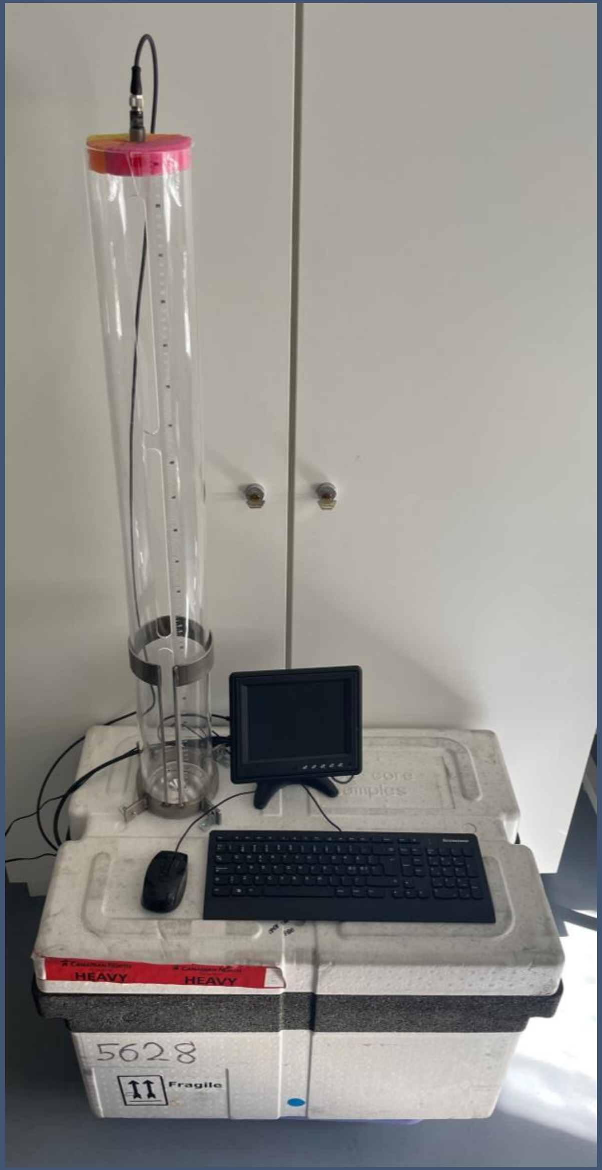
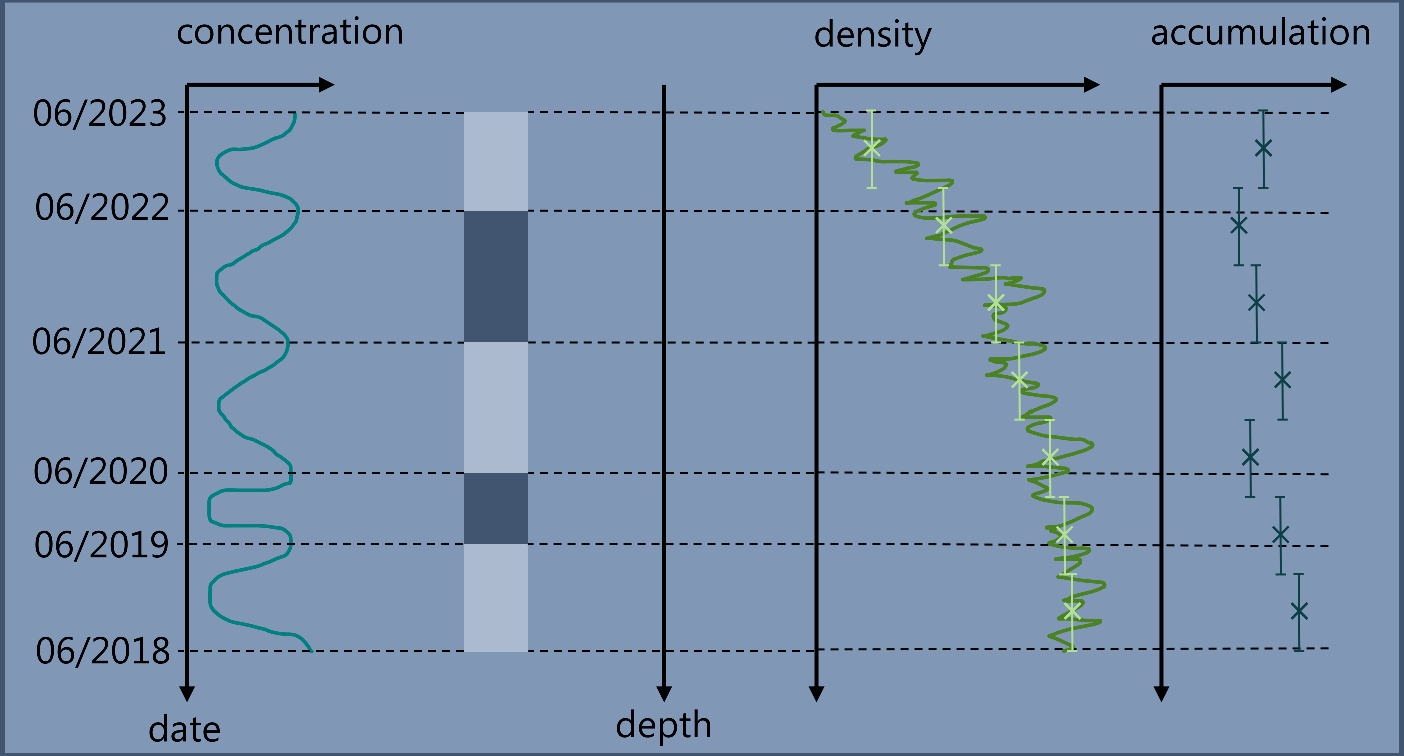


Lightweight in Situ Analysis of Snow Density and Accumulation

Johanna v. Drachenfels, Helle Astrid Kjær, Josephine Lindsey-Clark

University of Copenhagen



PICO spot 4
PICO 4.5
11:15 – 12:30

Structure

1 Motivation

- WHY measure accumulation with the LISA box?

2 Measurements

- HOW measure accumulation with the LISA box?

3 LISA parts

- Explore the different LISA box instruments and their functions

Navigation

① ② ③

Click on the symbols in the bottom right corner to navigate between sections

⬅ ➡

Use the arrows in the bottom left corner to click through the slides chronologically

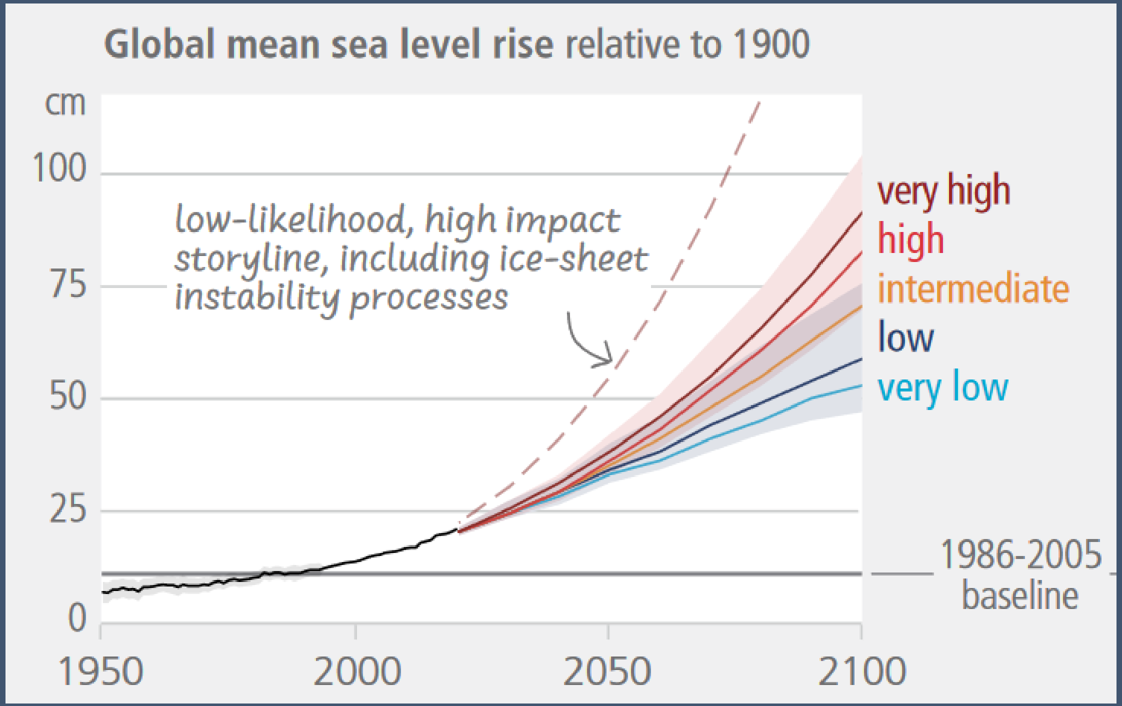
Click on text marked by boxes framed in green to jump to a slide with more information

1 2 3

Motivation

- Why measure accumulation with the LISA box?

Why Snow and Ice Core analysis?

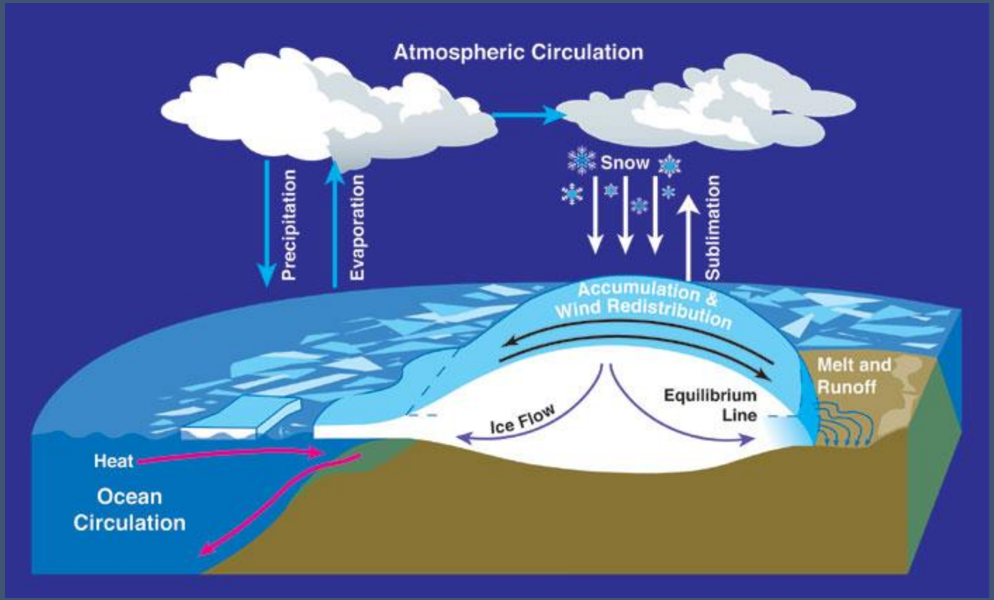


IPCC, 2023: *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 184 pp., doi: 10.59327/IPCC/AR6-9789291691647.

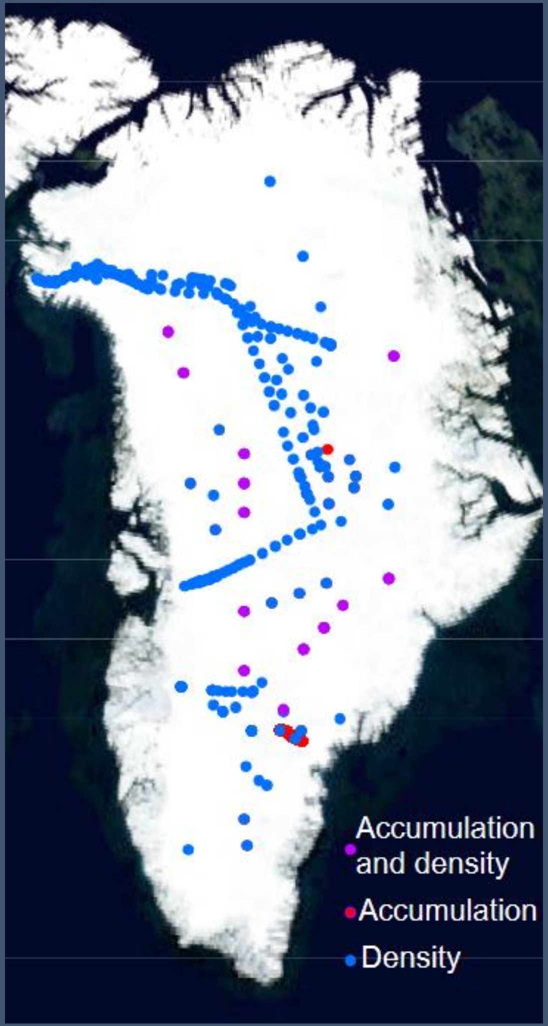
Over the last century, the global mean temperature has risen increasingly fast and will continue to do so, entailing changes in the earth system including a higher frequency in extreme weather events a rise in sea level. The latter is directly connected to the mass loss of polar ice sheets: the water stored in the ice in Greenland and Antarctica would raise the sea level by 7m and 57m, respectively.
It is therefore important to follow and predict the evolution of ice sheets.

Why Snow and Ice Core analysis?

Computer models simulating the surface mass balance of ice sheets include all the surface processes that can change the mass of an ice sheet, with snow accumulation and melt being the most significant. However, these models carry uncertainties and require tuning and validation through observational data, but there is a lack particularily in accumulation observations.



https://www.antarcticglaciers.org/glacier-processes/mass-balance/introduction-glacier-mass-balance/

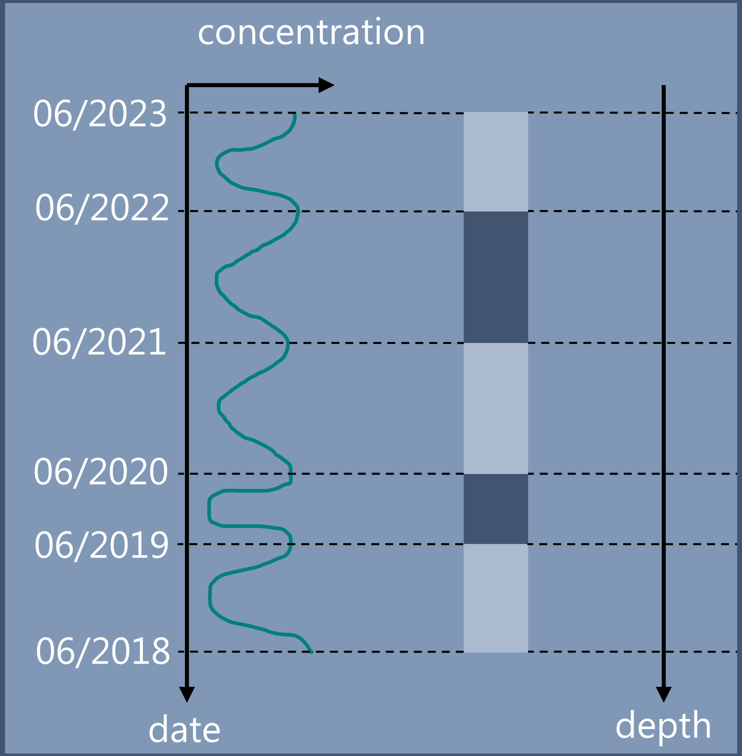


L. Montgomery, L. Koenig, and P. Alexander, "The SUMup dataset: compiled measurements of surface mass balance components over ice sheets and sea ice with analysis over Greenland", Earth System Science Data 10, 1959–1985 (2018).

