Nonlinearity of Ice-Water-Air Exchanges: Numerical Simulations of Remotely-Sensed Surface States

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Motivation

- The "New Arctic" is undergoing changes due to the gradual warming of Earth's atmosphere
- These changes include the reduction in Arctic sea ice and creation of leads in early Spring and fractured sea ice in late Spring/Summer
- This changing surface can lead to modifications in the Arctic meteorology, which can spread to lower latitudes

Research Questions

1) How does a single crack or multiple fractures in Arctic sea ice affect an otherwise stable Arctic atmospheric boundary layer (AABL)?
2) What are the characteristics of the convective plumes[1] and secondary circulations generated by the strong thermal contrast between warm sea water and cold Arctic air?
3) How might these processes be represented in large-scale climate models that cannot currently resolve them?

Sea Ice SEB

The surface energy balance (SEB) of the top of the sea ice is represented as a balance of fluxes

$$F_t^{net} = R_{net} + H_t + L_{s,t} + G_t.$$

Terms are defined for the bottom of the sea ice in the same way with a few modifications

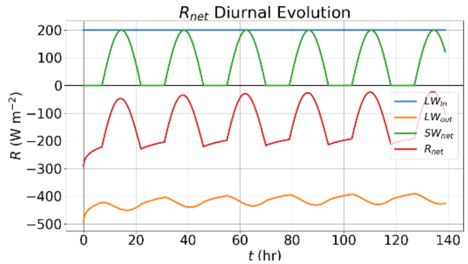
$$F_b^{net} = H_b + L_{f,b} + G_b.$$

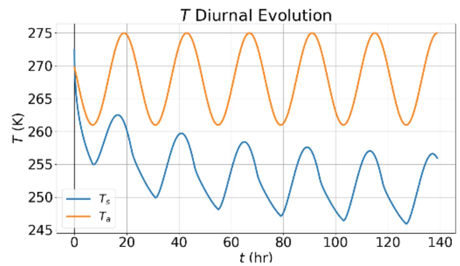
The interior nodes of the ice are solved via the 1D heat equation

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2}.$$

The Crank–Nicolson method is used to solve the heat equation at every time step. After each time step, the SEB is solved using the secant method for a new $T_{i,top}$ to be used in the next iteration.

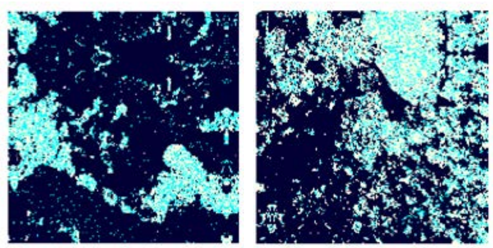
Ice Sheet Model Tests: SEB



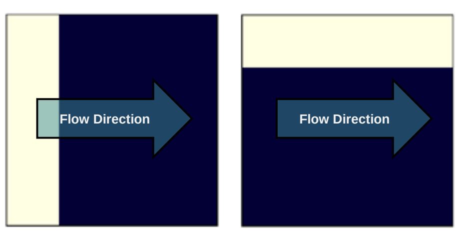


Satellite Imagery

Below are examples of pre-classified 10 km x 10 km images from the Arctic Ocean[2] with cells classified as either seawater, ice, or pond.



Bottom boundary conditions are the focus of these simulations. For a single ice map, two other ideal surfaces can be created (ignoring ponding).



