Role of Subglacial Discharge from Tidewater Glaciers in Driving Fjord and Coastal Circulation Dynamics

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Contents

1. Introduction

2. Methodology

3. Results

4. Discussion

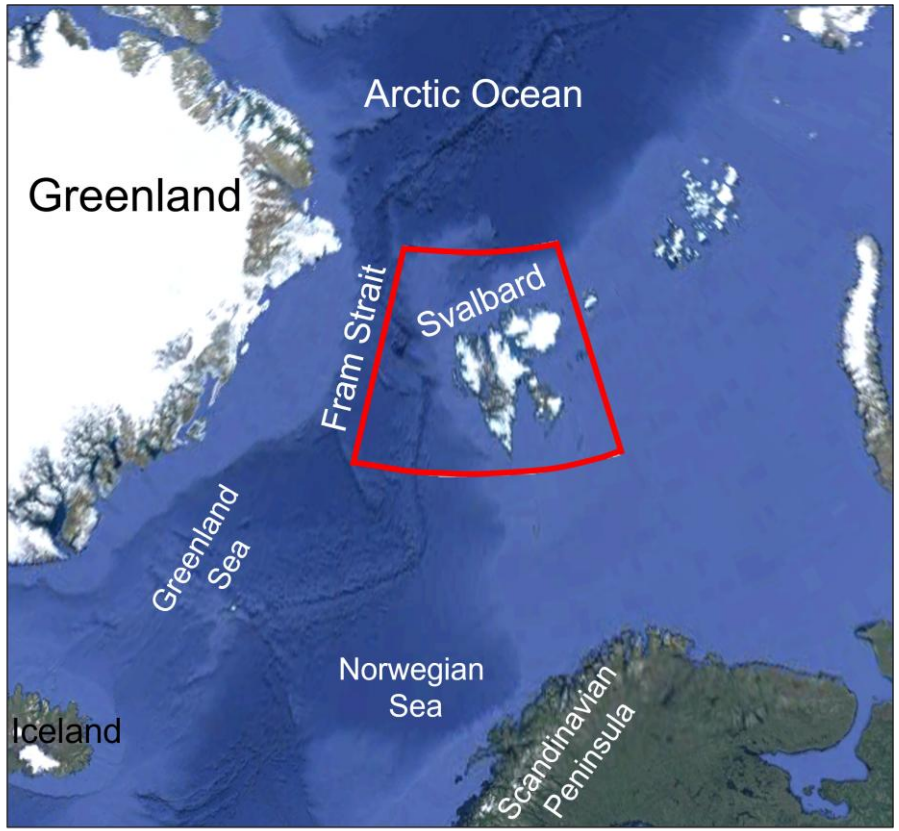
5. Conclusions

1. Introduction

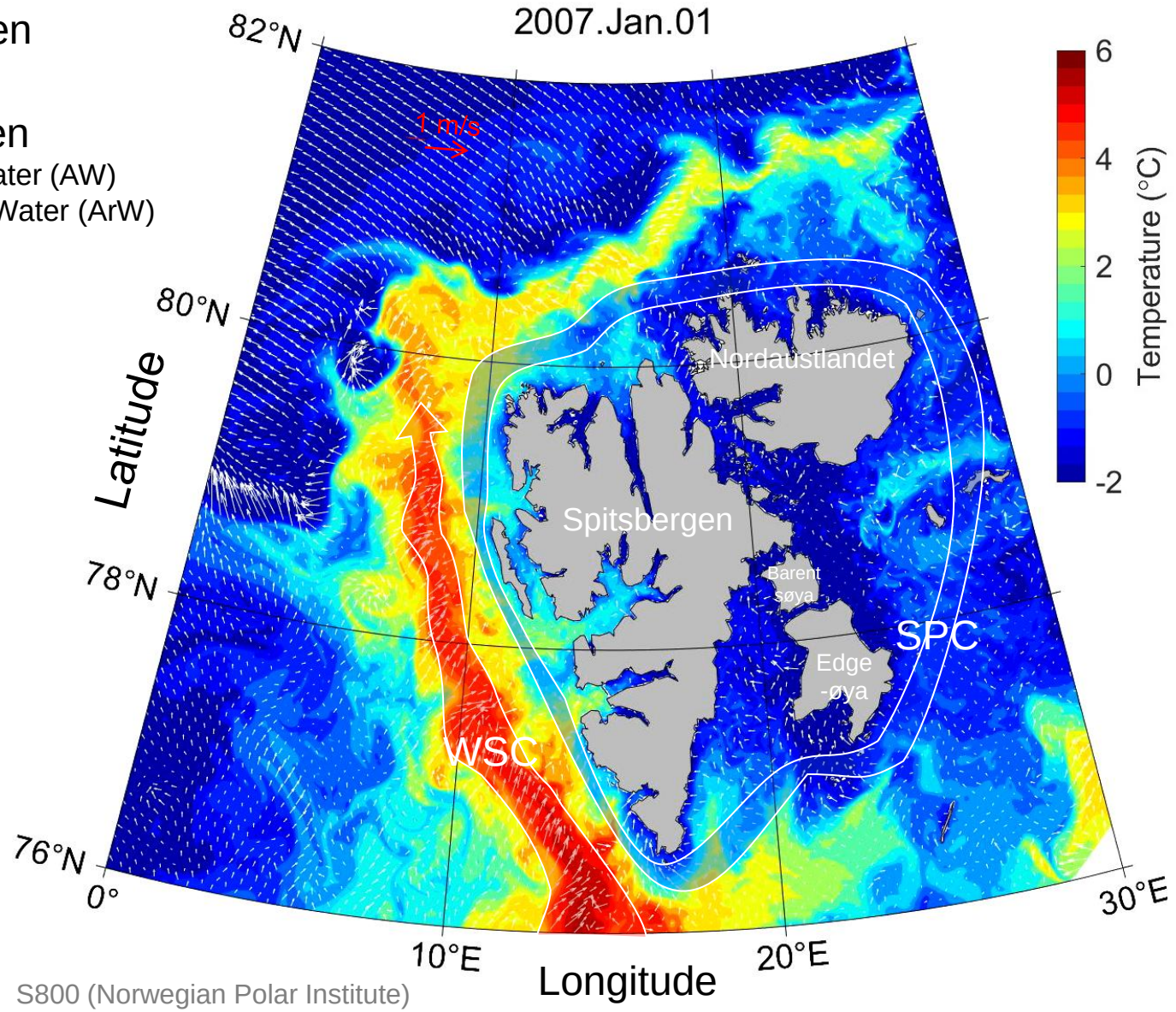


Spitsbergen, in Svalbard

- Svalbard archipelago located at gateway between North Atlantic Ocean and Artic Ocean
- **Two major currents** in west coast of Spitsbergen
  1) West Spitsbergen Current (WSC) : warm (>3.0°C) of Atlantic Water (AW)
  2) Spitsbergen Polar Current (SPC) : cold (-1.5 to 1.0°C) of Arctic Water (ArW)



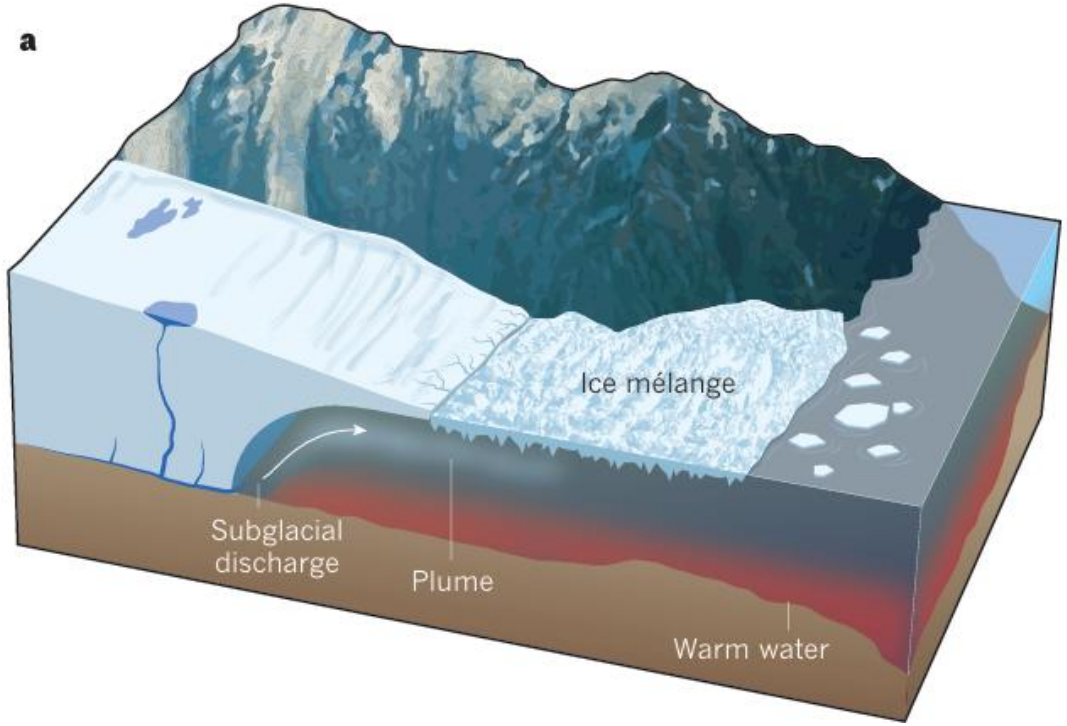
Google Earth



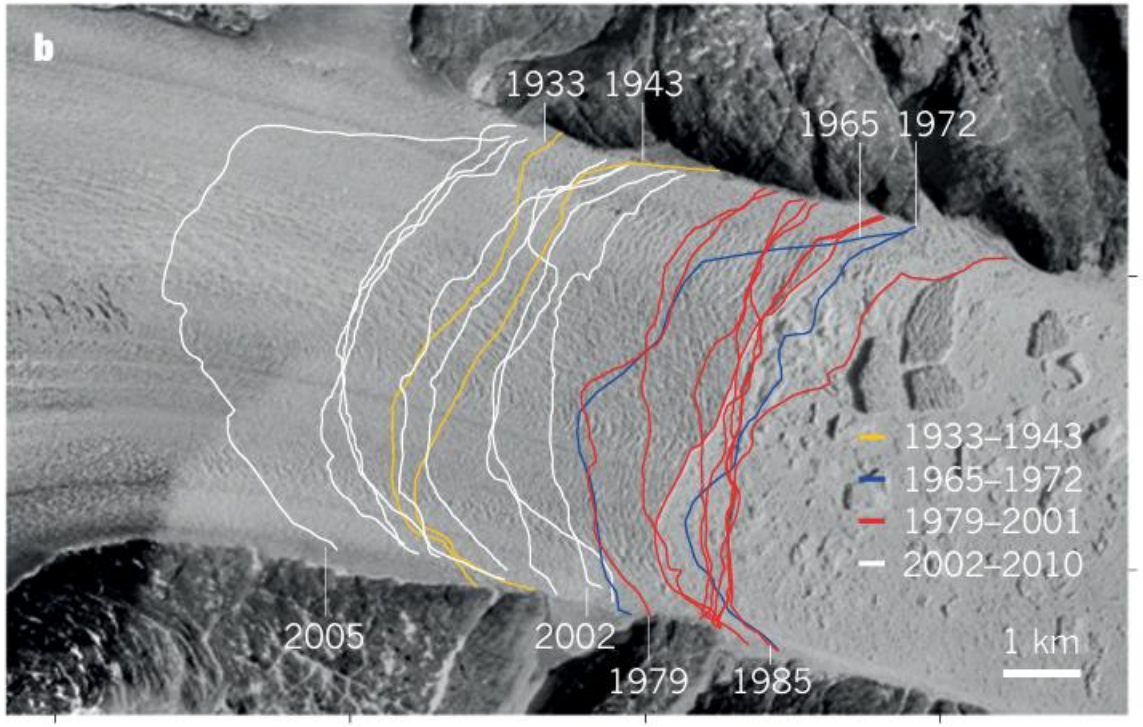
S800 (Norwegian Polar Institute)

Increase of meltwater runoff

- The **melting rate** of tidewater glaciers on Arctic fjord coastlines **has increased** in recent decades (Vaughan et al., 2013; Huss and Hock, 2018)
- **The inflow of warm water** from the outside of fjord can induce tidewater glaciers melting (Straneo and Heimbach, 2013; Sutherland et al., 2019)



