ASR Atmospheric System Research

CIWRO — Cooperative Institute for Severe and High-Impact Weather Research and Operations

Disentangling the roles of large-scale subsidence, moisture flux, and aerosol effects on Arctic cloud lifetime

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Overview of Project

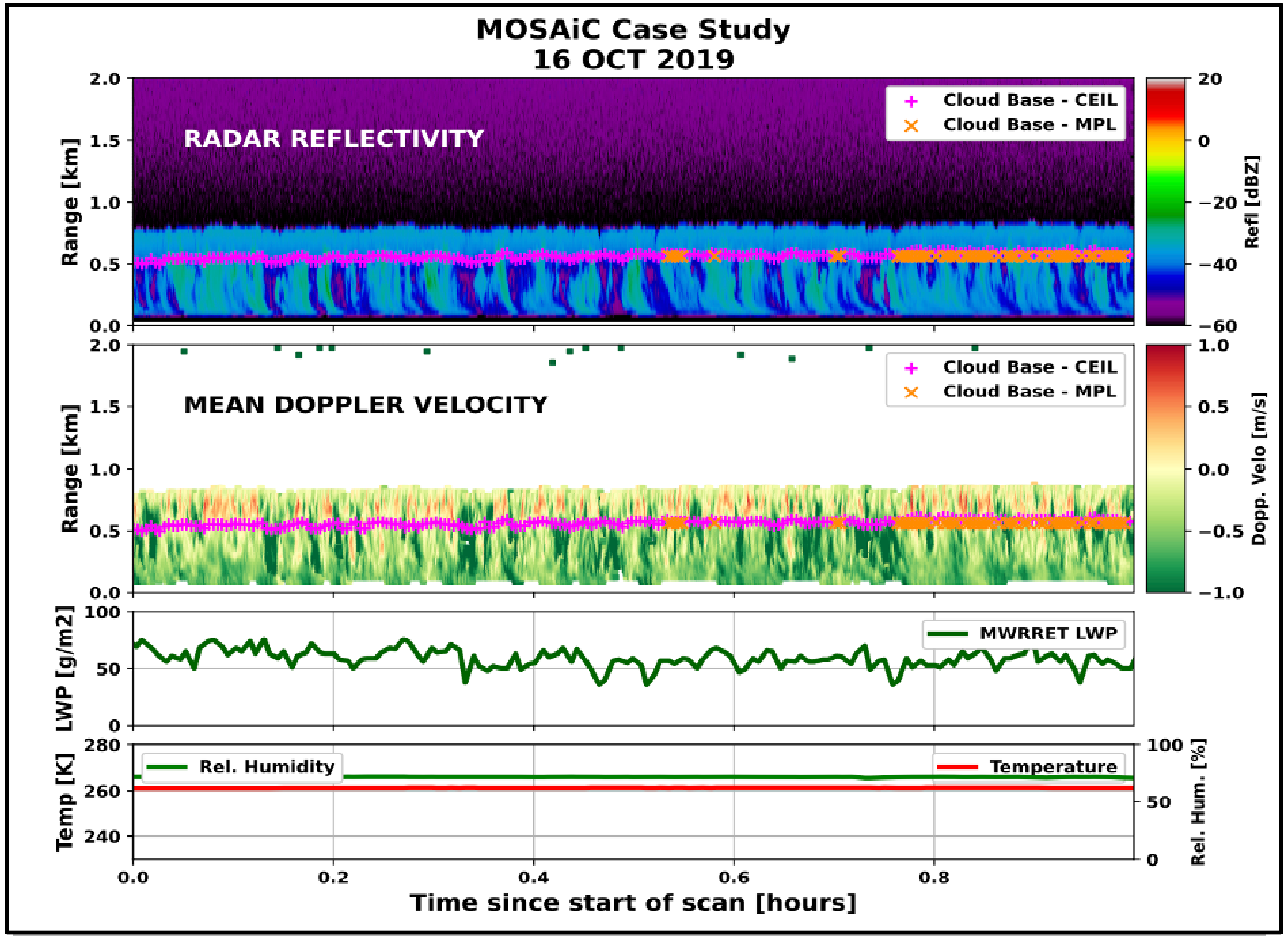
- Recently funded work titled **Surface, Aerosol, and Meteorological controls on Arctic Boundary Layer Clouds: Observations and Simulations from MOSAiC and COMBLE**

- **Overarching Hypothesis:** "*For given surface conditions, tropospheric states promoting large thermodynamic stability and weak large scale lower-tropospheric subsidence (or ascent) lead to maximal Arctic PBL cloud fraction.*"

- Three working hypotheses that address these general topics:
  1. The role of **surface fluxes** (latent and sensible fluxes) on Arctic cloud fraction.
  2. The role of **aerosols and aerosol effects** on Arctic cloud properties.
  3. The importance of **meteorological influences** relative to surface fluxes and aerosol effects.

