Laptev Sea landfast ice: Probing a frozen estuary with SAR

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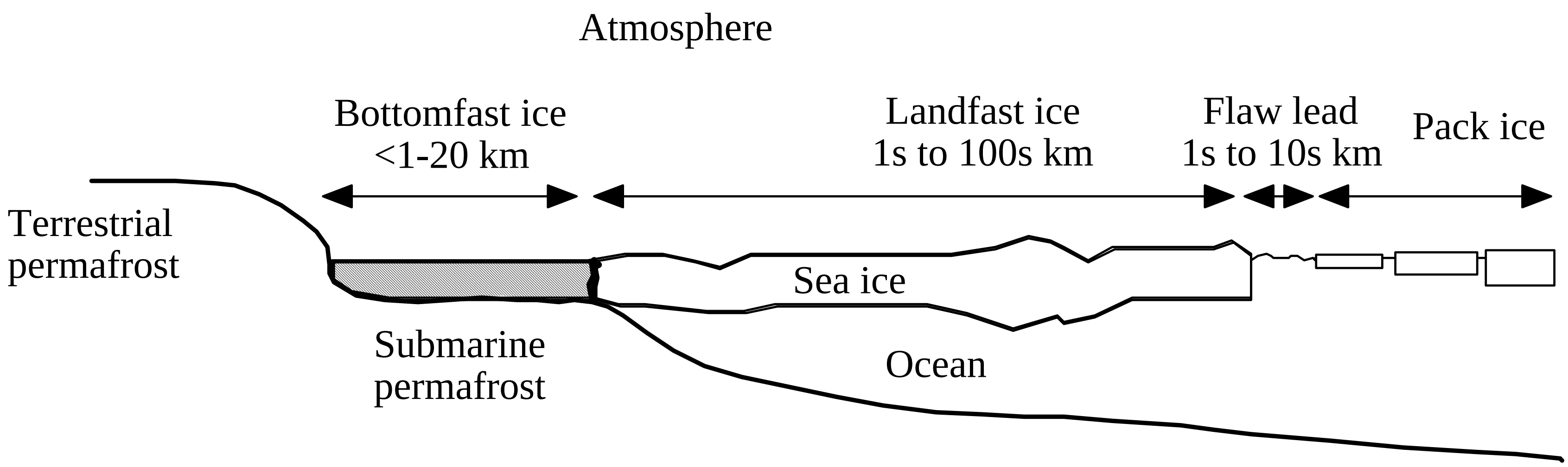
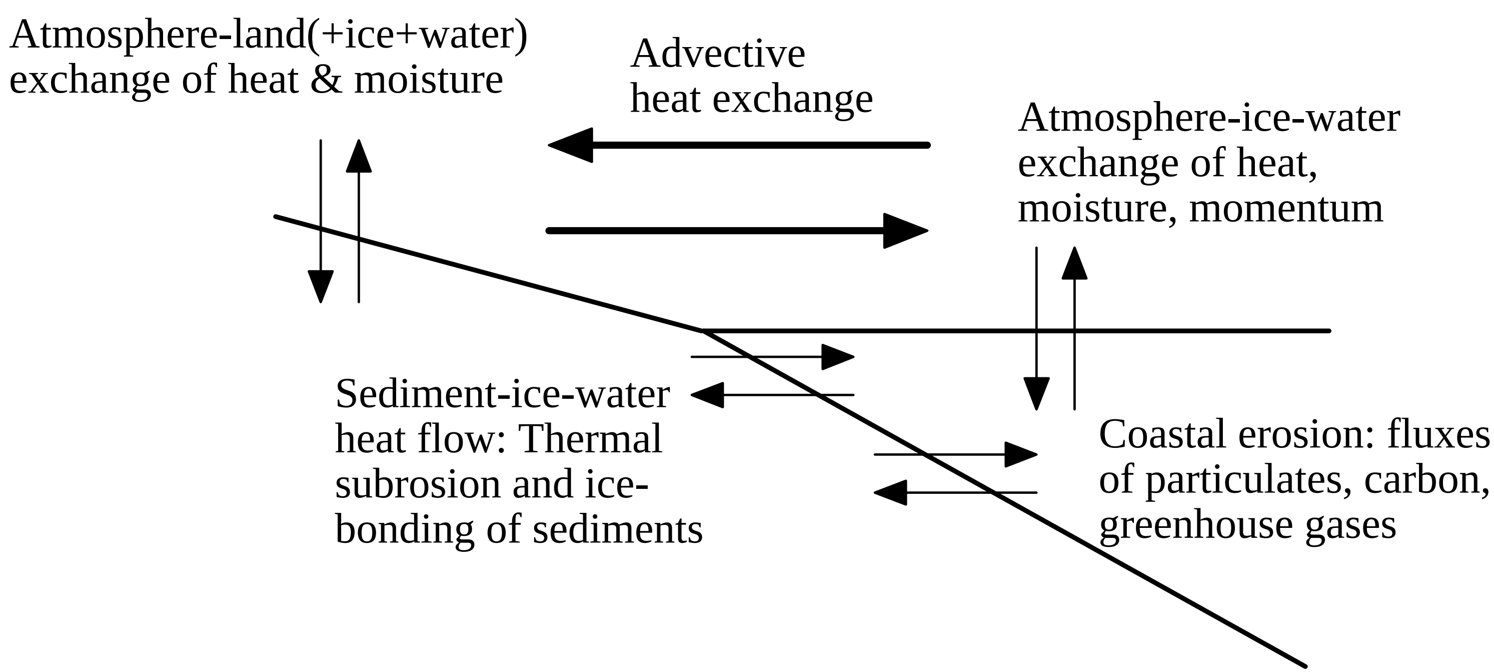
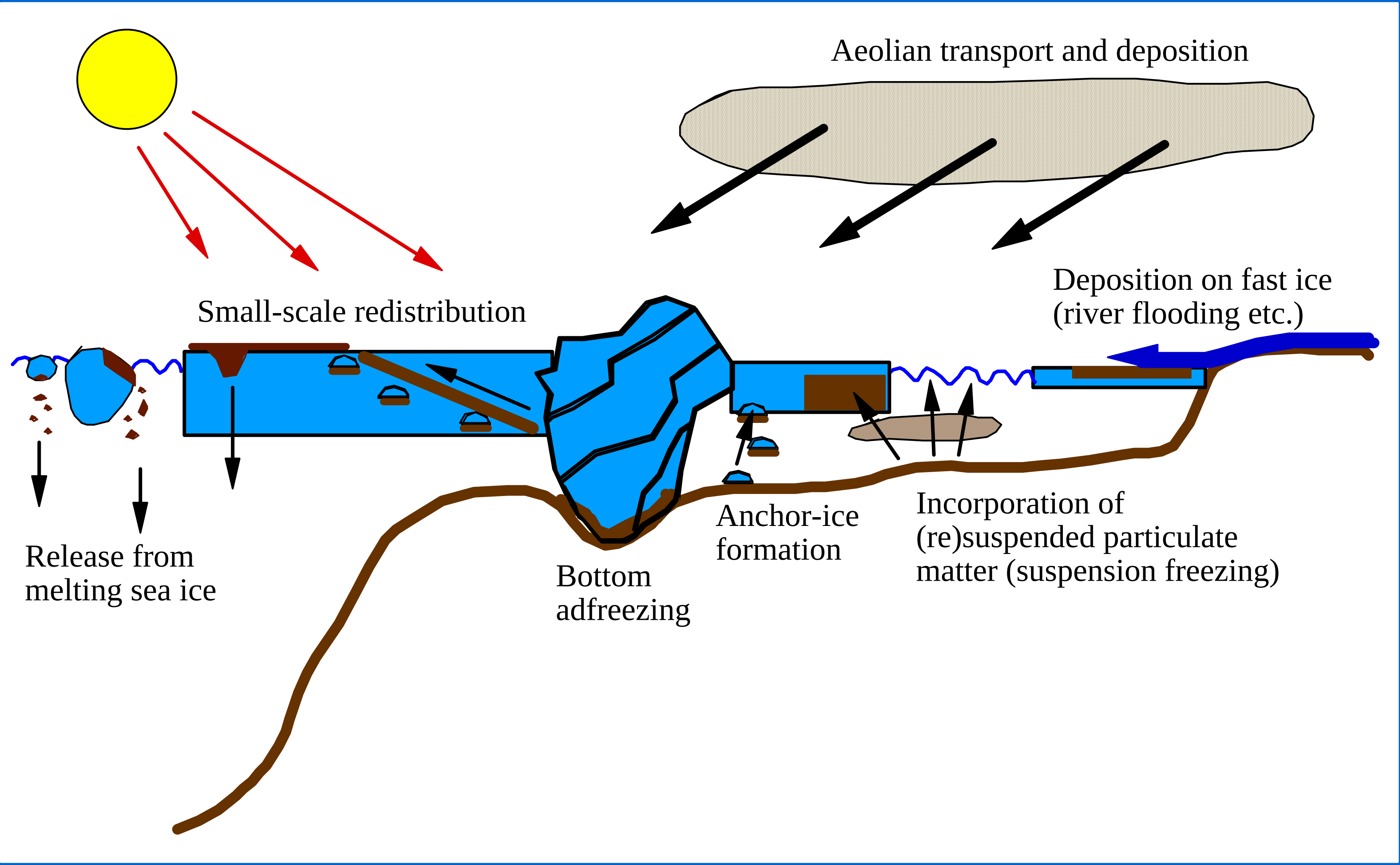
- Introduction
    - Fluxes of freshwater and dissolved/particulate across the Siberian shelves
    - Study area in the Laptev Sea
- The Lena Delta
    - Anatomy of the delta and ice cover
    - Probing the ice cover with SAR
- The Laptev Sea as a frozen estuary
    - Zonation of the landfast ice cover
    - Contribution of riverine water to ice mass balance
    - Under-ice mixing and freshwater dispersal
- Conclusions

The Arctic coastal zone as a multi-phase boundary





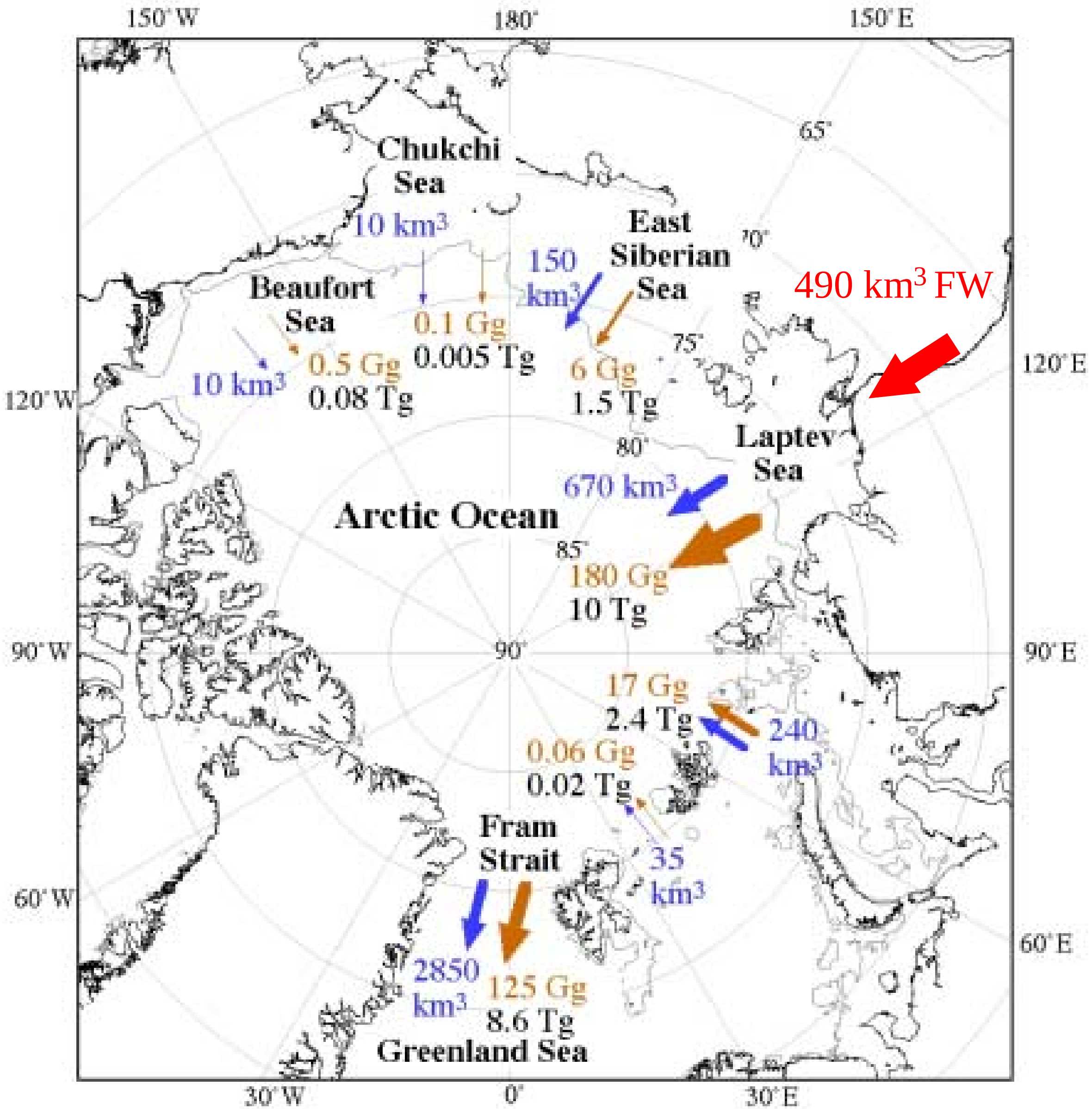
Ice entrainment and export of sediments



Annual transport of sediment and organic carbon by sea ice

Shown are best estimates for annual fluxes of
- sea ice (in km^3)
- particulates transported by sea ice (in Tg = 10^6 t)
- terrestrial organic carbon transported by sea ice (in Gg = 10^3 t)