1 2 3
1 2 3

Accumulation from Snow and Ice Cores

A vertically cut core from an ice sheet contains snow deposited within one or several years. Analysing the seasonally varying concentration of chemical impurities in the core allows to establish a relation between the depth and age of the snow layers (see figure below).



Examples for impurities with seasonally varying concentrations:

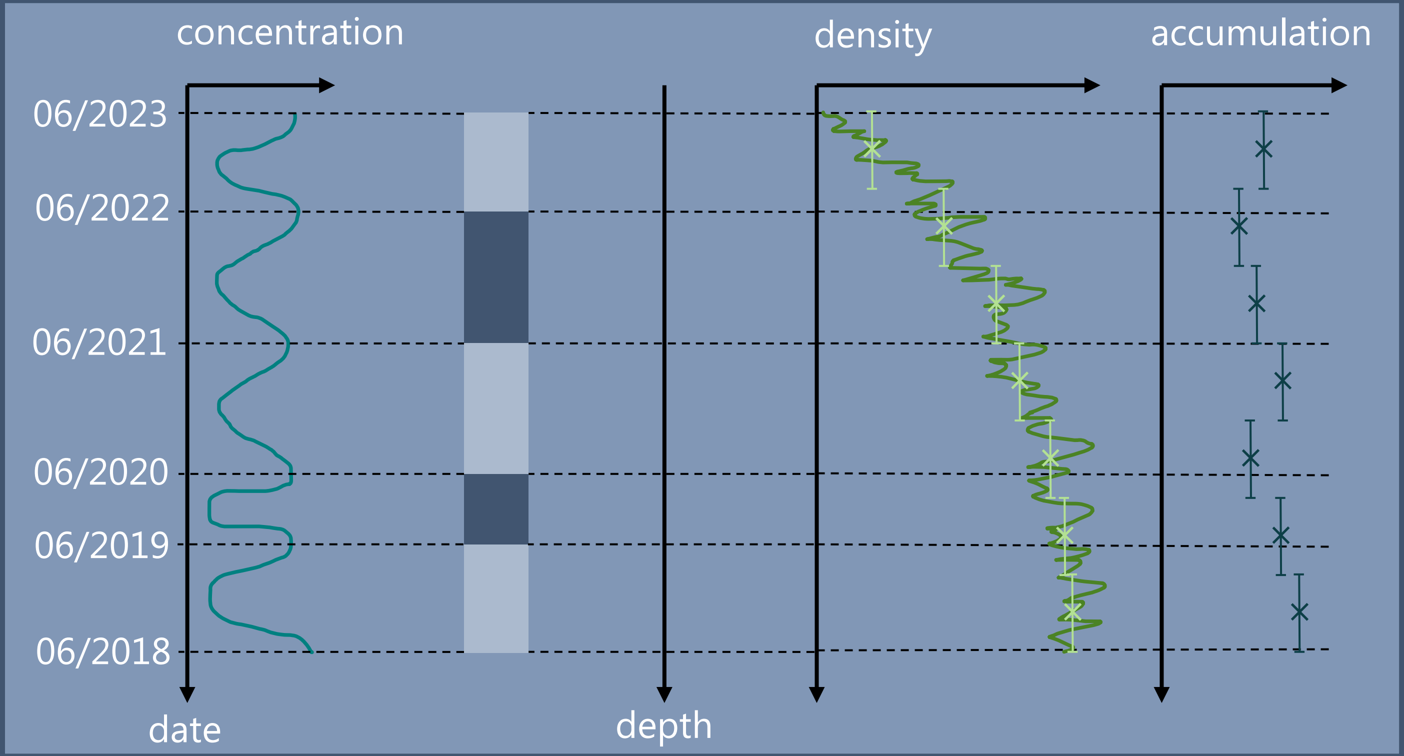
Calcium

Conductivity

Hydrogen peroxide

Accumulation from Snow and Ice Cores

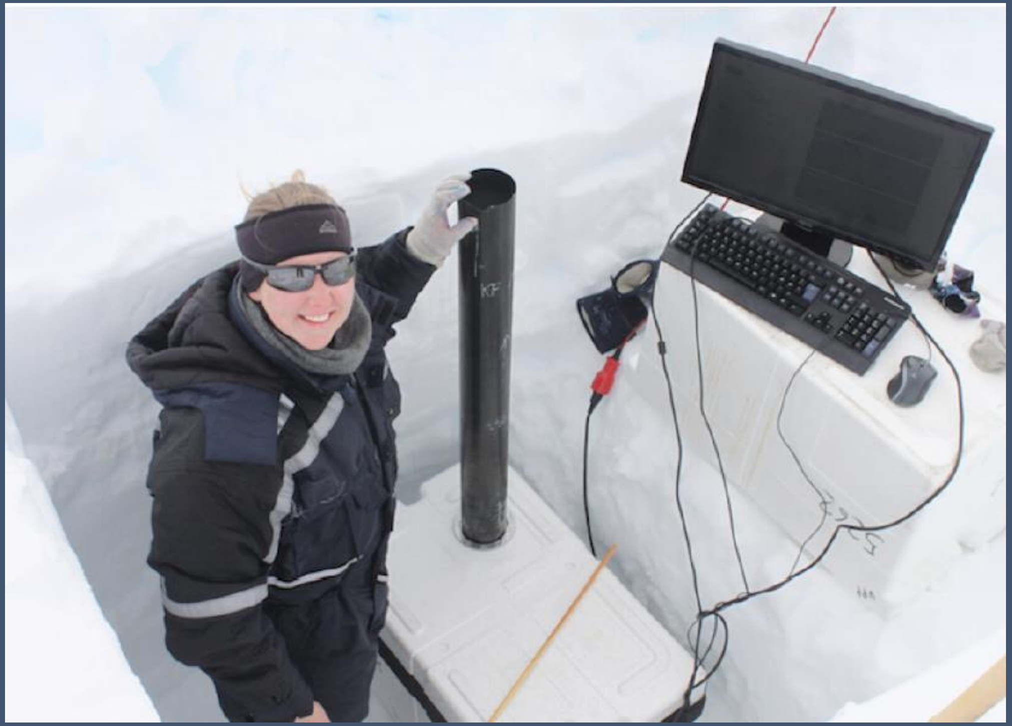
The **accumulation** in each year can be reconstructed from the **density and thickness** of the corresponding annual layer. In practice, three things have to be measured: the concentration of one **chemical species** (or several, to reduce uncertainties), the **layer density** and the relative **depth** of the layers to the surface.



Accumulation from Snow and Ice Cores

The portable Lightweight In Situ Analysis (LISA) box presents a simple, fast and inexpensive method to obtain accumulation data through continuous flow analysis (CFA) of annual layers in snow and firn cores in the field.

Foam box with
- Outer dimensions: 0.58 m x 0.47 m x 0.76 m
- Inner dimensions: 0.35m x 0.35m x 0.58m
- Weight: <50kg



Kjær, H. A., Lolk Hauge, L., Simonsen, M., Yoldi, Z., Koldtoft, I., Hörhold, M., Freitag, J., Kipfstuhl, S., Svensson, A., and Vallelonga, P.: A portable lightweight in situ analysis (LISA) box for ice and snow analysis, The Cryosphere, 15, 3719–3730, https://doi.org/10.5194/tc-15-3719-2021, 2021.

1 2 3

Measurements

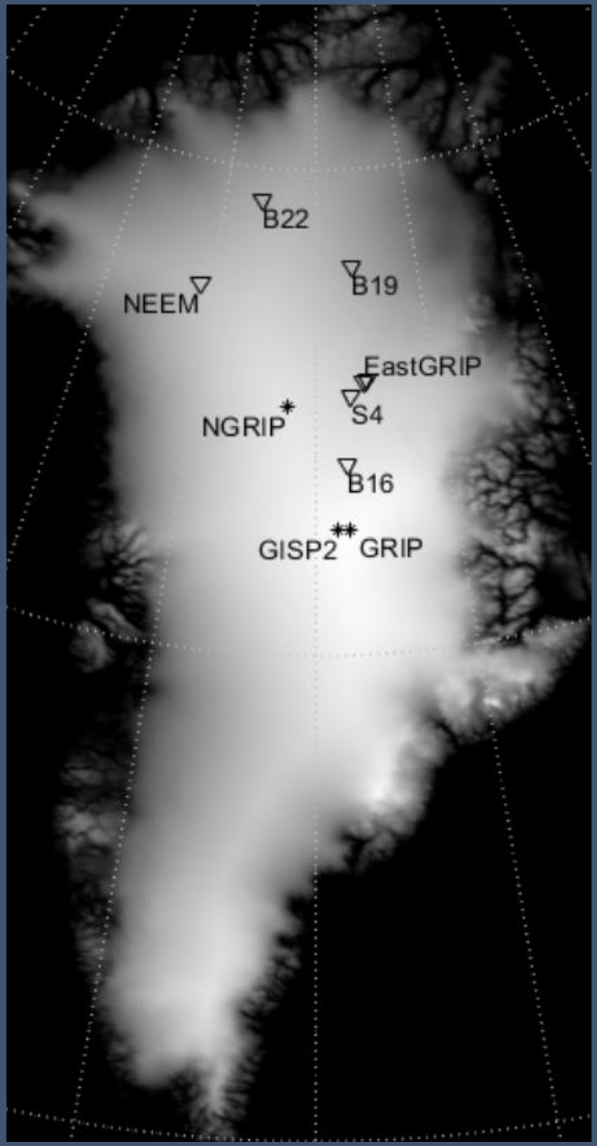
How measure accumulation with the LISA box?

Positions of Measurements taken with the LISA box

The map shows the drill sites of the seven snow cores that were analysed with the LISA box in 2019. For each core, its depth, weight, the H2O2 concentration and conductivity were measured in order to determine the snow density and accumulation (see next slide or the LISA paper for results)

LISAbox paper (2021):

Kjær, H. A., Lolk Hauge, L., Simonsen, M., Yoldi, Z., Koldtoft, I., Hörhold, M., Freitag, J., Kipfstuhl, S., Svensson, A., and Vallelonga, P.: A portable lightweight in situ analysis (LISA) box for ice and snow analysis, *The Cryosphere*, 15, 3719–3730, https://doi.org/10.5194/tc-15-3719-2021, 2021.



Kjær, H. A., Lolk Hauge, L., Simonsen, M., Yoldi, Z., Koldtoft, I., Hörhold, M., Freitag, J., Kipfstuhl, S., Svensson, A., and Vallelonga, P.: A portable lightweight in situ analysis (LISA) box for ice and snow analysis, The Cryosphere, 15, 3719–3730, https://doi.org/10.5194/tc-15-3719-2021, 2021.

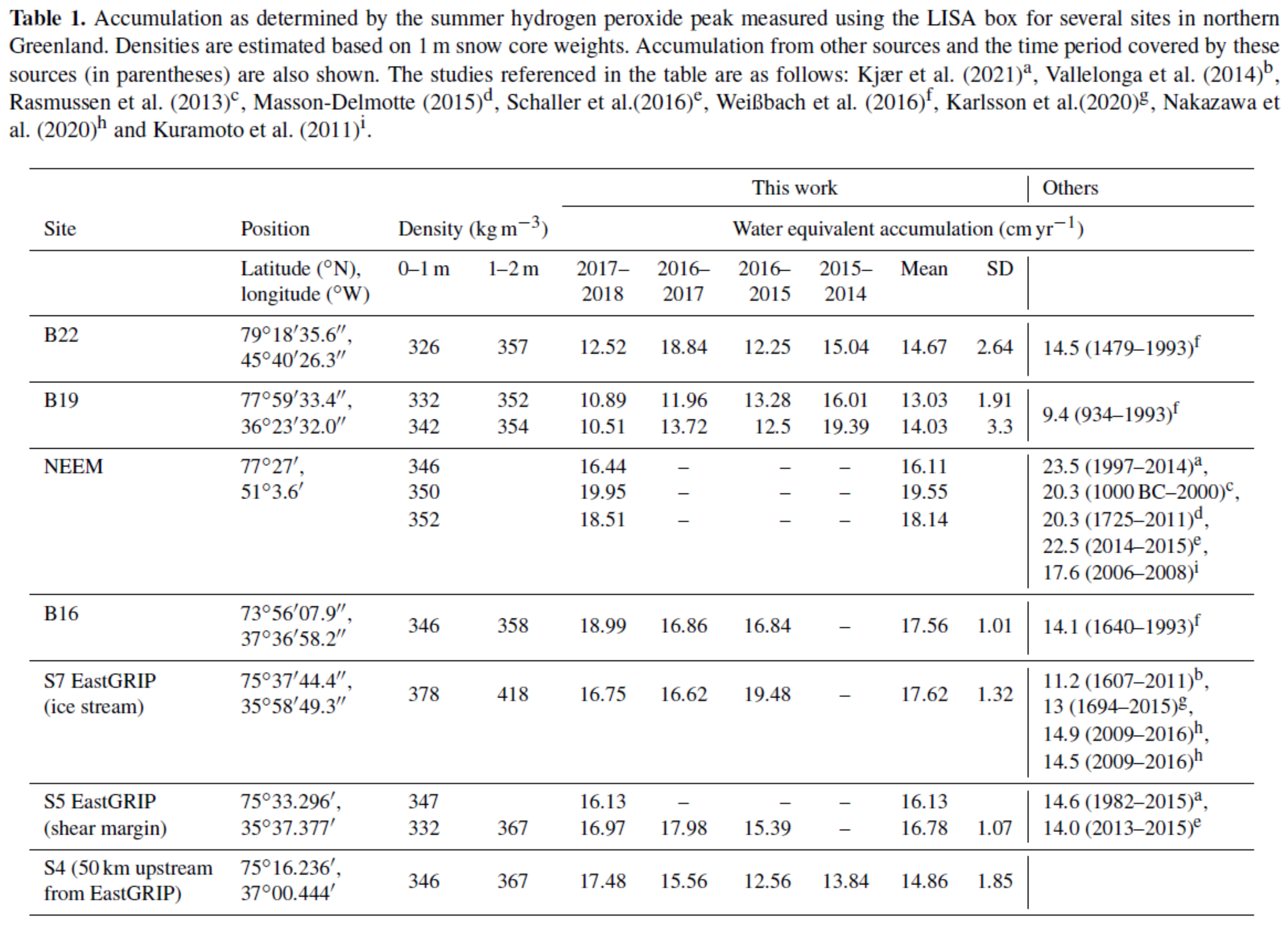
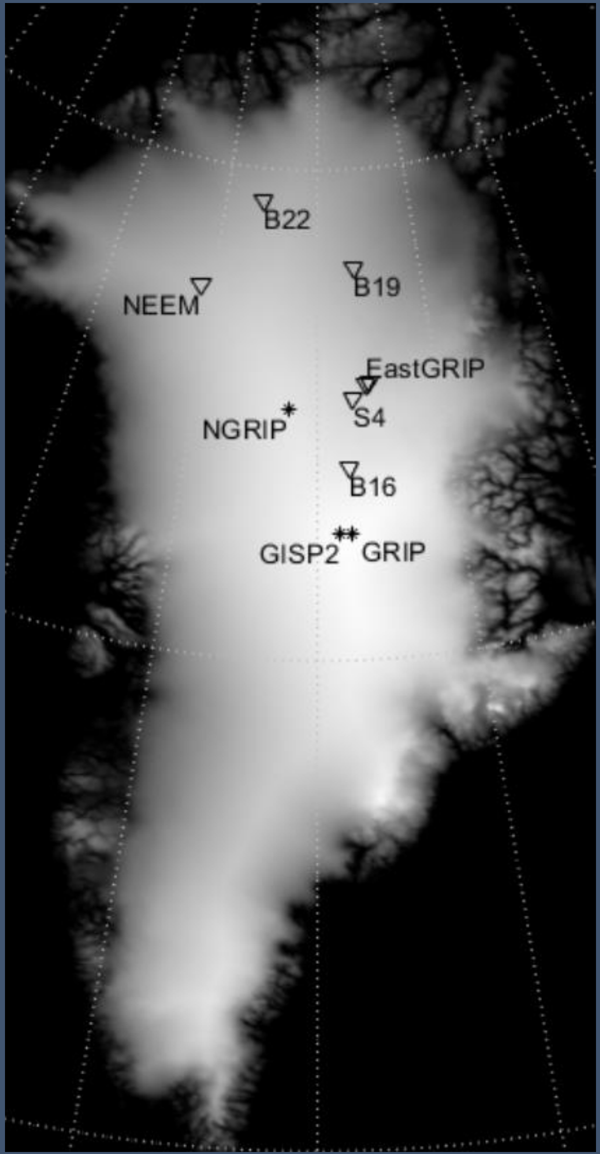


