TNA User Report

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Project title	Optical properties of first-year sea ice under formation and decay conditions
Name of the accessed chamber	Roland von Glasow – Air, Sea, Ice Chamber
Number of users in the project	1
Project objectives (max 100 words)	The aim of the project was to to gain important insights into the physics of radiation transfer within young sea ice and to test newly developed instruments for light measurements in sea ice for their potential use in the field. In the RvG-ASIC they were to obtain the in-ice irradiance at different depths in artificially grown sea ice. The change of irradiance in the ice was to be monitored during one or more cycles of freezing and melting of the ice layer.
Description of work (max 100 words):	To measure the light profile in the ice during two freeze and melt cycles a set of new sensors were left to freeze into the ice. Each of the eight sensor sticks was installed at a different height in the tank, so that one stick remained above the ice surface and the rest were frozen in at 2.8 cm intervals. Six optical fibres were installed as well to measure the albedo and transmission through the ice as well as provide reference measurements for the new sensor sticks.

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1 Physics; Chemistry; Earth Sciences & Environment; Engineering & Technology; Mathematics; Information & Communication Technologies; Material Sciences; Energy; Social sciences; Humanities.

2 UNI= University and Other Higher Education Organisation;
RES= Public Research Organisation (including international research organisations and private research organisations controlled by public authority);
SME= Small and Medium Enterprise;
PRV= Other Industrial and/or Profit Private Organisation;
OTH= Other type of organization.

3 UND= Undergraduate; PGR= Post graduate; PDOC= Post-doctoral researcher; RES= Researcher ENG= Engineer; ACA= Academic; TEC= Technician.

4 Reproduce the table for each user who accessed the infrastructure

Trans-National Access (TNA) Scientific Report

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Instructions

Please limit the report to max 5 pages, you can include tables and figures. Please make sure to address any comments made by the reviewers at the moment of the project evaluation (if applicable, in this case you were informed beforehand). Please do not alter the layout of the document and keep it in Word version.
The report will be made available on the eurochamp.org website. Should any information be confidential or not be made public, please inform us accordingly (in this case it will only be accessible by the European Commission, the EUROCHAMP-2020 project partners, and the reviewers). Please include:

- Introduction and motivation
- Scientific objectives
- Reason for choosing the simulation chamber/ calibration facility
- Method and experimental set-up
- Data description
- Preliminary results and conclusions
- Outcome and future studies
- References

Name of the PI: Verena Hof
Chamber name and location: RvG-ASIC, University of East Anglia, Norwich, UK
Campaign name and period: Optical properties of first-year sea ice under formation and decay conditions, January 8th - 22nd 2018
Text:

Introduction and motivation

Arctic sea-ice is currently retreating rapidly (e.g. Perovich, 2011; Nicolaus, 2012). To quantify the impact of this retreat on the energy balance of our planet, we need a better understanding of the optical properties of sea ice and the way light is transferred into or through the ice.
The main motivation of our study lies in the fact that the distribution of solar radiation between the sea ice cover, the ocean and the atmosphere governs the Arctic energy balance and hence the evolution of sea ice (Light, 2008; Arndt, 2014). The sea ice itself is a key driver of this distribution, as its optical properties determine how much of the incident solar energy is reflected, transmitted or absorbed, i.e. how much light can reach the ocean water below or is available for primary production within the ice and internal heat storage (Hunke, 2011; Katlein 2015). Based on our measurements, we can better inform and plan upcoming field projects, and develop parameterisations for large scale models that allow for a more realistic simulation of the energy budget in high latitudes. As such, the experiments in the Roland von Glasow Air-Sea-Ice chamber have large potential for follow-on work, both by us and by the sea ice research community as a whole. Greater knowledge of the physics of the young ice pack and how heat is transferred will also be of great interest to the shipping community as the Arctic opens up for potentially year-round shipping lanes. In addition, knowledge of the optical properties will allow photochemical modellers to determine how rapidly sea-ice acts as a photo-reactor, potentially emitting photo-produced species such as NOx to the atmosphere.

