Forskningsrådet
The Research Council of Norway

the Nansen LEGACY

Tidally forced ocean mixing north of Svalbard, Arctic Ocean

Ilker Fer

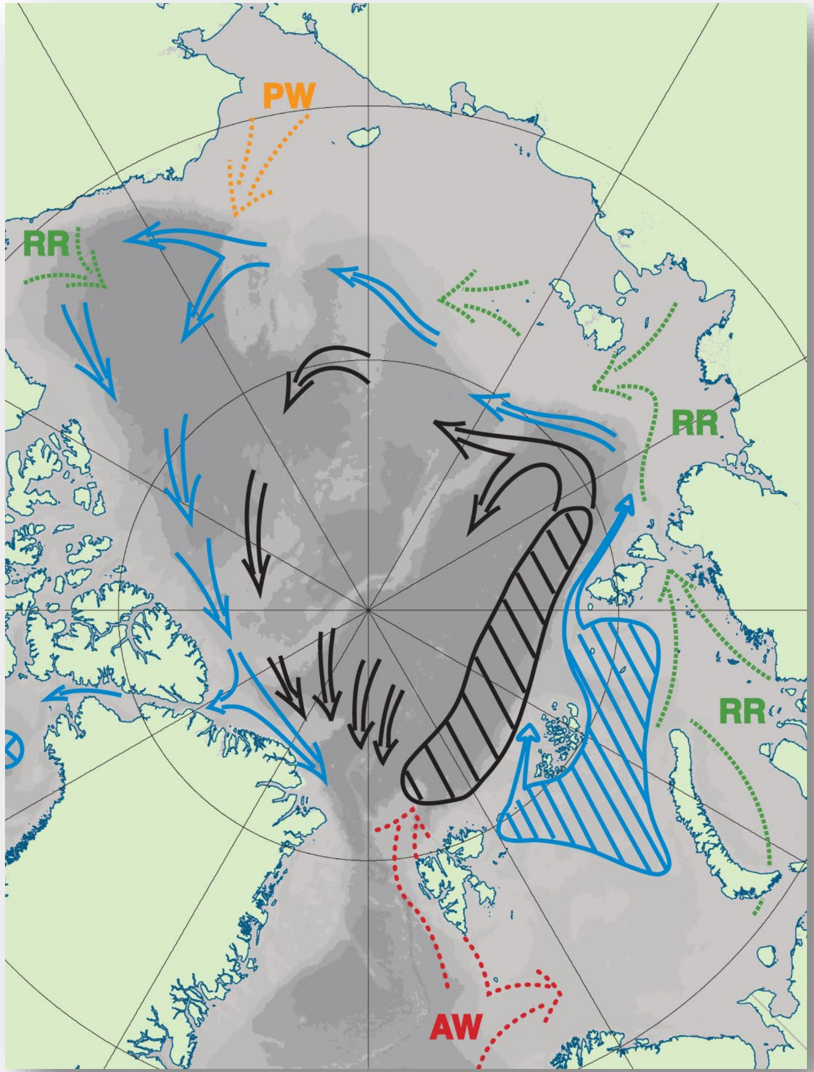
Geophysical Institute, Bergen, Norway

UNIVERSITY OF BERGEN

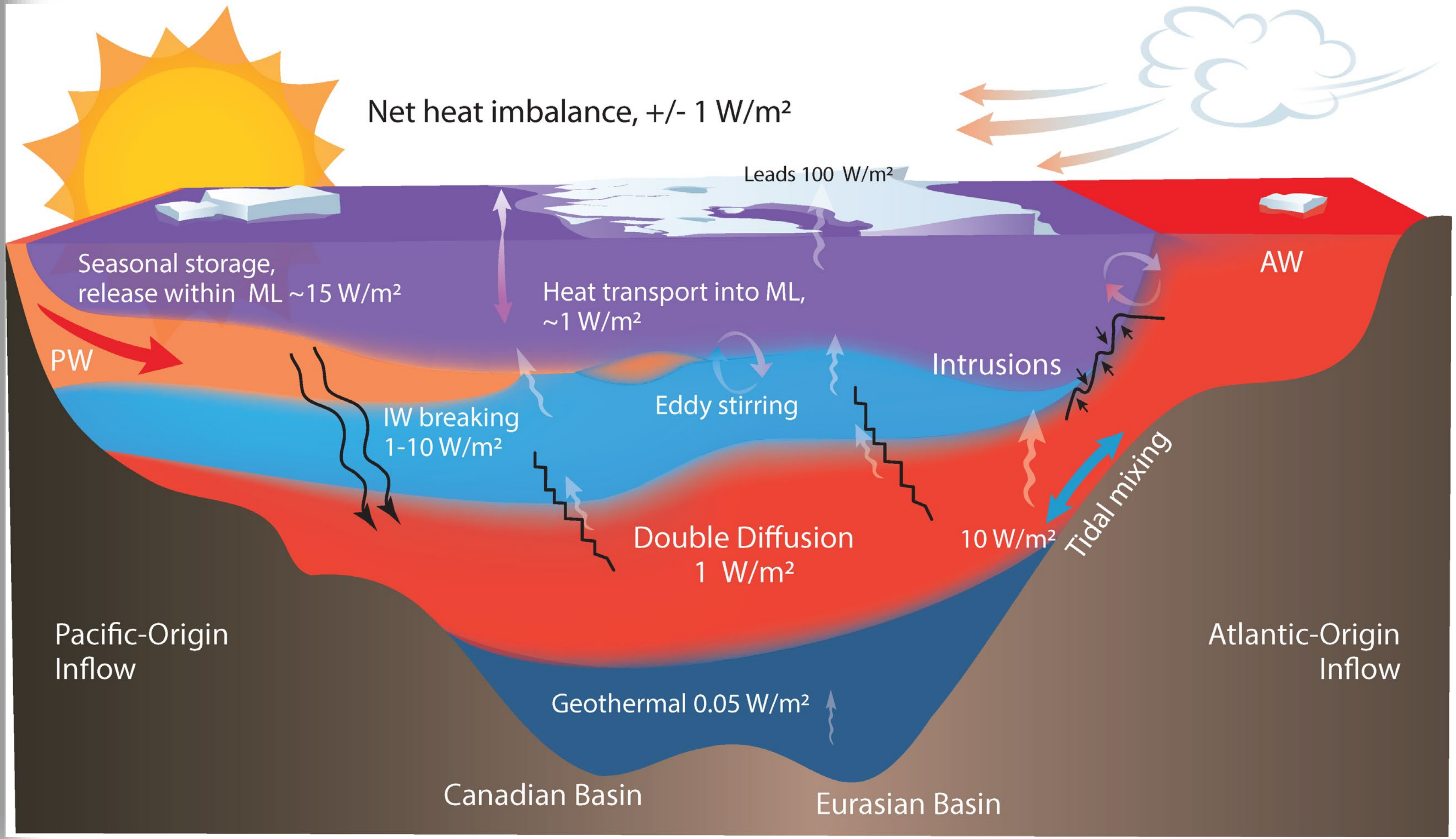
Results from:

Fer, I., Z. Koenig, I. E. Kozlov, M. Ostrowski, T. P. Rippeth, L. Padman, A. Bosse, and E. Kolås (2020), Tidally-forced lee waves drive turbulent mixing along the Arctic Ocean margins, *Geophys. Res. Lett.*, 47, https://doi.org/10.1029/2020GL088083

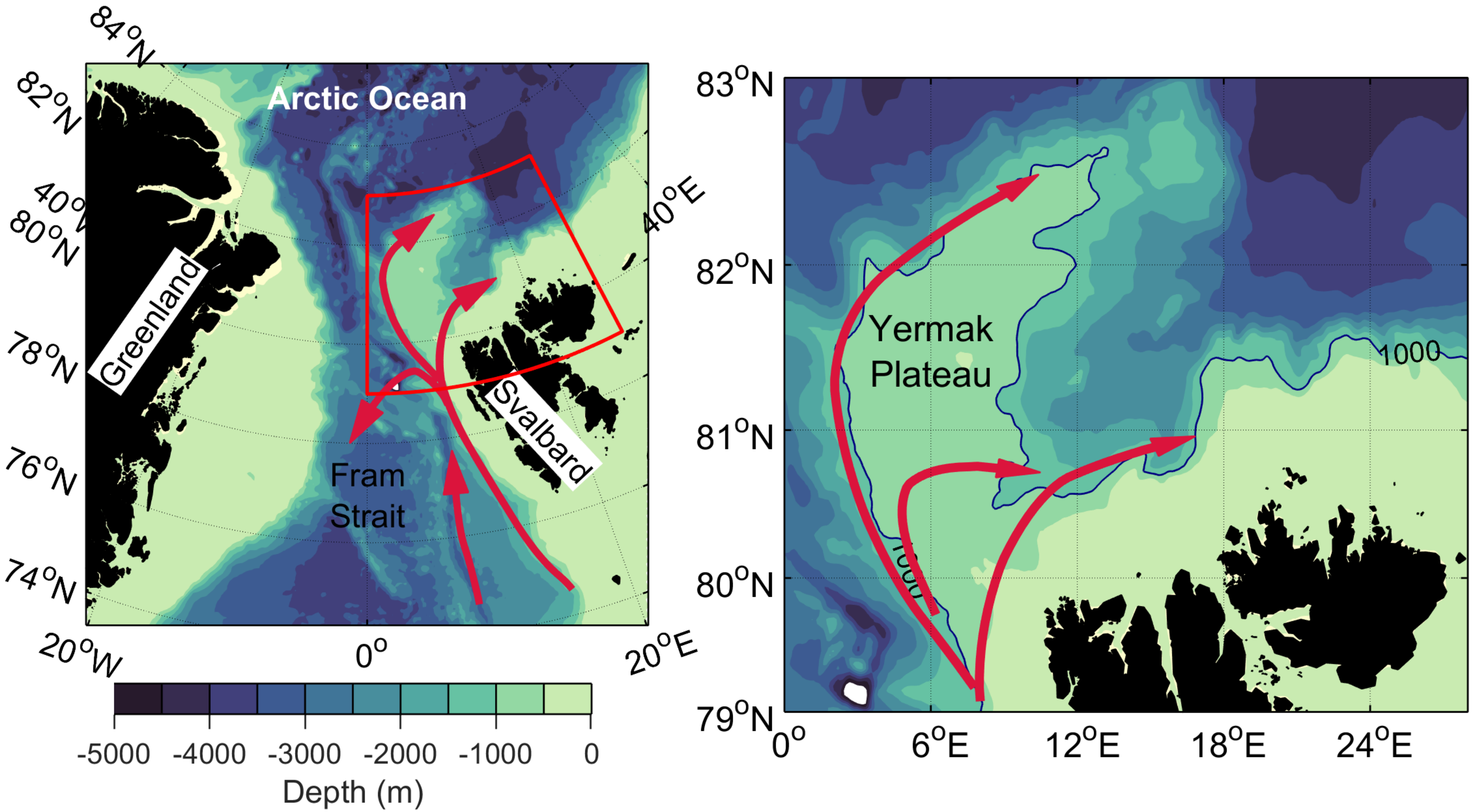
Koenig, Z, E. Kolås, and I. Fer (2021). Structure and drivers of ocean mixing north of Svalbard in summer and fall 2018, *Ocean Sci.*, 17, 365–381, https://doi.org/10.5194/os-17-365-2021 , 2021.



(Rudels et al. 2004)

