Evaluating short-term forecasts of the Arctic ocean-sea ice-atmosphere coupled system using wintertime statistics from the MOSAiC campaign

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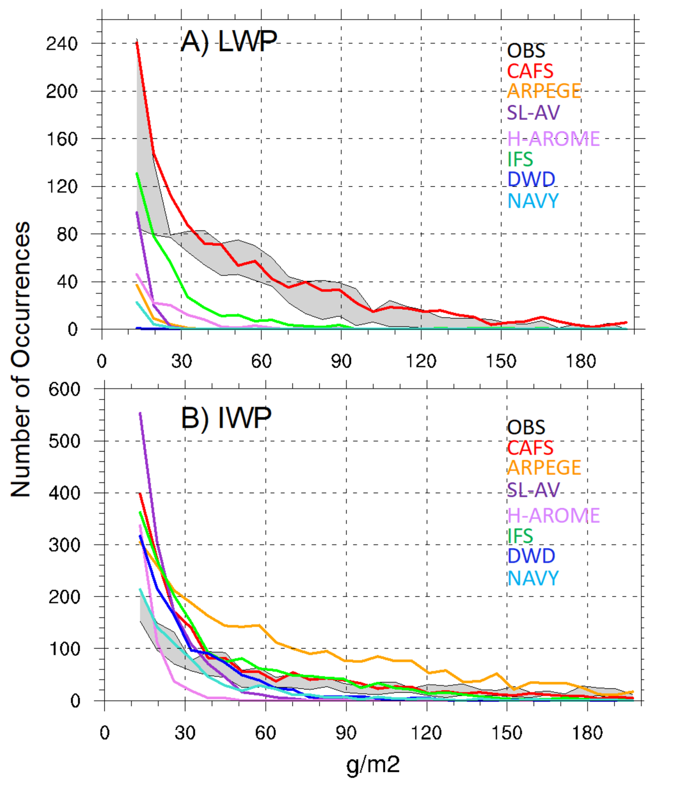
Introduction

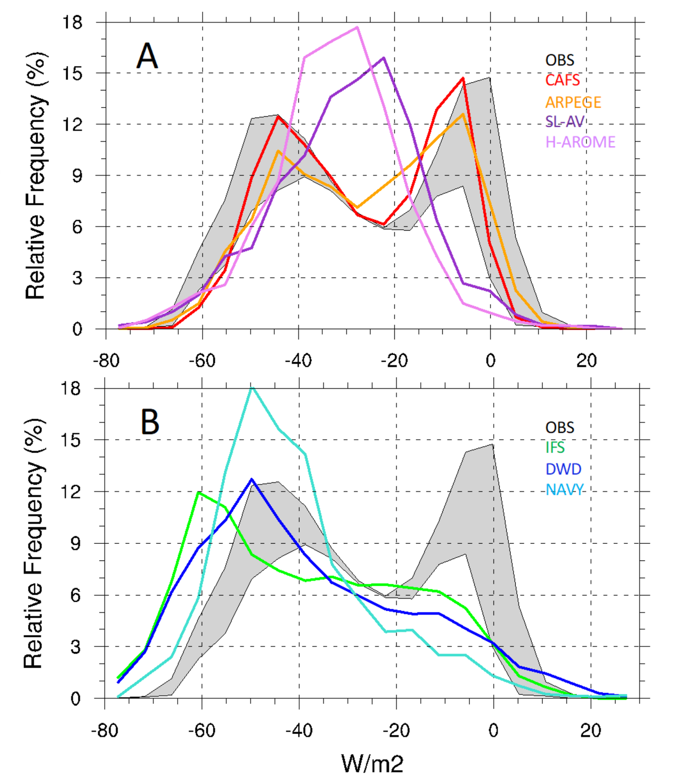
- We use coupled model simulations of the Arctic system to evaluate the atmospheric processes that impact the surface energy budget and feedback to the ocean and sea ice.
- Wintertime observations (period without solar radiation during MOSAiC, 15 October 2019 – 15 March 2020) are used to evaluate coupled processes unique to the Arctic:
  - o representation of liquid-bearing clouds at cold temperatures;
  - o representation of a persistent stable boundary layer
  - o limiting impact of atmospheric variability on sea ice by snow.
- Forecasts from seven state-of-the-art operational and experimental forecast systems are used, five of these systems are fully-coupled ocean-sea ice-atmosphere models.
- Short-term forecasts are used to identify potential errors in the representation of "fast" processes, such as cloud feedbacks and surface fluxes, that cause biases in climate model projections of Arctic climate change.
- Relative importance of these processes in the models is studied, particularly the surface energy budget.