Scientific objectives

Our study aims primarily at examining young sea ice in the Roland von Glasow Air-Sea-Ice chamber due to the current transition in Arctic sea ice from a primarily thick multi-year ice cover, to much thinner seasonal first-year ice with different optical properties (e.g. Nicolaus, 2012).
In the past, optical properties of sea ice have mostly been measured from above or below the ice, rather than within the ice (Grenfell, 1977; Perovich, 1998). The few measurements that tried to get information on the vertical structure of extinction coefficients in the ice were usually carried out on extracted ice cores, which are not necessarily representative for the properties of the floating ice pack (Light, 2008; Perovich, 1998). In the project "Optical properties of first-year sea ice under formation and decay conditions" we are using newly developed instrumentation to measure directly from within the ice itself the optical properties of sea ice during an ice growth and melt experiment. Light intensities at several depths in the ice layer can be measured at all times providing a continuous profile of the distribution of solar radiation in the ice.

Reason for choosing the simulation chamber

The Roland von Glasow Air-Sea-Ice chamber provides an ideal facility to grow artificial sea ice under controlled external conditions and to understand the occurring changes in the optical properties of the ice. Such knowledge will allow us to develop new large scale parameterisations of the light transfer in sea ice and to more robustly interpret field measurements which are planned as a follow-up to the work suggested here. The 1 x 1.4 x 2m glass tank in the RvG-ASIC allows us to grow sea ice of 20 to 30 cm thickness at any chosen temperature between 0°C and -40°C. Our sensors are frozen into the ice and this way allow us to observe the ice in microphysical detail during a growth and melt cycle. This is a challenging task in the field owing to limited accessibility, power supply, safety and control of the experiment. Instrumentation employed in Arctic environments has to be very robust to withstand the cold temperatures and possibly high mechanical stress. Simple, power-saving electronics are desirable to ensure long measurement periods without the need for maintenance.

Method and experimental set-up

To serve this purpose, new instrumentation has been developed by Leif Riemenschneider from the Max Planck Institute for Meteorology in Hamburg, Germany. A set of instruments consists of eight rectangular sensor sticks (3 x 1.2 x 1.3 cm) of epoxy resin containing four photo-diodes and one temperature sensor each.

Figure 1: Light stick

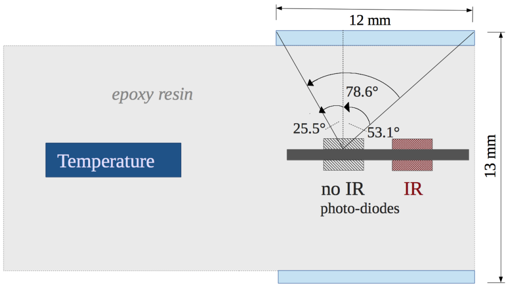

Figure 2: Internal structure of the light sticks

Two of the diodes are looking upwards and two downwards each (see figure 2) measuring the amount of light coming from above and below in the ice. In the following they will be referred to as "light sticks". They were fixed at different heights on a stand and slightly shifted from each other in the horizontal to avoid shading each other (see figure 3). A suite of five fiber optics connected to Ultraviolet (UV) and visible light (Vis) Spectrometers was also installed vertically in the water measuring the incident light at the fibre tips. Three of the fibers plus an extra one above the surface were used to measure the albedo of the ice and the transmission of light through the ice layer (see figure 4). The remaining two fibers were installed to serve as reference measurements to the new light sticks. The light source in the RvG-ASI chamber consists of eight LEDs made by BLM Horticulture, US. To minimize possible directionality of the light field a diffusing 3 mm polycarbonate sheet was mounted right underneath the lights. A spectral radiometer providing irradiance measurements integrated over a hemisphere was used to calibrate the fibre optics and the light sticks in this setup. To be able to model ice thickness and solid fraction, a set of temperature sensors was added to the setup, providing a temperature profile through the ice at a resolution of 1 cm in the upper most 10 cm, 2 cm down to 15 cm depth and 4 cm up to 25 cm deep into the ice (see figure 4).