Maximum particulate transport demonstrated for individual ice entrainment events (Laptev Sea):
18 Tg (18 x 10^6 t)



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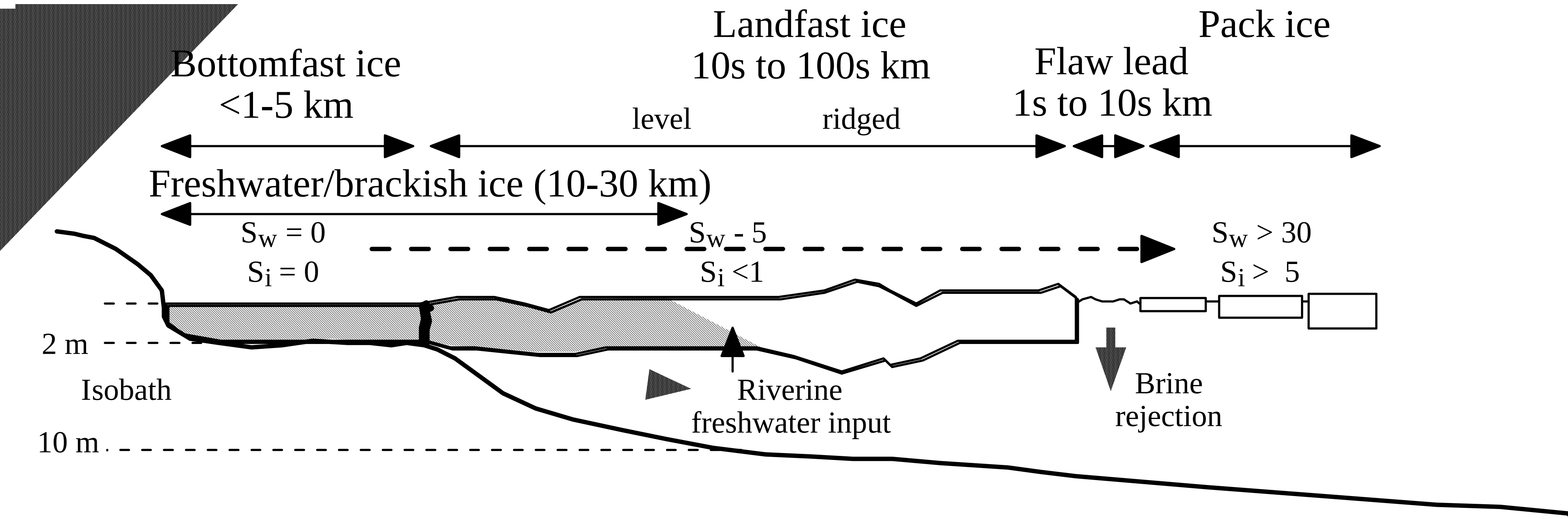
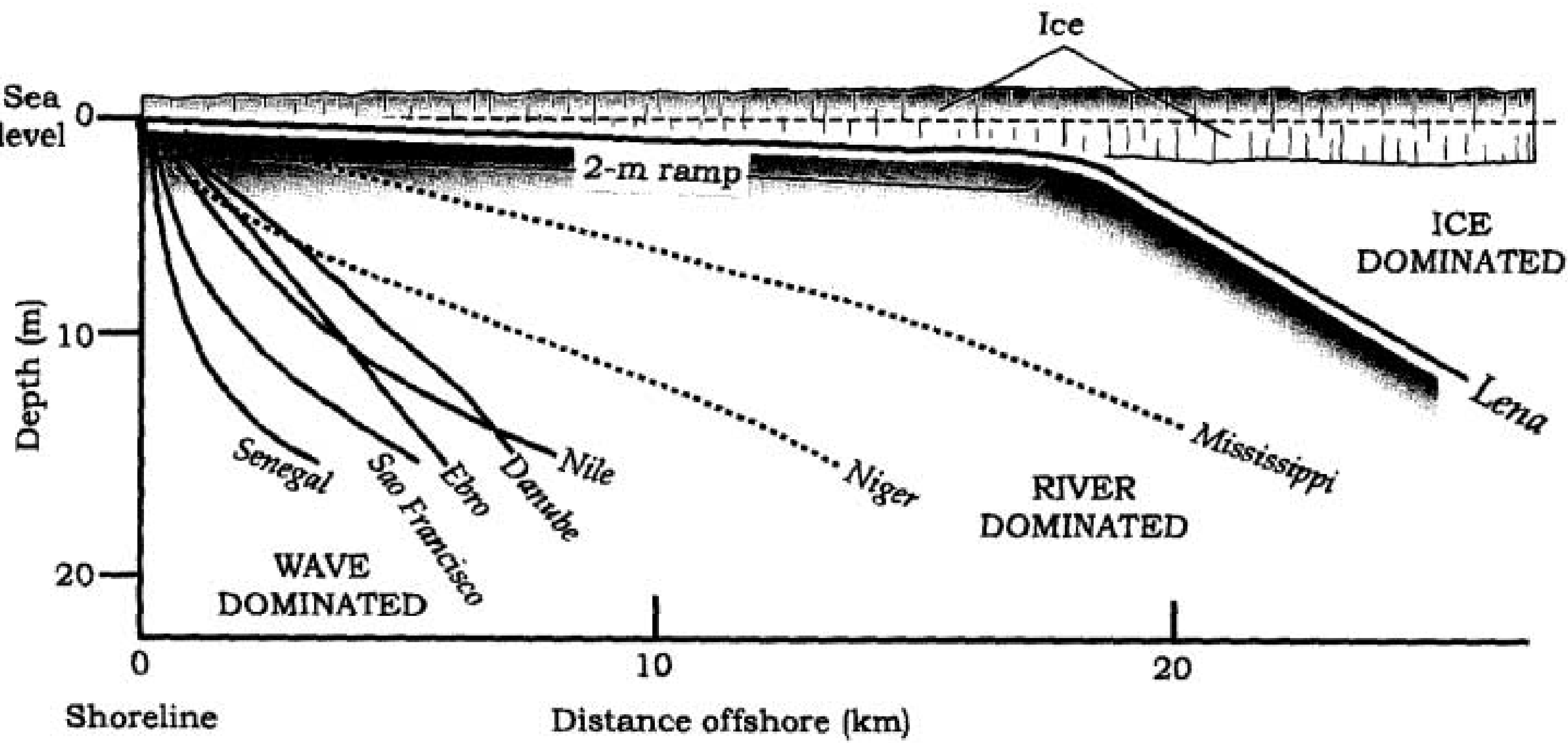
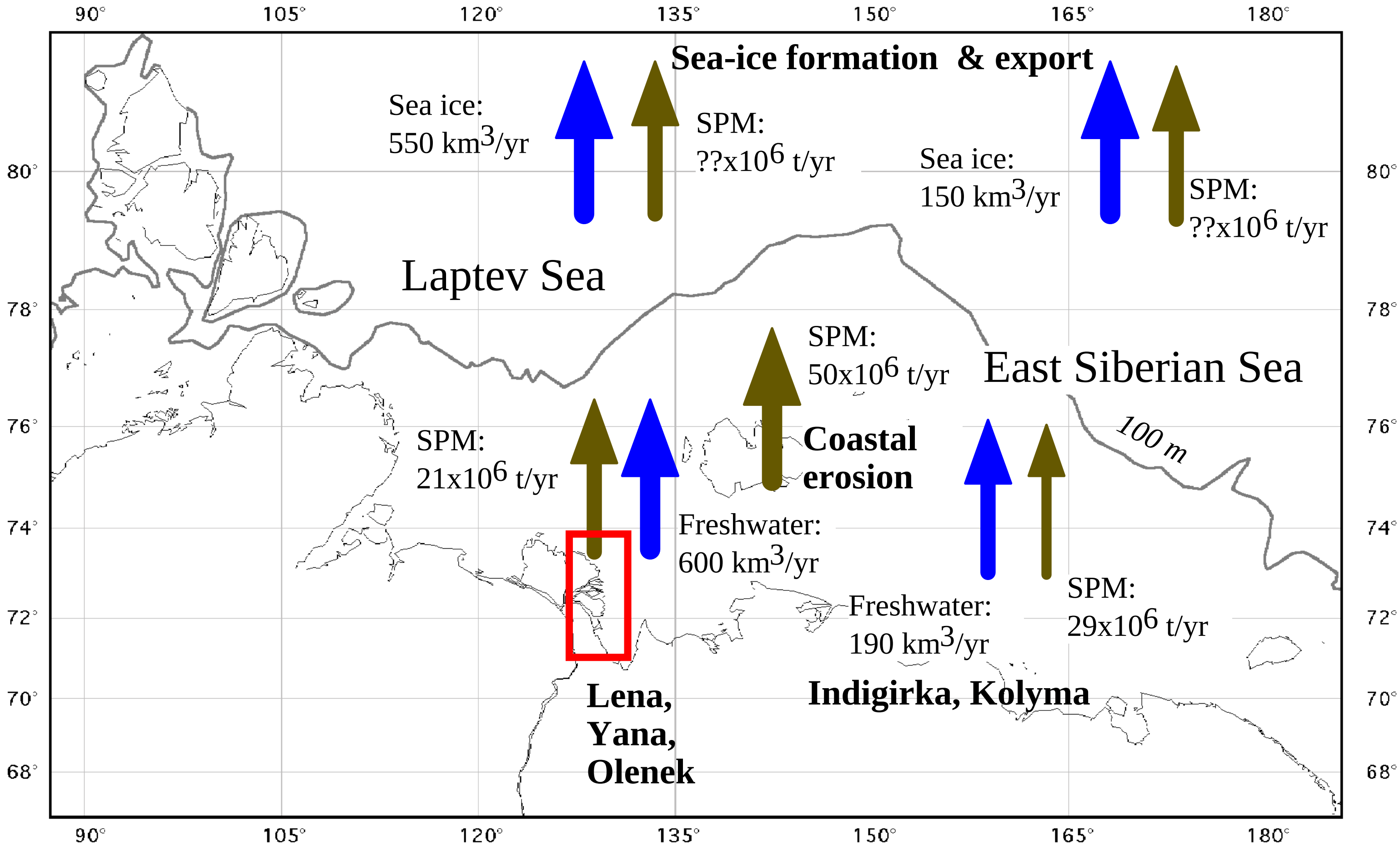