Observations and Datasets

- **Radar**: Ka-band ARM Zenith Radar (KAZR) and Marine W-band ARM Cloud Radar (MWACR).
- **Microwave Radiometer**: Microwave radiometer retrieval (MWRRET) retrieval products.
- **Aerosol Observing System (AOS)**: key meteorological data for sensible/latent heat flux computations, and aerosol data.
- **Radiosondes**: additional meteorological context/vertical profiles of temperature, humidity, wind, etc.
- **Synergistic cloud retrieval product**: merge MWR, radar and meteorological data for liquid/ice water path retrievals.
- **Reanalysis data**: ERA-5 and MERRA-2 can fill in data gaps and provide context for synoptic meteorological conditions.



MWACR W-band reflectivity (top panel), mean Doppler velocity (top-middle panel), MWRRET liquid water path (bottom-middle panel) and MOS temperature (red line) and relative humidity (green line). In the top two panels, ceilometer cloud base is denoted with magenta + symbols, while the MPL cloud base is denoted by orange x symbols.

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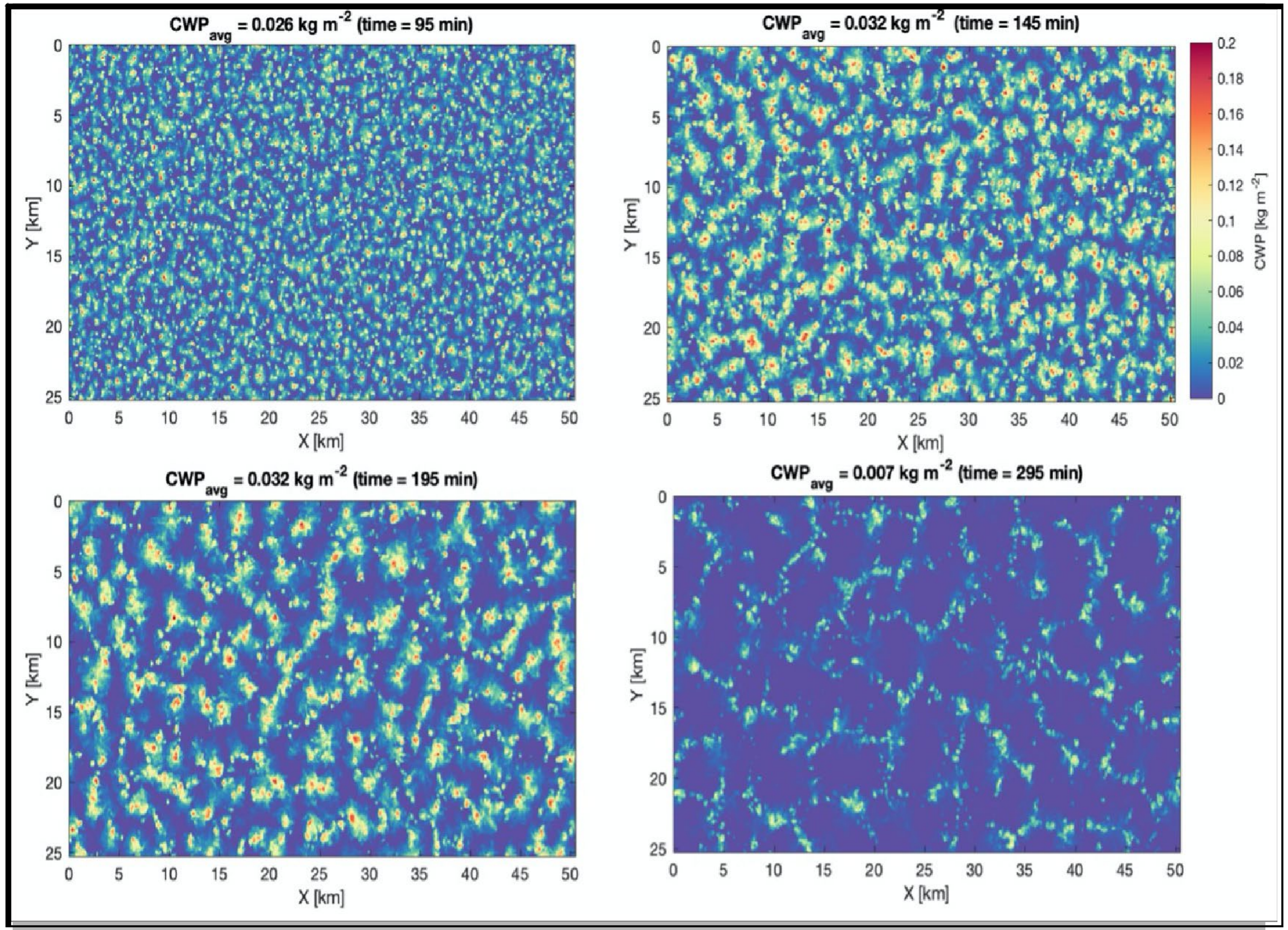
Lagrangian Cloud Model

