Shallow Convective Plume Drives Subsurface Mixing in the Seasonally Sea Ice-Covered Southern Ocean

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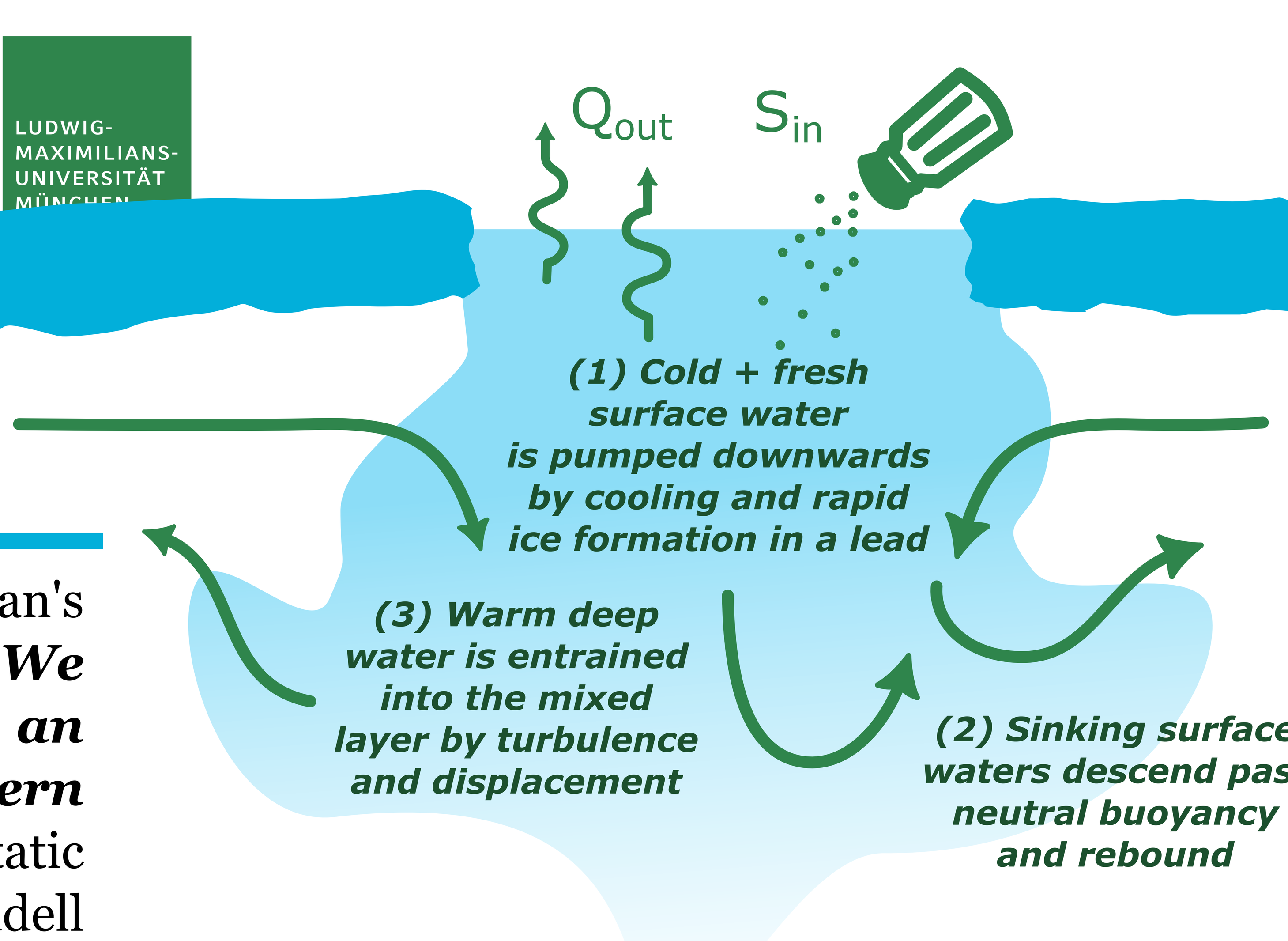
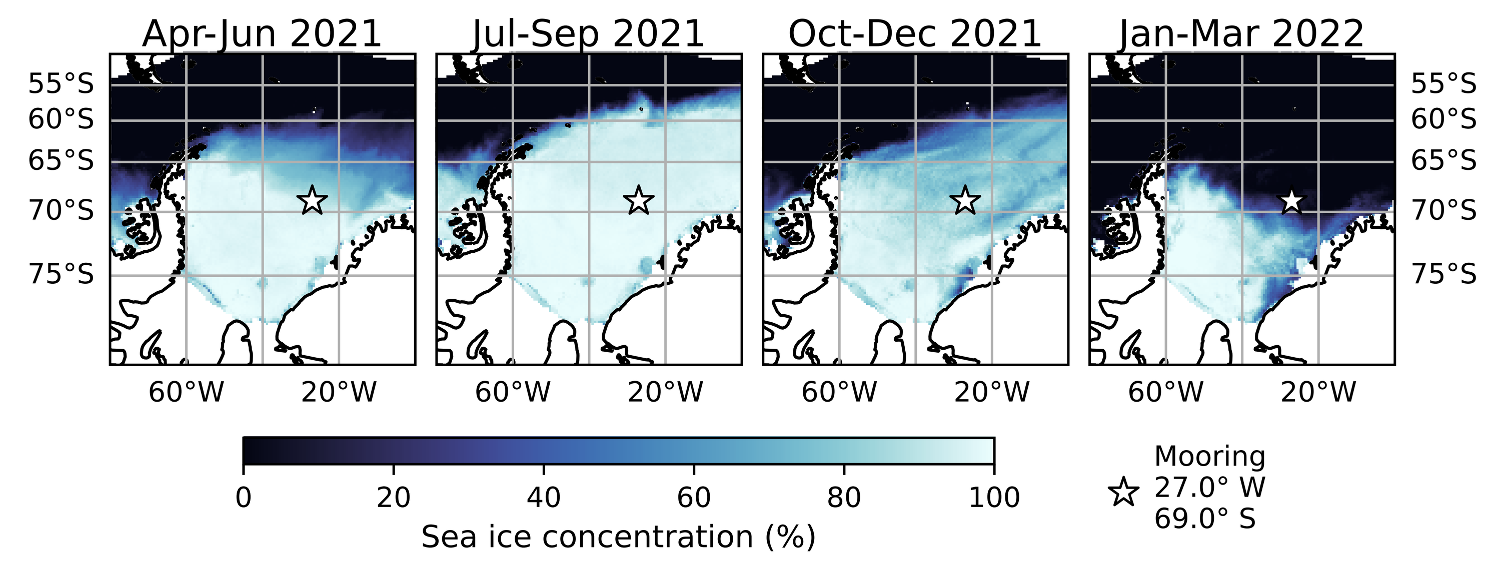


