UiT NORGES ARKTISKE UNIVERSITET

CIRFA

norut NORTHERN RESEARCH INSTITUTE NARVIK

The Research Council of Norway

HAVFORSKNINGSINSTITUTTET INSTITUTE OF MARINE RESEARCH

Examination of Sea Ice Cover in Norwegian Fjords

M. O'Sadnick[1,2], C. Petrich[1], C. Brekke[2] & J. Skarðhamar[3]

[1] Northern Research Institute (Norut) Narvik, Narvik, Norway
[2] UiT The Arctic University of Norway, Tromsø, Norway
[3] Institute for Marine Research, Bergen, Norway

/ ABSTRACT

Presented are two steps being taken to examine sea ice coverage in Norwegian fjords as part of a larger study to improve our understanding of ice formation and breakup processes in these regions and implications for oil spill response (Fig. 1 offers one example). First, working with Google Earth Engine, MODIS images will be analyzed to determine where and when seasonal ice formation occurred along the Norwegian coastline since 2000. Here we summarize a simple method developed to quantify ice area in these regions to examine trends through the ice season and between years. While the larger study will cover a number of fjords, as an example focus is placed on Efjord, located in Nordland county, which has experienced large variations in ice coverage between years. We discuss the use of other datasets to determine the causes of such fluctuations focusing on the close relationship between run-off and ice cover in Efjord.

Second, measurements of water temperature and salinity and ice thickness, stratigraphy, and salinity will be gathered over a three year period to better understand the ice observed in the MODIS images. The first set of measurements collected in November 2017 before freeze up are discussed below. In addition, initial images collected from time lapse cameras positioned to observe general weather and ocean conditions and the initial freeze up of ice are presented.

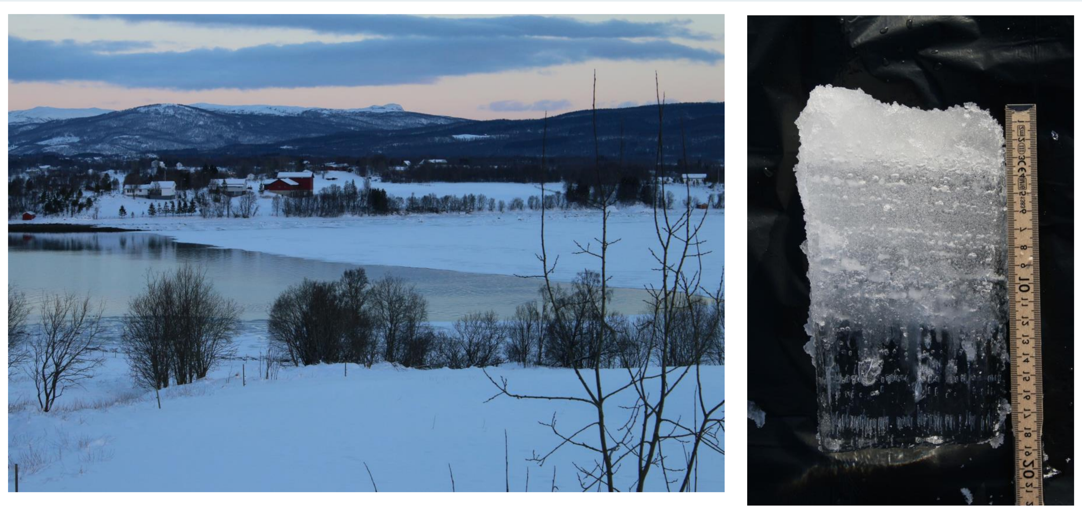


Fig. 1: Left- Ice formation in Trøsen located outside of Fjelldal, Nordland in February 2017. Right – thick section of ice. Bulk salinity of this ice was measured at 2.3 ppt, low in comparison to 'typical' sea ice which often ranges between 5 – 8 ppt. This layer of brackish ice could pose difficulties in predicting the surfacing of oil if a spill were to occur in a nearby area.