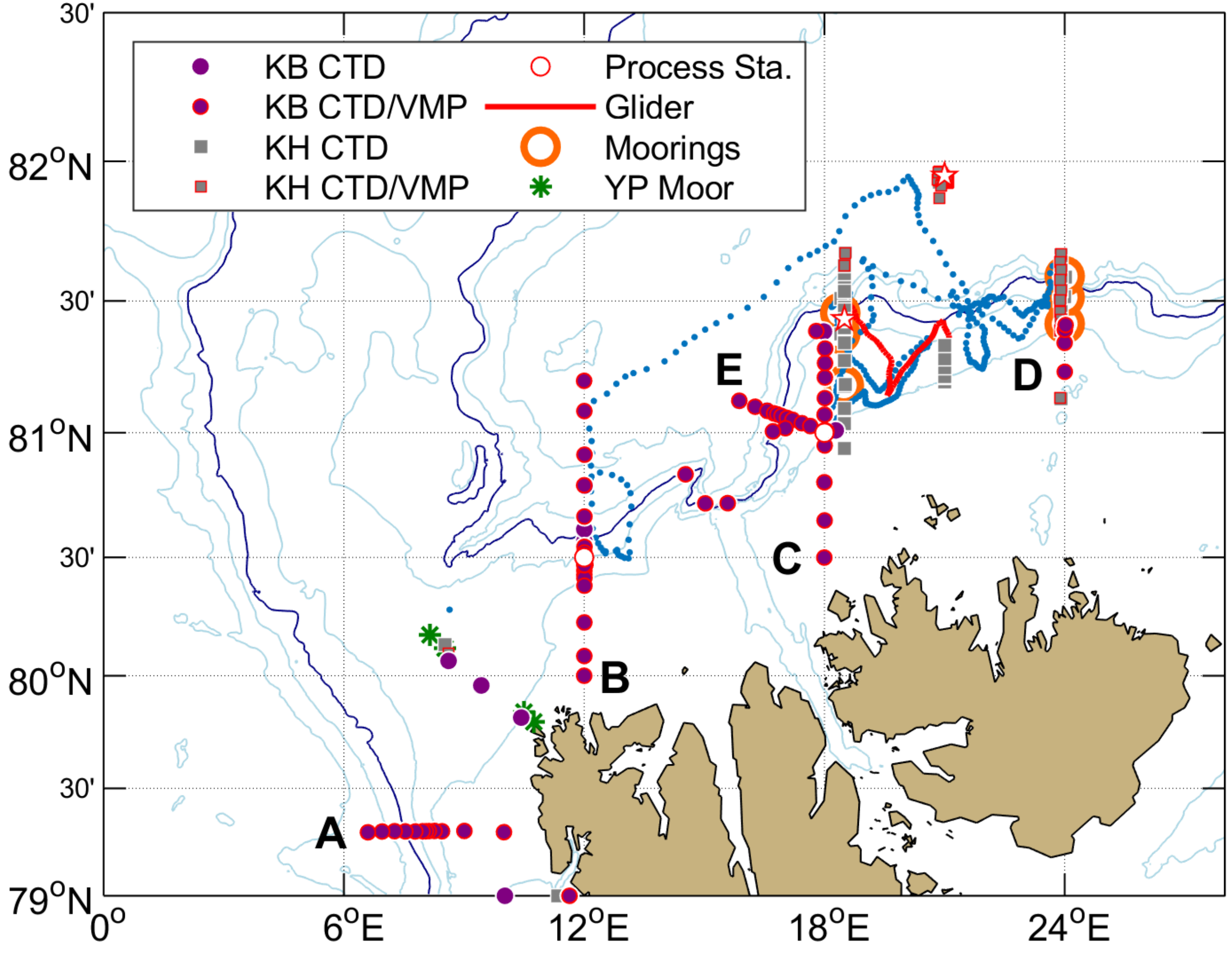


(Lenn et al. to appear in Naveira Garabato and Michael P. Meredith)



84°N
82°N
Arctic Ocean
40°W
80°N
78°N
76°N
74°N
Greenland
Svalbard
Fram
Strait
40°E
20°W
0°
20°E
-5000
-4000
-3000
-2000
-1000
0
Depth (m)
83°N
82°N
81°N
80°N
79°N
Yermak
Plateau
1000
0°
6°E
12°E
18°E
24°E