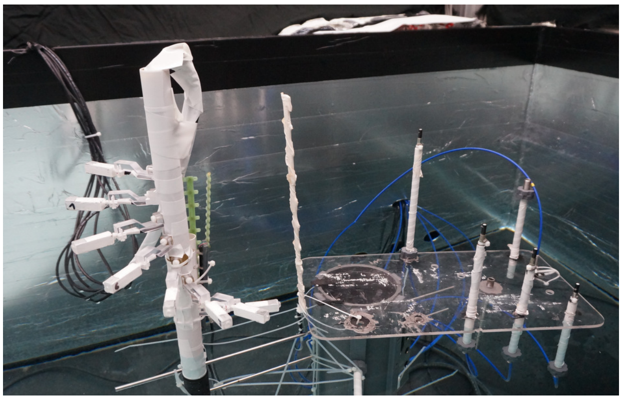

Figure 3: Experiment setup in the tank

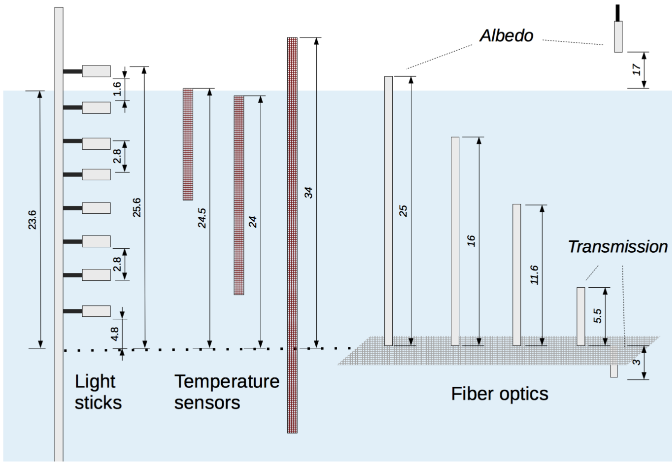

Figure 4: Schematic of experiment setup in cm, not to scale

Four experiments at different freezing temperatures were run in the RvG-ASI Chamber.
Each experiment started with a freezing phase at a constant air temperature.
Pumps at the bottom of the tank ensured a continuous mixing of the water and prevented any thermal stratification. Heating pads in the walls of the tank kept the ice layer from freezing to the tank sides which would create higher pressure in the water underneath the ice. Two cameras recorded the visual progress of the experiments from above and below the ice surface. After an ice thickness of approx. 18 cm was reached the air temperature was changed to -2°C to replicate a warming period. When the ice warms, the brine fraction of the ice increases and the internal structure starts to change, affecting the optical properties of the ice cover (Hunke, 2011; Light, 2003). With the light sticks and the fiber optics we hope to continuously monitor these effects, spatially resolved over the entire depth of the ice cover.
For a day the ice was left to acclimatize so that the whole ice pack had the same temperature as the air. Then the melting phase was initiated at +2°C, after a day the ice cover was melted so far that it became perforate and broken and the experiment was ended.

Experiment	Freezing temperature	Duration of freezing	Notes
1	-20°C	7 days	- Brine layer on the surface
2	-30°C	6 days	- Frost flowers on the surface
3	-10°C	16 days	- -
4	-20°C	8 days	- Data gap of 1.5 days - Step-wise temp increase each day after day 8

Table 1: Overview of experiment conditions

Data description

All light sticks are recorded by a controller and can be read out manually after the experiment or continuously via a USB to Serial Port Adapter. The fibre optic data is recorded via the respective spectrometers and saved in .txt files. Several corrections have to be applied to the fibre optic and the light stick data before analysis. This has not been possible yet due to complications in the calibration procedures and lack of time.

