TNA User Report

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Project title	Effect of experimental scale on the growth processes of artificial columnar sea ice
Name of the accessed chamber	RvG-ASIC
Number of users in the project	2
Project objectives (max 100 words)	The Polar Engineering Research Group (PERG) has recently built a cold lab facility equipped with ice tank to simulate sea ice growth. This is the first sea ice facility in Africa which has made this project both exciting and challenging. At present, our facilities allow small-scale (400L and 50L) tank experiments. The biggest challenges faced is the gap in experience in laboratory techniques and equipment. In the long term, conducting experiences at RvG-ASIC will allow us to develop our team's technical expertise. Beyond the training, we ran an experiment on the impact of experimental scale (tank size) on ice properties.
Description of work (max 100 words):	The project included a training experiment and a subsequent experiment, as described below, to address the research objective outlined above. , which will be replicated in our own 50L and 400L tanks. In each case, the ice will be grown to a thickness of 20 cm. Post-growth analysis following coring of sea ice: -grain size and orientation of ice by thin sectioning on microtome and subsequent cross-polarsiation imaging; bulk salinity analysis; micro CT-scanning to be performed to view internal structure, if such facility is available nearby or by transportation back to our own facilities (transportation arrangements to follow).

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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

User 2 Information	
First name	
Family name	
Nationality	
Activity domain	
Home institution	
Institution legal status	
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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: Ms Tokoloho Rampai
Chamber name and location: Roland van Glasow Air-Sea-Ice Chamber, University of East Anglia

Campaign name and period:

Introduction and motivation

We as the Polar Engineering Research Group (PERG) at the University of Cape Town have recently built a cold lab facility equipped with ice tank to simulate sea ice growth. This is the first sea ice facility in Africa which has made this project both exciting and challenging. At present, our facilities allows small-scale (400L and 30L) tank experiments. The biggest challenge faced for our new research group is the gap in experience of laboratory techniques and equipment.

There are several studies that require artificial sea ice to be grown within a very specific salinity range. This is especially useful for mechanical testing, where it may be necessary to use artificial sea ice with properties mimicking the natural sea ice in order to test a large enough sample group. Jones (1997) performed mechanical tests on artificial sea ice with properties similar to Baltic sea ice, and used the results from these tests to assume properties of the natural Baltic sea ice. To grow this artificial sea ice, Jones (1997) used seawater of similar salinity to Baltic sea water. However, it has been documented that a significant salinity increase occurs in the underlying bulk solution during the growth of artificial sea ice, due to the brine drainage from the ice (Cox and Weeks, 1975). This effect is amplified in smaller tanks in which higher bulk salinities are observed, and will affect the ice salinity, since it changes the salinity gradient present between in-ice and bulk salinity. This increased salinity also has other effects, such as a decrease in the ice-solution interface temperature, which during experiments by Cox and Weeks (1975) was found to be around -5ºC due to their bulk solution salinity of 66.6 PSU.

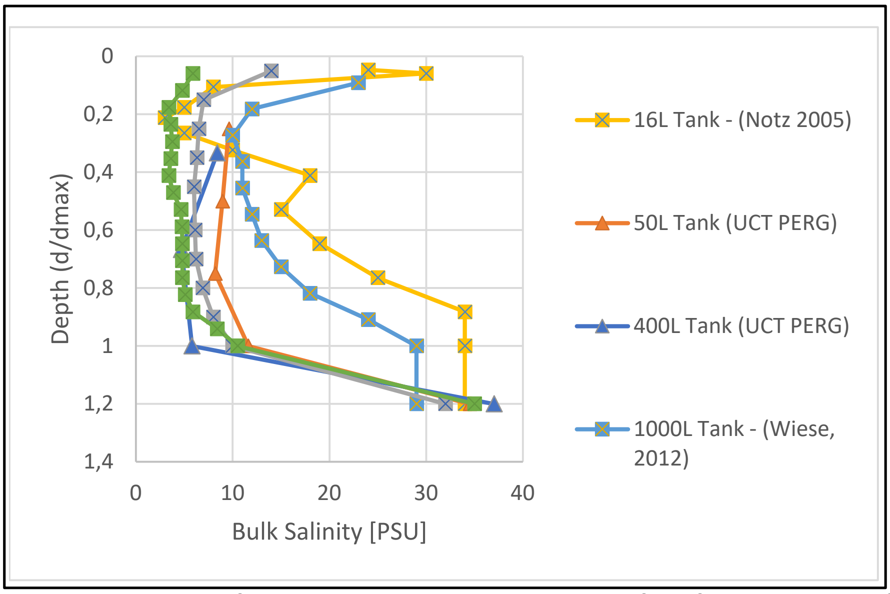

Figure 1: Review of bulk ice salinity versus depth profiles for a selection of studies using initial bulk salinities of close to ocean (35PSU) salinity

