The two Arctic atmospheric states and their impacts on the surface energy budget at MOSAiC

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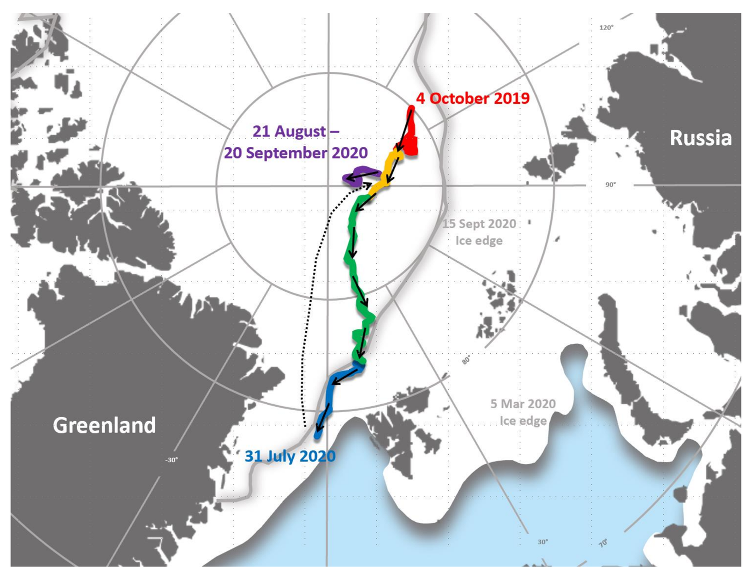
MOSAiC & its Observations

The ***Multidisciplinary drifting Observatory for the Study of Arctic Climate*** expedition drifted passively with the Arctic sea ice from September 2019 to October 2020. Based on the icebreaker *Polarstern*, the expedition targeted the coupled Arctic atmosphere-ice-ocean system by examining physical, chemical, and biological processes, all linked to the changing sea ice.



MOSAiC drift track. Note the September minimum and March maximum sea ice extents as context.

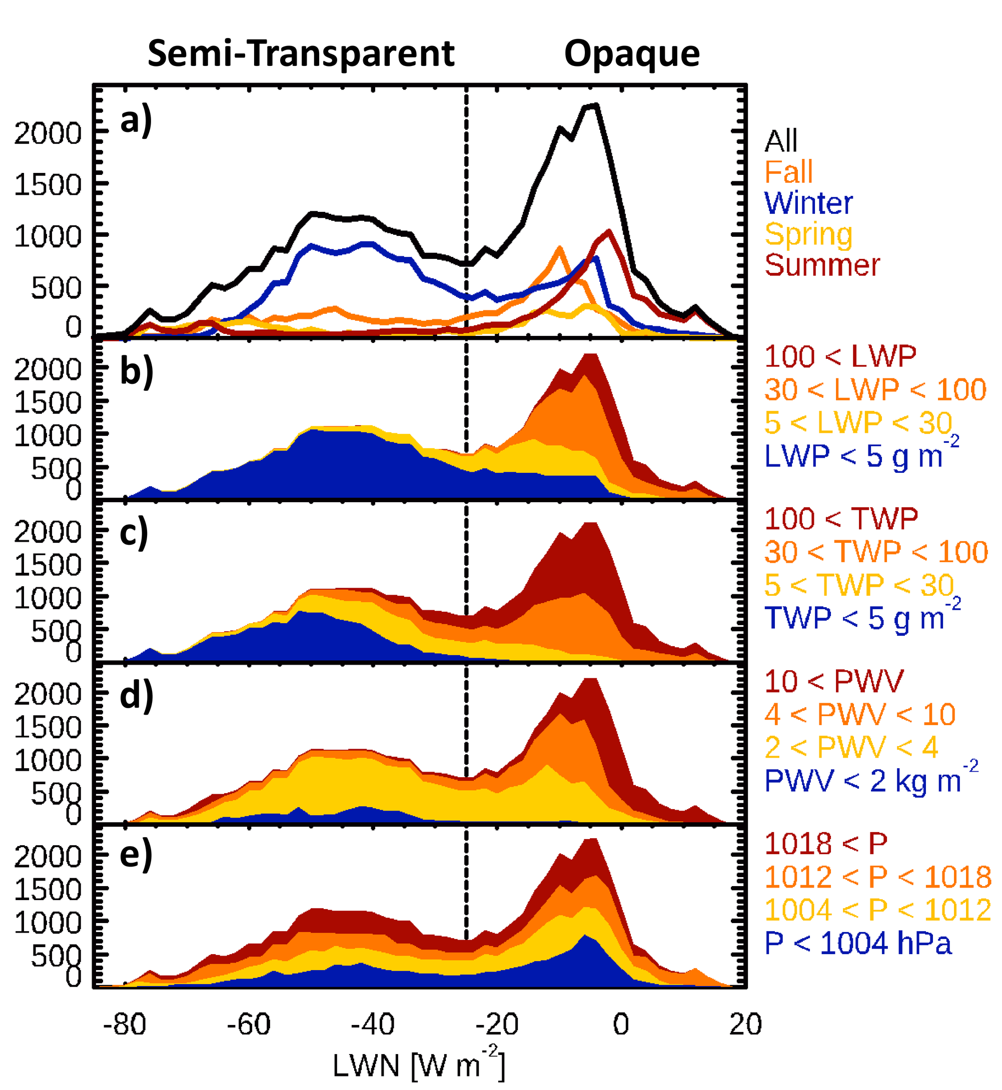
The following observations are used here to characterize atmospheric states and their implications for the surface energy budget:

