Subglacial discharges of melting water in tidewater glacier bays

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Observations:

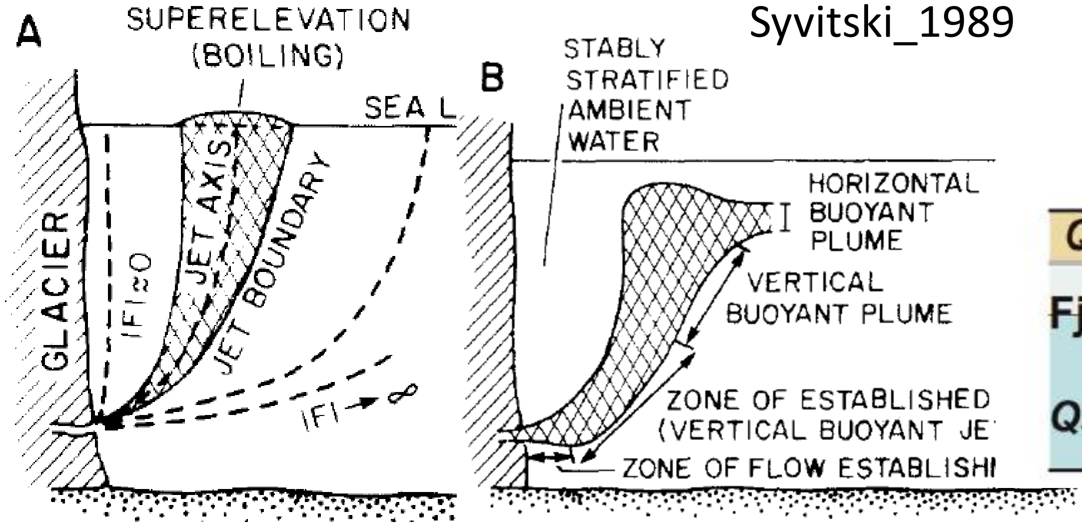
1. “bird” or “brown zones”, foraging hotspots especially for kittiwakes - marine zooplankton species stunned or killed from osmotic shock

Processes:

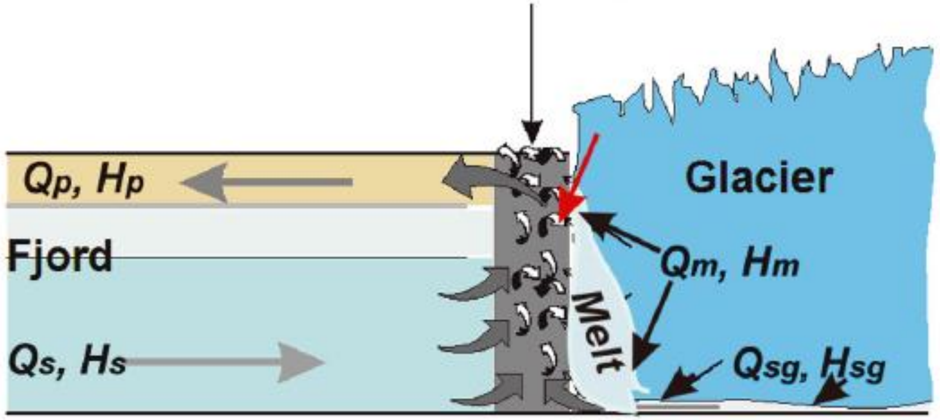
1. The ice-front melting due to the contact with marine water
2. The calving of glaciers
3. Huge flux of sediments which is delivered in this process

How we understand this process

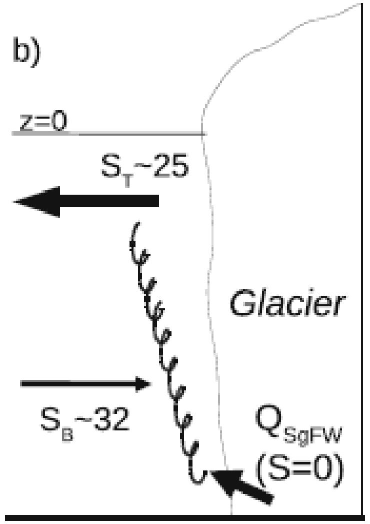
Syvitski_1989



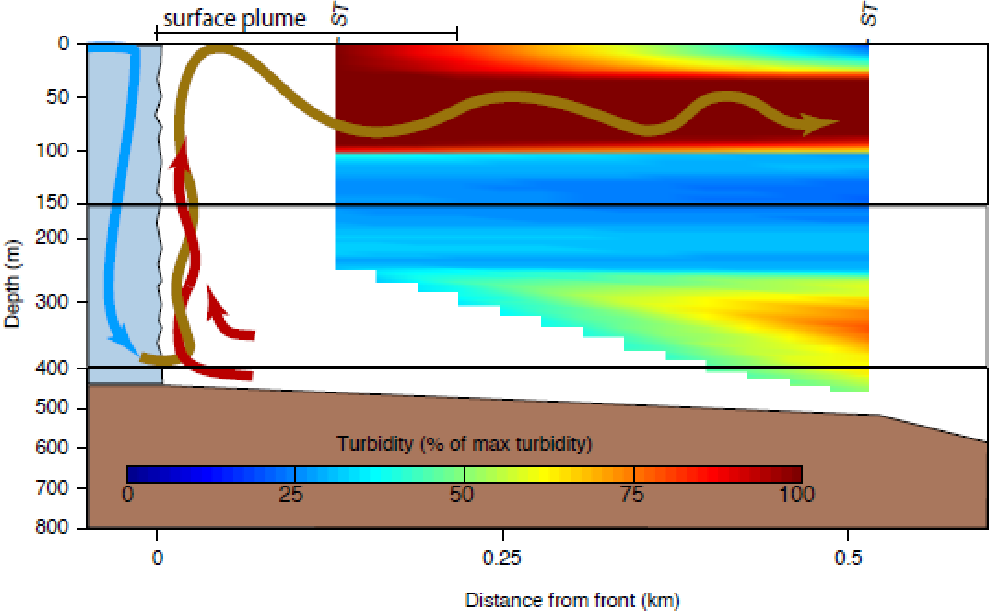
Motyka et al 2003/2013



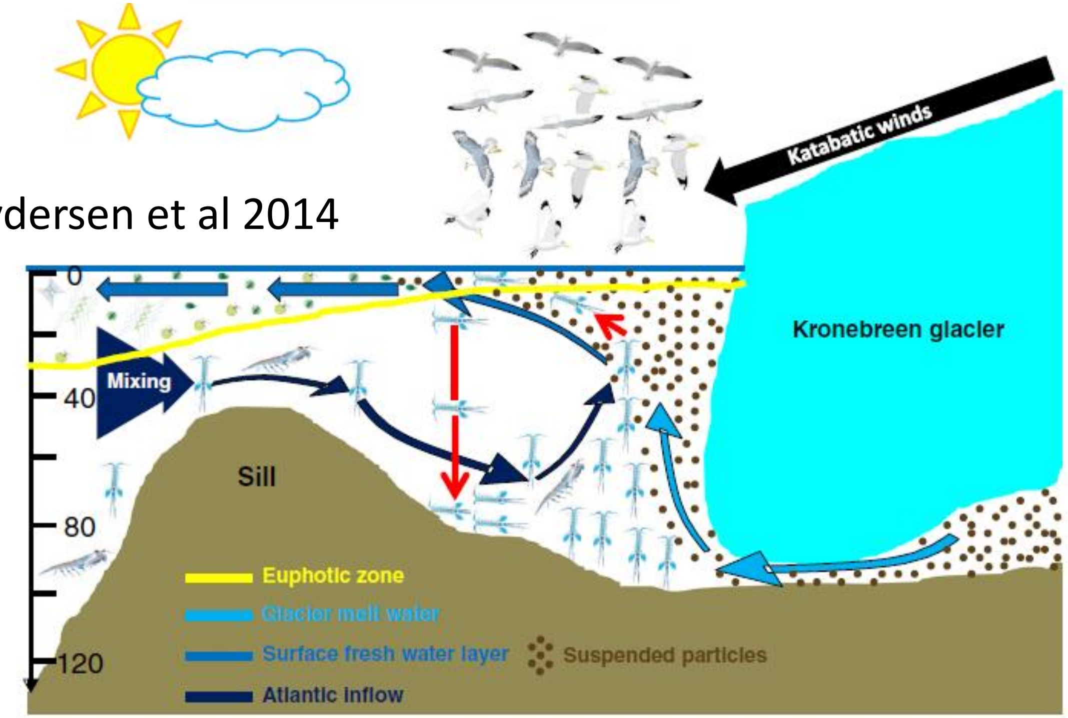
Bendtsen et al 2015



Chauche et al 2014



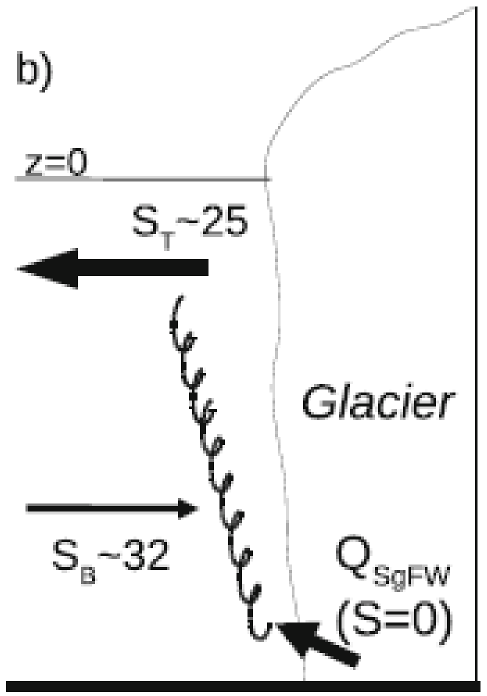
Lydersen et al 2014



Two models used:

1. The submarine melting is most often described using upwelling or buoyant convective plume models.

Authors use two or three-dimensional circulation models, assumes lack or presence of stratification and use different methods to describe the entrainment factor. In general resulting plumes grows with high through the entrainment of ambient water with nearly constant rate which increases the temperature and melting rate while moving up along the ice face.



1. Motyka, R.J. ……… . Submarine melting at the terminus of a temperate tidewater glacier, LeConte Glacier, Alaska, U.S.A. *Annals of Glaciology*. **36**, 57-65 (2003).
2. Bendsten, J., Mortensen, J. & Rysgaard, S. Modelling subglacial discharge and its influence on ocean heat transport in Arctic fjords. *Ocean Dynamics*. DOI 10.1007/s10236-015-0883-1 (2015).
3. Jenkins, A. Convection-Driven Melting near the Grounding Lines of Ice Shelves and Tidewater Glaciers. *J. Physical Oceanography*. **41**, 2279-2294 (2011).
4. Kimura, S., Holland, P.R. & Jenkins, A. The Effect of Meltwater Plumes on the Melting of a Vertical glacier Face. *J. Physical Oceanography*. **44**, 3099-3117 (2014).

2. Distribution of sediments - the submarine discharges has the form of buoyant jet which is also described as a forced plume whose behaver depends on the density difference between the plume and marine water and jet momentum

Froude number indicating ratio of inertia forces to buoyancy forces,

$$F = \frac{u_0^2}{\frac{(\rho_m - \rho_0)}{\rho_0} \times g \times D}$$

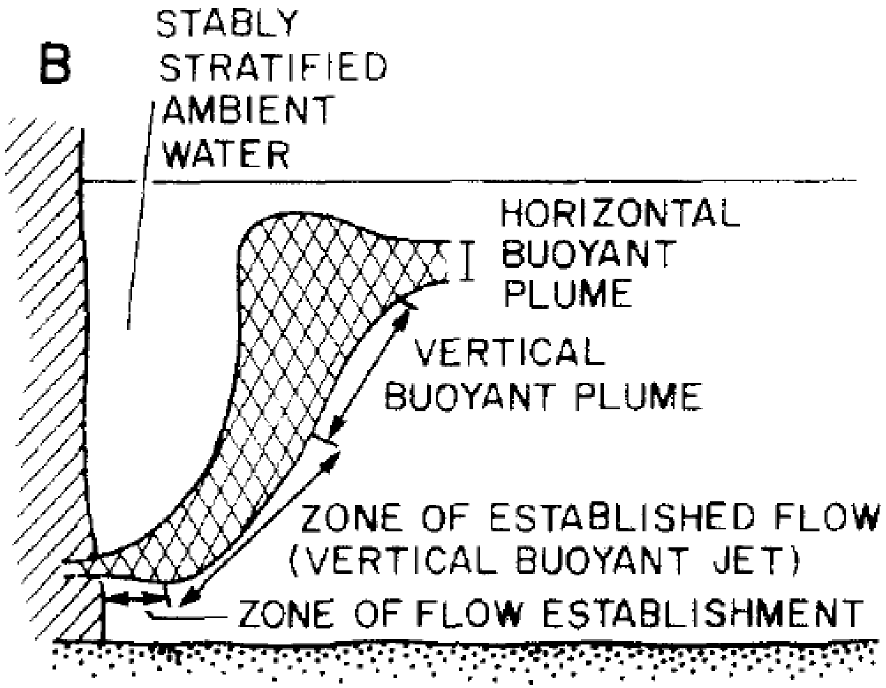
u_0 – initial jet velocity

ρ_m – density of marine water

ρ_0 – density of glacial water

D – diameter of the ice tunnel

g – gravity acceleration



Sediment concentration influence density

Measured 1000 – 12000 mg/l

1. Mugford, R.I. & Dowdeswell, J.A. Modeling glacial meltwater plume dynamics and sedimentation in high-latitude fjords. *J. Geophys. Res.* **116**, F01023, doi:10.1029/2010JF001735 (2011).
2. Salcedo-Castro, J. ………… . Non-hydrostatic modeling of cohesive sediment transport associated with a subglacial buoyant jet in glacial fjords: A process-oriented approach. *Ocean Modelling*. **63**, 30-39 (2013).