1. Motivation

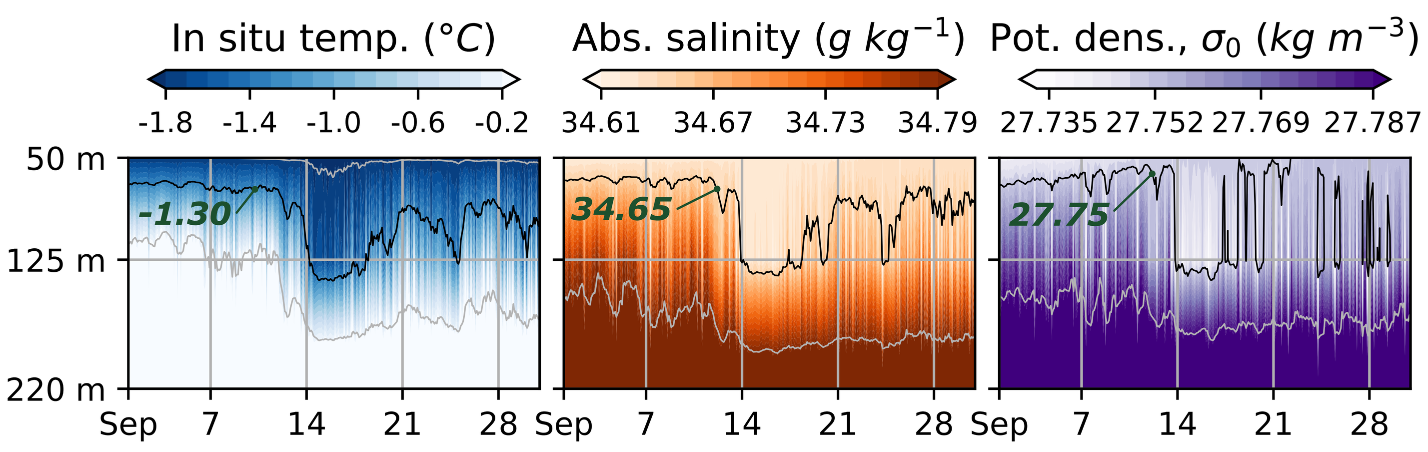
The Southern Ocean is a gateway for approx. 75% of the global ocean's anthropogenic heat uptake [1] and 40% of its carbon dioxide uptake [1,2]. ***We hypothesize that small-scale shallow convective plumes play an overlooked role in setting the water mass structure of the Southern Ocean, thereby influencing the global climate.*** We used a non-hydrostatic numerical model to reconstruct a plume observed by an AWI mooring in the Weddell Sea to investigate its dynamics and effects on the local water mass structure.