In Figure 1, we documented the salinity profiles of the two tanks (30L-400L) at Cape Town University (UCT-PERG), along with salinity data obtained from papers on a selection of different sized freezing vessels and tanks (Cottier and Wadhams, 1999; Galley et al., 2015; Hare et al., 2013; Notz et al., 2005; Wiese et al., 2015). All the profiles within Figure 1 are taken from experiments that have an initial solution salinity between 28.6 (Wiese et al., 2015) and 35 (Galley et al., 2015).

The maximum ice depth ranges between 10cm-25cm. The ice depth for each profile was normalized against the maximum ice depth reached in each study, thus the depth plotted here are "fractional depths". The salinity values at a depth of 1.2 are the salinity of the underlying solution. While there are undoubtedly differences between each experiment beyond just size of the tank, there seems to be a general trend (with a few outliers such as the 1000L and 400L tank) for an increase in ice salinity as tank size decreases. For the ease of reproducibility of in-ice salinity ranges for artificial sea ice set-ups, it would be beneficial to document a trend of in-ice salinity for a range of tank sizes as a function of underlying bulk solution salinity. This would enable the desired in-ice salinity to be achieved for a given tank size, by adjusting initial underlying bulk solution salinity.

Increasing the volume of the underlying solution by circulating it between the freezing vessel and a bigger tank could simplify the issue by lessening the salinity increase caused by brine drainage from the ice. However, this adds complexity to the system and is seldom seen to be implemented in start-up set-ups. It should be noted that to our knowledge none of the studies included in the profiles seen in Figure 1 had any method of counteracting the increasing salinity in the underlying solution. Such systems do not seem to be a necessity in the larger tanks such as the 216 000L Arctic Environmental Test Basin used by Cottier and Wadhams (1999) or the 400 000L Sea-ice Environmental Research Facility (SERF) used by Galley et al (2015).

Scientific objectives

As a small research group at the inception stage of our research, the primary objective of the visit to the RvG-ASIC was to receive training and make use of the knowledge and experience of the personnel at the facility to improve the PERG group's experience in laboratory techniques and equipment. In the long term, conducting experiences at RvG-ASIC will allow us to develop our team's technical expertise.

The second objective was to examine the effect of tank size and initial bulk solution salinity on in-ice salinity, by comparing the results of experiments conducted at UCT in 30 L and 400 L tanks to an experiment in the 3500L RvG-ASIC tank. During a typical experiment in the RvG-ASIC the ocean salinity will increase by around 3 g/kg and basal sea-ice temperatures remaining around -2^{o}C. During an experiment in the 400L UCT-PERG tank with an initial salinity of 34PSU, the ocean salinity increase was 6 g/kg with 20cm of ice growth.

Reason for choosing the simulation chamber/ calibration facility

The RvG-ASIC is a state-of-the art research facility for the growth of artificial sea ice, with a purpose built freezing chamber and a range of analytical measurement systems for ice, ocean and atmosphere. Since it is our aim as UCT-PERG to become a world class facility for the growth and study of artificial sea ice, we chose to visit the RvG-ASIC to learn from their experience and gain the relevant expertise for sea-ice research.

The focus of this study will be to investigate the effect of experimental scale on artificial columnar sea ice growth. Since the RvG-ASIC is approximately 10 times larger than our largest tank (at ~3000L), performing the same experiments at the RvG-ASIC will enable us to examine the effects of scale on artificial sea ice growth between the three tanks. The RvG-ASIC offers a wider range of instrumentation than what is currently available in our own facility, which gives the opportunity to have a greater array of data. This will enable better understanding of processes occurring during sea ice growth and inform us for future instrumentation purchases.

