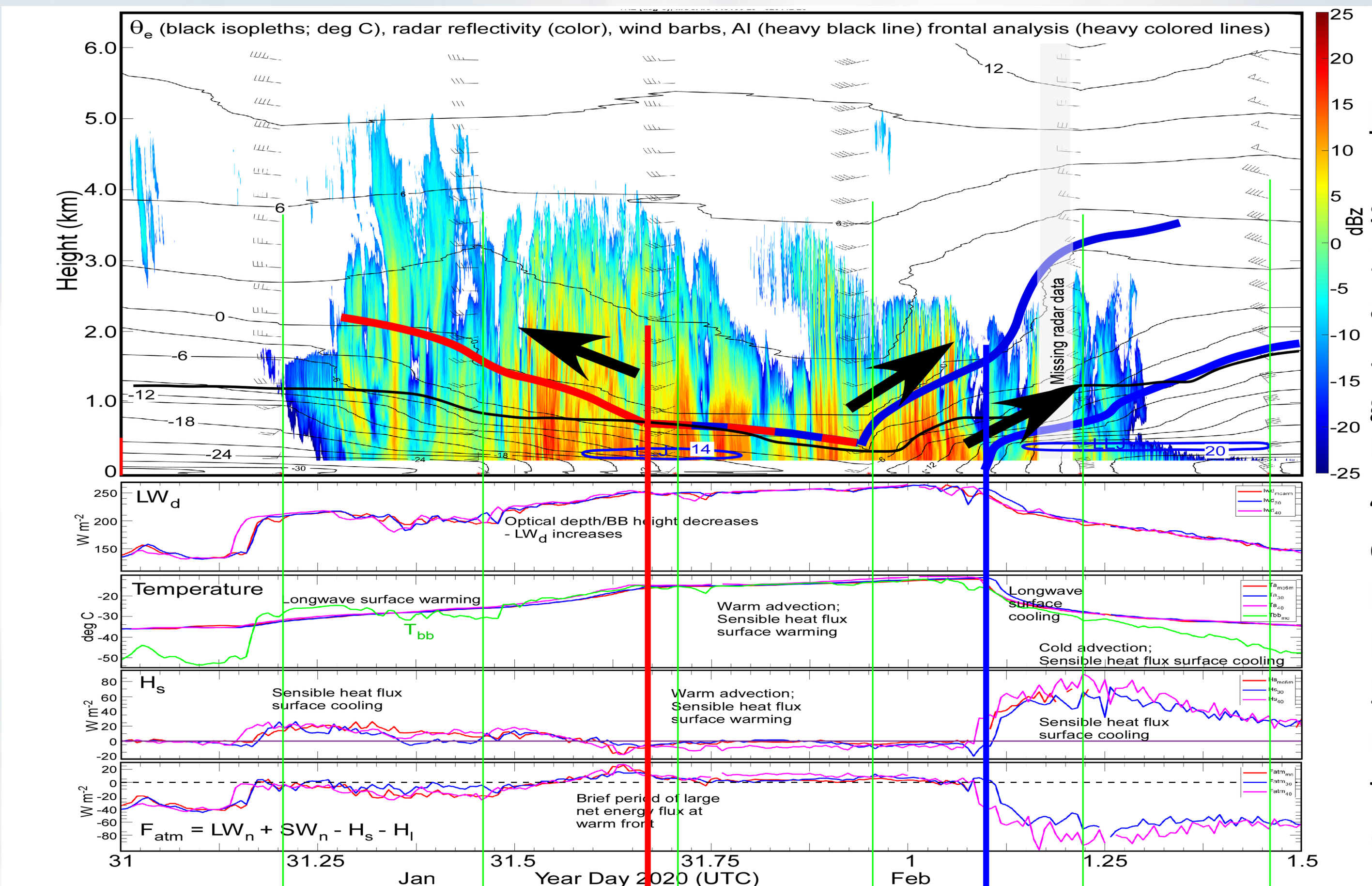
Fig 1: Schematic showing key components of the Arctic inversion (AI) dual mixed-layer paradigm.

