# Seasonal and Spatial Variability of Light Transmission Through Sea Ice

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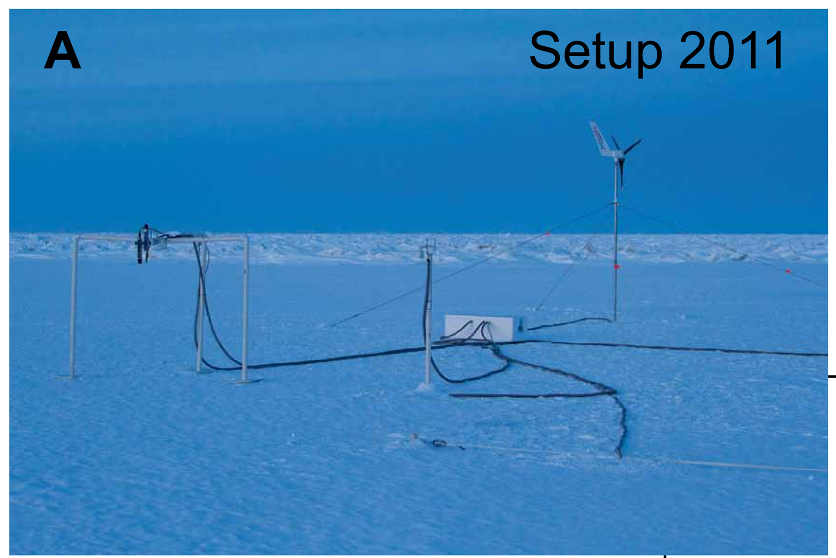
## Abstract

The amount of solar light transmitting through snow and sea ice is of critical importance for various **physical and biological processes** related to sea ice and the uppermost ocean. The vertical partitioning of short-wave radiation between atmosphere, snow, sea ice, and ocean affects freezing and melting at the sea-ice bottom as well as the timing and amount of biological primary production. At the same time, observations of light transmittance through sea ice are still sparse, because the under-ice environment is difficult to access and high quality measurements are challenging in the harsh polar environment. In addition, it is necessary to perform accurate **spectral measurements** to distinguish the influences of **snow and sea ice thickness, sediment, and biota** on under-ice irradiance.

Here we present results from field campaigns in 2007 and 2010 where we measured spectral irradiance (350 to 920 nm) above and below Arctic sea ice, co-located with physical ice and snow properties. Time series over several months highlight the **seasonality** of light penetrating snow and sea ice and suggest high biomass abundance below the sea ice during summer, absorbing a significant amount of light during photosynthesis. Horizontal transects of spectral irradiance measurements under sea ice reveal the **spatial variability** of light conditions as a function of snow cover, sediment load, and biomass.

## Setup and Instrumentation



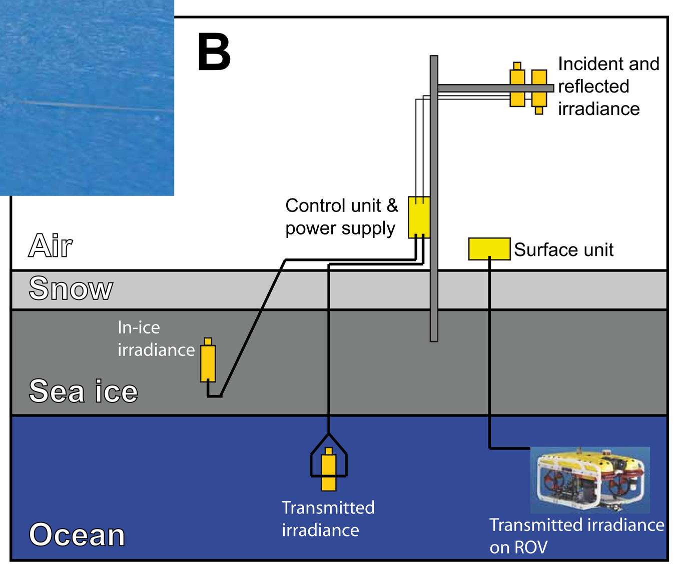




**Figure 1:** (a) Photograph and (b) schematic of the spectral raditation station on fast ice off Barrow, Alaska (see also Nicolaus et al., 2010a).