/ QUANTIFICATION OF ICE AREA IN NORWEGIAN FJORDS

To determine where ice forms along the Norwegian coastline, particularly fjords, Google Earth Engine is used to import the MOD09A1.006 Surface Reflectance 8-Day Global 500m dataset. Images in this data set are pre-processed to include the pixels over an 8 day period with the least amount of influence from cloud cover and aerosol loading. To determine pixels most likely containing ice, we have created an 'Ice Band' equal to the sum of band 6 (λ = 1652 nm) and band 7 (λ = 2,155 nm) subtracted from band 3 (λ = 479 nm). The two former bands are absorbed by ice while the latter is reflected. In addition bands 6 and 7 are reflected by clouds helping to filter out any remaining influence from clouds. As a result, ice is accentuated. Next, pixels having ice band values above 0.3, a threshold established by manually examining images, are counted and the total area of ice calculated.

Using this method, we can approximate ice extent and examine variations throughout the winter season and between years. We plan to further examine such variations by comparing findings to other climatological and oceanographic measurements including bathymetry, freshwater flux, climatic conditions, tides, and currents . One example of a fjord with unique behavior is Efjord. In Fig. 2, images are presented of Efjord in the summer, during a low ice year (2003), and during a high ice year (2002). In Fig. 3, a plot of ice area derived from MODIS images between 2000 and 2017 is provided. Through examining modelled values of runoff, it becomes clear that years of high ice extent occurred when large amounts of precipitation, likely in the form of rain, fell. How this impacts salinity in the water column and eventual ice formation is a question hoped to be answered through in situ measurements.

In future work we plan to examine other fjords in a similar manner. In addition, we will compare our findings of ice extent to modelled values from the Norkyst 800 model to determine its accuracy.

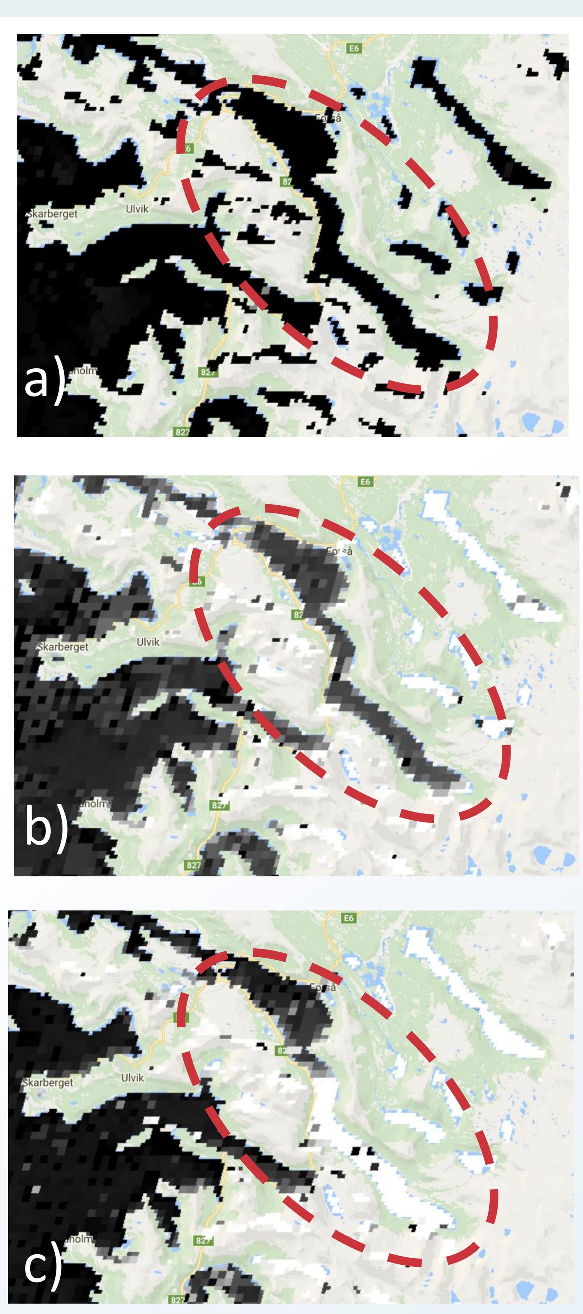


Fig. 2: Images of our 'Ice Band' in a) Summer 2002 when no ice is present b) Winter of 2003, a low ice year and c) Winter of 2002, a high ice year. Ice appears as white and open water as black. Further work is needed to identify the physical characteristics of gray pixels. A land mask was used in analysis but is not shown here.