In figure 5 the raw downward light intensity measured by the upward looking photo-diode of each stick is displayed relative to the initial intensity measured at the start of each experiment. The colors refer to a different stick each and hence the light at different depths. The height of the sticks is relative to the ice surface, i.e. +1.4 cm stands for the stick in the air above the surface, -1.4 cm is the first stick frozen into the ice by 1.4 cm, -4.2 cm stands for the second stick under the surface and so on. Once the freezing has started, a fast drop in light intensity is measured by all sticks below 1.4 cm in the ice. The uppermost stick above the surface (dark blue line on top) expectedly does not show a decrease in light intensity. The second stick (dark green line) is still very close to the surface and therefore subject to numerous refraction and scattering events.
All sticks react very sensitively to changes in the light field, e.g. scratching off frost flowers on day 4 and 6 of experiment 2 shows abrupt steps in the intensity of all sticks. As does an artificial snowfall event on day 10 of experiment 4 when snow was collected from outside and distributed on the ice. The sudden decrease in light intensity to 10% of the initial value can be explained by the very high extinction coefficient of fresh snow (Massom, 2001; Thomas, 1963).
Figure 6 shows the raw upward traveling light intensity which is measured by the downward looking photo-diodes in the sticks. It increases in this case with growing ice thickness as each stick which is frozen in receives more light from below due to enhanced backscattering. The actions during experiment 2 and 4 also show quite distinctly in this data.
All the diodes in both directions react almost instantly to the start of the artificial warming period at -2°C which followed the respective freezing periods as noted in table 1. Especially sticks closer to the surface show a distinct change in the measured light intensity. The upward facing photo-diodes experience a sudden rise in intensity as the brine volume increases making the ice more translucent. The downward facing diodes perceive less light from below due to decreased backscattering.
The fiber optics show a similar response overall, the sudden changes in light intensity during the frost

