

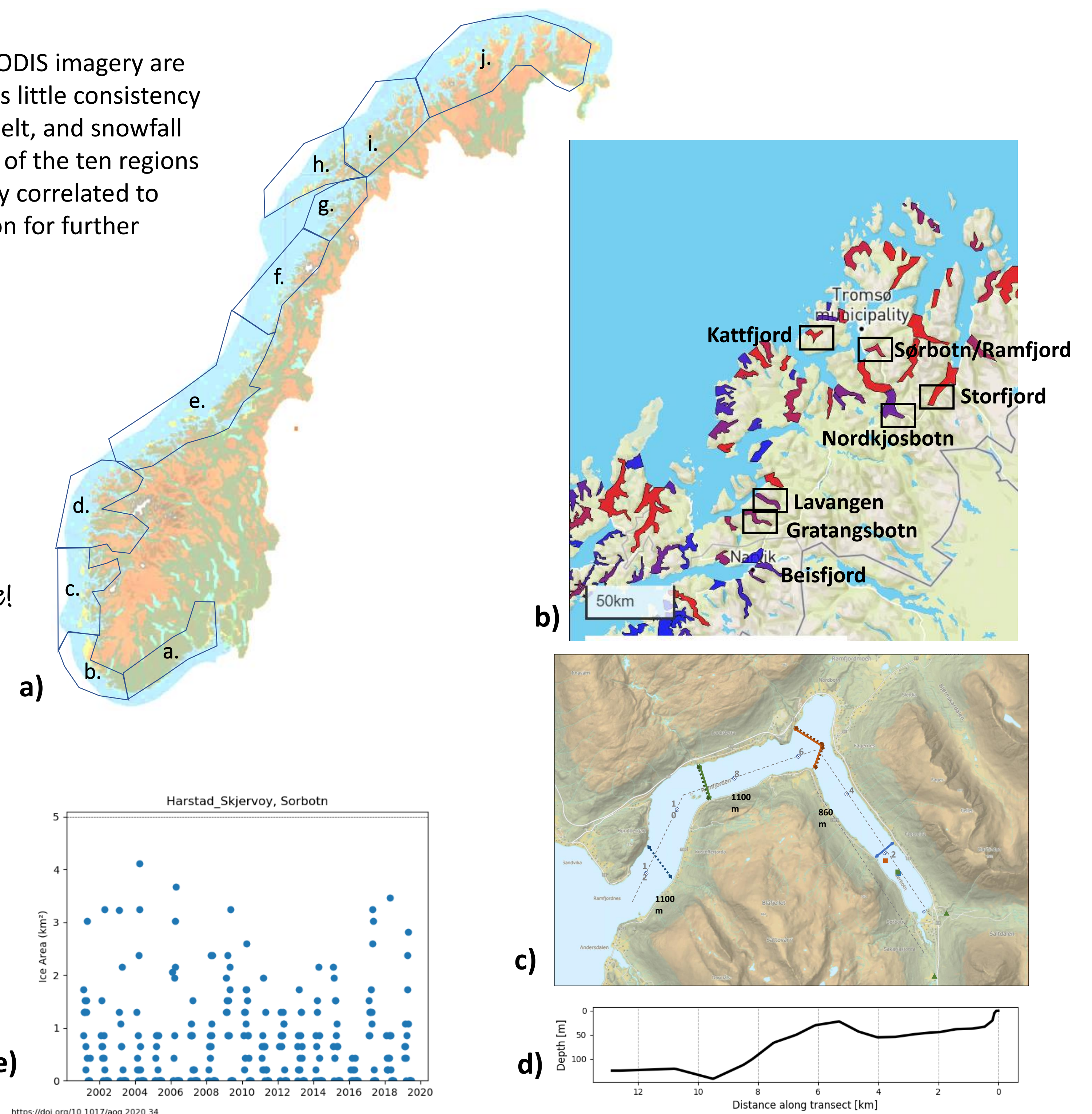
Where is the ice? And Why?

In O'Sadnick et al. (2020), estimations of ice extent along the coast of Norway since 2001 determined from MODIS imagery are presented. From our findings, it is evident that the amount of ice in one fjord over time often varies and shows little consistency leading to the next question of 'Why'? The study continues to relate freezing degree days, rainfall plus snowmelt, and snowfall to values of ice area to determine if significant correlations exist when fjords are grouped into regions. Six out of the ten regions were significantly positively correlated to freezing degree days ($p < 0.05$). Ice area in two regions was positively correlated to daily new snowfall, and in one region negatively correlated to rainfall plus snowmelt. Please see the publication for further description of methods and findings.

Figure 1 (right) – a) outline of regions examined in O'Sadnick et al. (2020); b) the Harstad – Skjervøy region (i) with the seven fjords where measurements were gathered marked; c) Ramfjord with ice extent in 2017/18 (blue), 2018/19 (green), and 2019/20 (red) marked. Solid line is extent on day visited, dashed line is maximum extent determined from MODIS and Sentinel imagery. d) Water depth along fjord, number on horizontal axis corresponds to those on (c). e) Ice extent since 2001 used in O'Sadnick et al. (2020) and accessed at: <https://ndat.no/fjords/ice/>

Table 1 (below): Correlation and significance between three variables as summarized in O'Sadnick et al. (2020) for the Harstad- Skjervøy region as a whole and specifically Sørbotn/Ramfjord. The strongest correlation was to freezing degree days although it did not meet the requirement of $p < 0.05$ to show significance. QA and State QA refers to data used in filtering, please see paper for further description.