2. Weddell Sea mooring

Unique upper ocean mooring located offshore in the seasonally-ice covered Weddell Sea.

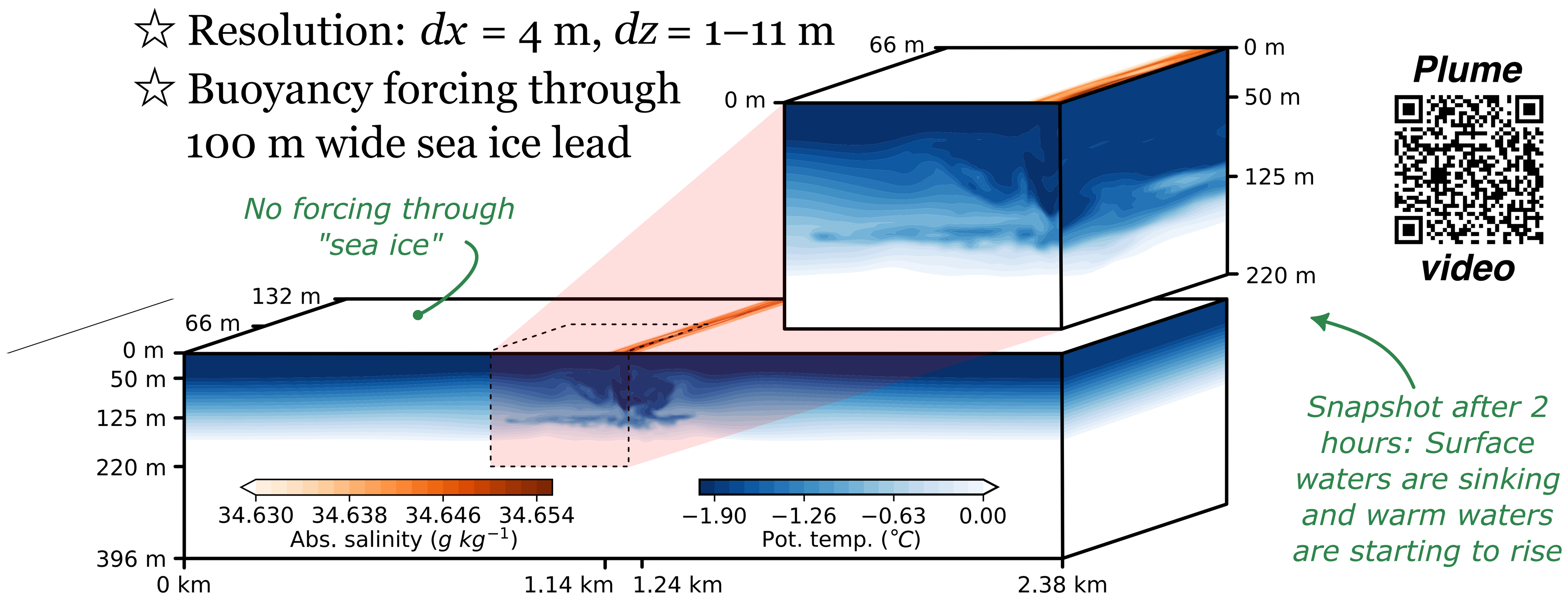


In September 2021, the sea ice concentration at the mooring dropped below 90% [3] after the passage of strong cool winds [4]. Air temperatures fell to -15 °C, driving down cold + fresh surface water due to cooling and salt rejection during ice freezing.

