Oceanic response to buoyancy, wind and tidal forcing in a Greenlandic glacial fjord

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1. Introduction

The Greenland Ice Sheet is losing mass at an accelerating rate[1]. This acceleration may in part be due to changes in ocean heat transport to marine-terminating outlet glaciers. Ocean heat transport to glaciers depends upon fjord dynamics, which include buoyancy-driven exchange flow, tides, internal waves, turbulent mixing, and connections to the continental shelf[2]. Submarine melting may be a significant component of tidewater glacier mass loss, and additional observations are needed to constrain the sensitivity of glacial melt to both ocean and atmosphere forcings[3]. This knowledge is critical for parameterizing the role of tidewater glaciers in future numerical models of ice-sheet dynamics.

2. The Problem

Direct observations of fjord circulation and heat transport towards the glacier face have been difficult to obtain due to the lack of sustained observations in Greenland's fjords[4]. Recent numerical models of glacier/fjord systems have focused on the 2D circulation[5]. We seek to investigate the following hypotheses in a newly developed 3D numerical model of *Rink Isbræ* fjord in west Greenland (Fig. 1):

The mean exchange flow of the fjord is sensitive to changes in subglacial discharge rates.

Bathymetric and rotational effects can strongly influence the buoyancy-driven circulation.

Tides and wind-forcing cause significant variability in heat and freshwater transport to the glacier.

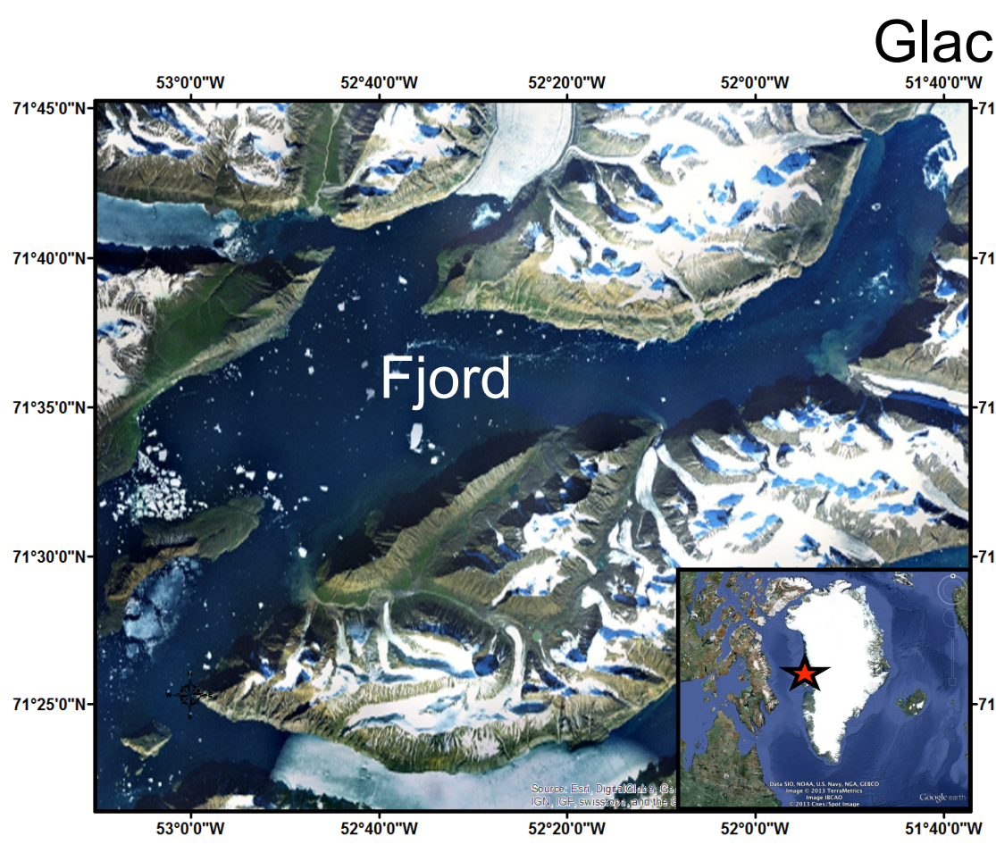

Figure 1: *Rink Isbrae* fjord, West Greenland.