Number of occurrences of modeled (A) LWP greater than 10 gm^{-2} and (B) IWP greater than 10 gm^{-2} over the winter season. The gray shading shows the observed range within each hour using one minute averages.

Current state-of-the art models struggle to maintain **liquid in clouds** at cold temperatures

Only one of the seven forecast systems used in this study has liquid water paths close to observations taken during MOSAiC, resulting in unrealistic **net longwave fluxes**.



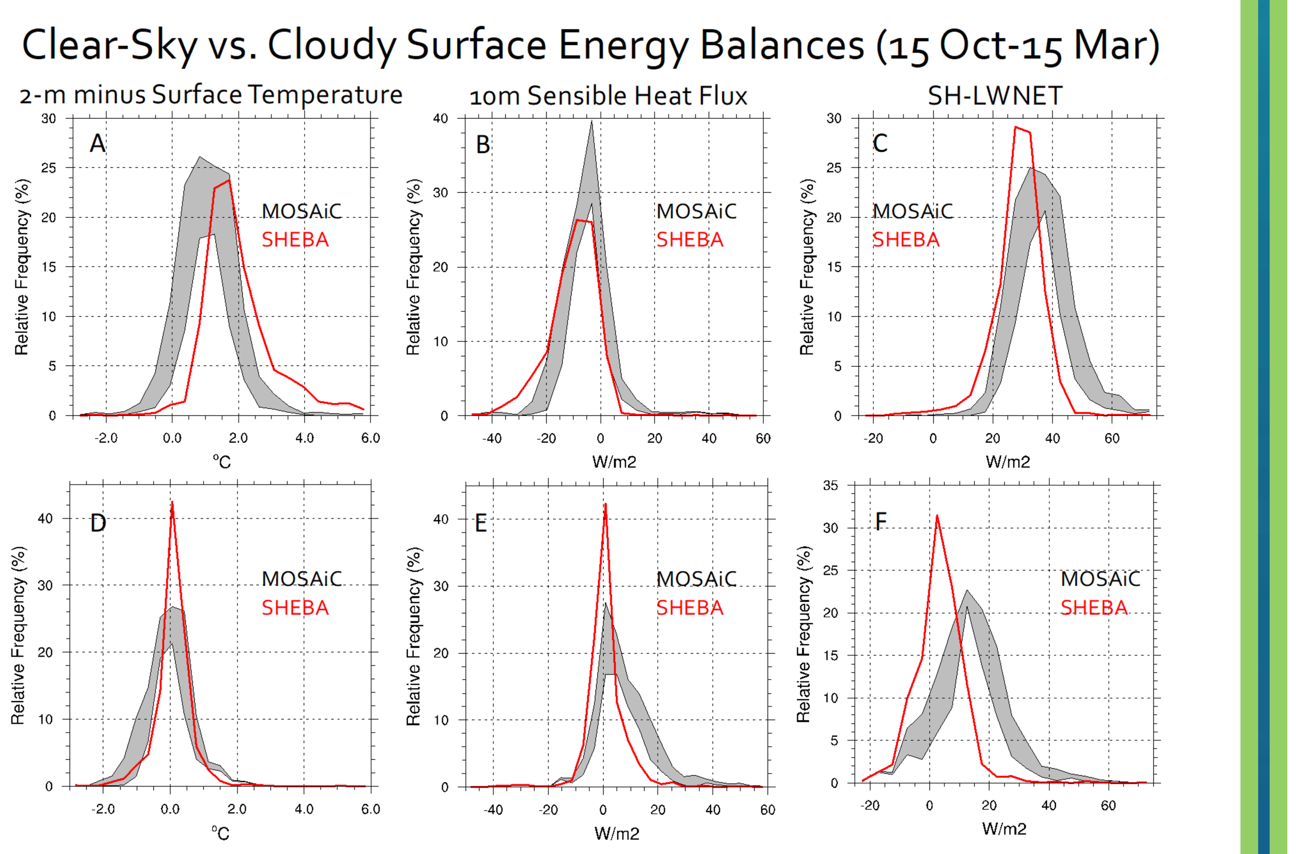
PDFs of model hourly-averaged net surface longwave fluxes, in units of Wm^{-2}, using 1 hour to 2 day lead times. The gray shading in both plots shows the range of the observed distributions using hourly-averaged measurements from the four MOSAiC sites.