	Ice Area and Freezing Degree Days		Ice Area and Rain + Snowmelt		Ice Area and Snowfall	
	QA/State QA	QA	QA/State QA	QA	QA/State QA	QA
Harstad-Skjervøy (i)	0.414 (0.078)	0.088 (0.721)	-0.13 (0.595)	-0.001 (0.997)	0.121 (0.623)	-0.221 (0.364)
Ramfjord	0.380 (0.109)	0.296 (0.219)	-0.241 (0.321)	-0.019 (0.940)	-0.157 (0.521)	-0.056 (0.819)

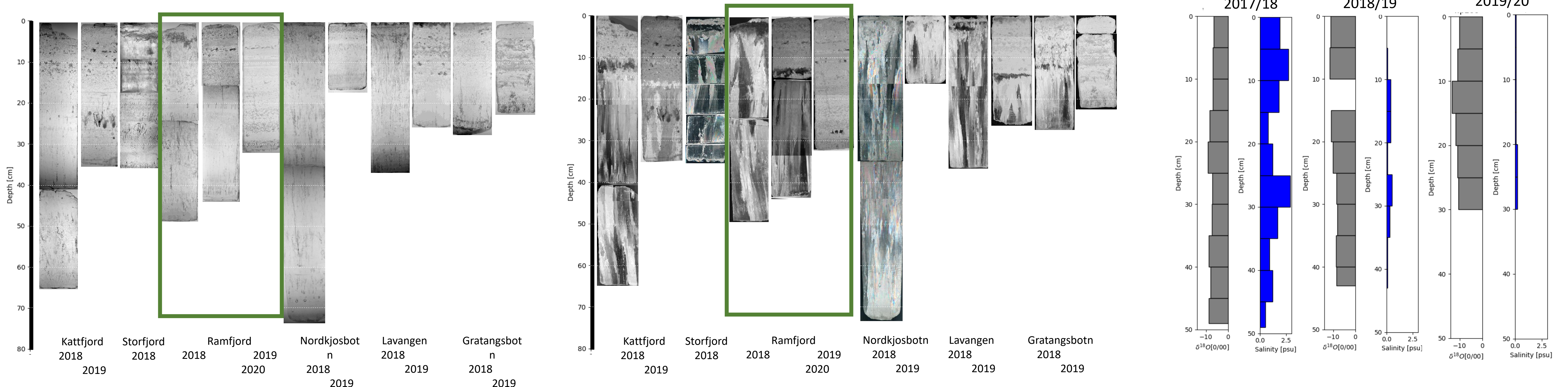


Have a fjord you're curious about? Go here!

How does ice compare in thickness, structure, texture and bulk properties?

The next step is to better understand not only where ice exists but the properties of the ice and, relatedly, what factors lead to ice formation each year. Seven fjords between Narvik and Tromsø, Norway have been studied: Beisfjord, Gratangsbotn, Lavangen, Nordkjosbotn, Storfjord, Ramfjord, and Kattfjord. Over three winters spanning 2017 – 2020, measurements of ice thickness, salinity, $\delta^{18}O$, texture, and microstructure were gathered. Analysis of these cores, what they tell us about mechanisms for fjord ice formation and how this relates to ice area throughout Norway is ongoing with some of the factors being considered summarized below.

Figure 2 (below): a) thick sections of cores gathered at six out of the seven fjords between the 2017/18 to the 2019/2020 season with differences in ice microstructure apparent. b) thick sections through cross-polarized filters to show ice texture. The three cores gathered in Ramfjord are outlined in green in both. c) Salinity and $d^{18}O$ profiles of each Ramfjord core.



Ice Microstructure: How does pore shape (elongated or spherical), size (big or small, density), & connectivity compare?

Ice texture- How much granular ice in comparison to conglation ice?

Ice Properties – how do bulk ice salinity and $\delta^{18}O$ compare and what can this tell us about how ice formed and how quickly?

What factors must be considered?

- ❖ Air temperature
- ❖ Freshwater flux – rainfall plus snowmelt
 - ❖ Snowfall
- ❖ River size and distribution
 - ❖ Wind
- ❖ Ocean currents and tides
 - ❖ Ocean temperature
- ❖ Size and shape of watershed surrounding fjord
 - ❖ Fjord bathymetry
 - ❖ And?

Where is this work of use?

- ❖ Operations along the coast of Norway
 - ❖ Oil spill and emergency response- interaction of oil with different ice types
 - ❖ Movement of boats unequipped to break through ice
- ❖ Construction around and across fjords - ex. Bridge across Ramfjord, use of Kattfjord for transport of wind turbines
- ❖ Ice fishing and other local uses – safety and expectations for the future
- ❖ Fish farming – impact of ice on operations, the ecology of the fjord through time if ice conditions change
- ❖ Broader application to coastal regions outside of Norway where freshwater may impact formation of ice and ice properties.