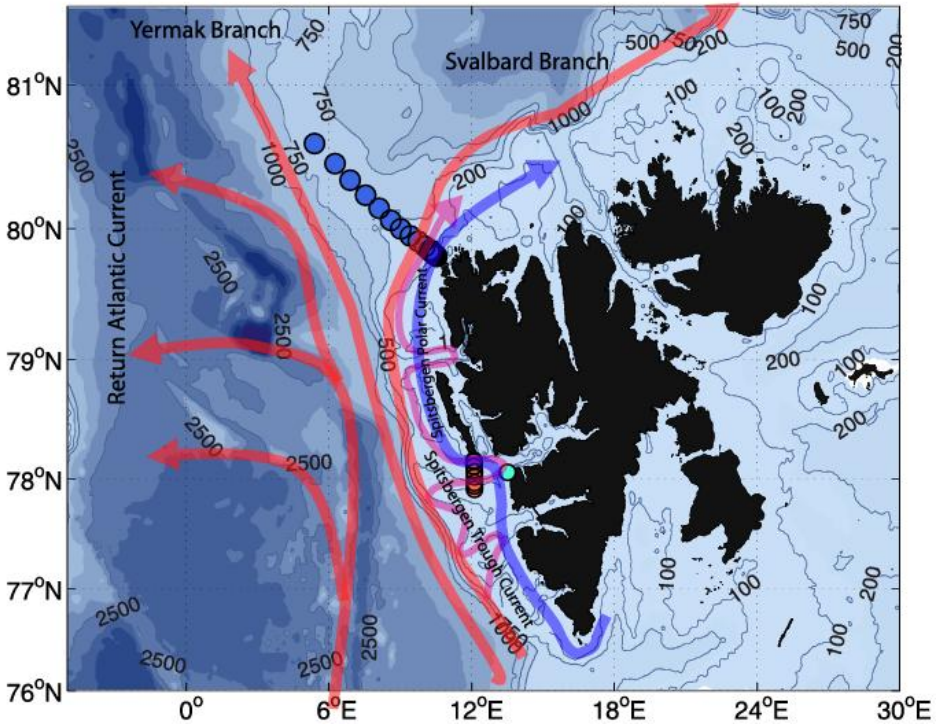
Submarine melting caused by warming subsurface ocean water (Straneo and Heimbach, 2013)



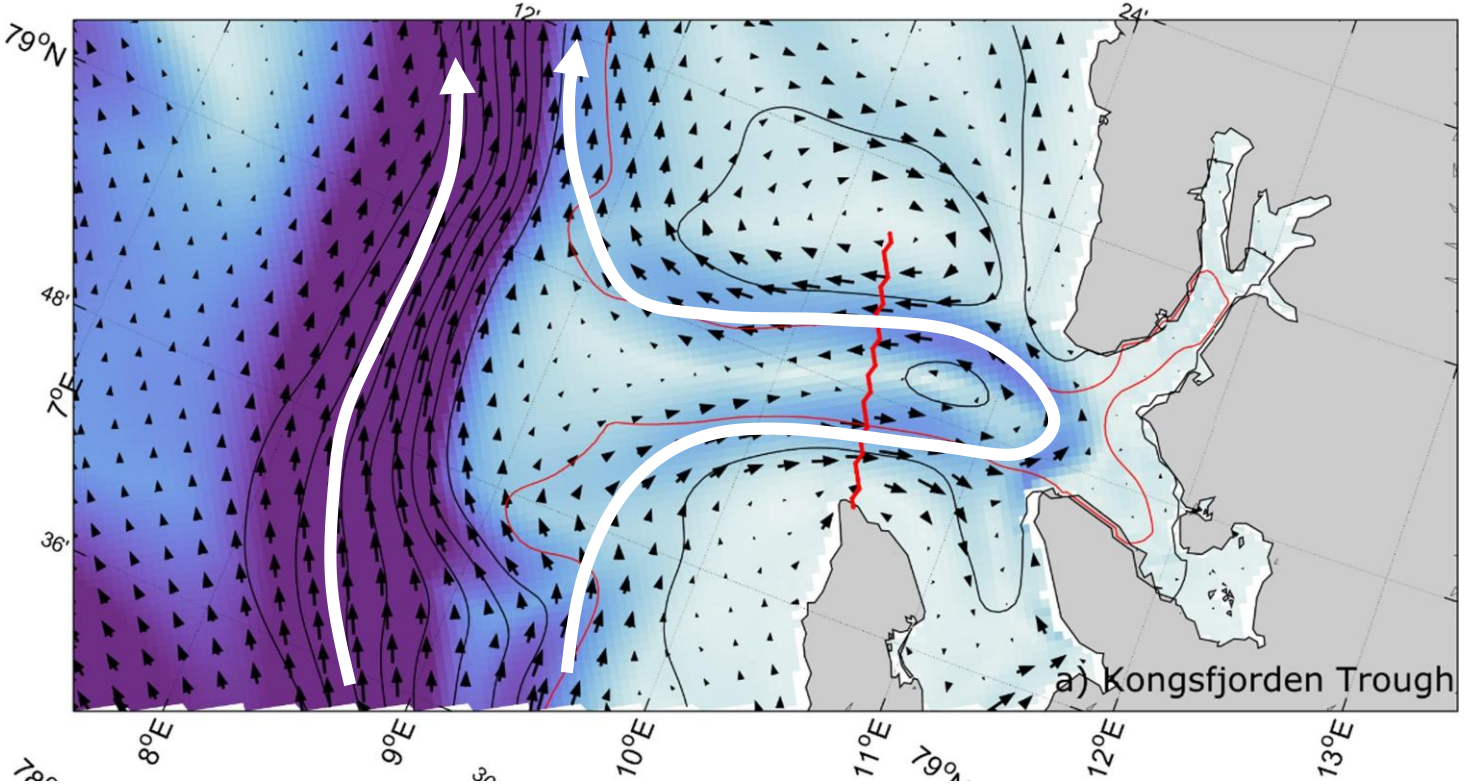
Tidewater glacier front change of Sermilik fjord, Greenland (Straneo and Heimbach, 2013)

Flow patterns at west coast of Spitsbergen

- The inflow of WSC and SPC to the fjords can affected by various factors
- Nilsen et al. (2016) suggested that the flow patterns are determined by bathymetry, while Cotteir et al. (2010) suggested that the horizontal density gradient have a significant impact on the inflow of warm water



Nilsen et al. (2016)

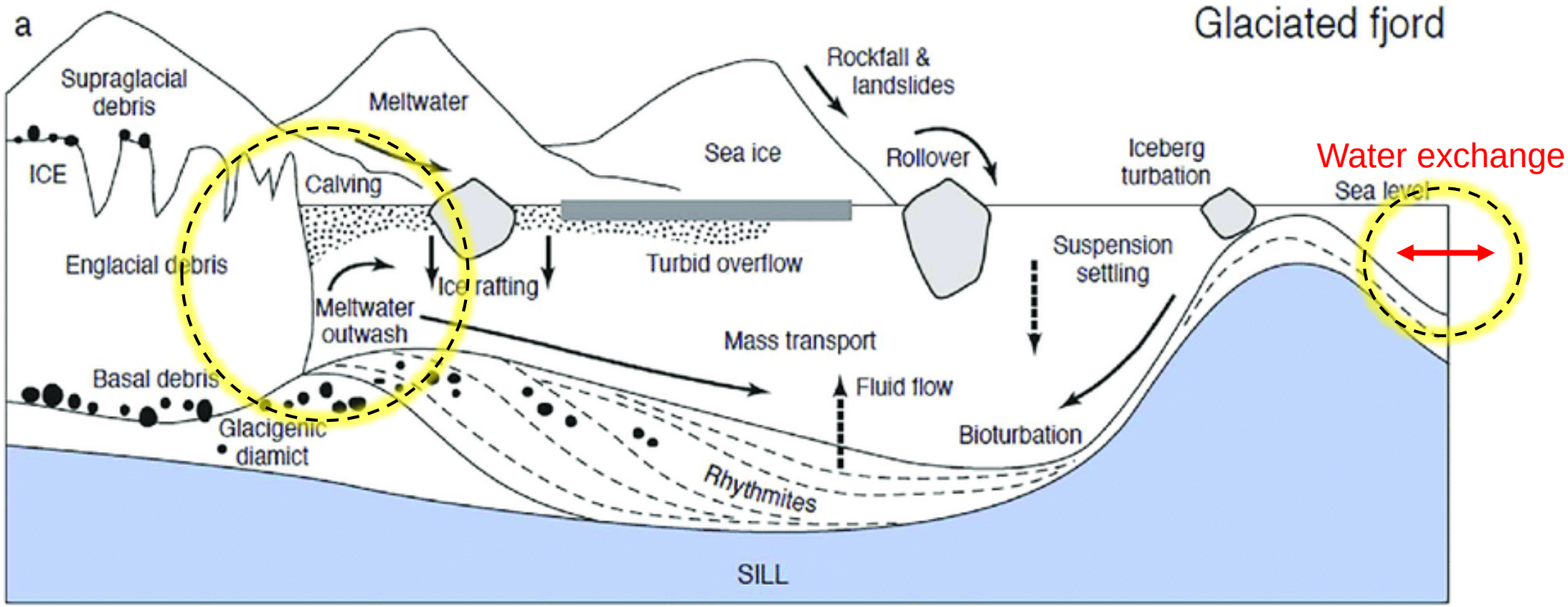


Trough current of S800 model result at Krongsfjorden (Menze et al., 2020)

Meltwater runoff ↑ → Horizontal density gradient ↑ → **Water exchange process change**

Ocean circulation in fjord system

- However, there is less study about the impact of meltwater runoff on water exchange between inner and shelf
- Also, questions remain over how the internal circulation interacts with exchange mechanisms (Fraser, 2017)

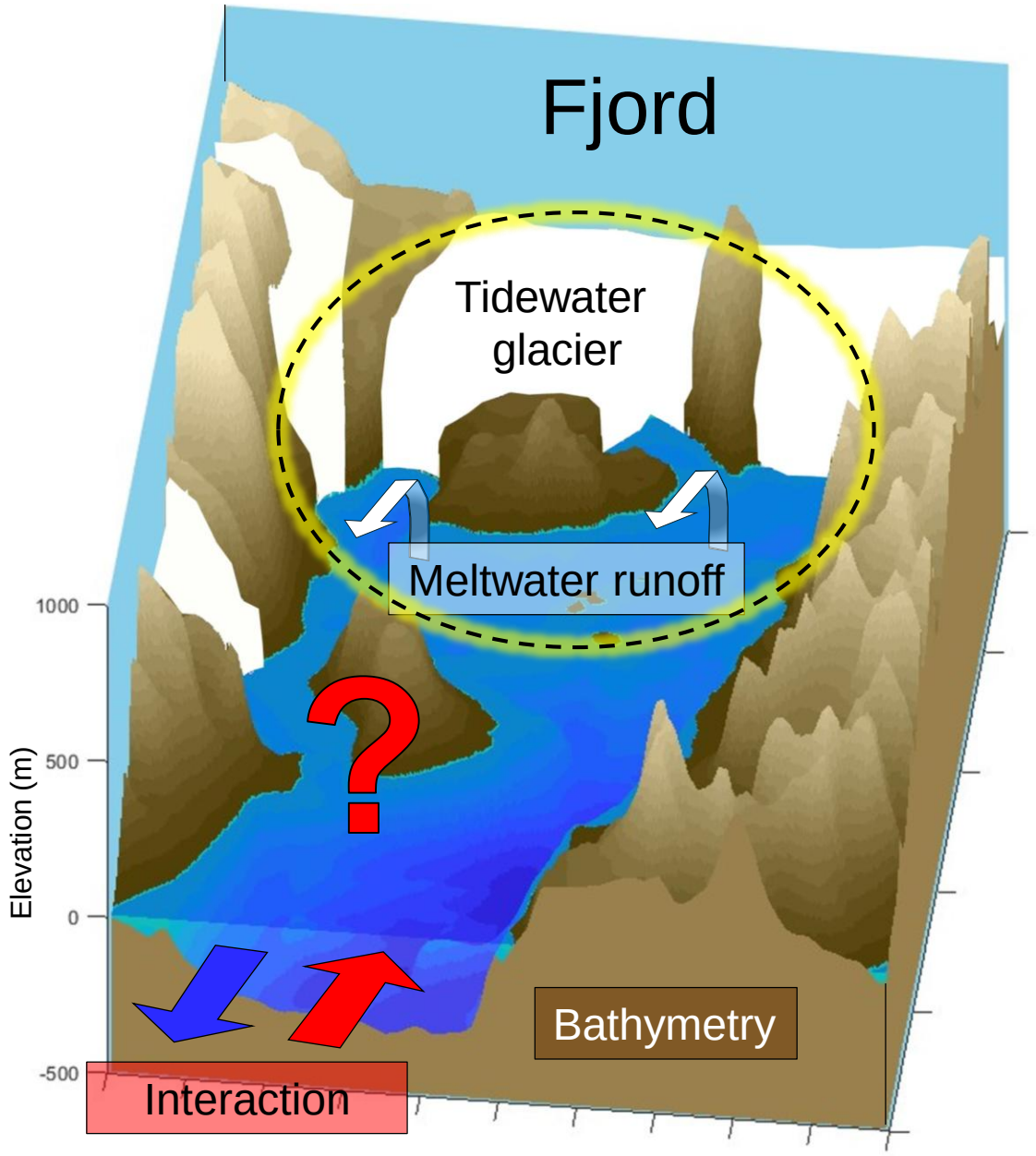


Principle physical processes within fjord (Bianchi et al., 2020)

Objectives

- The objectives of this study are change in
  1) the **flow patterns** inside the fjord, and
  2) the **volume transport processes** between inner and outer fjords system