- **LWN, SWN** = Surface net longwave and shortwave radiation measured by broadband radiometers (positive = warms surface)
- **Hs, Hl** = Sensible and Latent heat fluxes, derived using a combination of eddy correlation and bulk techniques (positive upward = cools surface)
- **C** = Sub-surface heat flux (Conductive heat flux plus Storage), derived from thermistor strings through ice and snow (positive upward = warms surface)
- **T2m** = Temperature at 2m height, measured directly
- **Tskin** = Surface skin temperature, derived from radiation
- **P** = Surface atmospheric pressure from met sensors
- **LWP, PWV** = Liquid water path and precipitable water vapor retrieved from microwave radiometers
- **IWP** = Ice water path derived from cloud radar
- **Cloud type / fraction**, derived from the multi-sensor ShupeTurner cloud properties product based on KAZR, WACR, MPL, ceilometer, MWR, and radiosonde observations.

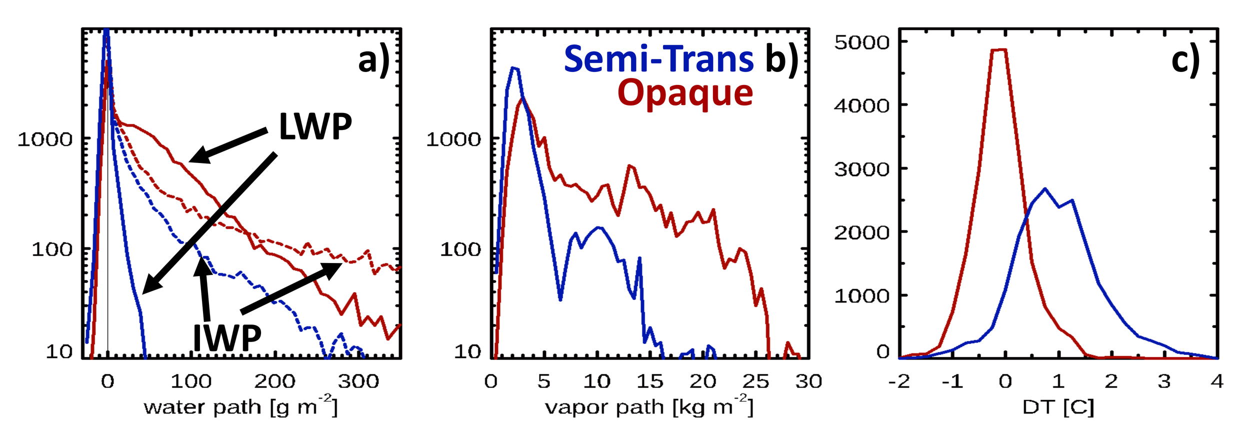
Observations are from DOE ARM, the University of Colorado, and Dartmouth University