Bottomfast ice: Ice bonding and coastal morphology

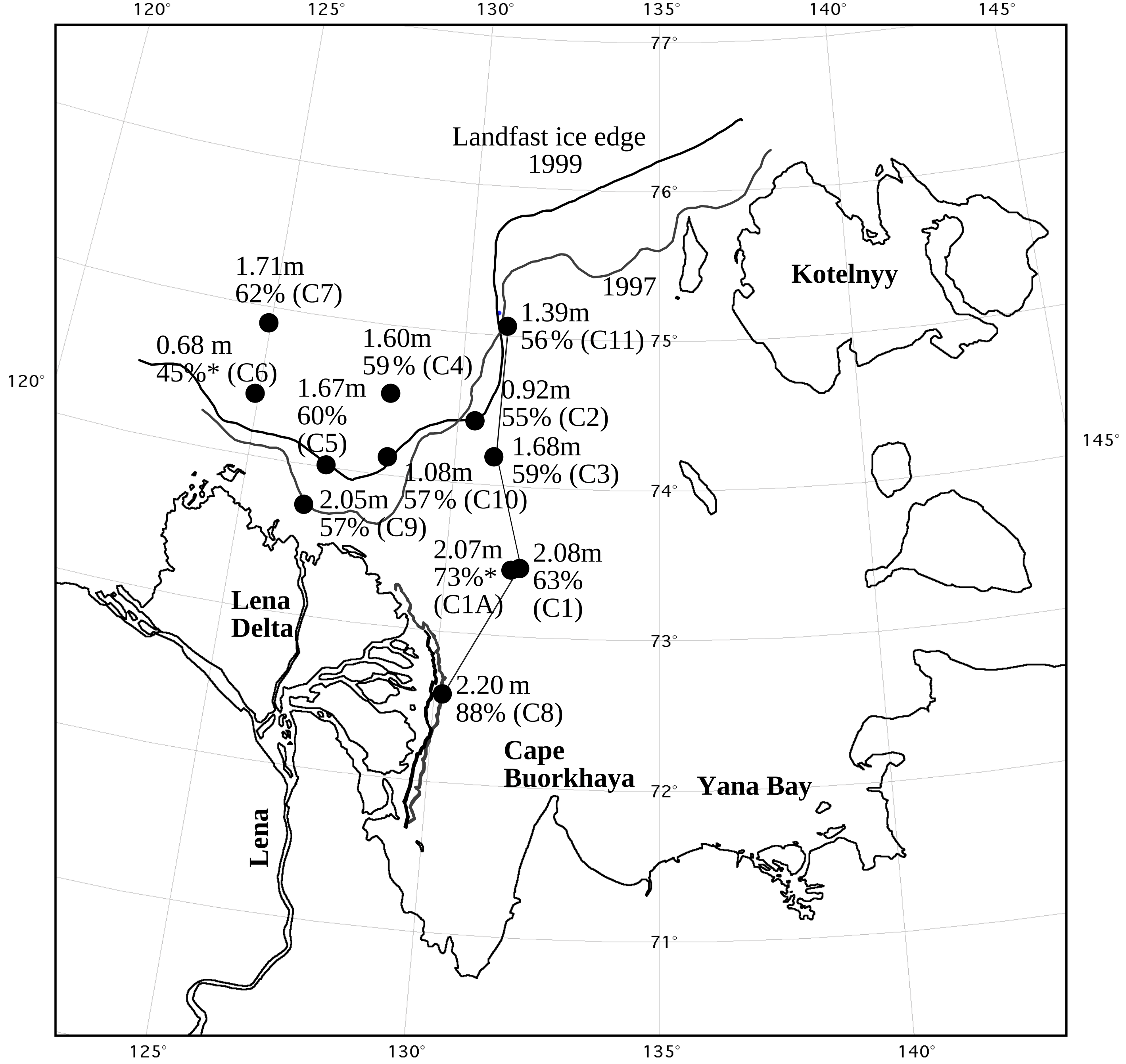


Reimnitz, 2002

Laptev Sea study area

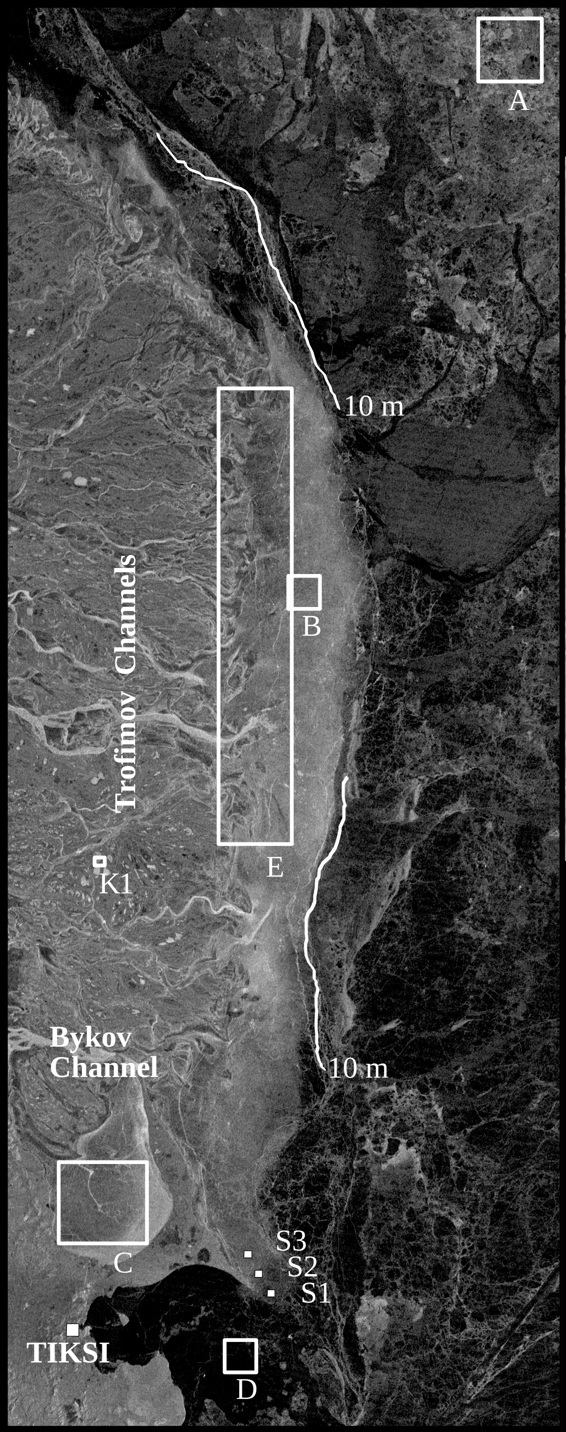


Data sources: Are, 1999, Gordeev et al., 1996, Timokhov, 1994, Eicken et al., 1997



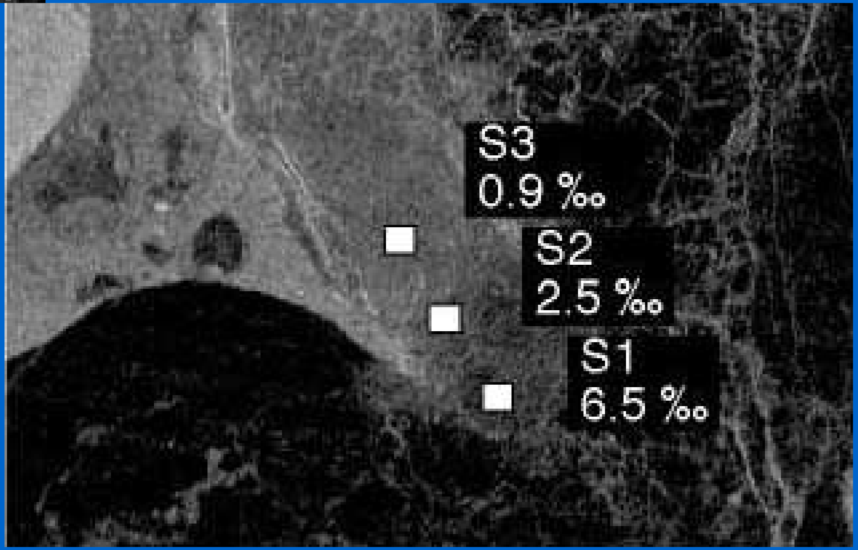
Landfast ice edge
1999
1997
Kotelnyy
1.71m
62% (C7)
0.68 m
45%* (C6)
1.60m
59% (C4)
1.67m
60%
(C5)
1.39m
56% (C11)
0.92m
55% (C2)
1.68m
59% (C3)
1.08m
57% (C10)
2.05m
57% (C9)
2.07m
73%*
(C1A)
2.08m
63%
(C1)
2.20 m
88% (C8)
Lena
Delta
Lena
Cape
Buorkhaya
Yana Bay
120°
125°
130°
135°
140°
145°
77°
76°
75°
74°
73°
72°
71°

Lena Delta sea ice and processes



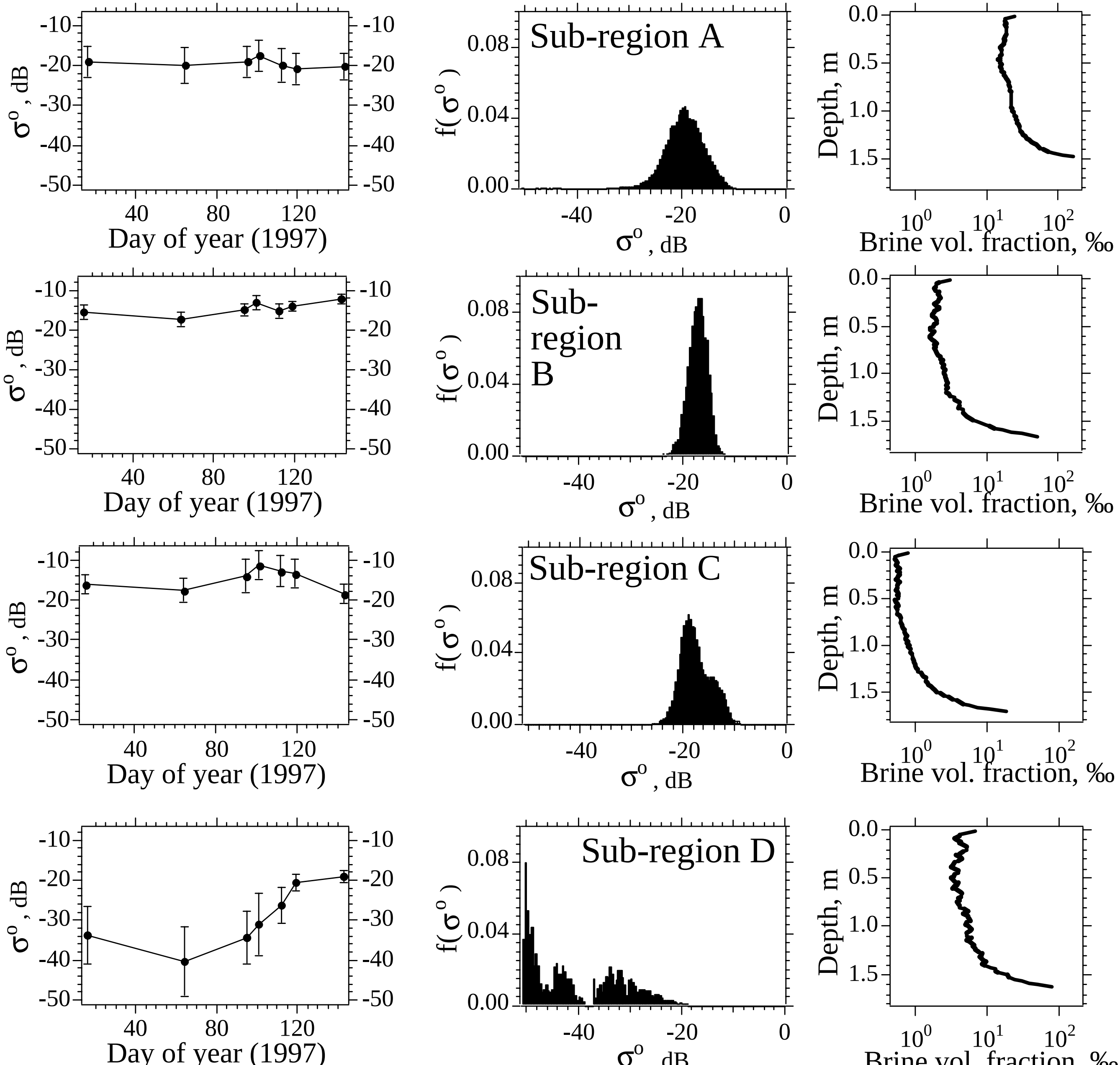
River channels and nearshore ridging (with containment of freshwater)

Transition between brackish and sea ice, Surface salinities, Nov. 1996 (data courtesy of I. Semiletov)



Radarsat ScanSAR Wide, March 5, 1997, incidence angle 45-50°

Backscatter signatures and textures



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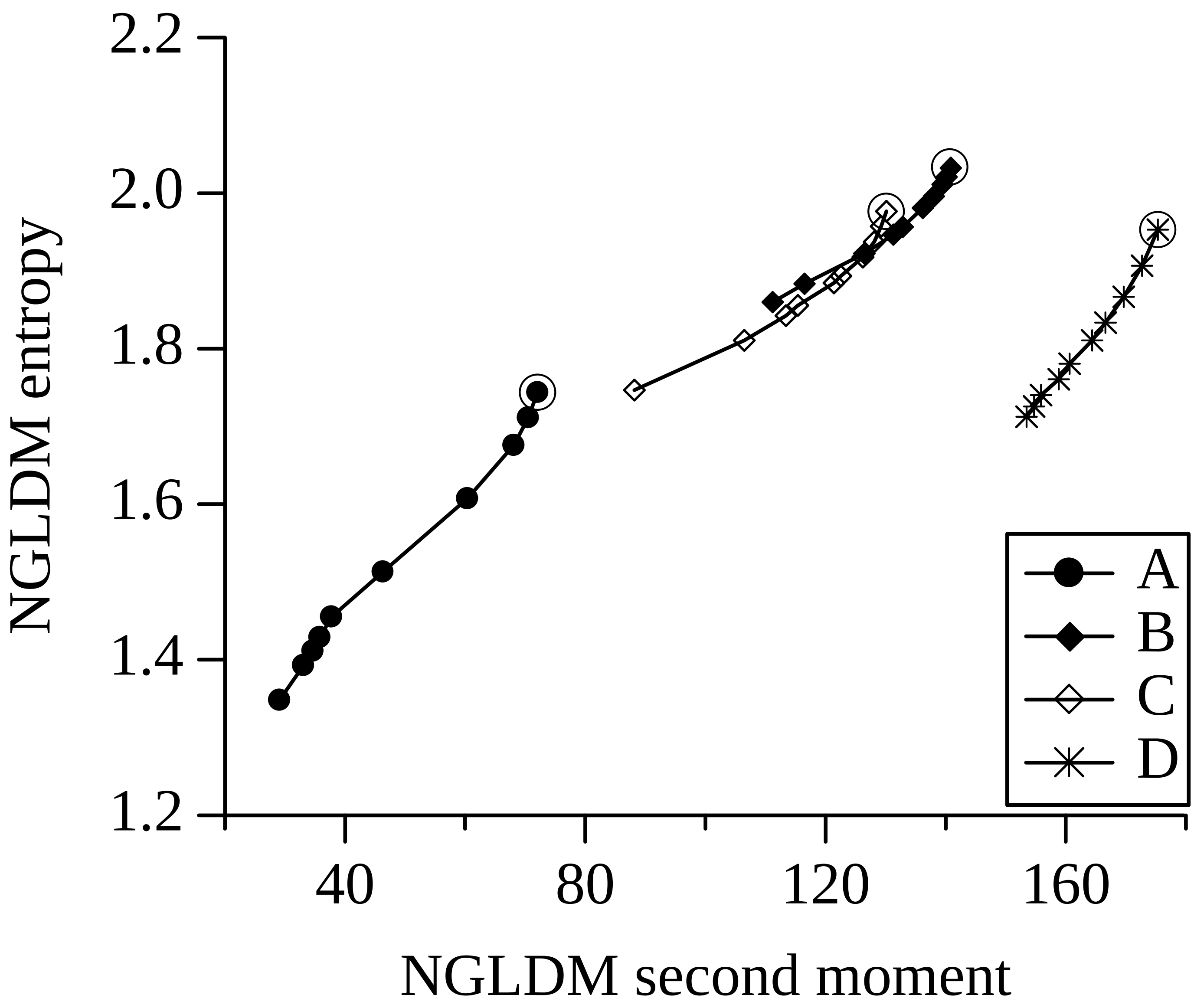
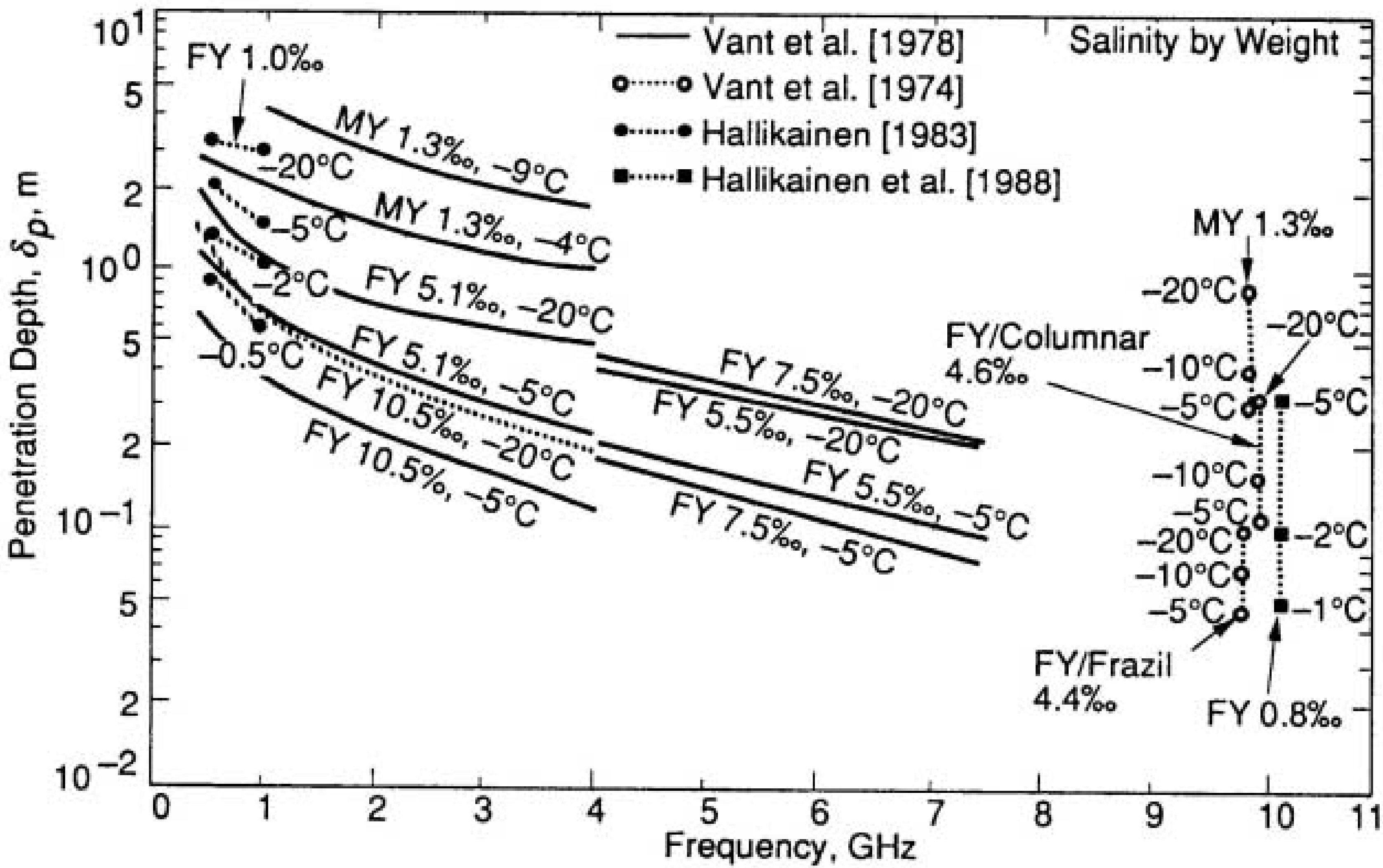