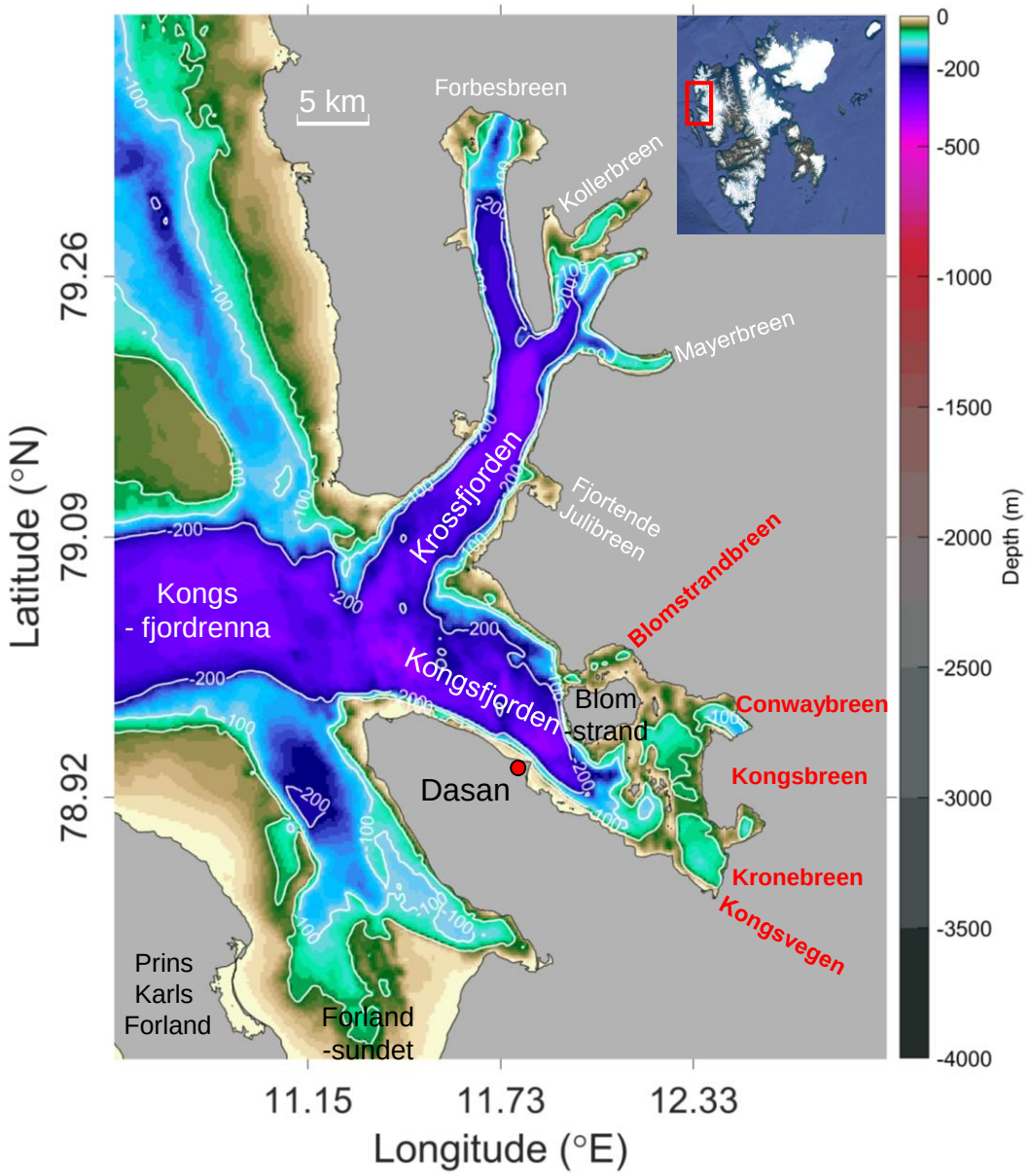
  due to the meltwater runoff using numerical modeling



2. Methodology



Study area

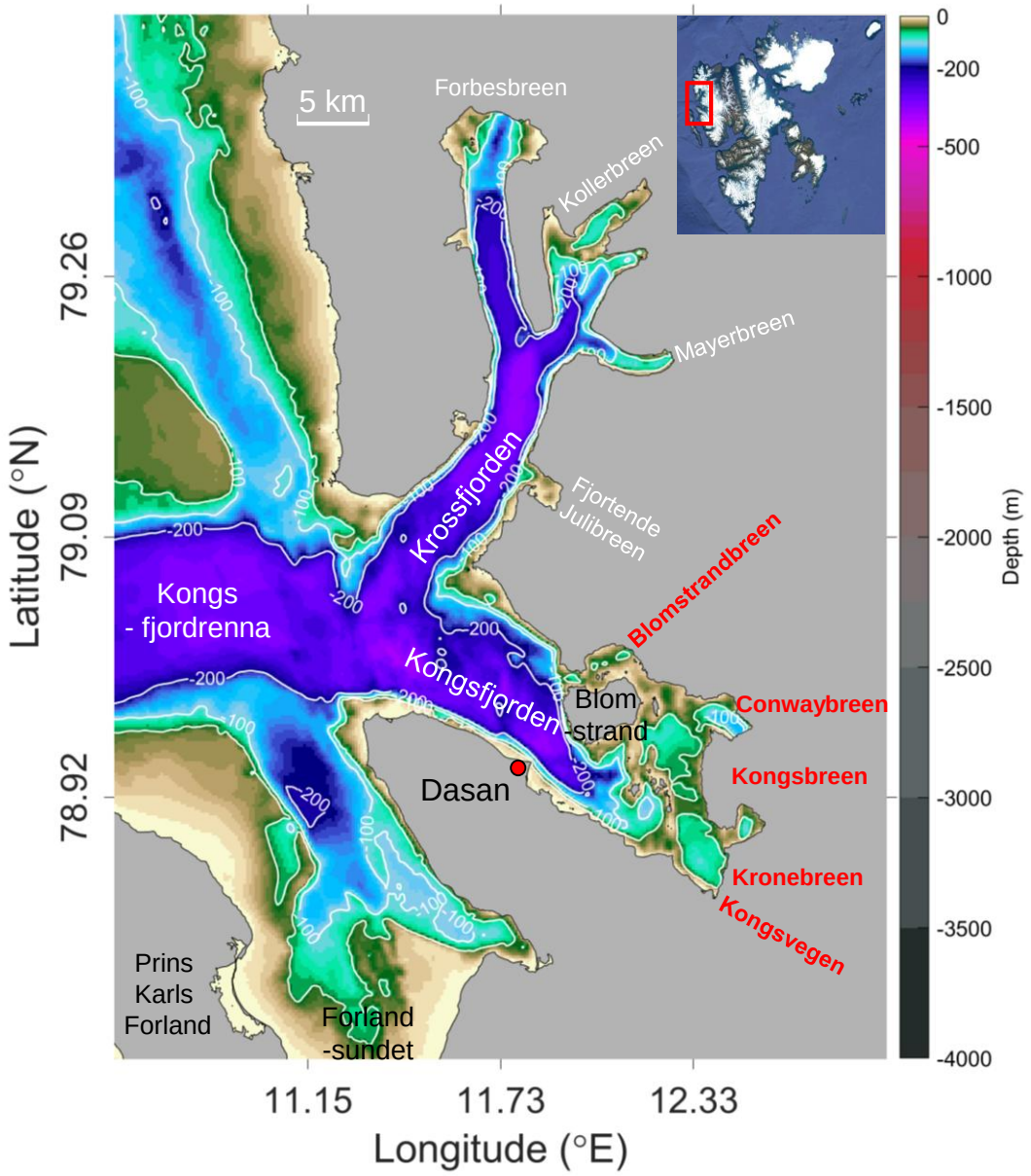


- **Kongsfjorden** located in the west coast of Spitsbergen
- Steep slope near Blomstrand (from 100–200 m)
- There is **5 tidewater glaciers** in Kongsfjorden
  (Kongsvegen, Kronebreen, Kongsbreen, Conwaybreen, Blomstrandbreen)