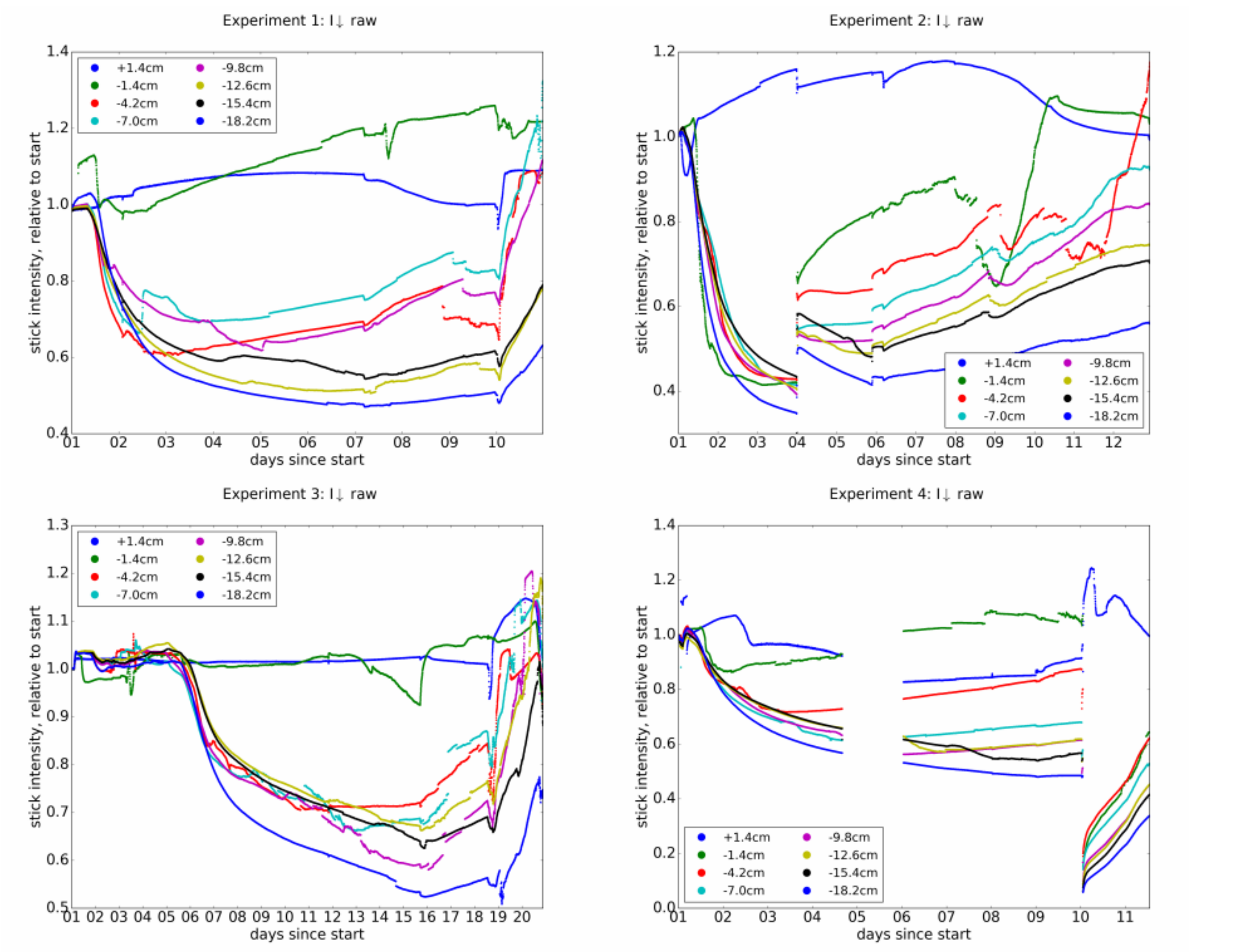

Figure 5: Light stick raw data, downward intensity relative to initial intensity measured. Heights relative to ice surface

flower removal and artificial snow event are even more distinct here (see figure 7). The blue line denoted “albedo” refers to the fiber optic which was fixed above the ice looking down onto the surface, whereas “down” represents the lowest fiber optic, which was also installed looking downwards to give a reliable measure of the radiation which travels upward from the bottom of the tank (see schematic in figure 4). The fiber at 12 cm depth seemed to be faulty during the second half of experiment 2 and the whole of experiment 3.