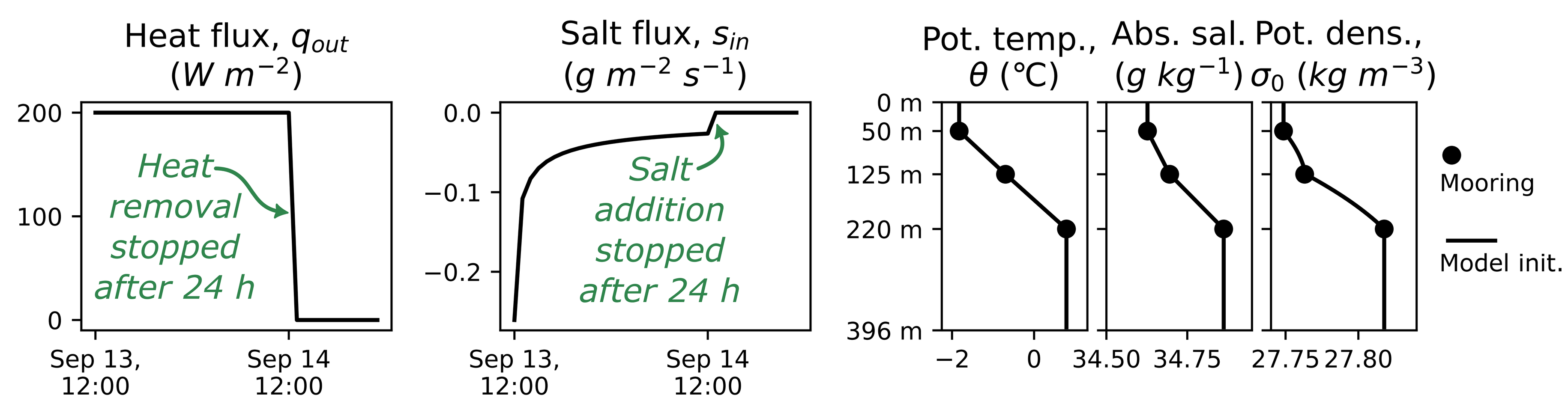


3. Model setup

☆ Non-hydrostatic implementation of MITgcm [5]
☆ Double periodic domain ($l \times w \times d$ = 2.38 km × 132 m × 396 m)
☆ Resolution: dx = 4 m, dz = 1–11 m
☆ Buoyancy forcing through 100 m wide sea ice lead