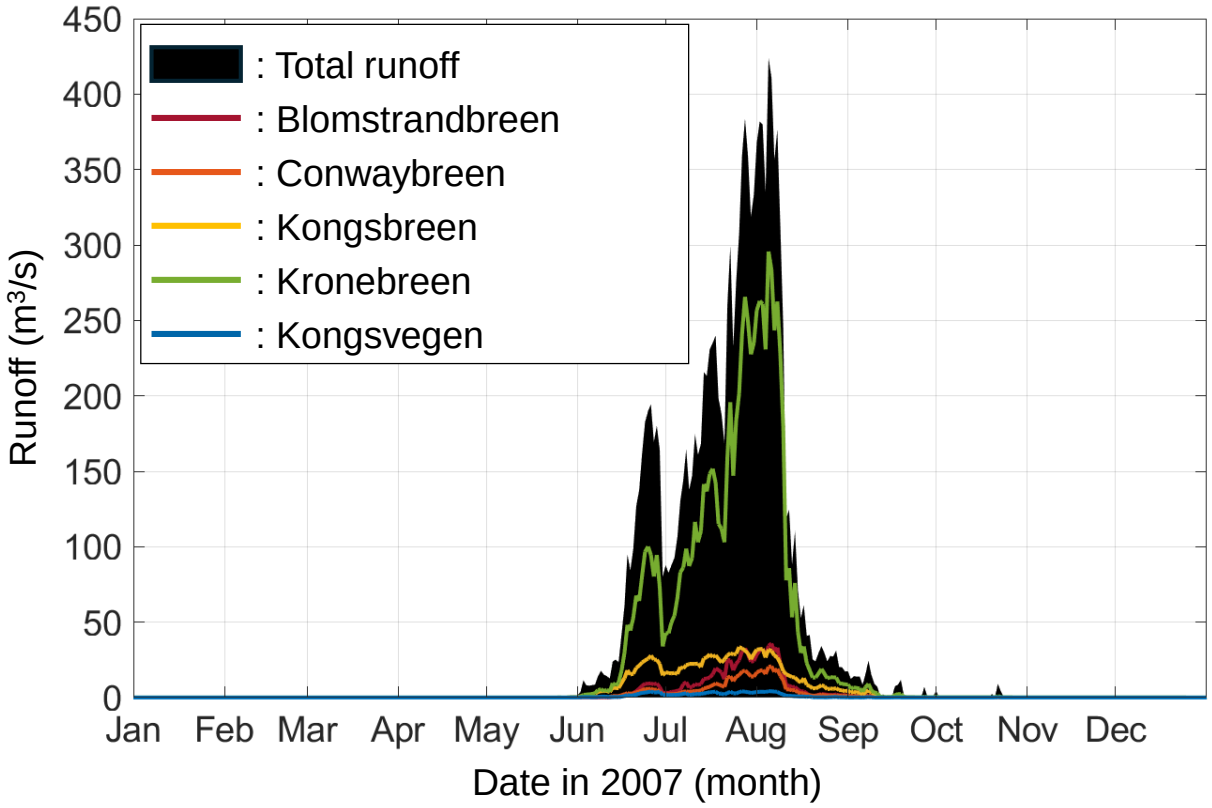


Google Earth

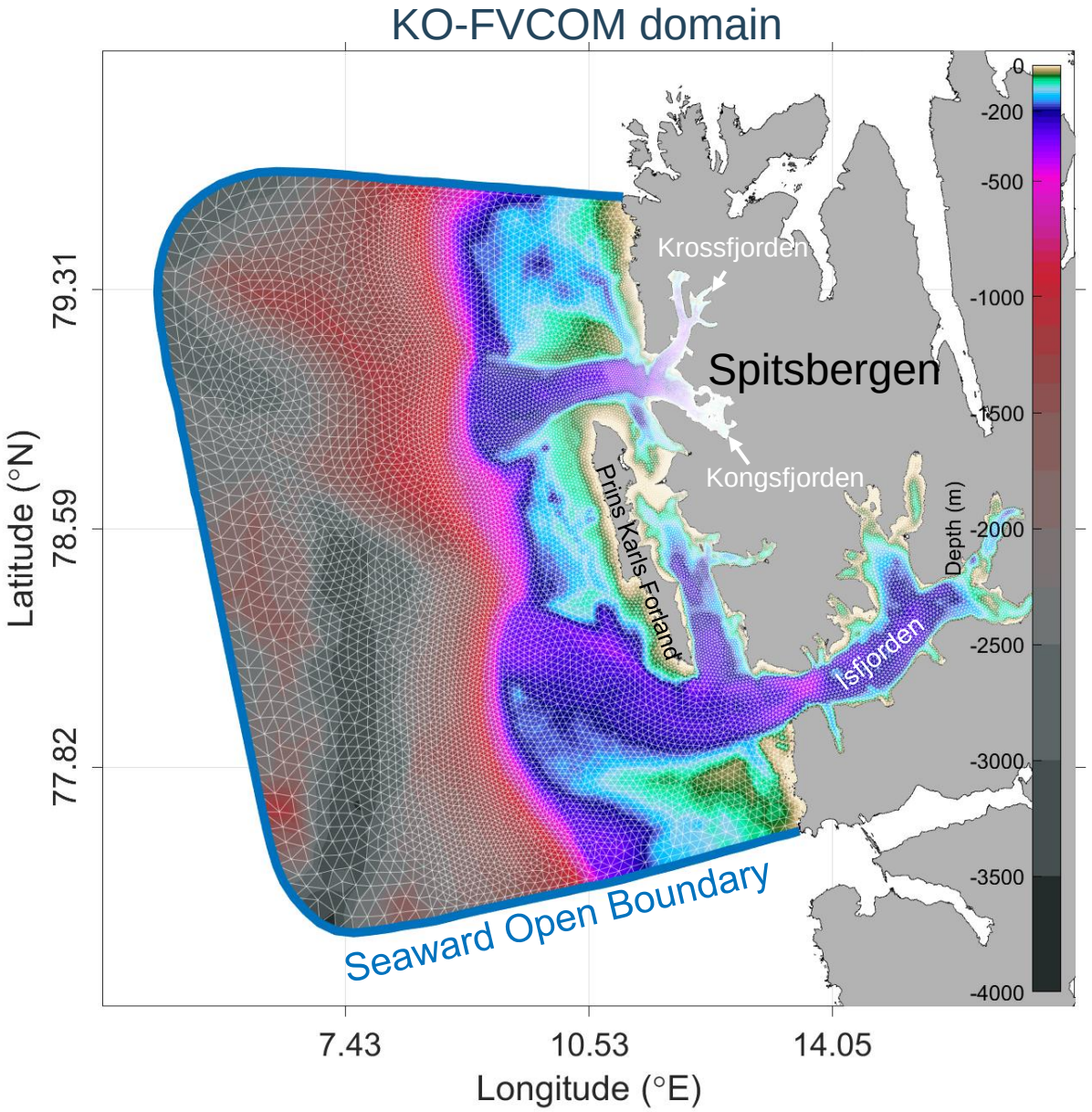
Study area



- 98% of meltwater runoff in 2007 occurred summer season (June-August)
- **86.57 % of meltwater runoff from 5 tidewater glaciers**



Model setup

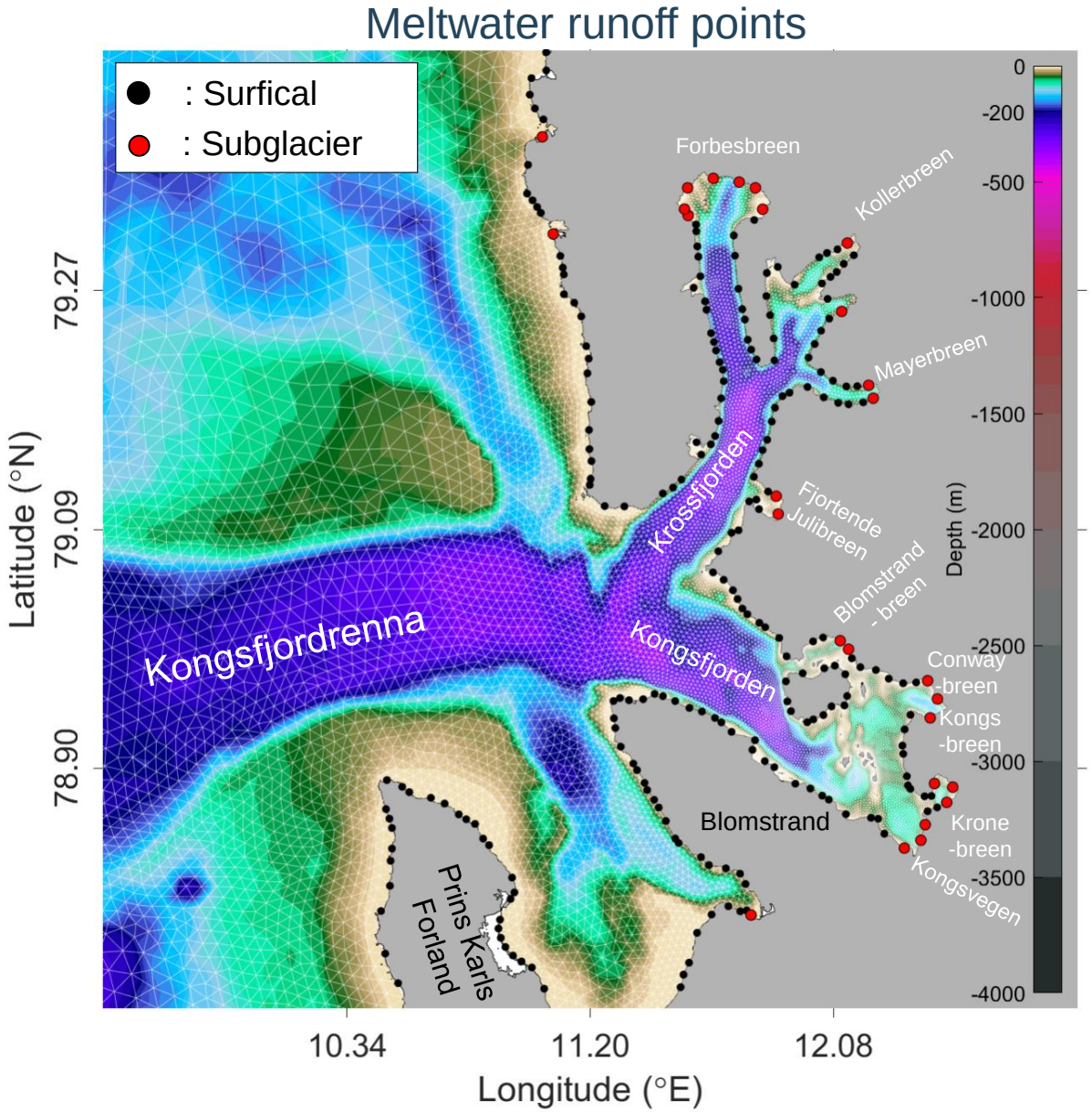


Model information	
Model	Finite-Volume Community Ocean Model (KO-FVCOM)
Grid type	Unstructured triangular grid
Vertical coordinate	Sigma coordinate
Horizontal resolution	70–5,300 m (28,020 nodes, 52,743 cells)
Model periods	2007.01.01–2007.12.31

KO-FVCOM setup			Data source
Domain	Coastline		NPI
	Bathymetry		IBACO 4.0
Initial condition	Salinity & Temperature		ROMS-S800
Input forcing	Seaward open boundary	Salinity & Temperature	
		Elevation	TPXO-atlas08
	Landward boundary	Meltwater runoff	Snow model (NPI, Dr. Pedro)
	Surface boundary	Wind, Air pressure, Heat flux	ECMWF-ERA5

Model setup

Meltwater runoff points

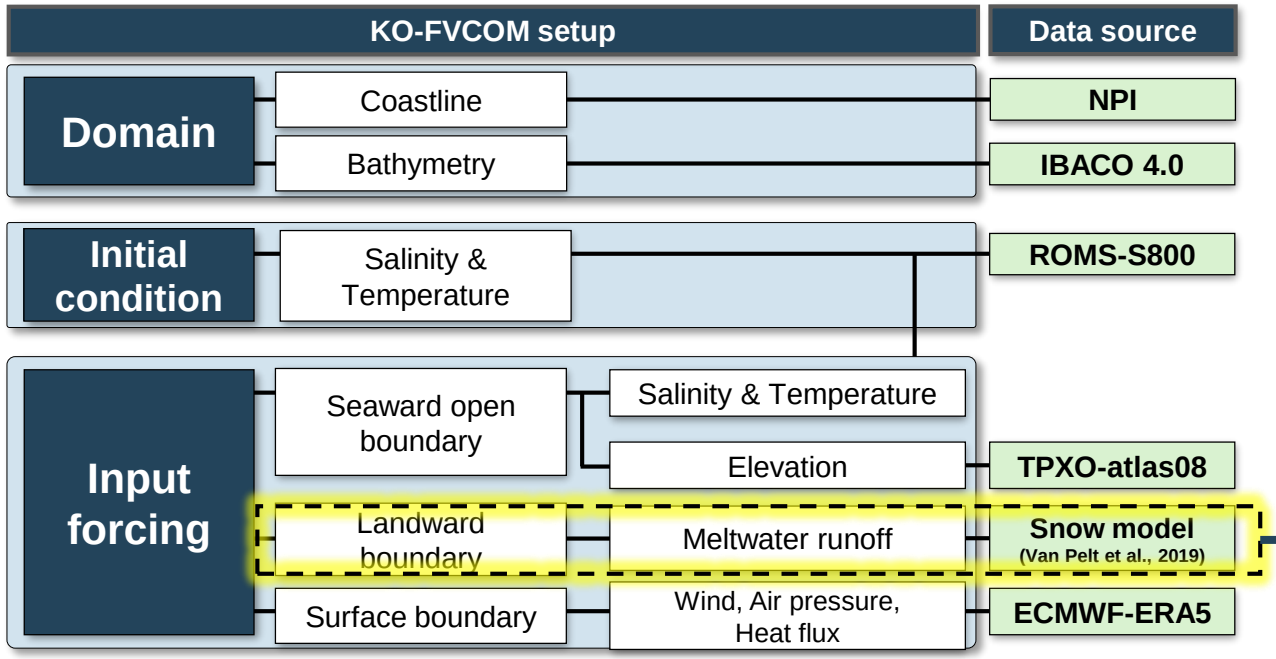


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Simulation cases

Model information	
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Model scenario cases

Case1: With Meltwater Runoff

Model scenario testcase which have meltwater runoff forcing from landward boundary

Case2: Without Meltwater Runoff

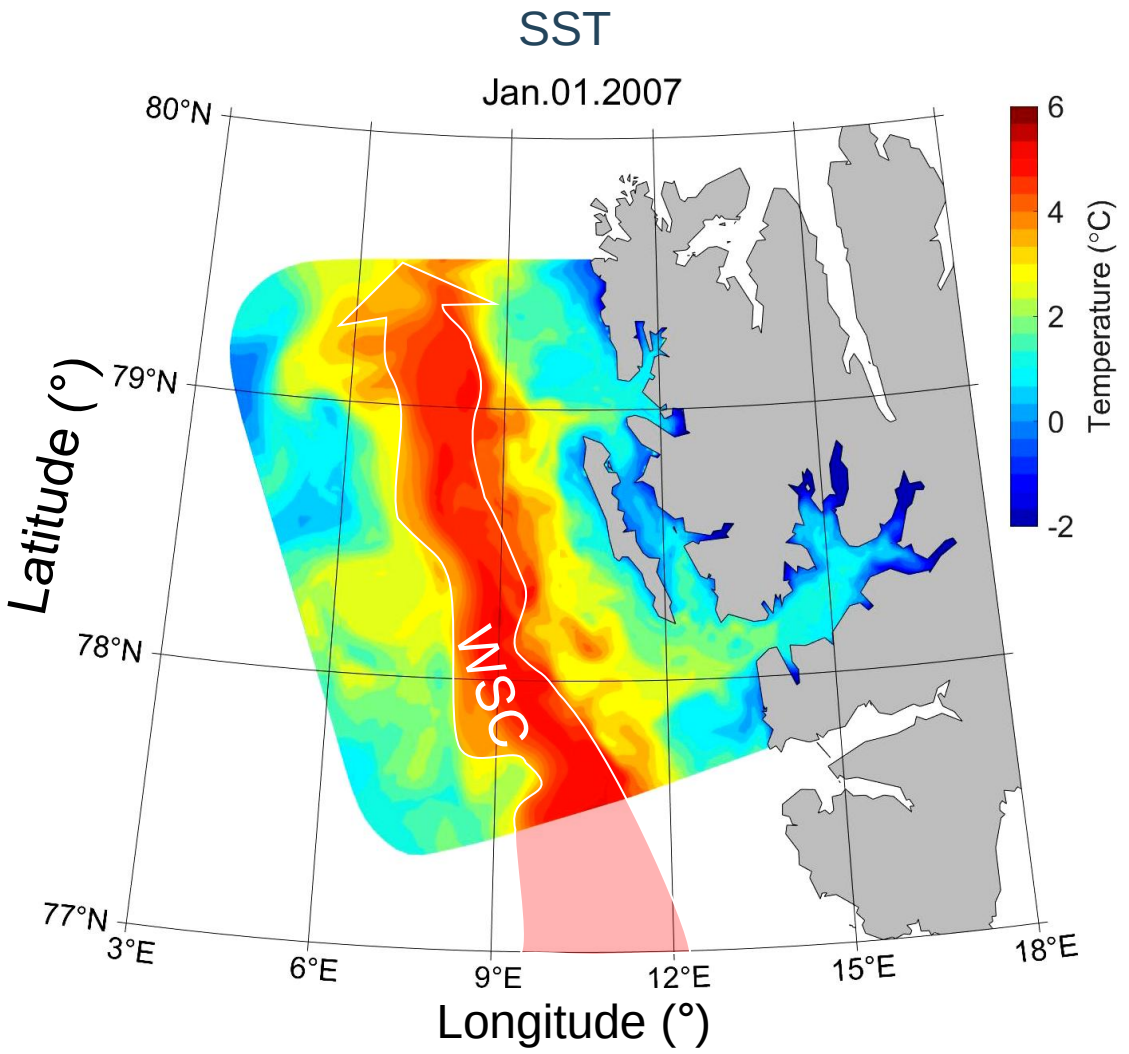
Model scenario testcase which don't have meltwater runoff forcing from landward boundary