The Multidisciplinary drifting Observatory for the Study of Arctic Climate

expedition (MOSAiC, see Shupe et al., 2022) was a year-long drift experiment that took place from Oct 2019 to Oct 2020 in the eastern Central Arctic.

Compared to SHEBA, a year-long drift experiment that took place in the western Central Arctic, separating clear-sky and cloudy statistics, MOSAiC has:

- Near-surface thermal stratification for clear-sky and cloudy conditions that is skewed towards negative values (less stably stratified) (left column)
- Sensible heat fluxes skewed towards larger positive (upward) fluxes (center)
- Weaker clear-sky near-surface thermal stratification during MOSAiC is consistent with a larger upward conductive flux. For cloudy cases, larger upward sensible heat flux during MOSAiC causes larger upward conductive flux since the net longwave flux is close to zero. During cloudy events, the near neutral conditions and upward sensible heat flux during MOSAiC cause snow & sea ice to be more responsive to atmospheric variability than during SHEBA (right column).

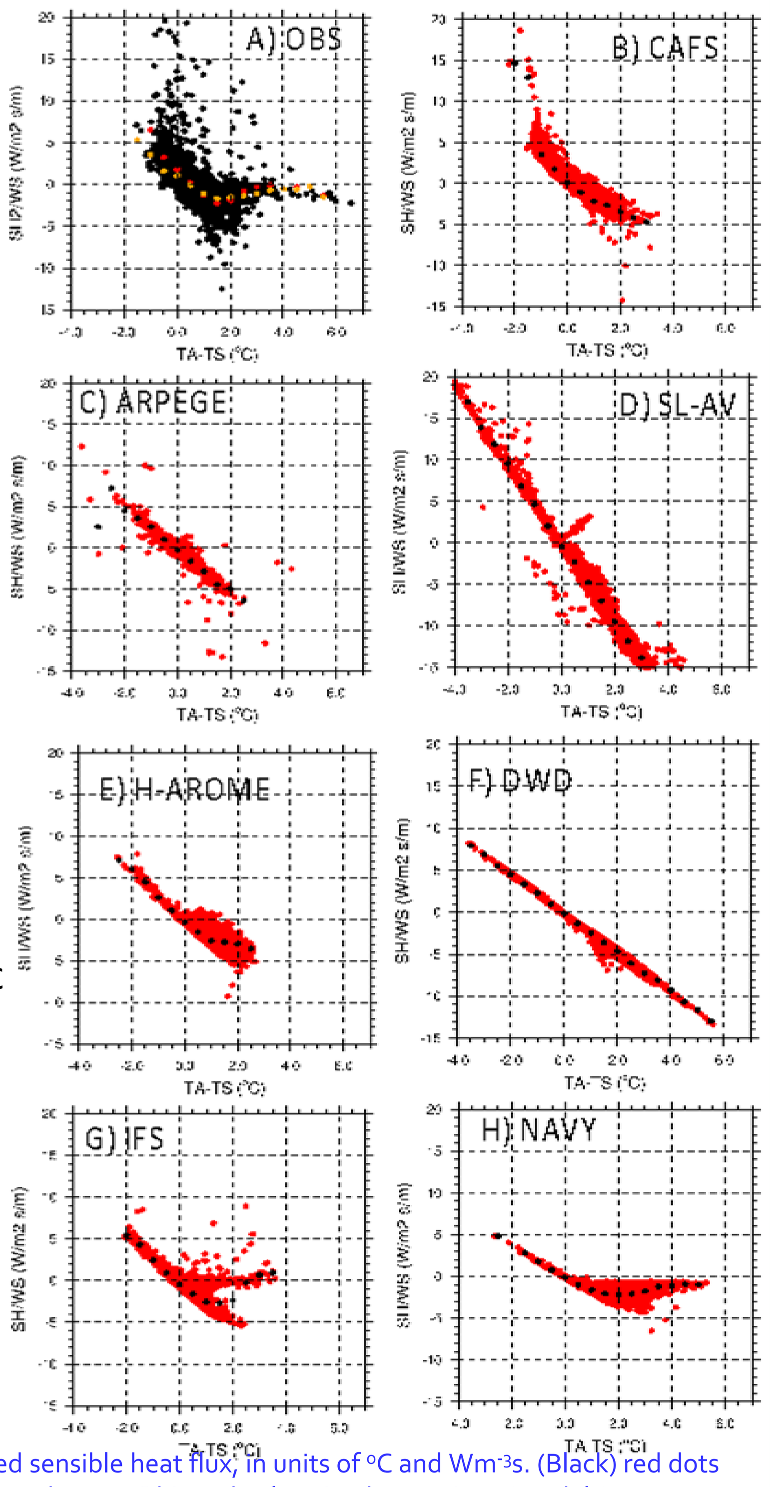


PDFs of hourly wintertime (A,D) ΔT, (B,E) 10-m sensible heat fluxes and (C,F) sensible heat flux minus net longwave surface radiation (an estimate of the net conductive flux) for (A,B,C) clear-sky and (D,E,F) cloudy-sky periods observed during SHEBA (red) and MOSAiC (gray shading shows range over the four MOSAiC sites), in units of °C, Wm^{-2}, and Wm^{-2}, respectively.

Scaled sensible heat flux relative to near-surface thermal stratification

Slope of this relationship is the diagnosed transfer coefficient in the parameterization for the sensible heat flux

- Obs. (A) show sensible heat flux decreases for ΔT > 1.5° and almost shut-off for strongly stably stratified conditions.
- Four models simulate the decrease in heat flux for increasing ΔT.
- Two models have a constant slope AND more occurrences of ΔT > 4°C, which is unrealistic since the parameterization for these models produce larger sensible heat fluxes as stratification increases.
- Only two models produce the near shut-down of the scaled sensible heat flux for strongly stably stratified conditions.