3. Model Setup

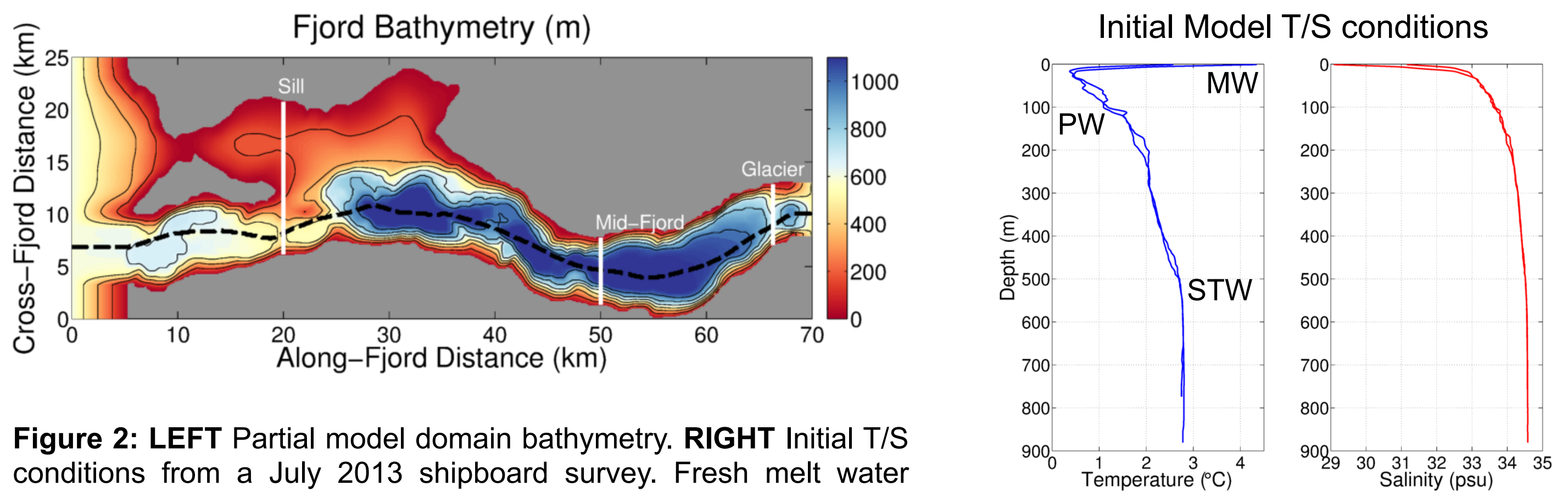

Figure 2: LEFT Partial model domain bathymetry. **RIGHT** Initial T/S conditions from a July 2013 shipboard survey. Fresh melt water (MW) from is present near-surface. Cold, fresh polar water (PW) overlays relatively warm, salty subtropical water (STW).

MITgcm (*Marshall et al.* 1997)
Grid (rotated 30°)

- 100 m horizontal resolution
- 39 vertical z cells (10-200 m)

Hydrostatic
Horizontal Eddy Viscosity (0.5 – 1 $m^2 s^{-1}$)
K-Profile Parameterization
Nonlinear E.O.S
Tides: AOTIM-5
Wind: Idealized zonal wind stress (0 - 1 N m^{-2})
Open Boundary Conditions: N,S,W,E

- N,S,W 100 km relaxation layer
- Relaxation time: Interior 5 days/exterior 1 day
- Subglacial discharge forced at eastern glacial boundary at 500 m depth

