Impact of ice covers on diel vertical migration of zooplankton in the Arctic marine environment

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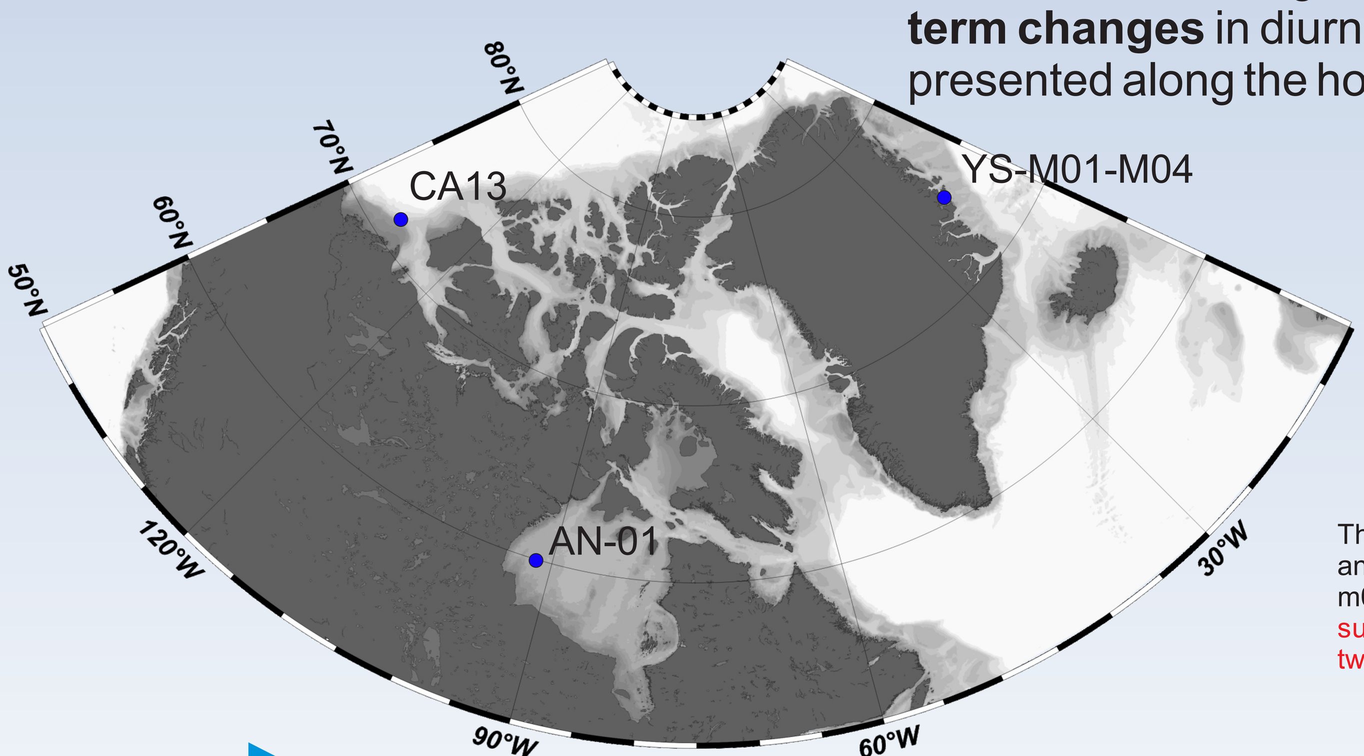
Diel vertical migration (DVM) of zooplankton is a process of synchronized movement of the organisms from the mesopelagic zone up to the epipelagic zone at night and returning back during the day. DVM is considered to be the **largest synchronized diel movement of biomass** on the planet. It also acts as a biological pump in transferring organic carbon from the surface of the ocean to depth.