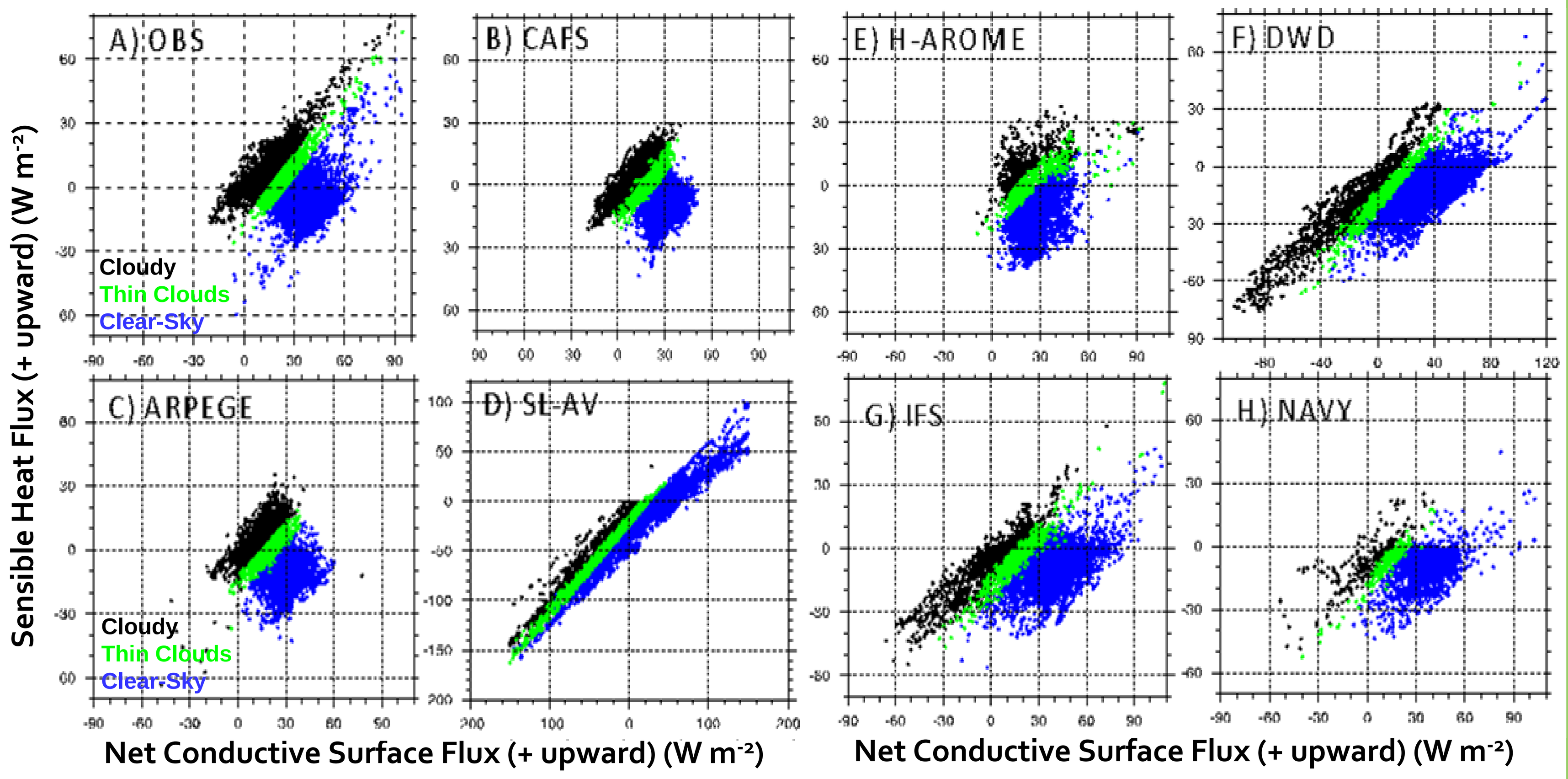


Scatterplot of modeled near-surface ΔT vs. scaled sensible heat flux, in units of °C and Wm^{-3}s. (Black) red dots show the individual samples, (red) black dots show the 0.5 °C binned values in observations (models).

The Surface Energy Budget

Scatterplots of the three terms in the surface energy budget; LWNET [cloudy (black), thin clouds (green), and clear-sky (blue) regimes]; the sensible heat flux on the y-axis; the conductive flux calculated as a residual on the x-axis.

1) **Cloudy conditions**: MOSAiC has limited occurrences with negative (downward) sensible heat flux that coincide with negative (downward) conductive flux, whereas four models have frequent occurrences in this regime, especially models that underestimate the cloudy mode.
2) **Clear-sky conditions**: Large scatter outside observed range for three models that underestimate cloudy mode.
   - o These models produce upward conductive flux >60 Wm^{-2}
   - o Downward sensible heat flux magnitudes > 30 Wm^{-2}
   - o A persistent clear-sky regime pushes the models into an unrealistic balance in the surface energy budget.



Scatterplot of net conductive surface flux vs. sensible heat flux for cloudy skies (black), thin clouds (green), and clear-sky (blue), in units of Wm^{-2}.

Conclusions

- Models struggle to maintain liquid water in clouds at cold temperatures, with only one of seven models producing cloud liquid water similar to observations.