Cruises: 27 June – 10 July 2018 and 12-24 September 2018

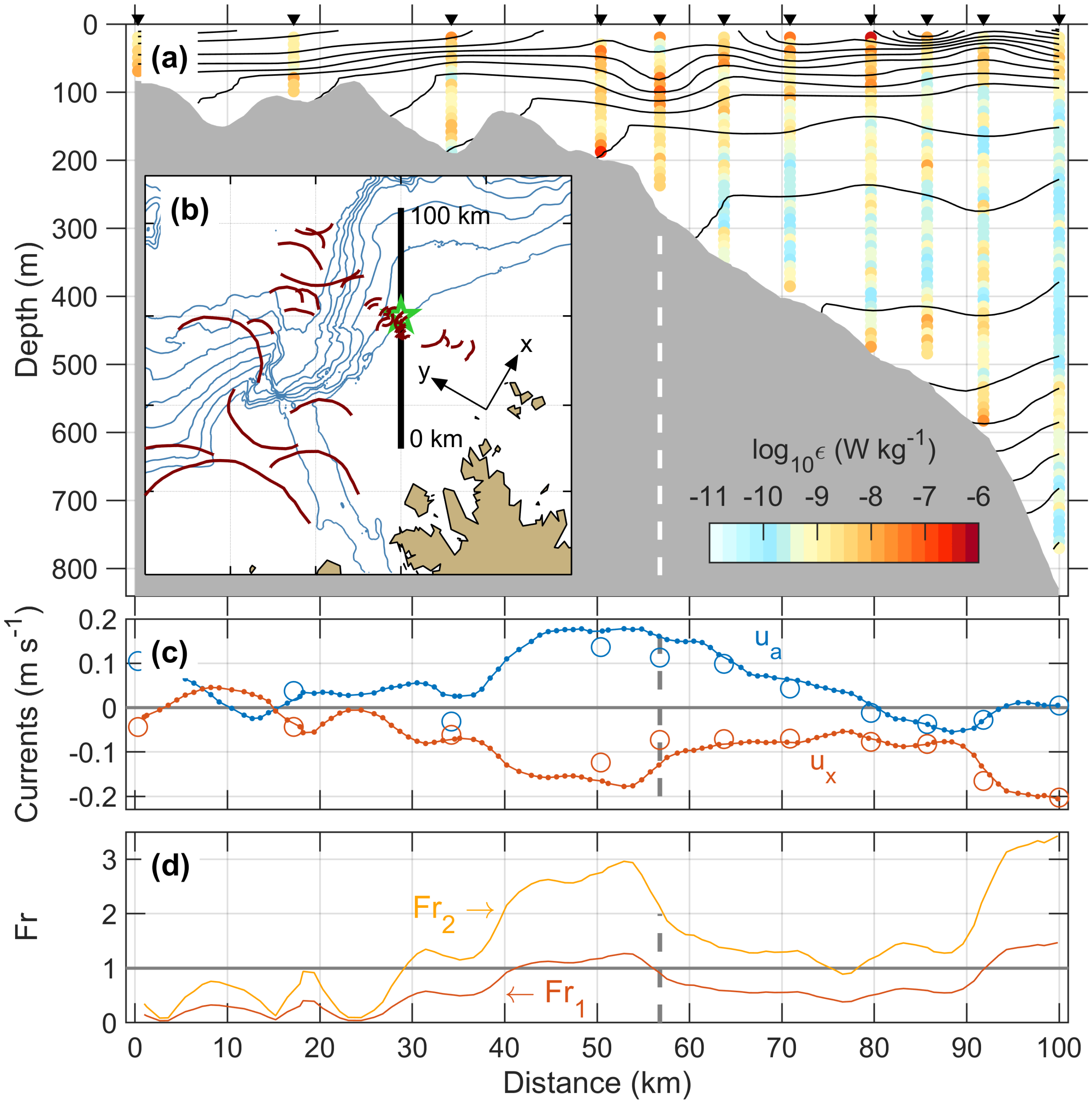


a) Transect: profiles collected within 14 hours from shelf toward deep water

b) Wave crests from a SAR image at the time of profile at 50 km

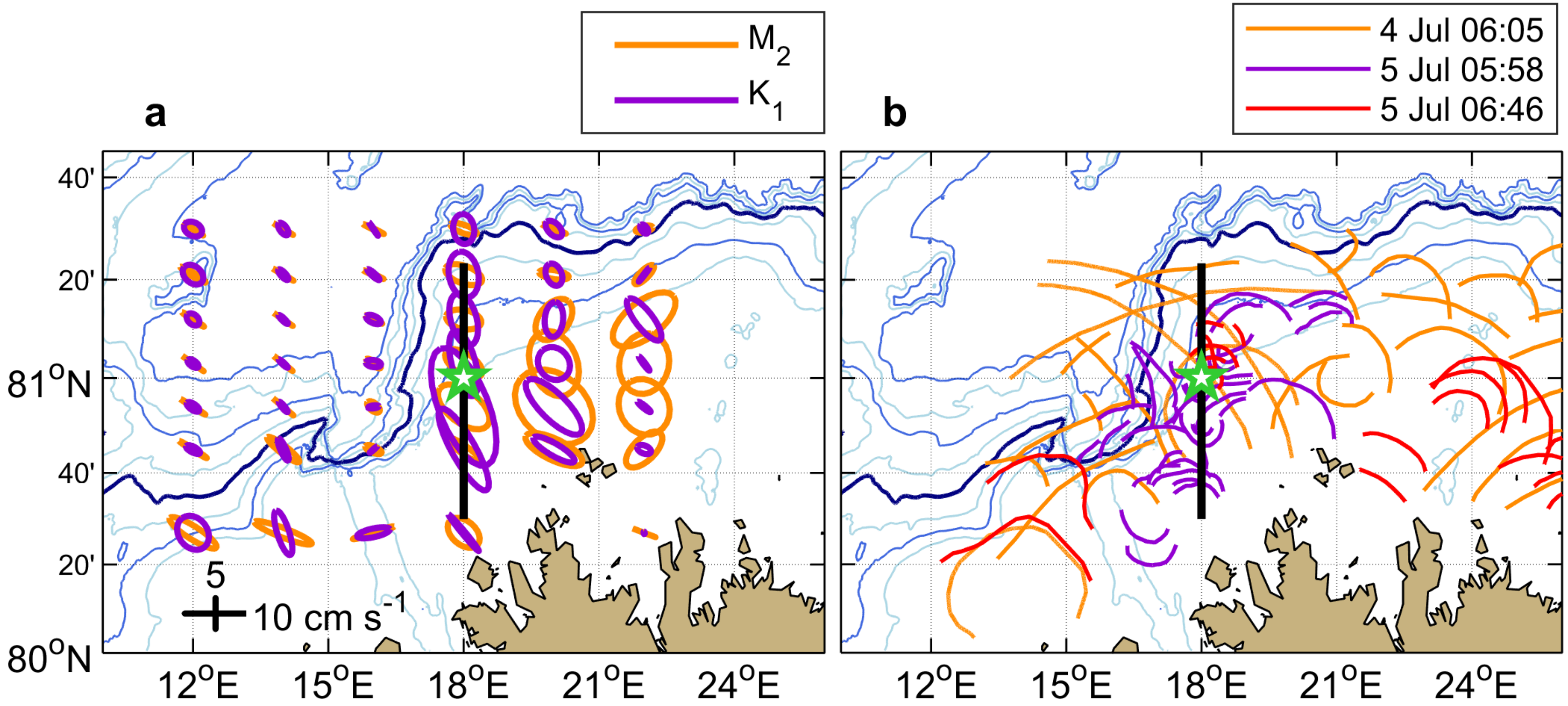
c) Depth-averaged currents of u_a (along isobath) and u_x (cross isobath) from the SADCP and LADCP

d) Froude number, Fr = u/c, using the depth-averaged u_x and the evanescent K_1 phase speeds for the first two baroclinic modes



40-60 km:

- about 50 m depression of isopycnal
- fully turbulent water column
- near-critical or supercritical flow



Selected tidal ellipses from Arc5km2018. Near the 300 m isobath (chosen repeat station), K_1 is particularly energetic and directed normal to isobaths, giving favorable forcing conditions for energy conversion.