Method and experimental set-up

The experiment as described below was carried out within the RvG-ASIC which was replicated in our own 30L and 400L tanks. In the UCT-PERG tanks, the ice was grown to 20cm depth. The ice depth of the RvG-ASIC experiment was grown to 10cm.

UCT PERG 400L Experimental Set-Up:

The tank was filled with 400L of de-ionised water and artificial sea salt (Aquaforest Sea Salt) to a initial solution salinity of 35PSU. The solution was pre-cooled to a uniform 1°C and then the chamber was set to -20°C, allowing the solution to cool and begin ice formation. Ice and solution temperature was monitored using PT100 temperature probes at 5cm resolution. The tank bottom temperature was maintained at -1.9°C, the freezing point of the solution. Once the ice reached a depth of 20cm, the chamber was set to -10°C and ice samples were cut using an electric Saber saw. The samples were examined to ensure columnar ice growth was maintained and sectioned into 2.5cm increments for salinity measurements. The sectioned ice pieces were placed in ziplock bags and allowed to melt before measuring the salinity.

UCT PERG 30L Experimental Set-Up:

The tank was filled with 30L of de-ionised water and artificial sea salt (Aquaforest Sea Salt) to a initial solution salinity of 35PSU. Methodology that followed was identical to 400L tank, though ice growth was stopped at 15cm due to increased solution salinity becoming too large following further ice growth.

RvG-ASIC Experimental Set-Up:

The tank was filled with a solution of de-ionised water and artificial sea salt was added to achieve a salinity of 28PSU. The mixing pumps were set to the maximum and the chamber temperature was set to -20°C to pre-cool the solution to the freezing point of -1.8°C. Once the solution reached its freezing point, the pumps were set to a lower rate to provide mixing of the underlying solution while allowing columnar ice growth. The ice was monitored remotely to minimize temperature fluctuations for the duration of the experiment. The following parameters were monitored during the experiment: CTD data of underlying solution, in-ice temperature at 2cm resolution; bulk salinity and depth profiles of growing ice; air temperature and humidity. Underlying water samples were taken at regularly intervals to measure salinity and isotopes.

Once the ice had reached a depth of 10cm, the chamber was set to -10°C and ice samples were taken using a Kovacs ice corer. The core samples were measured and sectioned for salinity measurements. The sectioned ice pieces were placed in ziplock bags and allowed to melt before measuring salinity. Block samples were taken by cutting an opening in the ice and sliding a container underneath the desired sample in order to prevent brine drainage and preserve the in-ice salinity profile. The block samples were placed in the freezer to freeze the surrounding solution.

Data description

The UCT-PERG tanks do not have a method of measuring salinity in-situ. The solution salinity was measured at the start of the experimental run and at the end using a conductivity meter (8303 AZ Instruments). In the 400L tank the initial solution salinity was measured as 34.7 $g.kg^{-1}$ and after the growth of 20cm of ice the underlying solution salinity at ice-ocean interface was 40 $g.kg^{-1}$. The salinity at the bottom of the tank was measured as 35.2 $g.kg^{-1}$. The 30L tank had an initial solution of 34.7 $g.kg^{-1}$ (same solution used as for 400L tank). The final salinity after 15cm of ice growth was 40.3 $g.kg^{-1}$. Salinity at the bottom of the tank was measured as 36.1$g.kg^{-1}$. Melted ice samples were used to obtain the in-ice salinity at various depths, shown in Figure 2.