Methodology

Extensive MOSAiC observational data set used, including: a) Met City and ASFS surface energy budget measurements; b) rawinsondes; c) vertically-pointing and scanning Ka-band Doppler radars; d) Shupe-Turner cloud macro- & micro-physical retrievals; e) Gallion and Halo doppler lidars; f) AERI microwave radiometer; g) DWD sea-level pressure analyses. Routine developed for automated identification of paradigm features from soundings.

Evolution of AI Boundary-Layer During an Arctic Cyclone

Open-wave cyclone over MOSAiC Jan 31 – Feb 1, 2020.



Key Points (Figs 2 & 3):
1) AI lowers in cyclone warm sector
2) Deep cyclone cloud tops well above AI
3) Cloud LW radiation forces gradual growth of SML (05-13 UTC Jan 31)
4) LLJ & rapid destabilization contribute to deeper SML and high TKE below LLJ (03-06 UTC Feb 1)
5) surface cooling & stabilization reduces downward momentum flux & creates shallow SML (0700-1200 UTC Feb 1)

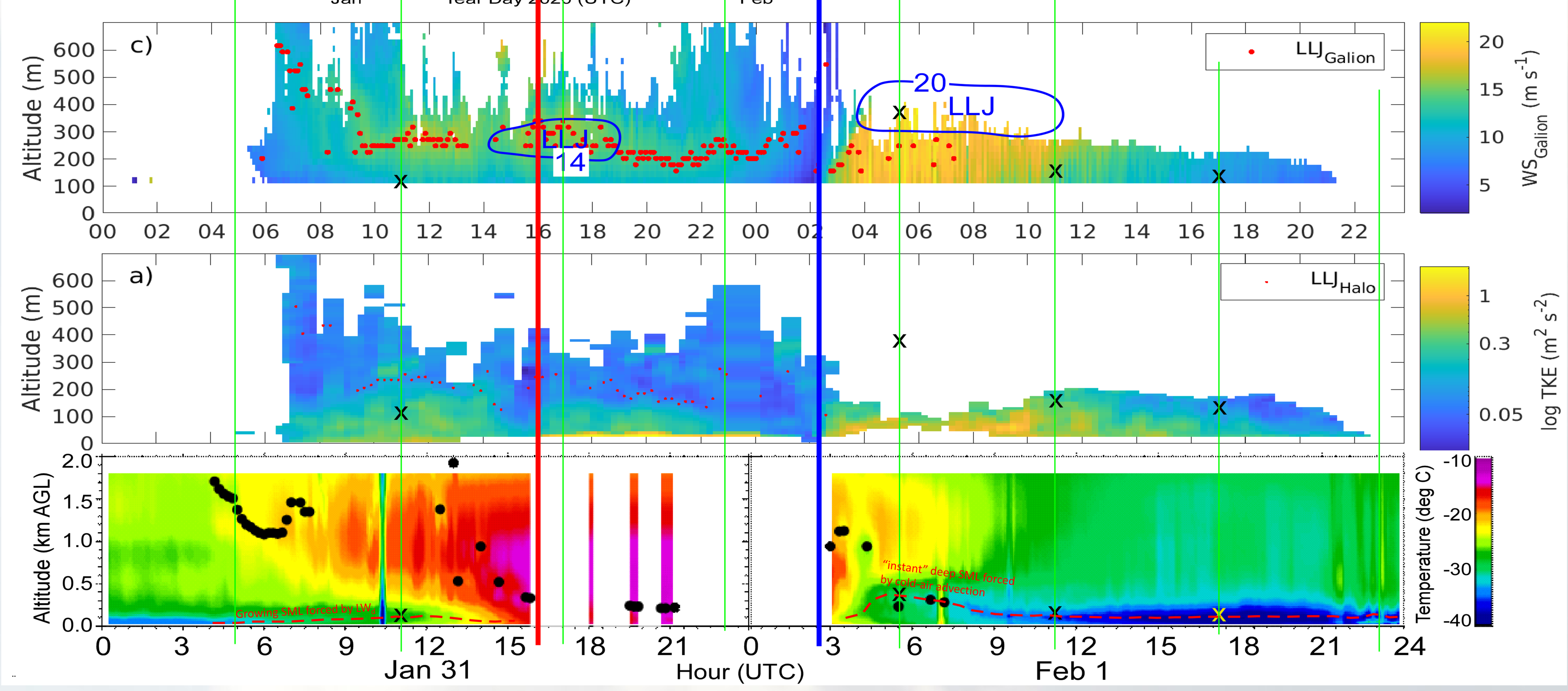


Fig. 2: Analyses of various boundary-layer relevant parameters for the Jan 31-Feb 1 cyclone. Top: Time-height section of virtual potential temperature (q_v) and radar reflectivity from the vertically-pointing Ka-band radar. Warm (red) and cold (blue) fronts are shown as heavy lines, and general front-relative airflow is shown as heavy arrows. The Arctic inversion (AI) is shown as a heavy black line, and the LLJs detected by the soundings are marked with the largest isotach. Next 4 panels: Near-surface time series of downwelling longwave radiation (LW_d), temperature (T) and blackbody temperature (T_{bb}), turbulent sensible heat flux (H_s), and net atmospheric energy flux (F_{atm}). The bottom three panels show time-height sections of wind speed from the Gallion lidar (with sounding LLJ isotachs), turbulent kinetic energy (TKE) from the Halo lidar, and temperature from the AERI radiometer. The vertical green lines show times of the rawinsondes, with the SML depth marked by an "X" in the bottom three panels. The times of the warm and cold-frontal passage are marked by vertical red and blue lines, respectively, for reference. The SML depth estimated from the AERI profiles is marked by a red dashed line in the lowest panel. The red dots on the lidar data show the LLJ heights, while the black dots show ceilometer estimates of cloud base.