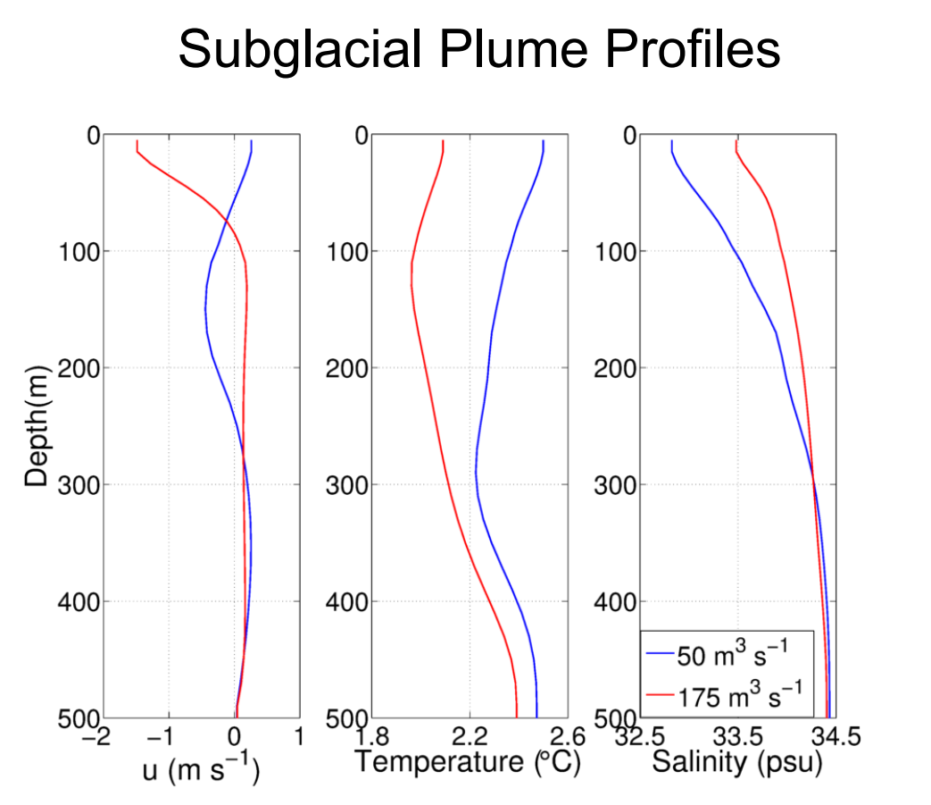

Figure 3: We use a non-hydrostatic 2D model to characterize the turbulent freshwater plume that results from submarine melting and subglacial discharge[6]. The resulting profiles are used to force the subglacial plume in the hydrostatic model.

4. Model Base Case: Buoyancy Forcing

The spatial structure of the plume is sensitive to the rate of subglacial discharge.

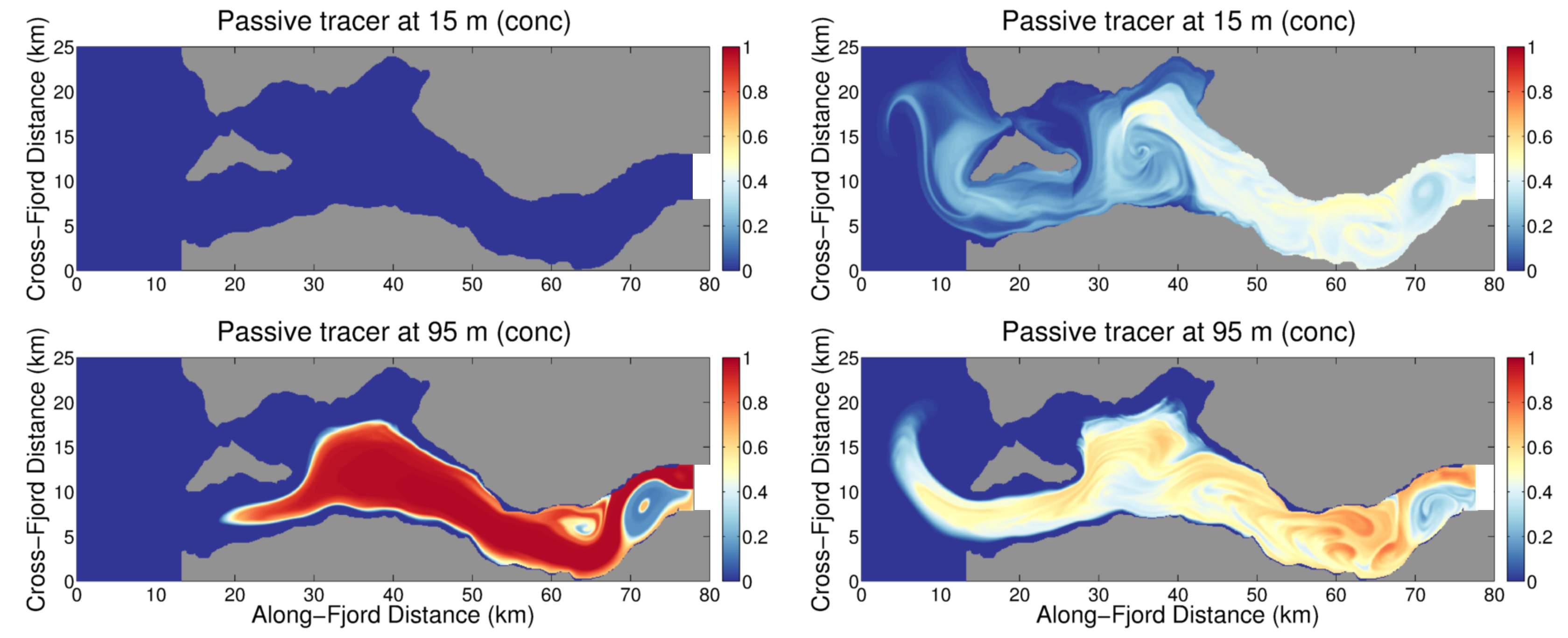

Figure 4: Snapshot of passive tracer concentration at a model run time of 60 days. Tracer is injected into the subglacial plume on the eastern boundary.