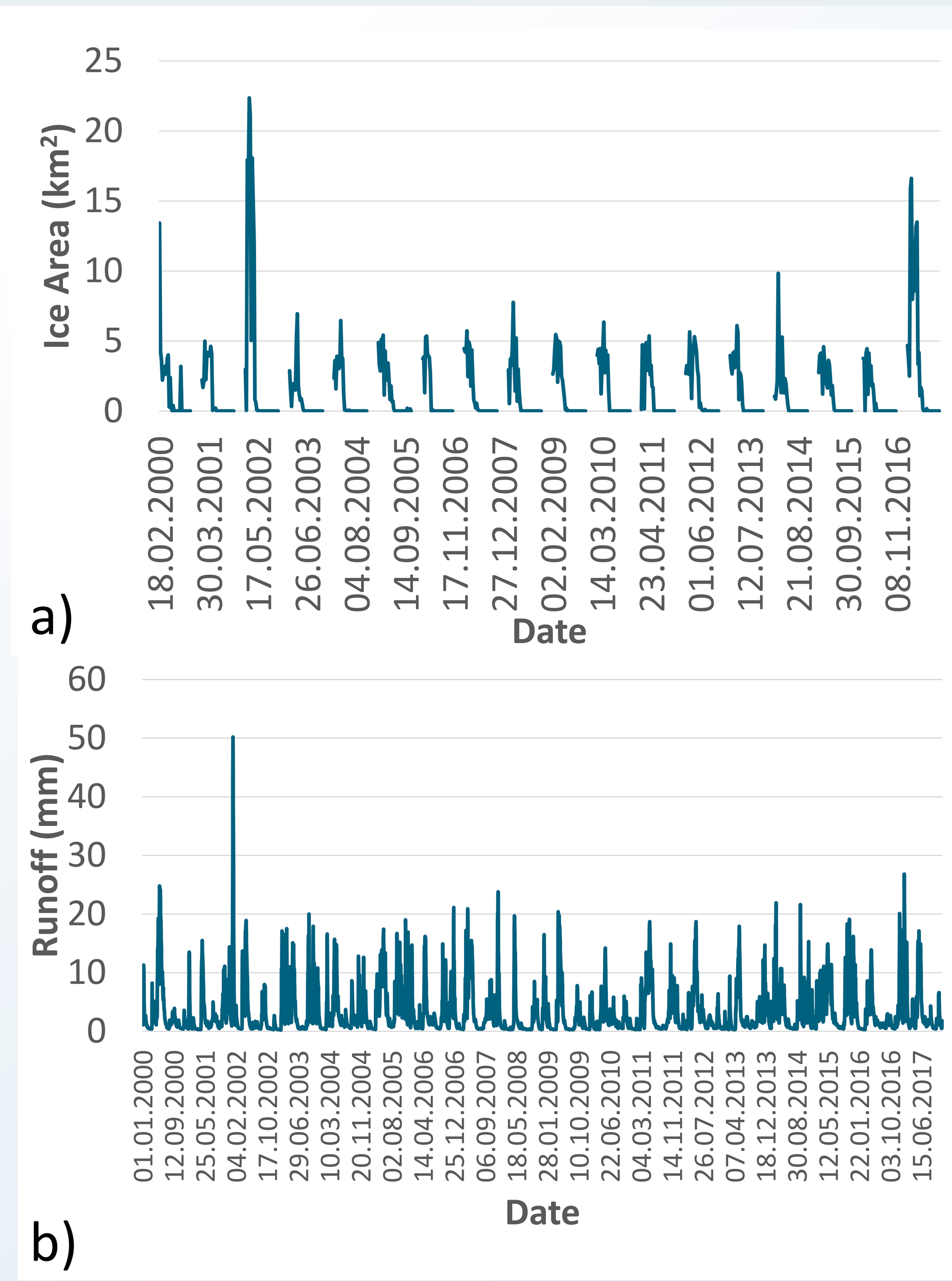


Fig. 3: a) Area of ice derived from MODIS images. Note- from approximately 9 November to 25 January a gap in data exists due to the polar night and resultantly no images being collected during this time. b) Modelled freshwater runoff (= precipitation – evaportranspiration – difference in water storage in soil or snow) developed by the Norwegian Water Resources and Energy Directorate (NVE) in partnership with seNorge and the Norwegian Meteorological Institute.