Dielectric properties and penetration in FW/brackish/sea ice



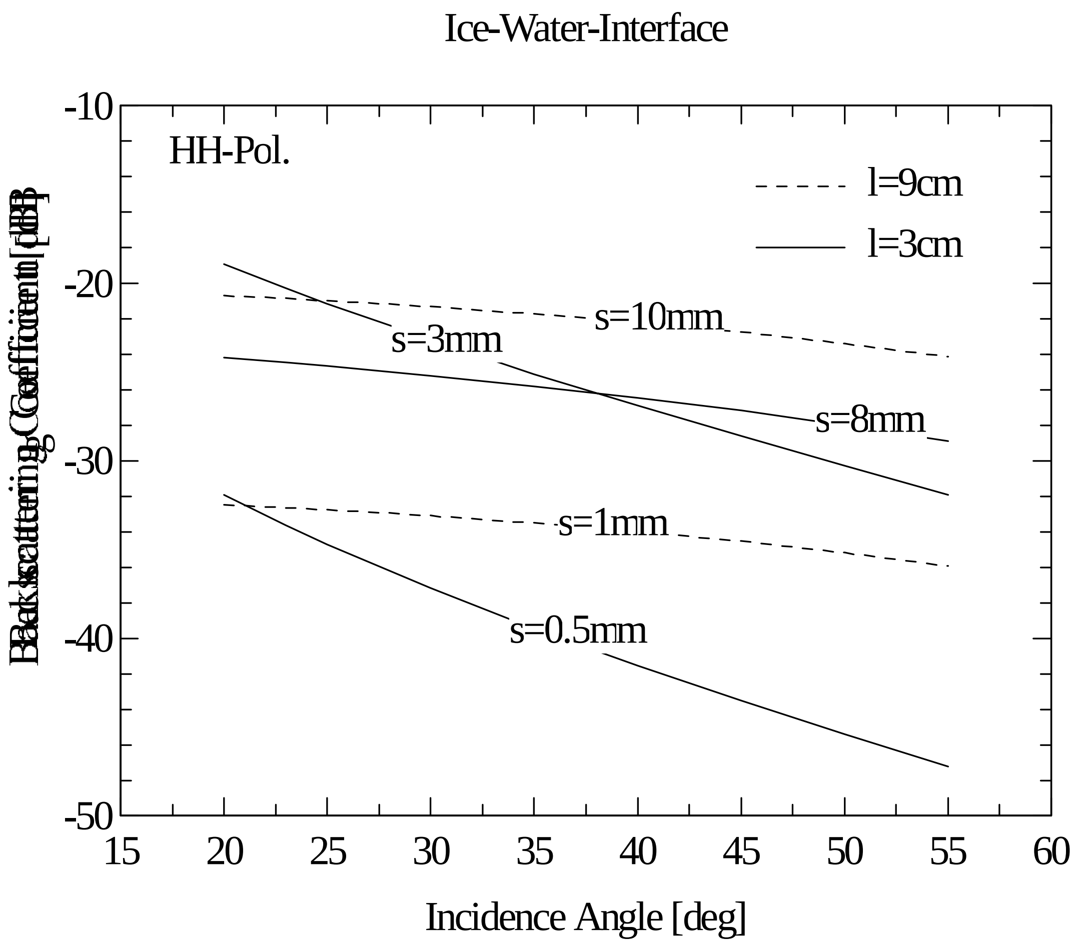
Hallikainen & Winebrenner (1992)

Dielectric properties and backscatter signatures of FW/brackish/sea ice

- *Sea-ice growth/salt-flux modeling for different surface water salinities*
  - finite-difference scheme ice growth model
  - coupled to salt-flux model based on Cox & Weeks (1988)
  - stable-isotope fractionation model (Eicken, 1998)
  - forced by weather station data for Tiksi (southcentral Laptev Sea

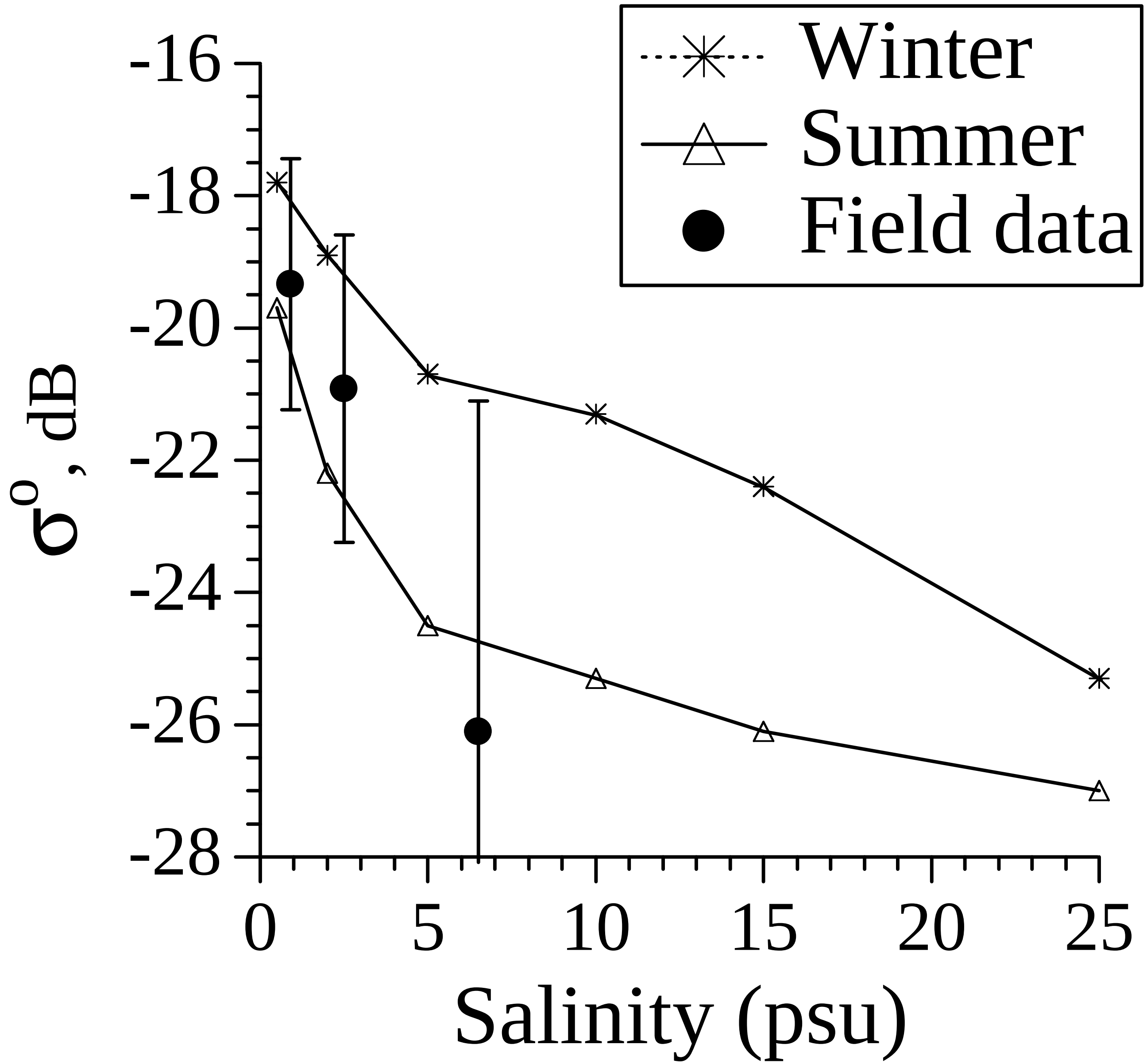
- *Sea-ice backscatter modeling*
  - Integral Equation Model for surface scattering, Independent Rayleigh Scattering Model for volume scattering (Fung, 1994)
  - ice cover represented by four layers of varying salinity and temperature, based on field measurements and ice-growth model simulations
  - dielectric properties from empirical data for complex dielectric permittivity from Hallikainen & Winebrenner (1992)
  - ice surface and bottom roughnesses based on data for smooth, level first-year ice as supported by field observations; size of scatterers (gas and brine inclusions) field observations and data compilations

Dielectric properties and backscatter signatures of FW/brackish/sea ice

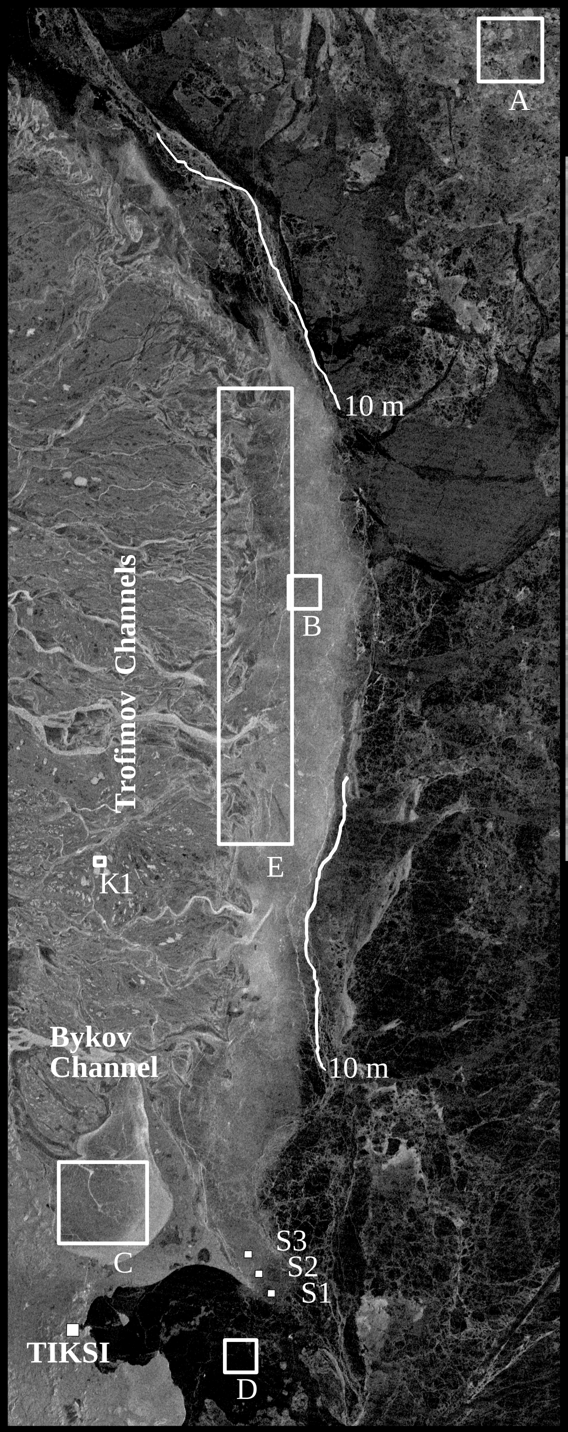


Scattering contributions of ice-water interface for freshwater ice in winter (varying correlation length *l* and rms-height *s)*