LEFT Q_{sg} of 50 $m^3 s^{-1}$ drives a concentrated subsurface plume in the fjord with little vertical mixing.

RIGHT Q_{sg} of 175 $m^3 s^{-1}$ results in a faster flowing surface plume. The interaction of the the plume with bathymetry leads to regions of vigorous mixing.

The subglacial plume drives an estuarine exchange flow.

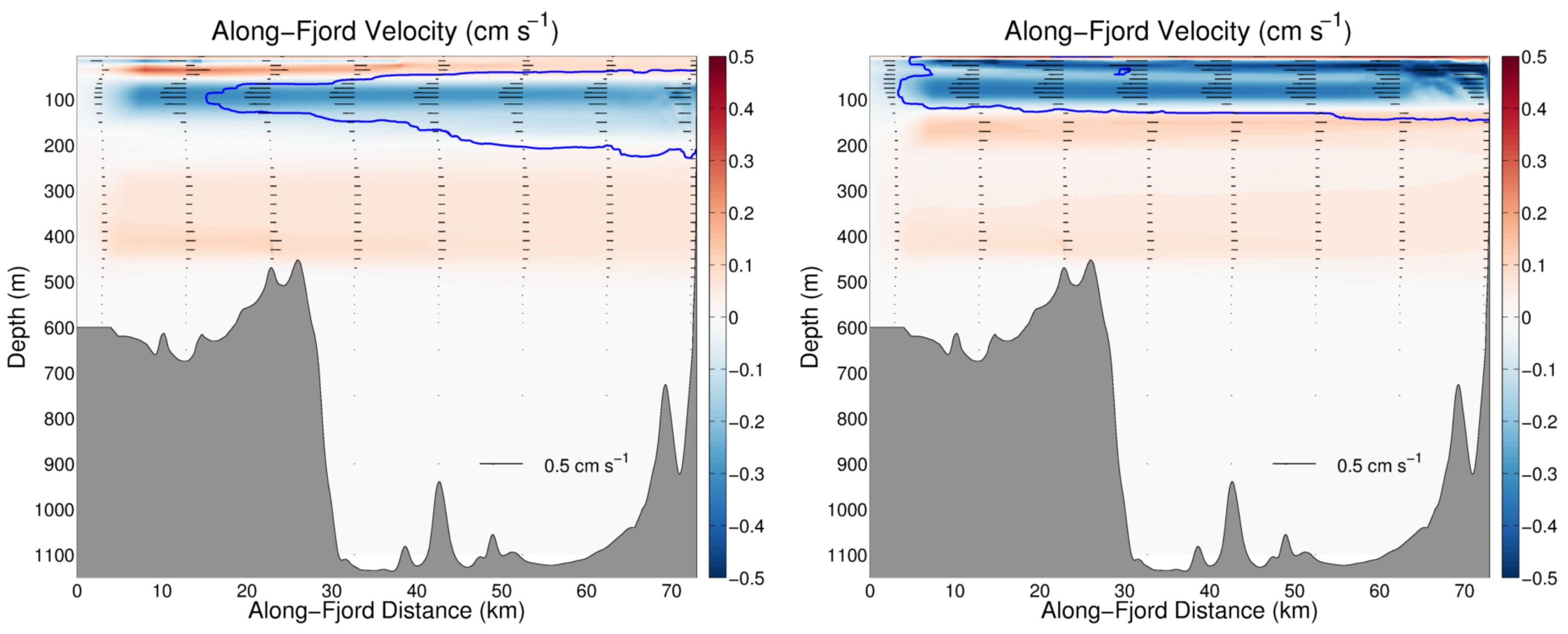

Figure 5: Mean 14 day along-fjord velocity profiles with varying Q_{sg}. Velocity is averaged in the cross-fjord direction. Plume tracer concentration of 0.01 is overlaid as a blue contour.

LEFT Q_{sg} of 50 $m^3 s^{-1}$ drives a multi-cell estuarine flow with a return flow of warm, salty subtropical water to the glacier face.