Paradigm Features Identified in Sondes During Feb 1 Cyclone

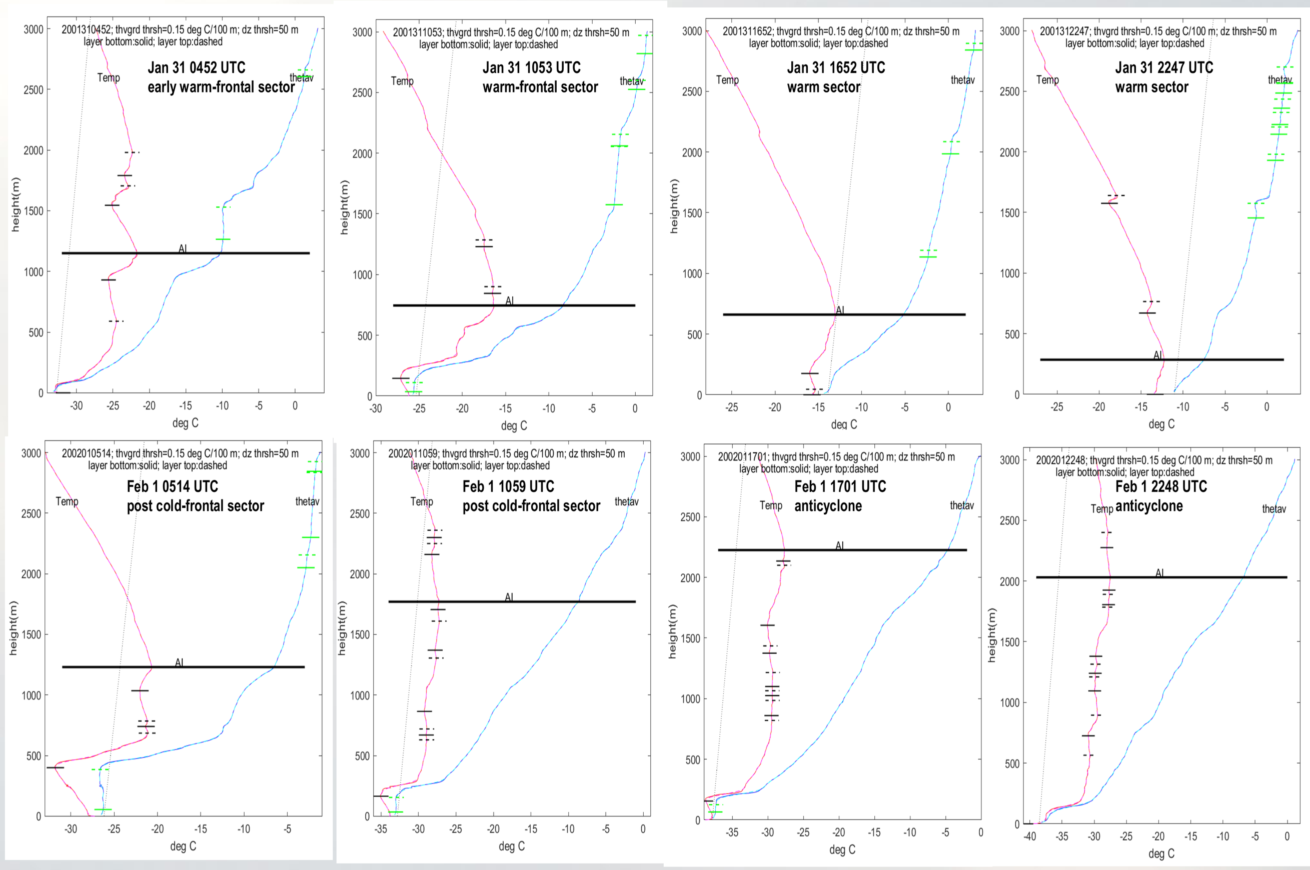


Fig 3: Diagnostics of paradigm features for 8 soundings during Jan 31 - Feb 1 cyclone passage showing temperature (solid red) and virtual potential temperature (dashed blue). The cyclone sector is identified for each sounding. The horizontal solid and dashed lines shows the bottoms and tops of each identified layer for a temperature inversion (black) and a mixed layer (green). SMLs only occur near the surface, while for this cyclone case CMLs occur only above the AI in the deep frontal clouds.

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Mid-December Anticyclone Period