Dielectric properties and backscatter signatures of FW/brackish/sea ice



Lena Delta sea ice and processes



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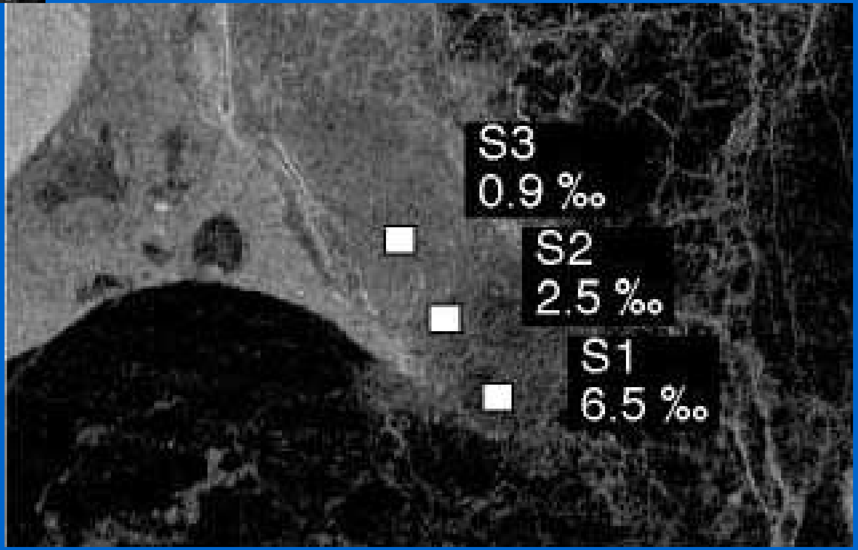
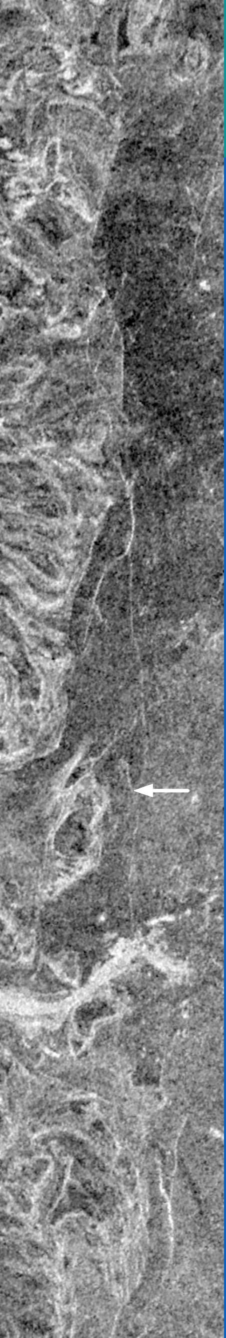
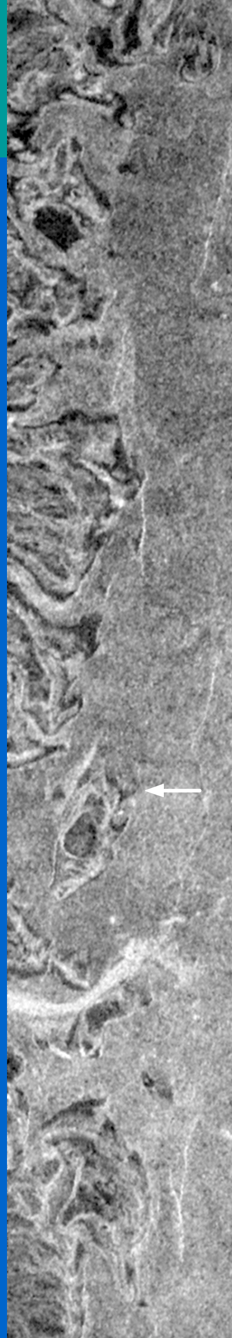