Questions:

What are the sizes of birds aggregations and how many birds may foraging there, how much food are there?

Does the hotspots distributions change in time and space? Why?

Does the experimental measurements confirm the theoretically based understanding of physical processes of subglacial waters discharge?

What is the mechanism of flux of macroplankton to foraging hotspots?

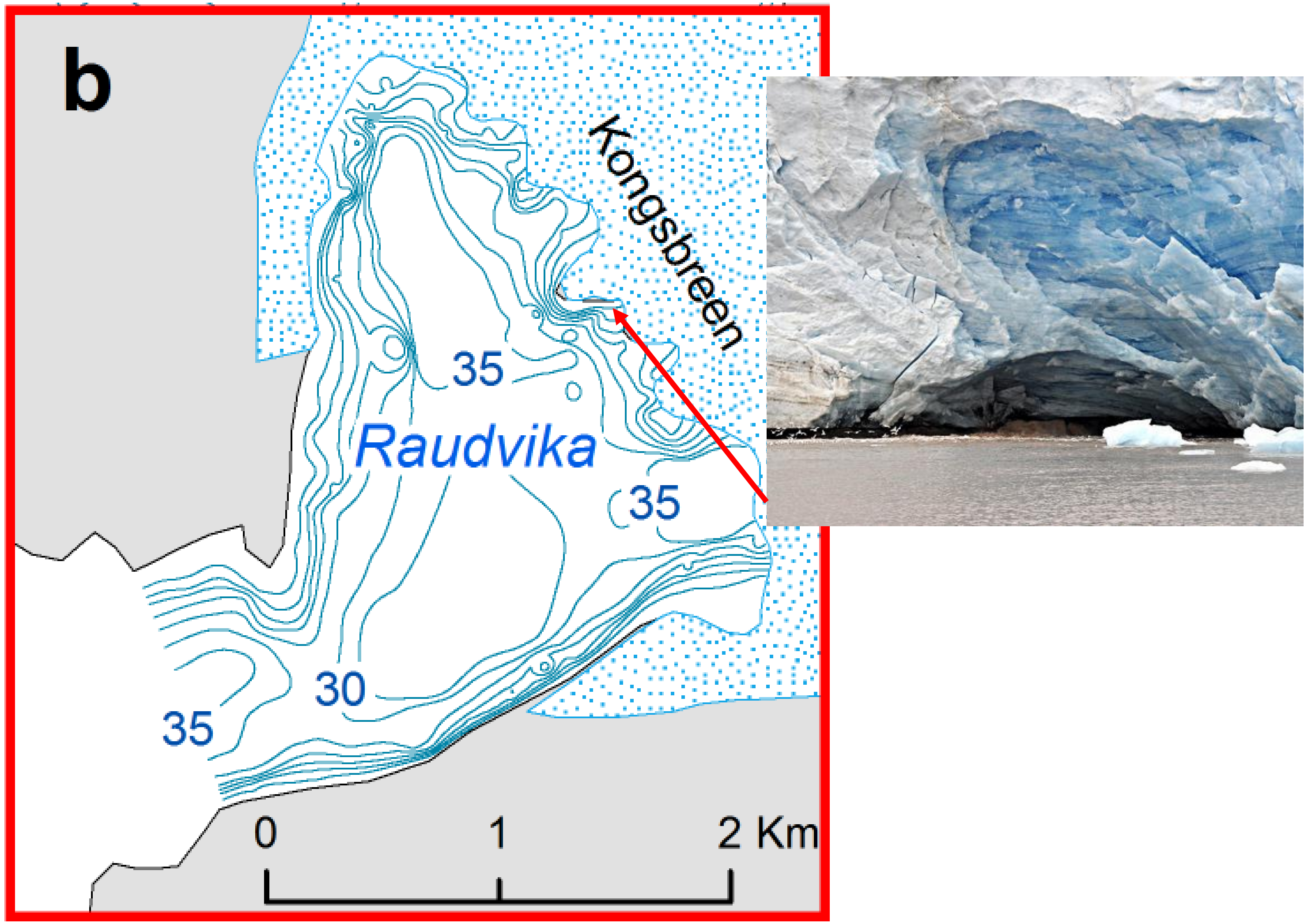
How the water is discharged in glacier bays and how this discharge influence the foraging hotspots?

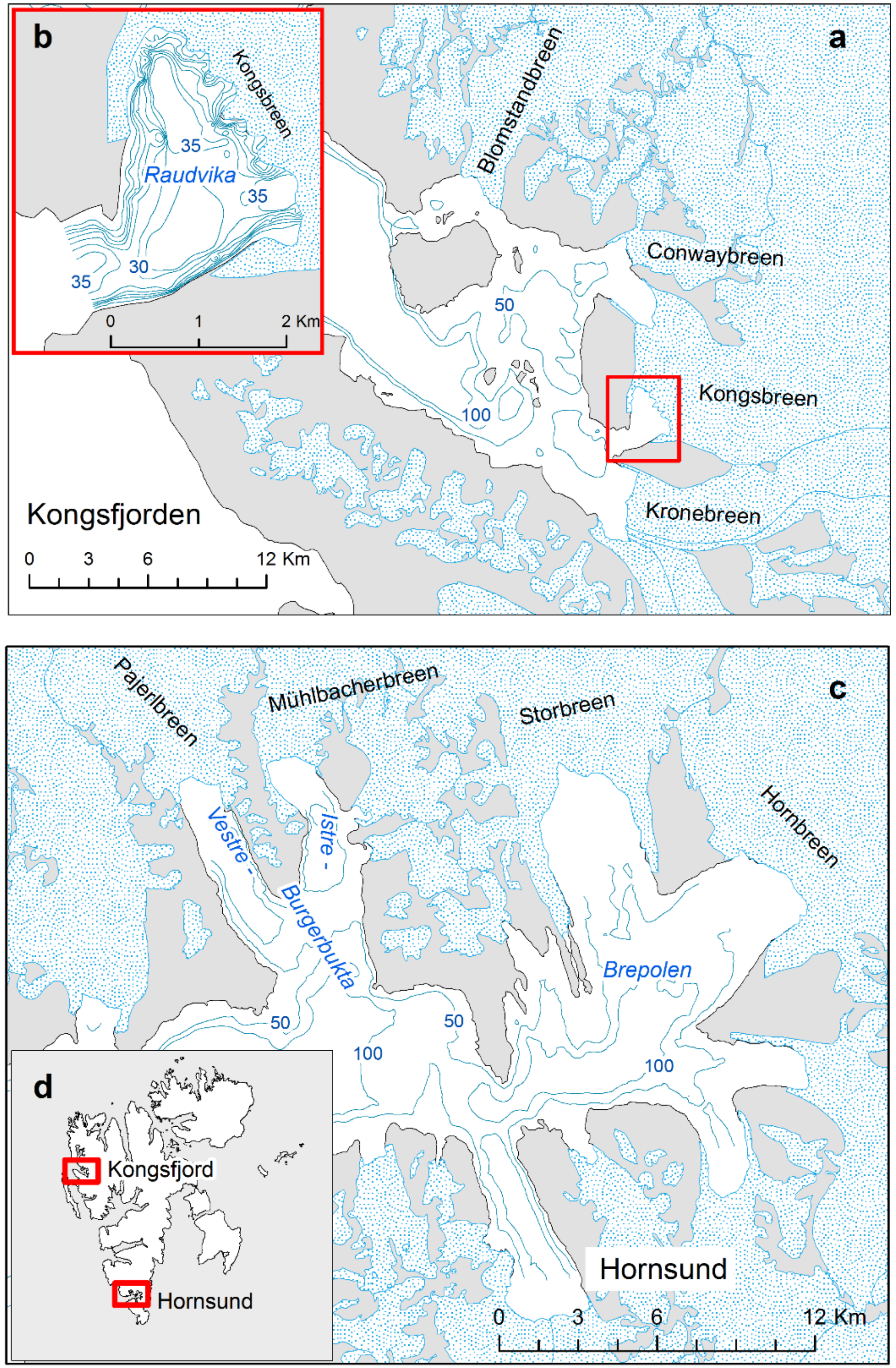
Experimental way:

1. Tracking birds using GPS telemetry radio method (L.Stempniewicz)

2. Coupling satellite images with in situ measurements of water temperature, salinity, turbidity and macroplankton (GIS Centre, M. Węsławski)

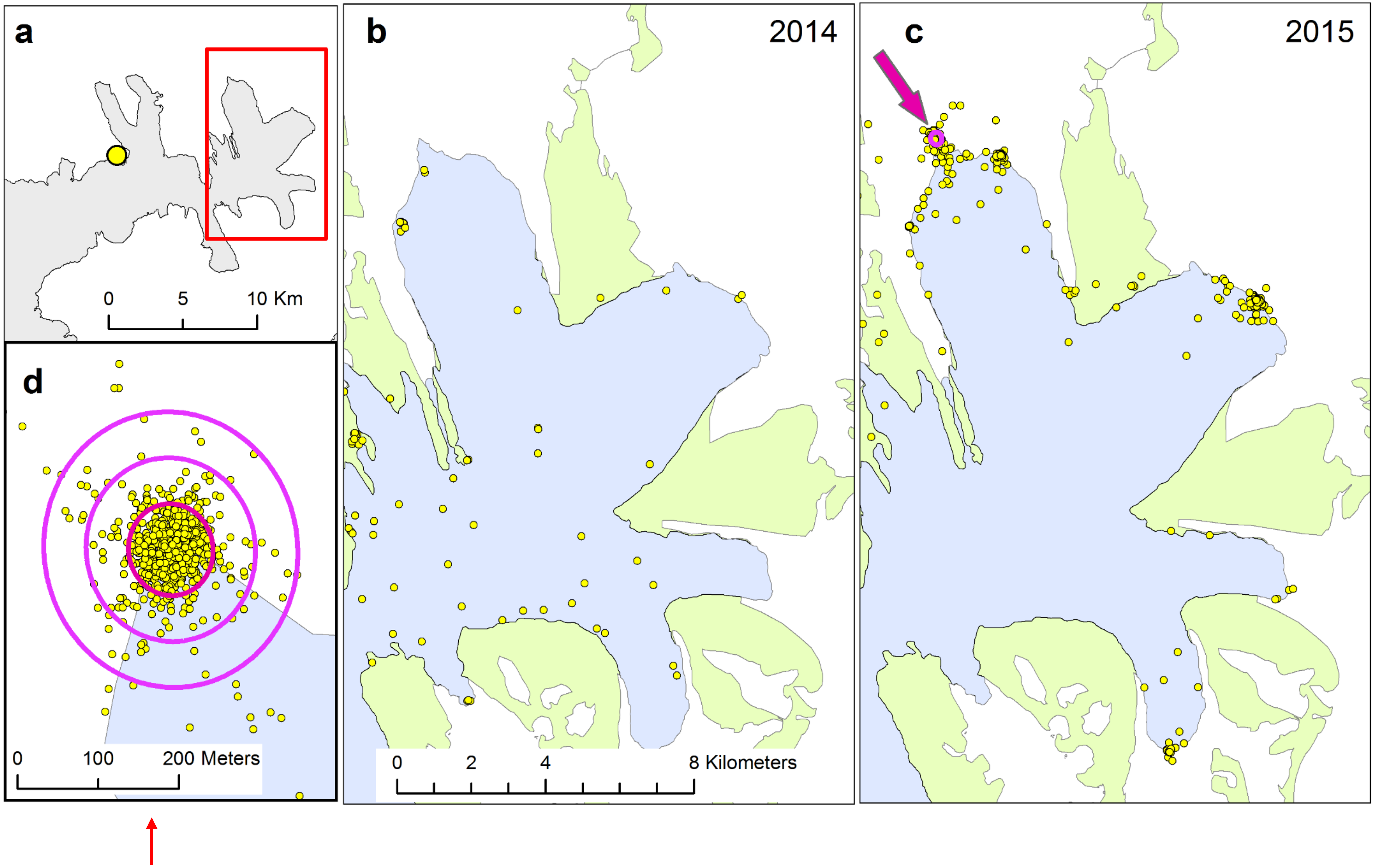
Tidewater glacier bays studied.