Study sites:

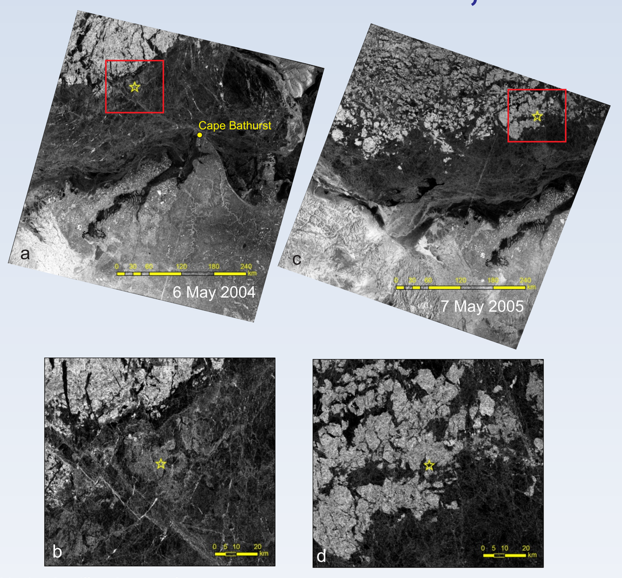
- **CA-13**. Beaufort sea, 2004-2004
- **AN-01**. Hudson Bay, 2016-2017
- **YS-M01-M04.** Young Sound fjord. 2013-2014

Actograms is a common method of data display in chronobiological research.

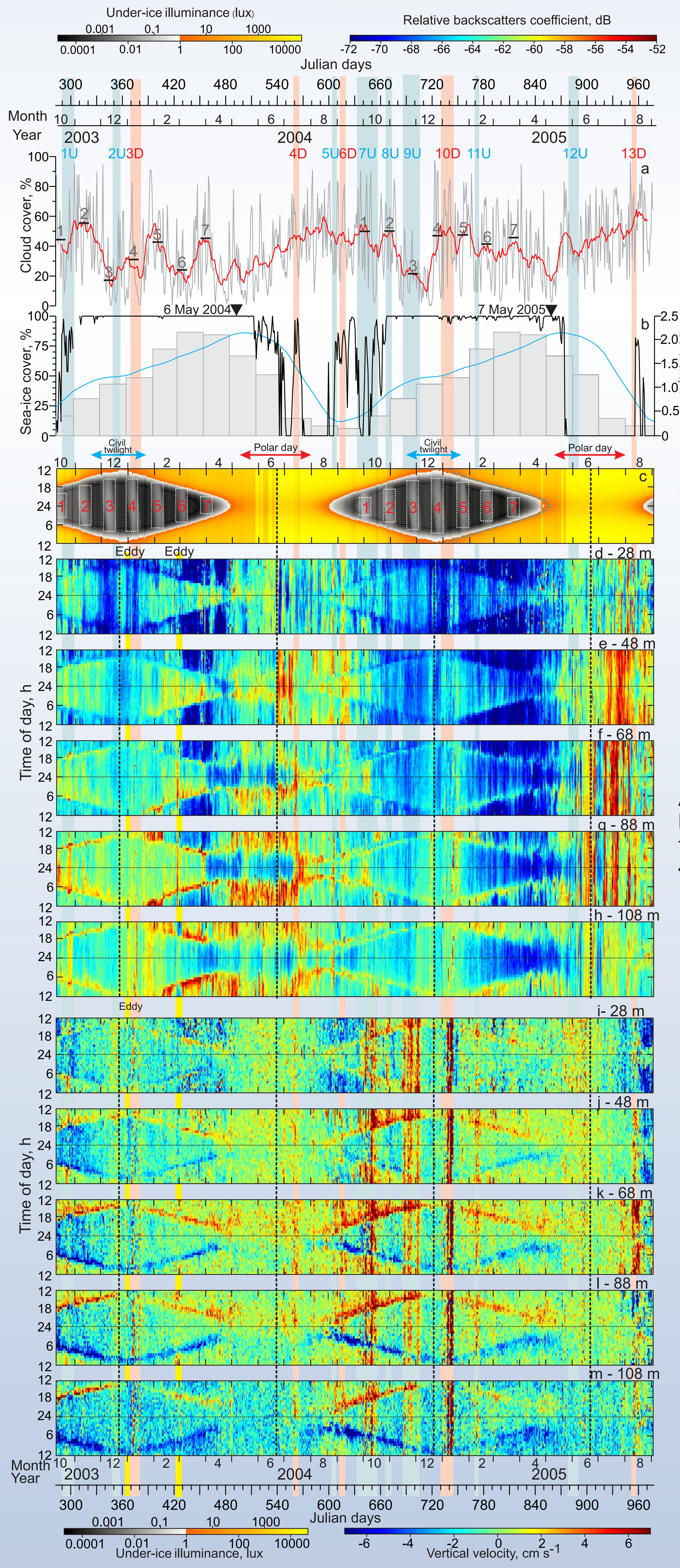
Actograms recently were successfully used for studying zooplankton DVM. The **diurnal** signal is presented at the vertical axis of actogram, and the **long-term changes** in diurnal behaviour are presented along the horizontal axis.



