Light transmittance and potential solar heating of the ocean water column following record low sea ice extents across the Distributed Biological Observatory in the Pacific Arctic Region

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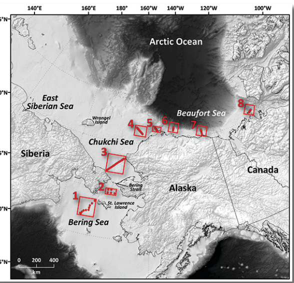
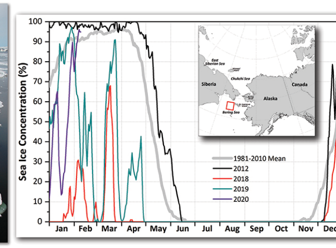
1 Background

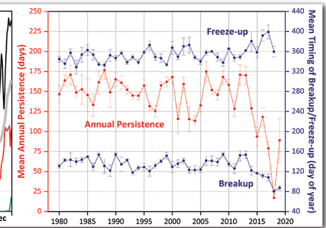
To more systematically track the broad biological response to sea ice retreat and associated environmental change across the Pacific Arctic Region (Frey et al., 2015), an international consortium of scientists have developed a coordinated "Distributed Biological Observatory" (DBO) that includes selected biological measurements at multiple trophic levels. These measurements are being made simultaneously with hydrographic surveys and satellite observations. The DBO currently focuses on five main regional biological "hotspot" locations along a latitudinal gradient in the Pacific Arctic Region from the northern Bering Sea to the northeastern Chukchi Sea, but has recently extended to eight DBO sites overall that extend into the Beaufort Sea. Sites have been occupied by national and international entities with a shared data plan since a successful pilot program began in 2010-2011. DBO sites (red boxes below) are the regional "hotspot" transect lines and stations located along the latitudinal gradient, with the Canadian Coast Guard Ship (CCGS) *Sir Wilfrid Laurier* cruises that have taken place each year in July the only mission that collects data at all five DBO sites synoptically (over a ~10-day time period).



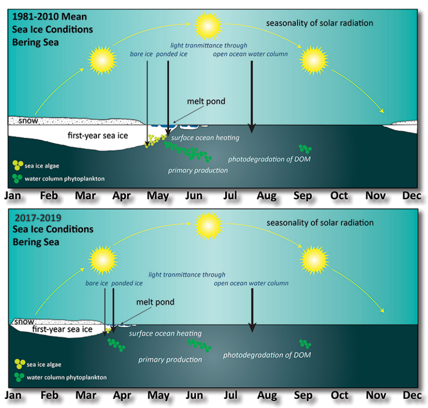
2 Motivation

Sea ice in the Bering Sea has shown unprecedented declines over the past ~6 years, as evidenced by shifts in the annual persistence as well as the timing of breakup/freeze-up of sea ice cover. In particular, annual sea ice persistence varied without obvious trends in the St. Lawrence Island Polynya (SLIP) region (DBO1) for the length of the passive microwave satellite record (SMMR, SSM/I, SSMIS) until 2012, when precipitous declines in sea ice cover began. The low seasonal sea ice extent at DBO1 in 2018 is apparent below, which is juxtaposed against 2012 as an example endmember year of highly extensive sea ice cover throughout the region (Frey et al., 2018, 2019; Grebmeier et al., 2018).





3 Conceptual Framework



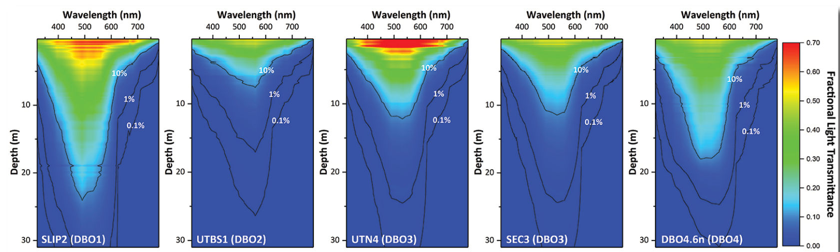
The transmittance of solar radiation through sea ice and the open ocean water column is extremely important for numerous biophysical processes, including surface ocean heating, primary production, and biogeochemical processes such as the photodegradation of dissolved organic matter (DOM). In the Bering Sea, sea ice typically forms in December and breaks up in May through early June. In addition, melt ponding on sea ice surfaces is an important process as sea ice begins to melt through the season.