/ INTRODUCTION

Fjords are generally defined as glacially carved basins partially filled with seawater

- Vary in depth and experience differing combinations of currents, tides, fresh water flux, and atmospheric conditions
- Even those located within close proximity to each other can often be influenced be different oceanic conditions
- Formation of ice or lack of ice provides one indication of how the variables listed above interact.

The fjords dotting the coast of mainland Norway occupy a distinct place in the larger field of fjord oceanography.

- While many are located in the arctic based on latitude, they lack the influence of glaciers and the seasonal ice cover found in regions like Svalbard (Cottier et al., 2010).
- Cannot be grouped with lower latitude fjords either where conditions are warmer and sea ice consistently does not form (Inall & Gillibrand, 2010).

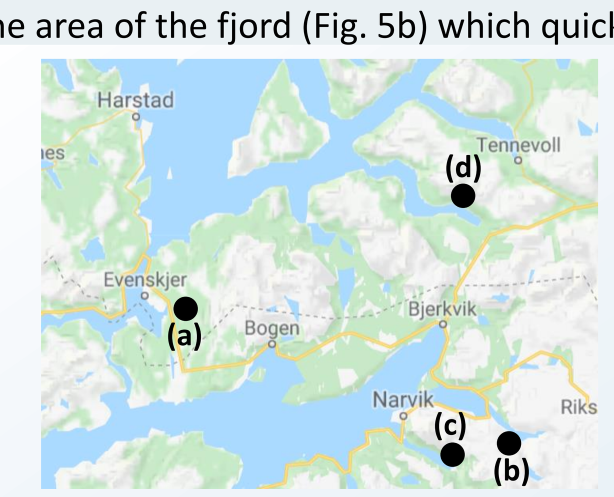
Measurement campaigns have been undertaken to better understand the oceanic conditions specific to these regions (Cushman-Roisin, Asplin, & Svendsen, 1993; Eilertsen & Skardhamar, 2006; Svendsen, 1995; Tverbergl, Cushman-Roisin, & Svendsen, 1991) but these works have not addressed sea ice formation.

Fjords and the ice that has the potential to form, pose a risk due to the complications the latter may cause for ship traffic and the possible impact on response activities if an emergency arises such as an oil spill. Sea ice in fjords is also used for recreational activities and provides training grounds for oil spill response programs.

/ FIELD CAMPAIGN IN LOCAL FJORDS

Field work began in November 2017 and will continue through approximately April of 2021. Measurements of ice thickness and properties along with water temperature and salinity are planned for February through April as historically this is when ice extent is at its greatest. Measurements of water temperature and salinity will be obtained in the late Fall and into Winter to better understand conditions previous to freeze up. To further support our measurements, four time lapse cameras have been placed in fjords located within a short distance to Narvik, Norway. We hope to capture freeze-up, breakup, as well as any other events that may impact these processes (Fig. 4).

The first set of measurements made in a small and relatively shallow fjord (44 m at its deepest) , Beisfjord, were obtained on 13 November 2017 (Fig. 5). Already apparent are regions of higher and lower salinity likely influenced by freshwater input from a large river feeding into the fjord (seen in the right side of Fig. 5a). A thin layer of ice was observed in one area of the fjord (Fig. 5b) which quickly dispersed with rainfall.