CA-13. Beaufort sea, 2004-2004



RADARSAT satellite images taken before sea-ice breakup over the CA13-03 location northeast of Cape Bathurst on (a) 6 May 2004 and (c) 7 May 2005. Yellow stars depict mooring position. Red rectangular show mooring region enlarged in b and d. The dark areas are associated with first year pack ice (< 2 m thick). The lighter areas indicate the multi-year pack ice (> 2 m thick).



(a) Time series of total cloud cover (gray) with 15-day running mean in red. black horizontal lines indicate the mean cloud cover for these periods

(b)Time series of sea-ice draft (gray and blue) and concentrations (black) Red and blue shading highlight the downwelling (D) and upwelling (U) events, respectively, with their reference numbers on the top. Yellow shading highlights eddies.

Actogram of modeled under-ice illuminance. Dotted blue line depicts 1 lux threshold estimated for 2.6 m thick ice. Red and blue arrows at the top indicate the polar day and civil twilight, respectively. White dashed rectangles depict the full moon occurrences ±6 days with their reference numbers Black dashed lines depict solstices

Actograms of volume backscatter strength at five depth levels: 28 m, 48 m, 68 m, 88 m and 108 m.

ADCP-measured vertical velocity (cm/s) at five depth levels:) 28 m, 48 m, 68 m, 88 m and 108 m.

Positive/negative values correspond to the upward/downward flow.

