Differential melting of western Antarctic Peninsula glaciers by modified upper circumpolar deep water along a latitudinal gradient

LARISSA Ecoystems: biology at land-ice-ocean boundary

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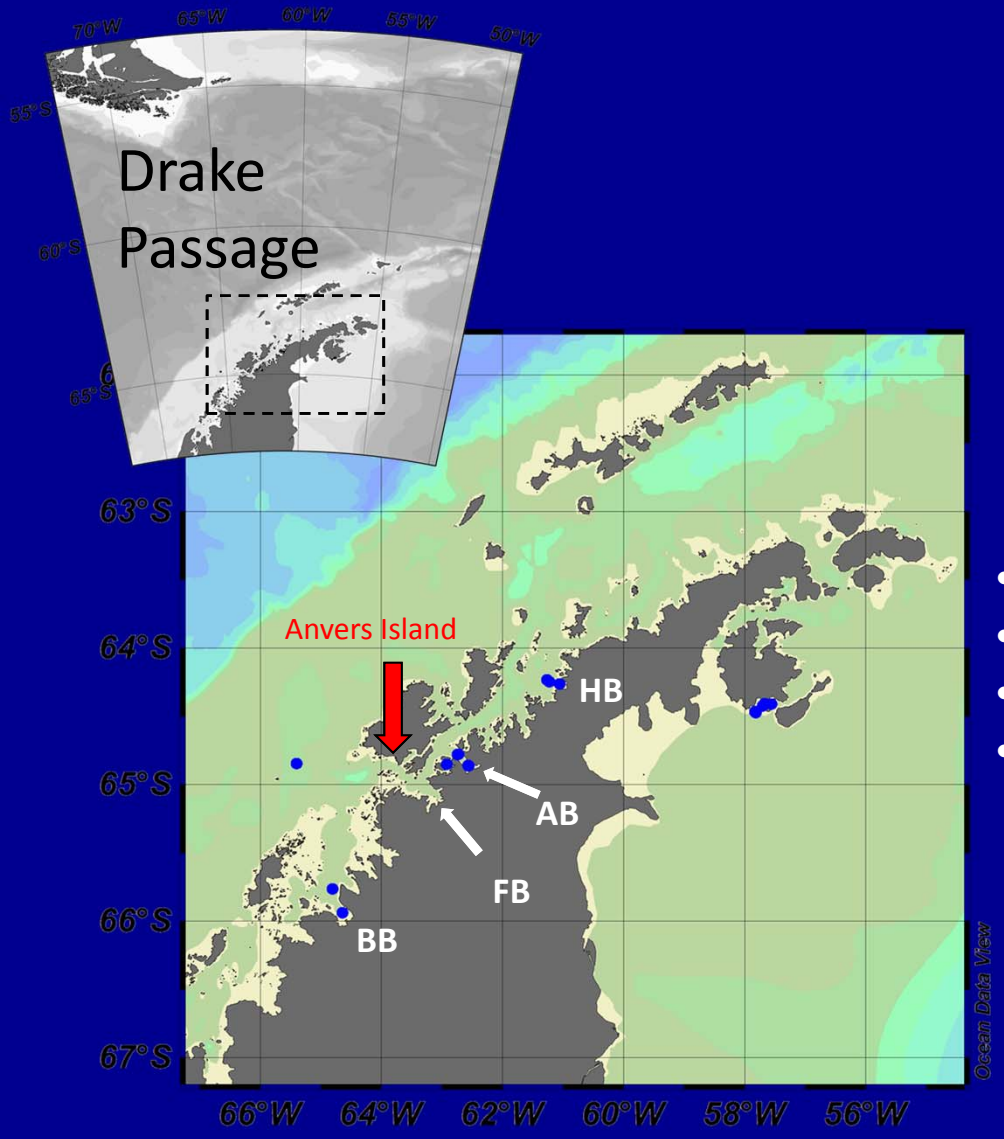
Questions

How do volume and processes of ice delivery and meltwater distribution affect ecosystems?

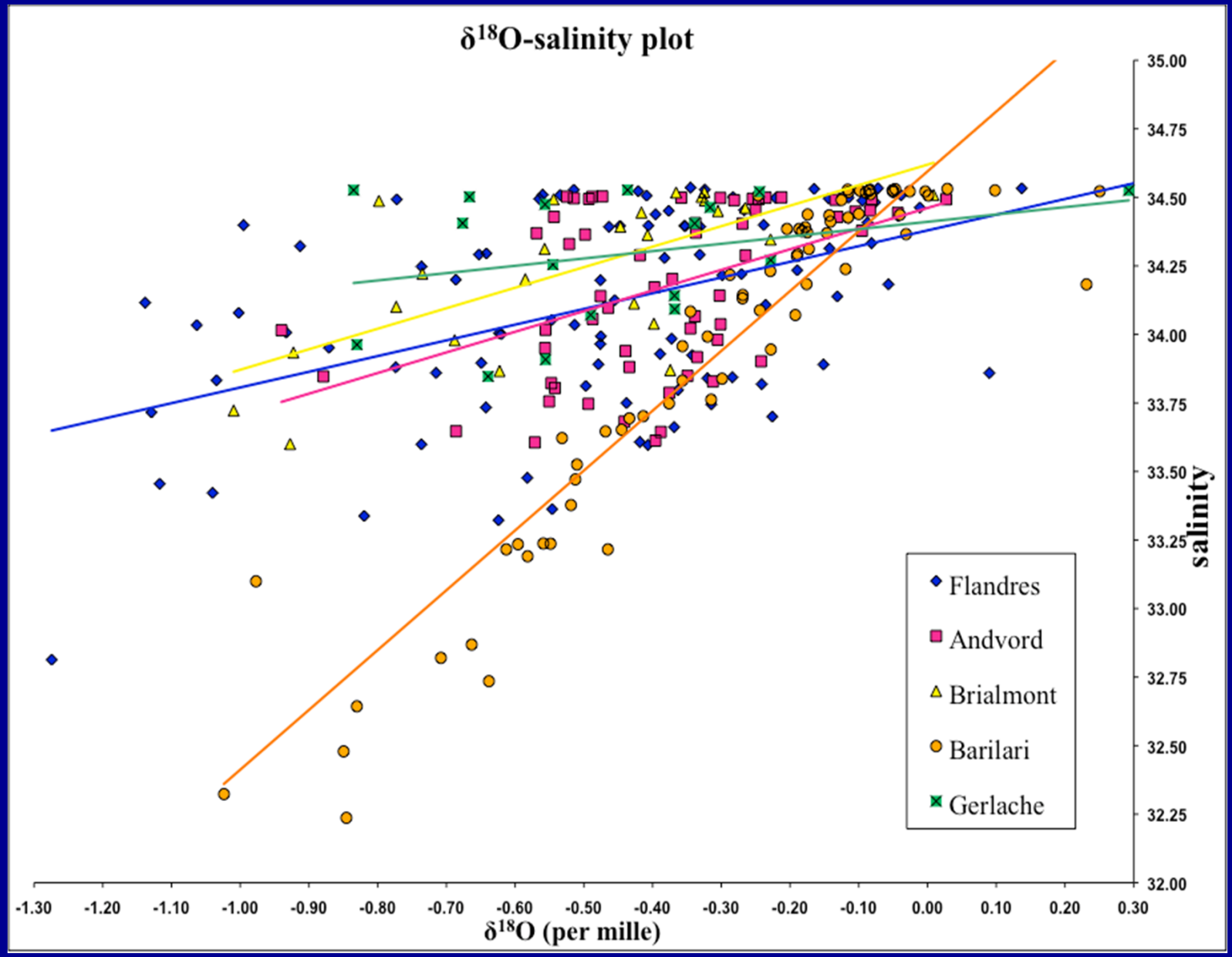
- What are the patterns of glacier melt?
- What is the influence of the ocean on glaciers?

Antarctic Peninsula Fjords during NBP1001



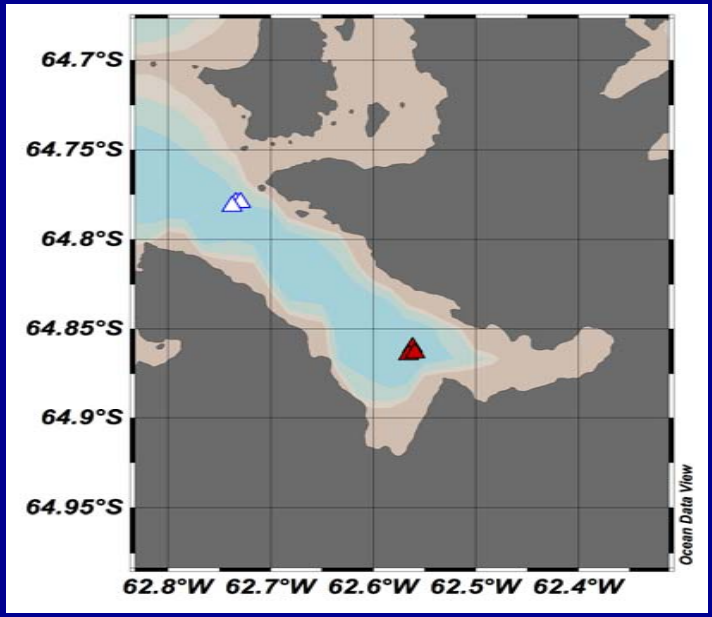
- HB: Hughes Bay
- AB: Andvord Bay
- FB: Flandres Bay
- BB: Barilari Bay