Characterizing the Arctic Radiative States

What cloud and atmospheric properties comprise the two modes of the net surface LW radiation?



Distributions of the surface net LW radiative flux: (a) For the full year and for each of the primary seasons; (b) Partitioned into different ranges of retrieved cloud liquid water path (LWP); (c) Partitioned into different ranges of retrieved total water path, including LWP plus ice water path; (d) Partitioned into different ranges of retrieved precipitable water vapor (PWV); and (e) Partitioned into different ranges of surface pressure (P). The distinction between the semi-transparent and Opaque states is given by the black dashed line at -25 W/m².



Distributions of different parameters for the Semi-Transparent (blue) and Opaque (red) states of: (a) LWP (solid) and IWP (dashed); (b) PWV; and (c) near-surface temperature gradient (T2m – Tskin).

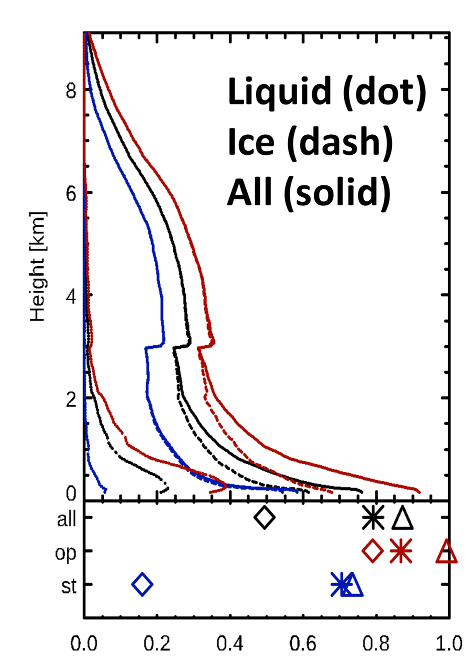
Opaque state

- Near-neutral LWN
- 80% of cases w/ cloud liquid
- 20% of cases w/ ice but no liquid
- Often higher integrated water vapor
- Near-neutral surface profile

Semi-Transparent state

- Large surface radiative cooling
- 75% of cases w/ cloud ice
- ~15% w/ very thin liquid (within uncertainty of 0 g/m²)
- 25% clear sky
- Often lower integrated water vapor
- Stable near surface profile

No state dependence on atmos. pressure!