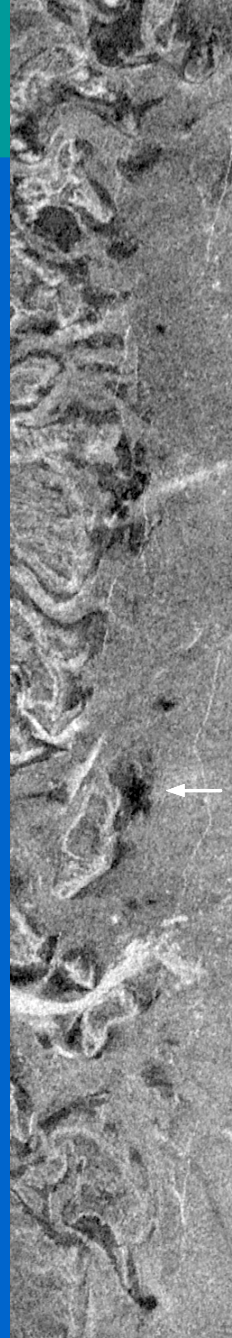
Detecting bottomfast ice with SAR



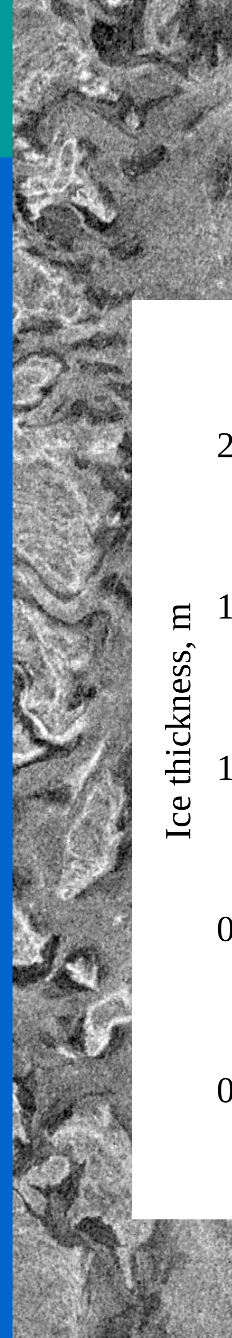
A: Dec. 13, 1996
5.5 km^2



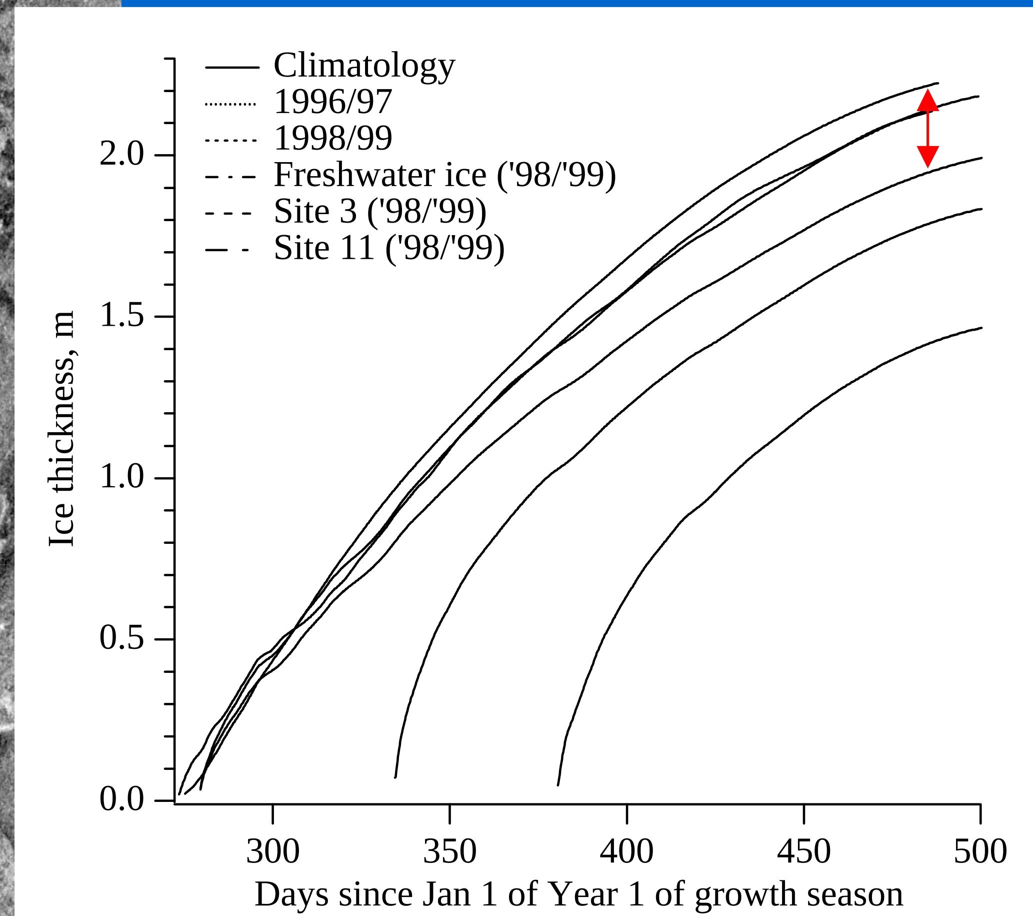
B: Jan. 16, 1997
51.0 km^2



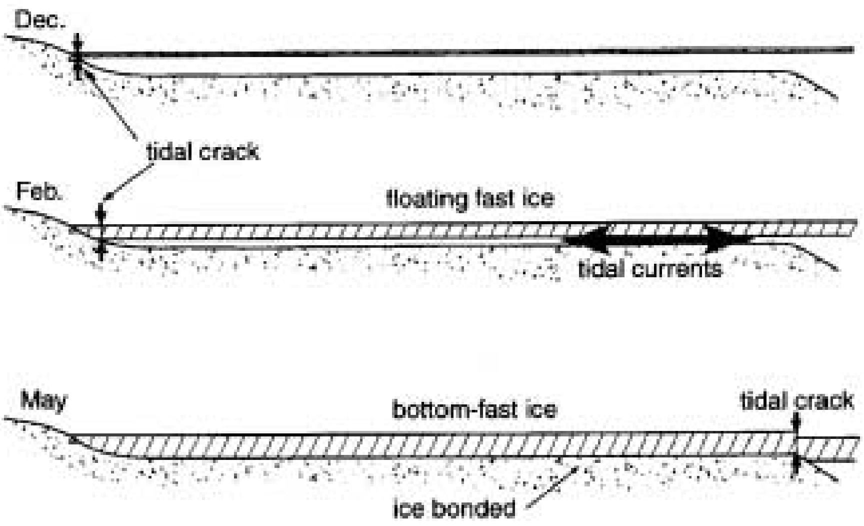
C: April 29, 1997
77.0 km^2

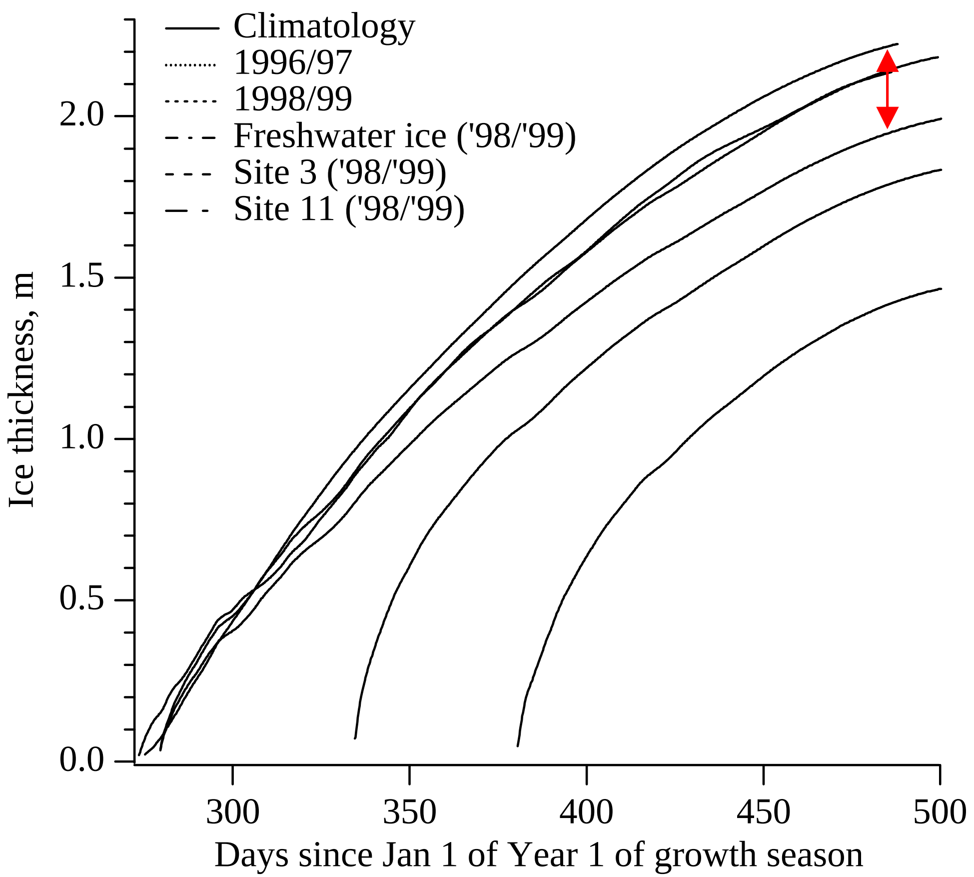


D: May 23, 1997
89.8 km^2

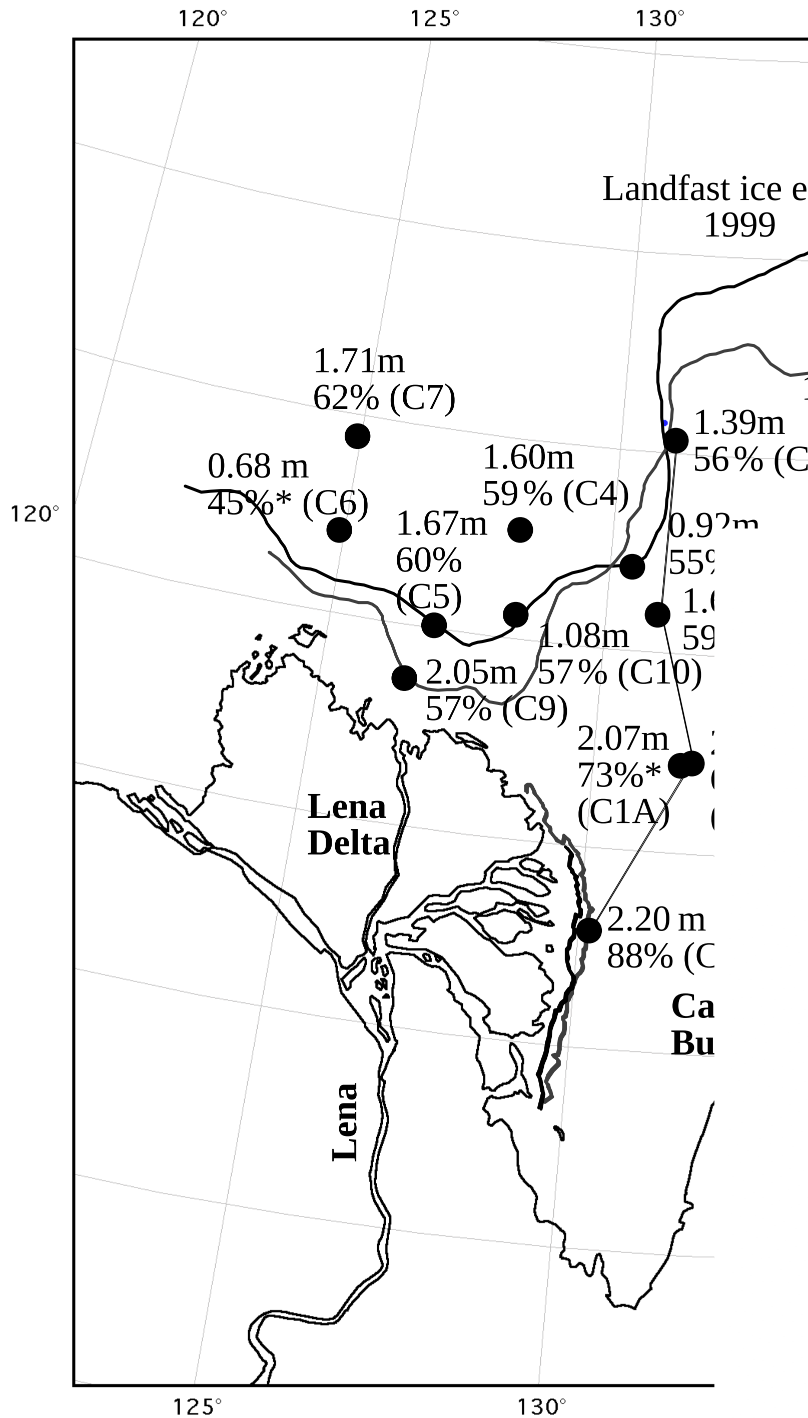


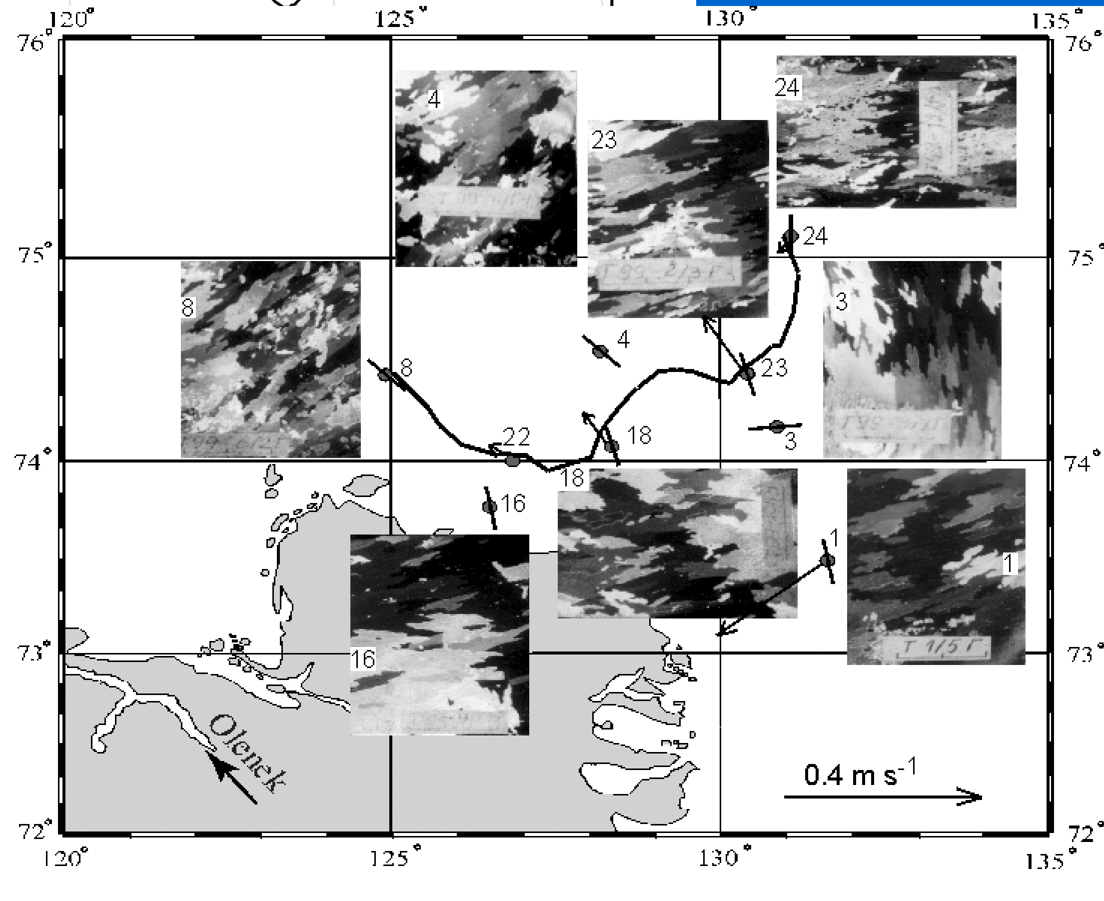
Changes in bottomfast ice regime: Reduced ice thickness