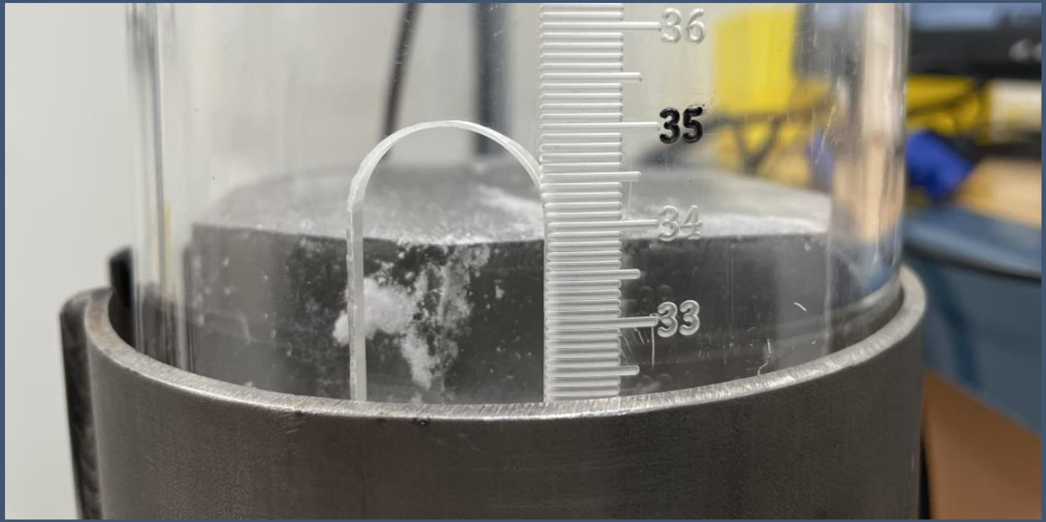
Table 1. Accumulation as determined by the summer hydrogen peroxide peak measured using the LISA box for several sites in northern Greenland. Densities are estimated based on 1 m snow core weights. Accumulation from other sources and the time period covered by these sources (in parentheses) are also shown. The studies referenced in the table are as follows: Kjær et al. (2021)[a], Vallelonga et al. (2014)[b], Rasmussen et al. (2013)[c], Masson-Delmotte (2015)[d], Schaller et al.(2016)[e], Weißbach et al. (2016)[f], Karlsson et al.(2020)[g], Nakazawa et al. (2020)[h] and Kuramoto et al. (2011)[i].

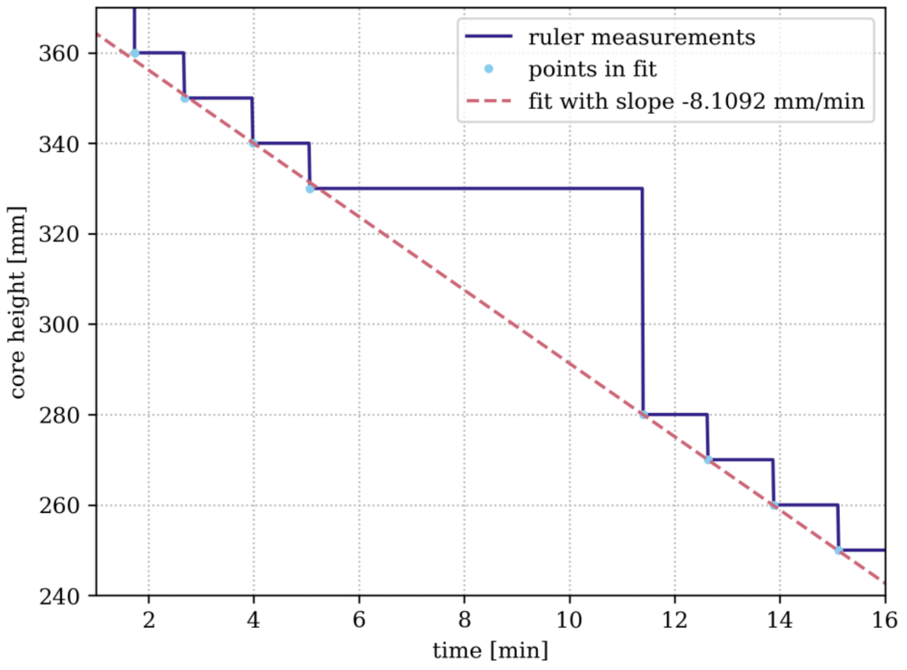
				This work						Others
Site	Position	Density (kg m^{-3})		Water equivalent accumulation (cm yr^{-1})						
	Latitude (°N), longitude (°W)	0–1 m	1–2 m	2017–2018	2016–2017	2016–2015	2015–2014	Mean	SD	
B22	79°18′35.6″, 45°40′26.3″	326	357	12.52	18.84	12.25	15.04	14.67	2.64	14.5 (1479–1993)[f]
B19	77°59′33.4″, 36°23′32.0″	332	352	10.89	11.96	13.28	16.01	13.03	1.91	9.4 (934–1993)[f]
		342	354	10.51	13.72	12.5	19.39	14.03	3.3	
NEEM	77°27′, 51°3.6′	346		16.44	–	–	–	16.11		23.5 (1997–2014)[a], 20.3 (1000 BC–2000)[c], 20.3 (1725–2011)[d], 22.5 (2014–2015)[e], 17.6 (2006–2008)[i]
		350		19.95	–	–	–	19.55		
		352		18.51	–	–	–	18.14		
B16	73°56′07.9″, 37°36′58.2″	346	358	18.99	16.86	16.84	–	17.56	1.01	14.1 (1640–1993)[f]
S7 EastGRIP (ice stream)	75°37′44.4″, 35°58′49.3″	378	418	16.75	16.62	19.48	–	17.62	1.32	11.2 (1607–2011)[b], 13 (1694–2015)[g], 14.9 (2009–2016)[h], 14.5 (2009–2016)[h]
S5 EastGRIP (shear margin)	75°33.296′, 35°37.377′	347		16.13	–	–	–	16.13		14.6 (1982–2015)[a], 14.0 (2013–2015)[e]
		332	367	16.97	17.98	15.39	–	16.78	1.07	
S4 (50 km upstream from EastGRIP)	75°16.236′, 37°00.444′	346	367	17.48	15.56	12.56	13.84	14.86	1.85	



Depth measurement

Melt speed of the core is an important parameter, since it is used to reconstruct the depth of the sample. In the LISA box so far, the melt speed has been measured manually through the height of the core with a ruler on the core holder in frequent time intervals. This method is somewhat imprecise and has a low resolution, but has the advantage of being very simple and not needing any additional instruments.
The plot on the right shows the melt speed of a core of test ice. The fit of the data points gives a melt speed of around 8 mm/min.

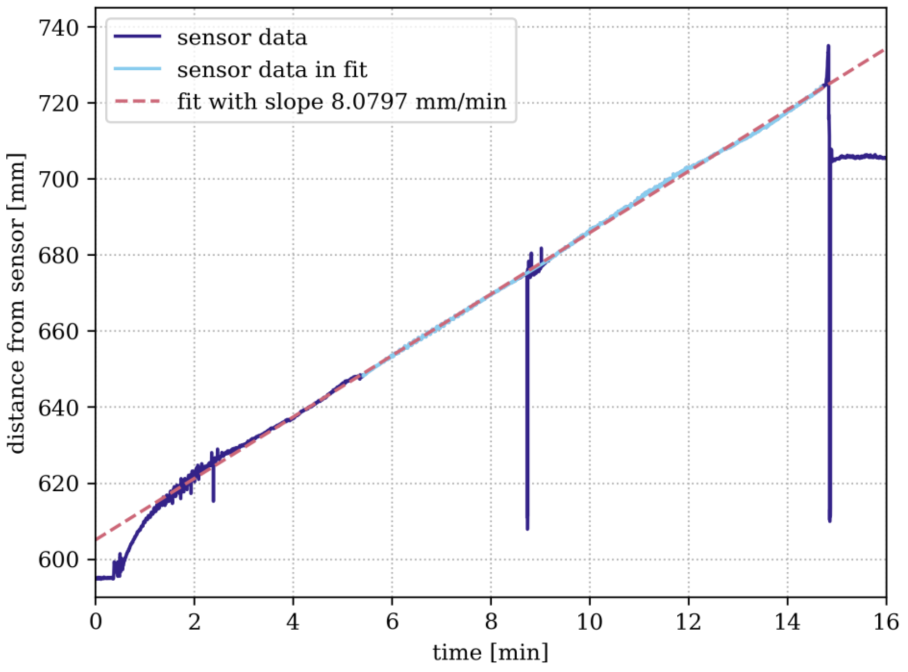




Depth measurement

In order to fully **automate** the measurement and **increase its precision**, an **ultrasound sensor** will be installed at the top of the core holder that measures the relative distance to the core continuously. This will also increase the resolution.

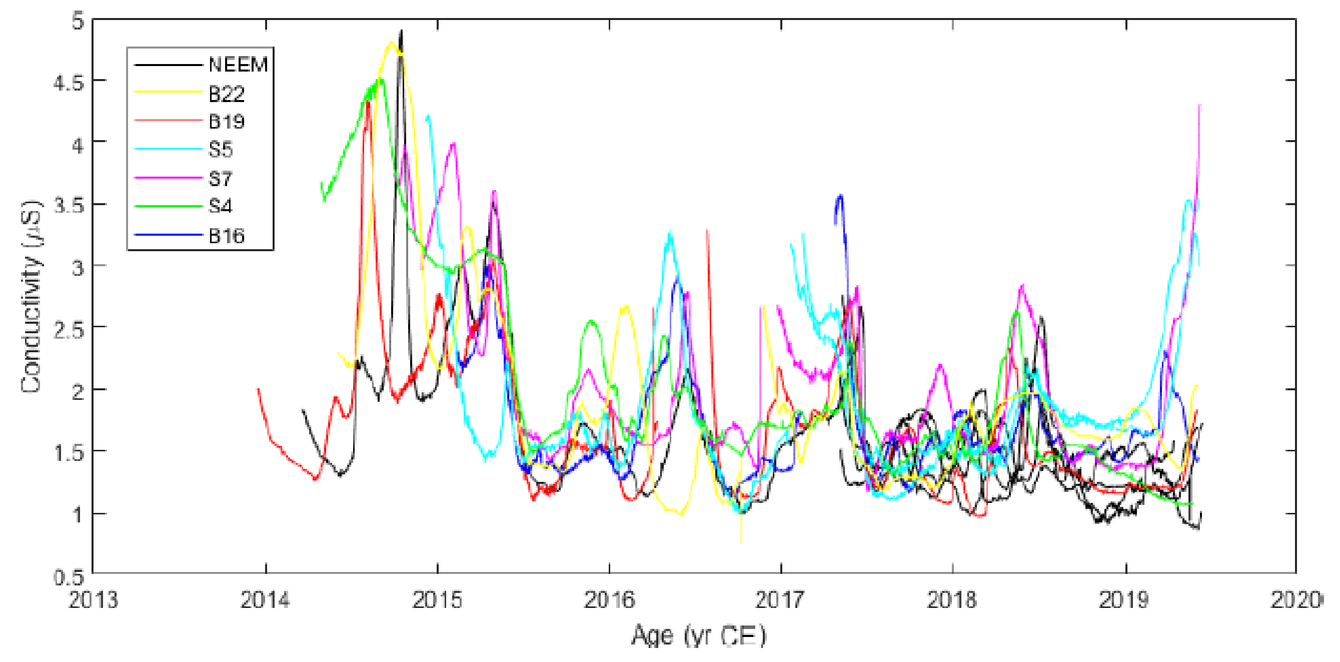
The plot on the right shows the melt speed of a core of test ice. The fit of the data points gives a melt speed of around 8 mm/min.



Seasonal cycles: Conductivity

Kjær, H. A., Lolk Hauge, L., Simonsen, M., Yoldi, Z., Koldtoft, I., Hörhold, M., Freitag, J., Kipfstuhl, S., Svensson, A., and Vallelonga, P.: A portable lightweight in situ analysis (LISA) box for ice and snow analysis, The Cryosphere, 15, 3719–3730, https://doi.org/10.5194/tc-15-3719-2021, 2021.