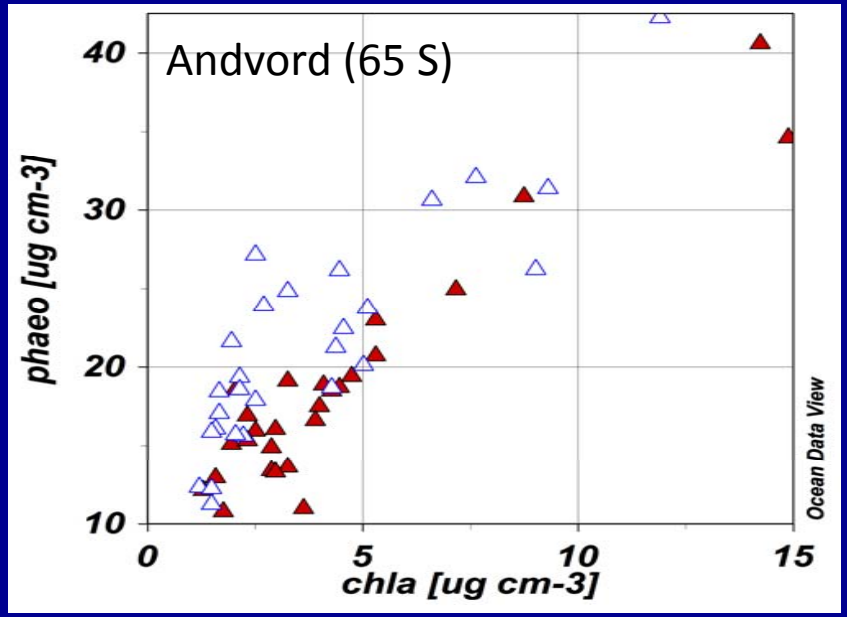
Presence of glacier meltwater

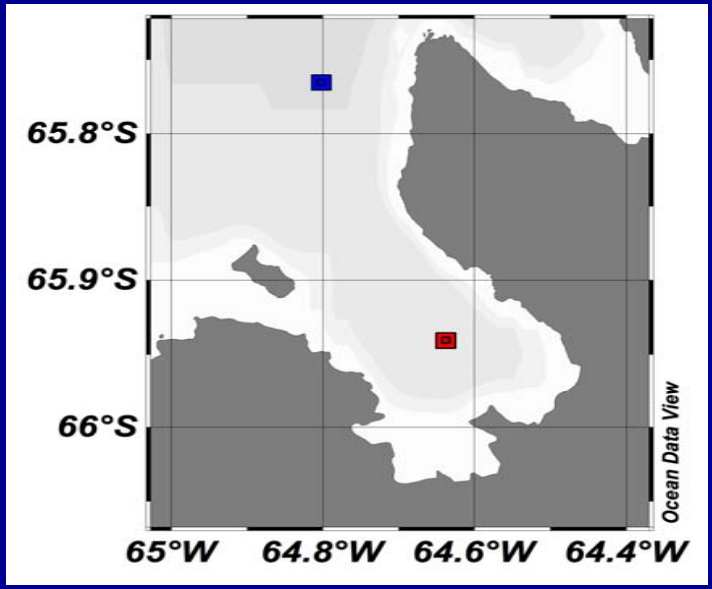


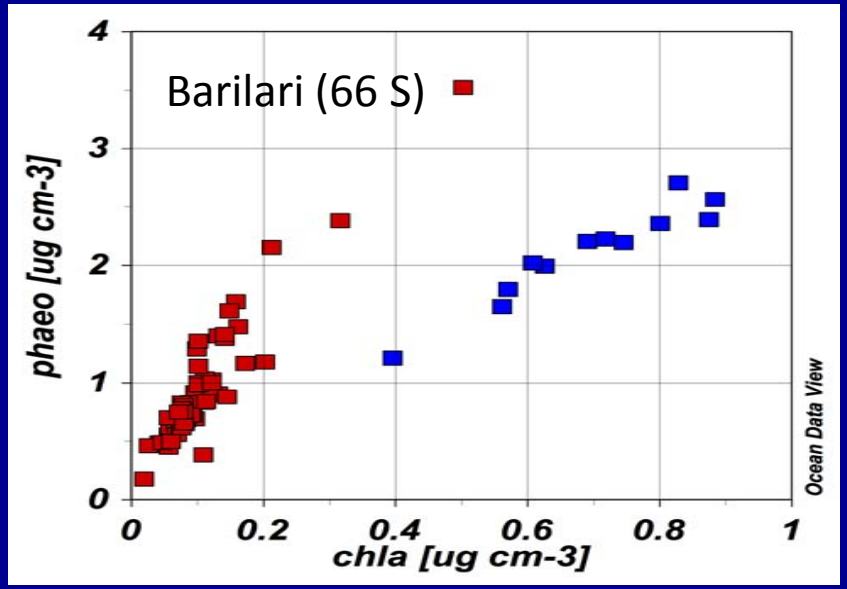
Long-term fjord primary productivity

Based on pigment concentration









Western Antarctica Peninsula glaciers

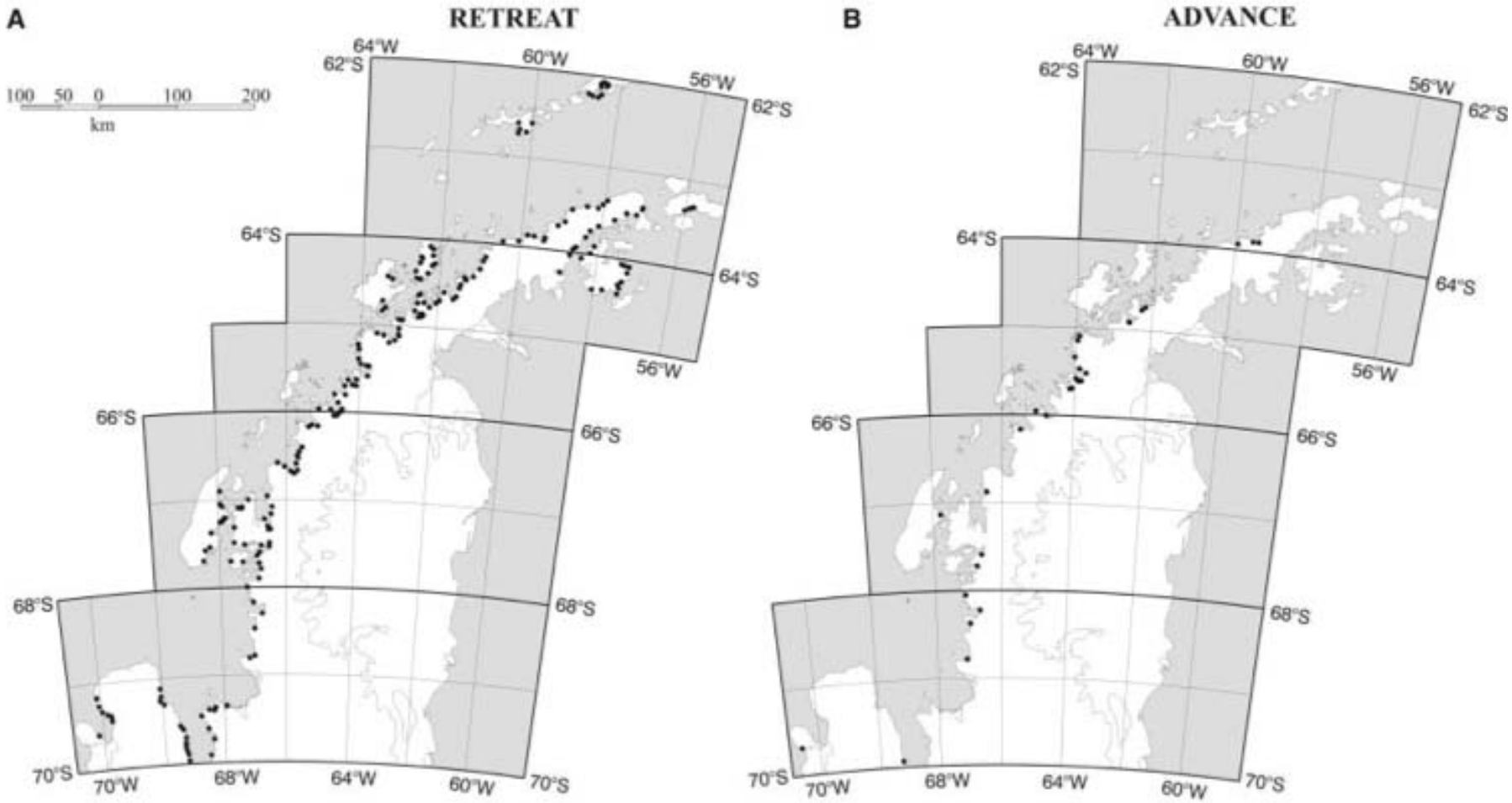
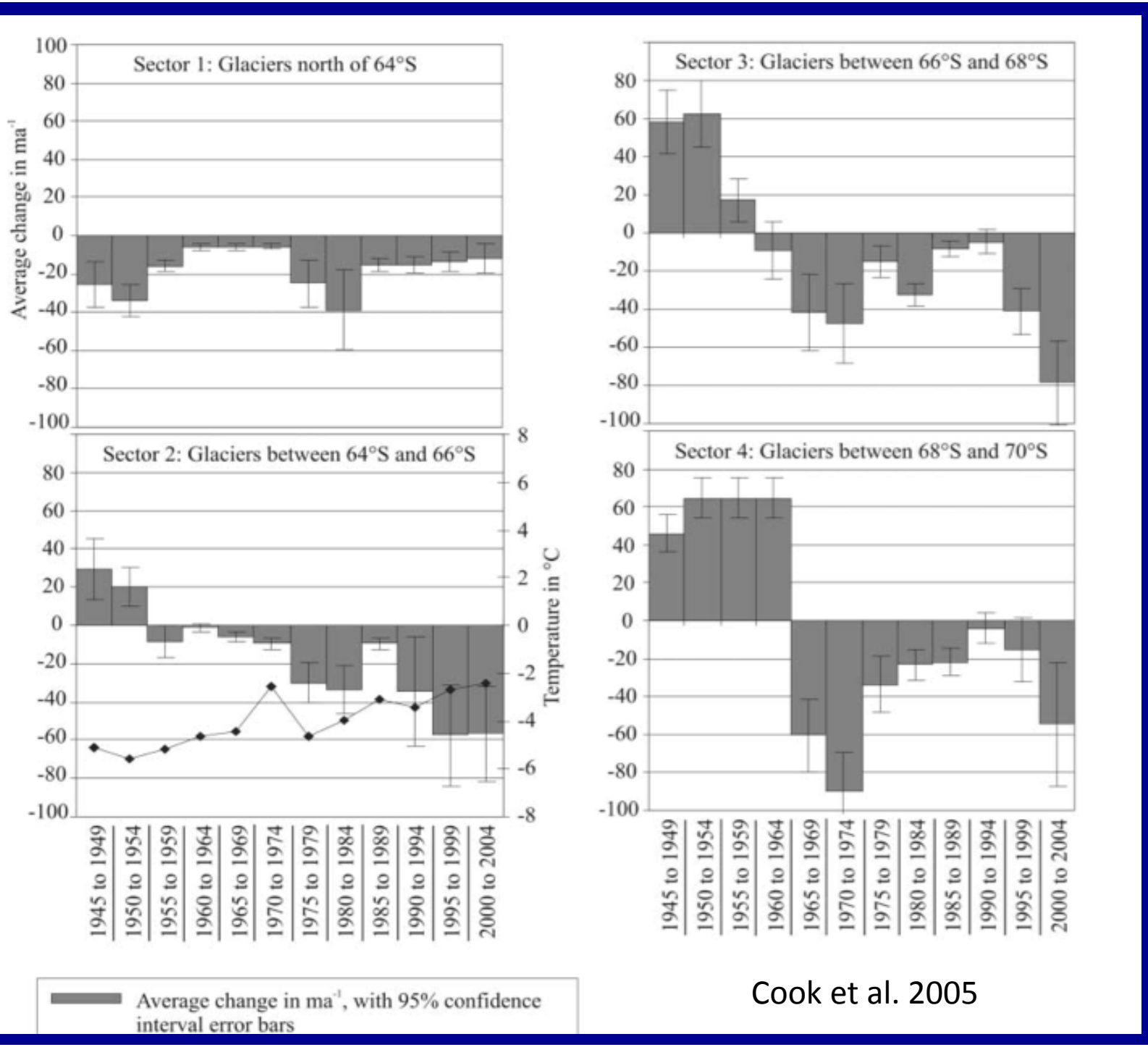


Fig. 2. Overall change observed in Antarctic Peninsula glacier fronts since earliest records.

Cook et al. 2005



Cook et al. 2005

Vaughn & Doake
1996

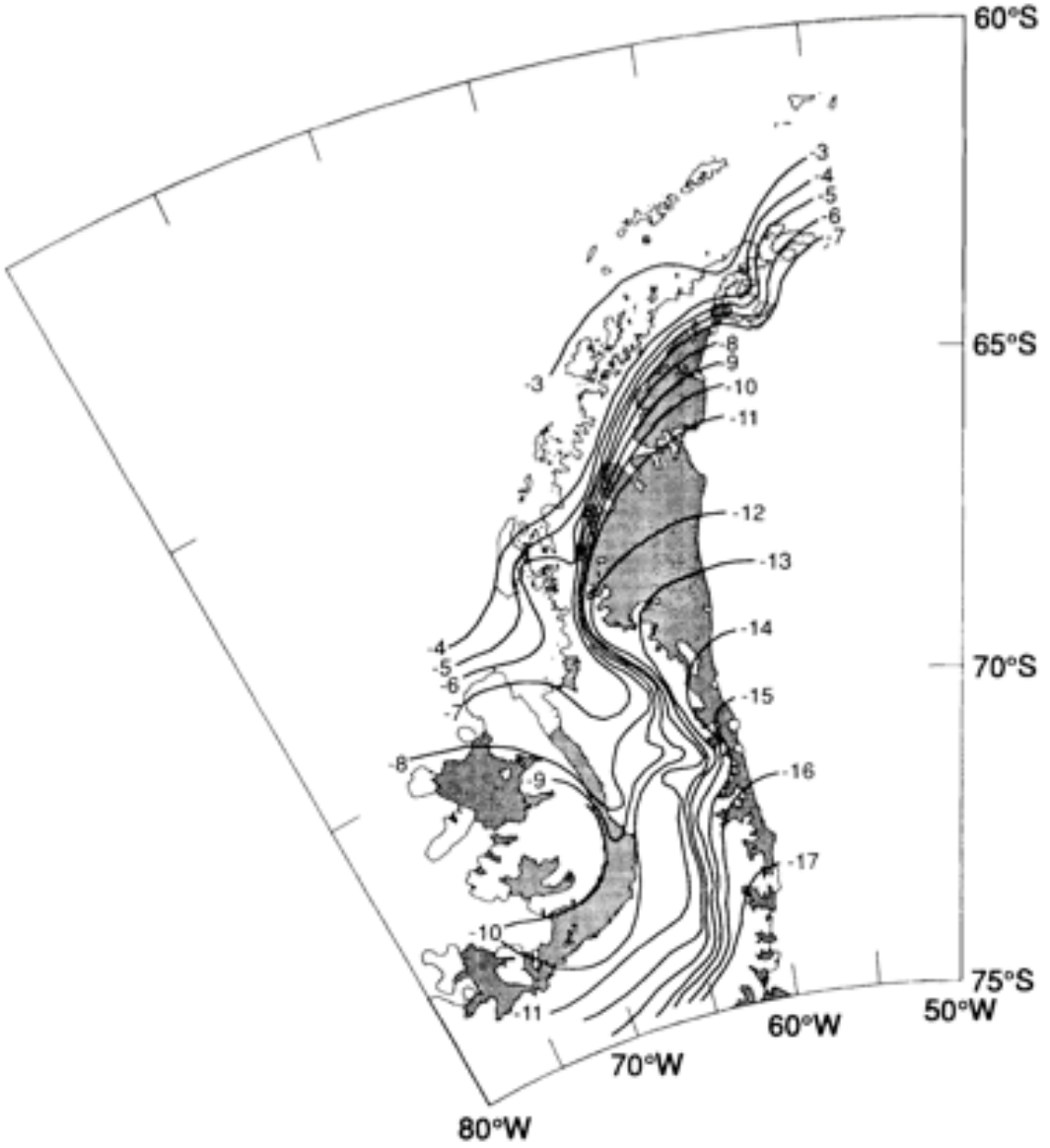
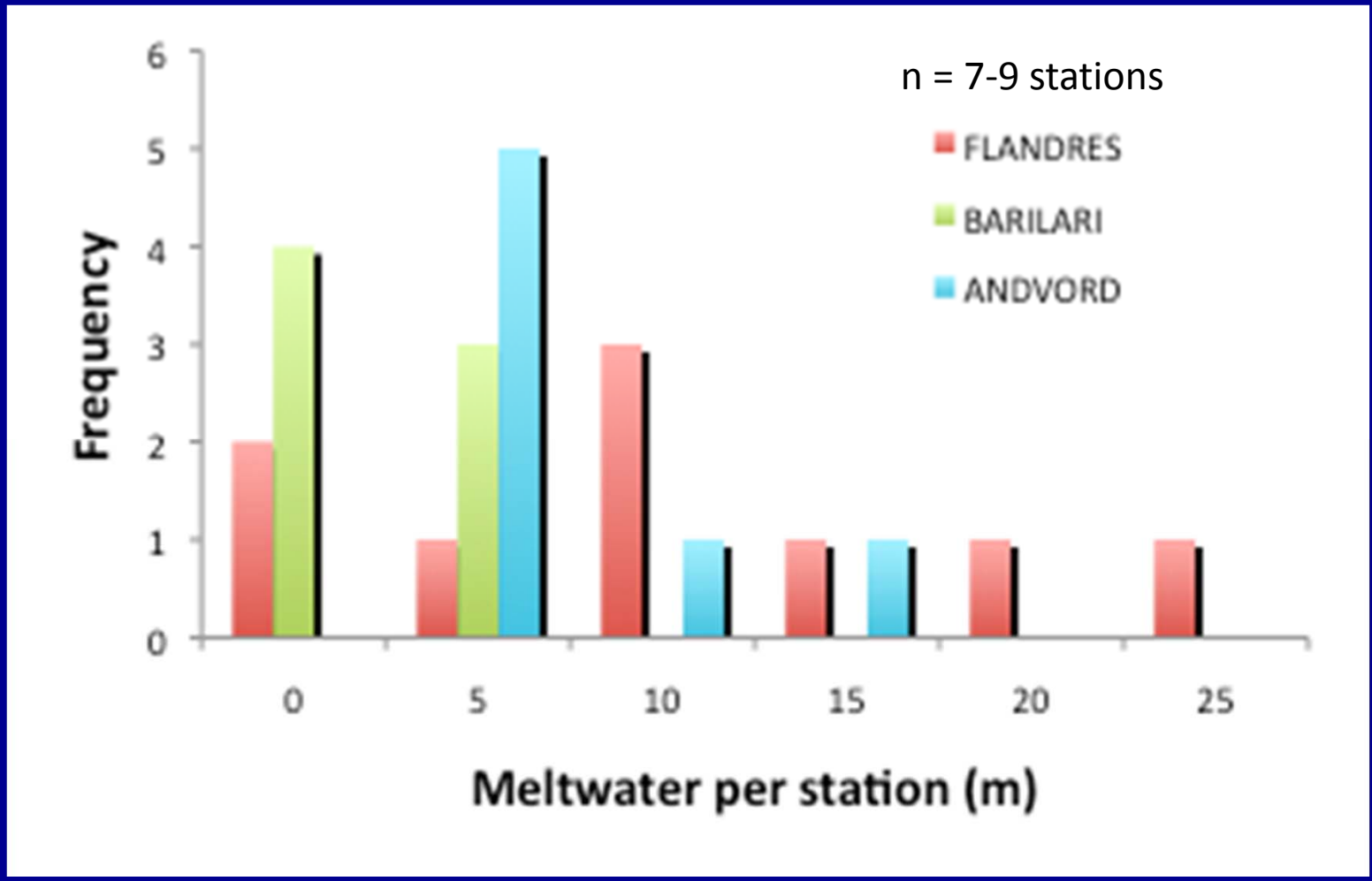


FIG. 1 Map of pre-1981 mean annual air temperatures in °C. Derived from temperatures 10 m below the ice surface, normalized to sea-level by Reynolds[16]. Ice shelves (shaded) are indicated at their mid-1970s extent.

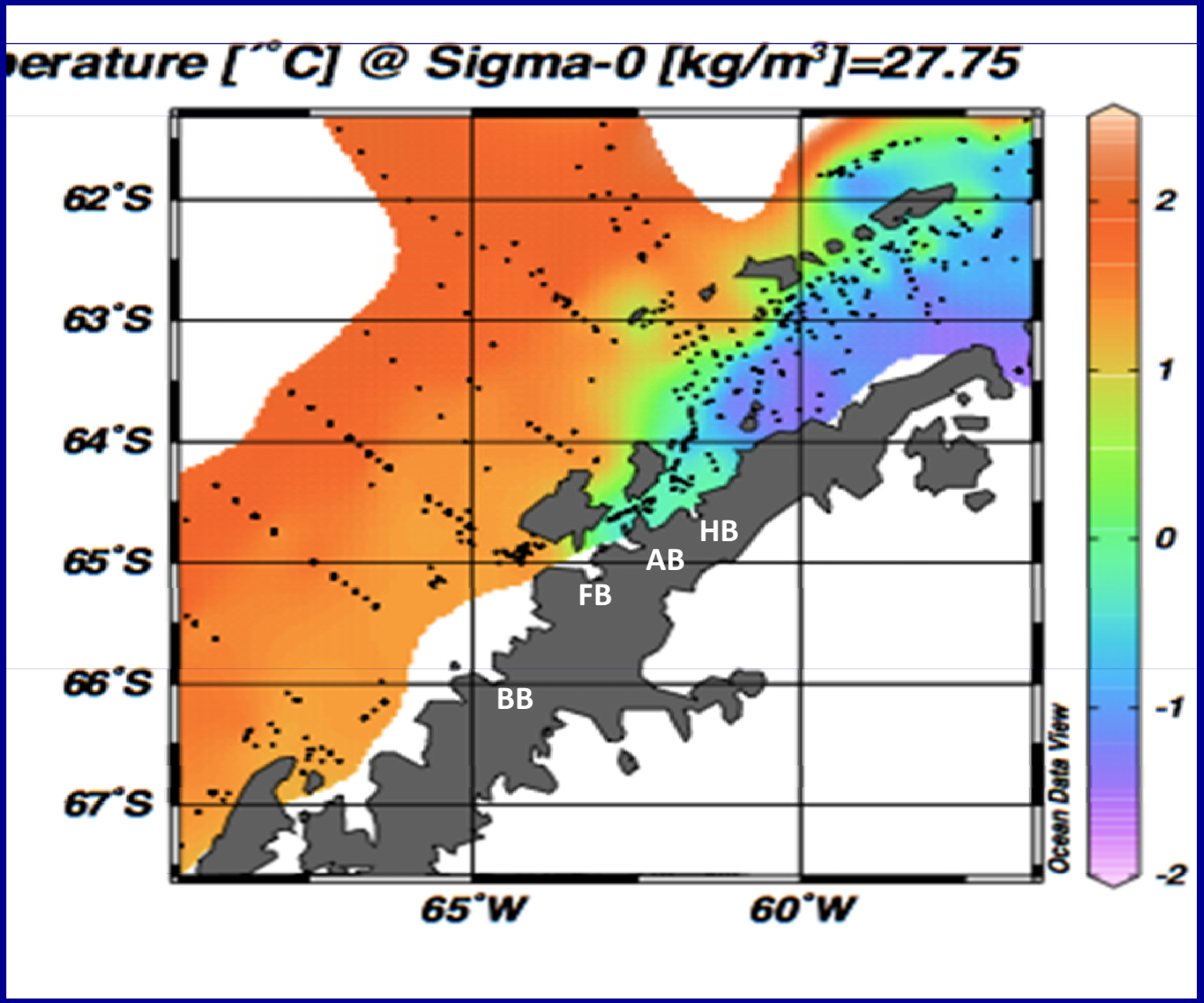
Total meltwater in water column



wAP glaciers

- What is the total ice delivery/meltwater in these fjords?
- What is the balance of air and oceanic influence on glacier melt and ice delivery to the ocean?