- Only 2 models simulate observed distinct bi-modal clear-sky & cloudy modes.
  - o One model has cloud liquid similar to observations and the other produces enough cloud ice without cloud liquid to produce two distinct modes.
  - o 3 models have distinct clear-sky modes but underestimate the cloudy mode.
  - o Only 2 models produce the observed near shutdown of turbulence for strongly stably stratified near-surface conditions.
- Diagnosis of the three surface energy budget terms, 3 models have variability in regimes with few observed occurrences; clear-skies with large upward conductive surface flux and small sensible heat flux, and large downward sensible heat flux and small conductive surface flux.
- Focused model studies are required to improve these parameterizations in order to produce reliable forecasts of the Arctic system and projections of the role of the Arctic in the climate system

References:

Shupe, MD, et al., 2022: Overview of the MOSAiC expedition: Atmosphere. *Elementa, Science of the Anthropocene* 10 (1). DOI: 10.1525/elementa.2021.00060.

Solomon, A, Shupe, M, Svensson, G, Batrak, Y, Barton, N, Bazile, E, Day, J, Doyle, J, Frank, H, Keeley, S, Remes, T, Tolstykh, M, 2022: An Evaluation of Short-Term Forecasts of Wintertime Boundary-Layer and Surface Energy Budget Statistics in the Central Arctic. Submitted to *Elementa MOSAiC Special Issue*.

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MOSAiC The International Arctic Drift Expedition

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