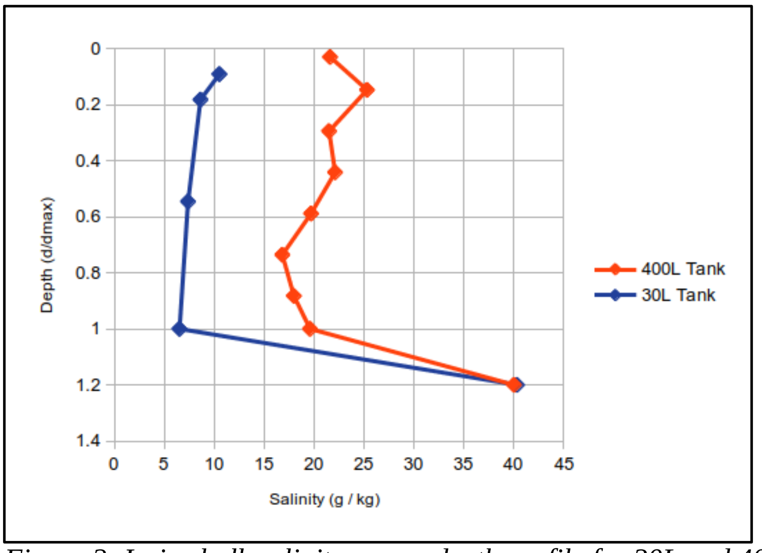

Figure 2: In-ice bulk salinity versus depth profile for 30L and 400L tank

The bulk salinity profiles did not show the characteristic "C" shaped salinity profile usually associated with columnar sea ice growth (Nakawo and Sinha, 1981).The salinity of the ice from the 400L tank showed particularly high salinity values, with an average of 20.57 $g.kg^{-1}$. Using the formula for sea ice salinity developed by Kovacs (1996), sea ice of 20cm thick should have an average salinity of around 9 $g.kg^{-1}$.

Figure 3 shows the (a) ocean salinity, (b) sea ice thickness and (c) in-ice bulk salinity during the course of the experiment carried out in the RvG-ASIC tank. The ocean salinity showed an increase of 4.25 $g.kg^{-1}$ over the duration of the experiment. The pumps ensured the solution was well mixed. Sea ice thickness, measured using sonar transducers, recorded a steady growth in sea ice thickness. Measurements of core thicknesses at the end of the experiment (seen by red line in Figure 3) were recorded as 15cm and correlated well with the sonar measurements. In-ice salinity was measured using the salinity harps developed by Notz et al. (2005). Within the first 12 hours of the experiment, the results showed oscillations with values not representative of reality. The thin ice and its tiny variations at this stage causes large oscillations in bulk salinity. After 1cm of ice had formed, the salinity values began to stabilise and showed the characteristic decrease associated with brine drainage. It can be seen that there was a large variation in salinity measurements as recorded by the two salinity pairs. This was caused by a slight discrepancy in the ice thickness measurement, and this difference resulted in a 40% difference in the calculated in-ice salinity for each of the transducer pairs. Core samples were taken for in-ice salinity profiles but these results have not yet been received by from RvG-ASIC. However, it is known that the ice grown in the RvG-ASIC generally follows a "C" shaped salinity curve. The cores showed ice of columnar structure.