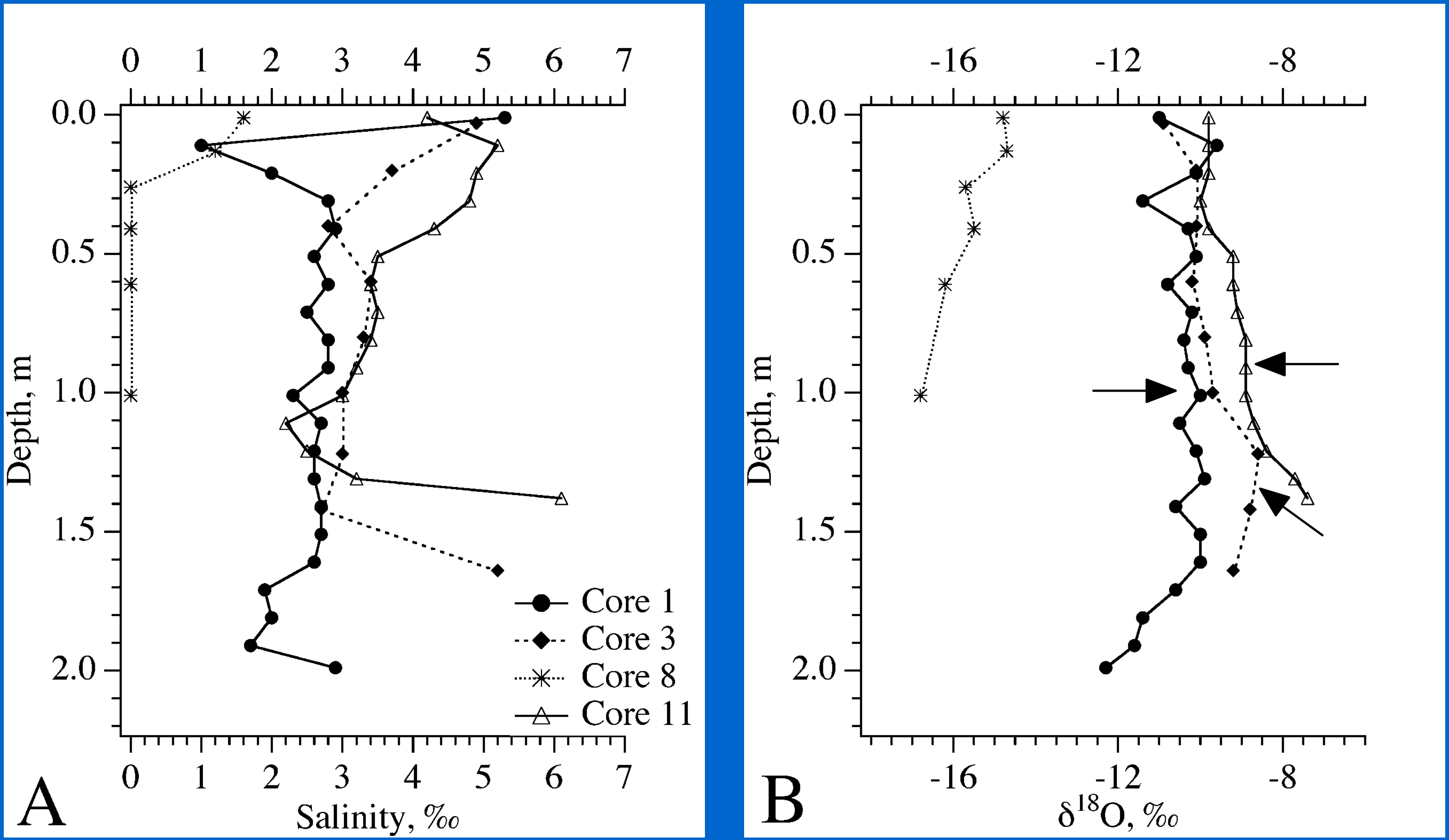


Zonation of landfast ice

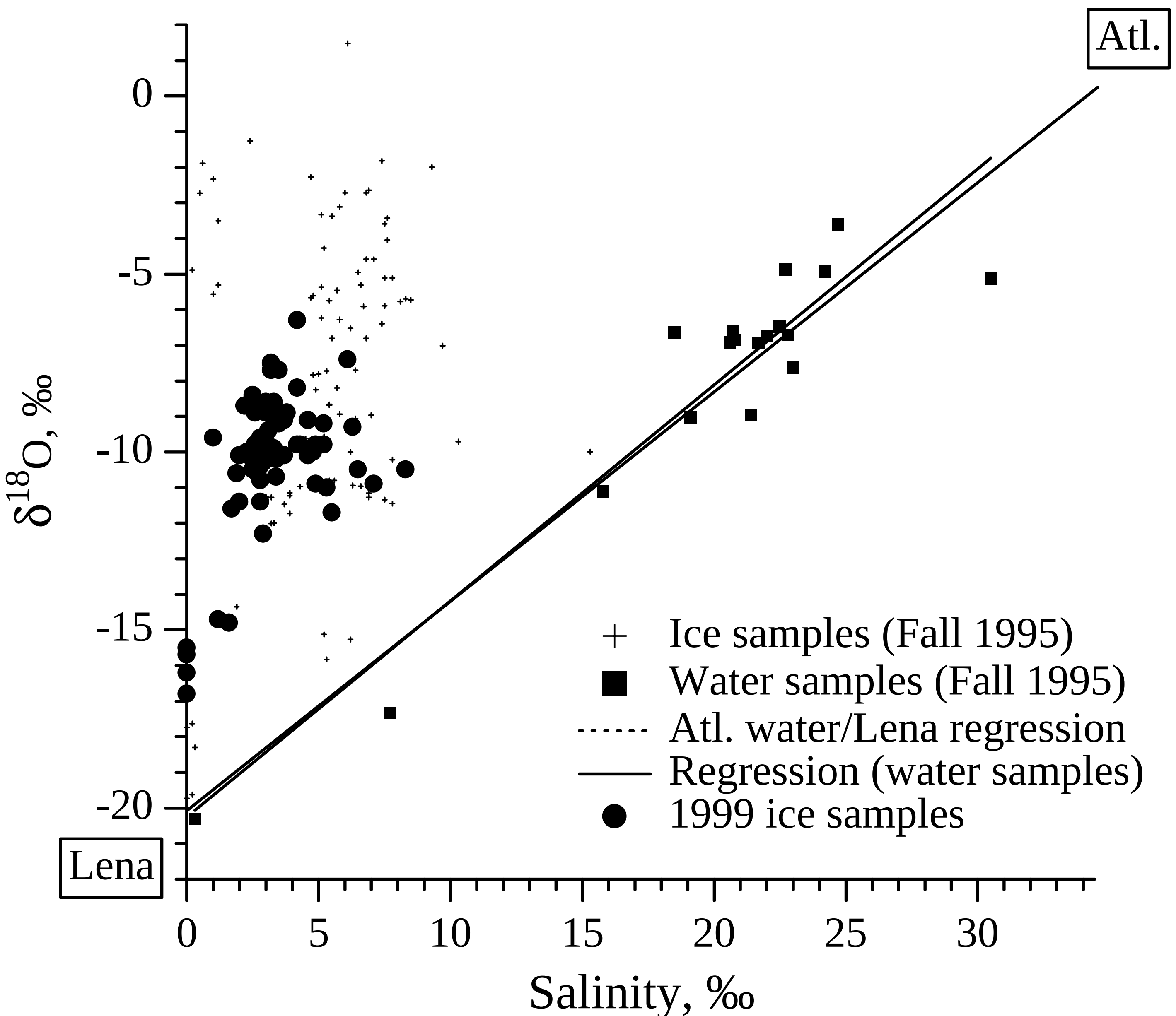




Landfast ice core properties



Landfast ice core properties: Riverine water fraction from $\delta^{18}O$



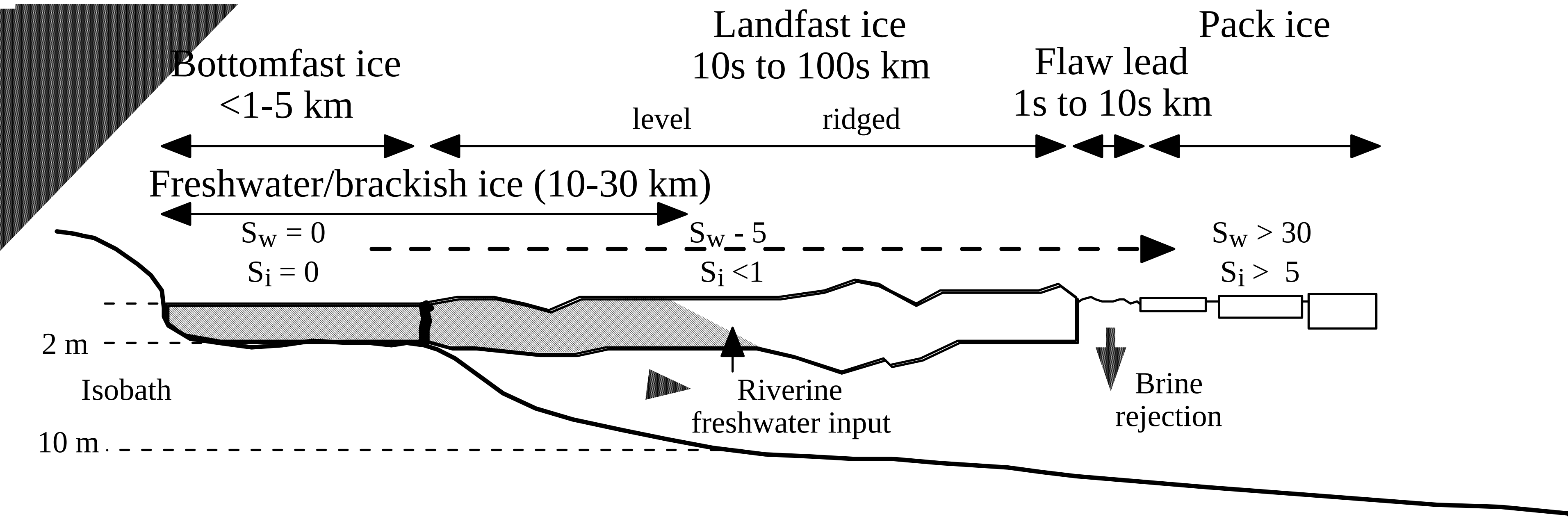
Landfast ice core properties

Table 1: Landfast ice core data

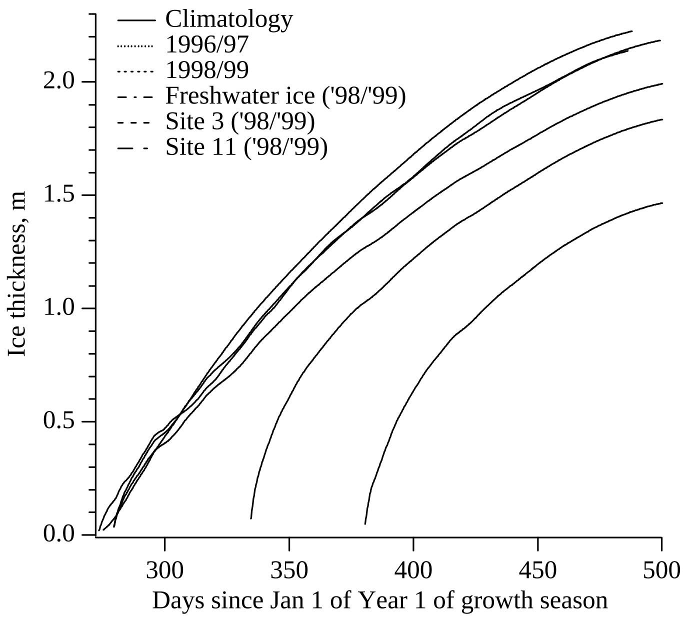
Site	Sampl. date	z_i, m	S_i, ‰	$\delta^{18}O$, ‰	f_{riv}, %	z_{align}, m	Alignm. date
1	4/17/99	2.08	2.6	–10.5	63	1.00	12/22/98
1A	4/17/99	2.07	2.0		73*		
2	5/6/99	0.92	4.0	–8.9	55	0.70	4/5/99
3	4/21/99	1.68	3.6	–9.7	59	1.35	2/18/99
4	4/23/99	1.60	4.7	–9.6	59	0.80	n/a (drift ice)
5	4/24/99	1.67	3.6	–9.8	60		
6 (8)	4/26/99	0.68	5.6		45*	0.30	n/a (drift ice)
7	4/27//99	1.71	4.2	–10.3	62		
8	4/30/99	2.20	0.5	–15.6	88		n/a (freshwater ice)
9(16)	4/30/99	2.05	4.4	–9.1	57	1.70	3/14/99
10(18)	5/1/99	1.08	4.3	–9.3	57	0.80	3/23/99
11(24)	5/6/99	1.39	3.8	–9.0	56	0.90	3/17/99

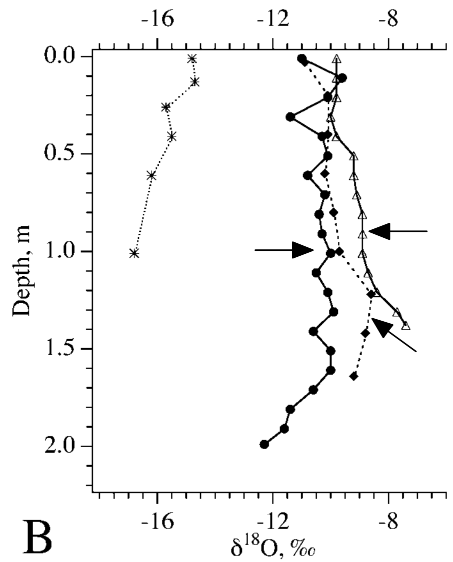
z_i – ice thickness, S_i – ice salinity, f_{riv} – fraction of riverine water (*based on ice salinity only), z_{align} – depth of first azimuthal crystal alignment

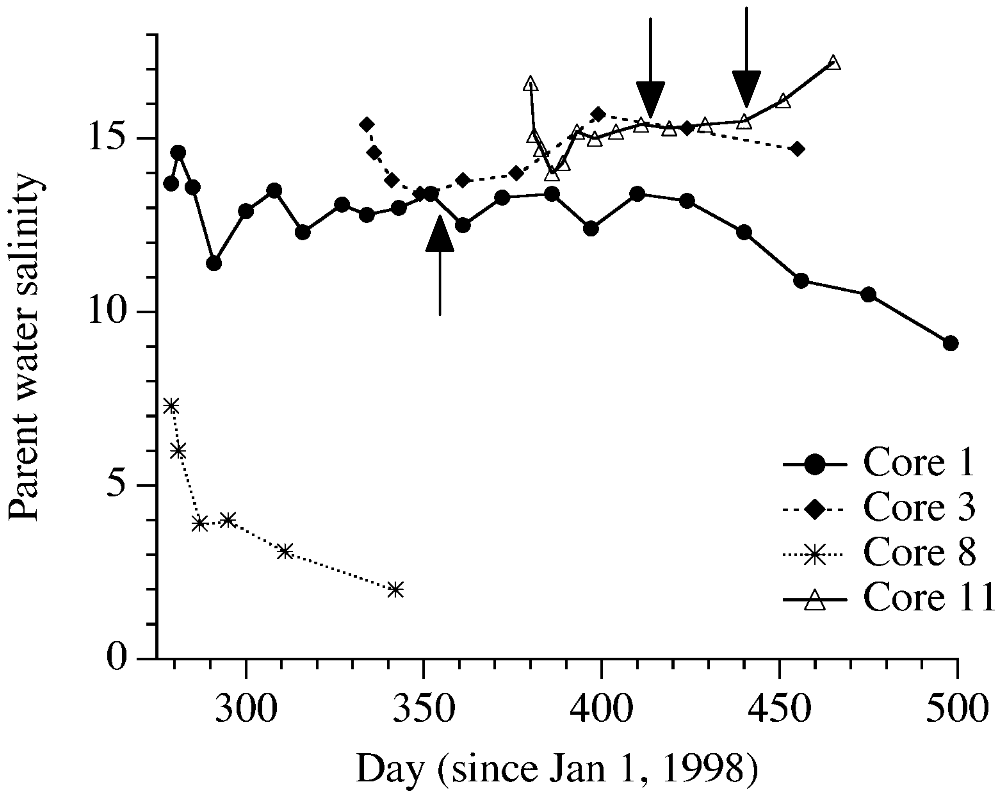
The Arctic coastal zone as a multi-phase boundary