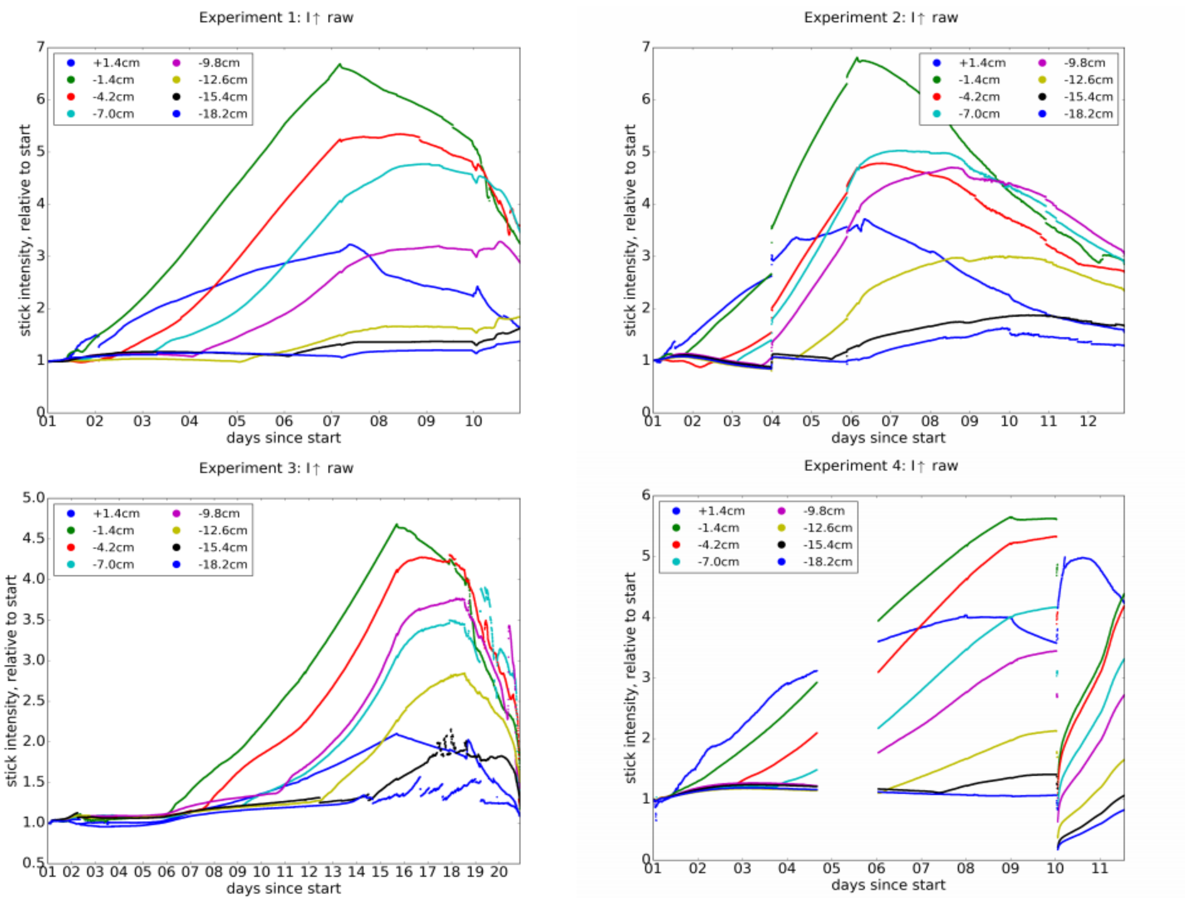

Figure 6: Light stick raw data, upward intensity relative to initial intensity measured. Heights relative to surface.

Figure 7: Fiber optic raw data, intensity relative to initial intensity measured. Heights relative to ice surface.

Preliminary results and conclusions

The raw data already gives us valuable information about the light field and the optical properties within an artificial ice pack. We see a significant drop in the downward traveling intensity with growing ice thickness, while the light intensity from lower layers in the ice increases with thickness due to enhanced scattering. If the air temperature is raised close to the freezing point the optical properties of the ice show quite a distinct change. The downward propagating light intensity increases almost instantly throughout the whole ice pack with the temperature rise. For the light traveling upwards from lower layers the response is faster in the upper layers which are closer to the surface. In the lower layers which are closer to the bottom of the ice changes in the optical properties seem to occur more slowly. Events on the ice surface like frost flower formation or snow fall show a strong effect on the light intensity in all layers. With the proper calibration we hope to be able to calculate the light fluxes at different depths quantitatively and gain more detailed insight into the variation of the optical properties in the vertical. A second set of experiments might have to be performed to increase our certainty in these calculations and evaluate how much the light field is affected by the tank itself and the inside of the chamber. Even though we tried to recreate a natural framework as best as possible, the light outside in the field will be quite different from our setup in the chamber.

Outcome and future studies

For possible follow-on projects in the field it is also important to take in to account how sensitive the light sticks react to small variations in the light field or even just a slight alteration of the angle of view. A good protocol of the experiment itself and the surroundings is essential for subsequent analysis, especially in the field where unexpected changes to the light (e.g. through animals, plants, wind and weather) are much more probable.

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