SAR images near the start and end of the process station show the presence NLIWs

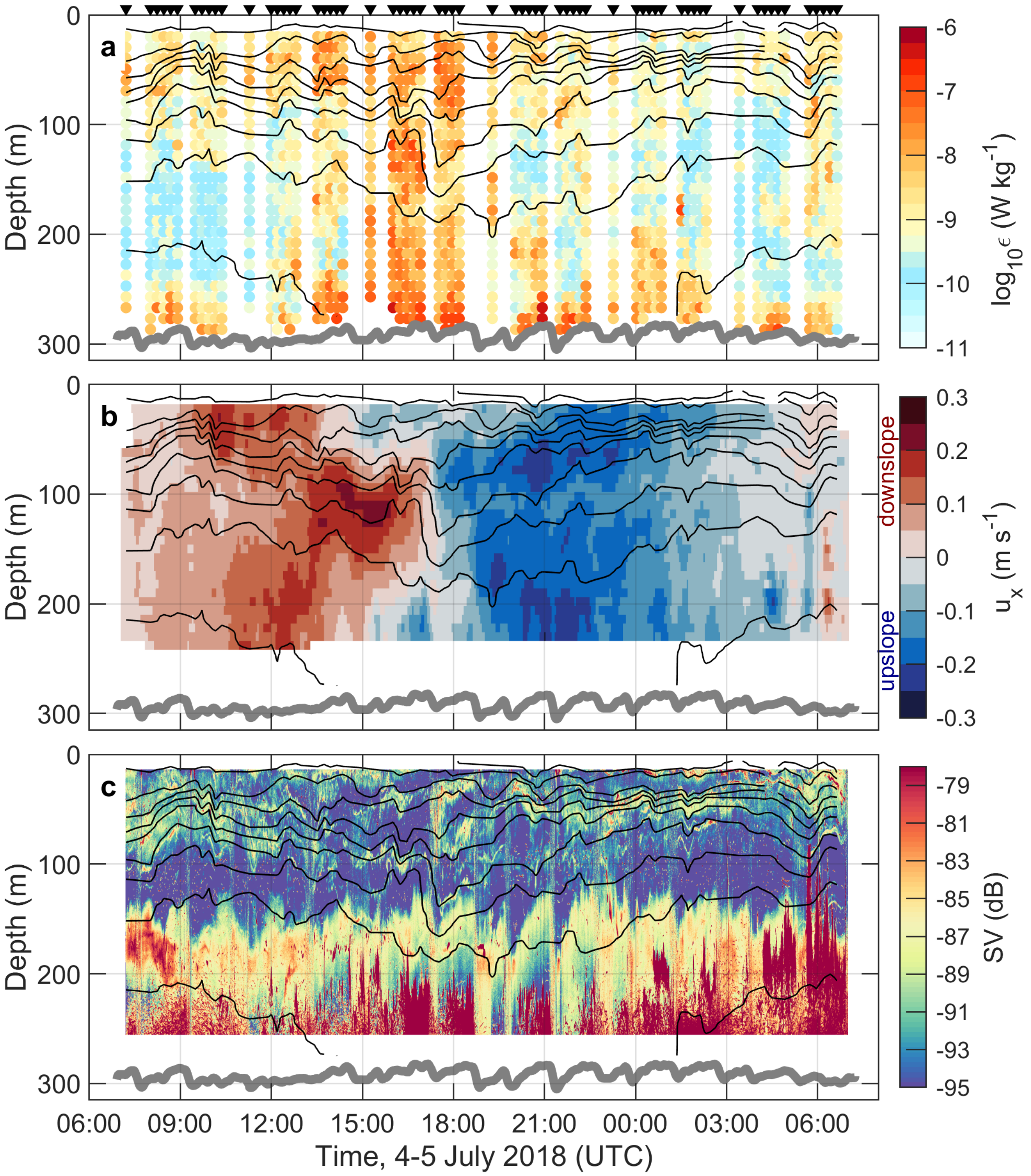
Repeat profiles at the process station

a) Dissipation rate ϵ and isopycnals (@ 0.02)

b) u_x from the SADCP (negative directed upslope)

c) EK80 backscatter intensity.

- strong variability of isopycnal depths
- highly intermittent turbulence
- Turbulent event coincided with the slackening and reversal of u_x
- u_x was complex but showed an overall diurnal cycle
- acoustic trace of the internal wave was observed with the EK80



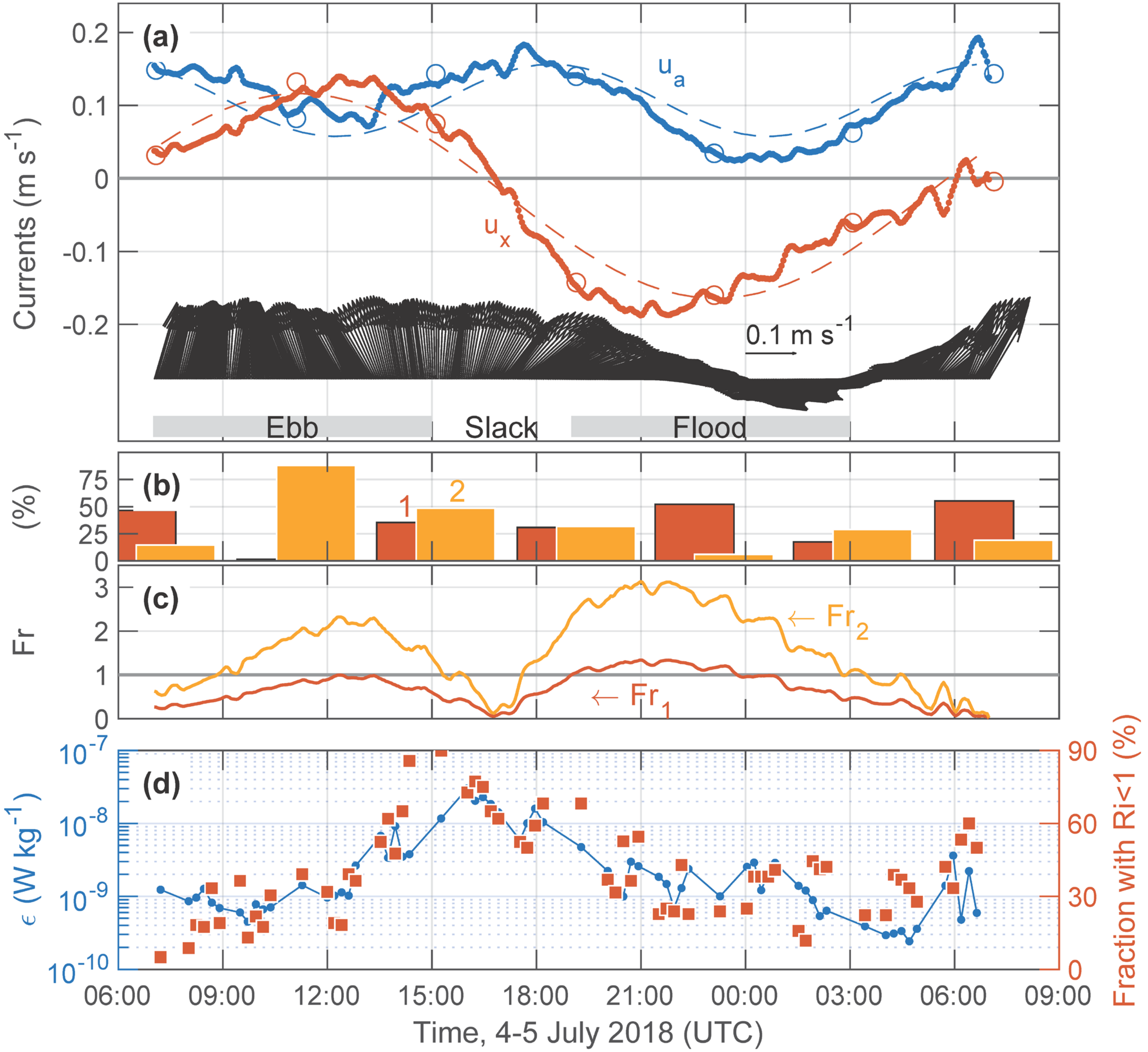
a) Depth-averaged currents
  diurnal fit to u_x (0.15 m s^{-1}; 93%)
  semidiurnal fit to u_a (0.04 m s^{-1}; 62%)