**RAMSES Advanced Cosine Collector**
- Spectral range: 320 to 950 nm (3.3 nm resolution)
- 256 chan. photodiode array (incl. dark current)
- Pressure and inclination module option
- Waterproof (to 300 m) stainless steel casing



**Figure 2:** (a) Sensor mounted on under-ice sled for transmittance measurements (b) under-ice sensor in operation.

## Seasonal Variability

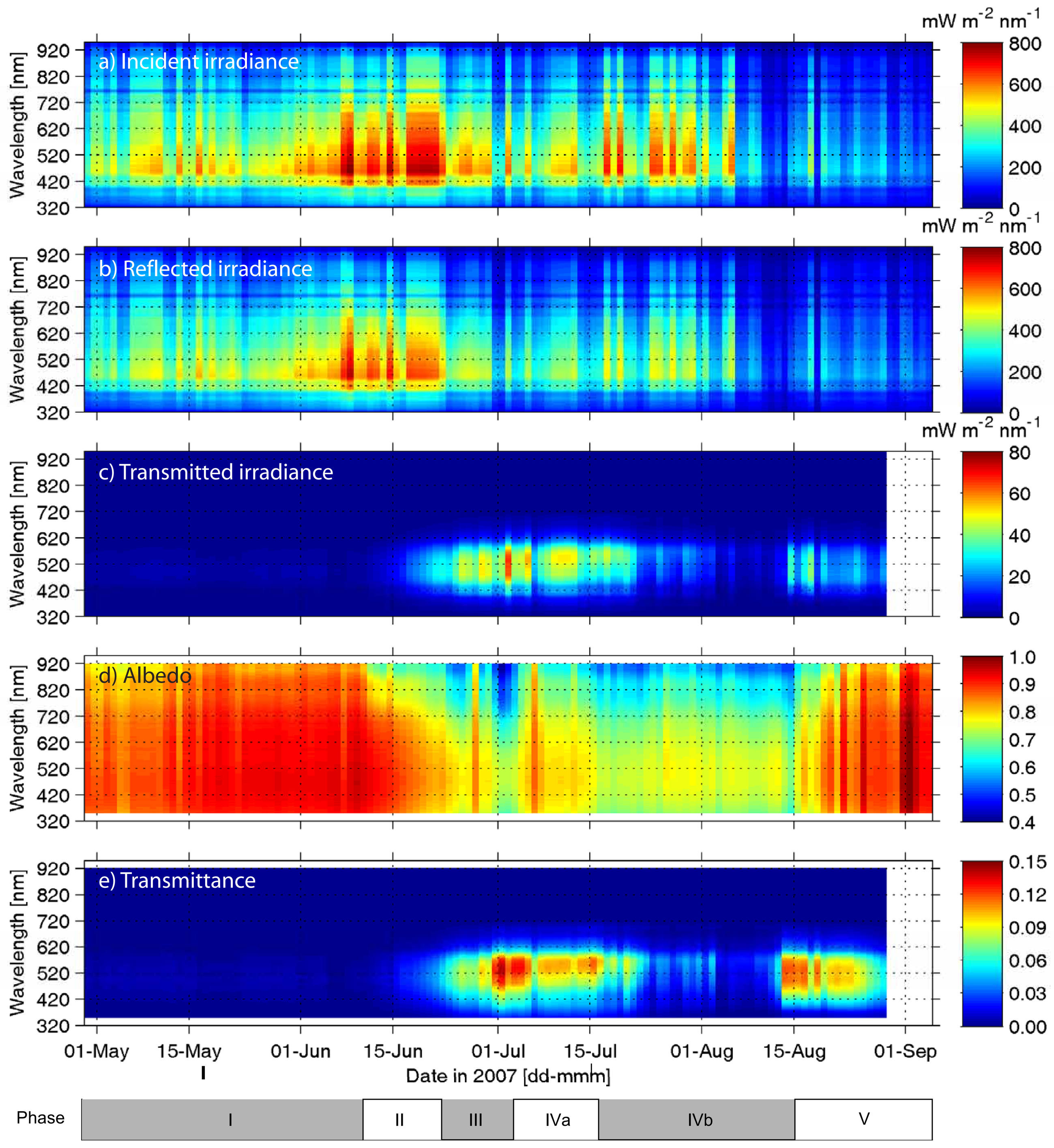



**Figure 3:** Time series (one spectrum per day) of (a) incoming, (b) reflected, and (c) transmitted spectral irradiance, (d) spectral albedo, and (e) spectral transmittance measured in the Central Arctic at Tara 2007 (from Nicolaus et al., 2010b). As the under-ice sensor had to be retrieved on 28 Aug., no transmitted data are available afterwards.