Water temperature at depth (°C)



Huber (unpublished)

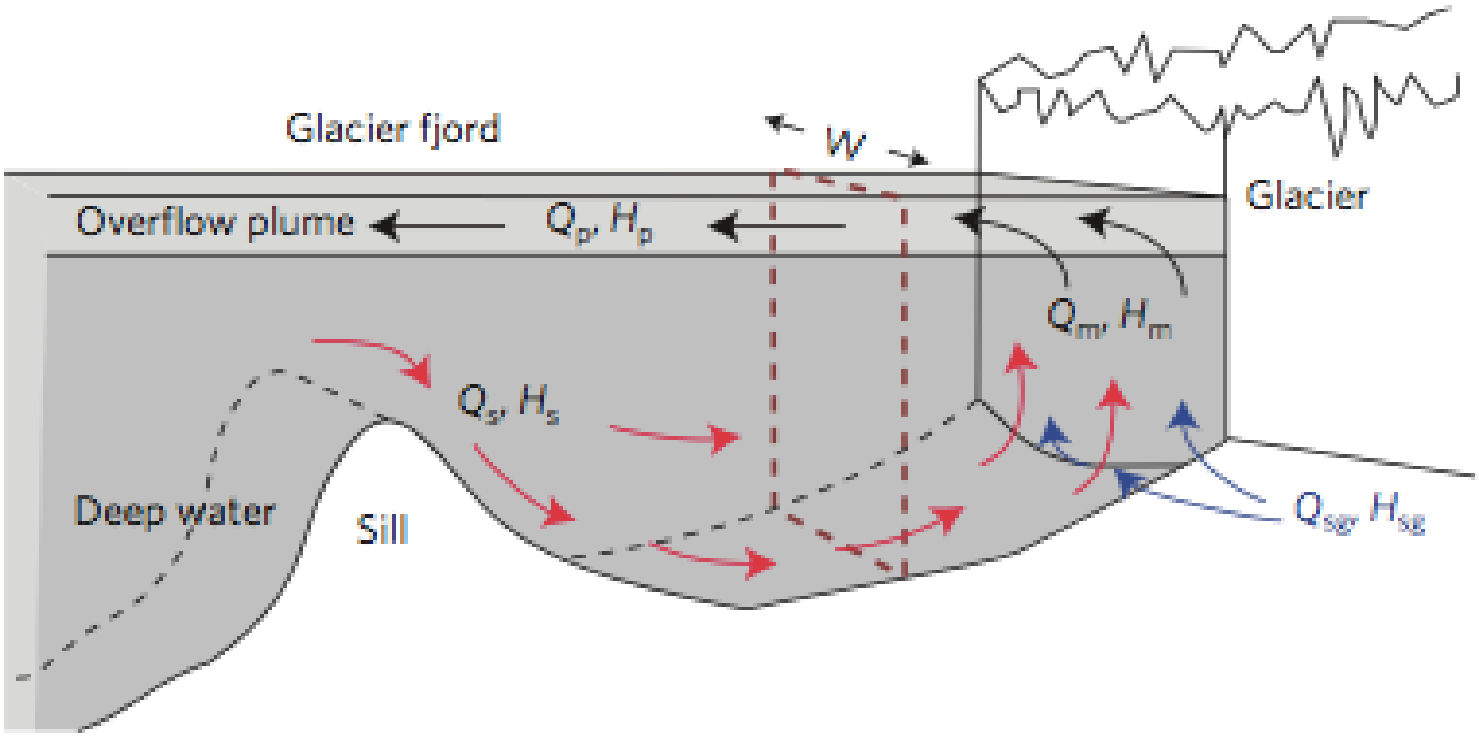
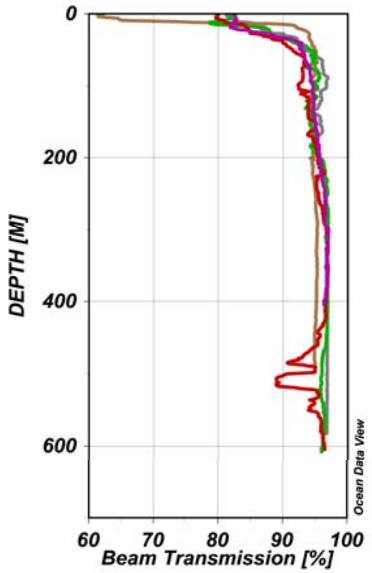


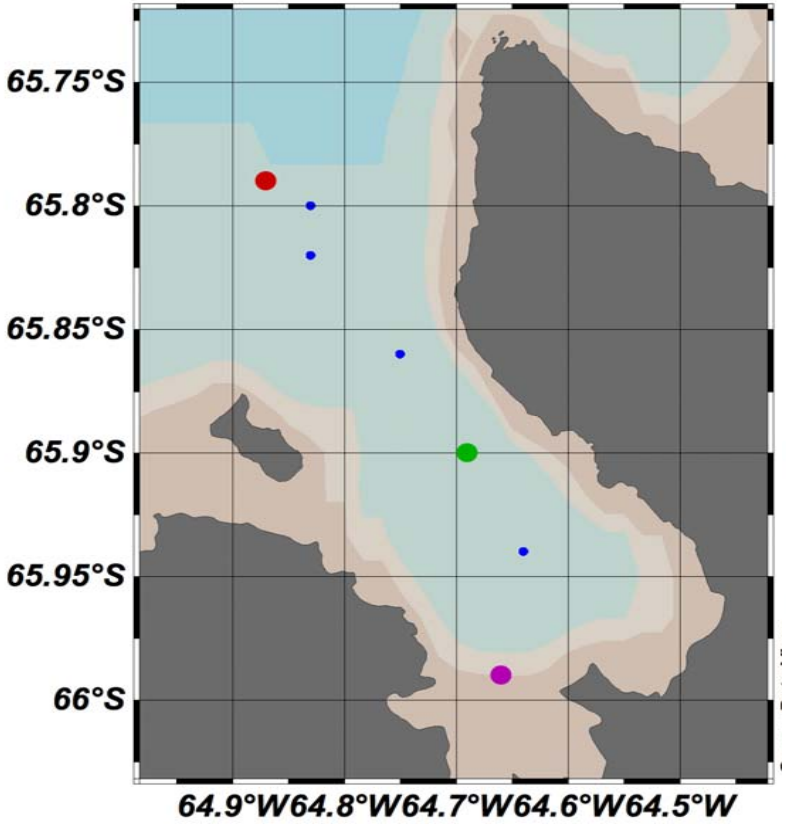
Figure 2 | A simplified two-layer model of forced convective flow in a glacier fjord. Deep-water access is guarded by a sill and terminated by a calving front[9]. The incoming mass flux from the deep ocean, Q_s, and from subglacial water, Q_{sg}, is balanced by the mass flux from the overflow plume, Q_p, and the submarine meltwater, Q_m. The incoming deep-ocean heat flux, H_s, and subglacial water heat flux, H_{sg}, melt submarine ice with a heat flux, H_m, to yield an overflow plume with a heat flux, H_p. The overflow plume is not homogeneous in velocity structure.

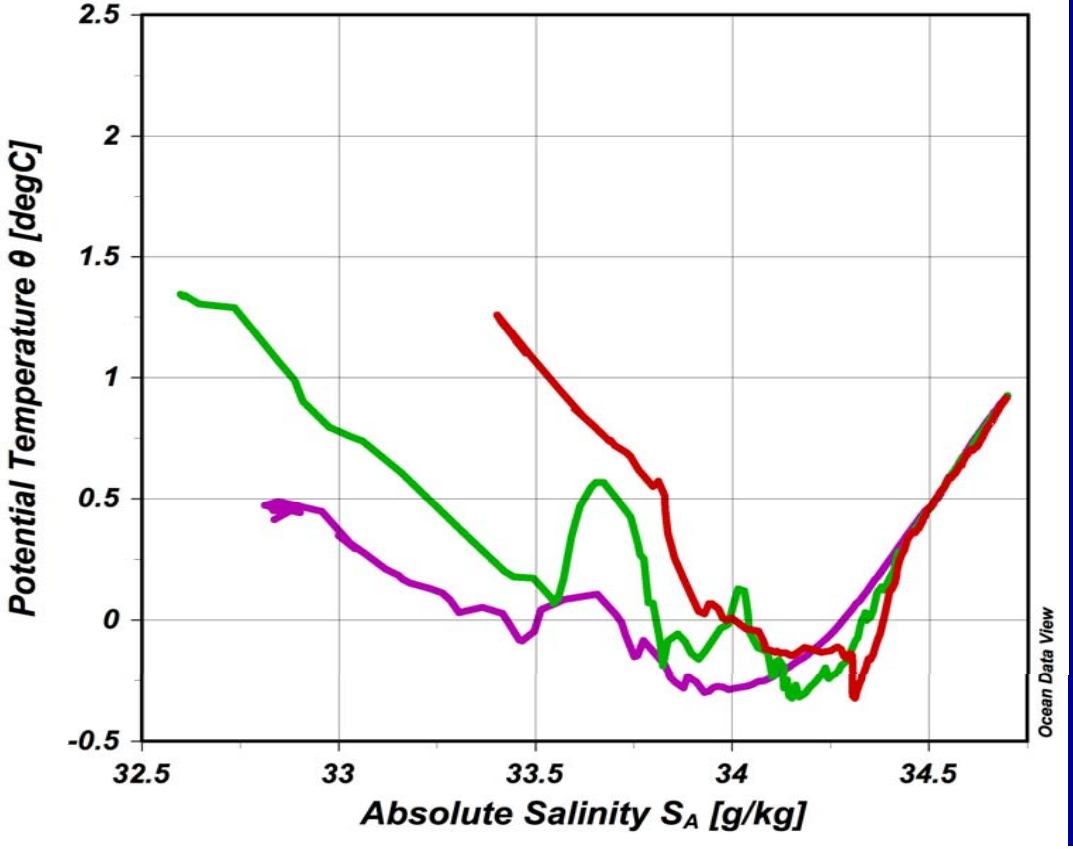
Rignot et al. 2011 based on Motyka et al. 2005

Barilari

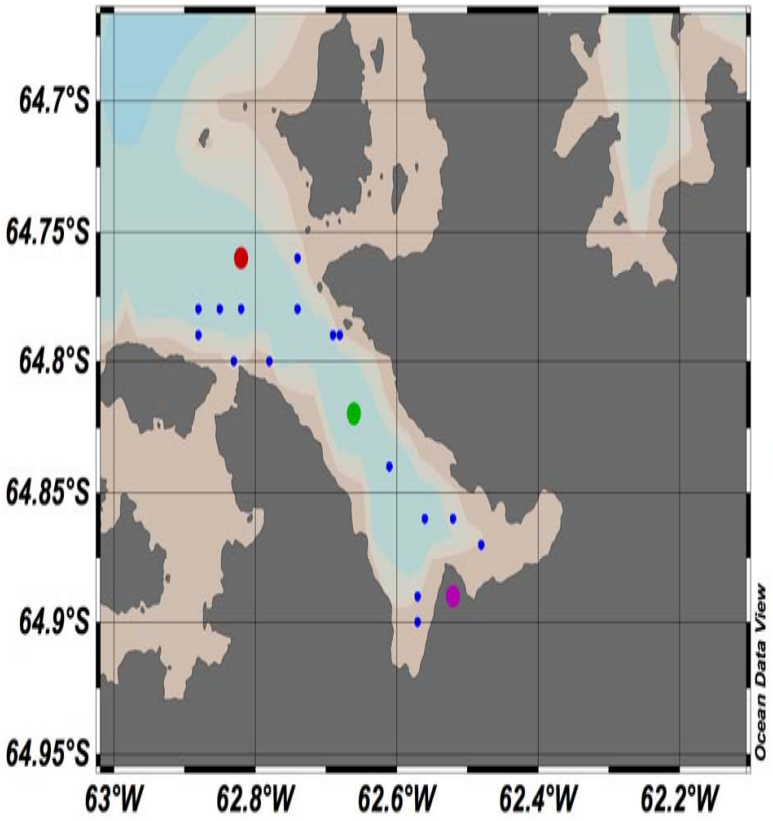
Sediment in Water Column

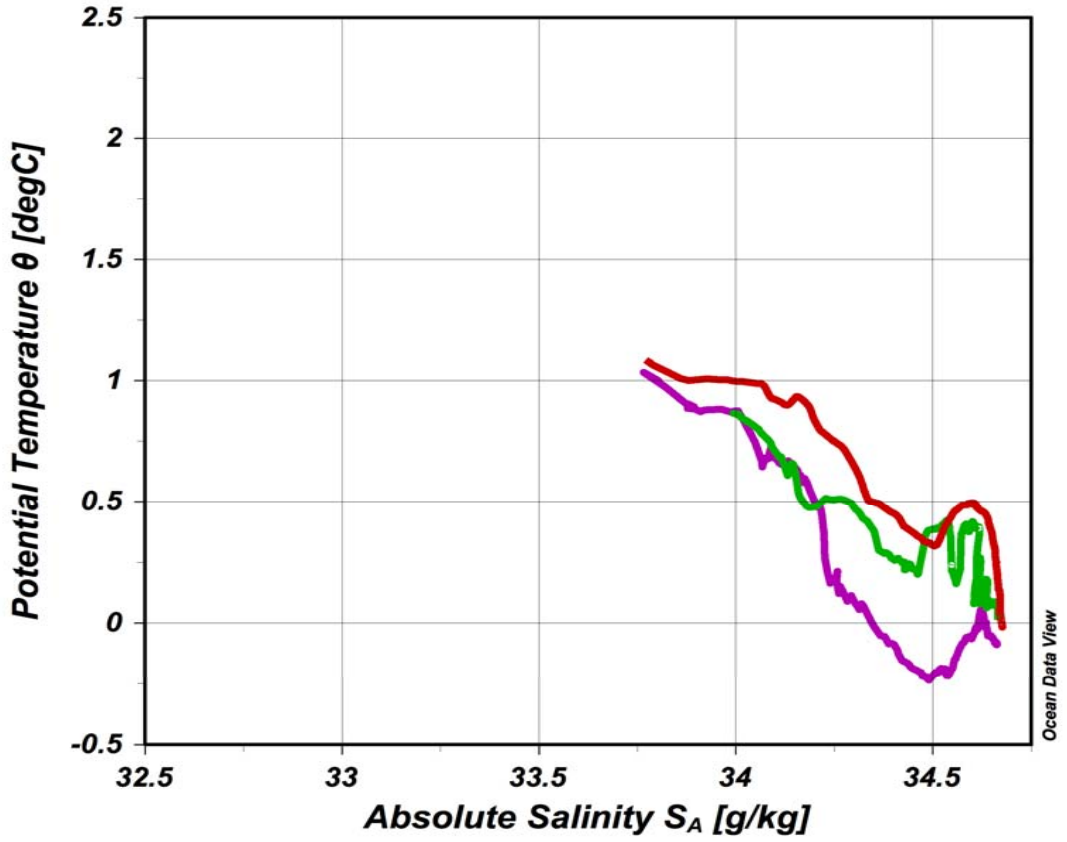






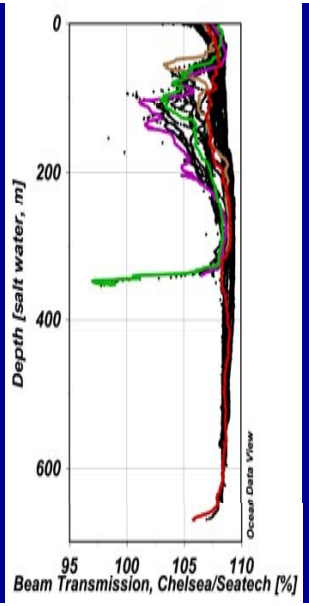
Andvord

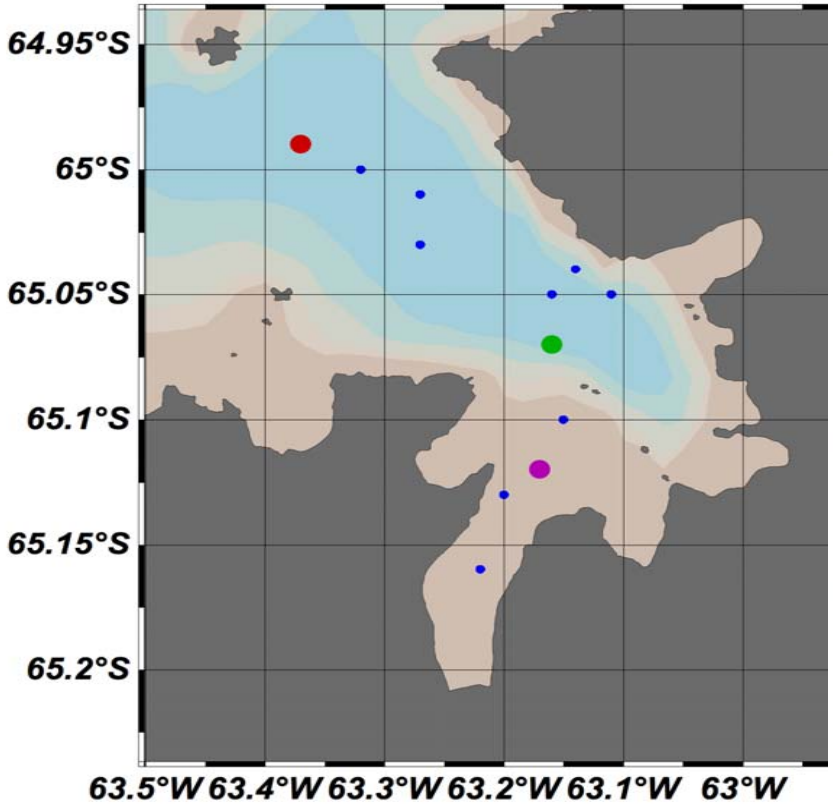

64.7°S
64.75°S
64.8°S
64.85°S
64.9°S
64.95°S
63°W
62.8°W
62.6°W
62.4°W
62.2°W
Ocean Data View