- Conductivity in ice cores is mostly dependent on the **presence of H^+ ions**
- H^+ forms when **atmospheric pollutants** are deposited on the ice and react with water forming **acids**, releasing H^+
  - Conductivity is **quantitative estimate of acidity**
- Presence of **sea salt** can also increase acidity



Seasonal signal: peak in early spring

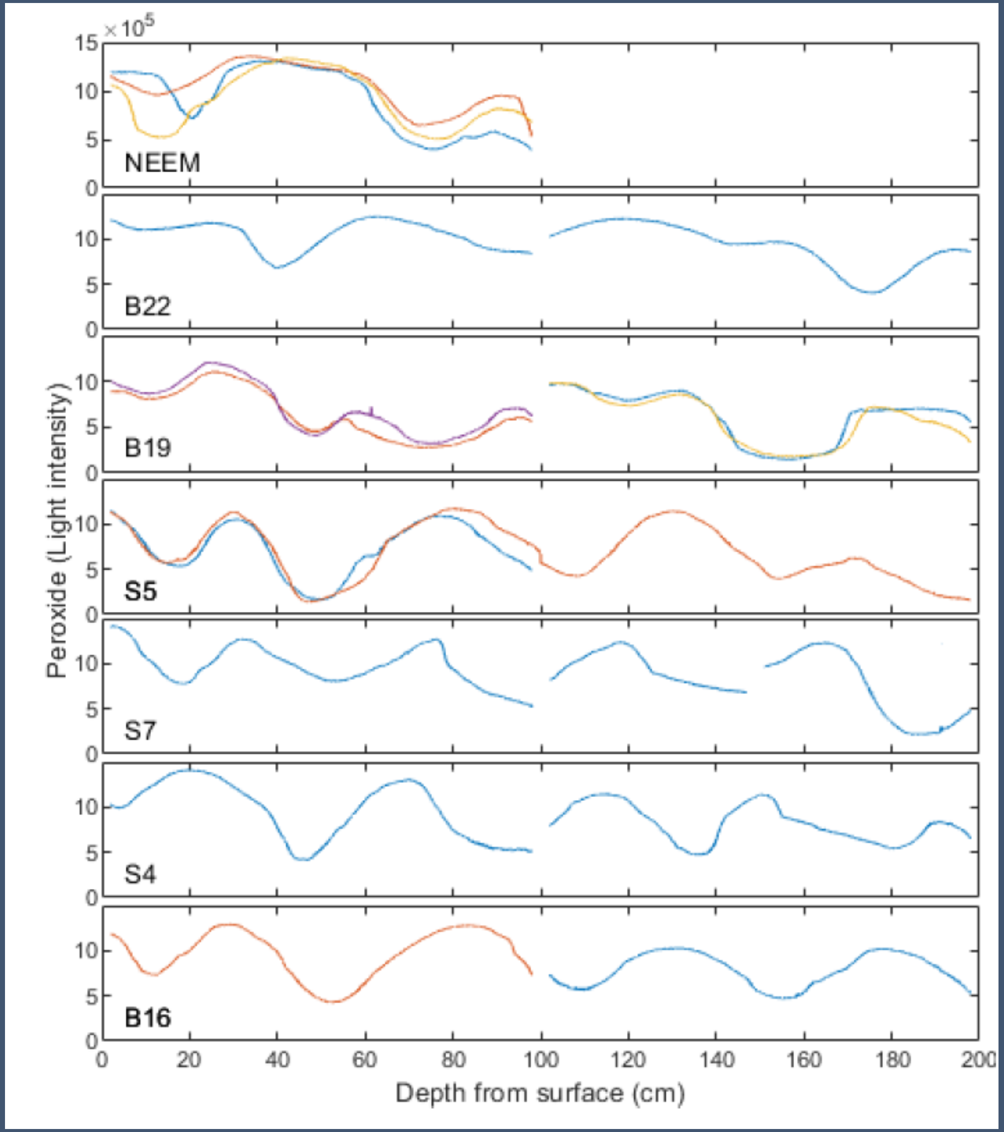
- **Reason:** build-up of anthropogenic pollutants in atmosphere during dry winter (arctic haze) that get deposited when atmospheric conditions change in spring

High peaks: volcanic eruptions

Seasonal cycles: Hydrogen Peroxide

Seasonal signal: peak in midsummer

- Reason: In the summer months, higher solar radiation levels lead to increased photochemical reactions in the atmosphere. Among these reactions, the photolysis of species like formaldehyde (HCHO) and ozone (O3) generates free radicals such as hydroxyl radicals (OH) and peroxyl radicals (HO2 and RO2), which are the building blocks for hydrogen peroxide (H2O2).



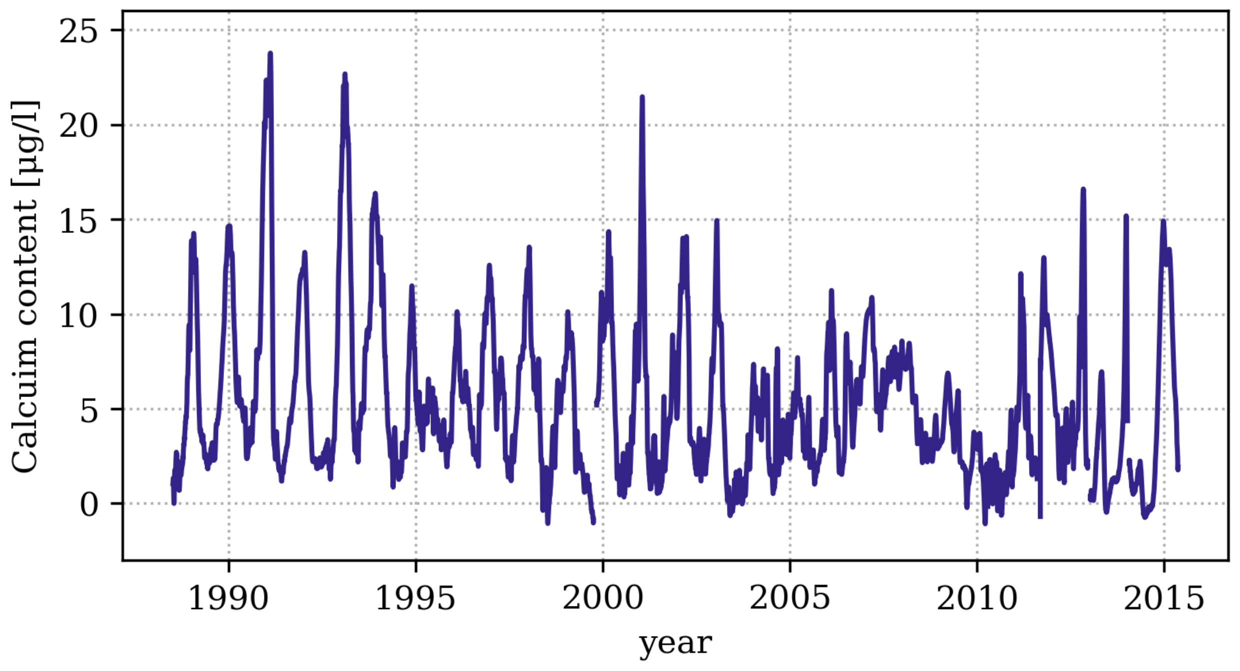
Kjær, H. A., Lolk Hauge, L., Simonsen, M., Yoldi, Z., Koldtoft, I., Hörhold, M., Freitag, J., Kipfstuhl, S., Svensson, A., and Vallelonga, P.: A portable lightweight in situ analysis (LISA) box for ice and snow analysis, The Cryosphere, 15, 3719–3730, https://doi.org/10.5194/tc-15-3719-2021, 2021.

Seasonal cycles: Calcium

Seasonal signal: peak in spring

- Reason: increasing storms in spring pick up continental dust as well as sea salt particles, both a source to calcium, and deposit it on the ice sheet. Calcium therefore serves as a proxy for wind strength and aridity

Calcium signal measured with the CFA system in Copenhagen in a core drilled between EastGRIP and NEEM in 2015



Kjær, Helle Astrid; Zens, Patrick; Black, Samuel; Lund, Kasper Holst; Svensson, Anders M; Vallelonga, Paul T (2022): Canadian forest fires, Icelandic volcanoes and increased local dust observed in six shallow Greenland firn cores. *Climate of the Past*, 18(10), 2211-2230, https://doi.org/10.5194/cp-2021-99

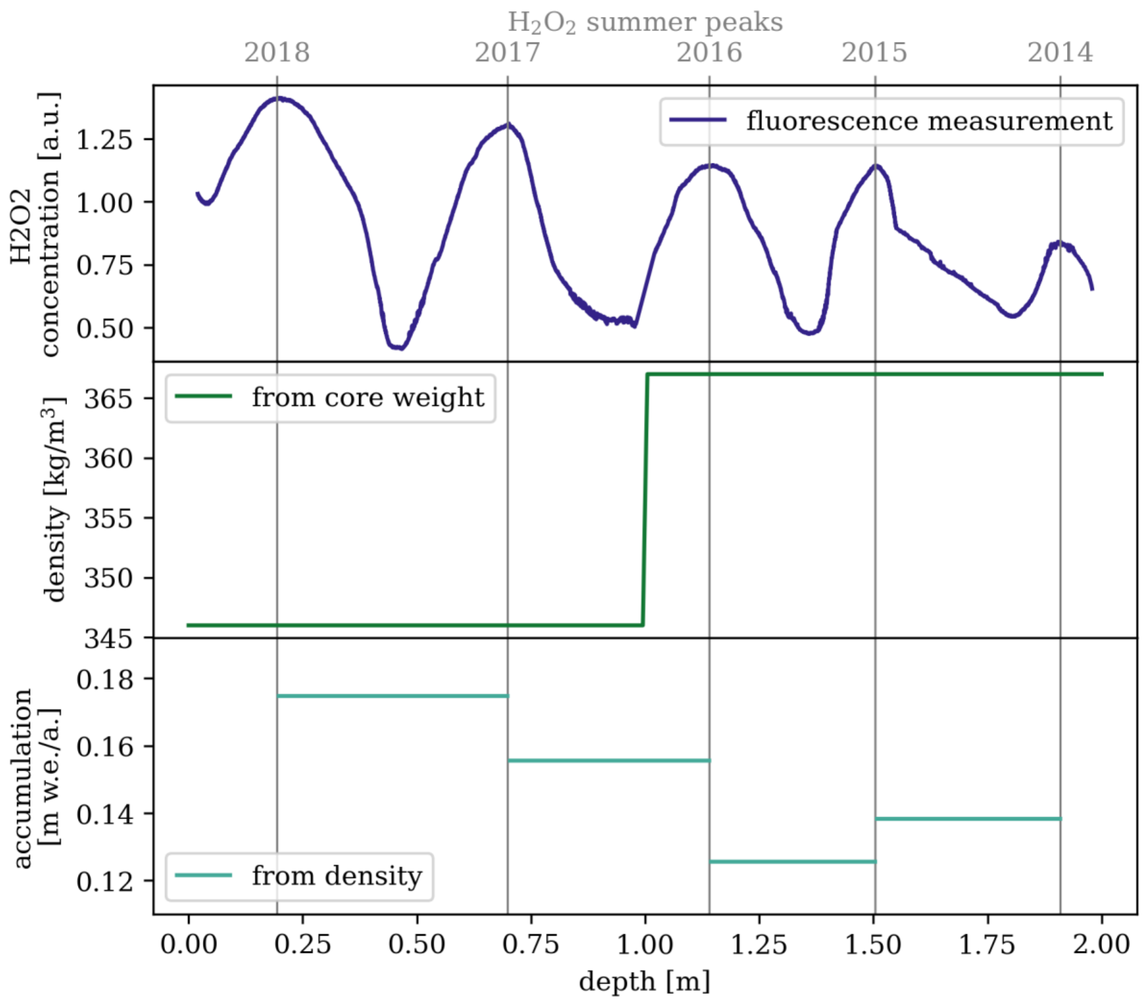
Density from weight

Weigh each core before melting and measure its dimensions

- Gives average density for each core
- Resolution limited by length of core

Combine with depth scale obtained from chemical impurities

- Accumulation variability with annual resolution



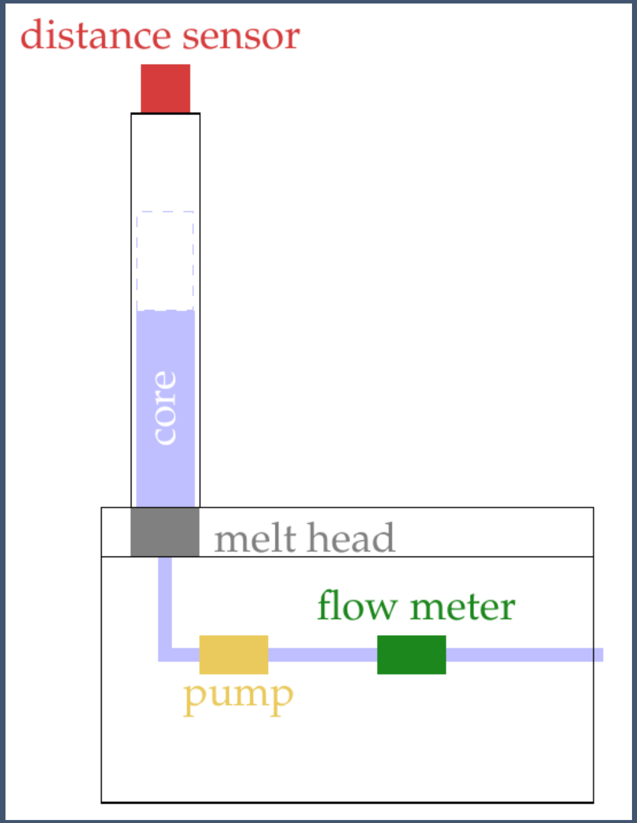
Data from: Kjær, H. A., Lolk Hauge, L., Simonsen, M., Yoldi, Z., Koldtoft, I., Hörhold, M., Freitag, J., Kipfstuhl, S., Svensson, A., and Vallelonga, P.: A portable lightweight in situ analysis (LISA) box for ice and snow analysis, The Cryosphere, 15, 3719–3730, https://doi.org/10.5194/tc-15-3719-2021, 2021.