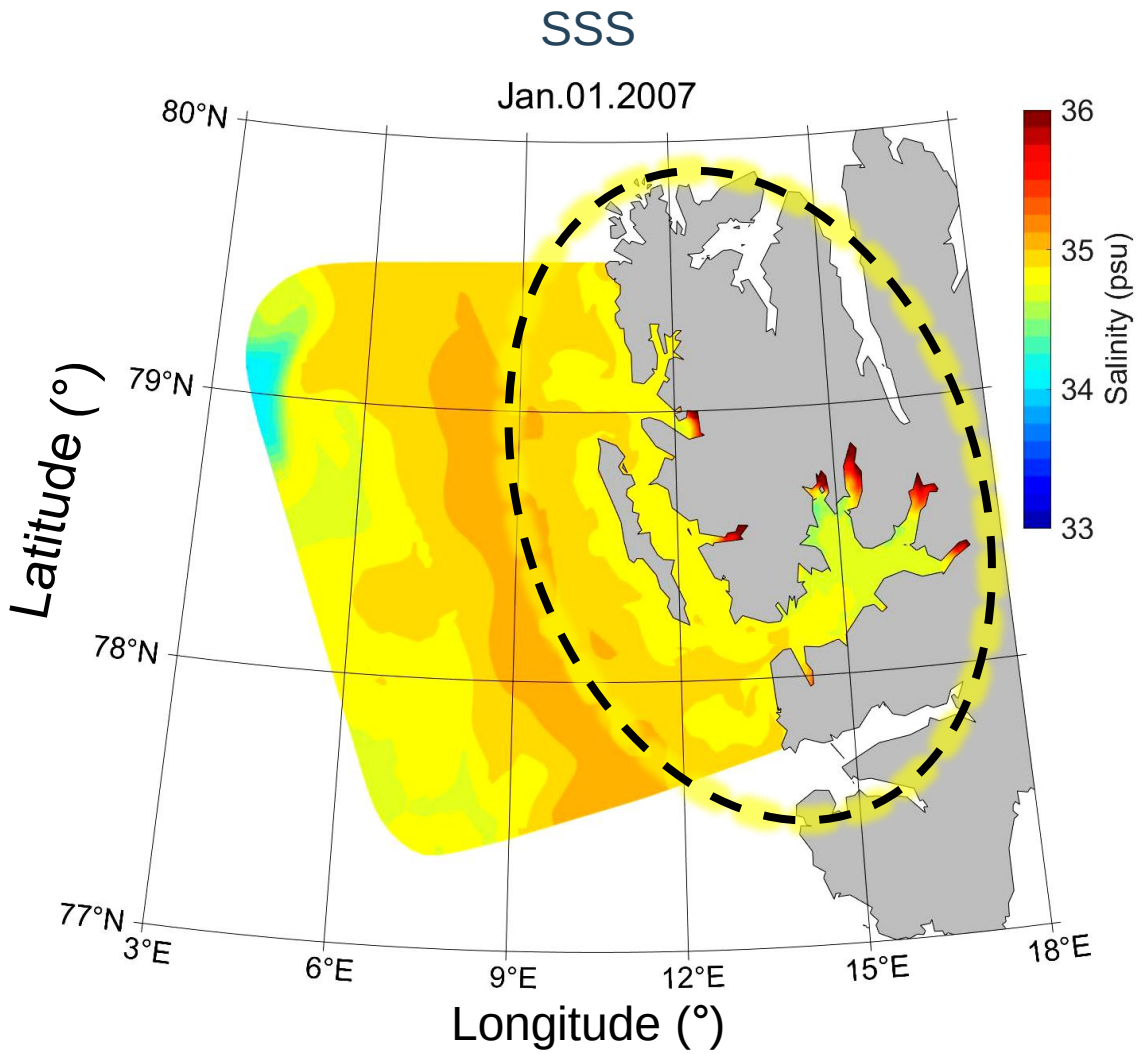
3. Results



Model-data comparisons

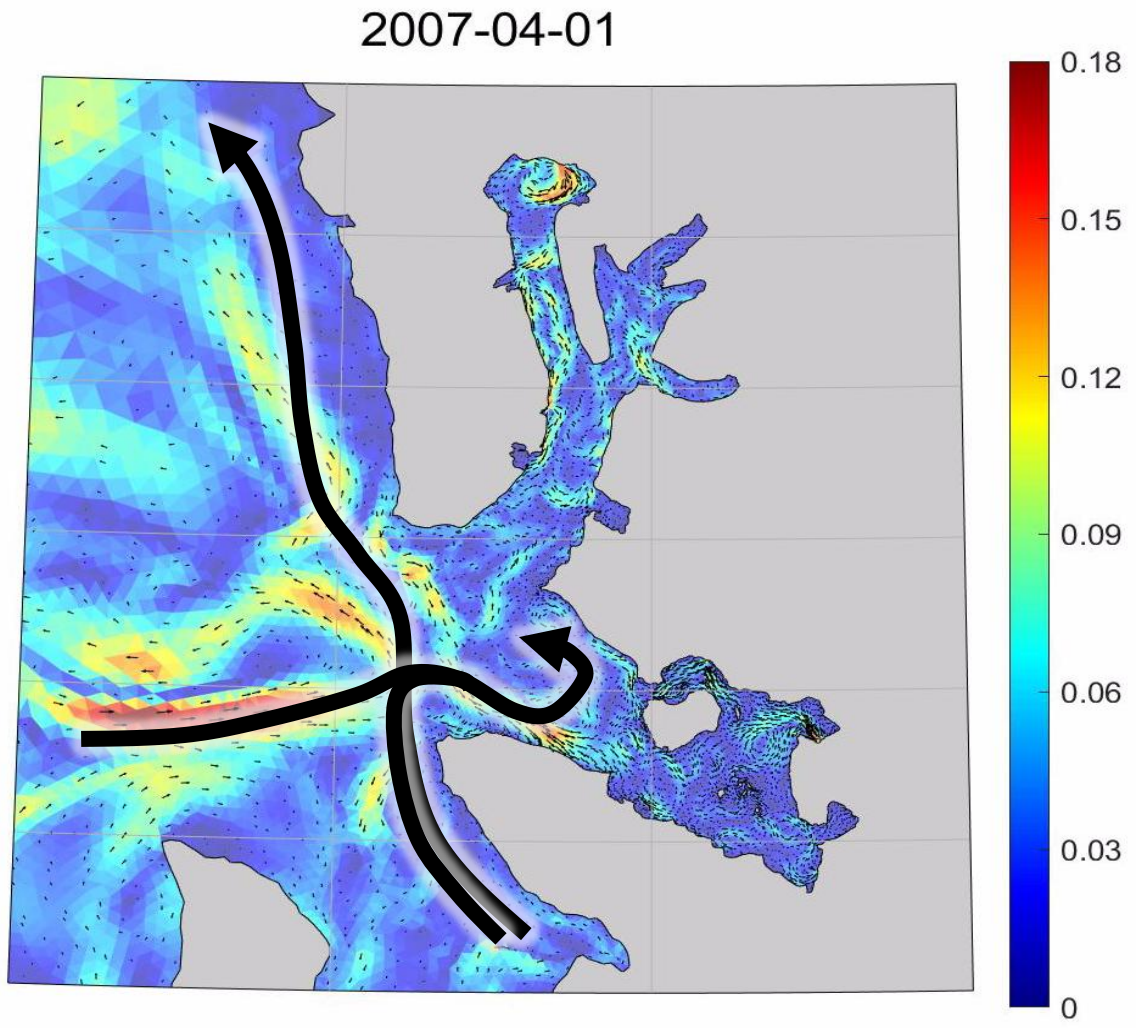
- KO-FVCOM results in Sea Surface Temperature (SST) and Salinity (SSS)