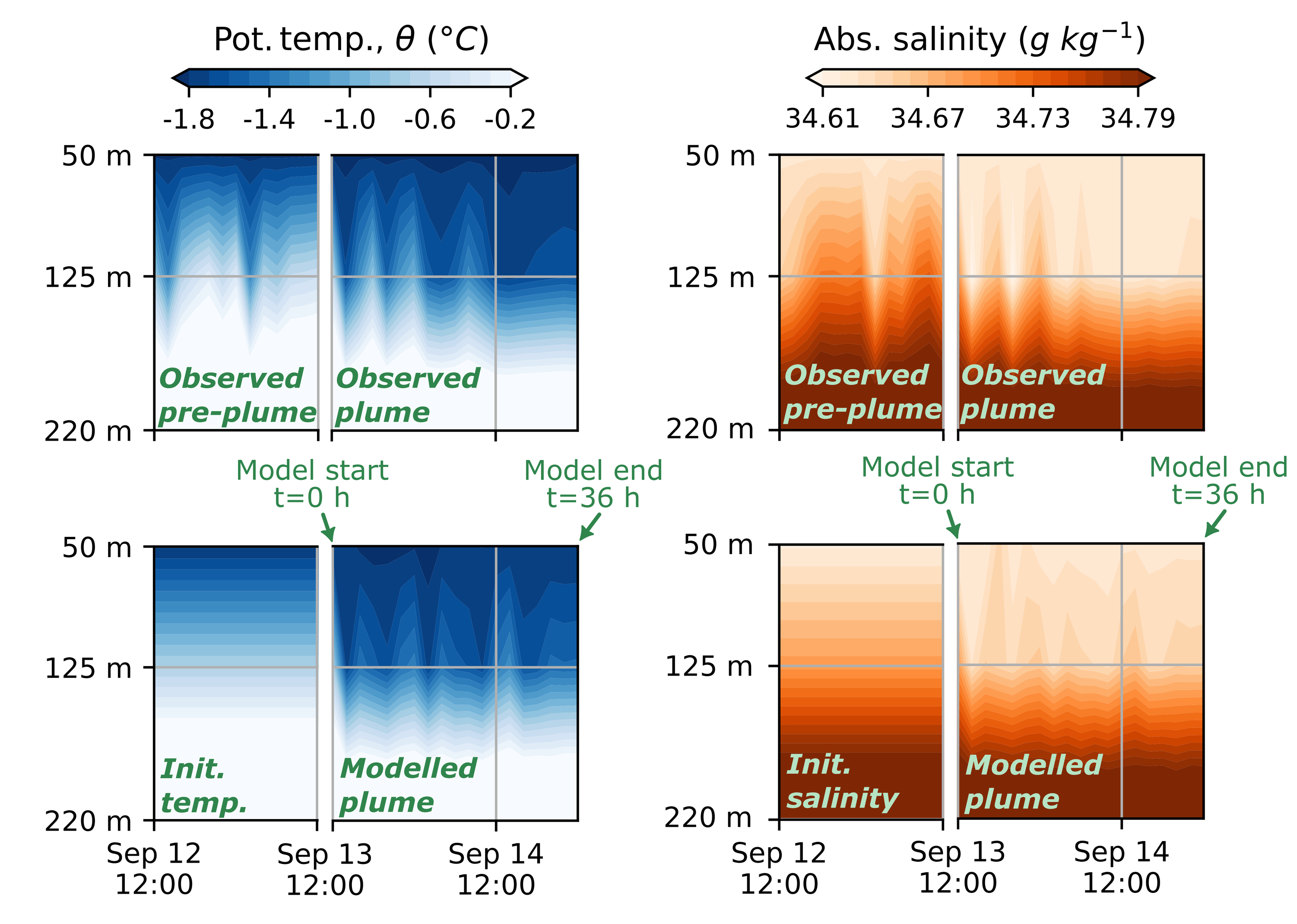


☆ Initial conditions (temperature and salinity profiles) from mooring
☆ Constant heat flux (-200 W m^{-2}), with pot. temp. limited to -1.9 °C
☆ Ice growth and salt rejection following Stefan's law [6]