## Spatial Variability

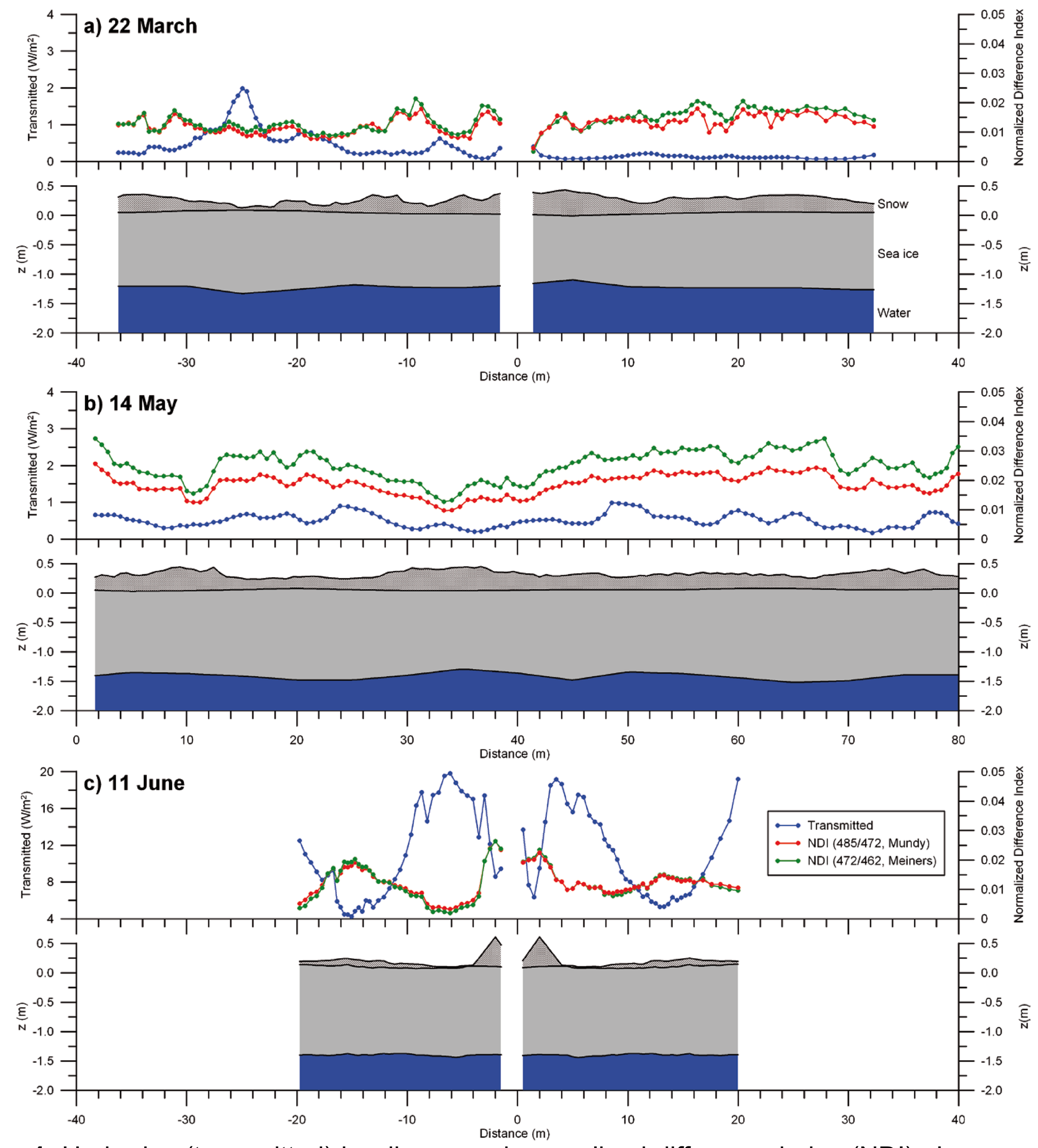



**Figure 4:** Under-ice (transmitted) irradiance and normalized difference index (NDI) along profiles on first-year fast ice off Barrow, Alaska, on (a) 22 March, (b) 14 May, and (c) 11 June 2010. In March and June, two transects were performed away from the same access hole (x=0) and are considered as one profile each. The NDIs are calculated as suggested by Mundy et al. (2007) and K. Meiners (pers. comm.). Note the different scaling of transmitted irradiance in (c).


**Figure 3:** Seasonal changes of surface conditions at the radiation station on Arctic multi-year ice in 2007 (from Nicolaus et al., 2010b). All photos were taken by Tara crew members and post-processed by the authors.

## Summary and Perspectives

**The autonomous station** performed well under the challenging climatic conditions and allowed observations with minimal maintenance. The combination of optical and ice-mass-balance data is most beneficial and allows comprehensive descriptions of snow and sea-ice processes, even with minimal additional in-situ observations (Nicolaus et al., 2010a and 2010b). Ongoing observations will include **real-time data** access and developments towards a **buoy system**. This will allow for more remote and unmanned data acquisition and increase flexibility to facilitate collaborative research campaigns.

Under-ice measurements with a **remotely operated vehicle** (ROV) resulted in one of the first under-ice transects of this kind. Further developments will enable studies of under-ice irradiance over larger areas, including various sea-ice and snow characteristics.