- Cloud Model 1 (CM1) non-hydrostatic in LES configuration to simulate Arctic mixed-phase boundary layer clouds.
- Proposed simulations will utilize a Lagrangian particle-based microphysics scheme, which is a significant advance for representing cloud microphysics in models compared to Eulerian bin microphysics.
- Lagrangian Cloud Model or Super-Droplet Method (SDM):
- Super-droplets (or super-particles) are a statistical representation of physical particles (e.g., aerosols, cloud droplets, rain, ice, etc.) with a given set of physical properties.
- The number of real particles that a super-particle represents is one of its attributes.
- Lagrangian particle-based schemes mitigate many issues present with bin microphysics.



Cloud water path (CWP) of a stratocumulus cloud field at different times from a CM1-SDM simulation of DYCOMS-RF02 case. The domain average CWP and the simulation time are mentioned at the top of each panel.

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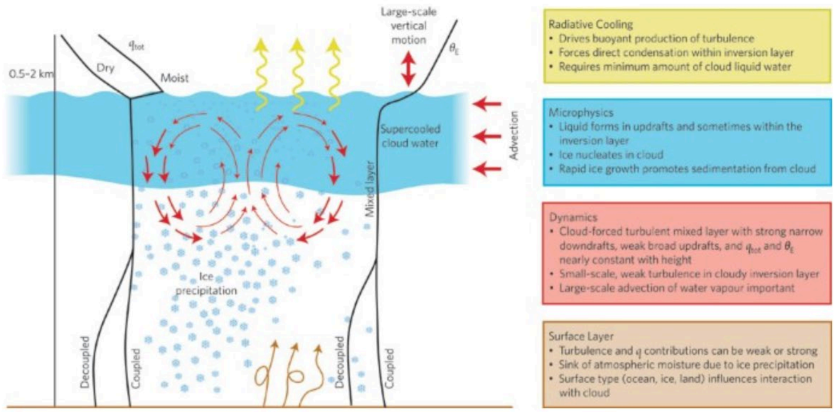
Morrison et al., 2012, Nature Geosciences

Planned Analysis

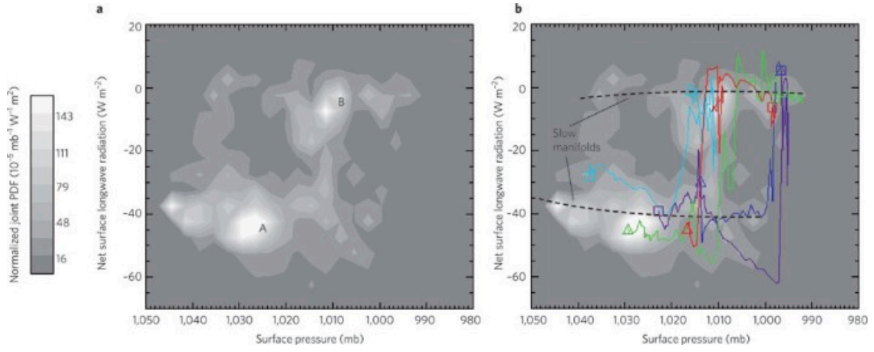
- Using observations: find initial representative case studies in the following regimes:
    1. Strong subsidence vs. weak subsidence.
    2. Strong aerosol loading vs. weak or limited aerosol loading.
- Run Lagrangian Cloud Model guided by these observations.
- Follow Morrison et al. (2012) as guidance for initial analyses.

Figure 3: A conceptual model that illustrates the primary processes and basic physical structure of persistent Arctic mixed-phase clouds.



The main features are described in text boxes, which are colour-coded for consistency with elements shown in the diagram. Characteristic profiles are provided of total water (vapour, liquid and ice) mixing ratio (q_{tot}) and equivalent potential temperature (θ_E). These profiles may differ depending on local conditions, with dry versus moist layers/moisture inversions above the cloud top, or coupling versus decoupling of the cloud mixed layer with the surface. Cloud-top height is 0.5–2 km. Although this diagram illustrates many features, it does not fully represent all manifestations of these clouds.

Figure 4: Preferred Arctic states evident from observations of net surface longwave radiation.



a, A normalized joint probability density function (PDF) of longwave radiation and surface pressure is derived from hourly SHEBA measurements[84] over the period from 1 November 1997 to 26 May 1998, excluding periods with clouds above three kilometres in altitude. The two preferred states[82] correspond to PDF maxima indicated by A (radiatively clear) and B (opaquely cloudy). **b**, The PDF in the left panel superimposed with five different time series of longwave radiation versus surface pressure over periods of one to five days (coloured lines) illustrates transition between the states. Triangles and squares indicate the start and end of the time series, repectively.

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