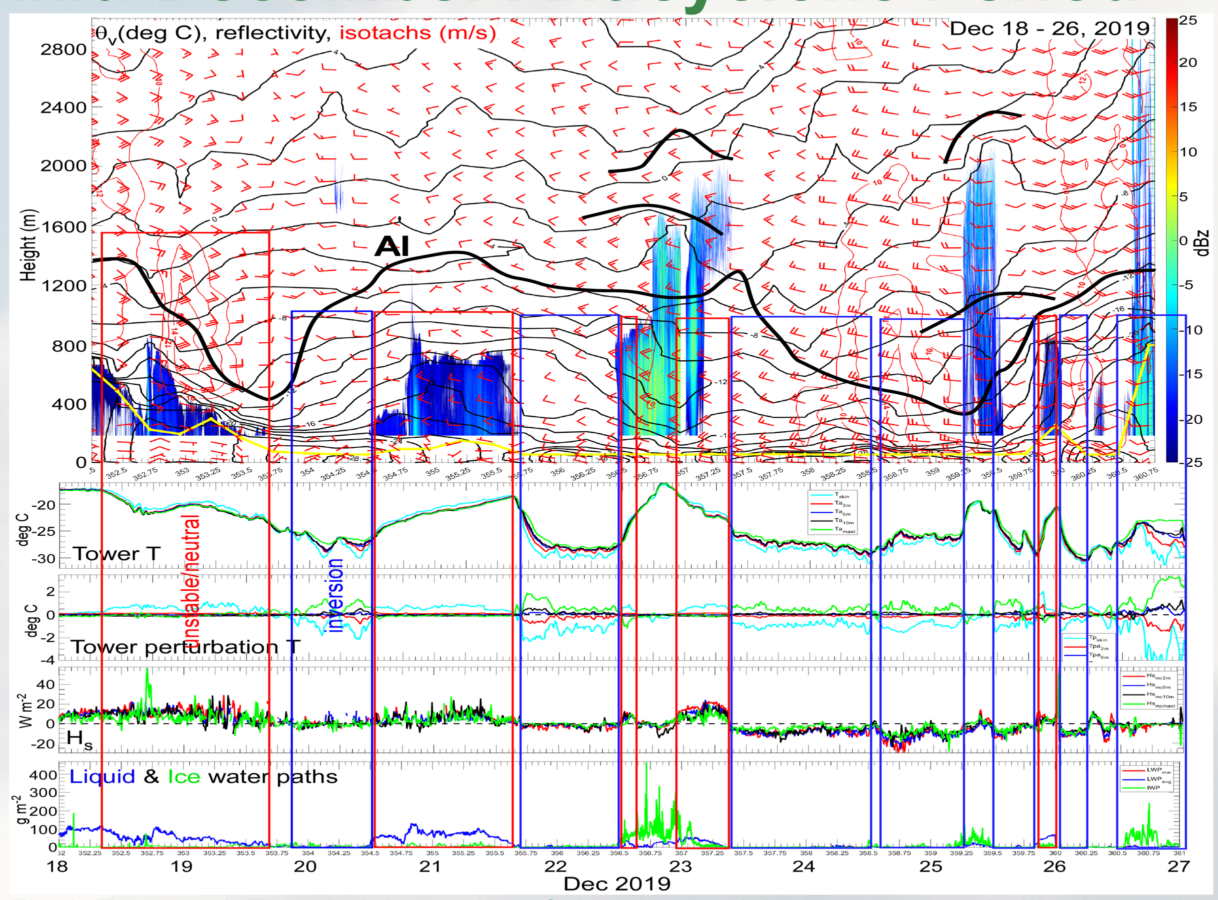

Fig 4: Top panel: Time-height section of virtual potential temperature, wind barbs, and KAZR radar reflectivity for an anticyclonic period Dec 18-26, 2019. Bottom four panels show time series of surface and air temperature at the Central Observatory 10-m tower, perturbation temperatures, measured turbulent sensible heat flux, and liquid and ice water paths.

Key Points (Fig 4):
1) Clouds within AI tend to be mostly liquid; those with tops above contain ice
2) Clear skies rapidly produce surface-based inversion in ABL
3) Cloudy skies have SML in ABL