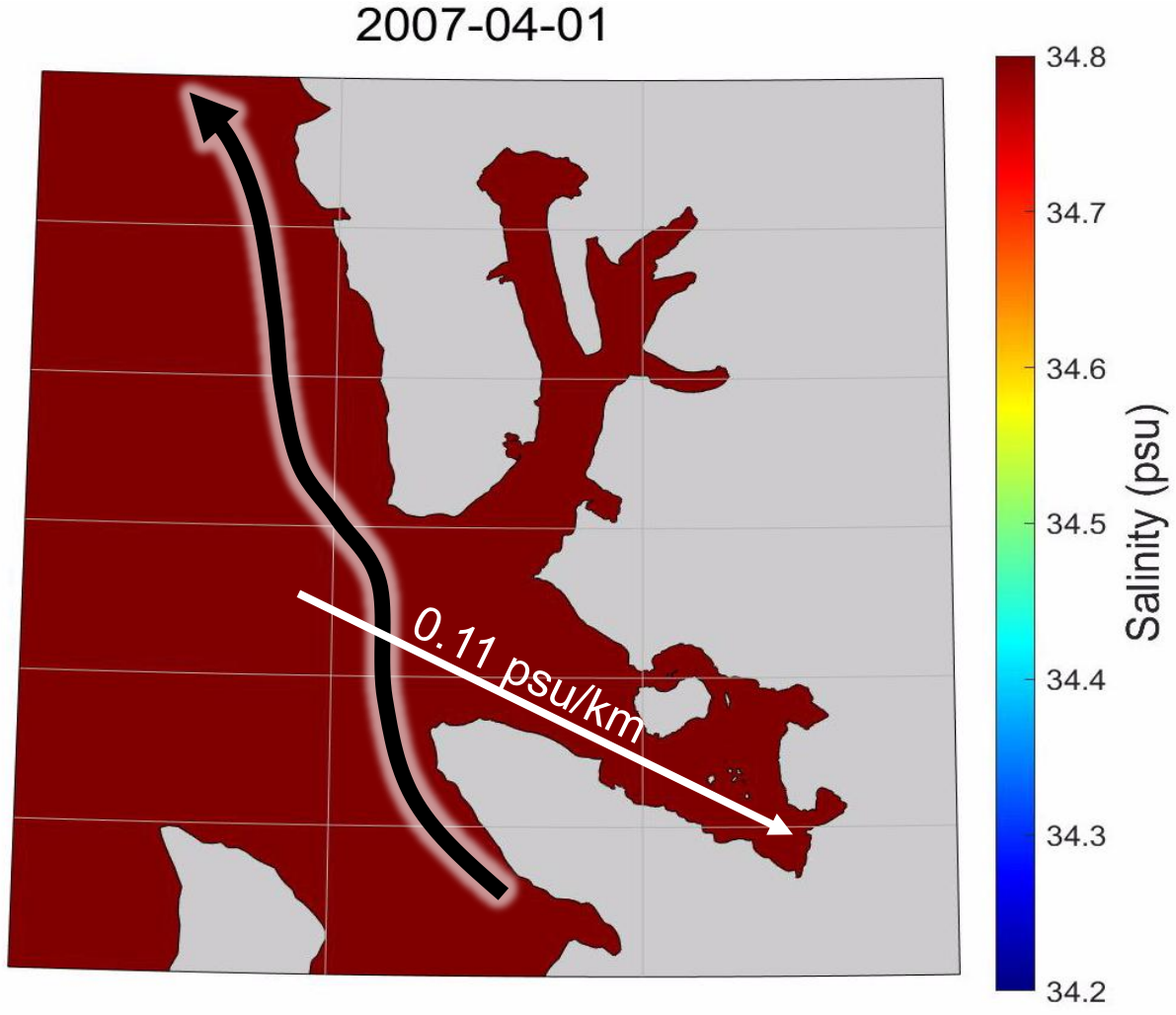




Model-data comparisons

- Model results for the velocity field and SSS near the Kongsfjorden

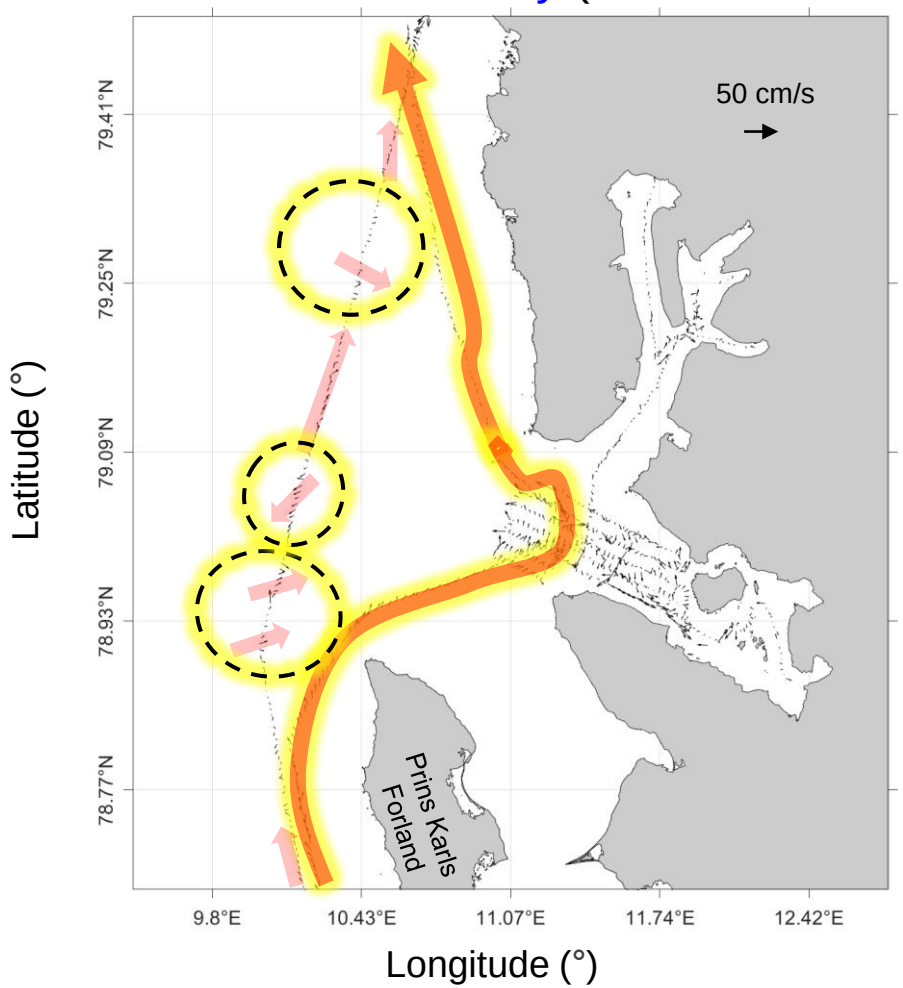




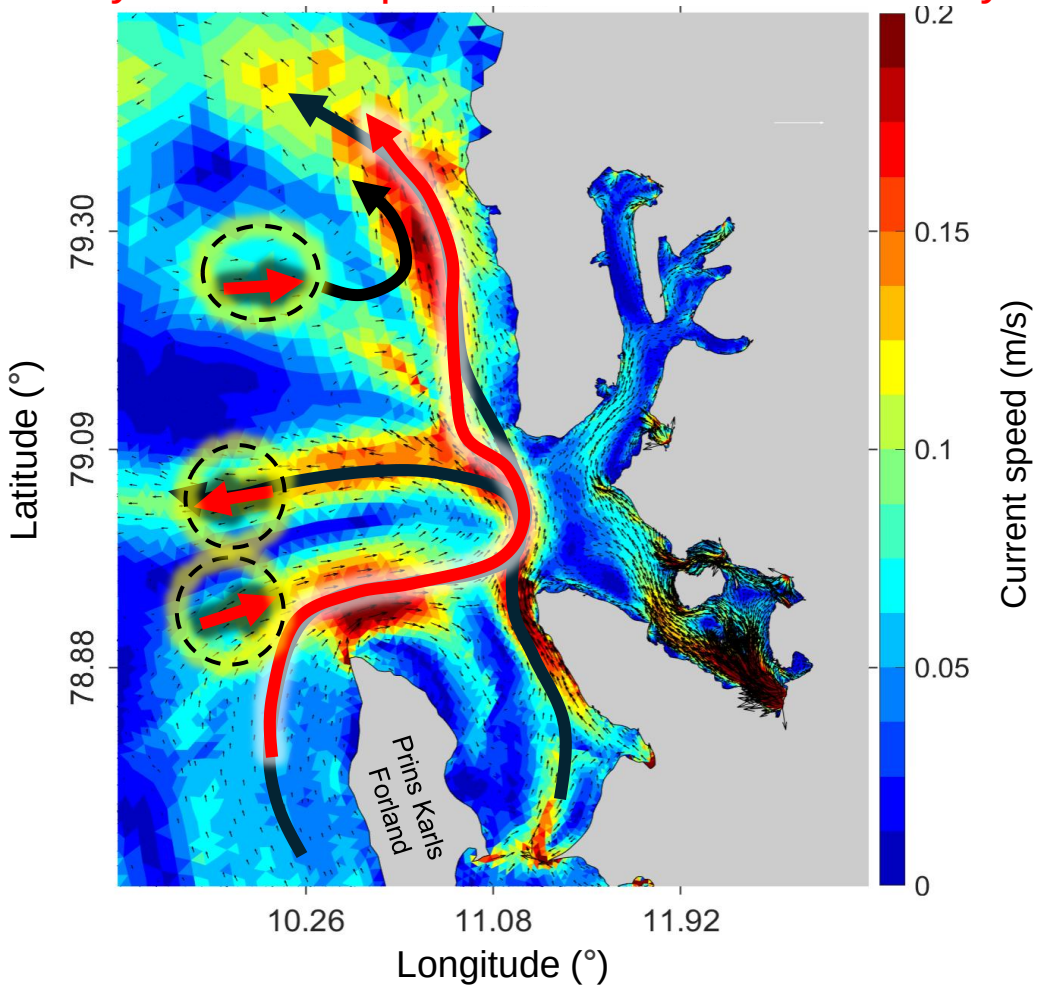
Model-data comparisons

- Validation for the flow pattern at 0 m
  - Model results for velocity matched well with the observed velocity in July

Observation data in July (KOPRI, Dr. Nam)



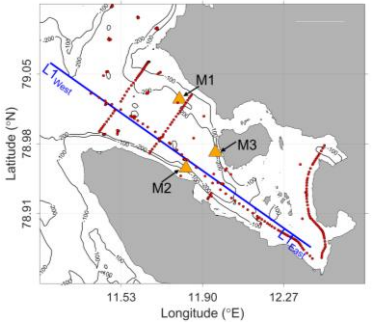
Monthly mean flow pattern of KO-FVCOM in July



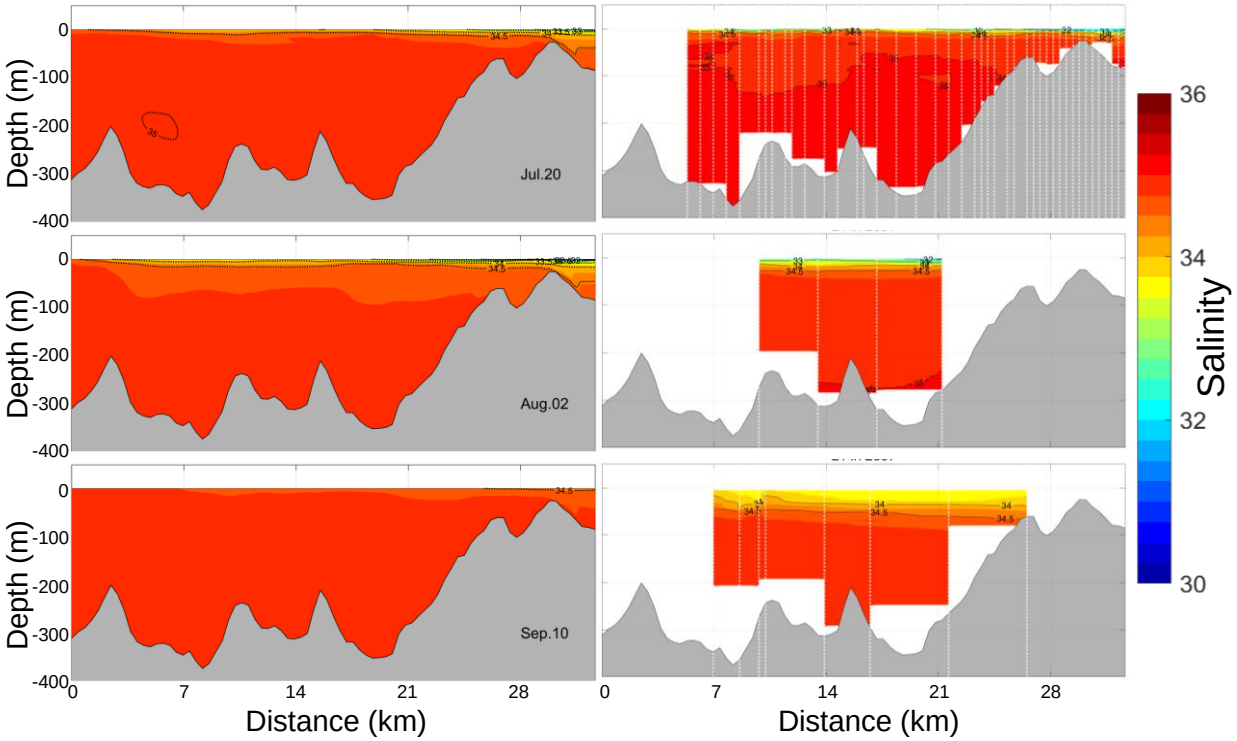
Model-data comparisons

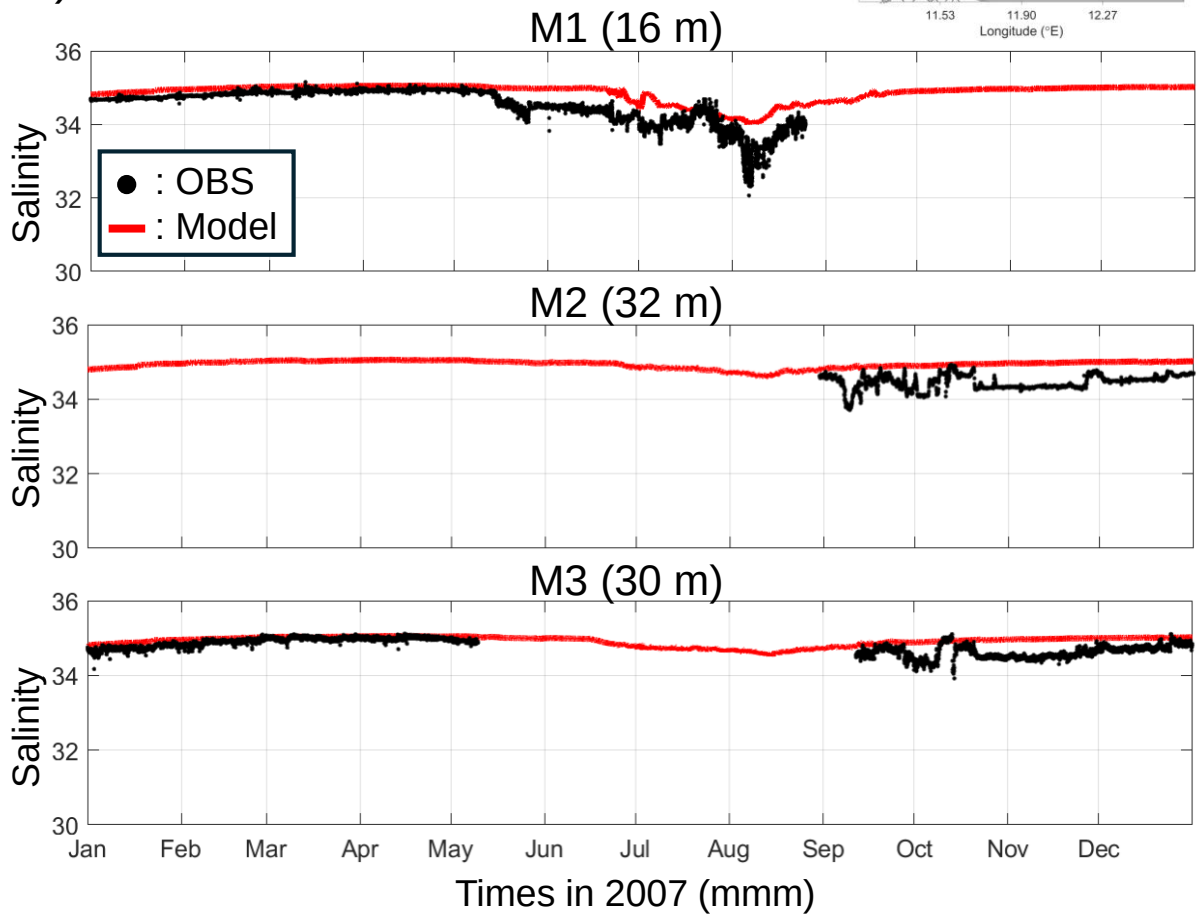
- Validation for salinity
  - Meltwater runoff from tidewater glacial formed the low salinity near the surface layer (<34.00 psu)
  - Modeled salinity is higher than observed salinity (~1 psu)