The foraging was registered in 2014 and 2015 in area of Brepolen outlined as red rectangle (**a**) for a sample of kittiwakes from colony in Hornsund – yellow dot (**a**). In 2014 no aggregation of kittiwakes was recorded in Brepolen (**b**). In 2015 three "hot spots" of foraging were recorded in Brepolen where 36% of foraging activity of kittiwakes sample took place (**c**). The measured compactness of kittiwakes distribution at ice face of Stornbreen - magenta arrow at (**c**) shows that 66% of birds foraging takes place in "hot spot" in circular shape with radius of about 40-60m, and 99% with radius of 120-180m from central point of subglacial discharge (**d**).

Birds foraging "hot spots" at glaciers fronts.



standard deviational ellipse method

Birds foraging “hot spots” at glaciers fronts.

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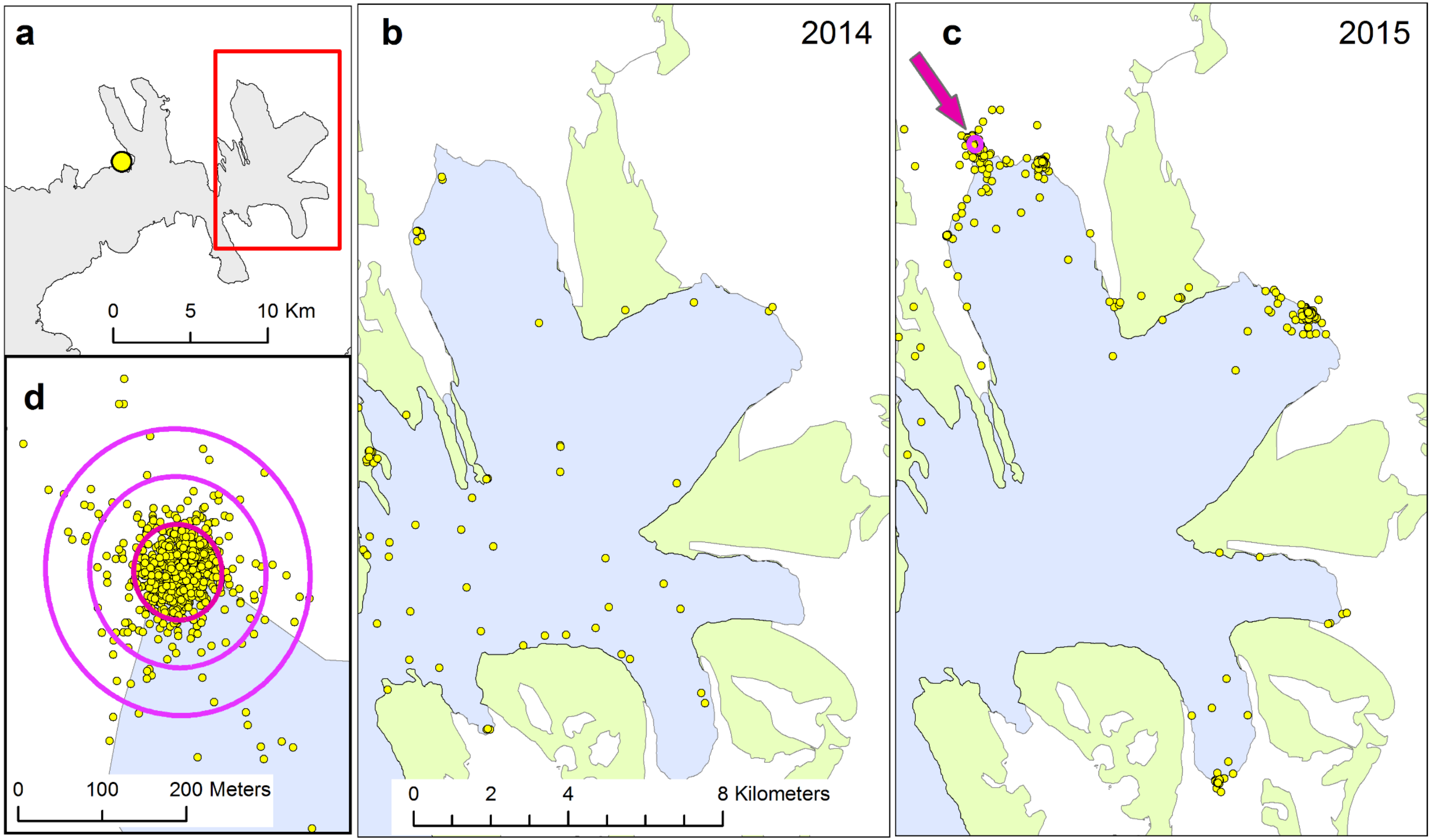
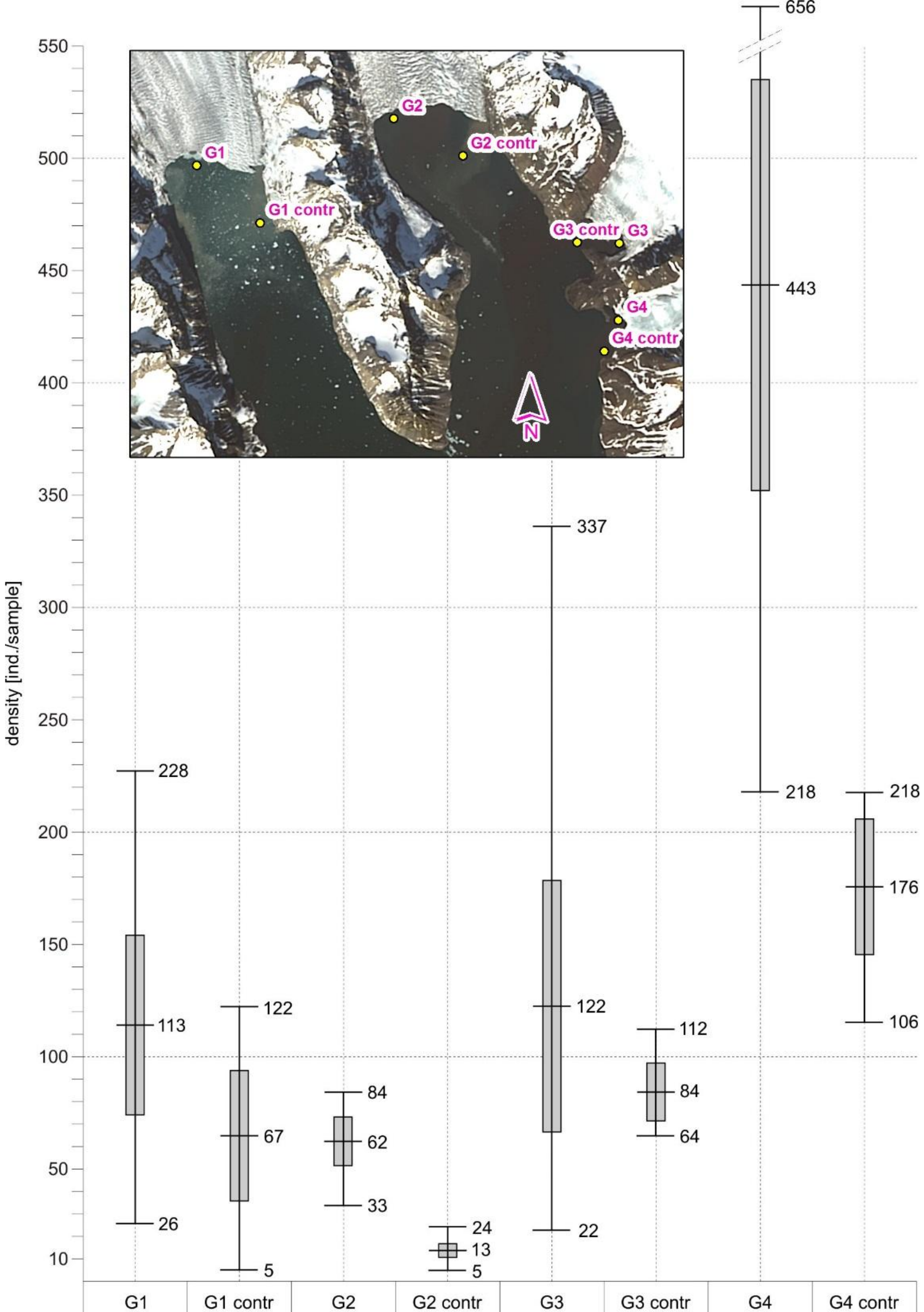
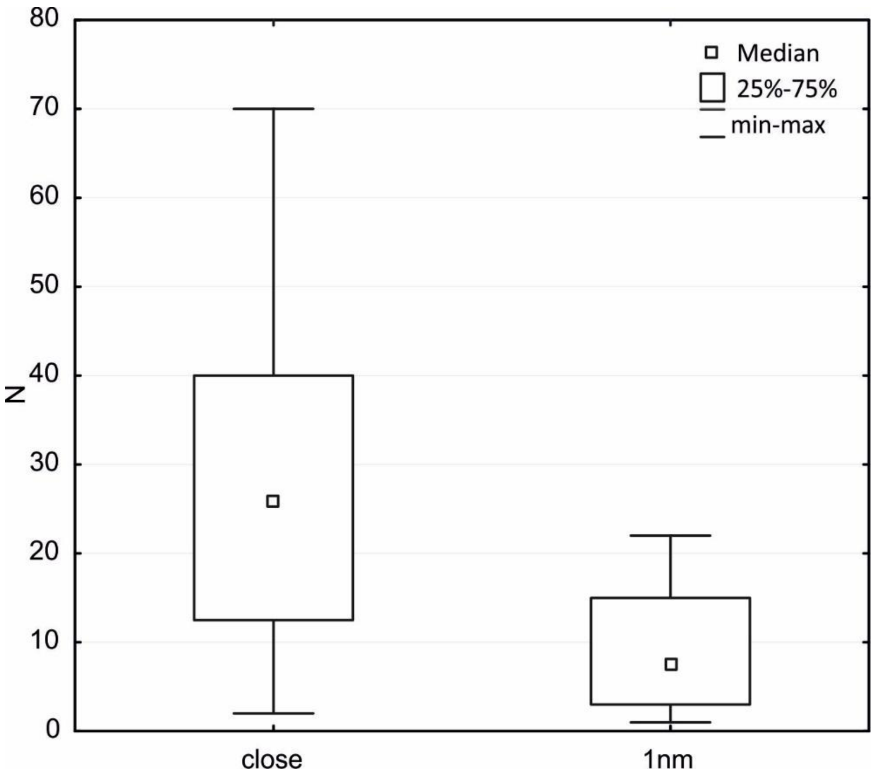


???? Food = 3000 birds X 30 days X 0.1 kg = 9 tons ?????

macroplankton



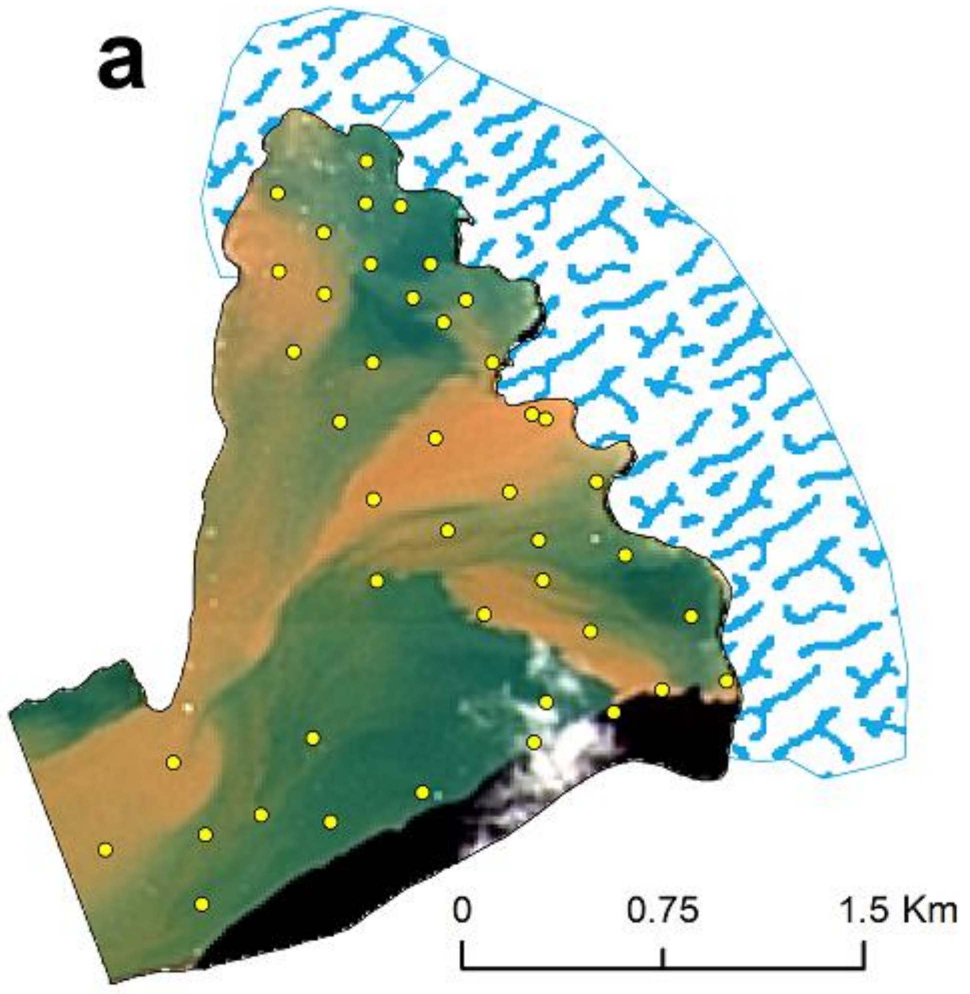


Surface distribution of suspended particulate matter.