b) Variance explained by the first two baroclinic modes fitted to u_x

c) Fr, using the depth-averaged | u_x | and the evanescent K_1 phase speeds for the first two baroclinic modes

d) Dissipation averaged between 50 and 250 m and the fraction of the water column with Ri < 1

Over the 6-hr turbulent period, heat fluxes averaged 15 W m^{-2} with some estimates exceeding 100 W m^{-2}

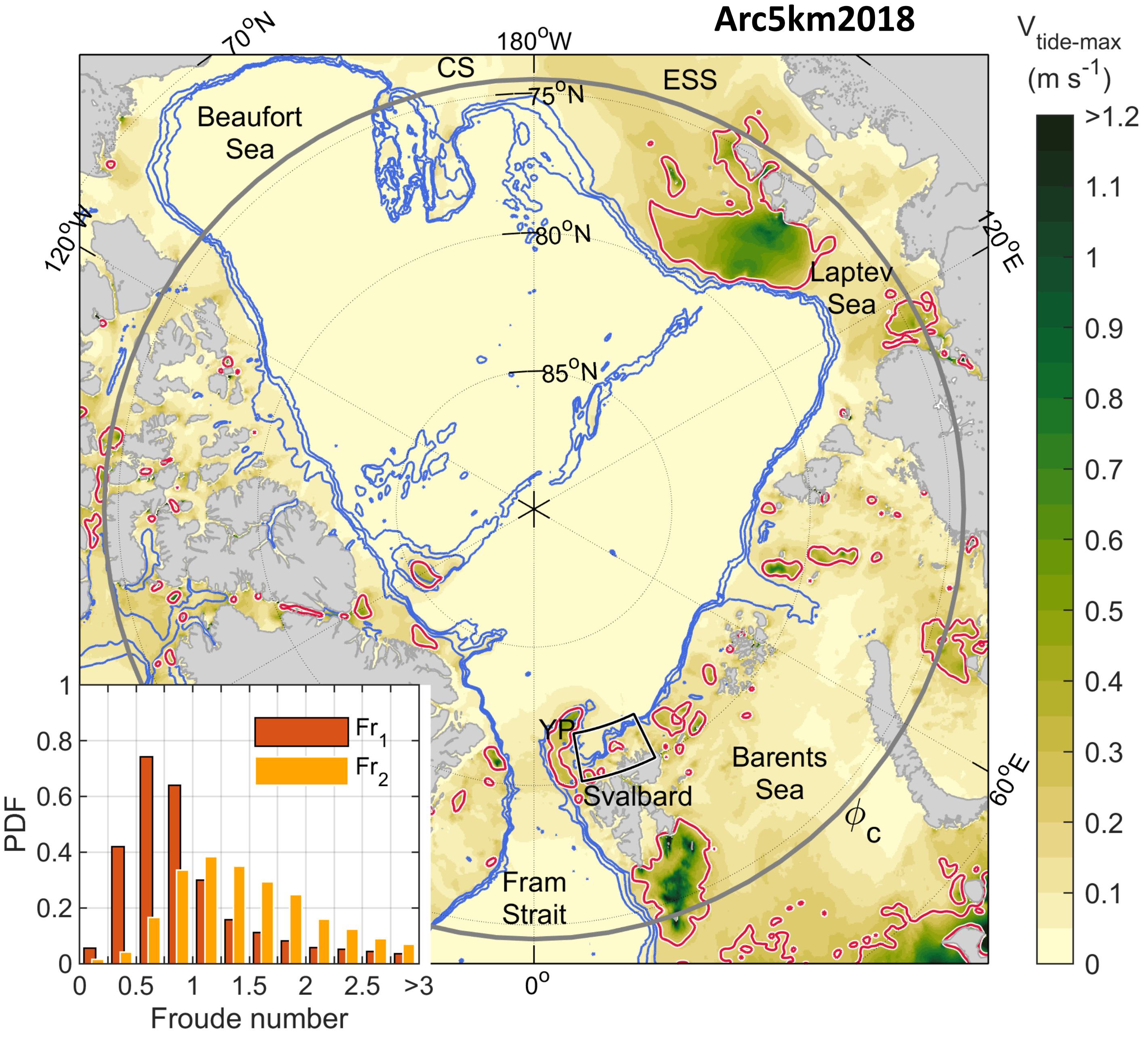


The inset shows the PDF for Froude number calculated insider red contours using $|u_{x-max}|$, the first two baroclinic K1 phase speed and the MIMOC August stratification