The temporal extent of sea ice in 2017-2019 was much shorter than normal, forming later and breaking up earlier throughout the region. Although the seasonality of sea ice cover has shifted throughout the region, the seasonal inputs of solar radiation is constant. This raises important questions about how the Bering Sea ecosystem will respond to a shifting relationship between the seasonality of solar radiation and sea ice cover, in particular as it relates to surface ocean heating, the timing and rate of seasonal primary production, and the photodegradation of DOM.

4 Optical Profiles

We present a subset of observations of downwelling irradiance profiles in the top ~30 meters of ocean waters, collected at numerous sites in the northern Bering and Chukchi Seas. Profiles were collected during July 2018 and 2019 as part of the DBO program onboard the CCGS *Sir Wilfrid Laurier*, and represent a first report on the optical consequences of the extremely low sea ice year observed in 2017–2018. The profiling radiometers collected measurements with 19 channels (320, 340, 380, 395, 412, 443, 465, 490, 510, 532, 555, 560, 625, 665, 670, 683, 710, and 780 nm, as well as photosynthetically active radiation (PAR)), with concurrent measurements made by a surface reference radiometer with identical channels to allow for the calculation of fractional light transmittance through the water column.

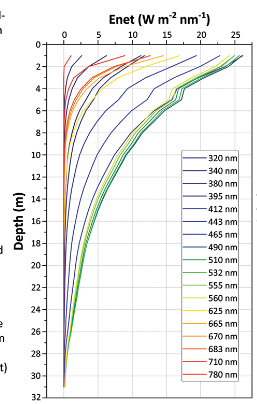
Below are examples of optical profiles across a latitudinal gradient for DBO1-4, with isolines of 10%, 1%, and 0.01% light levels highlighted to facilitate comparison. As of late July, DBO1 had been sea ice free for nearly four months (several months longer than a typical sea ice year) and light transmittance was relatively high through the water column. Moving northward, sites exhibited varying levels of light transmittance owing to the presence of light-absorbing impurities in the water column (e.g., phytoplankton, suspended particular matter, and dissolved organic matter). The melt progression of sea ice cover and resulting surface characteristics of sea ice also greatly impact the amount of light transmittance through to the underlying ocean water (e.g., Frey et al., 2011).

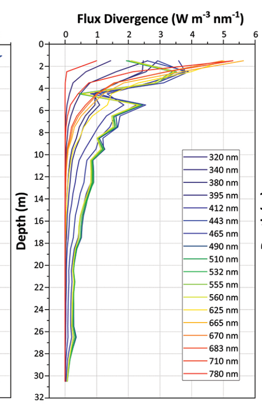


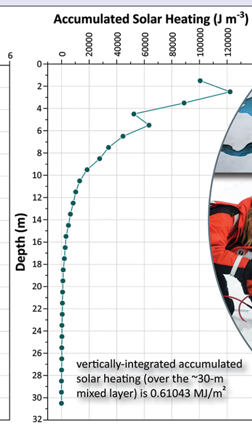
5 Solar Heating

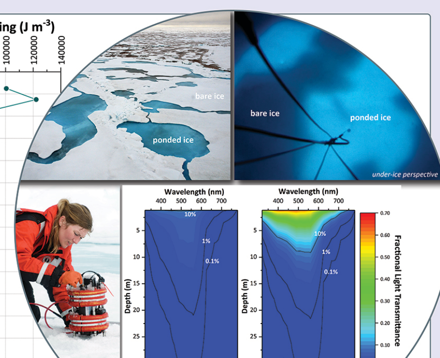
Here, we illustrate the feasibility of calculating instantaneous solar heating in the water column (at station SEC3) based on a simple radiative transfer model that ingests our observed optical profiles. Enet (estimated using downwelling irradiance and upwelling radiance) is first used to compute flux divergence (the energy absorbed) at 1-m layers through the water column. Once the flux divergence is integrated across all wavelengths, accumulated solar heating can be estimated (in this case, we estimated this over a one-hour period). For SEC3, the vertically-integrated accumulated solar heating (over the surface ~30-m mixed layer) is 0.61043 MJ/m².

Important to note is that all light that enters the water column will be absorbed, but the ability to model where in the water column this occurs (driven by light-absorbing impurities, sea ice cover/melt ponding etc.) (inset at right) is critical and can be highlighted through these methods.









Transmittance of Light Through Bare Sea Ice vs. Ponded Sea Ice
Optical profiles have also been collected at numerous sites in the Chukchi Sea as part of NASA's ICESCAPE mission and show that on average, ponded ice allows for the transmittance of ~60% of PAR through the sea ice medium compared to ~15% through bare sea ice. As such, ponded sea ice surfaces acts as "skylights" and are incredibly important for light-sensitive processes such as surface ocean heating and primary production beneath the sea ice cover (e.g., Frey et al., 2011).

Acknowledgements

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