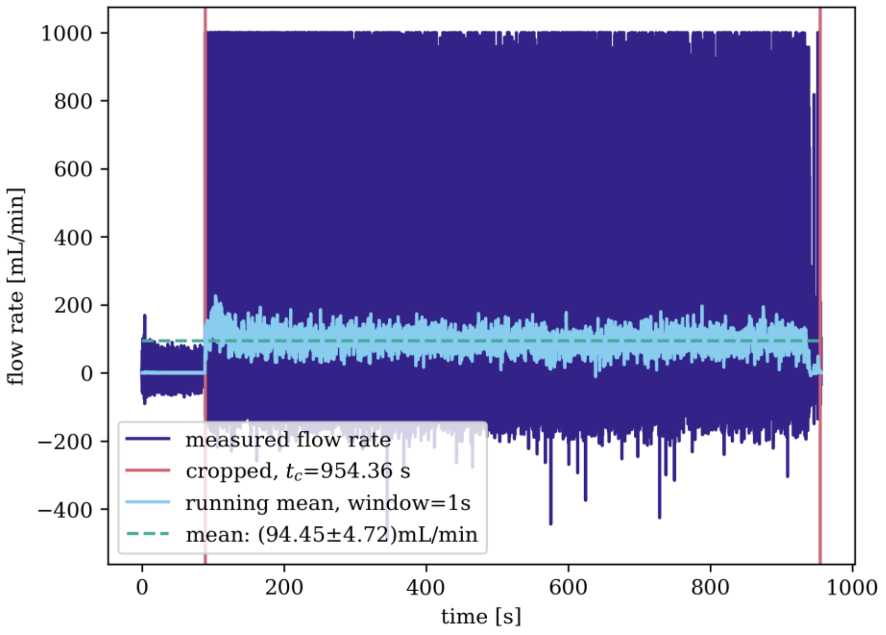
Density from flow

Measure core dimensions before melting and measure flow of waste line meltwater continuously

Combine with depth scale obtained from chemical impurities
- ➢ Gives volume and average mass (and thus density) for core segment at any depth
- ➢ Resolution limited by resolution of depth- and flow measurement

Challenges:
- Pump rate is set high to avoid overflow at melt head
  - ➢ Flow meter has to function with bubbles in melt water
- Pump pulsates strongly
  - ➢ flow meter has to cover wide range of flow rates

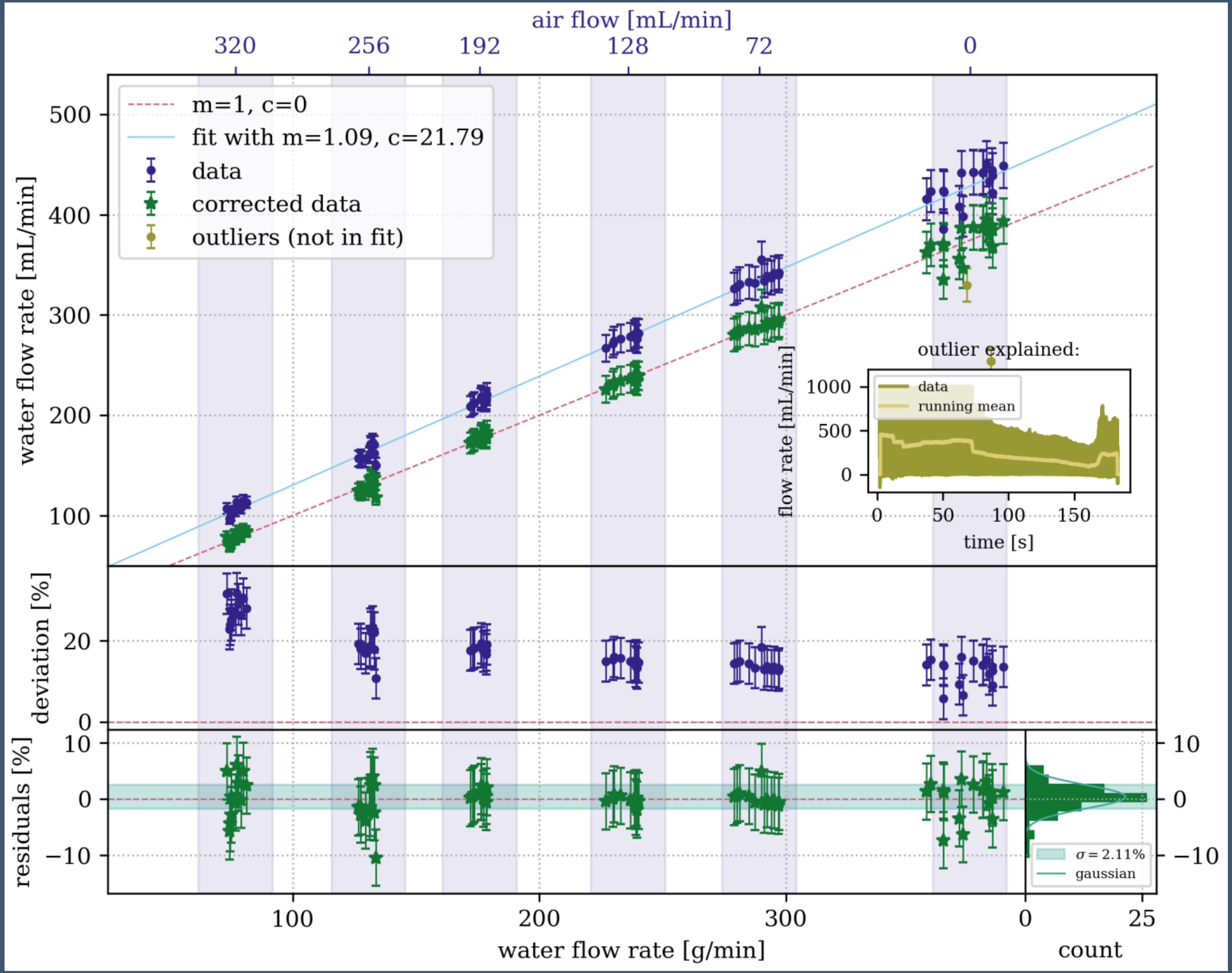


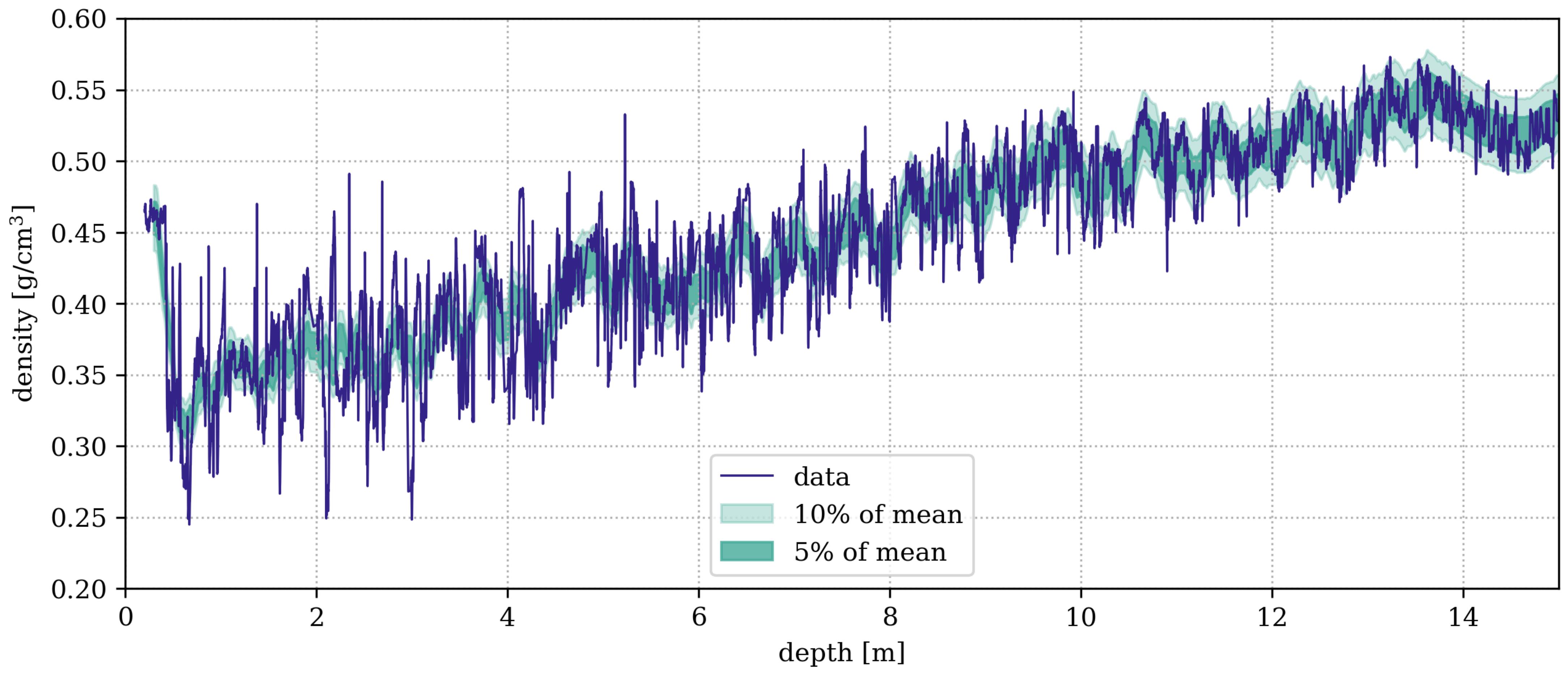


Above: flow rate during the melting of a section of test ice

Right: calibration for different ratios sample water to air bubbles

Conclusion: linear correction for flow meter measurements

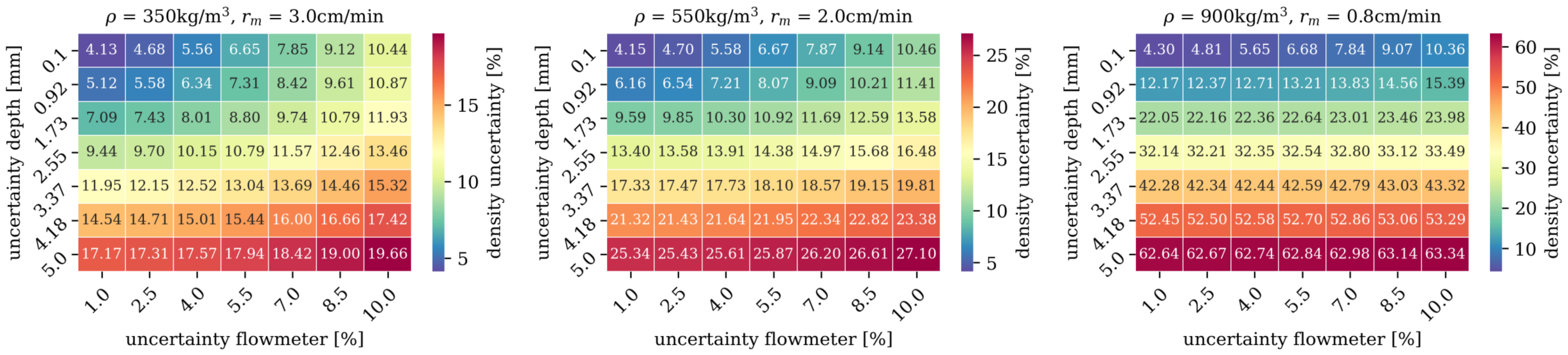




Miller, Heinz; Schwager, Matthias (2000): Density of ice core ngt37C95.2 from the North Greenland Traverse. doi:10.1594/PANGAEA.57798

Exemplary high resolution **density profile** obtained through measurements of gamma ray attenuation

Core radius: (50 ± 1) mm



ρ = 350kg/m^3, r_m = 3.0cm/min

uncertainty depth [mm] \ uncertainty flowmeter [%]	1.0	2.5	4.0	5.5	7.0	8.5	10.0
0.1	4.13	4.68	5.56	6.65	7.85	9.12	10.44
0.92	5.12	5.58	6.34	7.31	8.42	9.61	10.87
1.73	7.09	7.43	8.01	8.80	9.74	10.79	11.93
2.55	9.44	9.70	10.15	10.79	11.57	12.46	13.46
3.37	11.95	12.15	12.52	13.04	13.69	14.46	15.32
4.18	14.54	14.71	15.01	15.44	16.00	16.66	17.42
5.0	17.17	17.31	17.57	17.94	18.42	19.00	19.66

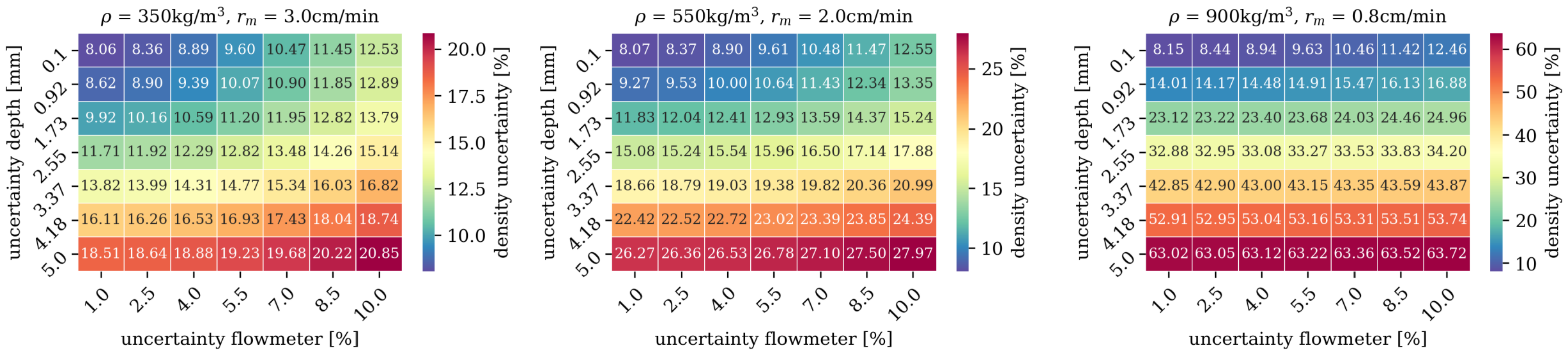
ρ = 550kg/m^3, r_m = 2.0cm/min

uncertainty depth [mm] \ uncertainty flowmeter [%]	1.0	2.5	4.0	5.5	7.0	8.5	10.0
0.1	4.15	4.70	5.58	6.67	7.87	9.14	10.46
0.92	6.16	6.54	7.21	8.07	9.09	10.21	11.41
1.73	9.59	9.85	10.30	10.92	11.69	12.59	13.58
2.55	13.40	13.58	13.91	14.38	14.97	15.68	16.48
3.37	17.33	17.47	17.73	18.10	18.57	19.15	19.81
4.18	21.32	21.43	21.64	21.95	22.34	22.82	23.38
5.0	25.34	25.43	25.61	25.87	26.20	26.61	27.10

ρ = 900kg/m^3, r_m = 0.8cm/min

uncertainty depth [mm] \ uncertainty flowmeter [%]	1.0	2.5	4.0	5.5	7.0	8.5	10.0
0.1	4.30	4.81	5.65	6.68	7.84	9.07	10.36
0.92	12.17	12.37	12.71	13.21	13.83	14.56	15.39
1.73	22.05	22.16	22.36	22.64	23.01	23.46	23.98
2.55	32.14	32.21	32.35	32.54	32.80	33.12	33.49
3.37	42.28	42.34	42.44	42.59	42.79	43.03	43.32
4.18	52.45	52.50	52.58	52.70	52.86	53.06	53.29
5.0	62.64	62.67	62.74	62.84	62.98	63.14	63.34

Core radius: (50 ± 2) mm



ρ = 350kg/m^3, r_m = 3.0cm/min

uncertainty depth [mm] \ uncertainty flowmeter [%]	1.0	2.5	4.0	5.5	7.0	8.5	10.0
0.1	8.06	8.36	8.89	9.60	10.47	11.45	12.53
0.92	8.62	8.90	9.39	10.07	10.90	11.85	12.89
1.73	9.92	10.16	10.59	11.20	11.95	12.82	13.79
2.55	11.71	11.92	12.29	12.82	13.48	14.26	15.14
3.37	13.82	13.99	14.31	14.77	15.34	16.03	16.82
4.18	16.11	16.26	16.53	16.93	17.43	18.04	18.74
5.0	18.51	18.64	18.88	19.23	19.68	20.22	20.85

ρ = 550kg/m^3, r_m = 2.0cm/min

uncertainty depth [mm] \ uncertainty flowmeter [%]	1.0	2.5	4.0	5.5	7.0	8.5	10.0
0.1	8.07	8.37	8.90	9.61	10.48	11.47	12.55
0.92	9.27	9.53	10.00	10.64	11.43	12.34	13.35
1.73	11.83	12.04	12.41	12.93	13.59	14.37	15.24
2.55	15.08	15.24	15.54	15.96	16.50	17.14	17.88
3.37	18.66	18.79	19.03	19.38	19.82	20.36	20.99
4.18	22.42	22.52	22.72	23.02	23.39	23.85	24.39
5.0	26.27	26.36	26.53	26.78	27.10	27.50	27.97

ρ = 900kg/m^3, r_m = 0.8cm/min

uncertainty depth [mm] \ uncertainty flowmeter [%]	1.0	2.5	4.0	5.5	7.0	8.5	10.0
0.1	8.15	8.44	8.94	9.63	10.46	11.42	12.46
0.92	14.01	14.17	14.48	14.91	15.47	16.13	16.88
1.73	23.12	23.22	23.40	23.68	24.03	24.46	24.96
2.55	32.88	32.95	33.08	33.27	33.53	33.83	34.20
3.37	42.85	42.90	43.00	43.15	43.35	43.59	43.87
4.18	52.91	52.95	53.04	53.16	53.31	53.51	53.74
5.0	63.02	63.05	63.12	63.22	63.36	63.52	63.72

Density uncertainty for cores of different densities and melt rates from measurement uncertainties of core radius, depth and flow rate.