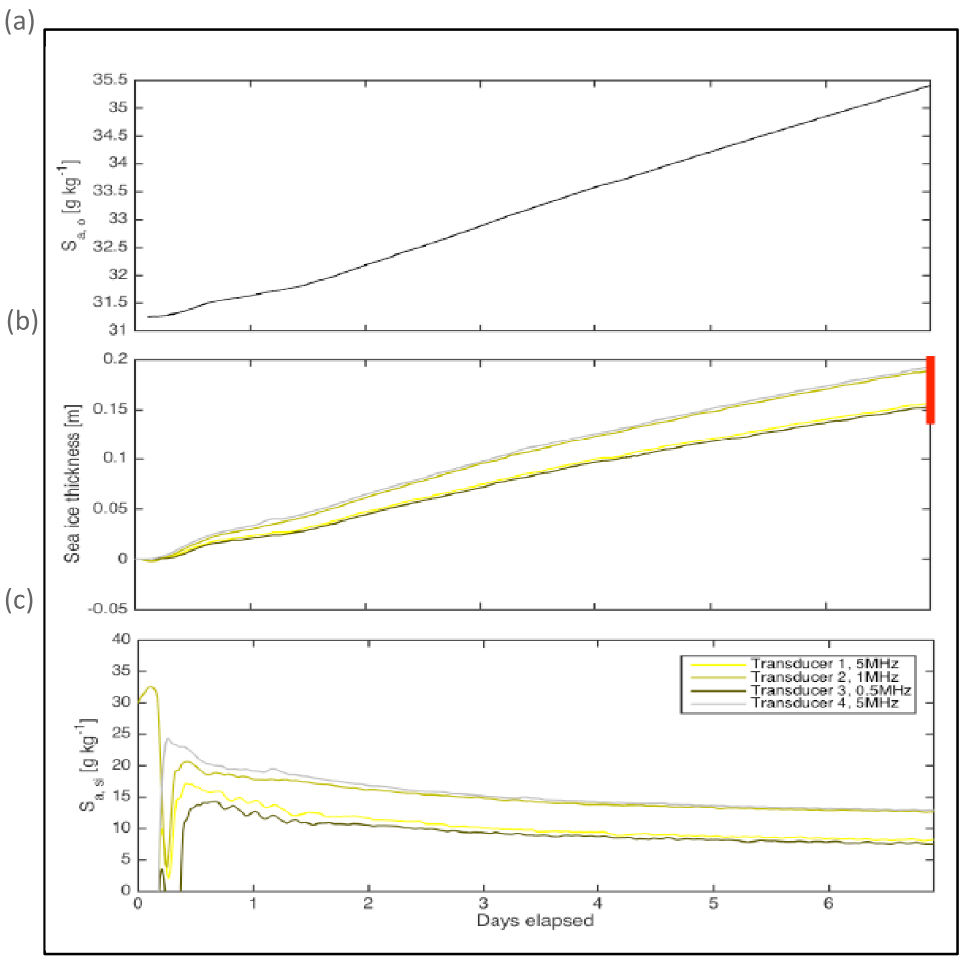

Figure 3: Graph of (a) ocean salinity, (b) sea ice thickness and (c) in-ice bulk salinity for the RvG-ASIC freezing experiment over 6 days

Preliminary results and conclusions

The ice grown in the UCT-PERG tanks showed salinity values greater than those of the RvG-ASIC. In addition, the expected "C" shaped salinity curve was not present for the ice grown in the UCT-PERG tanks. It is theorised that this difference in the salinity curves of the UCT-PERG tanks and the RvG-ASIC tank experiments is due to the lack of mixing pumps in the underlying solution in the UCT-PERG tanks. This resulted in the high salinity of around 40g.kg^{-1} in both the 30L and 400L UCT-PERG tanks at the ice-ocean interface, despite the average solution salinity after mixing being around 35g.kg^{-1}. The high salinity layer (40 g.kg^{-1}) would have lessened if not entirely removed the salinity gradient between brine channels and underlying solution, which would have prevented brine drainage. The UCT-PERG tanks also do not have free-floating ice, as accomplished in the RvG-ASIC tank. Free-floating ice is known to be difficult to accomplish without drastically limiting ice formation, but it has the advantage of maintaining a natural ice freeboard. Furthermore, sea ice is so permeable that despite the pressure relief pipe within the UCT-PERG tanks, ice expansion causes a heightened permeation of high salinity solution through the ice. The effect of this was a very saline, liquid layer remaining on the surface of the ice, throughout the experiment. By accomplishing free-floating ice, this would also result in a more natural salinity profile within the ice grown within the UCT PERG tanks.

There were unfortunately too many physical differences in the setup of the UCT-PERG tanks and the RvG-ASIC tank to draw any meaningful results for determining a trend of initial salinity and tank size towards in in-ice salinity. However, identification of the differences and methods of improvement was beneficial, since the primary aim of this trip was to be a learning experience for the UCT-PERG research group, whereby we could improve the methodologies and equipment set-up of our laboratory for the growth of artificial sea ice that more accurately mimicks natural sea ice.

Outcome and future studies

The outcome of this research visit is a better understanding of the methodologies and equipment needed to accurately grow artificial sea ice. Thus, we shall be incorporating the following additions to our tank set-ups;

- Pumps to create a well-mixed solution and to prevent the formation of a high salinity layer at the ice-ocean interface.
- Determination of a method and heating control to maintain free-floating ice.
- In addition to the existing temperature measurement system, we shall look into the purchase of salinity harps to provide in-situ ice salinity measurements.

Once these changes have been incorporated, we can repeat the experiments presented within this report, and re-examine the difference of in-ice bulk salinity experienced between the 30L and 400L UCT-PERG tanks and the 3500L RvG-ASIC tank to answer our original research question.

We would like to thank the research staff of the RvG-ASIC facility for hosting us and the opportunity to learn from your experience. We would also like to thank Eurochamp for providing the means of realising this research visit.

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