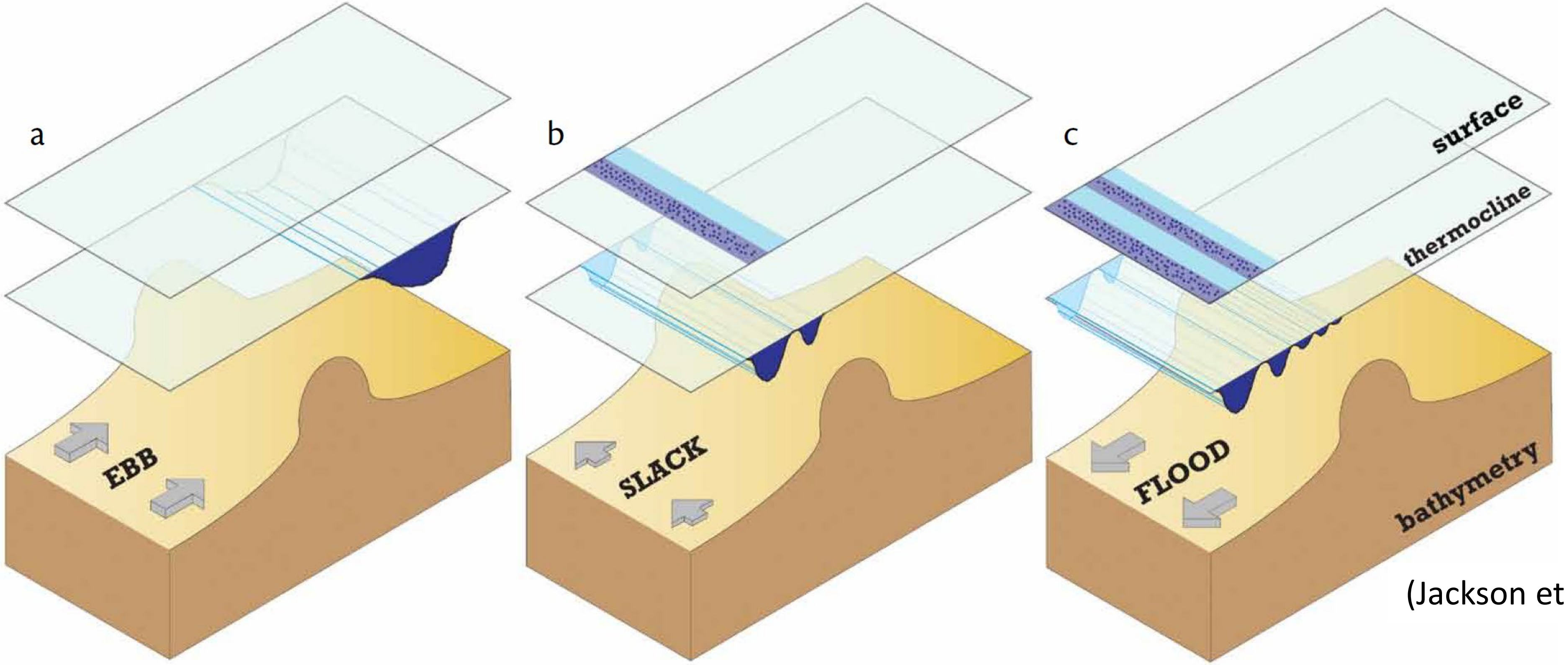
Red: $|u_{x-max}| = 0.2$ m s^{-1}

Energetic cross-isobath tidal currents are common along the Arctic Ocean margins

Near-critical or supercritical Froude numbers in these regions will allow trapping and unsteady evolution of lee waves and NLIWs



Similar to the NLIW generation via lee waves….



(Jackson et al. 2012)

A schematic showing nonlinear internal wave generation via the lee wave mechanism of Maxworthy (1979).
(a) As the stratified flow moves over the sill, the initial lee wave develops on the downstream side
(b) As the flow slackens, the lee wave steepens nonlinearly and propagates upstream over the sill
(c) The lee wave evolves into a nonlinear internal wave packet

also note- nonlinear response to typical tidal forcing at these latitudes will be similar to lee waves (Vlasenko et al., 2003)

Observations from both cruises: attempt to generalize / parameterize

Tidally driven processes may lead to

(1) interior mixing away from the seabed and

(2) dissipation through bottom stress from barotropic tidal currents

$$\boldsymbol{\tau}_b = \rho_0 C_D \mathbf{u} \cdot |\mathbf{u}|$$
$$W = \boldsymbol{\tau}_b \cdot \mathbf{u} = \rho_0 C_D \, |\mathbf{u}|^3$$

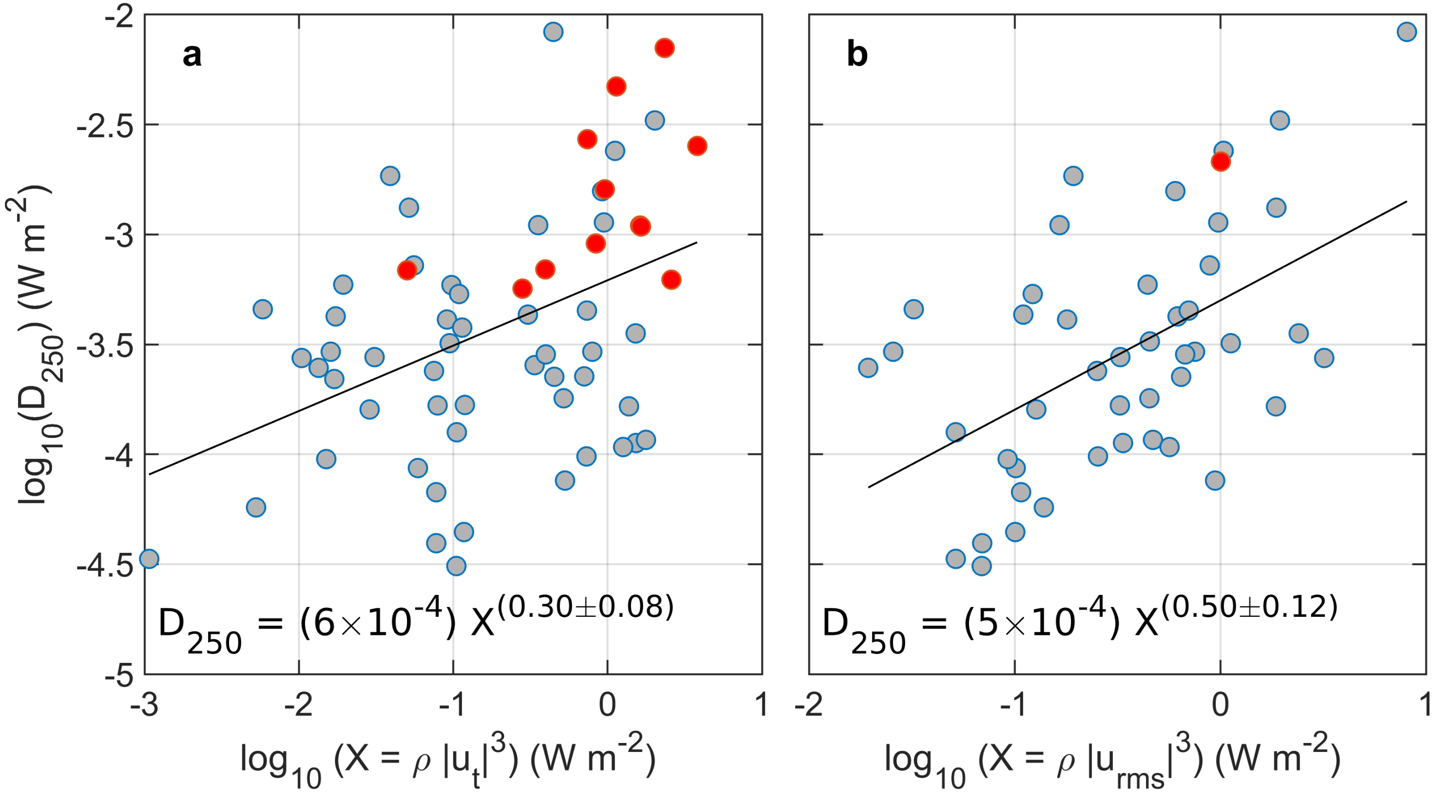
Method: regress depth-integrated dissipation rate in the bottom 250 m (D_{250}) against tidal forcing.