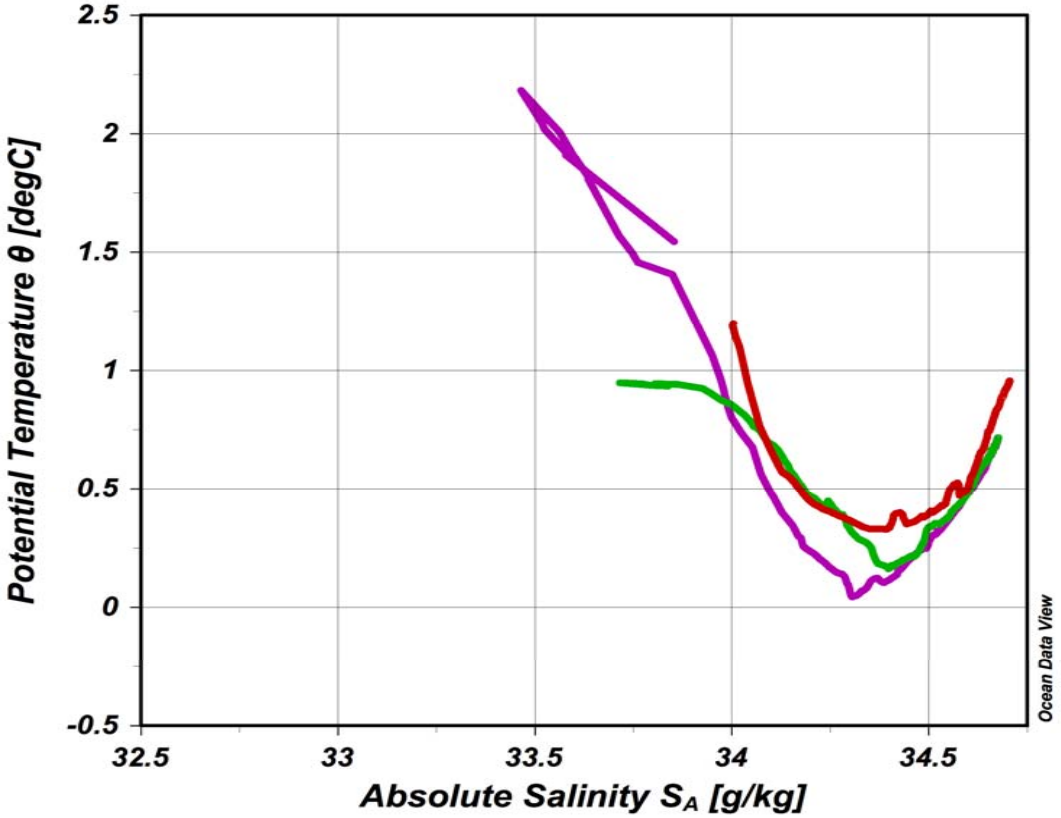

Potential Temperature θ [degC]
2.5
2
1.5
1
0.5
0
-0.5
32.5
33
33.5
34
34.5
Absolute Salinity S_A [g/kg]
Ocean Data View

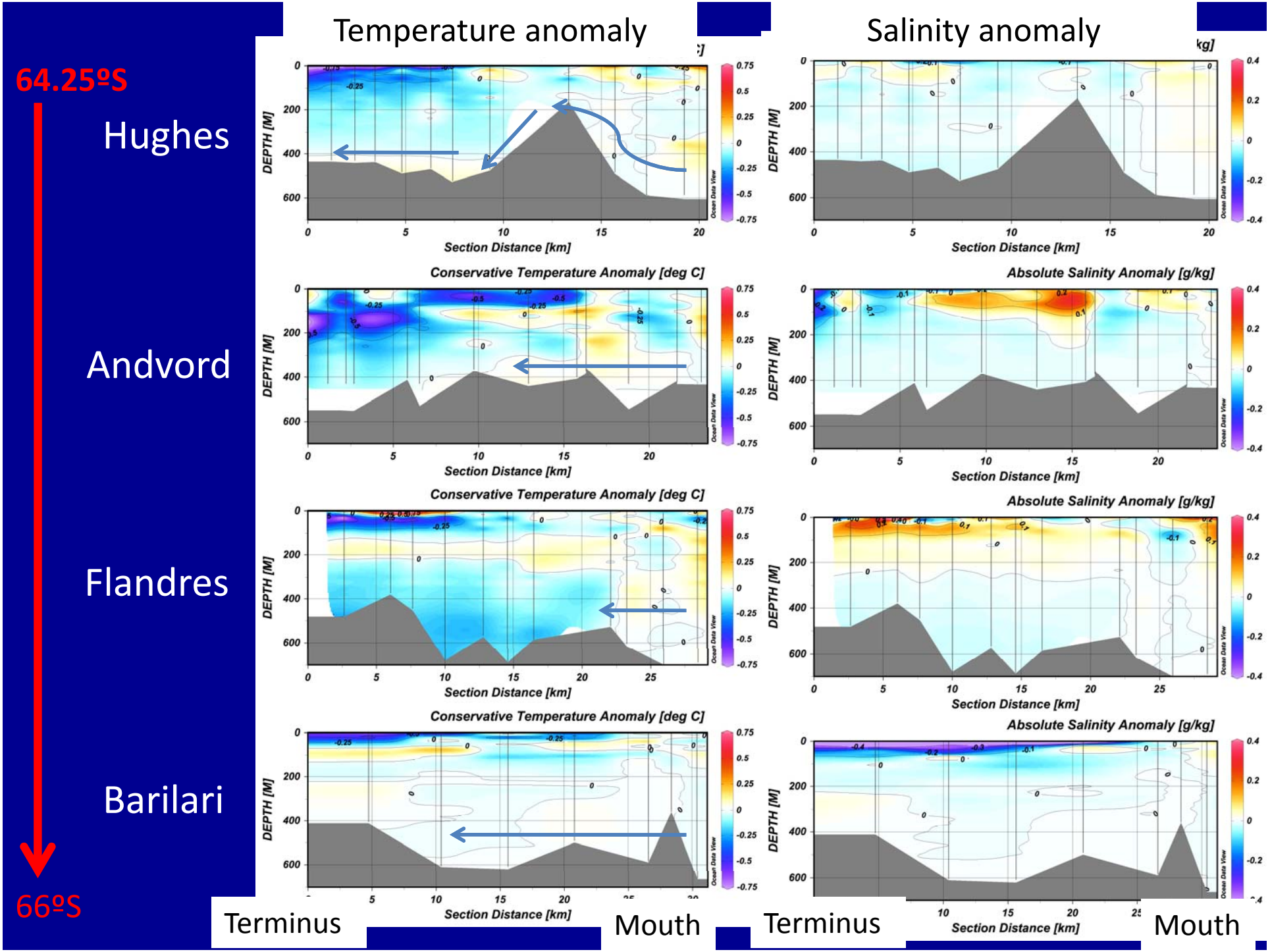
Flandres

Sediment in Water Column

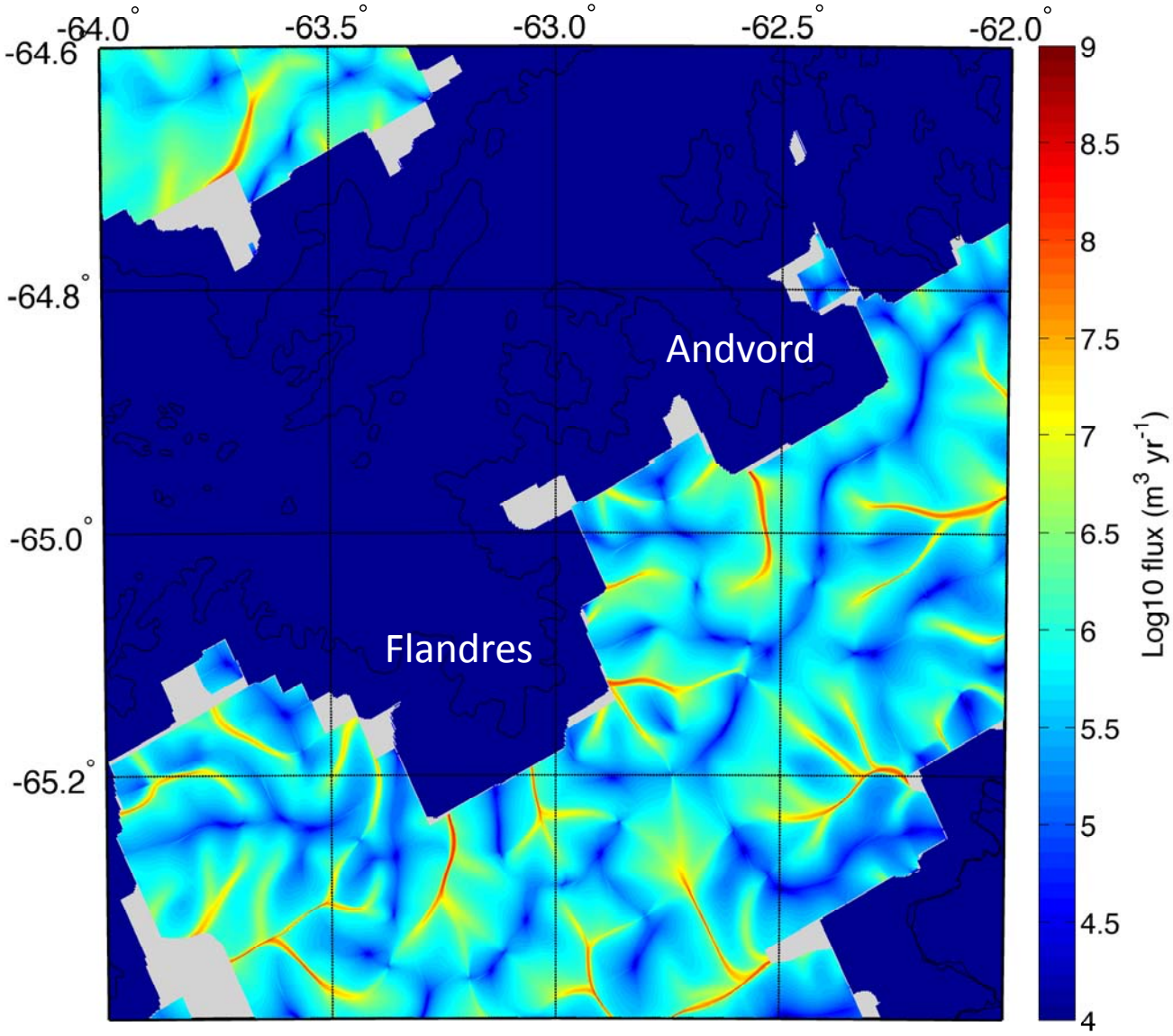




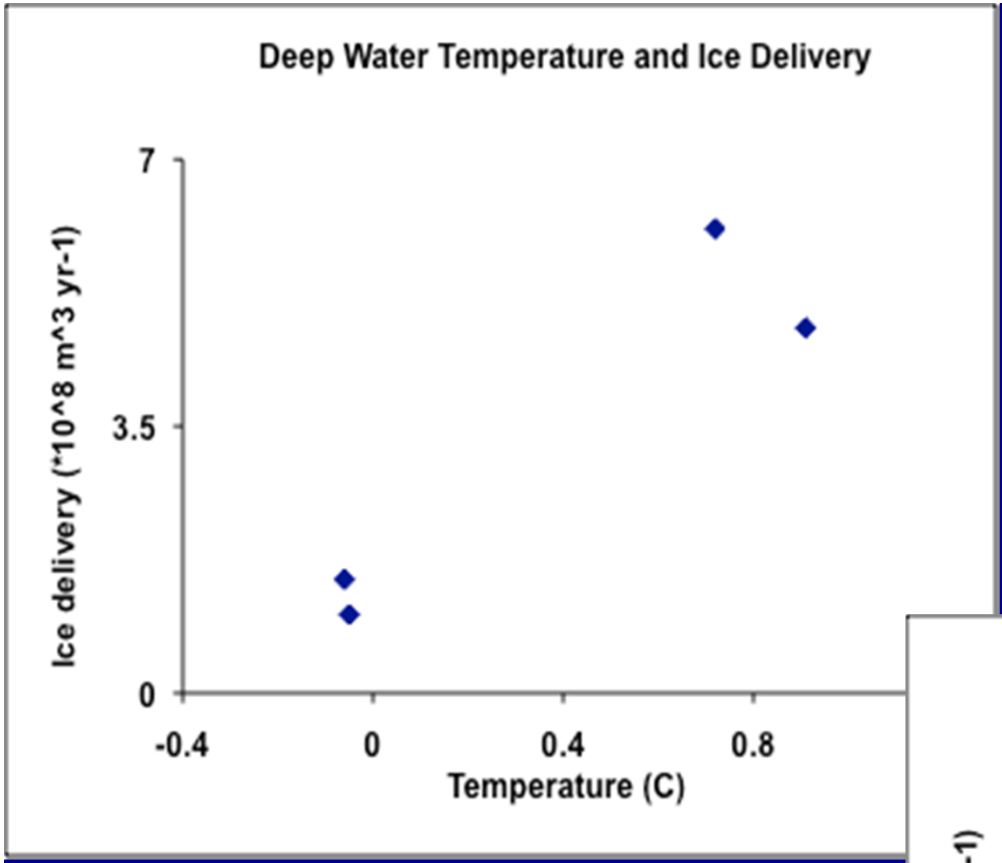


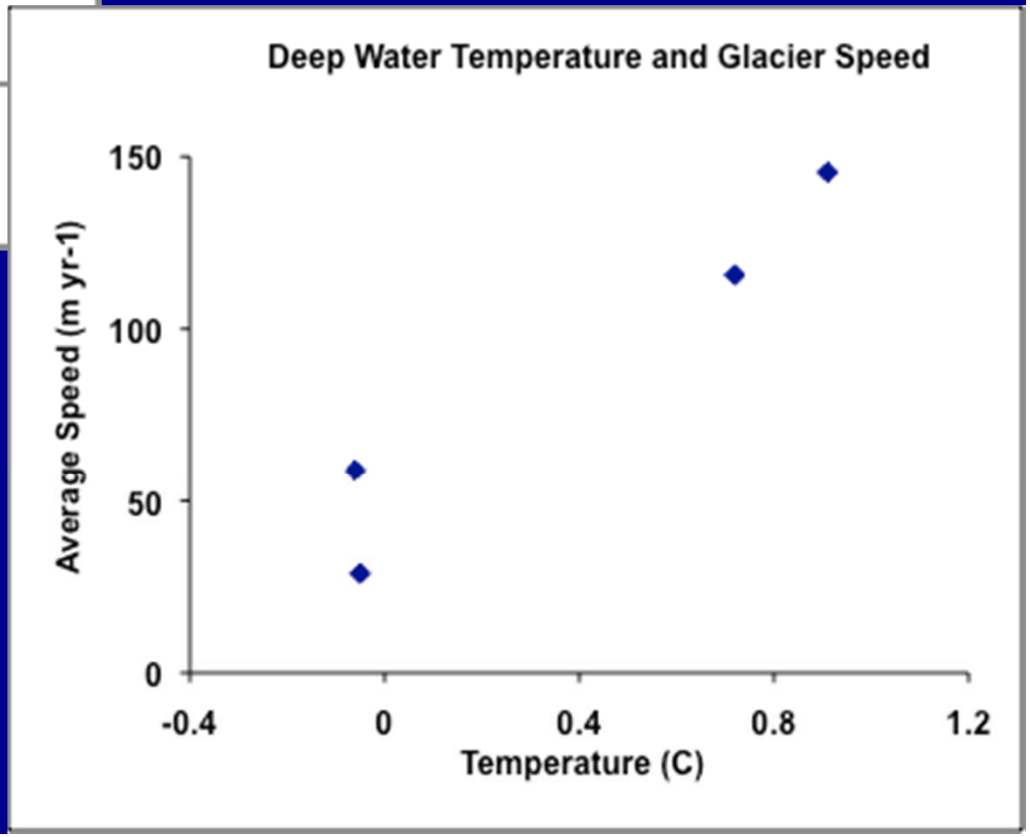

Temperature anomaly
Salinity anomaly
64.25ºS
66ºS
Hughes
Andvord
Flandres
Barilari
Terminus
Mouth
Terminus
Mouth
DEPTH [M]
Section Distance [km]
Conservative Temperature Anomaly [deg C]
Absolute Salinity Anomaly [g/kg]