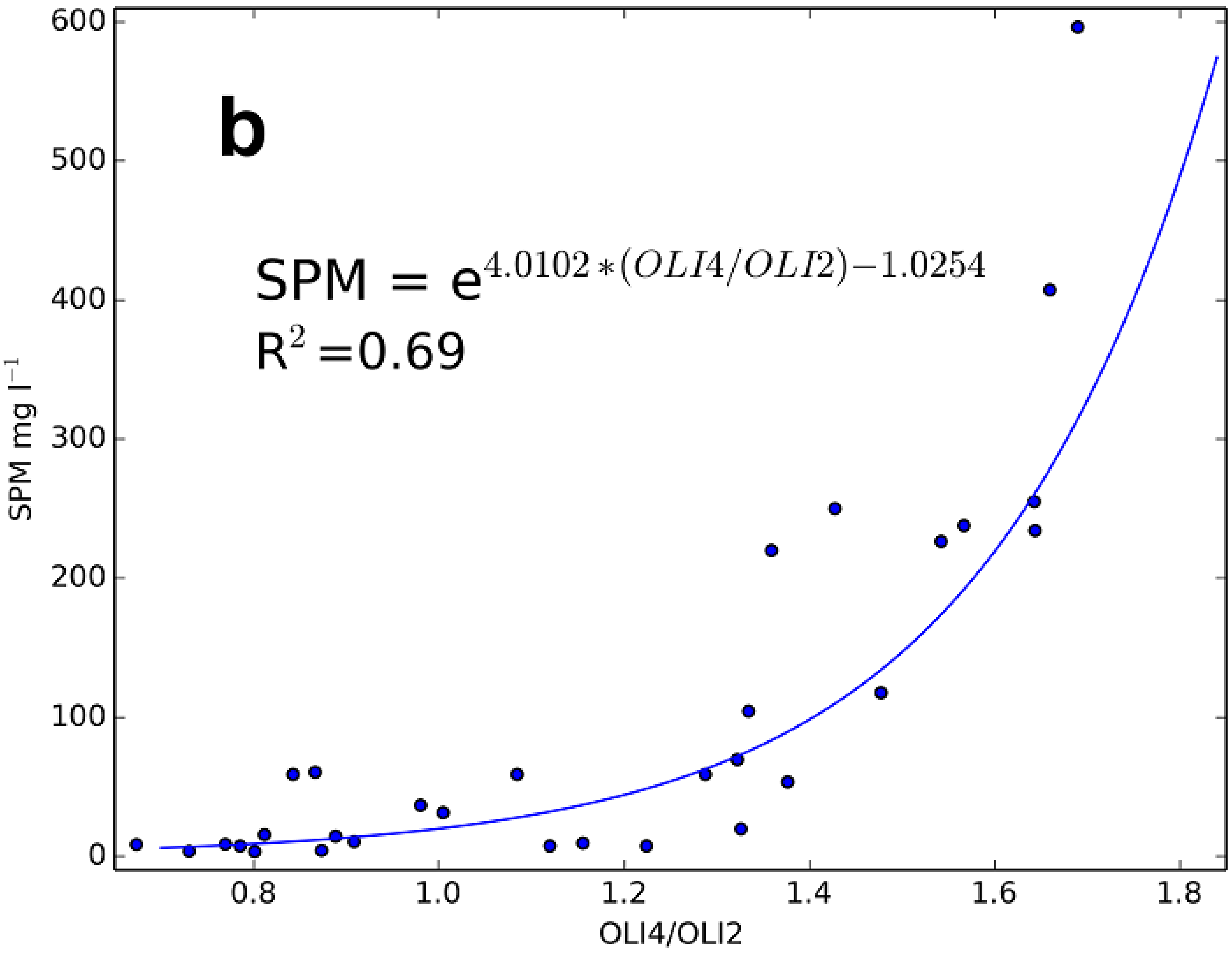
Landsat 8 image taken 8th August
(in-situ measurements ± 3h)
spatial resolution 30m

The turbidity were measured using backscatter sensor in FTU (Formazin Turbidity Units). The sensor was calibrated to SPM using the conversion formula which was derived from linear relation between turbidity and measured SPM in the same place (with R^2=0.82).

SPM values (2 – 600 mgl^{-1})



Surface distribution of suspended particulate matter.