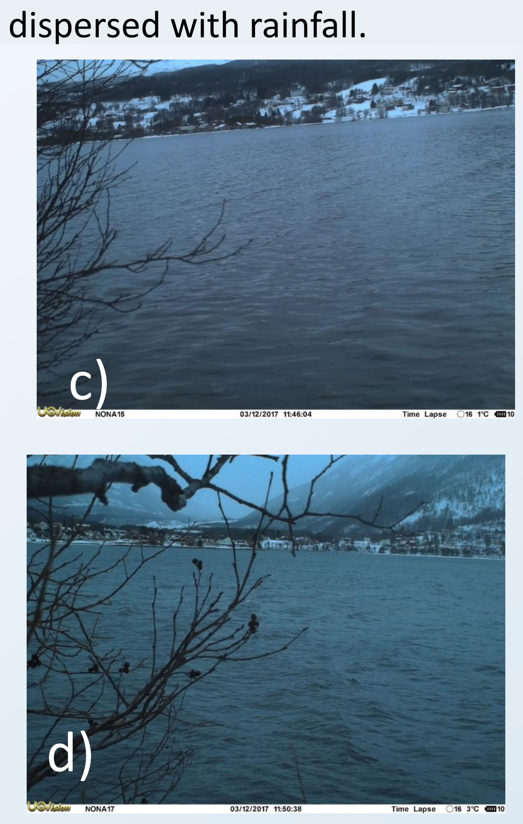


Fig. 4: Above – map showing locations of UOVision UM- 785 field cameras. a) Trøsen, b) Rombaksfjord, c) Gratangsbotn, d) Beisfjord. Images are are collected at 15 minute intervals. One image is transmitted from each camera daily at 12.00 pm and can be found at http://ndat.no/fjords/

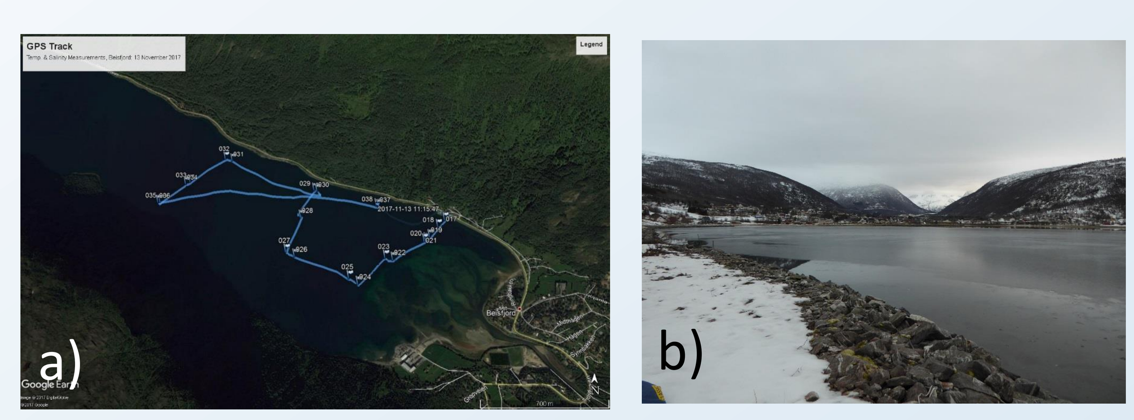
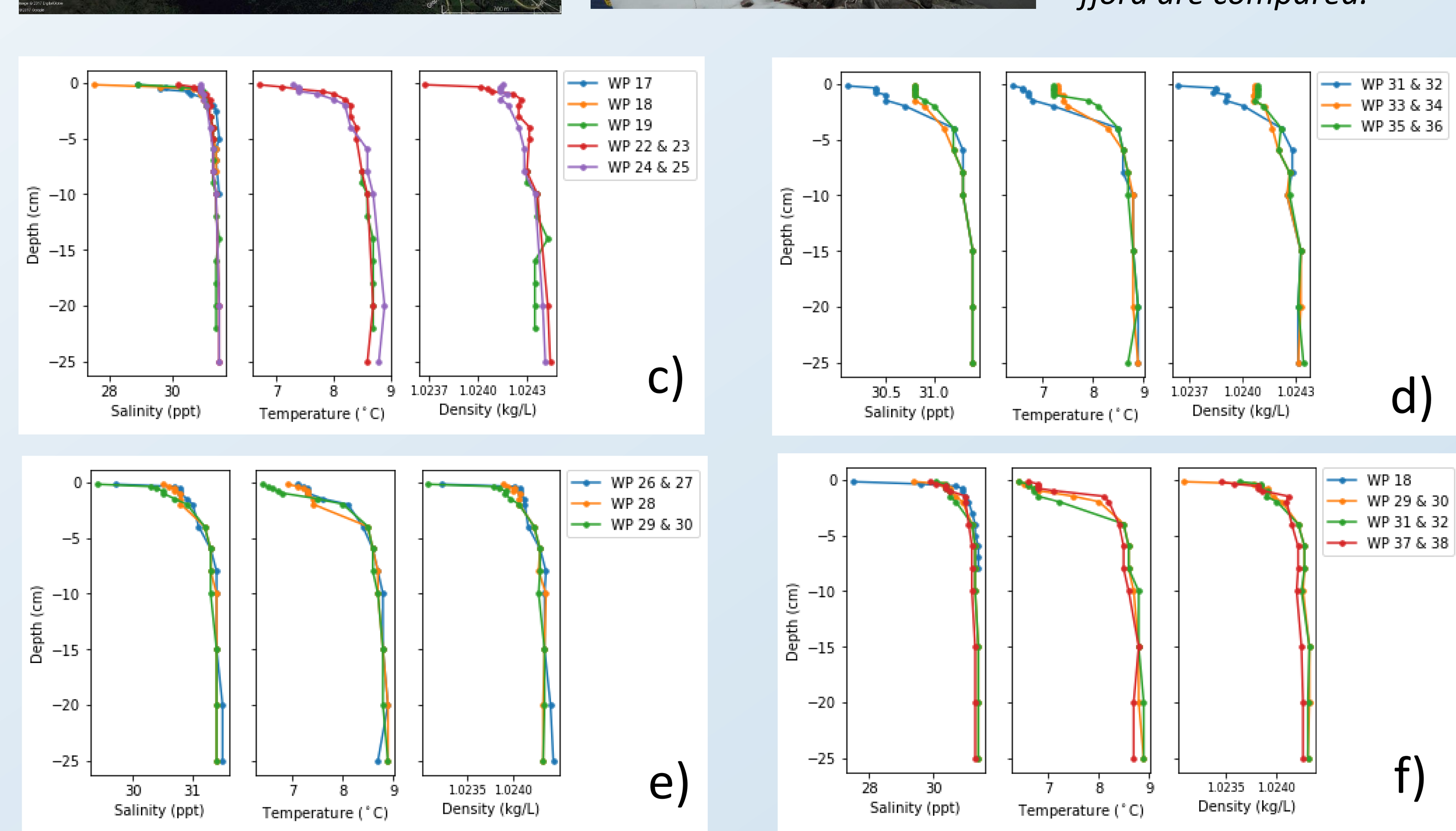