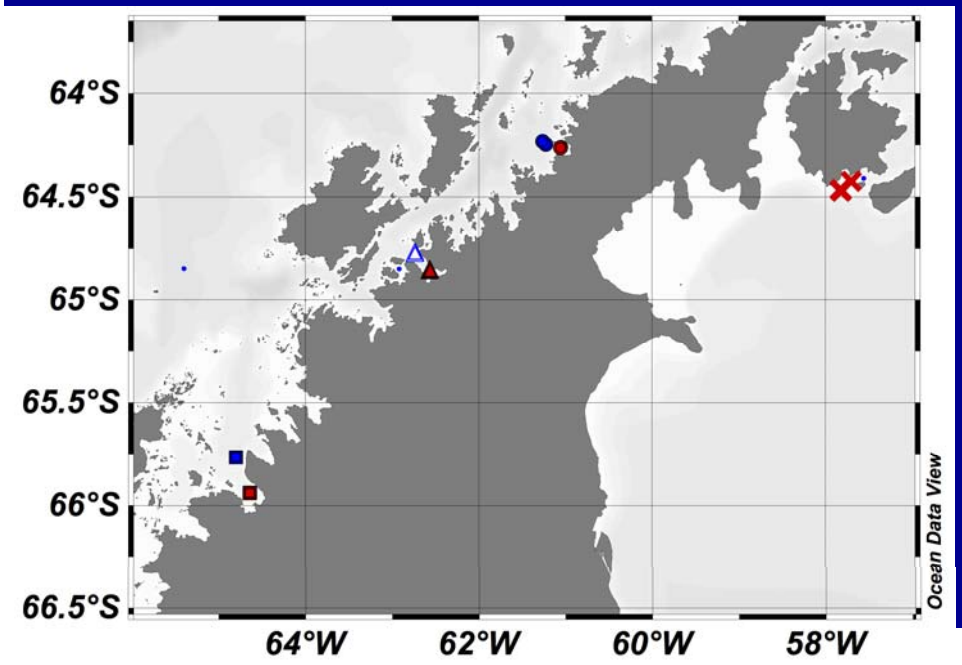
wAP Central Fjords



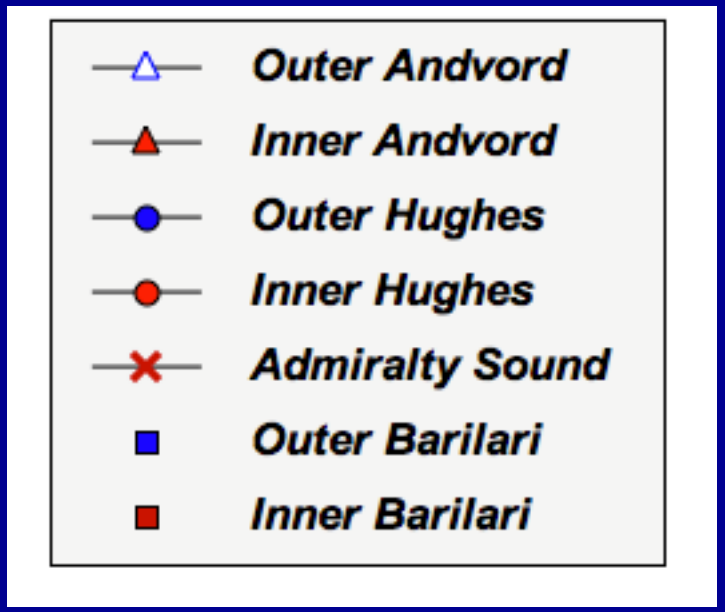
Pettit, unpublished

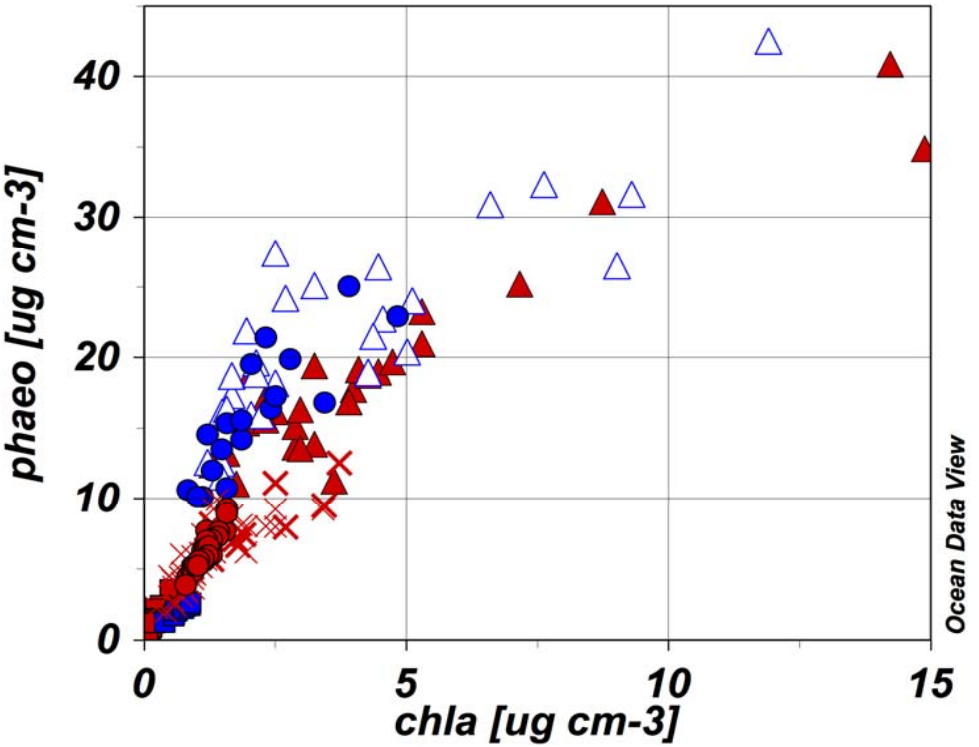

Deep Water Temperature and Ice Delivery
Ice delivery (*10^8 m^3 yr-1)
7
3.5
0
-0.4
0
0.4
0.8
Temperature (C)


Deep Water Temperature and Glacier Speed
Average Speed (m yr-1)
150
100
50
0
-0.4
0
0.4
0.8
1.2
Temperature (C)

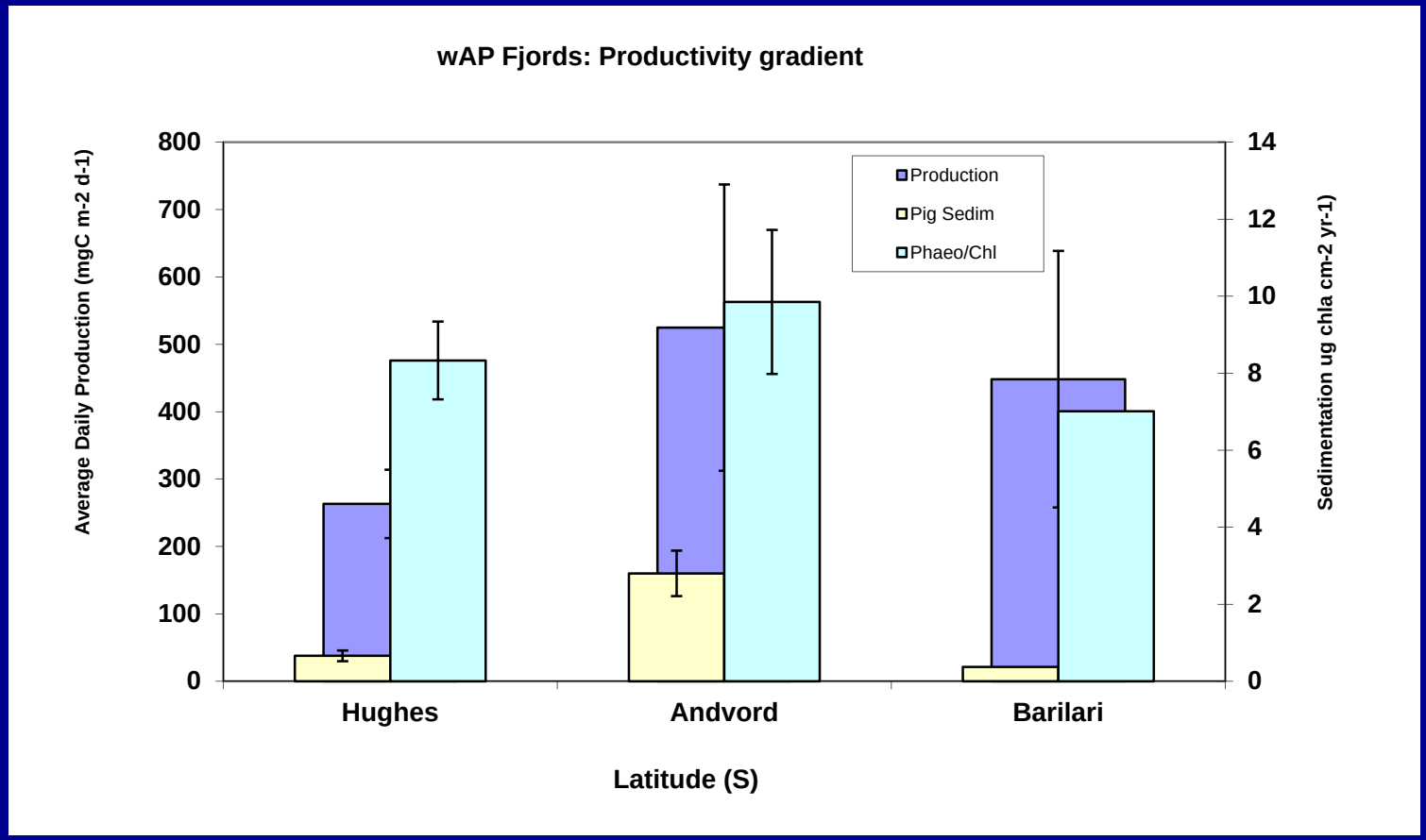


Andvord is most productive, Barilari is least





Primary production, pigment sedimentation and freshness of organic matter

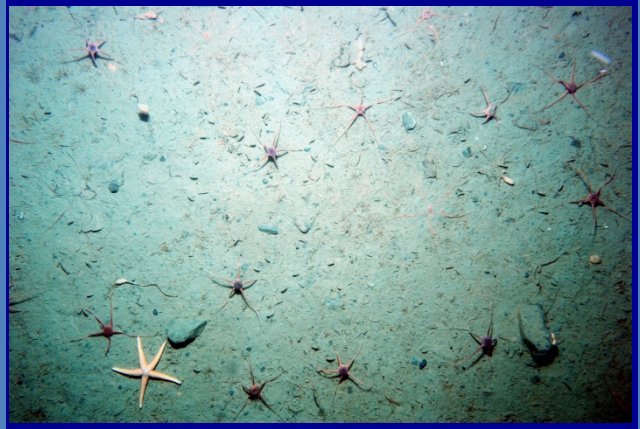


Typical megafaunal abundance

Grange & Smith, subm

FLANDRES BAY

ANDVORD BAY



Maximum megafaunal abundance

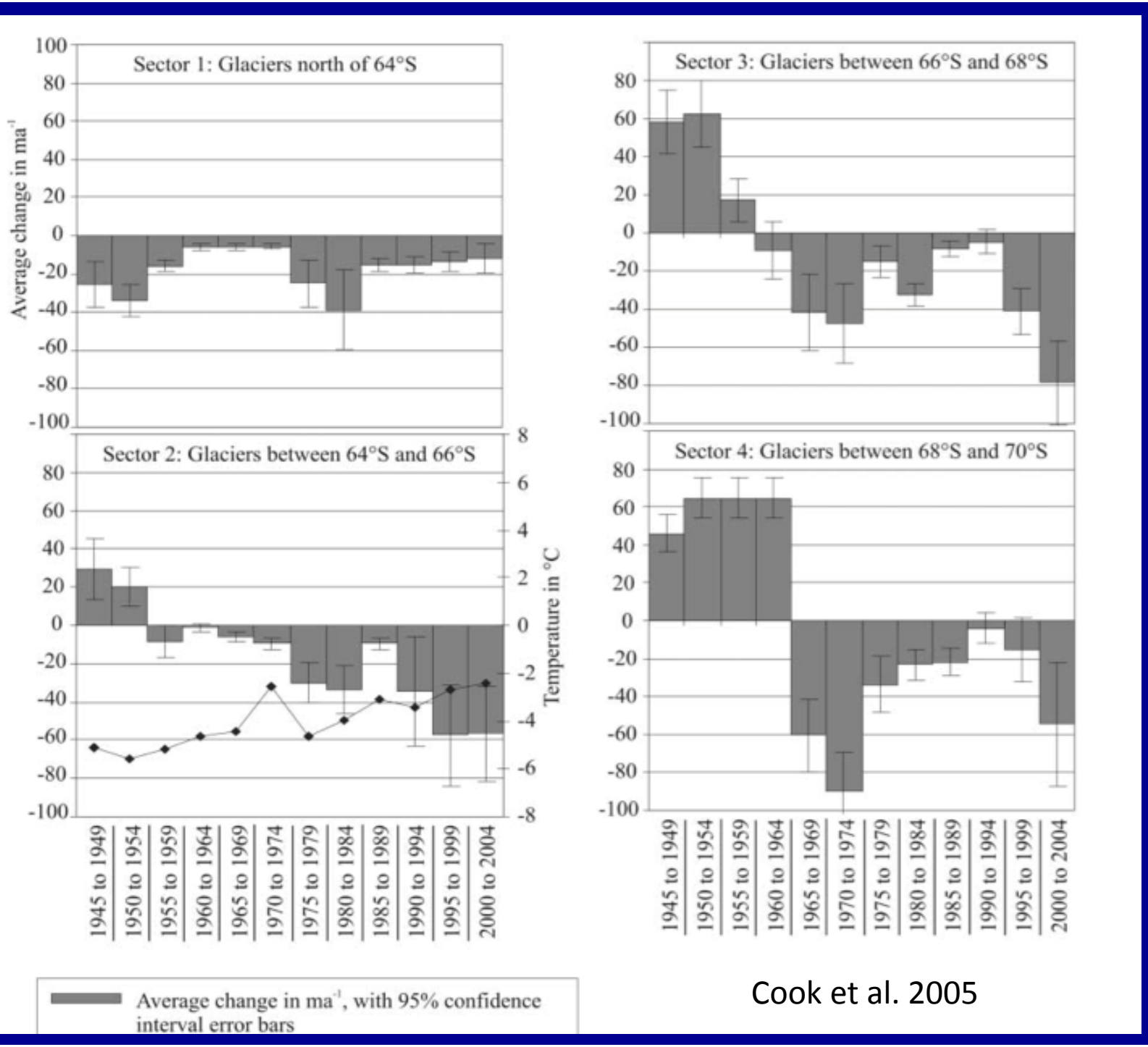

Chaetopterus in tube


Rhipidothuria racowitzai

Ampharetids &
Ampelliscids

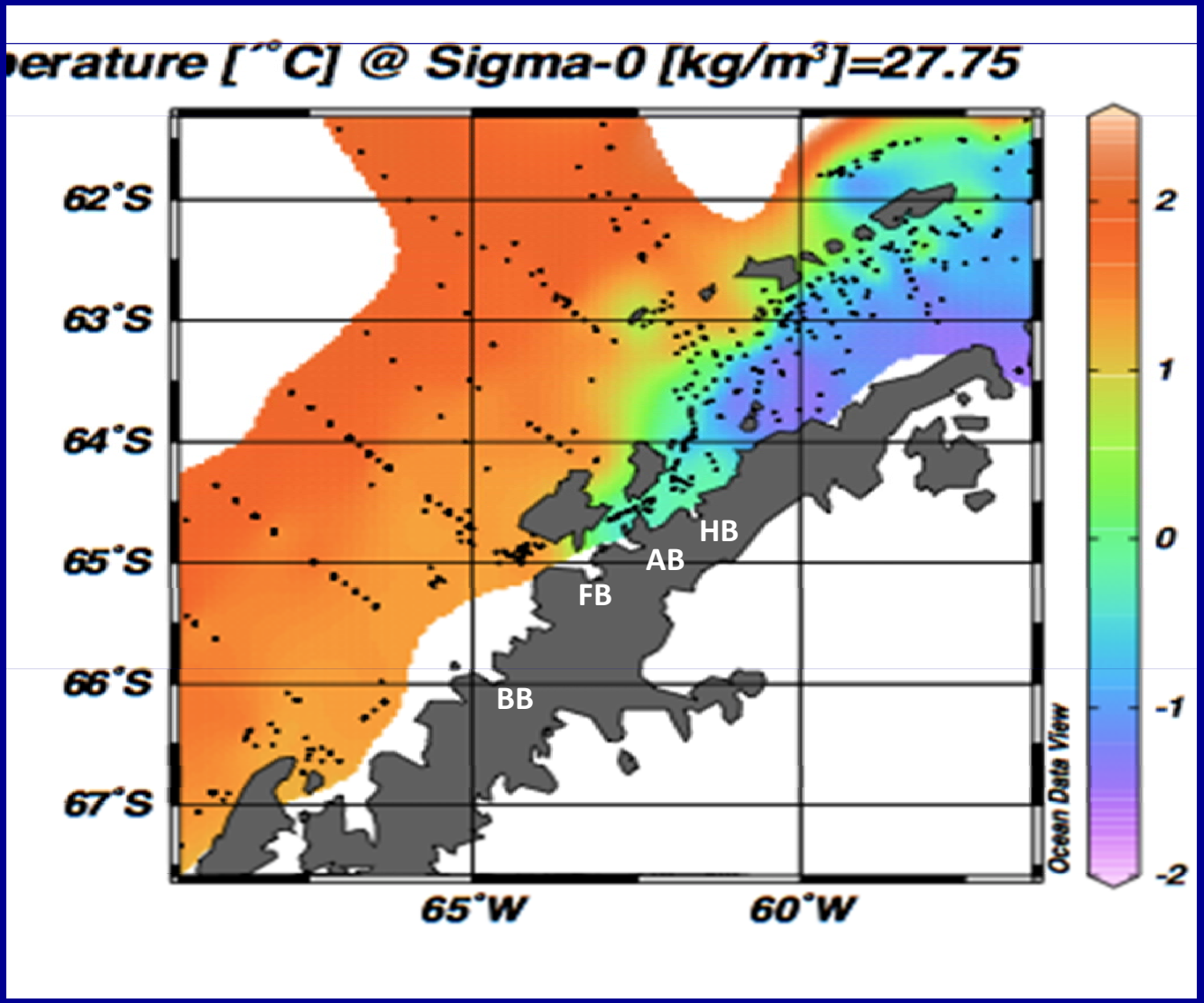
In Summary

- Glacier retreat has a north-south gradient, however the ice delivery is larger and glacier speed is faster towards the south, correlating with warmer deep water. At the southernmost fjord, meltwater drives an estuarine circulation.
- Hypothesis: the balance of atmospheric vs ocean influence on glacier dynamics changes with latitude
- Modern productivity and abundance of benthic fauna gradients are non-linear with latitude, highest in central fjords, at the boundary of the MUCDW reaching glaciers
  ⟶ Decoupling of biological and physical/cryosphere dynamics.