RIGHT At Q_{sg} of 175 $m^3 s^{-1}$ upwelling along the glacier face increases in speed, resulting in a vertically narrow surface plume.

Glacial fjord circulation is a complex, 3D process.

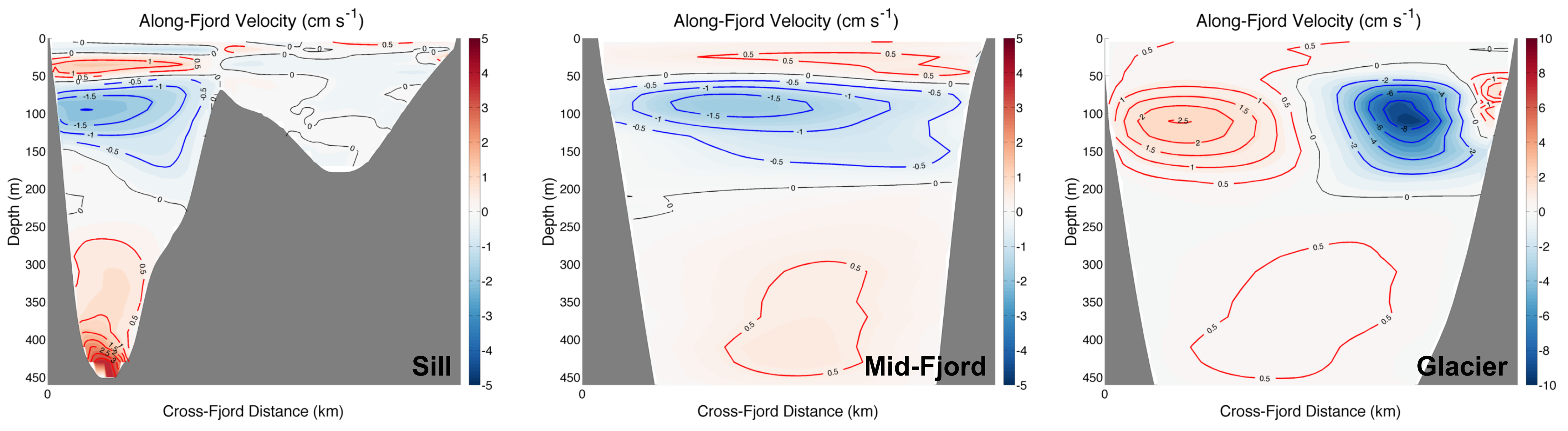

Figure 6: Mean 14 day cross-fjord velocity profiles for a Q_{sg} of 50 $m^3 s^{-1}$. Inflow velocity contours are solid red – outflow is blue. In both values of Q_{sg} tested, the near-glacier plume is constrained to the northern wall. As the outflowing plume flows downstream of the glacier, it spreads laterally before becoming constrained by the narrow sill.

5. Model Results with Wind and Tidal Forcing

Buoyancy driven results are forced with katabatic winds and tides to investigate the fjord/plume response and estimate the variability in heat and freshwater transport.