The **seasonality** of physical and biological processes of snow and sea ice can be characterized based on time-series of spectral albedo and transmittance. It was found that 2/3 of the transmitted energy reached the ocean during a 66-day long melting season. During the second half of July, transmitted irradiance decreased by 90%, most likely related to biological activity.

Transect measurements of transmitted irradiance allowed to quantify **spatial variability** of under-ice irradiance and optical properties of snow and sea ice. The snow cover dominated the amount and variability of under-ice irradiance. Light levels under sea ice varied by a factor larger than five. The analysis of normalized difference indices (NDI) indicates a large variability of biomass in the sea ice and at its base.

**Further data processing** and including more in-situ observations, particularly of biological parameters, are expected to allow **quantification of biomass** and biological processes with respect to their seasonal cycles and spatial variability.

## References

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## Acknowledgements

We strongly acknowledge the support of the *Tara Arctic* project, which enabled the measurements in the Transpolar Drift in 2007. Great thanks to Timo Palo (University of Tartu, Estonia, and Tara crew), who was heavily involved in maintaining the station and documenting changes. Hajo Eicken and his colleagues from the University of Alaska Fairbanks are thanked for their support and valuable contributions to the measurements in Barrow. This study was funded through the DAMOCLES project, financed by the European Union, the SIZONET project, financed by the National Science Foundation, and the AMORA project, financed by the Norwegian Research Council.

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Gordon Research Conference, Ventura, USA, 20 – 25 March 2011