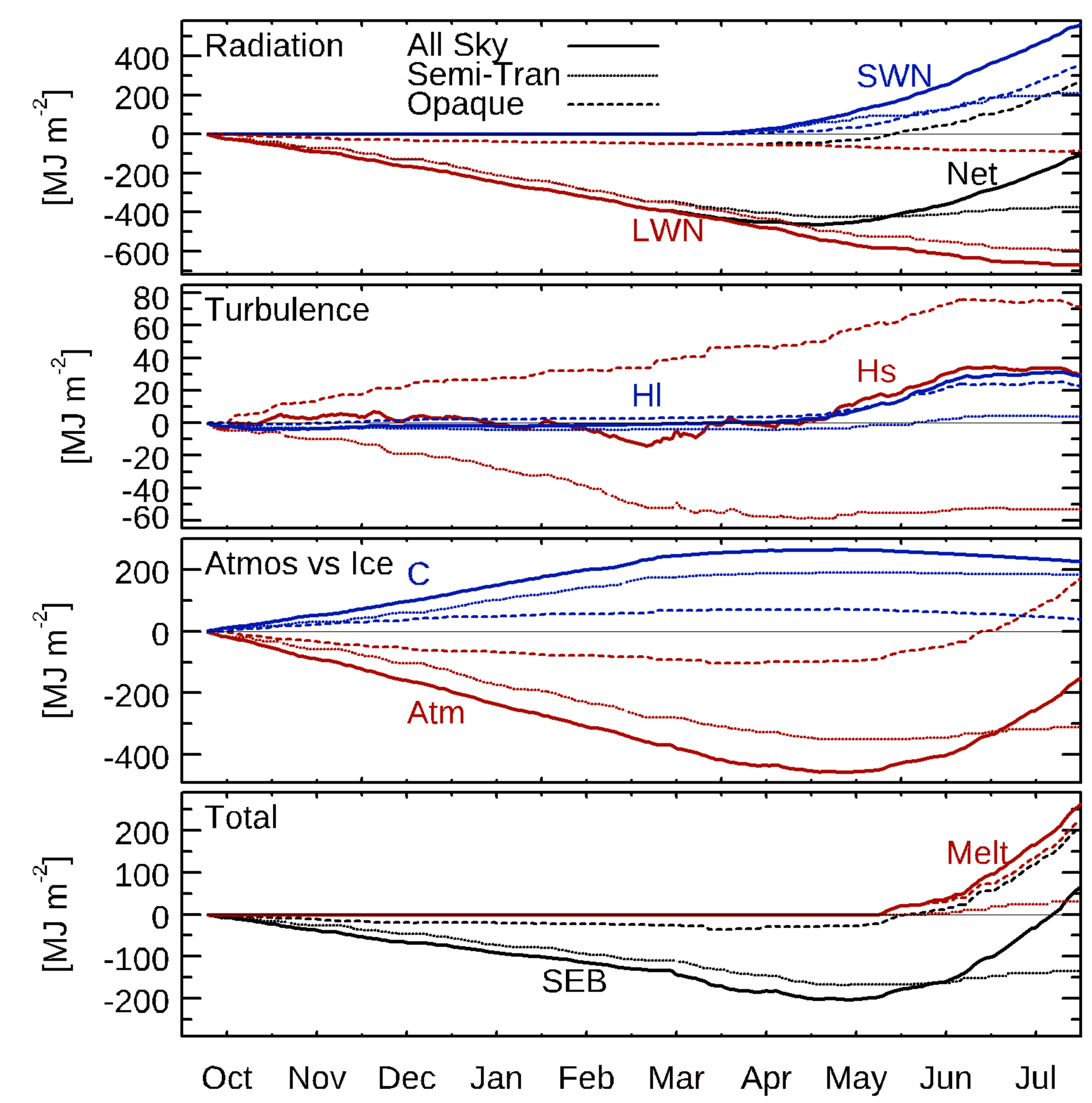


Vertical profiles (top) and net column total occurrence fractions of all clouds (solid and triangle), ice in clouds (dashed and asterisk), and liquid in clouds (dotted and diamond) for all states (black), the Semi-Transparent state (blue), and the Opaque state (red).