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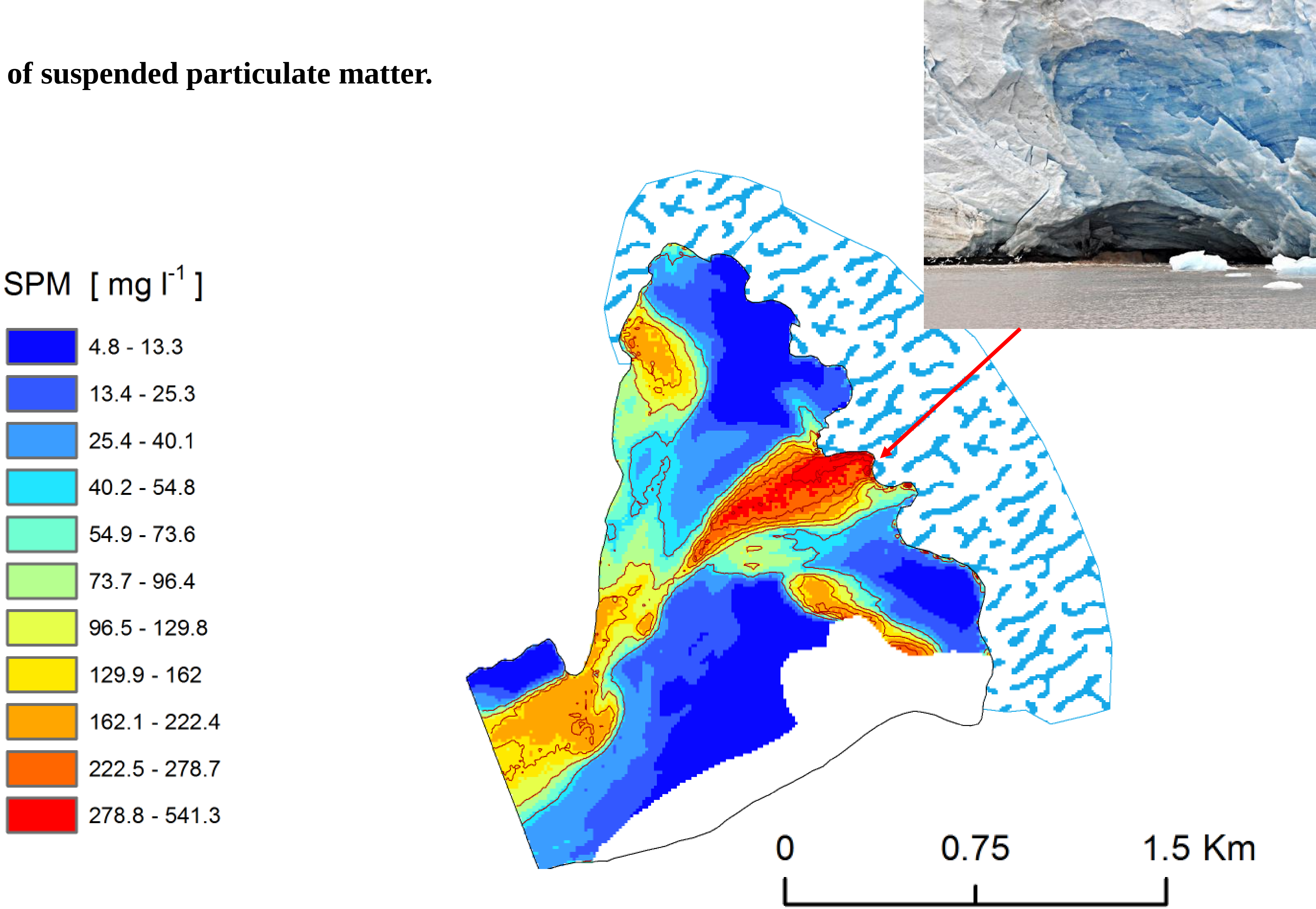
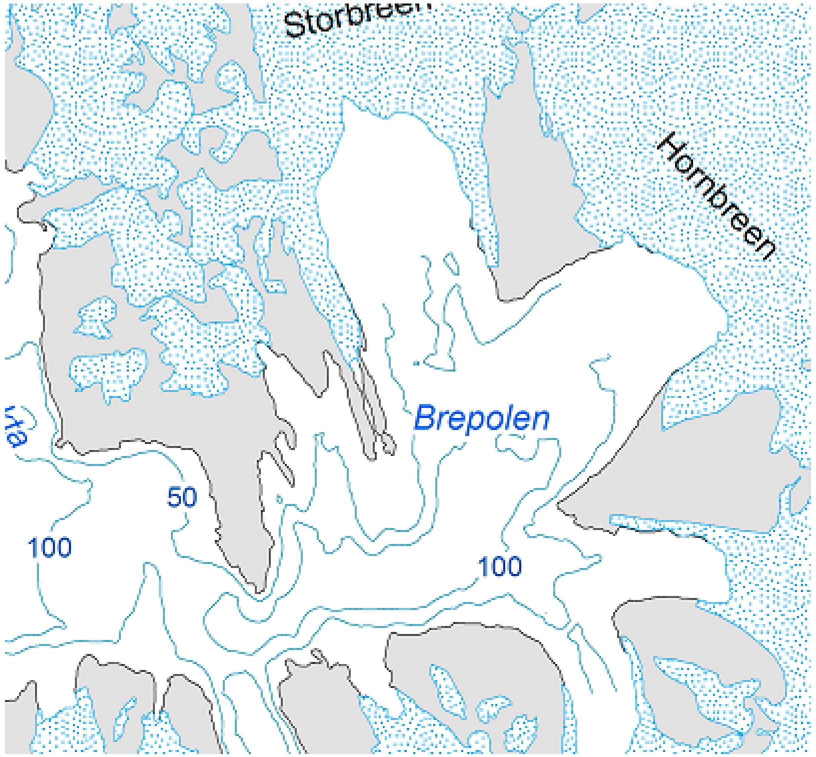
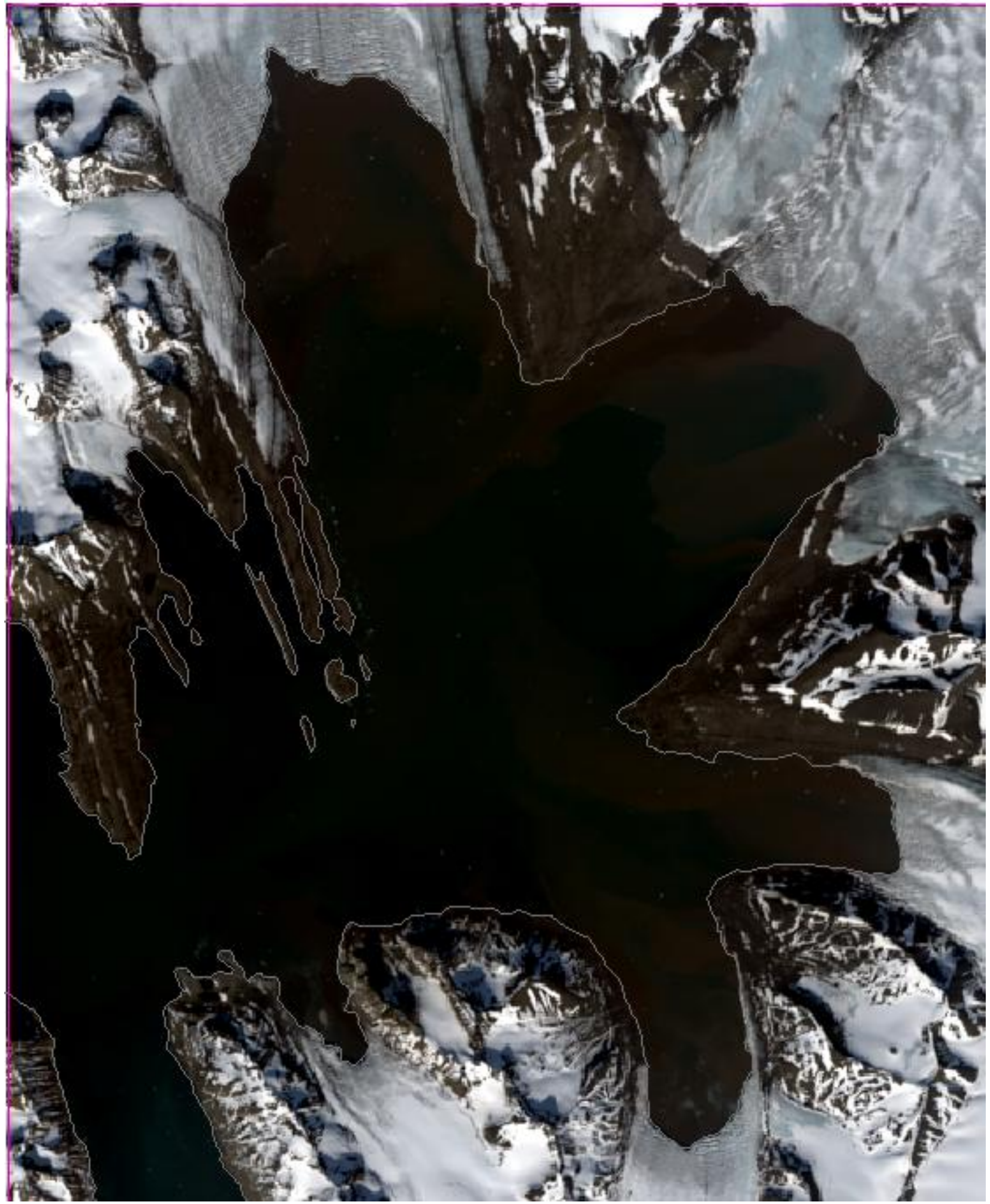
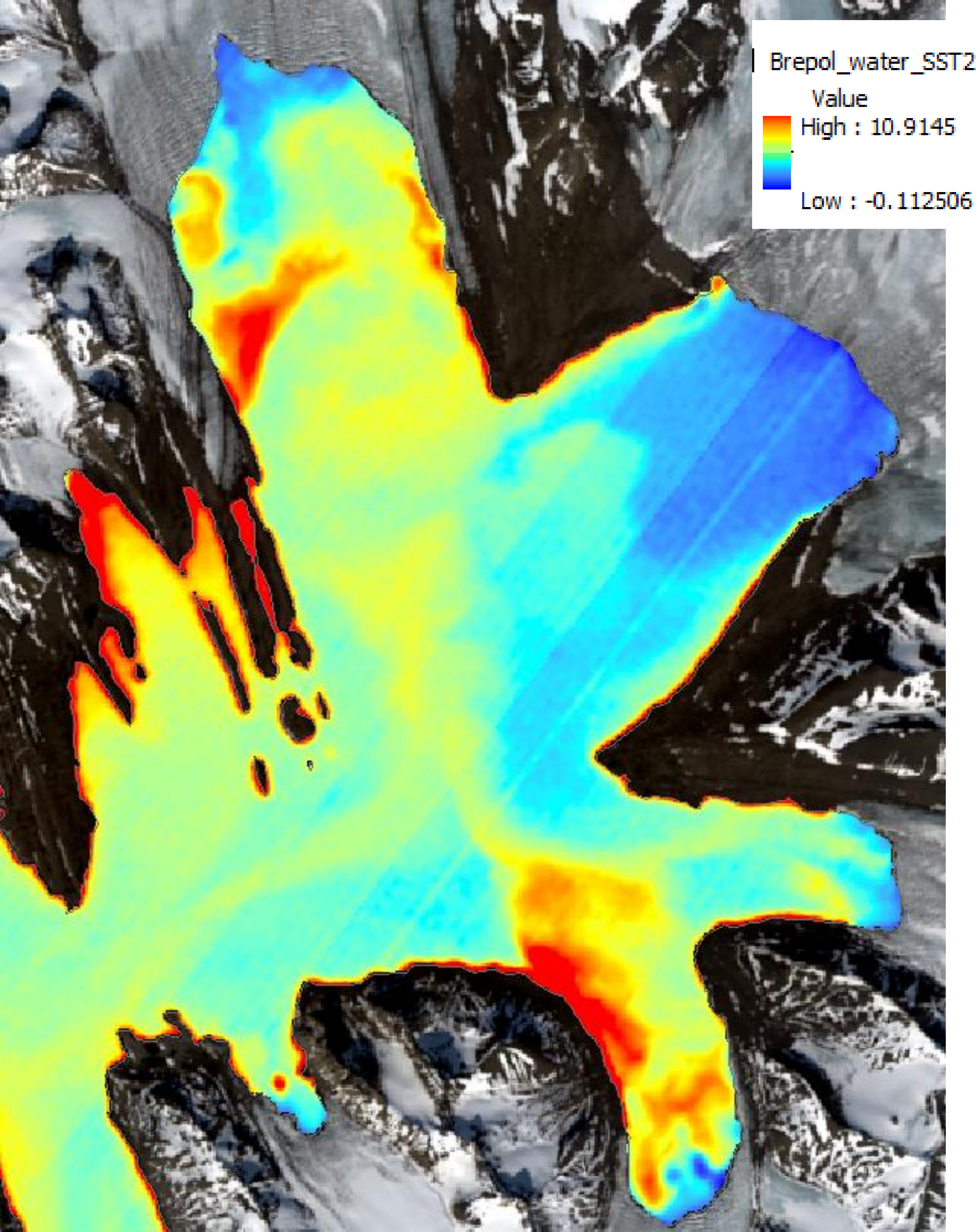
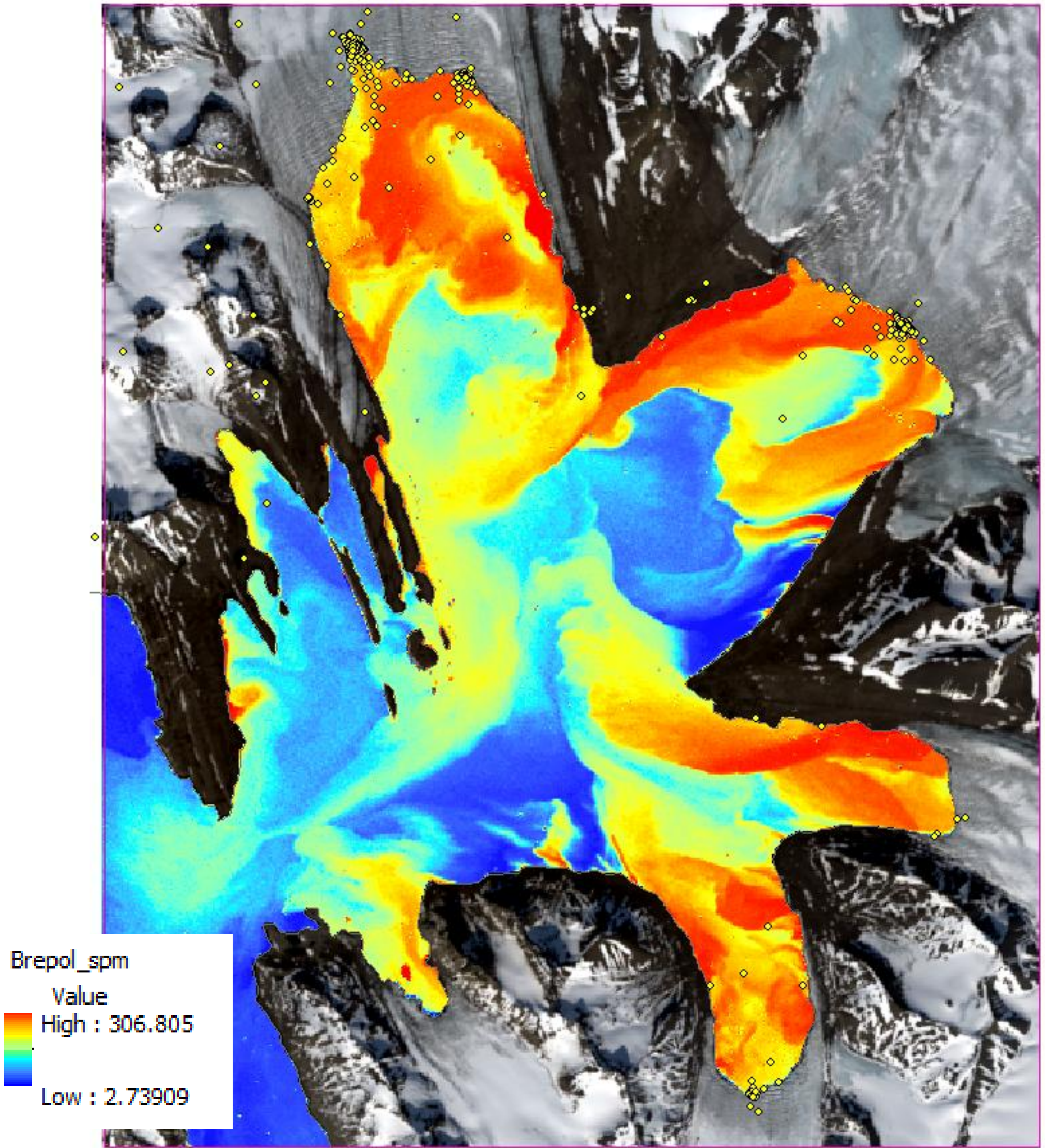






SPM and SST Brepolen 31.07.2015

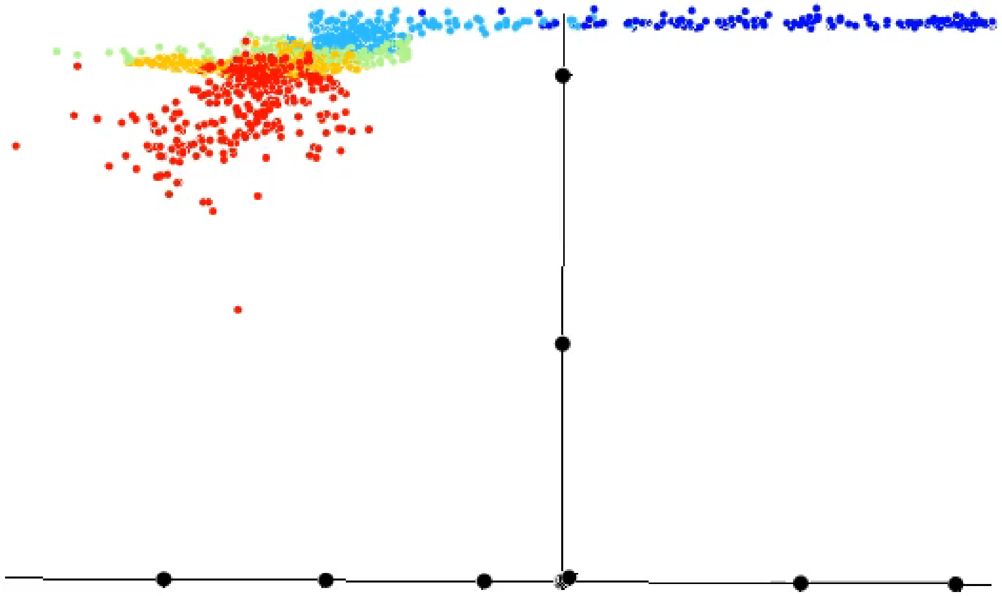

Brepol_water_SST2
Value
High : 10.9145
Low : -0.112506


Brepol_spm
Value
High : 306.805
Low : 2.73909

Water structure in tidewater glacier bay.

T-S-SPM diagram

To analyze the water structure in Raudvika we used the similar tool to T-S diagram but extended to third dimension by the SPM.