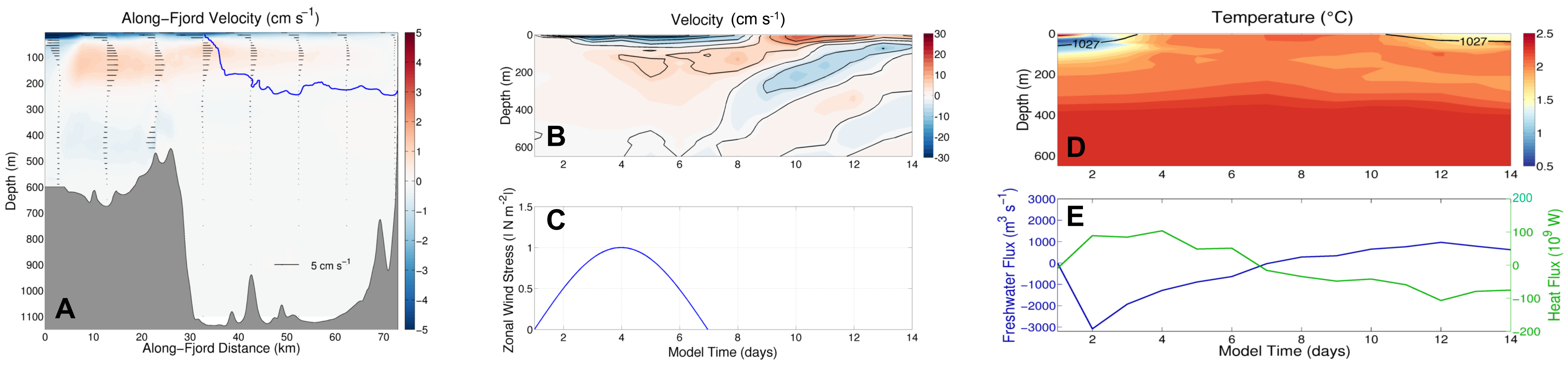

Figure 7: Katabatic winds causes a strong surface outflow and upwelling near the glacier potentially leading to a more rapid flushing of fjord waters and significant variability in heat transport. **A)** Mean 14 day along-fjord velocity profile. Velocity is averaged in the cross-fjord direction. Plume tracer concentration of 0.01 is overlaid as a blue contour. **B)** Time series of along-fjord velocity at the greatest depth on the 'Glacier' section. **C)** Idealized katabatic wind forcing. **D)** Time series of temperature at the greatest depth on the 'Glacier' section. 1027 kg m^3 Isopycnal is overlaid as a black contour. **E)** Net heat and freshwater flux calculated between 'Mid-Fjord' and 'Glacier' section.

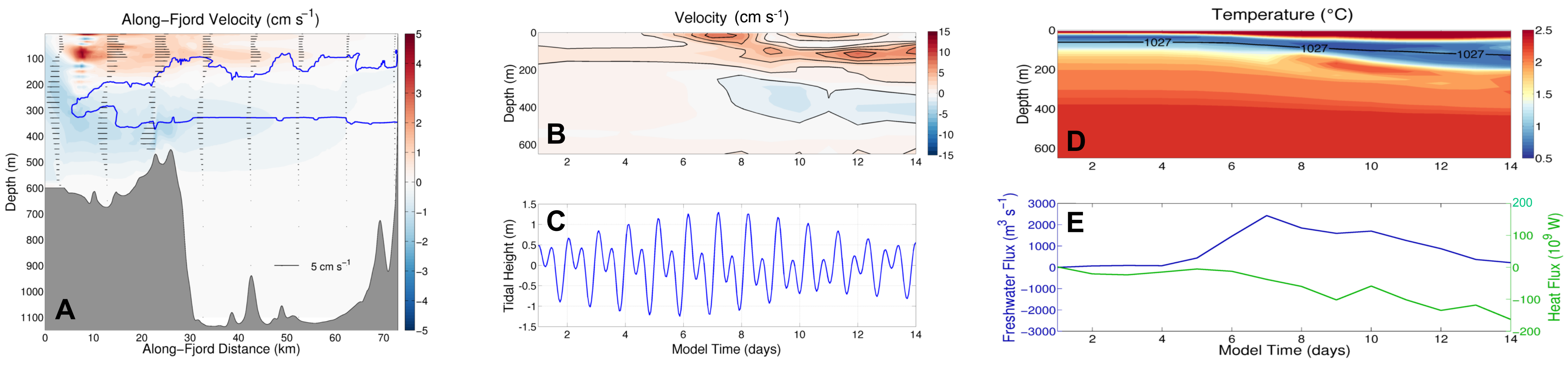

Figure 8: Tidal forcing modifies the buoyancy driven circulation, resulting in a two layer flow over the sill. Tidal mixing deepens the pycnocline, pushing the subglacial plume downwards. **A)** Mean 14 day along-fjord velocity profile. Velocity is averaged in the cross-fjord direction. Plume tracer concentration of 0.01 is overlaid as a blue contour. **B)** Time series of along-fjord velocity at the greatest depth on the 'Glacier' section. **D)** AOTIM-5 tidal forcing. **D)** Time series of temperature at the greatest depth on the 'Glacier' section. 1027 kg m^3 Isopycnal is overlaid as a black contour. **E)** Net heat and freshwater flux calculated between 'Mid-Fjord' and 'Glacier' section.

6. Summary

The estuarine circulation and plume structure is sensitive to the rate of subglacial discharge.

Bathymetry and rotational effects strongly influence the buoyancy-driven circulation.

Ocean and atmosphere forcing such as tides and wind can significantly modify the heat and freshwater flux towards the glacier.

Future work will included a coupled fjord model of two outlet glacier systems in close proximity to each other yet with different glacial mass balances (*Rink Isbræ* and *Kangerdlugssup Sermerssua*). By investigating a region where the ocean and atmosphere forcing is expected to be similar we can characterize the key ocean processes that may cause variability in glacier response.

References

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