Clouds & the SEB

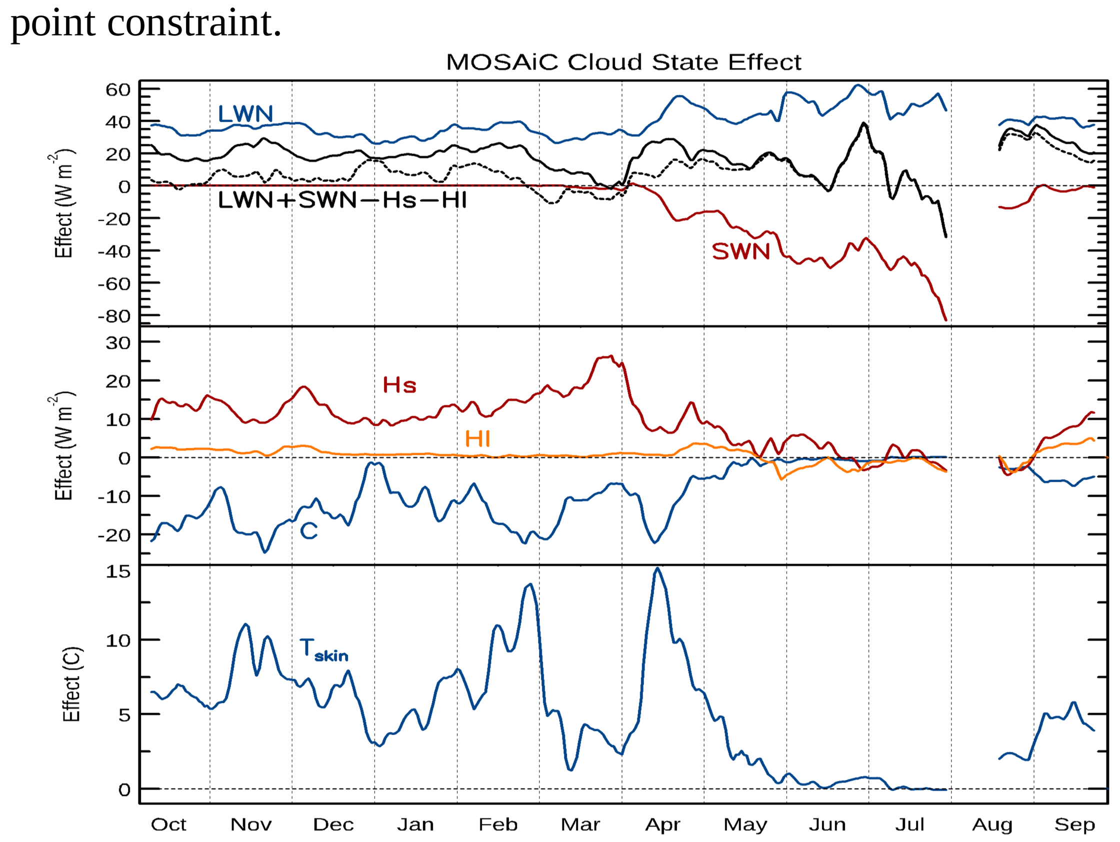
SEB = LWN + SWN – Hs – Hl + C

@ T = 0 C, the SEB ~ the energy available for melt



Cumulative energy fluxes starting on 10 October 2019 and extending through the end of July 2020 (the main MOSAiC ice floe). Plotted terms include: Net shortwave (SWN), longwave (LWN), and total (Net) radiative fluxes; turbulent sensible (Hs) and latent (Hl) heat fluxes; conductive (C) and total atmospheric (Atm) heat fluxes; and the total surface energy budget (SEB) and the component that is available for sea ice melt (Melt). Each set of curves represents all sky conditions (solid), the semi-transparent state (dotted), and the opaque state (dashed).