Cook et al. 2005

Water temperature at depth (°C)



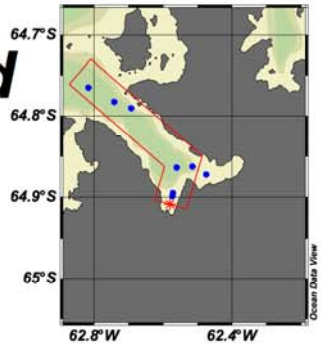
Huber (unpublished)

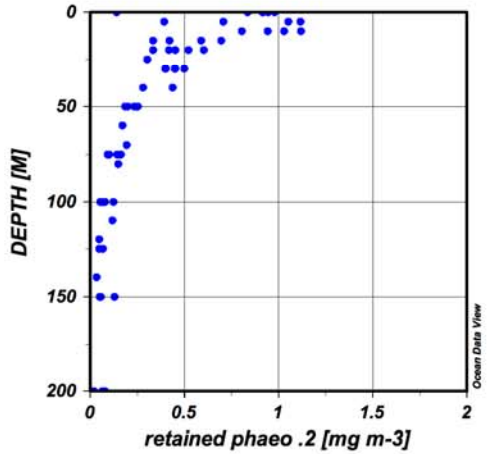
Thank you

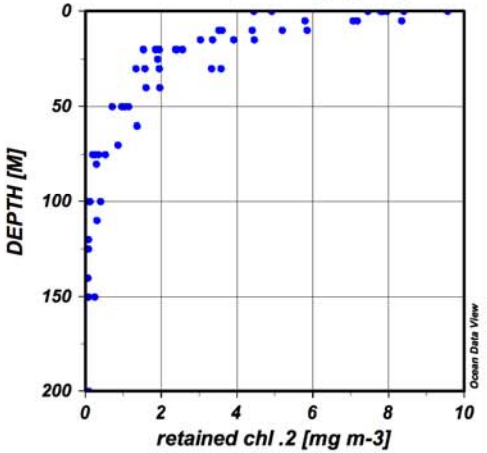
Western Weddell Sea – near James Ross Island – January 2010

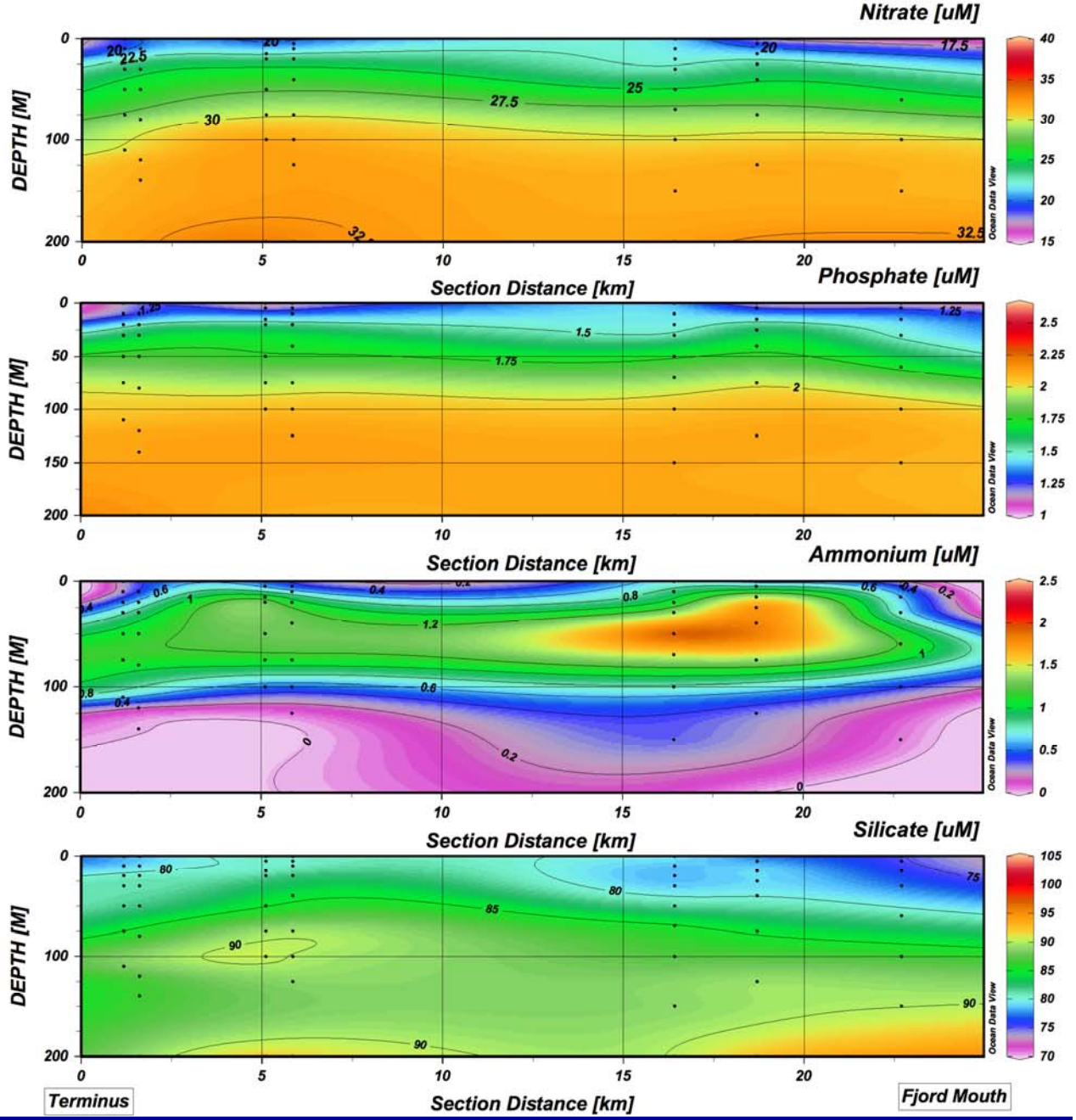
Thank you

Andvord Bay

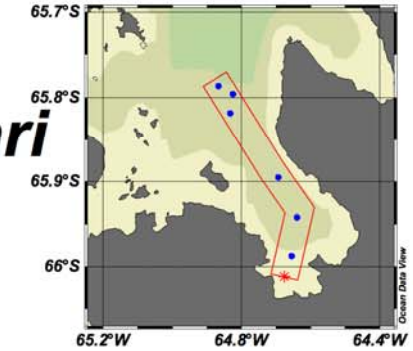

64.7°S
64.8°S
64.9°S
65°S
62.8°W
62.4°W
Ocean Data View

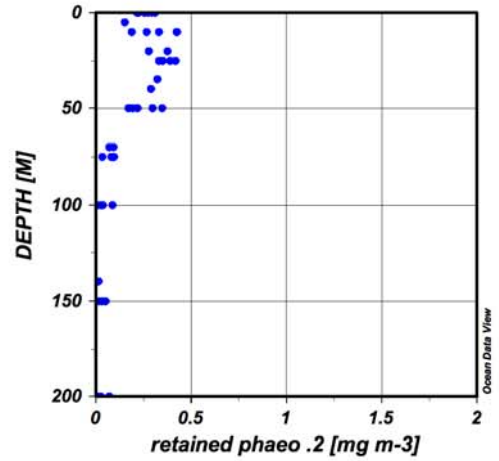

DEPTH [M]
retained phaeo .2 [mg m-3]
Ocean Data View

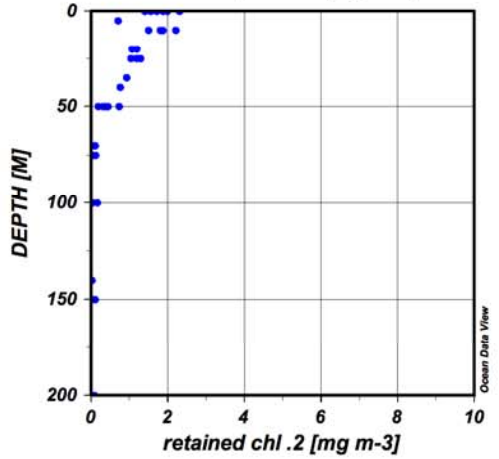

DEPTH [M]
retained chl .2 [mg m-3]
Ocean Data View

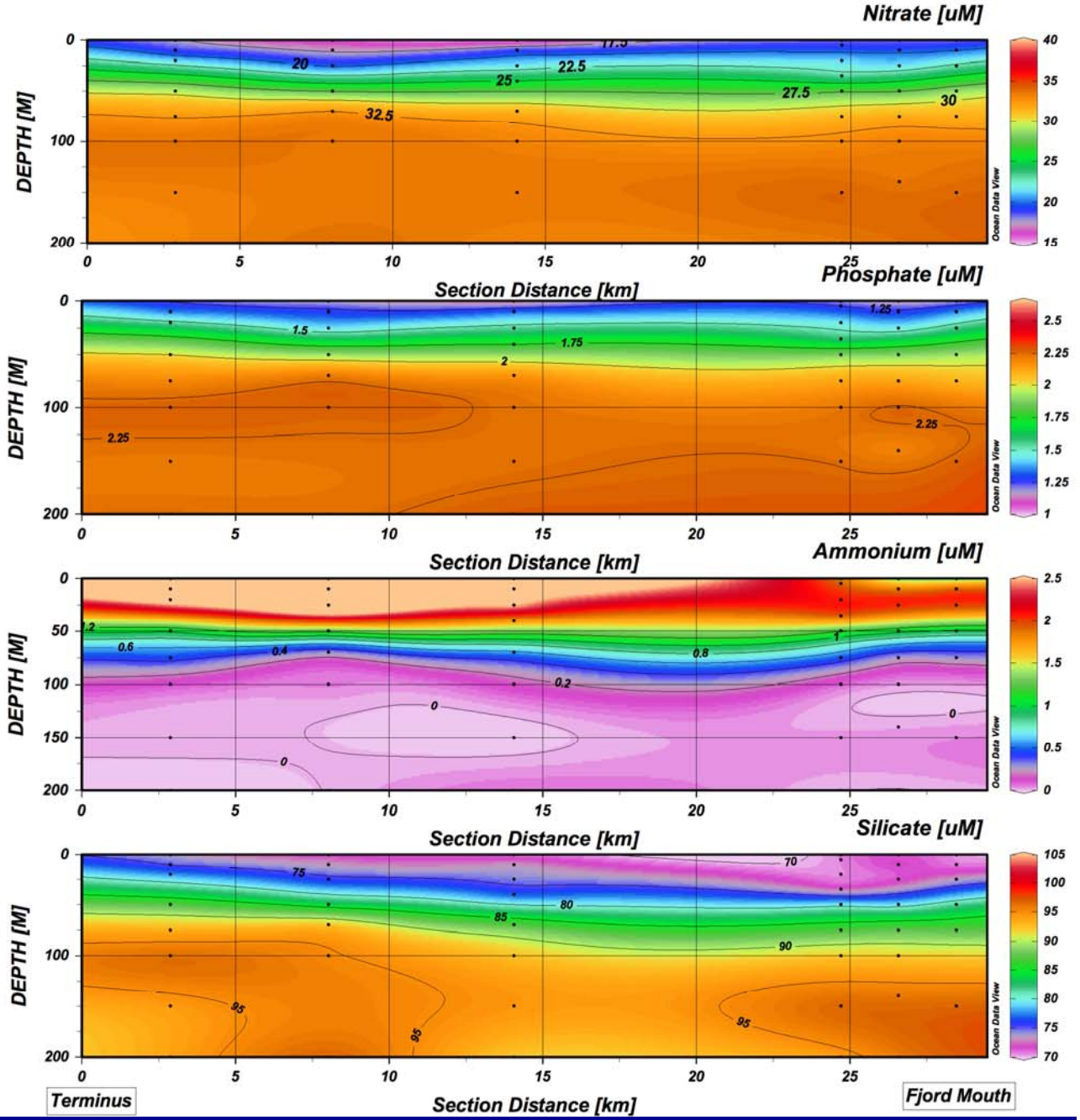

Nitrate [uM]
Phosphate [uM]
Ammonium [uM]
Silicate [uM]
DEPTH [M]
Section Distance [km]
Terminus
Fjord Mouth
Ocean Data View

Barilari Bay





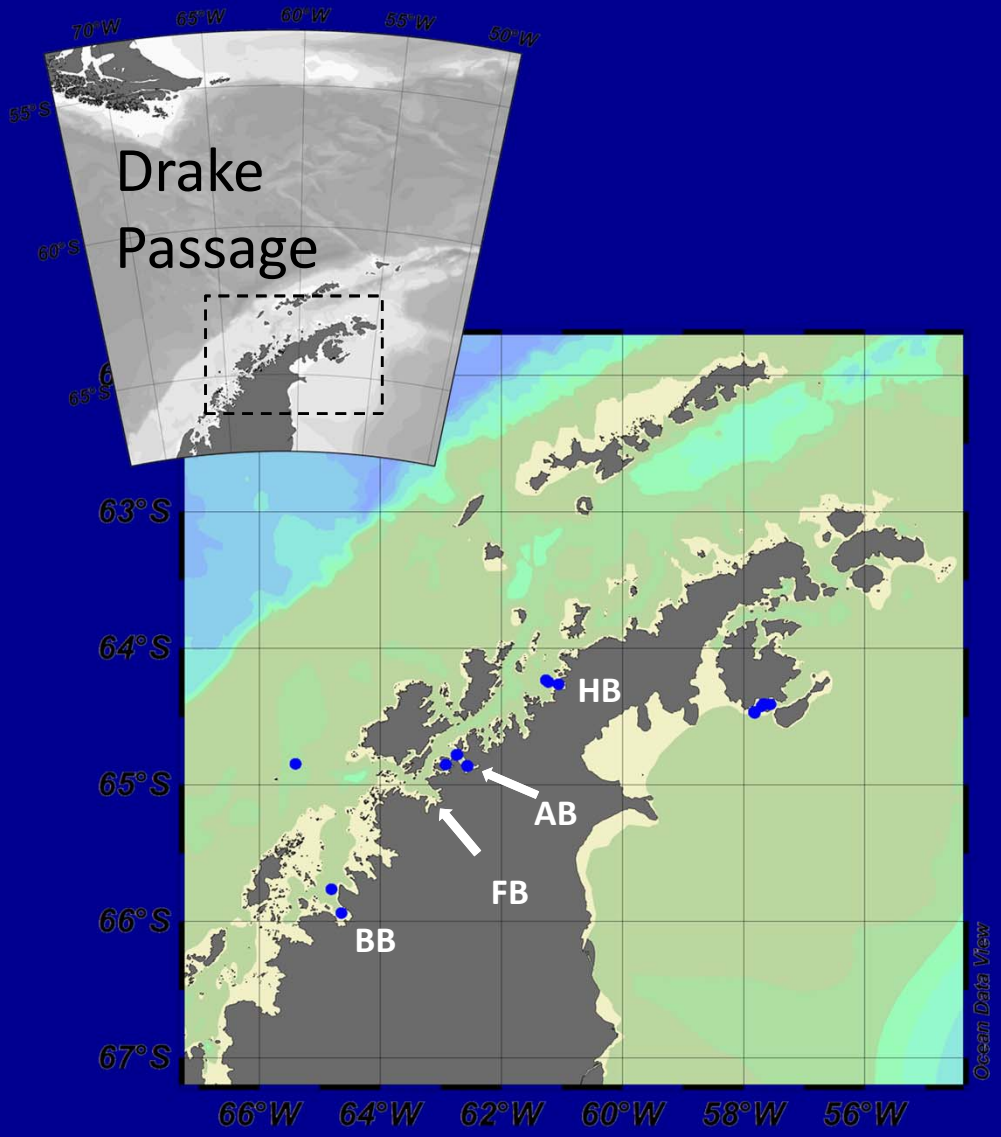




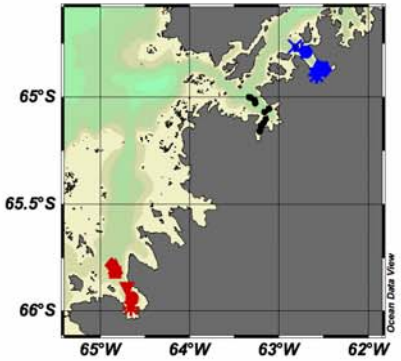
In Summary

- A north-south gradient of oceanic influence, not only due to deep water temperature, and resulting/related to varying modes of circulation
  - Deep water in Barilari (southern fjord) creates a 2-layer circulation, similar to Alaskan fjords (Motyka et al. 2005)
  - Northern fjords have more complex circulation, with subsurface plumes, even when deep water is warm, more similar to some Greenland fjords
- Hypothesis: the balance of atmospheric vs ocean influence on melting of glaciers changes with latitude

Pigments in sediments of Antarctic Peninsula Fjords

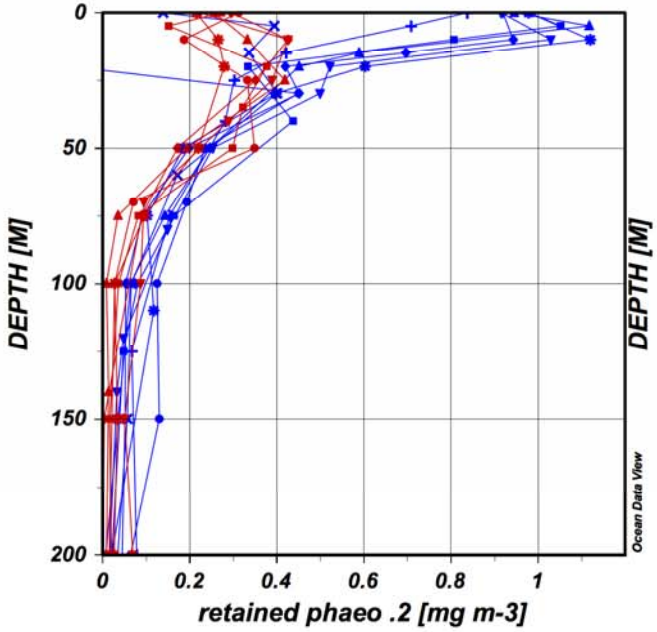


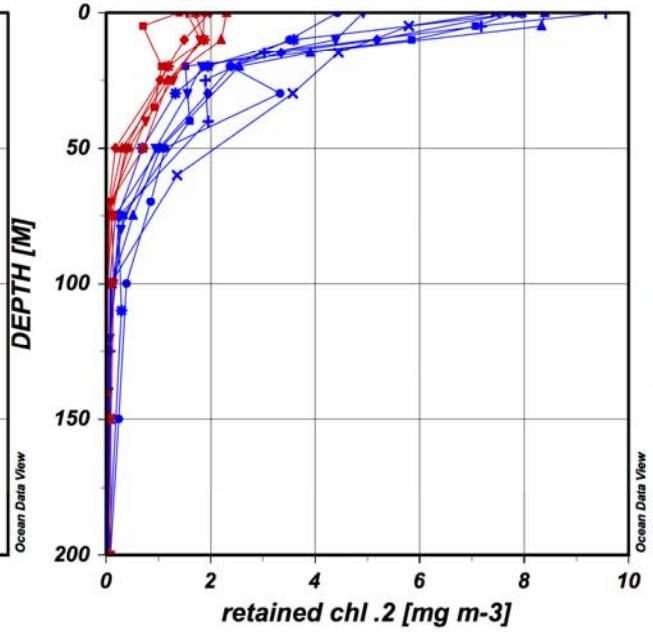
- HB: Hughes Bay: 1.75 mg cm-3
- AB: Andvord Bay: 2.75
- FB: Flandres Bay:
- BB: Barilari Bay: 0.7