Evolution Near Sc clouds Within AI

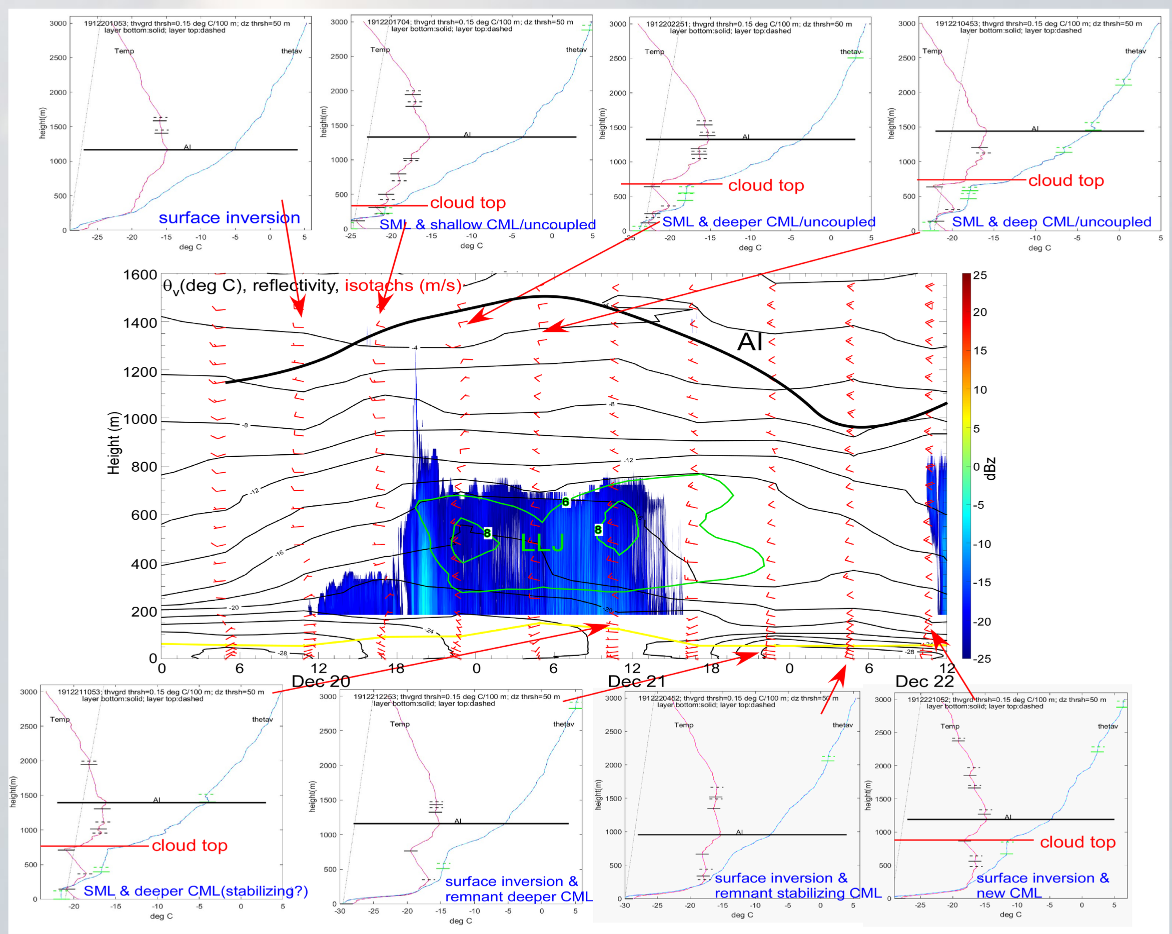

Fig 5: Middle panel: As for Fig. 4 top panel, but for time period Dec 20 -22. Surrounding panels show paradigm features found by automated routine for the soundings within this time period, highlighting the ABL stability and the CMLs. See Fig. 3 caption for additional information about surrounding panels.

Key Points (Fig. 5):
1) CML formed by clouds and CML depth proportional to cloud depth
2) LLJ present near top of cloud and CML – shear below help mixing?
3) CML uncoupled from SML throughout

Conclusions

Synoptic environment strongly influences the boundary-layer

During cyclones: 1) Deep frontal clouds extend above AI; 2) ABL stability modulated by longwave radiation, large-scale thermal advection, synoptically/mesoscale - forced low-level jets; and 3) CMLs rare below AI top, so do not couple with SML

During anti-cyclones: 1) Sc clouds often restricted to within AI, but sometimes extend above AI; 2) clouds within AI mostly supercooled liquid, while clouds with tops above AI have significant ice; 3) CMLs form rapidly within clouds, and slowly stabilize after clouds leave; 4) mid-winter period studied had no coupling between CMLs and SMLs.

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