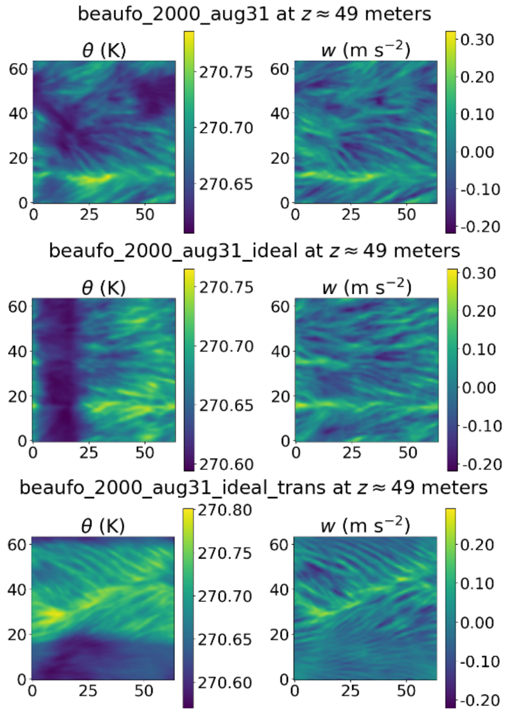
Large Eddy Simulation: Set Up

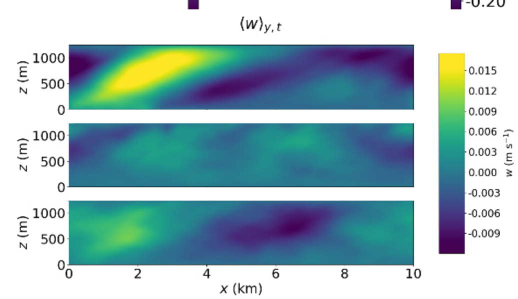
To simulate the atmosphere, we conduct a large eddy simulation (LES), a numerical technique that solves flow equations by resolving the largest eddies and modelling the smaller ones[3]. We utilize LES to model a periodic AABL.

Node Type	z_0 (cm)	T (K)
Water	0.2	274.15
Ice	0.02	270.14

$$u_g = 2.0 \text{ m s}^{-1}$$
$$T_a = 272.15 \text{ K}$$
$$z_i = 1250.0 \text{ m}$$

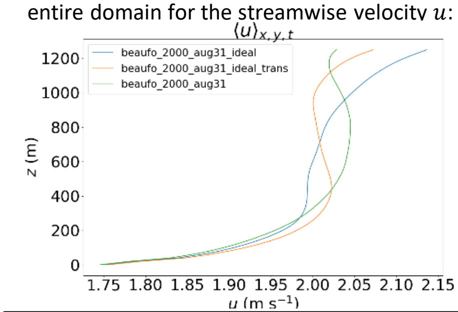
LES: Two-Dimensional Slices





LES: Averaged Flow Profiles

The following is an averaged flow profiles of the entire domain for the streamwise velocity u:

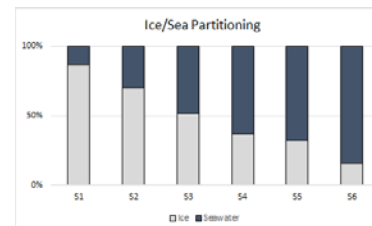


Conclusions

- The sea ice SEB is able to capture the basic processes that occur in the presence of diurnal cycles of temperature and solar radiation
- Different patterns of ice-water at the surface have an impact on the AABL even when the ice-water fractions are equivalent

Future Work

- Further implement in-situ field observations and remotely-sensed temperatures for values in the ice and LES model
- Use LES for different ice/sea partitions/patterns
- Couple the sea ice model with the AABL-LES



References

[1]Alam, Afshan, and Judith Curry. "Lead-Induced Atmospheric Circulations." *Journal of Geophysical Research: Oceans* 100, no. C3 (1995): 4643–51. https://doi.org/10.1029/94JC02562.

[2]Fetterer, F., S. Wilds, and J. Sloan. 2008. Arctic Sea Ice Melt Pond Statistics and Maps, 1999-2001, Version 1. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. https://doi.org/10.7265/N5PK0D32 . July 6, 2019.

[3]Huang, J and E. Bou-Zeid, 2013: Turbulence and Vertical Fluxes in the Stable Atmospheric Boundary Layer. Part I: A Large-Eddy Simulation Study. J. Atmos. Sci., 70, 1513–1527, https://doi.org/10.1175/JAS-D-12-0167.1 .