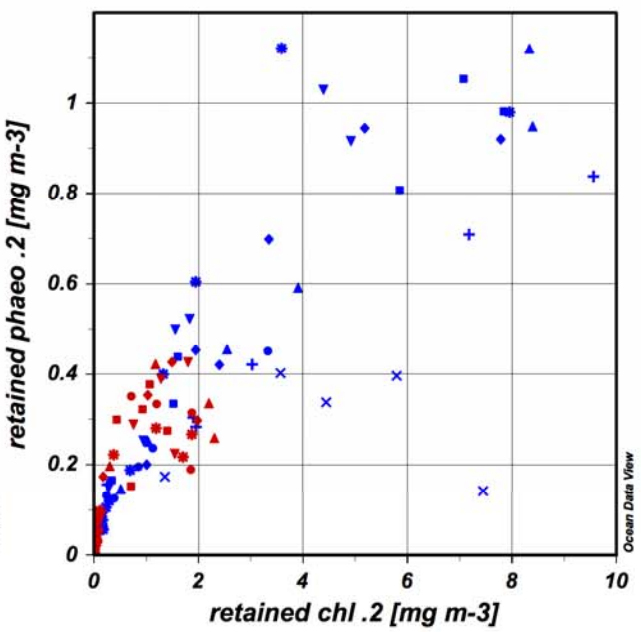


Barilari Bay

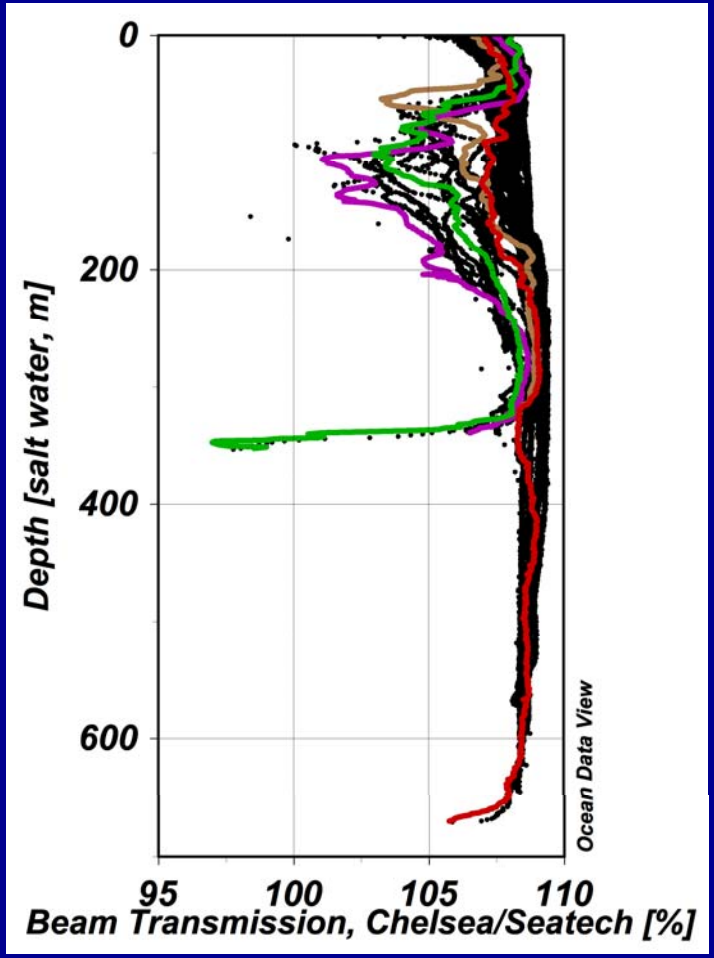
Andvord Bay



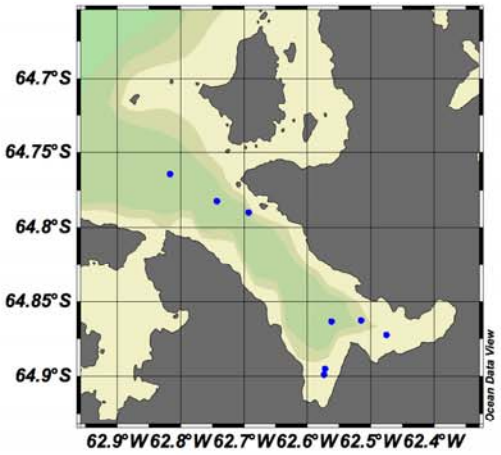


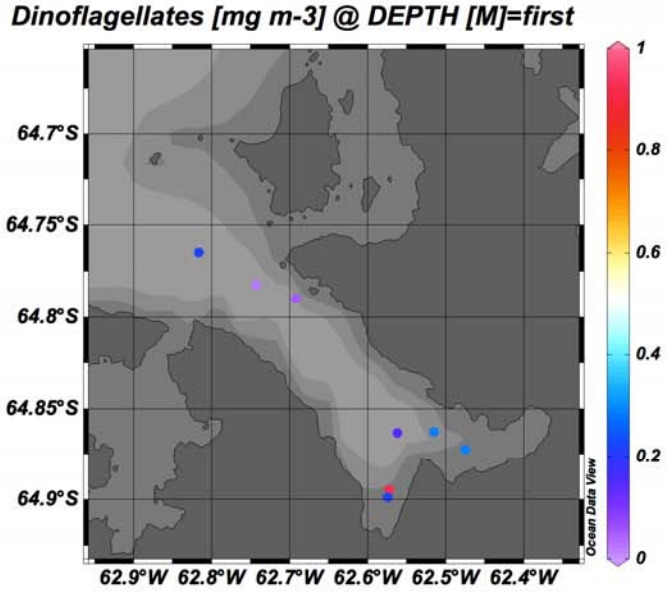


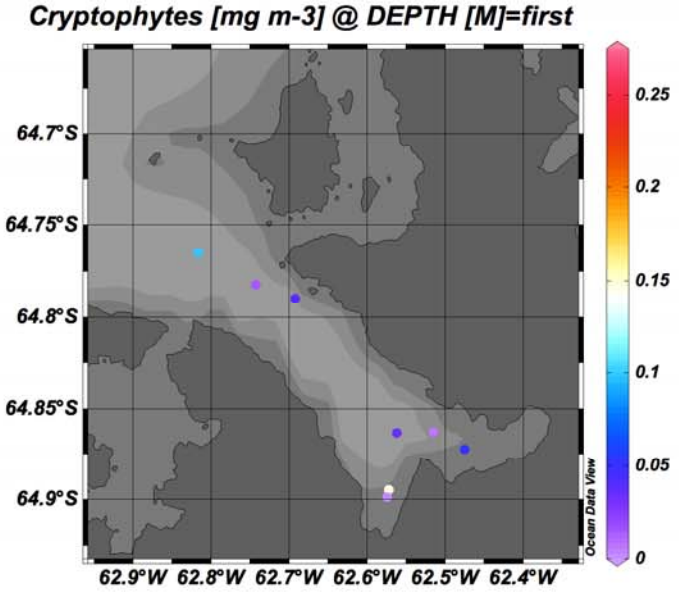
Flandres 2013
(subsurface plumes)

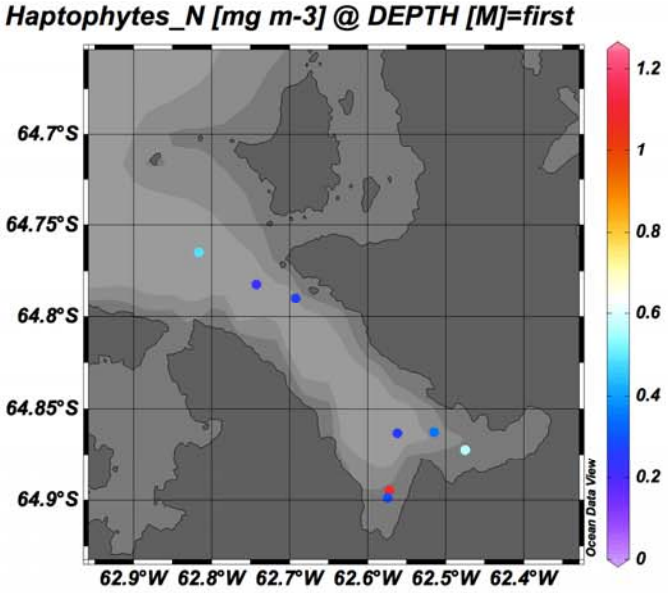


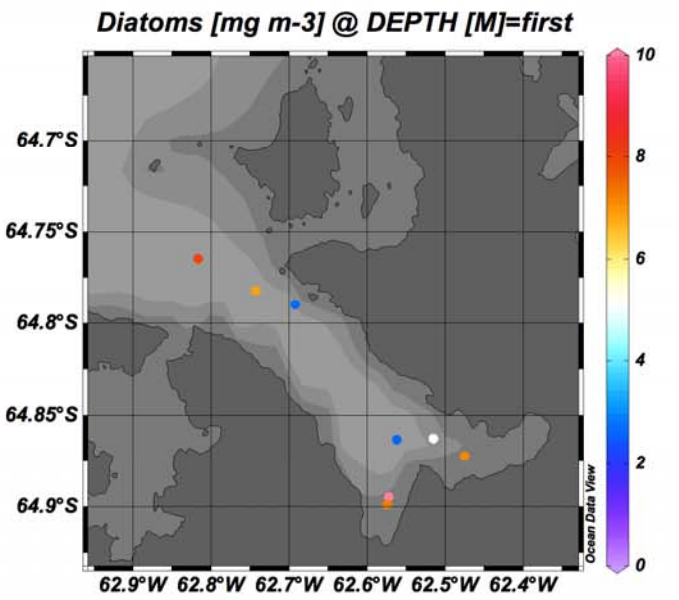
Diatoms dominate

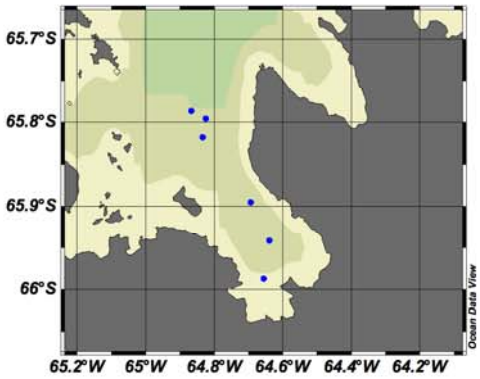


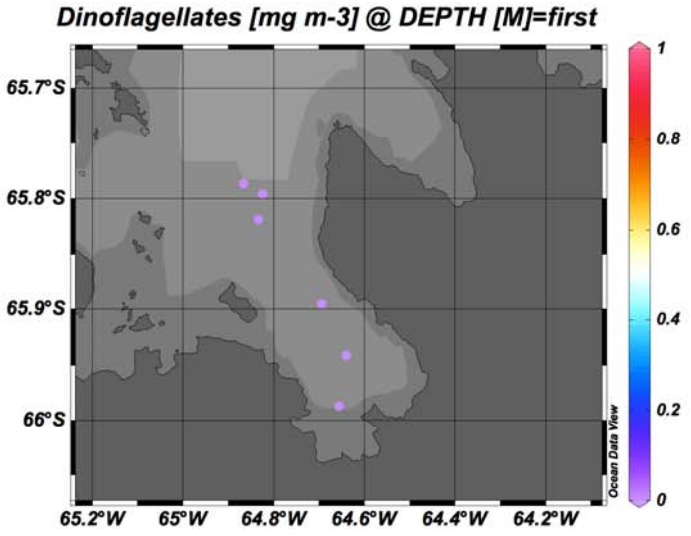


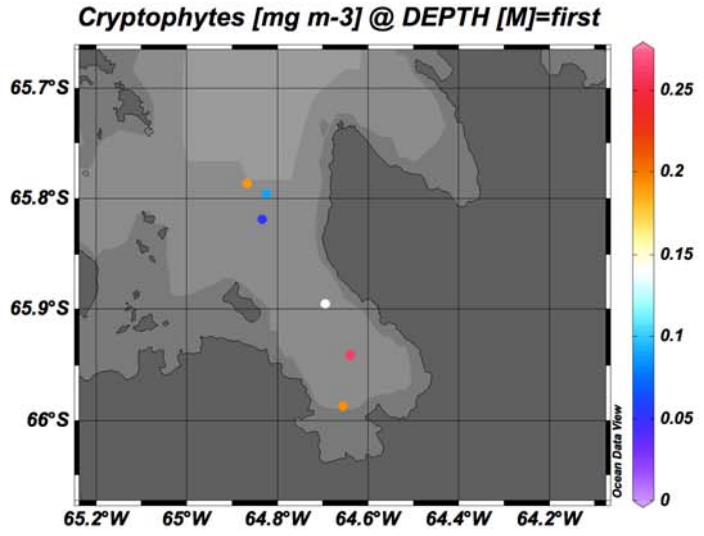




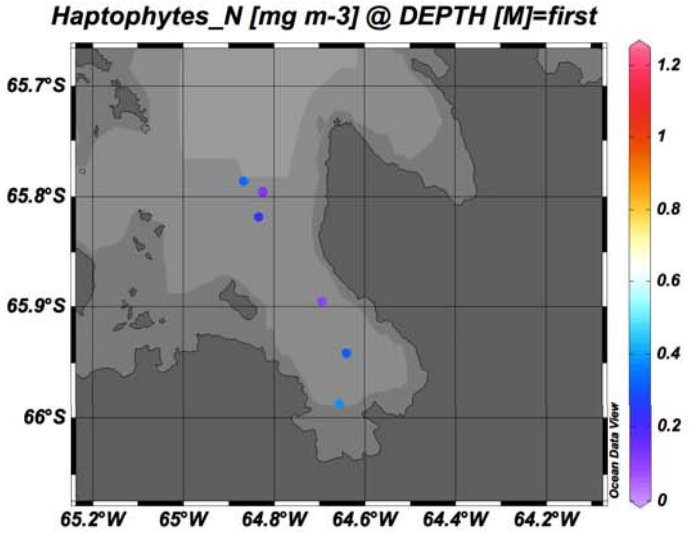


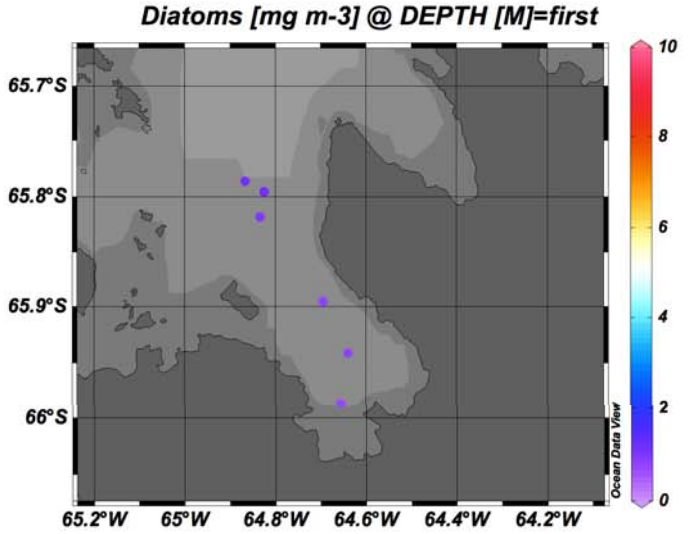






Diatoms still dominate Lower concentration than in Andvord





Phytoplankton Summary

- Central fjords (Andvord) are more productive. Water column stratification is lower, suggesting a higher input of nutrients in the mixed layer. Ice melting also brings iron.
- Data (pigments in sediments and water column concentrations) are in agreement
- Diatoms are most dominant in Barilari, although absolute concentration is lower in southern fjords.
- Grazing is more intense in Barilari (ammonium), suggesting higher carbon recycling in the water column