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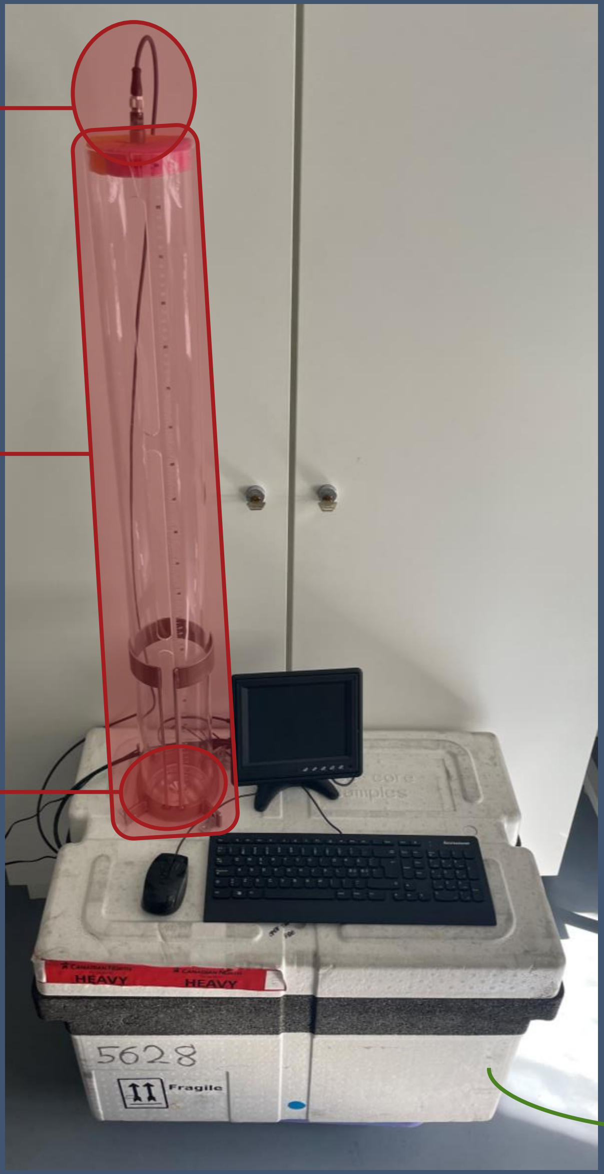
1 2 3