(1): against tidal work (product of Baines force and the barotropically induced vertical velocity). For the main diurnal and semidiurnal constituents, D_{250} does not correlate well with the tidal work

(2): against

(a) instantaneous tidal bottom drag

(b) “typical” (using r.m.s) tidal bottom drag



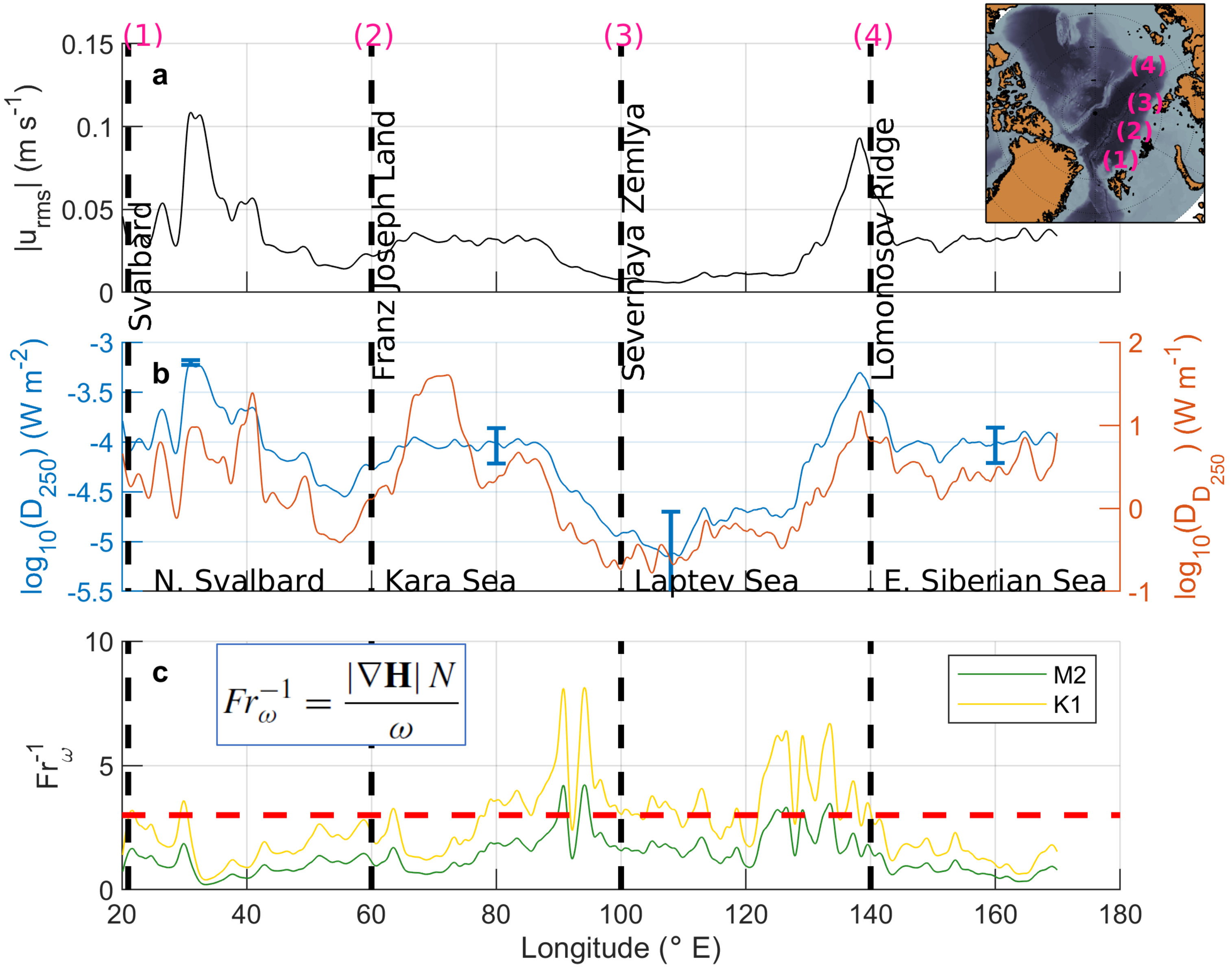
a) Typical cross-isobath tidal speed averaged meridionally between the 400 and 1200m isobaths

b) D_{250} calculated from regression result

Left axis: averaged between the 400 and 1200m isobaths

Right axis: integrated laterally between the 400 and 1200m isobaths.

c) Inverse Froude number. The red dashed line is a threshold for the development of nonlinear processes
(Legg and Klymak, 2008)



Concluding remarks

- Along the Arctic Ocean margins, the pathway for the energy from the tide to turbulence is nonlinear and dominated by breaking unsteady lee waves and critical flow

- All data are available from the Norwegian Marine Data Centre with CC-BY 4.0 License.
  July cruise : https://doi.org/10.21335/NMDC-2047975397
  September cruise : https://doi.org/10.21335/NMDC-2039932526

Average profiles for weak (blue) and moderate (red) tidal forcing

The shading is the 95% confidence envelope of the maximum likelihood.