Data we need

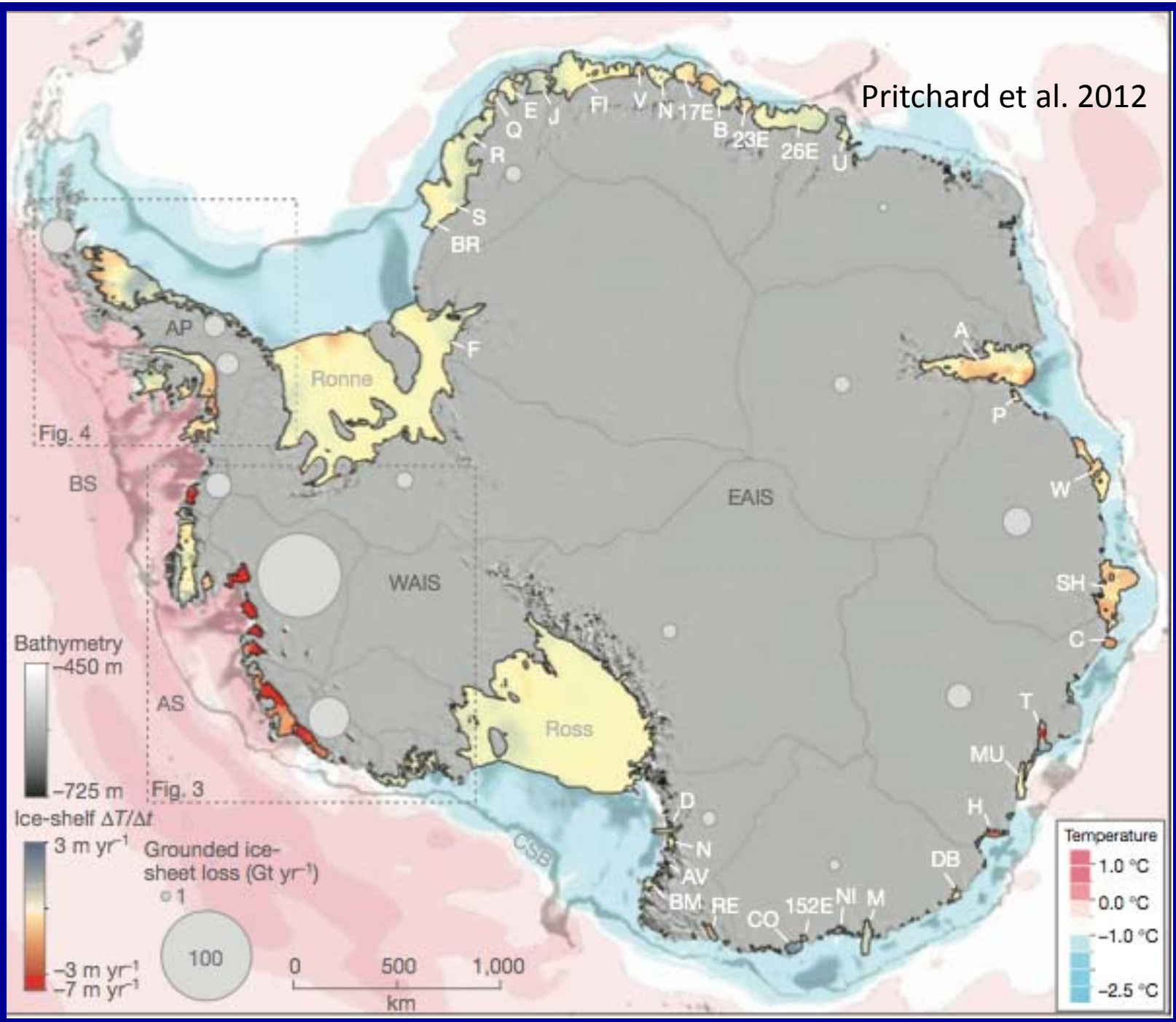
- Need more data to complete calculations.
  - PO: water velocities to model circulation and estimate residence time
  - Glaciology & MG&G: ice delivery
  - MG&G: sediment accumulation, mixing, inorganic/organic, diatom abundance and diversity
  - Morin: Brash ice and icebergs in bays
  - Climate: update position of air temperature isotherms

Fjords paper

- As discussed in Boulder, the plan is to write a fjords paper. Since Boulder we have added the 18-O data, that has help clarify the physics and melting dynamics in fjords.
- The paper will be an overview paper, relating the different disciplines, highlighting glacier melting, ice and sediment input, estuarine circulation and the combined effect of these processes on ecosystem structure (diversity of species) and ecosystem function (productivity, carbon recycling).

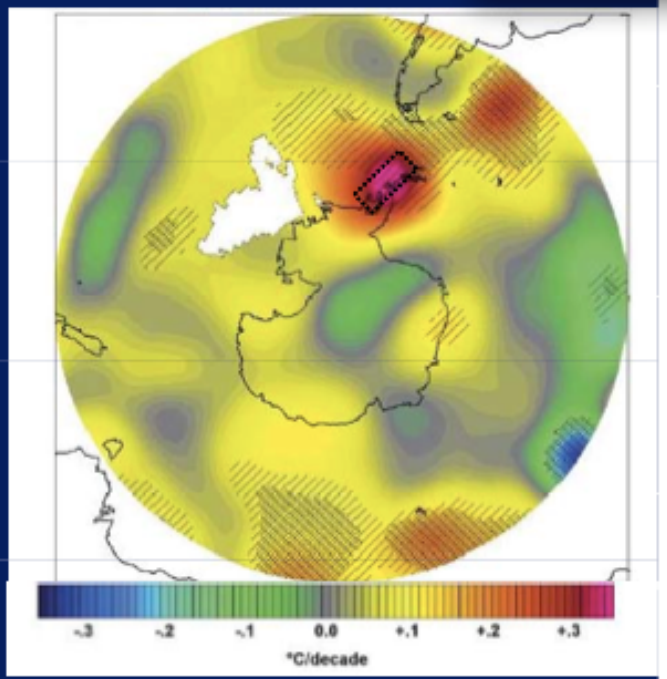
LARISSA wAP fjords - Ecosystems

- Mattias Cape/Maria Vernet: Phytoplankton
- Chung Yeon Hwang with Eun Jung Choy and Kitae Kim: Viruses, Zooplankton, Primary production, dissolved Iron
- Mike McCormick: sediment geochemistry
- Craig Smith/Laura Grange: Benthic communities


Pritchard et al. 2012
AP
Ronne
WAIS
EAIS
Ross
BS
AS
CSB
Fig. 4
Fig. 3
Bathymetry
−450 m
−725 m
Ice-shelf ΔT/Δt
3 m yr⁻¹
−3 m yr⁻¹
−7 m yr⁻¹
Grounded ice-sheet loss (Gt yr⁻¹)
1
100
0
500
1,000
km
Temperature
1.0 °C
0.0 °C
−1.0 °C
−2.5 °C
Q
R
S
BR
E
J
FI
V
N
17E
B
23E
26E
U
F
A
P
W
SH
C
T
MU
H
DB
M
NI
152E
CO
RE
BM
AV
N
D

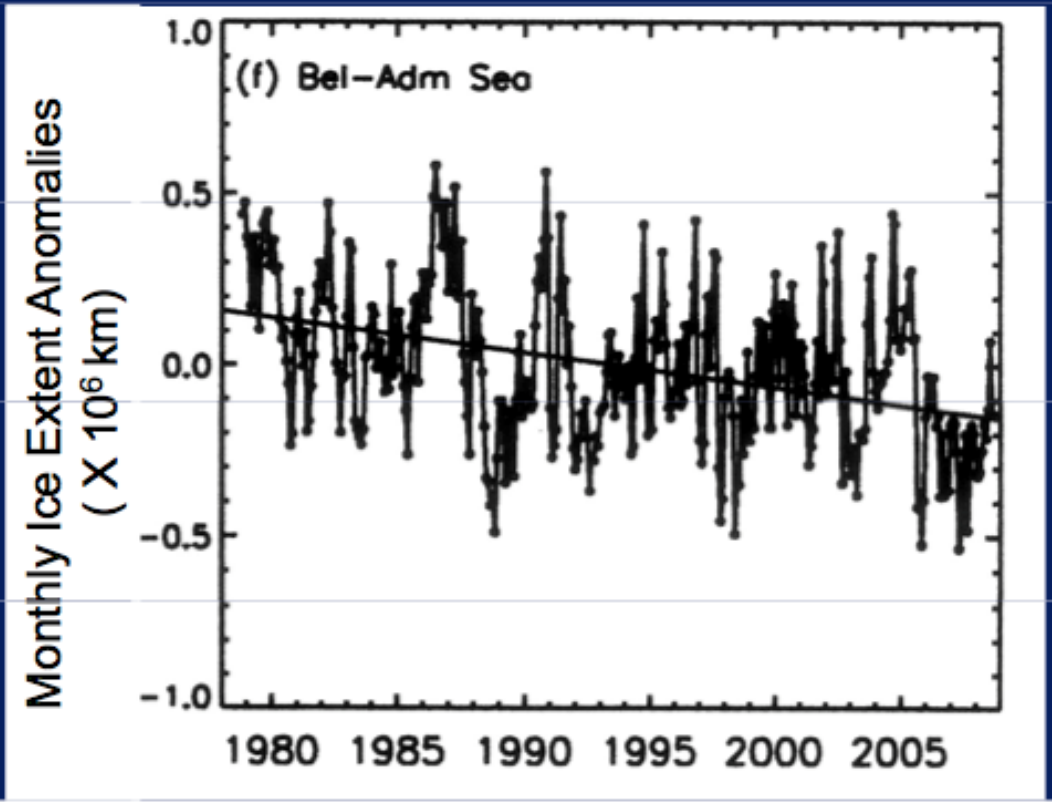
B) Climate is warming very rapidly along the West Antarctic Peninsula (WAP) –

Rising Annual Mean Air Temperatures
+1.6 º C from 1958–2002
(+5 º C for winter mean)
(Chapman and Walsh, 2007)



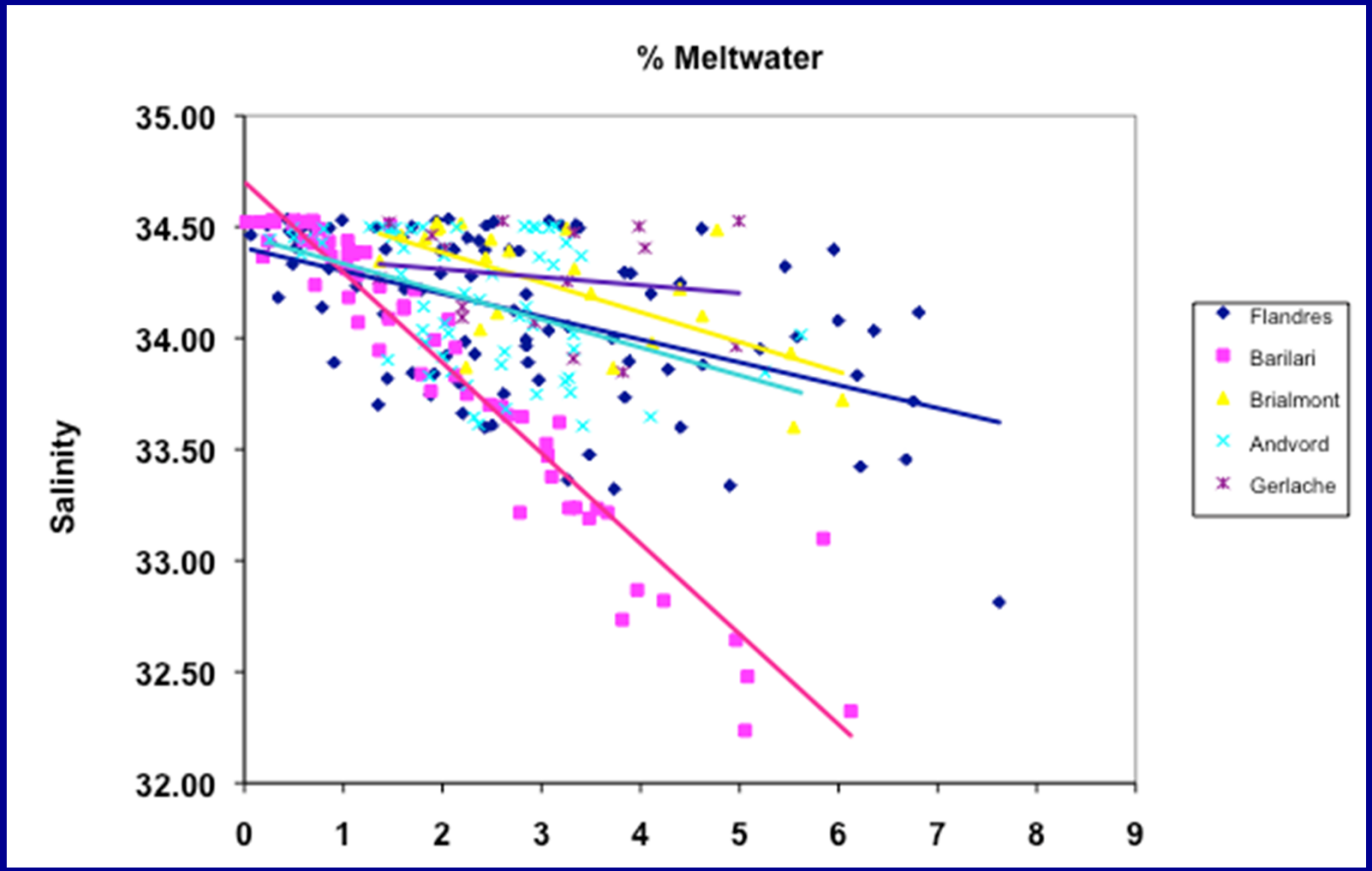
Leading to:

(i) Decline in extent/duration of sea-ice -



Declining Sea-Ice Extent in the Bellingshausen-Amundsen Seas
- 7% per decade
(Comiso, 2010)

Meltwater based on defficiency of 18-O in seawater (Jenkins et al. 2008)

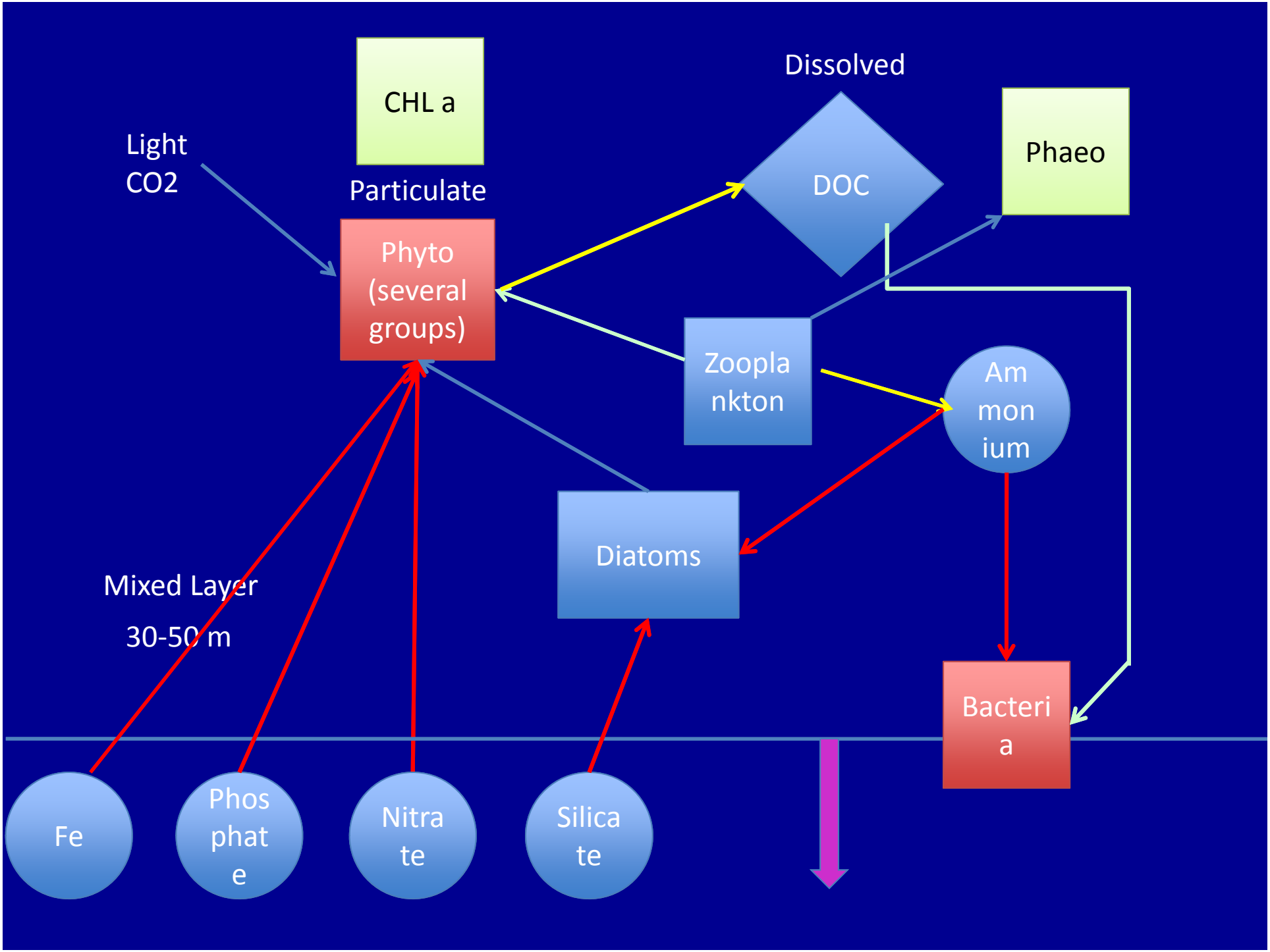


Antarctic Peninsula Fjords Phytoplankton

•OBJECTIVES

•Understand basic patterns of phytoplankton in water column

•Study mechanisms (physics, chemistry, biology, ice, meltwater) regulating phytoplankton, carbon production and food to benthos


CHL a
Dissolved
Light
CO2
Particulate
DOC
Phaeo
Phyto
(several
groups)
Zoopla
nkton
Am
mon
ium
Diatoms
Mixed Layer
30-50 m
Bacteri
a
Fe
Phos
phat
e
Nitra
te
Silica
te

Fjords TS diagrams

Flandres transmissometer subsurface plume

Applying Motyka's 2-layer fjord model circulation, we can estimate ~300 m yr-1 of melting.
Calculations based on January 2010 and assuming same melting in 12 months

Anomalies in 18-O

Mixed Layer Salinity and Meltwater content