	Profile	Mooring
RMSE	0.30 psu	0.35 psu
Skill	0.80	0.65
R	0.72	0.73



KO-FVCOM | Observed salinity at L1





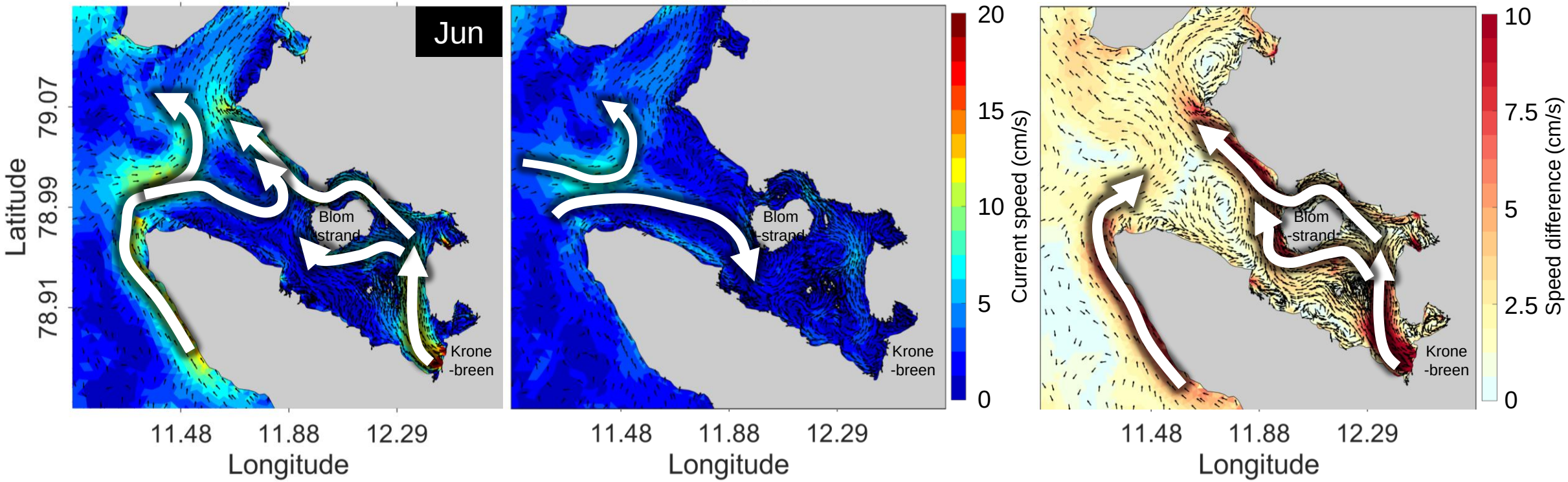
Impacts of runoff on spatial flow

- Monthly mean flow pattern in June (depth 0 m) (runoff: 72.1 m^3/s)
  - Relatively strong flow towards the north occur due to meltwater runoff from Kronebreen
  - Outflow increase over 7.5 cm/s at the northern part near fjord mouth

Case1 (With)

Case2 (Without)

Difference of velocity
(Case1 - Case2)



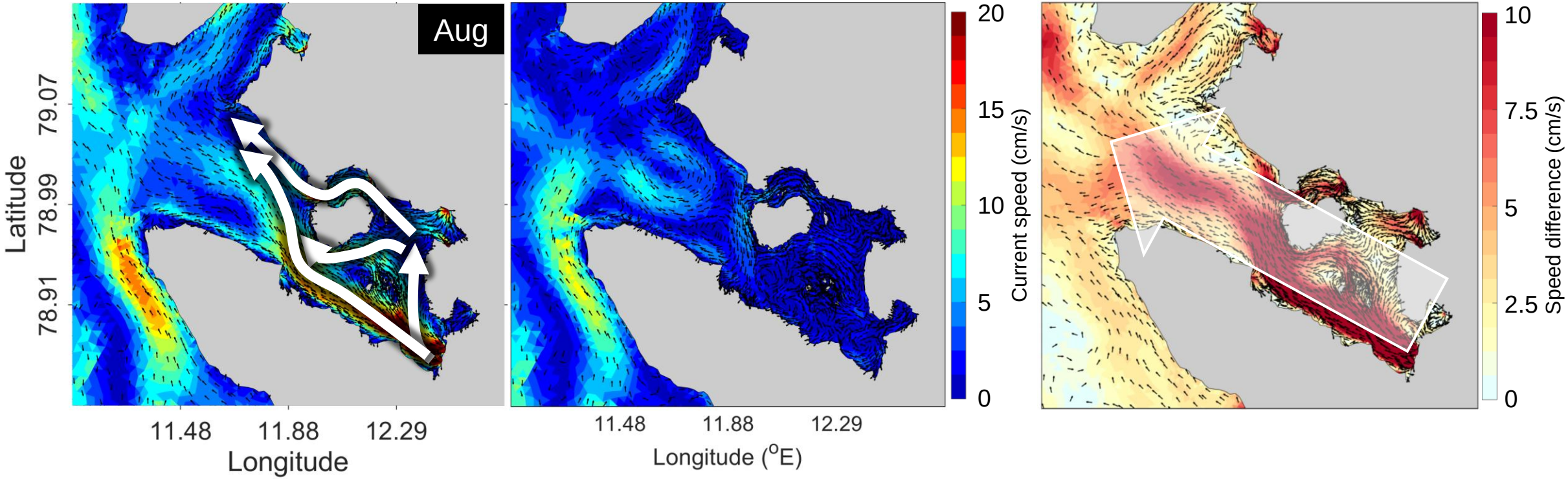
Impacts of runoff on spatial flow

- Monthly mean flow pattern in August (depth 0 m) (runoff: 148.7 m^3/s)
  - Outflow increase over 10 cm/s at southern part of Kongsfjorden due to higher runoff from Kronebreen
  - Anti-clockwise flow near the fjord mouth decrease due to meltwater runoff

Case1 (With)

Case2 (Without)

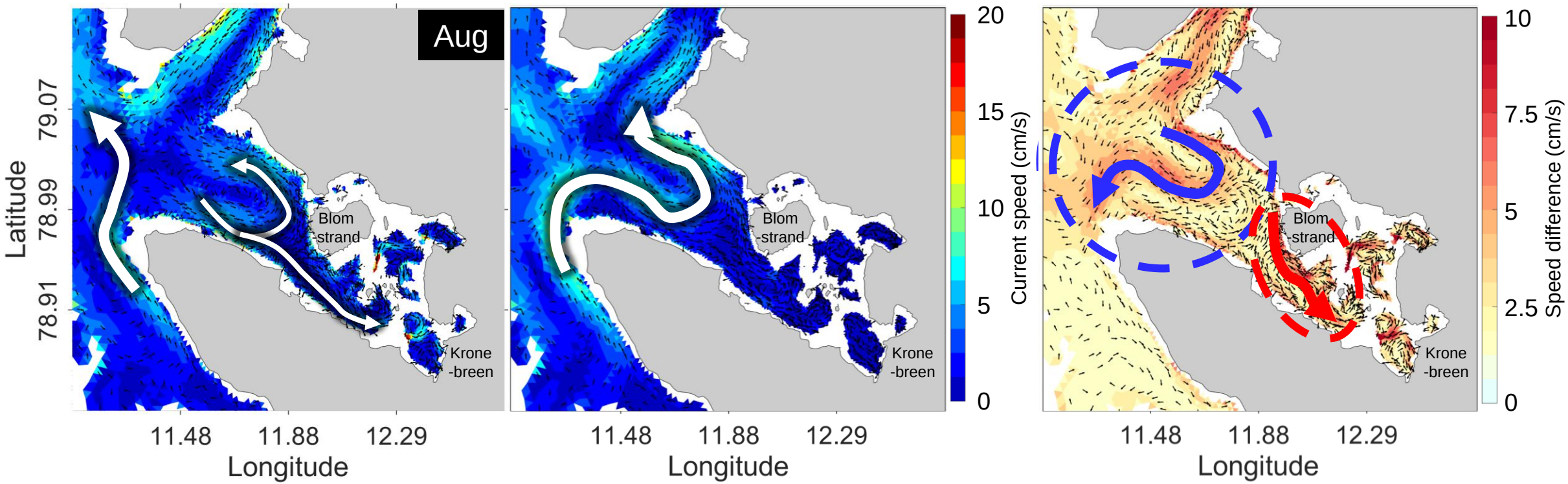
Difference of velocity
(Case1 - Case2)



Impacts of runoff on spatial flow

- Monthly mean flow pattern in August (depth 50 m) (runoff: 148.7 m^3/s)
  - Meltwater runoff decrease anti-clockwise flow near the fjord mouth (Blue)
  - Inflow current which following the bathymetry slop occurred due to meltwater runoff (Red)

Case1 (With) | Case2 (Without) | Difference of velocity (Case1 - Case2)



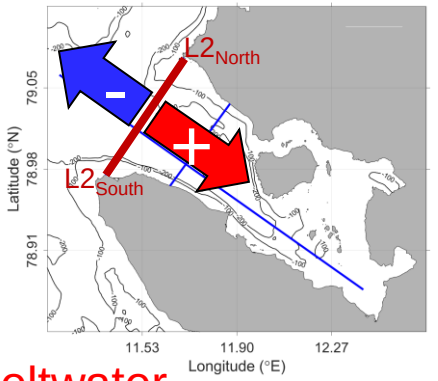
4. Discussion

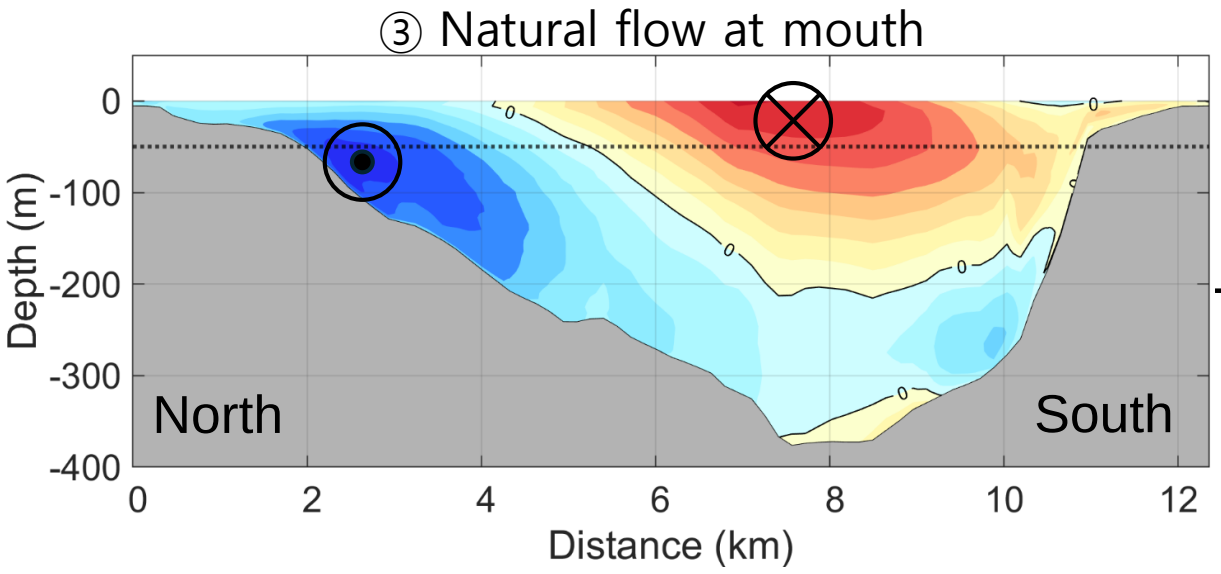


Change in flow pattern at fjord mouth

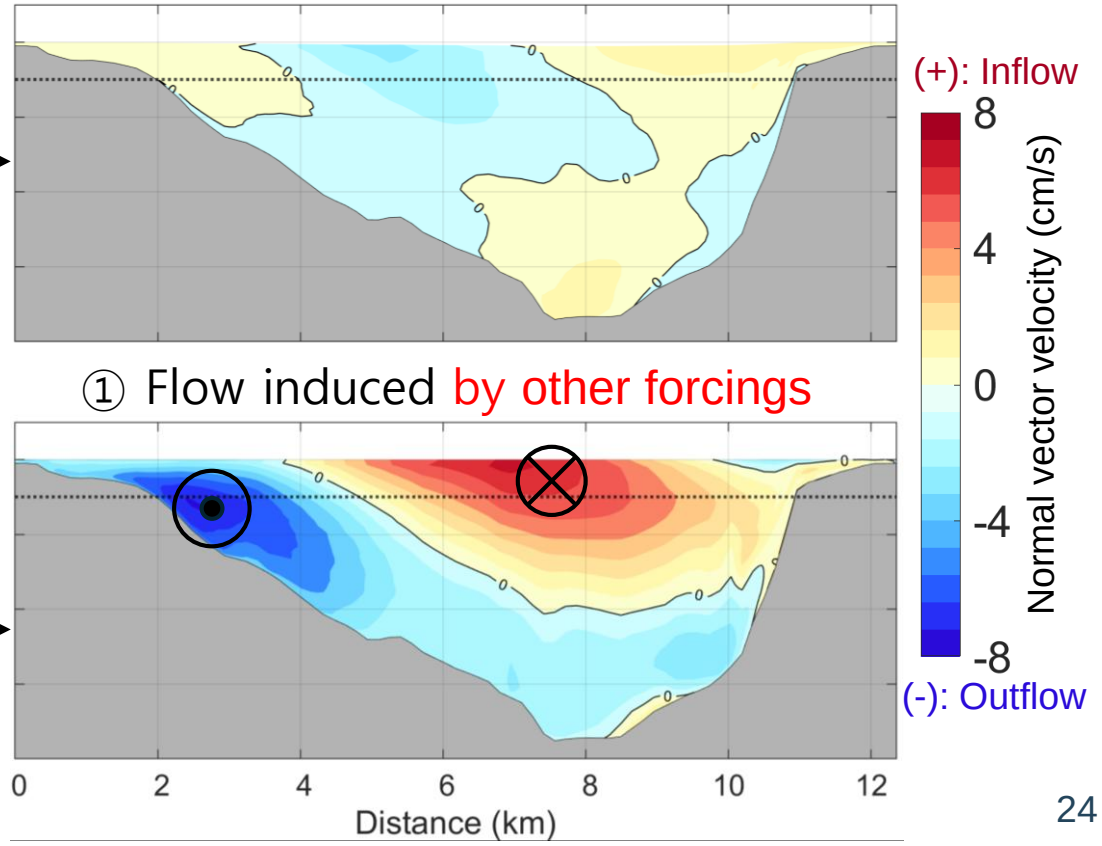
❖ Monthly mean cross-transect velocity at L2