LISA parts

- Explore the different LISA box instruments and their functions

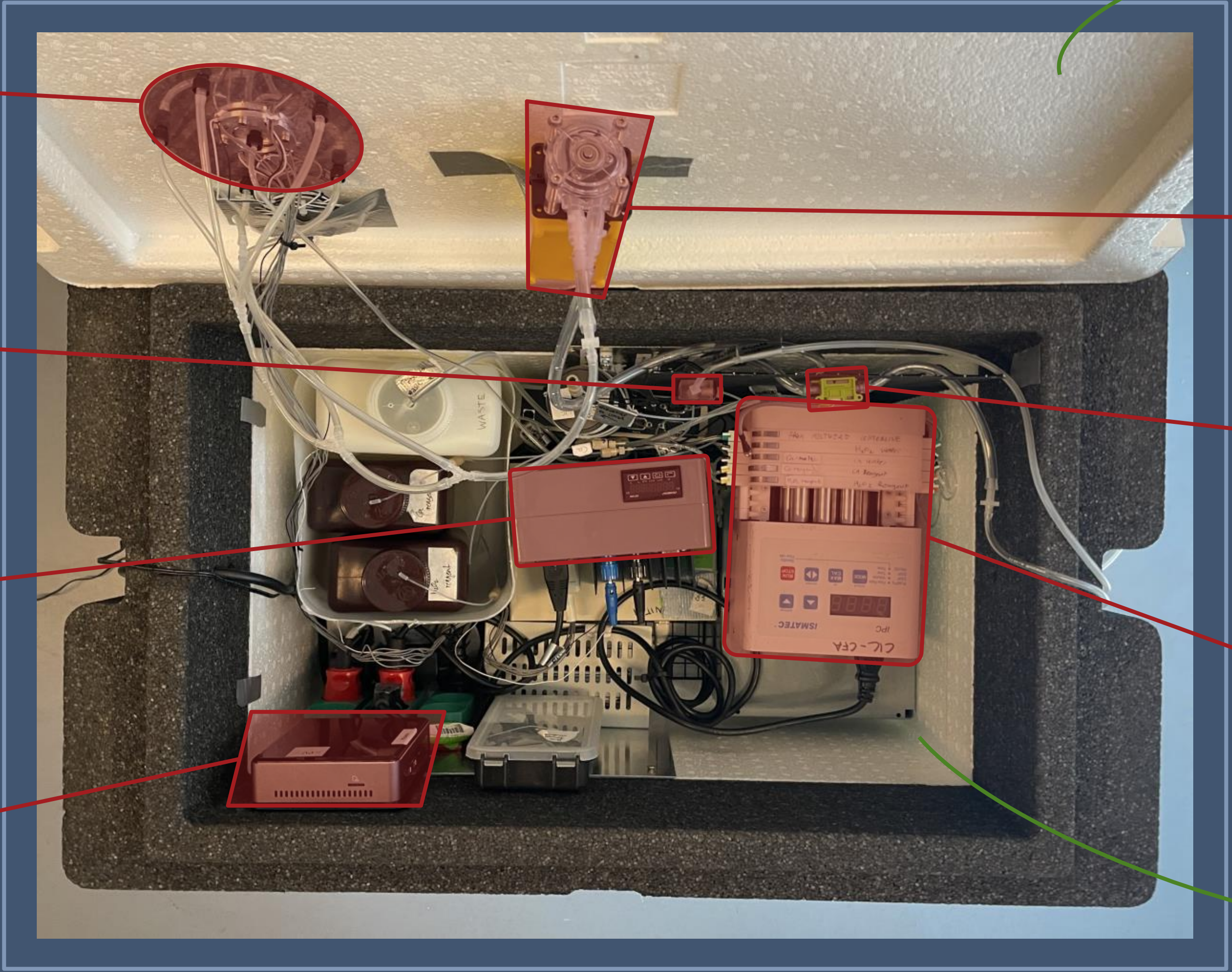


Depth sensor

Core holder

Melt head

Open box



Close box

Melt head

Outer line pump

Debubbler

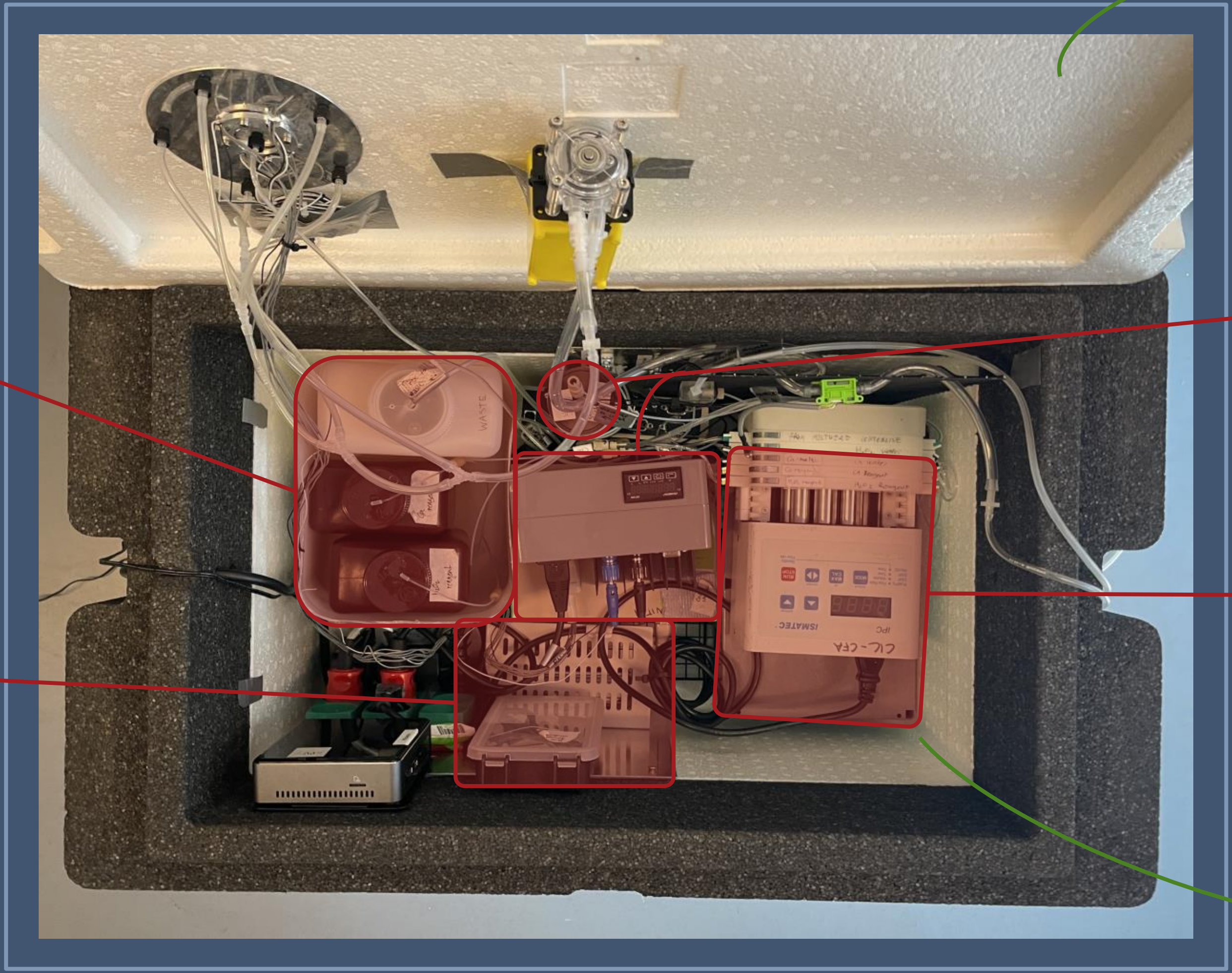
Flow meter

Proportional integral derivative device

Peristaltic pump

Computer

Look at instruments below



Close box

Reagent & waste container

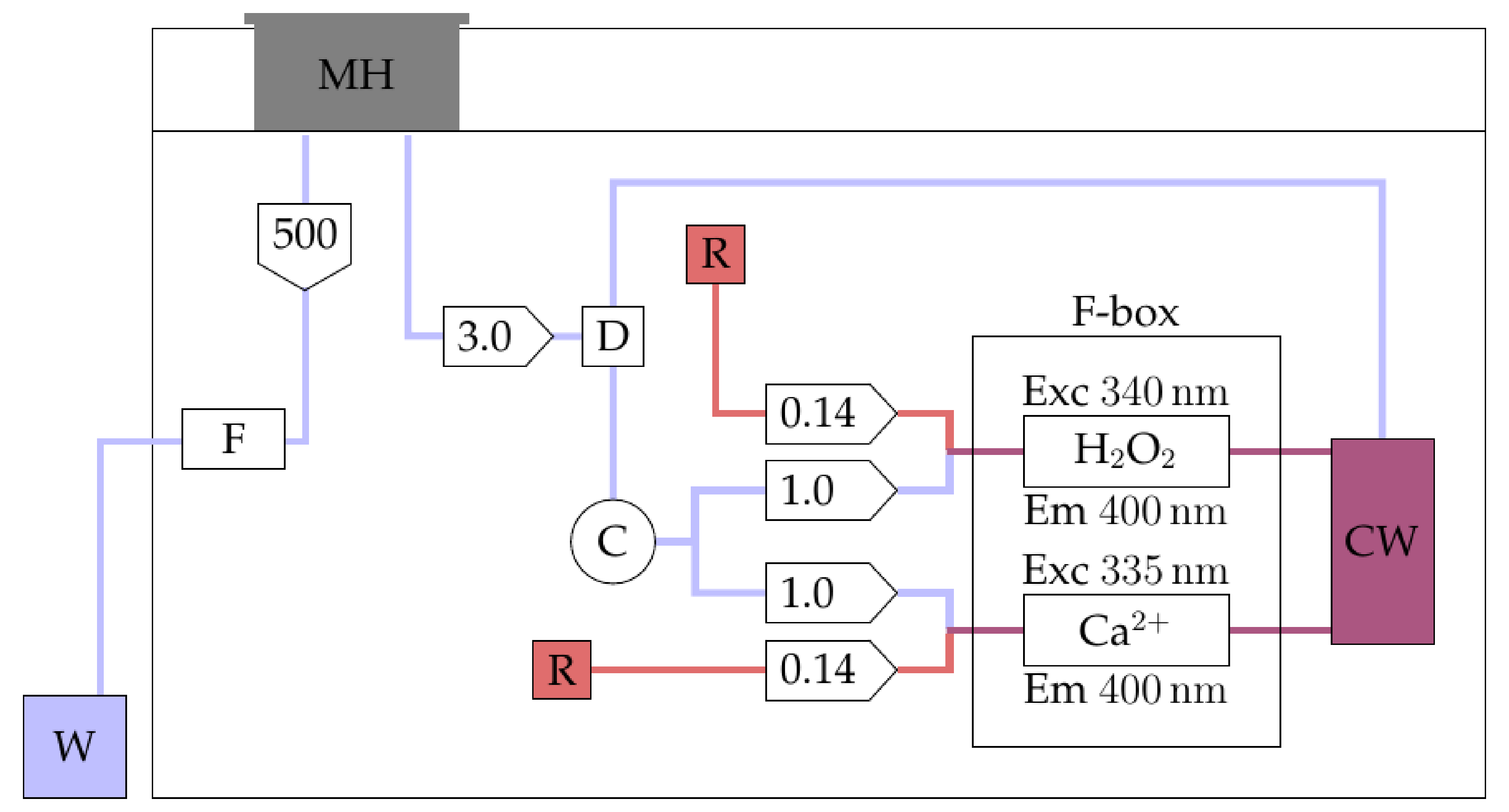
Conductivity meter

Fan heater & thermostat

Fluorescence box

Look at instruments above

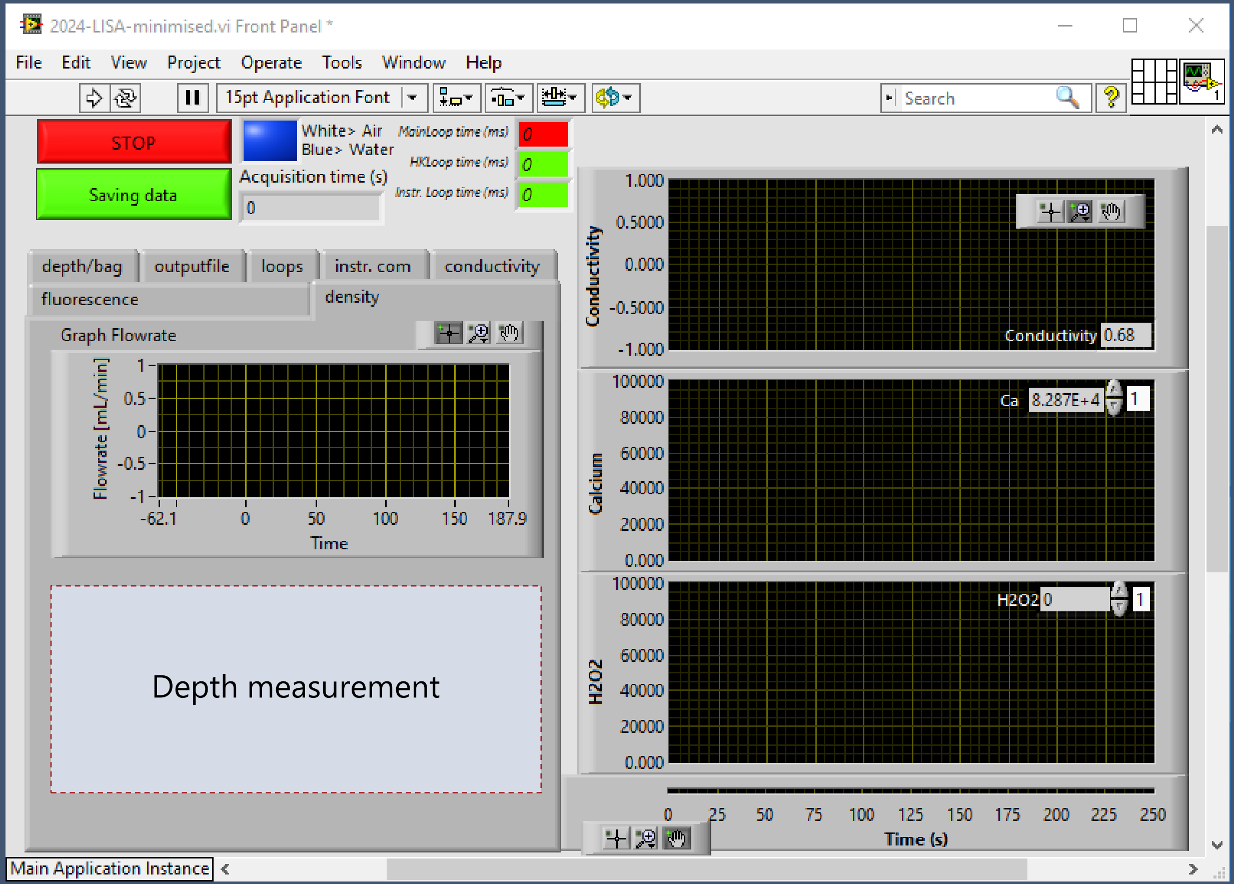
Flow Scheme



MH: melthead
F: flow meter
W: waste
D: debubbler
C: conductivity meter
R: reagent
CW: chemical waste

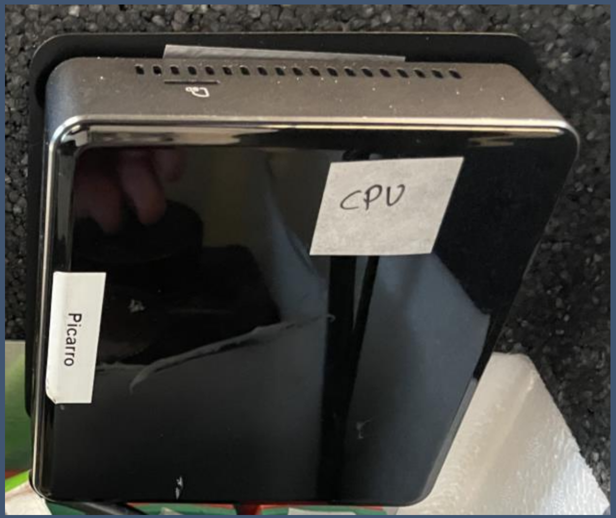
Pump rates (marked by pentagons) are given in mL/min

Computer & LabView Program



MainLoop time (ms) 0
HKLoop time (ms) 0
Instr. Loop time (ms) 0
Acquisition time (s) 0
Conductivity 0.68
Ca 8.287E+4 1
H2O2 0 1

Back to instrument overview



The instruments are read out and monitored via a **LabVIEW program** installed on a small computer that is fixed to the wall inside the LISA box. A screen, mouse and keyboard can be placed next to the box.

Depth registration

Core holder:

- Guides core onto melt head
- Ruler for manual melt speed measurement

Ultrasound sensor:

- Continuous depth measurement
- Higher precision

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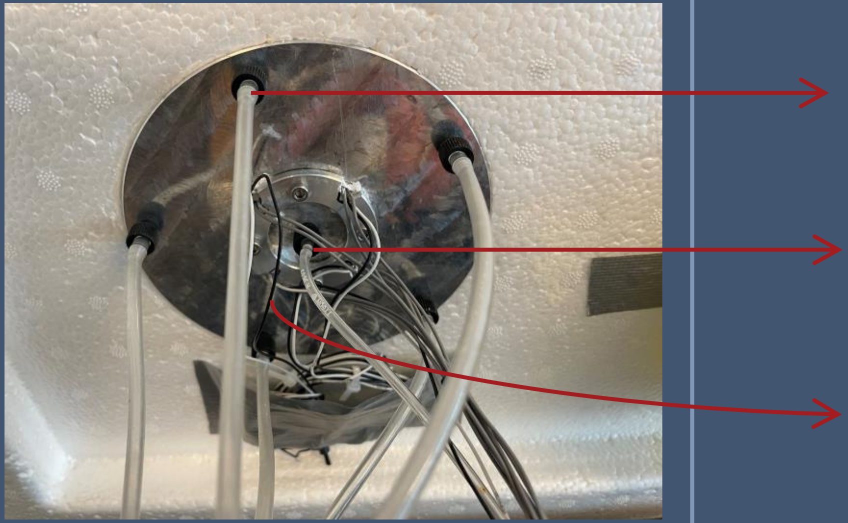
Melt head

- Aluminium
- Outer diameter 14 cm
- Height 7 cm
- Melts full cores of 10 cm diameter



Five outer lines for waste water

One sample line

Four heat cartridges

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Melt head

Melt rate and inner line drainage should be adjusted to generate overflow of inner cone – reduces bubbles

Custom build **Proportional Integral Derivative (PID) device** to control temperature of heat cartridges in melt head

For melting: ~50°C

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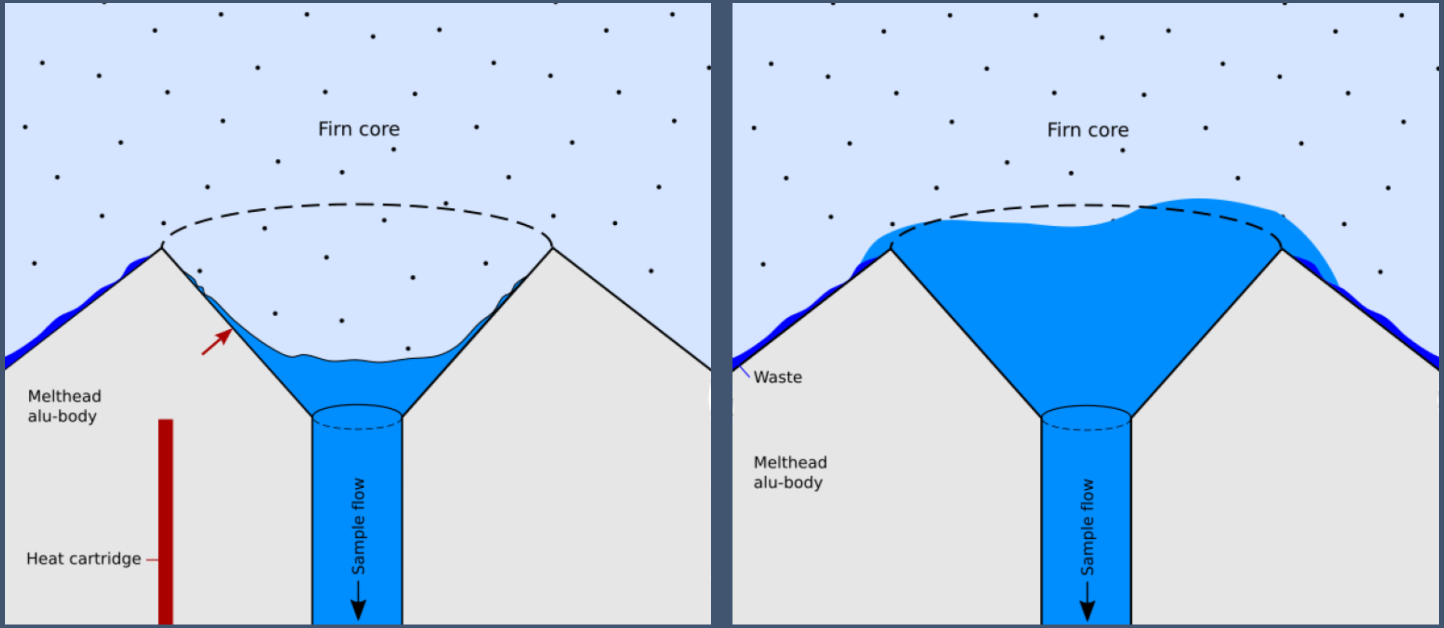

Lolk Hauge, Lisa (2017). *“The Lightweight In-Situ Analysis Box – Constructing a Portable Firn Core Melter for Greenland Snow Accumulation Studies”*. MSc thesis. University of Copenhagen.

1 2 3

Thermostat & fan heater

- Temperature sensor
- Digital controller with display
- Compact fan heater guarded by metal enclosure

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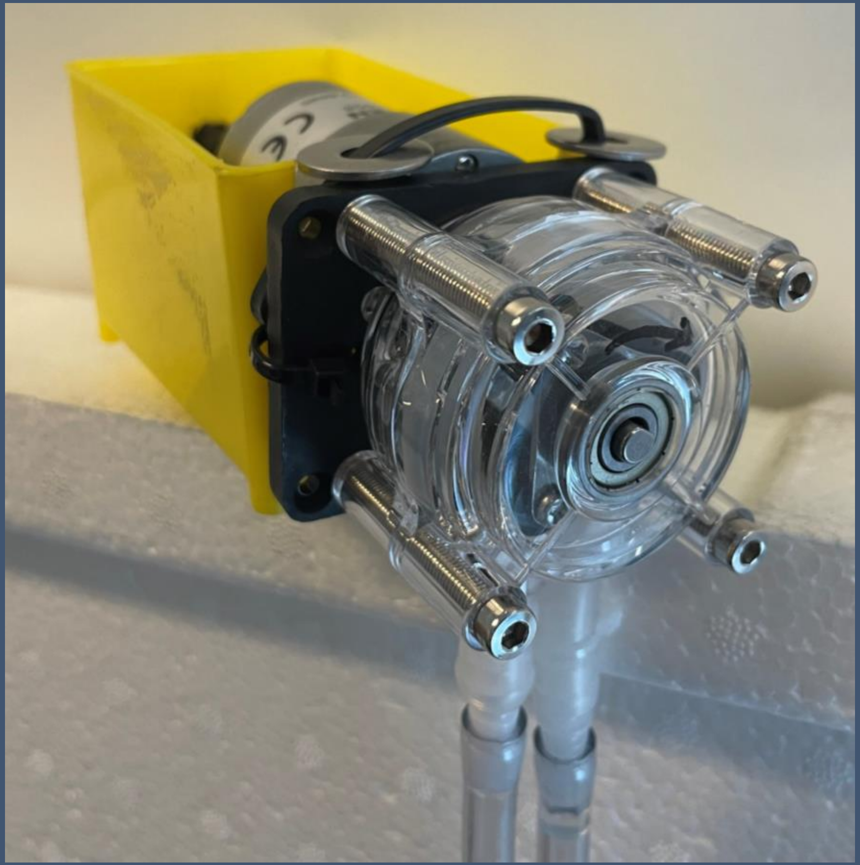
Function:

heating and mixing the air inside the box to a constant ~17°C to allow operation in field conditions.

Warming up the box from frozen takes ~15min.

Outer line pump

Peristaltic pump with 3 rollers
Pump rate: ~500mL/min



Function:

Draining all the meltwater from the five outer lines of the melt head. The pump rate was chosen in consideration of the melt speed to avoid overflow

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Flow meter

Sensirion Liquid Flow Meter
Flow range: 0-600mL/min
Output limit: 1000mL/min

Function:

Continuous measurement of outer line flow rate to obtain the full volume of melt water produced by each sample segment.
This is used to estimate the density variation throughout the sample

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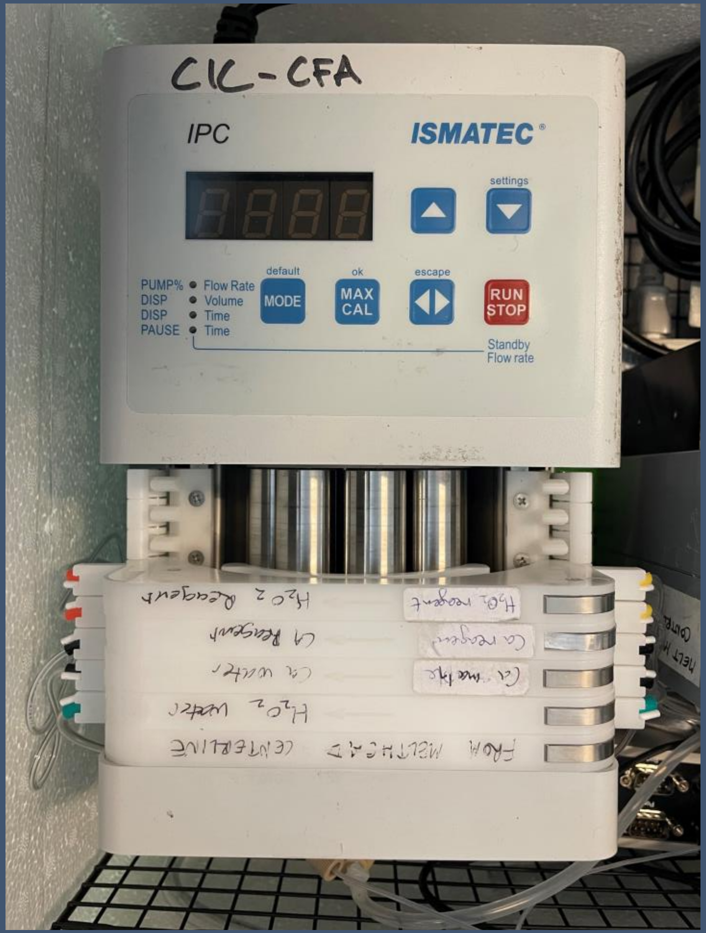
Peristaltic pump