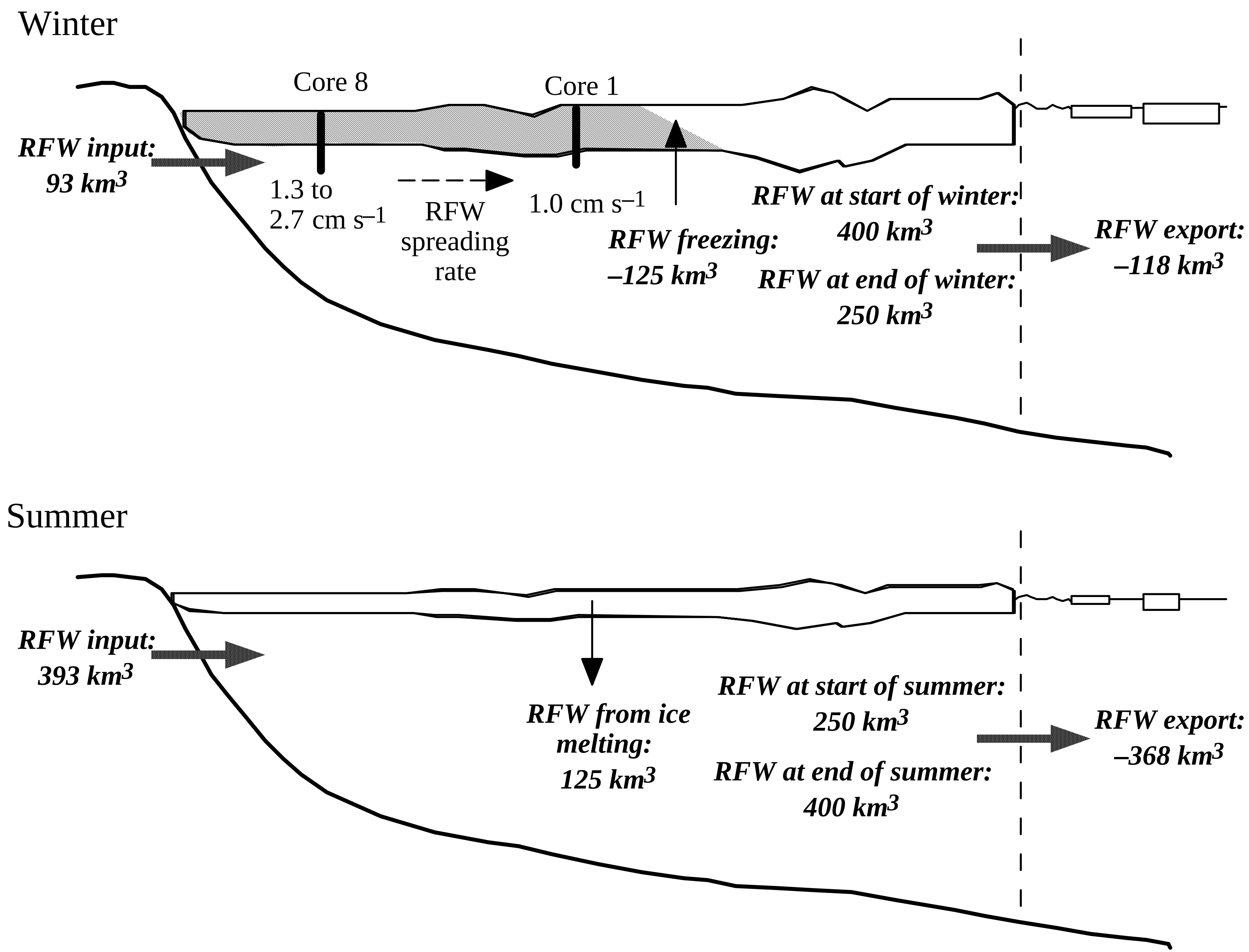
Landfast ice: Under-ice plume spreading



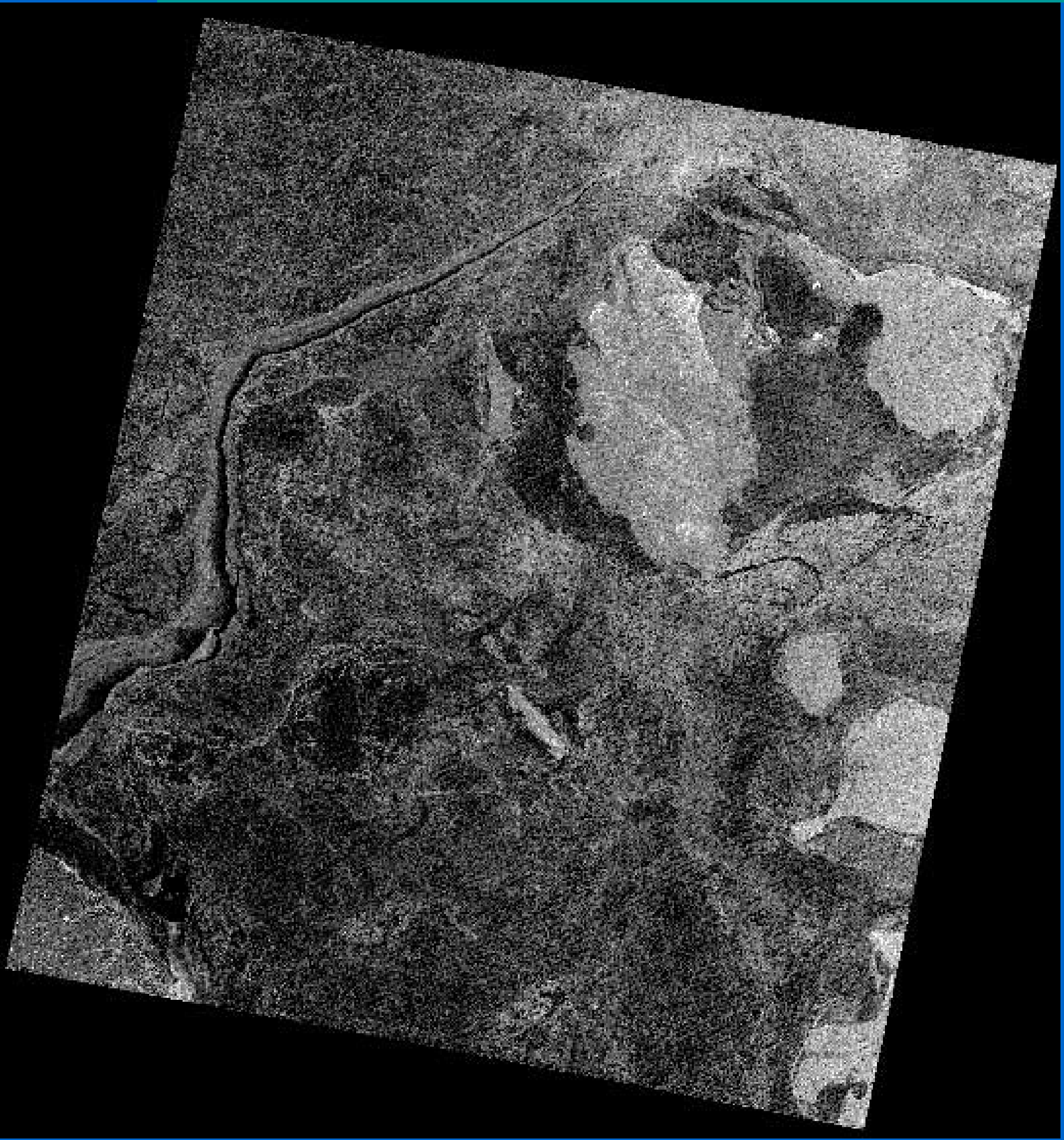




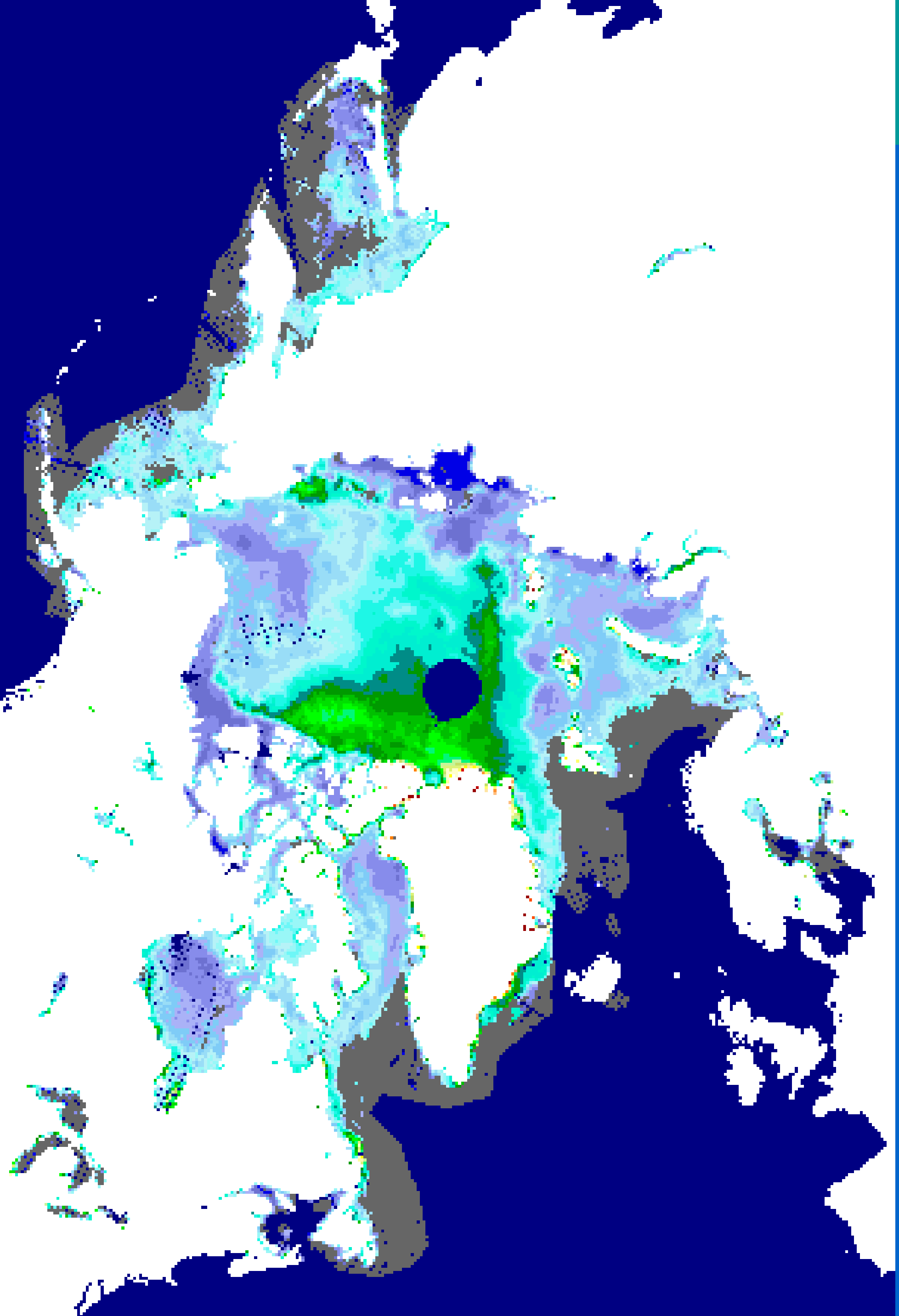
Under-ice plume spreading (freshwater volumes preliminary data!)



Under-ice plume spreading and the role of ice roughness



- under-ice plume spreading in Laptev Seat larger than under Mackenzie shelf ice cover by up to one order of magnitude
- critical role of ice roughness
- field observations and Radarsat SAR scenes indicate general lack of deformed ice and prominent ridges in Laptev Sea landfast ice

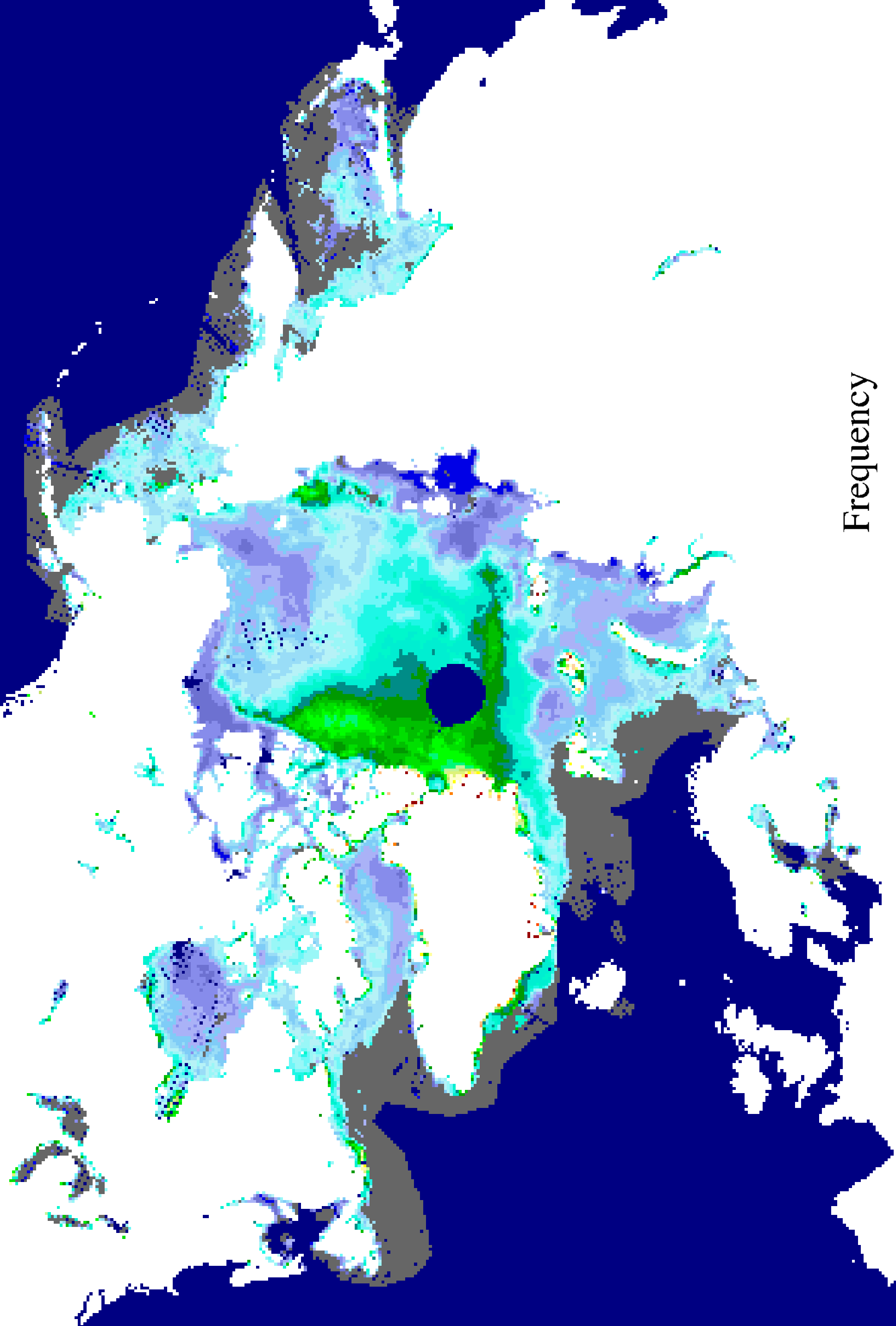


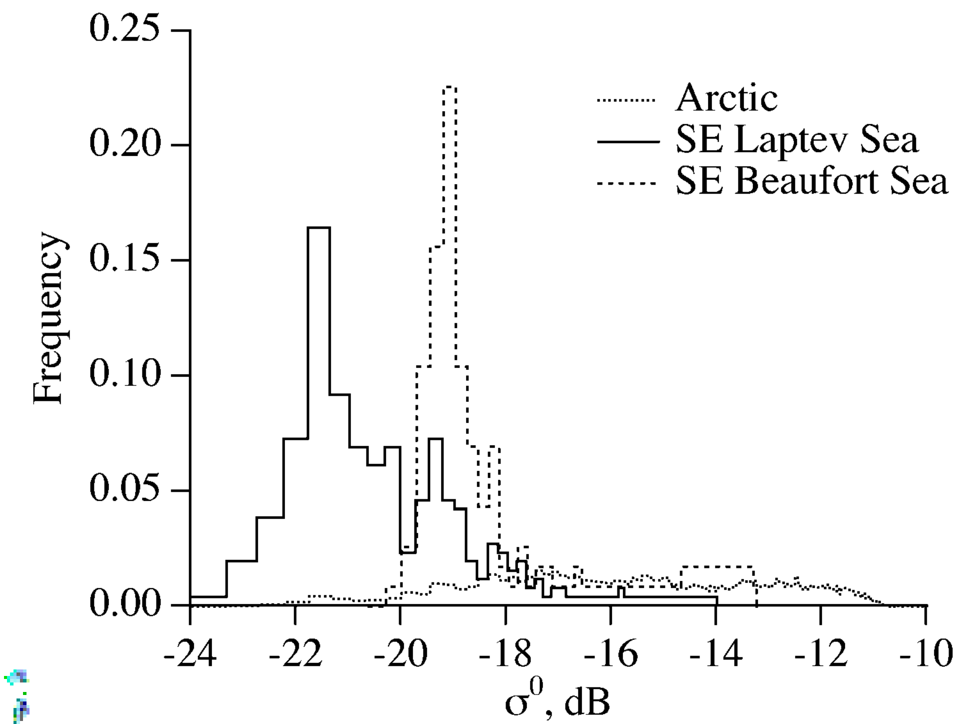
Under-ice plume spreading and the role of ice roughness

• ERS-Scatterometer data show lowest backscatter coefficient for Laptev Sea

April 19-25, 1999

Under-ice plume spreading and the role of ice roughness





April 19-25, 1999

Conclusions

- SAR helps probe variability patterns in frozen estuarine systems (sensitive to 1‰ sea-ice or 5 psu surface-water salinity contour; potential utility of multi-frequency (L-Band!), polarimetric SAR
- Value of SAR in monitoring bottom-fast sea ice in estuarine regions; significant discrepancies between current understanding and observations in extent of bottomfast ice need to be resolved
- Laptev Sea landfast ice composed to 60 % of riverine freshwater; impact of river discharge on ice mass balance and ice-mediated coastal processes (erosion, aggradation etc.)
- As much as 1/3 of annual riverine discharge into Laptev Sea locked up in landfast ice (compare to <5 % for Mackenzie River); ice-river plume interaction explains long residence times of river water over shelves and interannual variability in freshwater export; landfast ice furthermore restricts mixing over shelf
- Under-ice plume spreading more rapid than in Mackenzie estuary by up to factor of 10; most likely result of smooth ice cover
- Sensitivity of system to changes in freshwater influx or in the ice regime?