- Low runoff period (May, 0.3 m^3/s)
- Water exchange process concentrated in upper layer
- Small meltwater runoff impact
- Author forces caused water exchange at upper layer





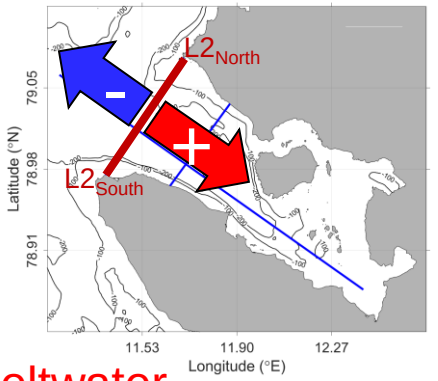
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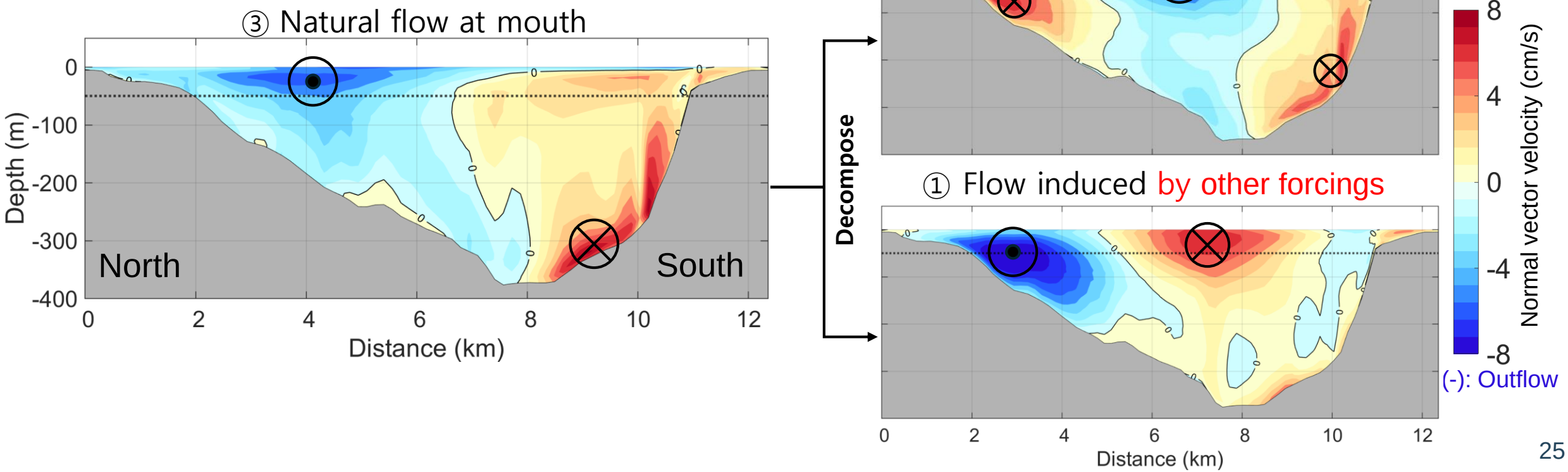


Change in flow pattern at fjord mouth

❖ Monthly mean cross-transect velocity at L2

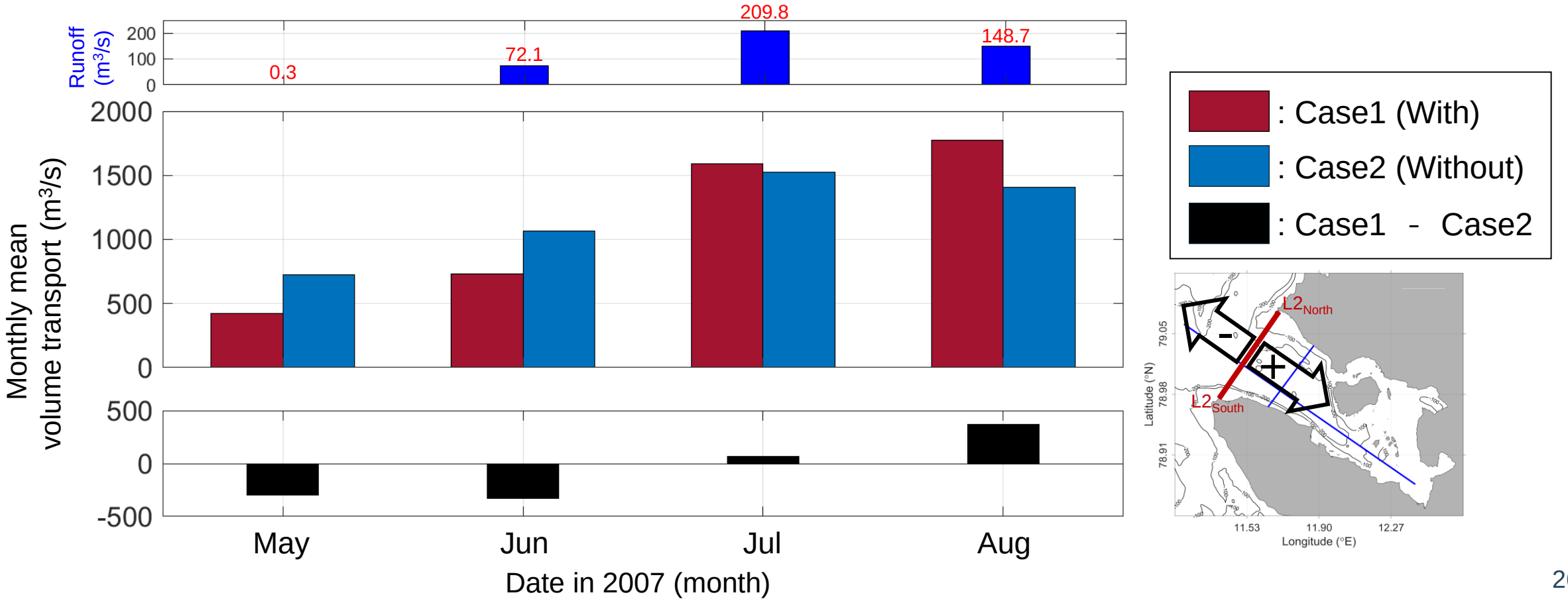
- High runoff period (August,148.7 m^3/s)
- Outflow caused by meltwater at upper layer
- Inflow concentrated at lower layer by the stratification
- Strong inflow near the bed near the south coastline





Effects of runoff on volume transport

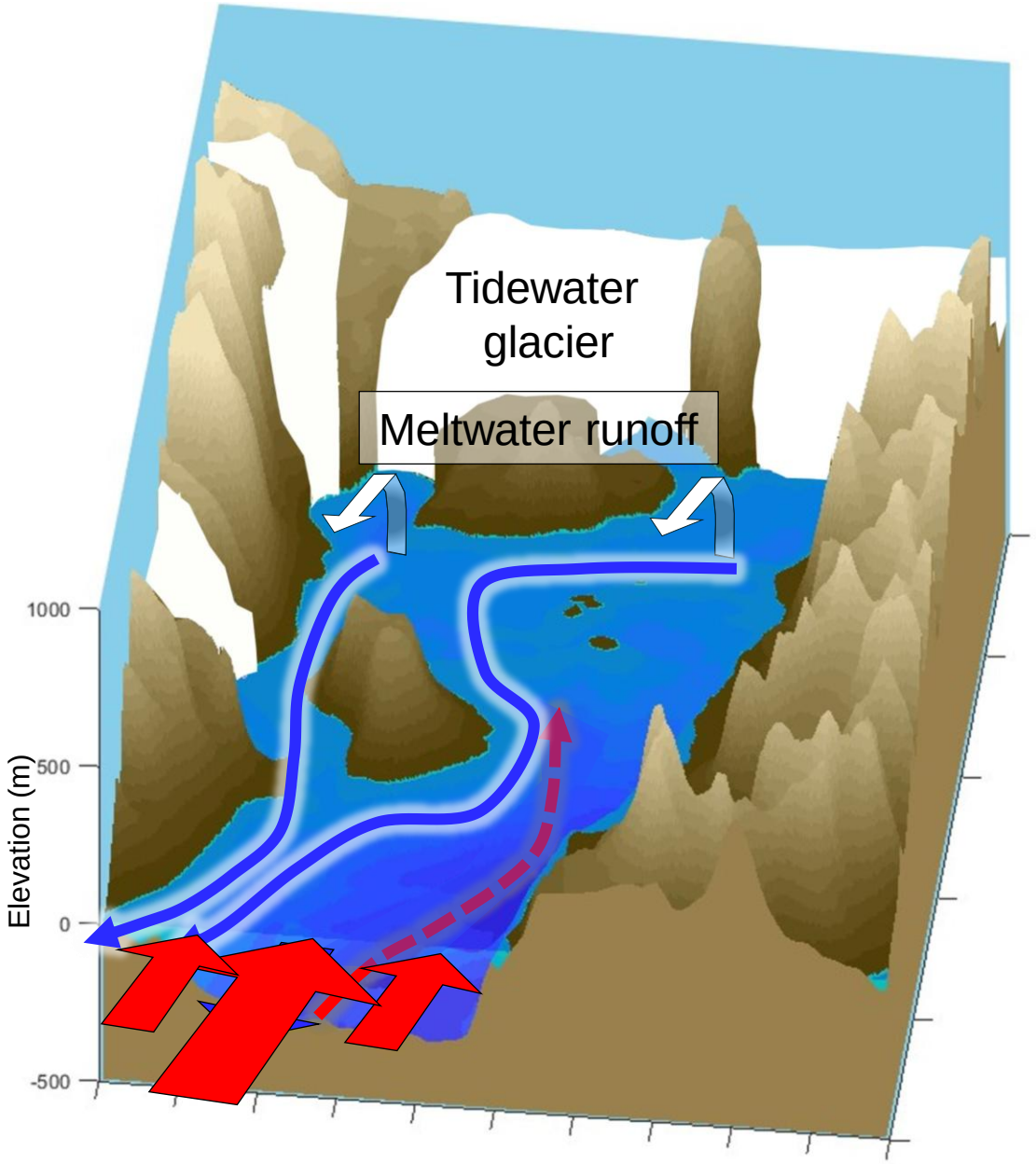
- Monthly mean volume transport at L2
  - Volume transport from outside to inside of fjord is increasing in summer season (June – August)
  - In May and Jun, net volume transport decrease 41.23 % and 31.27 % due to meltwater runoff
  - In **July** and **August**, net volume transport increase **4.42 %** and **26.04 %** when there is meltwater runoff



4. Conclusions



Summary

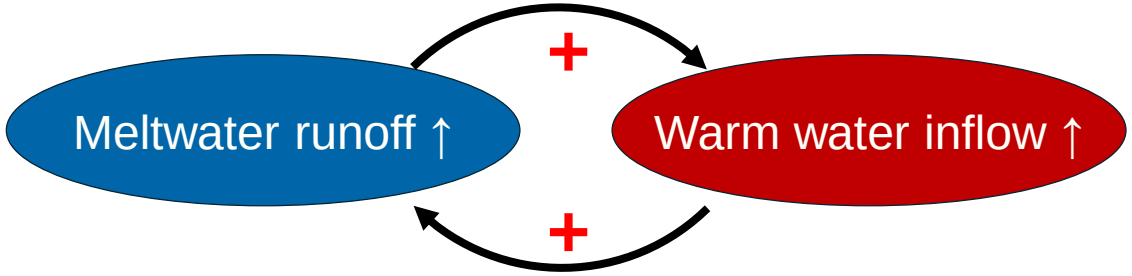


Due to meltwater runoff,

1. **(Spatial flow)** Meltwater runoff weakens the anti-clockwise rotational flow that occur at the entrance to the fjord.

2. **(Vertical distribution of velocity)** The vertical flow during low runoff is a two-layer structure, whereas that shows a uniform direction in the entire column during high runoff period

3. **(Volume transport)** When the **runoff exceeds about 200 m^3/s**, the volume transport at bottom layer toward the fjord increased





Thank you

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