Fig. 5: a) Map of boat track and way points (WP) made on 13 November 2017,. b) Ice observed on that day. Thickness was approximately 4 mm, c), d), & e) show measurements obtained during transects across the fjord while in f) measurements along fjord are compared.



This project is funded by UiT The Arctic University of Norway's Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA), RCN grant no. 237906.

Cottier, F. R., Nilsen, F., Skogseth, R., Tverberg, V., Skarðhamar, J., & Svendsen, H. (2010). Arctic fjords: a review of the oceanographic environment and dominant physical processes. *Geological Society, London, Special Publications*, *344*(1), 35–50. https://doi.org/10.1144/SP344.4
Cushman-Roisin, B., Asplin, L., & Svendsen, H. (1993). Upwelling in Broad Fjords. *Continental shelf research*, *14*(15), 1701-1721.
Eilertsen, H. C., & Skardhamar, J. (2006). Temperatures of north Norwegian fjords and coastal waters: Variability, significance of local processes and air-sea heat exchange. *Estuarine, Coastal and Shelf Science*, *67*(3), 530–538. https://doi.org/10.1016/j.ecss.2005.12.006
Inall, M. E., & Gillibrand, P. A. (2010). The physics of mid-latitude fjords: a review. *Geological Society, London, Special Publications*, *344*(1), 17–33. https://doi.org/10.1144/SP344.3
Mankettikkara, R. (2013). Hydrophysical characteristics of the northern Norwegian coast and fjords. *PhD Dissertation*, University of Tromsø (August).
Svendsen, H. (1995). Physical oceanography of coupled fjord-coast systems in northern Norawy with special focus on frontal dynamics and tides. *Ecology of Fjords and Coastal Waters*, 149–164.
The Fate and Persistence of Stranded Crude Oil: A Nine-year Overview from the BIOS Project, Baffin Island, NWT, Canada. (n.d.).
Tverbergl, V., Cushman-Roisin, B., & Svendsen, H. (1991). Modeling of internal tides in fjords. *JournaL of Marine Research*, *49*, 635–658. https://doi.org/10.1357/002224091784995729