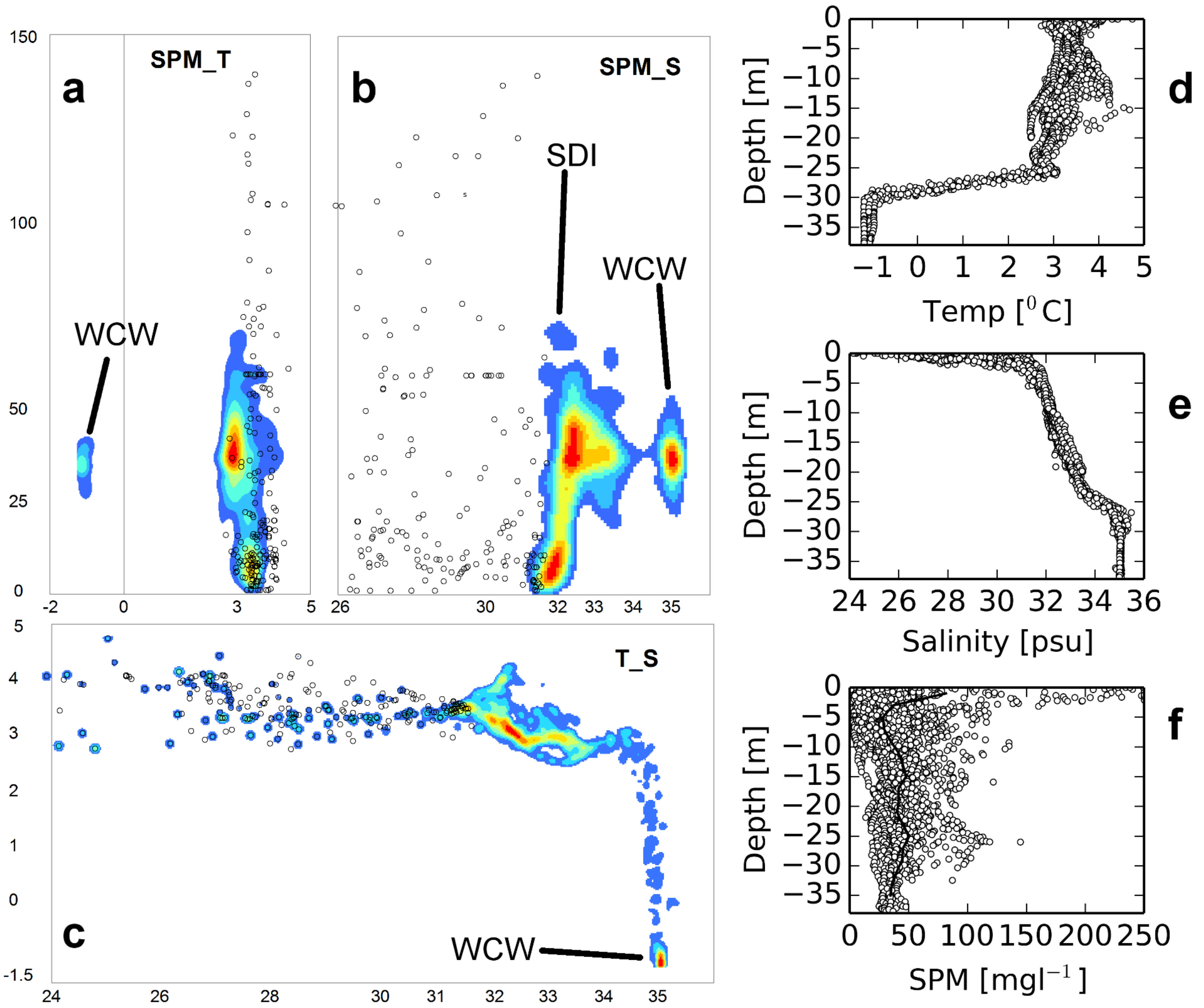


Three dimensional cloud of 2600 points of measured T,S and SPM on sampling stations in the bay

Three stable layers of water.

The first is only two meters high and is characterized by temperature ranging from 3 to 4.5°C and very strong variations in salinity (24 to 31.5 psu) and SPM (0.2-600 mgl[-1]).

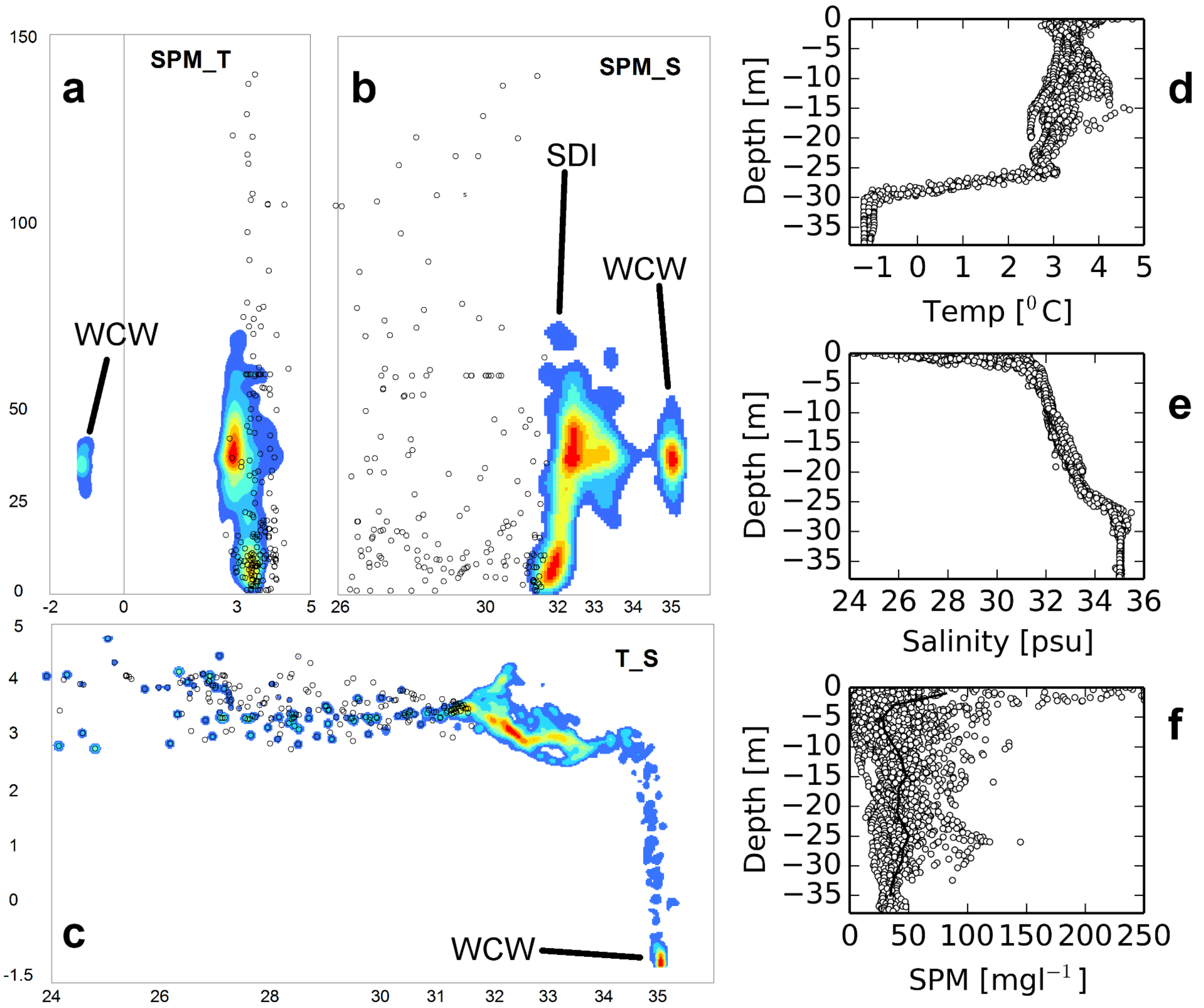
This layer may have very strong stratification caused by vertical salinity gradient and a large SPM values associated with glacier melt water discharge at surface.



Three stable layers of water.

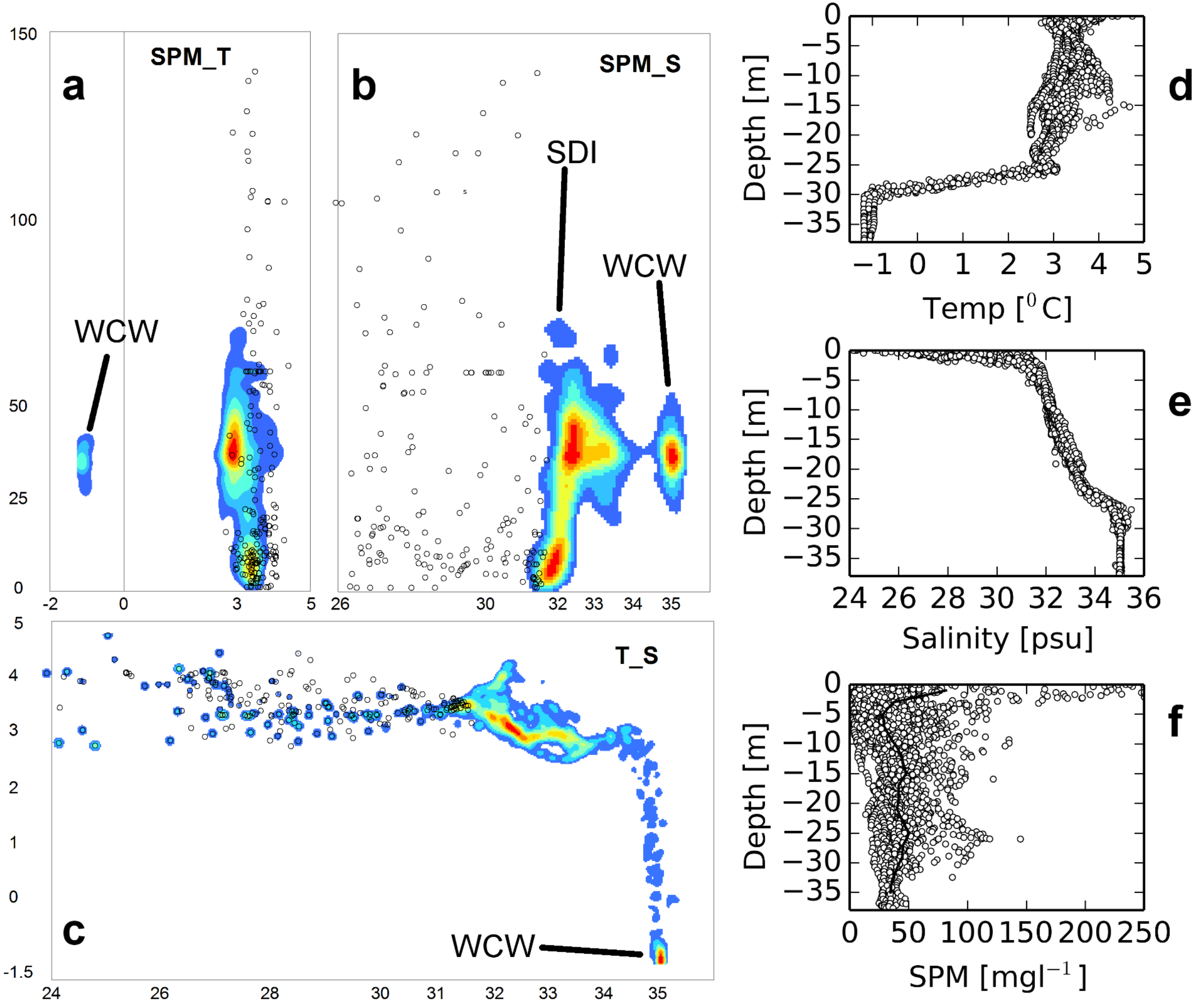
The second layer in which salinity is the dominant factor determining stratification is 25m high with strong uniform stability.

However in this stable layer there are strong variability of temperature and SPM what may be explained as a result of subglacial discharges which are stabilized in intermediate water layers at depth of about 12-20m.



Three stable layers of water.

The third layer is created by Winter Cooled Water (WCW) with temperature below -1°C and salinity above 35psu. This layer has uniform SPM concentration with values of about 50 mgl^{-1}.



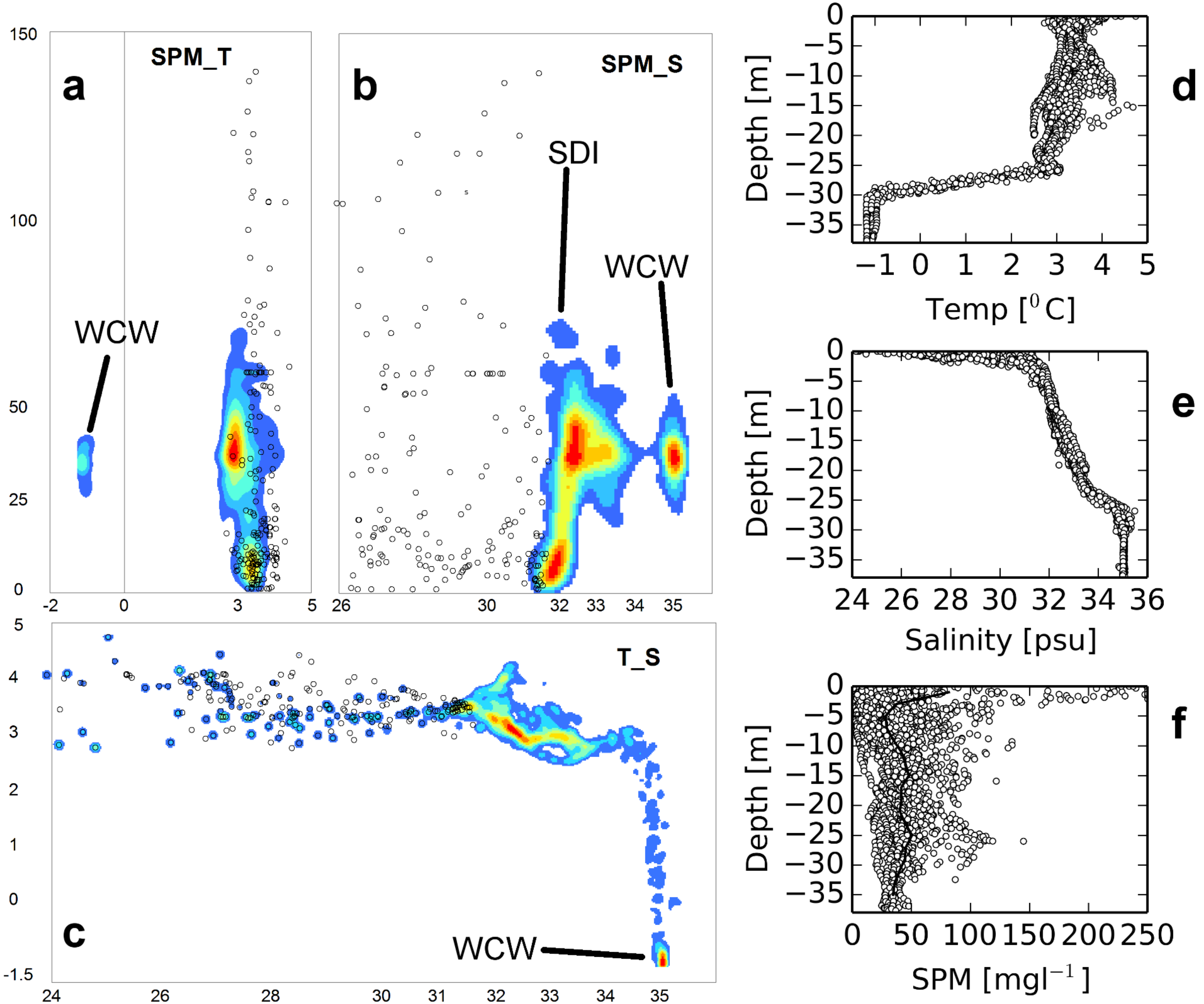
The concentration of points on T-S-SPM diagram shows the centers of water masses.