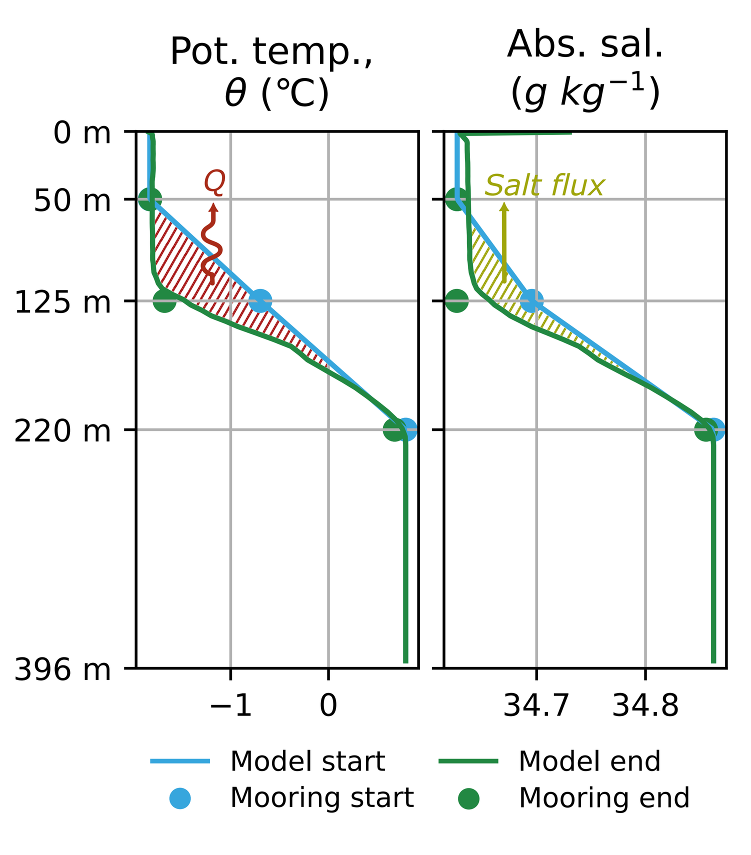


4. Results

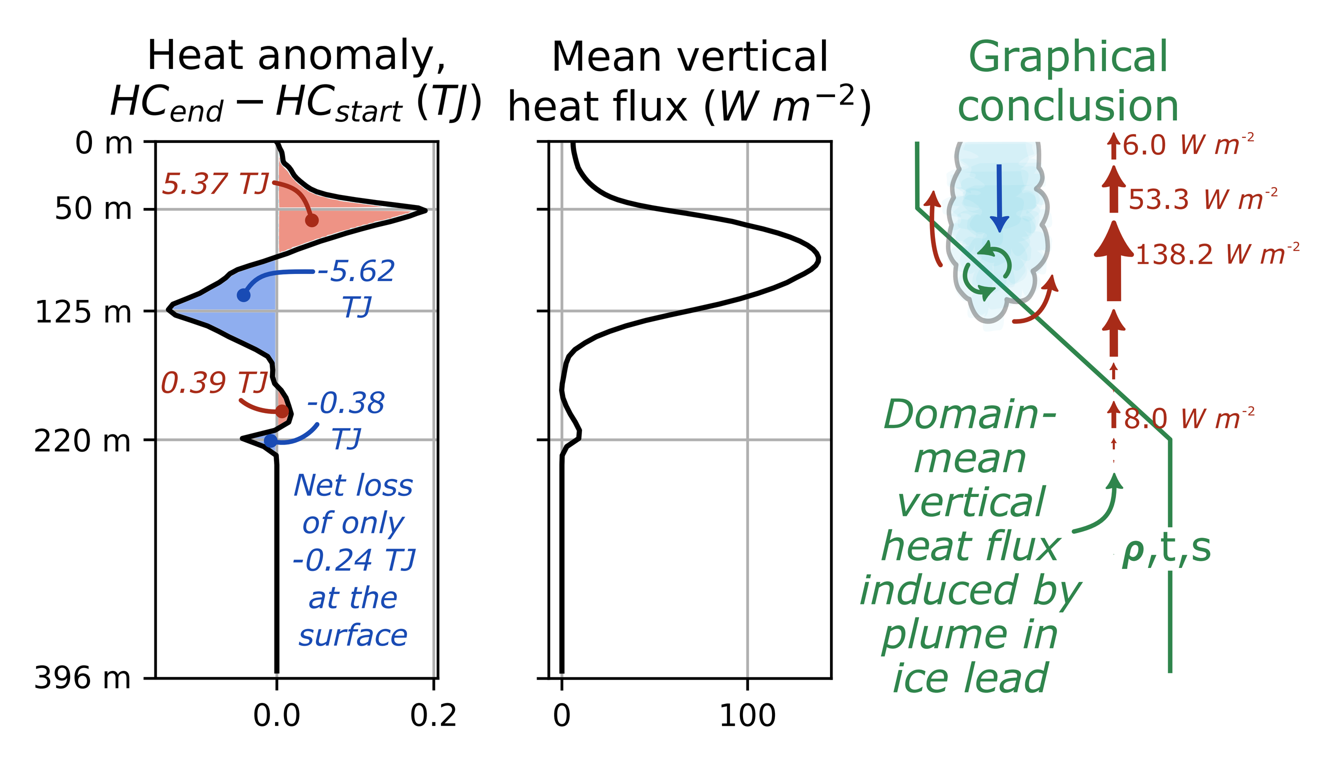
The model was initialised using means from the mooring for 24 h leading up to the plume. Subsequent modelled temperatures and salinities compare well with observations and show rapid plume formation.



The mixed layer under the lead deepened by approx. 75 m, becoming on average saltier and slightly warmer due to entrainment from the thermocline and halocline.



The plume pumped cold + fresh surface waters downward at the sea ice lead, leading to a net increase of heat in the mixed layer (i.e., a downgradient flux of thermocline heat). The resulting domain-mean entrainment heat flux (138.2 W m^{-2} at 88.5 m) was over 25x higher than expected throughout the Weddell Sea [7].



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