8 roller peristaltic pump from Ismatec
8 channels with different pump rates

Function:

Pumps sample water from the inner line and reagents through the system for continuous flow analysis



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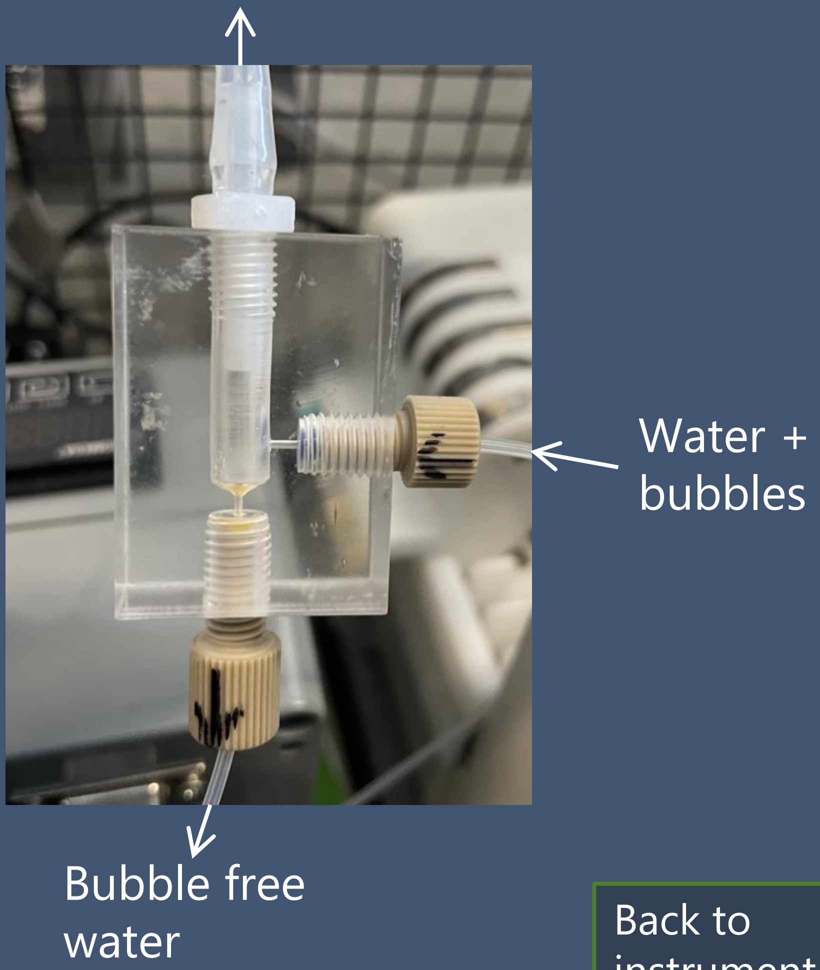
Debubbler



Fixed volume debubbler

Function:

melt water with bubbles is pumped in from the side at a rate of mL/min and bubble free water is pumped at 1mL/min from the bottom of the open volume. The top is left open as an overflow for air and water

Back to instrument overview

Conductivity meter

Function:

Measures ionic bulk signal of meltwater as the reciprocal of resistance. Since ionic movement increases with temperature, the conductivity measurement in liquids is temperature dependent, but the conductivity meter has a buildt in thermometer and calibrates accordingly.

Why conductivity?

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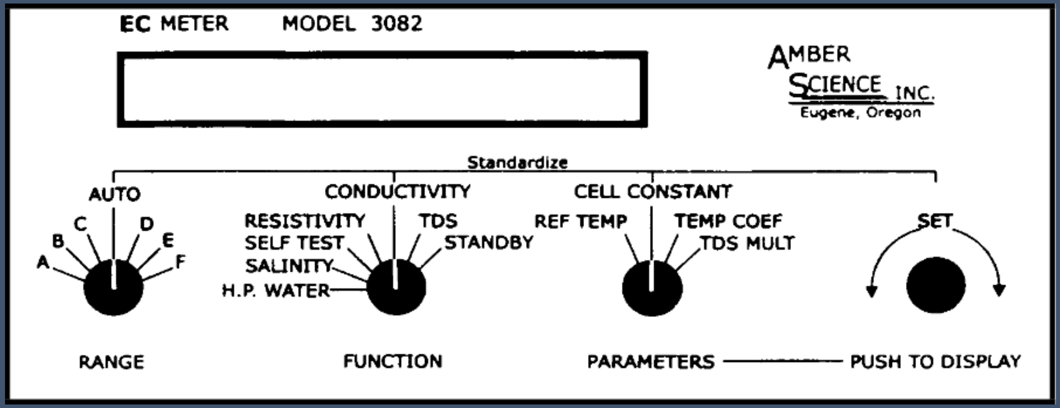
Flow cell

EC meter



Reagents and Chemical Waste

H_2O_2 reagent:
4-ethylphenol
Peroxidase type II
H_3BO_3
KCl
NaOH (30 %)

Ca reagent:
QUIN-2 potassium hydrate
PIPES
NaOH (30 %)

The sample is mixed with chemicals and collected in a 2L waste container, so it can be disposed of after the field day. Around 2.3mL waste water is produced per minute – if cores melt with 3cm/min, the container has to be replaced after around 29m of analysed core.

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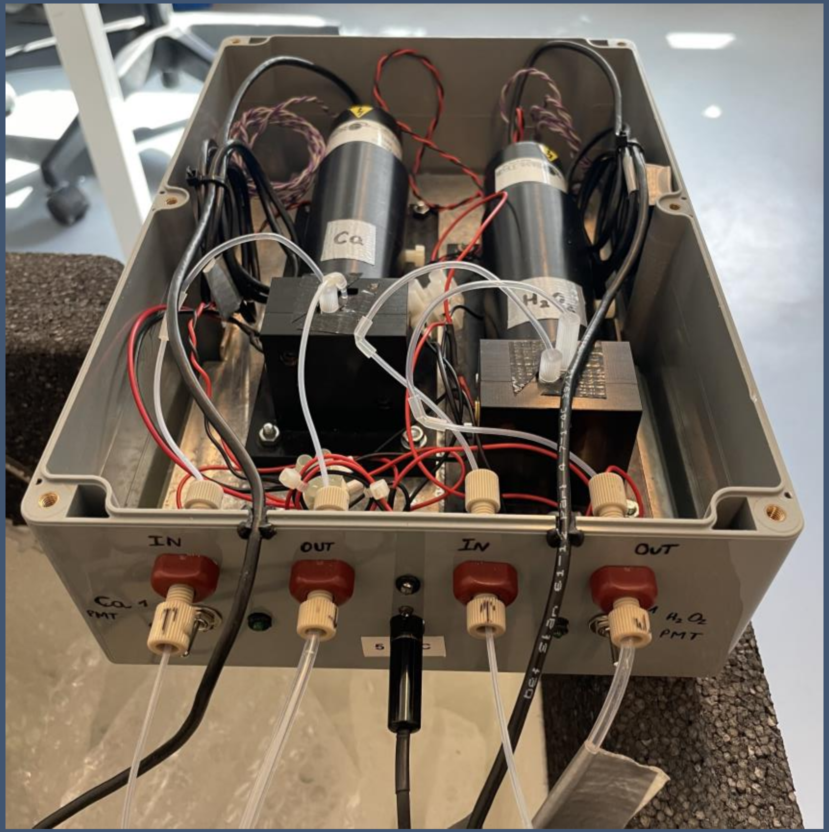

Fluorescence box

Function:

- Sample is mixed with reagent that reacts with the species to be measured, inducing fluorescence if it is present
- Fluorescence is detected in fluorescence cell consisting of a cuvette, an LED and a photomultiplier tube (PMT)
- Resulting signal is proportional to concentration of species to be measured

Purpose:

measure concentration of calcium and hydrogen peroxide

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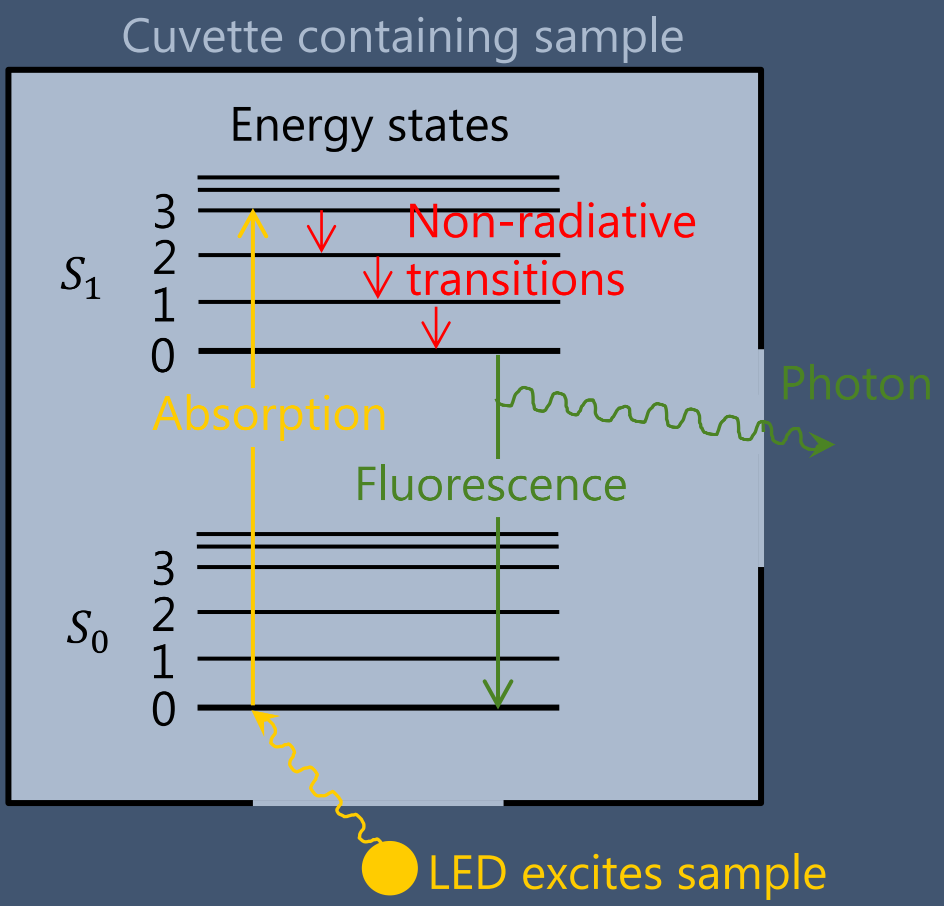
How does the fluorescence cell work?

Why calcium?

Why hydrogen peroxide?

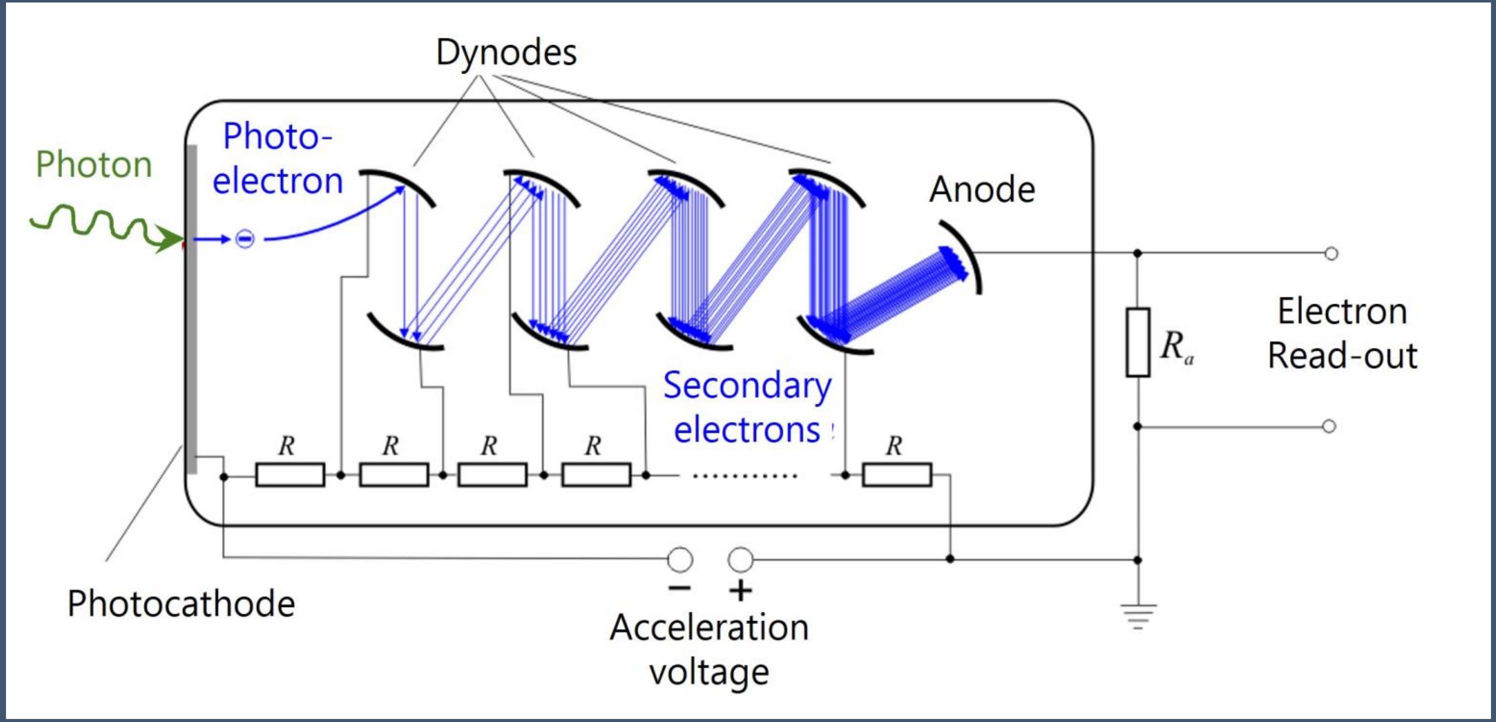
Fluorescence detection



The fluorescent sample in the cuvette is excited to an **energetically higher state** using an LED, causing it to **emit photons** at a lower wavelength when it transitions back to its ground state.

Fluorescence detection

The emitted photons enter the **PMT** where they hit a **photosensitive surface**, generating **photoelectrons**. These photoelectrons are then **accelerated** as they pass through a series of dynodes with increasing voltage, causing the release of more **secondary electrons** at each stage. The resulting **amplified signal** is collected by the anode for measurement



https://study.com/academy/lesson/how-photomultiplier-tubes-array-detectors-work.html

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LISAbox paper (2021):

Kjær, H. A., Lolk Hauge, L., Simonsen, M., Yoldi, Z., Koldtoft, I., Hörhold, M., Freitag, J., Kipfstuhl, S., Svensson, A., and Vallelonga, P.: A portable lightweight in situ analysis (LISA) box for ice and snow analysis, The Cryosphere, 15, 3719–3730, https://doi.org/10.5194/tc-15-3719-2021, 2021.

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