The WCW center is clearly visible on all projections.

There are two others centers in intermediate layer of water

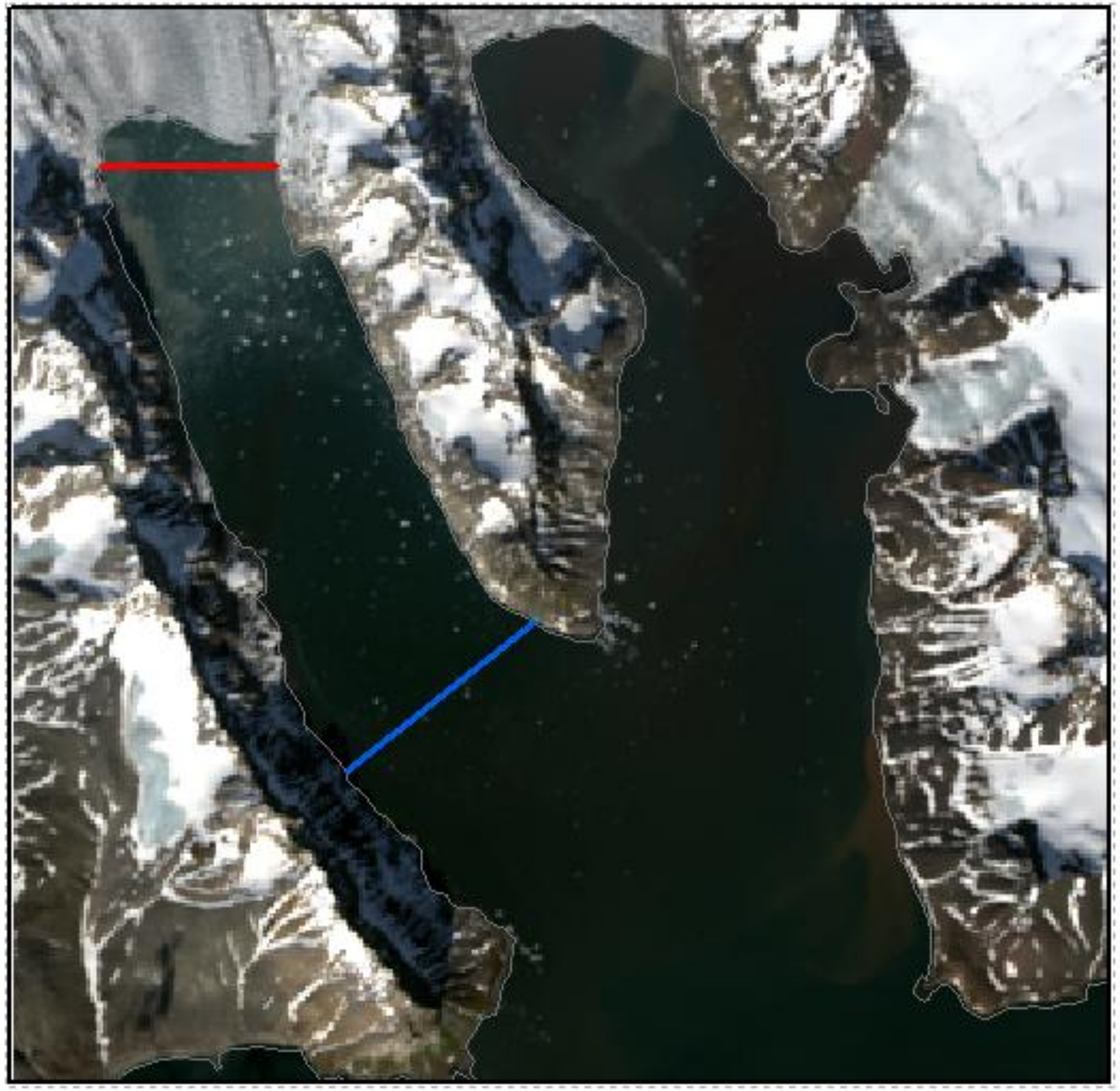
The first one with low salinity has small values of SPM.The second with salinity a little higher and higher values of SPM.

The claster of points with high SPM values may be identified as subglacial discharge water at intermediate layer SDI.



Variation of type of subglacial discharges.

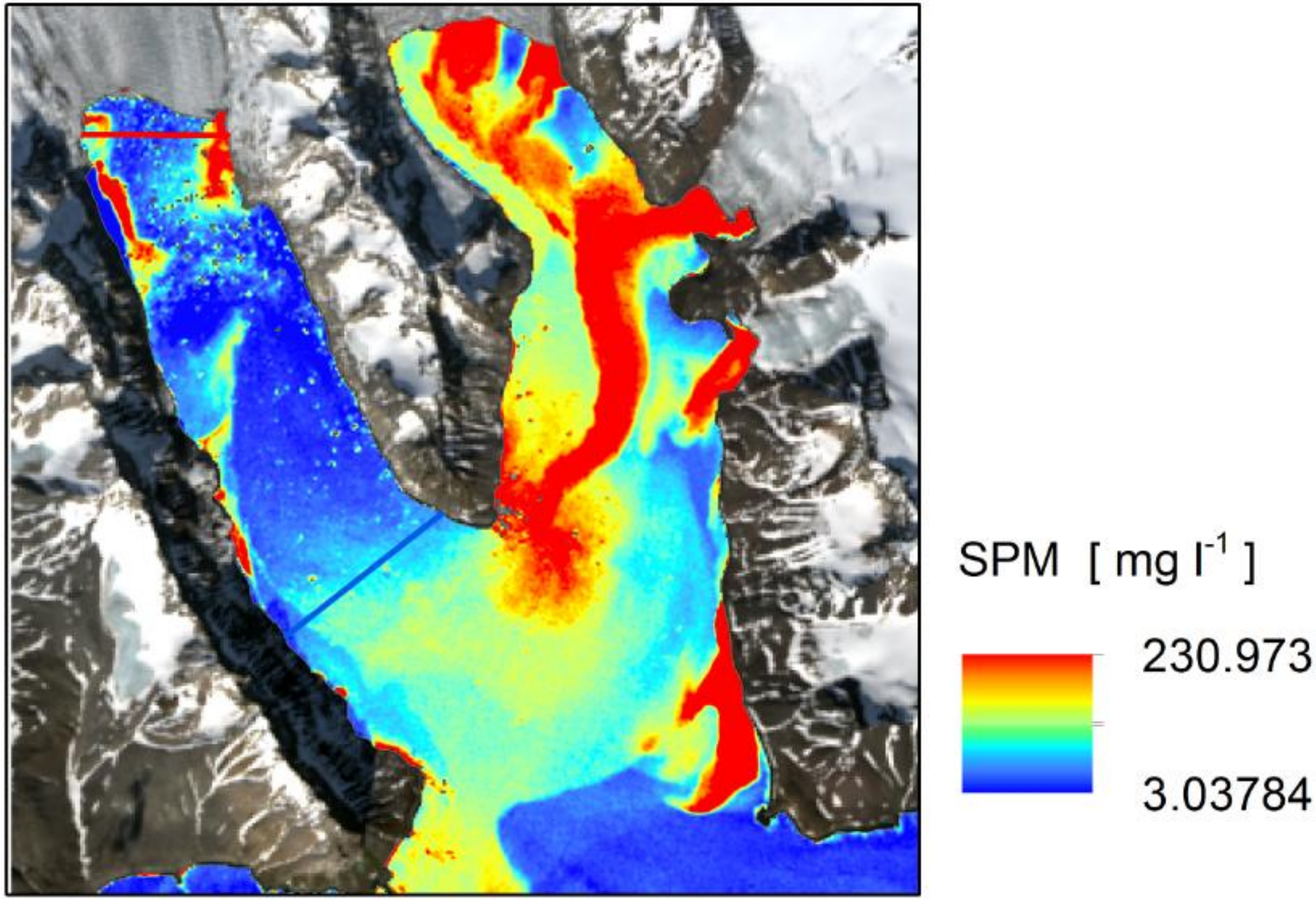
We compare subglacial discharges in two branches of Burgerbukta in Hornsund coupling satellite SPM mapping and T,S,SPM measurements at two cross-sections, one about 200m from Pajerlbreen and second about 3km from it



Variation of type of subglacial discharges.

The SPM looks very different.
In Vestre-Burgerbukta high values of SPM are observed only in two streams of melt glaciers water at two ends of glacier. The water in front of Pajerlbreen has limited concentration of SPM

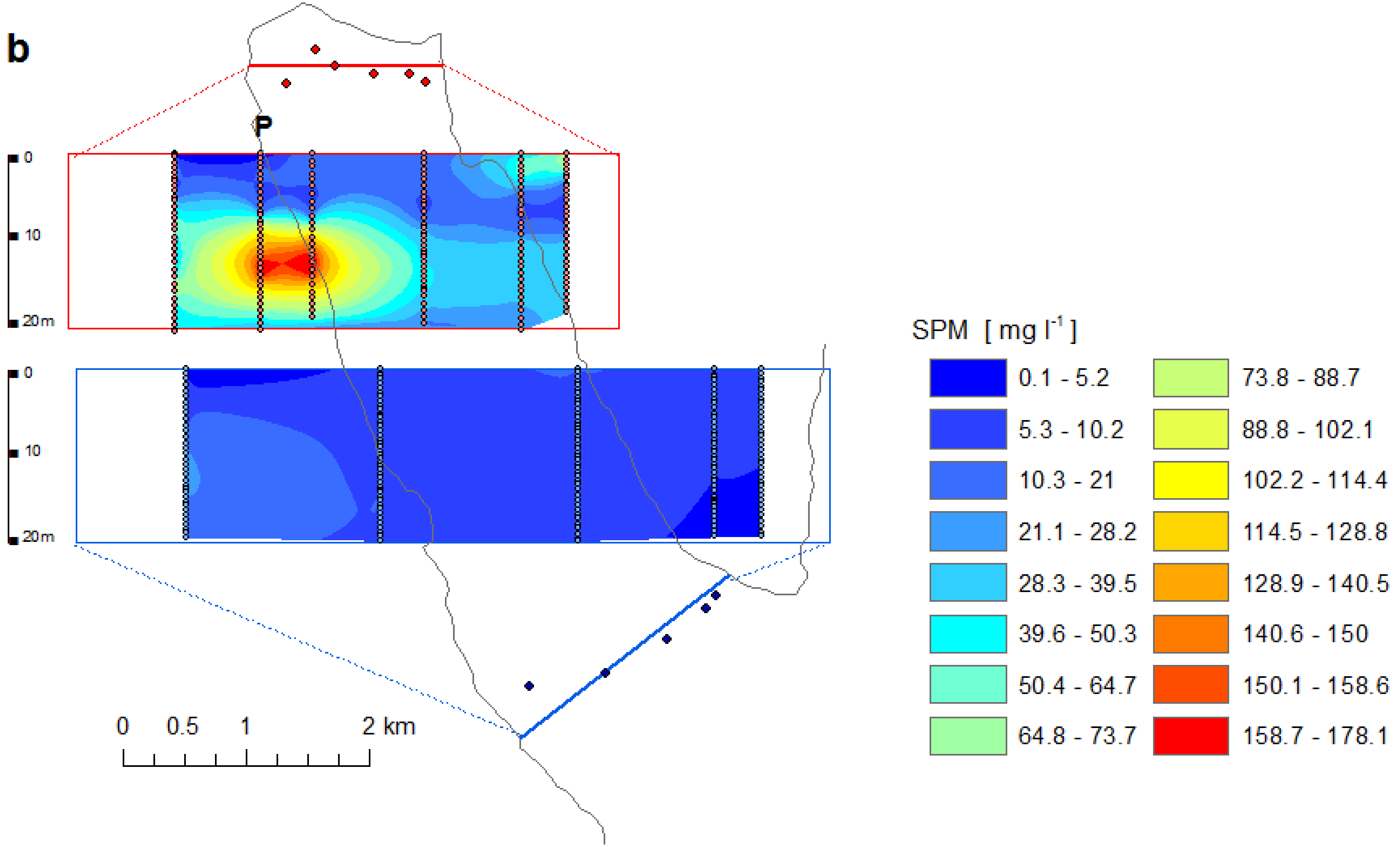
In Estre-Burgerbukta in front of Mülbrachenbreen very high concentration of SPM indicating the subglacial discharge was observed, however there is also a patch of water with lower concentration of SPM.