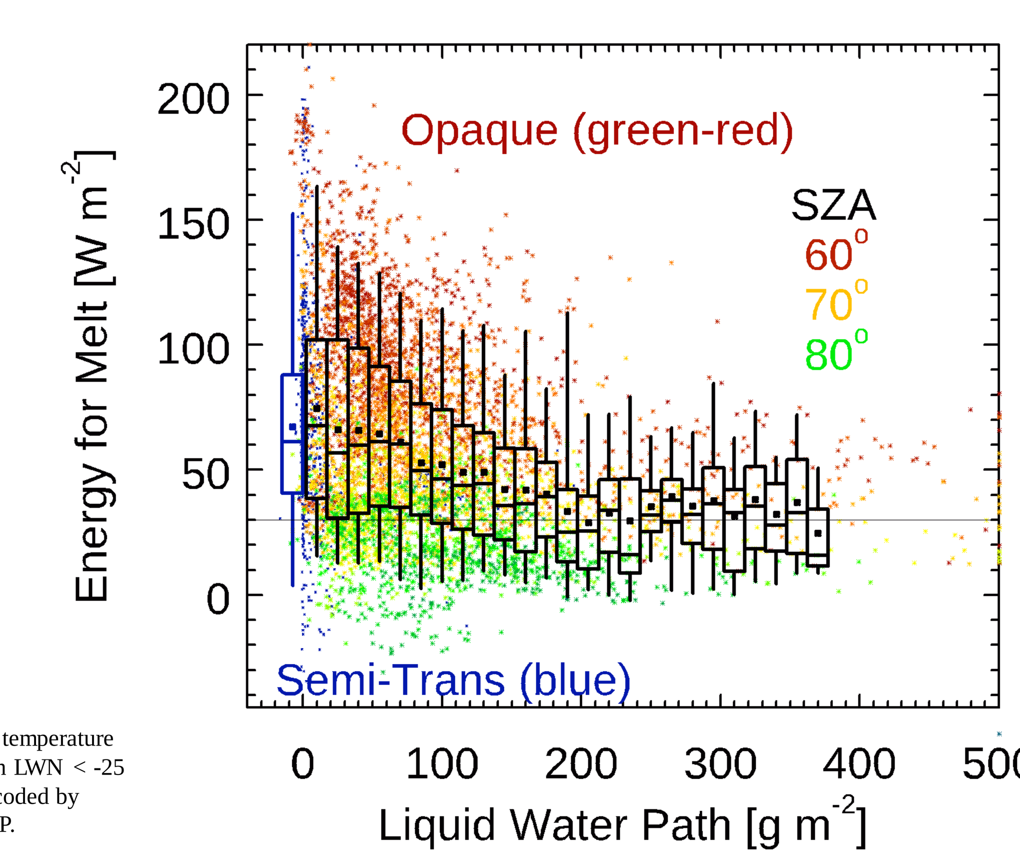
The net impact of the opaque state is quantified for each term of the SEB. The opaque state drives surface LW warming of 30-40 W/m² in winter and 50-60 W/m² in summer, but the surface overall loses lots of LWN due to the semi-transparent state. Cloud SW cooling is up to 80 W/m², yet due to the high cloud fraction in summer, most of the accumulated SW surface warming occurs during the opaque state, in spite of the general SW cloud cooling effect. For Hs, the opaque state (surface cooling) and semi-transparent state (surface warming) counteract, leading to a small cumulative cooling. Most upward conductive heat flux (warming surface but cooling ice) occurs under the semi-transparent state. In summer, the state-dependence of non-radiative fluxes is diminished because the surface temperature is fixed at 0 C. While the opaque state has a net surface warming of 5-10 C in winter, the opaque state instead drives significant melt in summer due to the melting point constraint.



The Cloud State Effect on each energy budget term for the full MOSAiC year. Each curve is computed by subtracting the mean flux for the opaque state from the mean flux for the semi-transparent state over running 14-day windows.

Drivers of Sea-ice Melt

When the skin temperature is at the melting point, the energy remaining from the balance between the surface net atmospheric heat flux and the surface sea ice conductive heat flux predominantly contributes to sea ice melt. (A small portion of solar radiation is transmitted through the ice and warms the upper ocean.) This energy available for melt is at a maximum under thin cloud conditions and when the sun is highest in the sky, showing contributions of both SW and LW radiative processes. As LWP increases, the energy available for melt decreases because the cloud LW blanketing effect is saturated at LWP > ~30 g/m², while the SW shading effect continues to increase with LWP.



Cloud liquid water path versus the residual SEB available for melt for all periods when the surface skin temperature is warmer than -0.2 C (i.e., at the melting point to well within the measurement uncertainty). Cases with LWN < -25 W/m² are in blue and represented by the blue box-and-whisker; cases with LWN > -25 W/m² are color coded by solar zenith angle and represented by the black box-and-whiskers calculated over bins of 15 g/m² in LWP.