Variation of type of subglacial discharges.

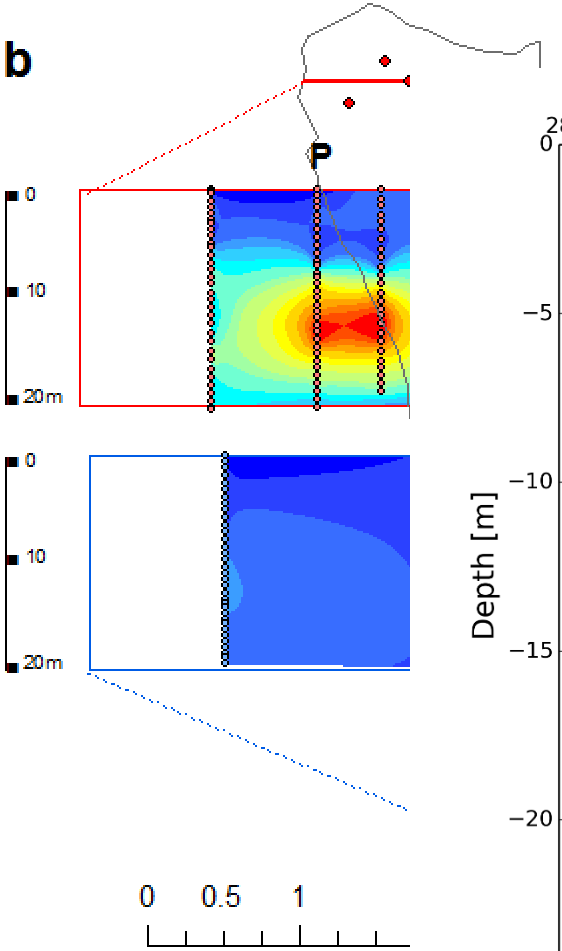
The cross-section of SPM in front of glacier shows the plum of water with high SPM concentration at depth of about 14 meters reaching 180 mgl^{-1}.

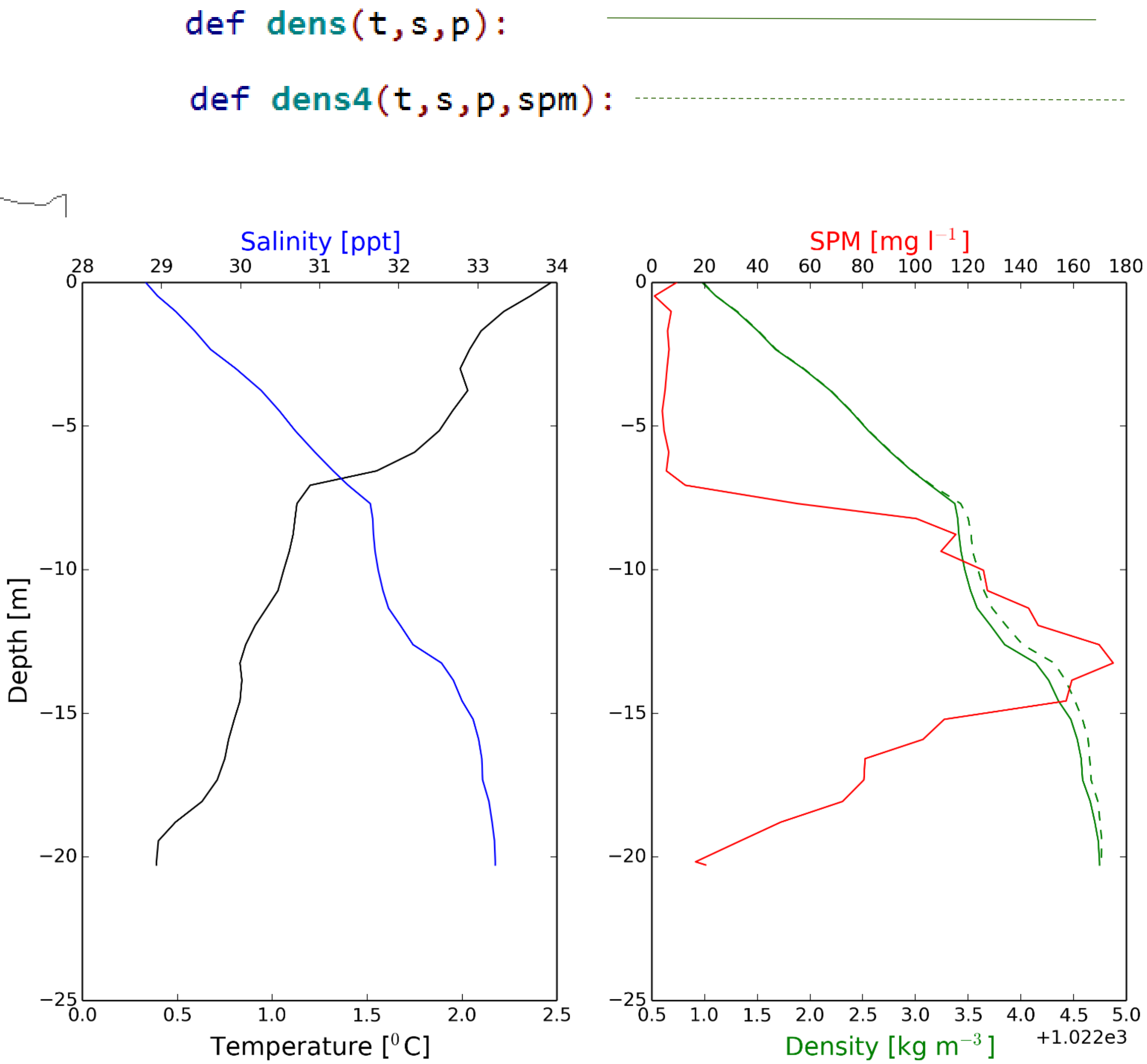
This indicate the subglacial discharge in form of buoyant plume which flow horizontally after reaching a density level of water column equal to plume density.



Variation of type of subglacial discharges.

The profile of density made in this place shows uniform stability situation in water column up to 20m.





Entrainment hypothesis of subglacial melting water discharge mechanism

1. At subglacial conduit may exist gradient of excess pressure over hydrostatic pressure due to overburden pressure of glacier. (Subglacial water pressure measured beneath the glaciers in Alps shows a pressure up to 10 bars . Such pressure may create water velocity much higher than in open channel. Recorded velocities under the glaciers were as high as 50 ms^{-1} .)

2. The mechanism by which a forced plume entrains ambient fluid is describe by **entrainment hypothesis**. According to this hypothesis which introduce the idea of **entrainment velocity** (the volume of entrained water per unit area per unit time, which has units of velocity)

$$E = \alpha \dot{V}_c$$

the volume ratio of entrainment water is proportional to the mean central velocity and reverse proportional to the jet radius.

3. As the subglacial discharge changes from forsed plume (or buoyant jet) to pure plume entrainment velocity changes along its trajectory :

This may create a very efficient local (position and layer) mechanism of mixing plume and ambient waters.

Results:

The fact that birds concentrate their foraging efforts in front of glaciers was known but the scale of this was not. The spot which we investigated with the size of about less than 1 km^2 was an equivalent to an area of 8500 km^2 taking to account the time spending on foraging by kittiwakes from one colony during breeding.

The most important process which makes glaciers bays very special is glacier melt water discharge.

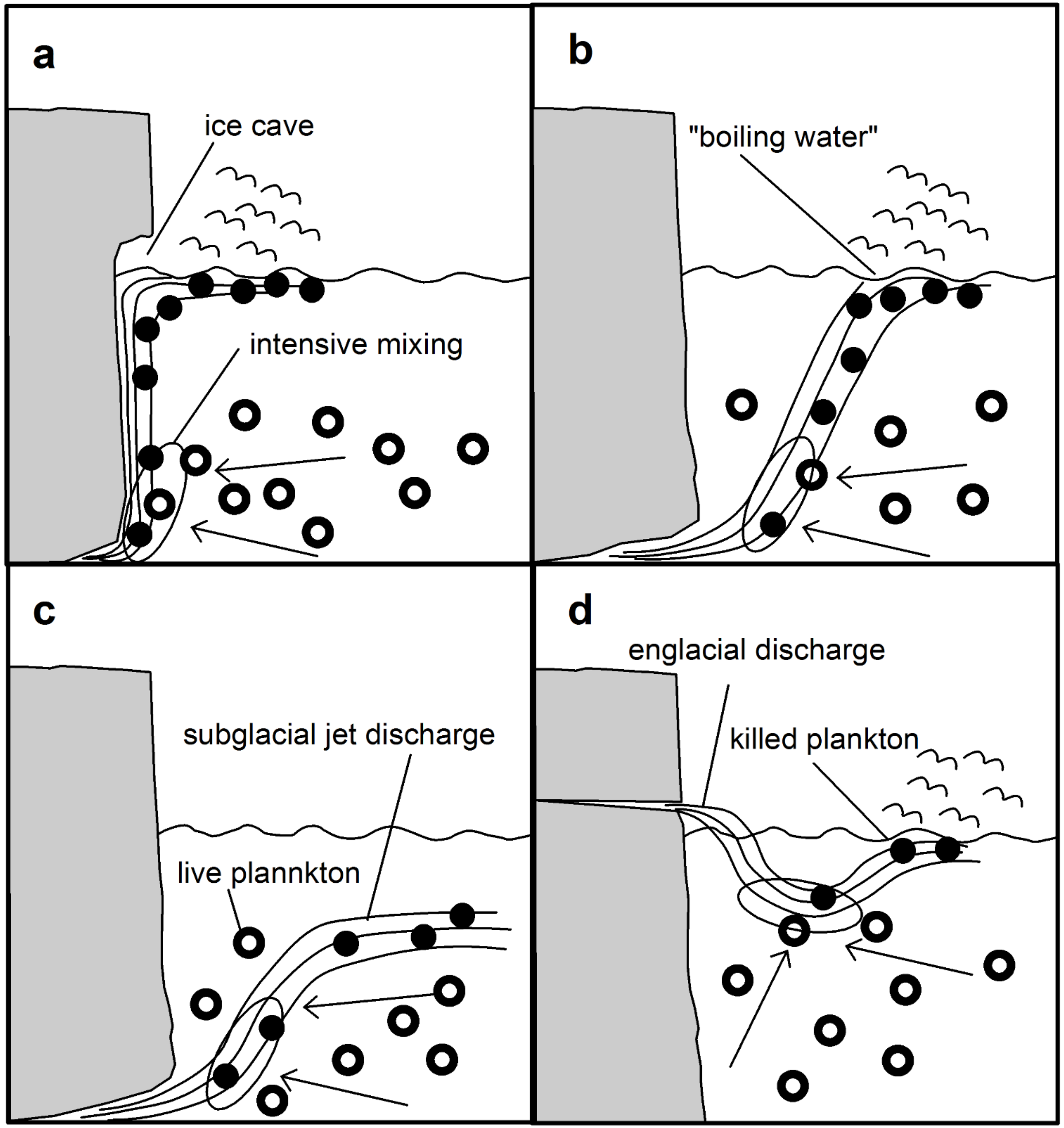
The subglacial discharges **occasionally create a mechanism to concentrate zooplankton**

Bird „hot spots: possible only if

the subglacial discharge reach the surface

the high entrainment velocity at conduit occurs

there be enough macroplankton in the layer of entrainment with high entrainment velocity.



Plan for 2016

Searis
Technologies

MUSE
Multipurpose Unmanned Surface Explorer

- Dimensions: 160 cm (length) x 92 cm (width) x 42 cm (transportation height) or 196 cm (operating height with raised mast and attached motor)
- Minimum operational water depth: 0,5m
- Weight: 40kg
- Payload: up to 30kg
- Central well for installing scientific equipment up to 27cm in diameter
- Flat keel allows for installation of through-hull devices
- Winch up to 50m, max load 10kg
- Propulsion: Noiseless 12V electric motor with trust vector control - zero radius turns
- Speed: max 4 m/s (8 kn), typical 2 m/s (4 kn)
- Seaworthiness: force 3 Beaufort scale
- Range: 25 km
- Work time on a single charge: 3,5h
- Precise positioning using DGPS
- Manual remote control, video and telemetry range: up to 3km*
- Autonomic navigation based on a course set on ground station
- Integration with QuantumGIS software allows for using public or custom maps and real time display of telemetry data

*subject to local law regarding maximum RF transmission power

- Water sampling
  - Onboard sampler, external bathometers
- Measurements on different depths using a winch
  - CTD, SVP, turbidimeter, pH meter