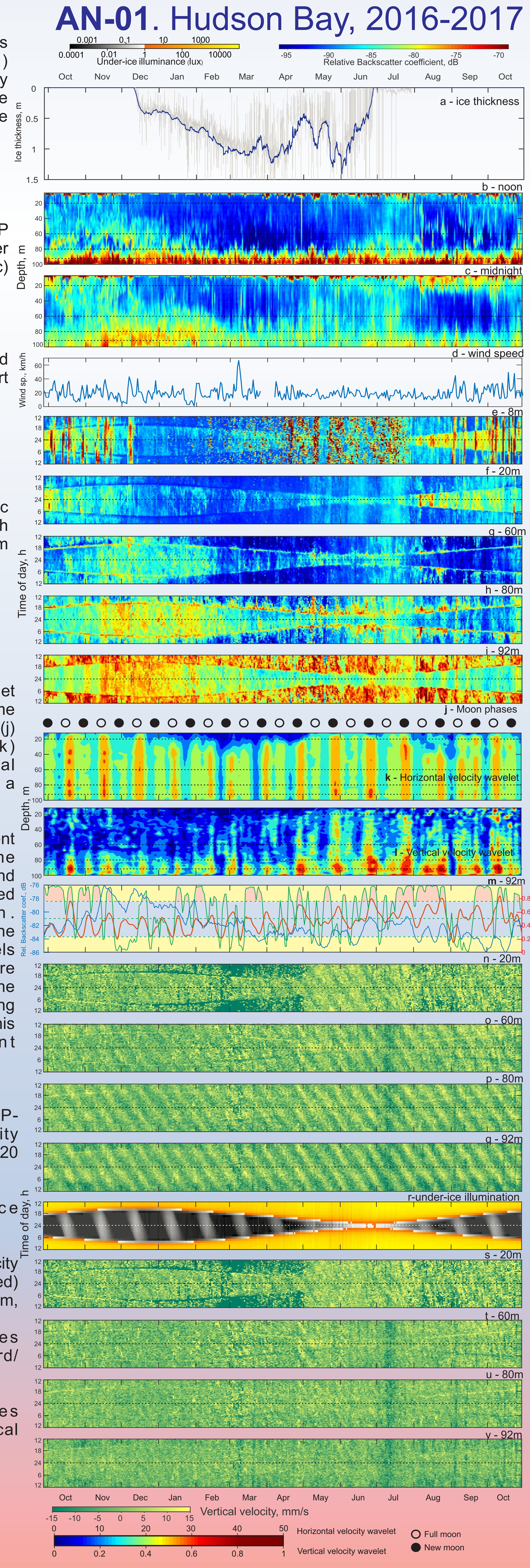
AN-01. Hudson Bay, 2016-2017

ADCP-measured ice thickness at the mooring location (AN01) during winter 2016-2017. Gray and blue lines represent the filtered and daily averaged ice thicknesses, respectively.

Time series of the ADCP acoustic volume backscatter coefficient (b) at noon and (c) at midnight.

Daily mean wind speed measured at Churchill airport (YYQ)

Actograms of ADCP acoustic backscatter at five depth levels: 8m, 20 m, 60 m, 80 m and 92 m



The absolute value of wavelet power spectrum for the time series of horizontal velocity (j) and vertical velocity (k) computed for semi-diurnal frequency band (12 h) as a function of depth.

(m) – the correlation coefficient (green line) between time series of VBS (blue line) and vertical velocity wavelet (red line) at 92 m depth. Yellow shading identifies the correlation coefficient levels exceeding ±0.53, which are statistically significant for the 95% confidence. Pink shading identifies the events when this statistically significant correlation was observed.

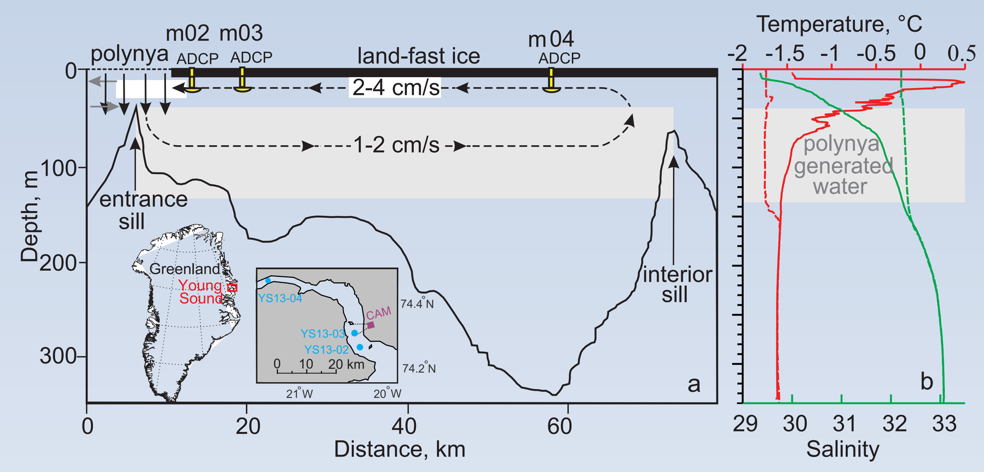
Actograms of (n-q) ADCP-measured vertical velocity (mm/s) at four depth levels: 20 m, 60 m, 80 m and 92 m,

(r) modelled under-ice illuminance

(s-v) Residual vertical velocity (mm/s, tidal signal subtracted) at four depth levels: 20 m, 60 m, 80 m and 92 m. Positive/negative values correspond to the upward/downward net flux.

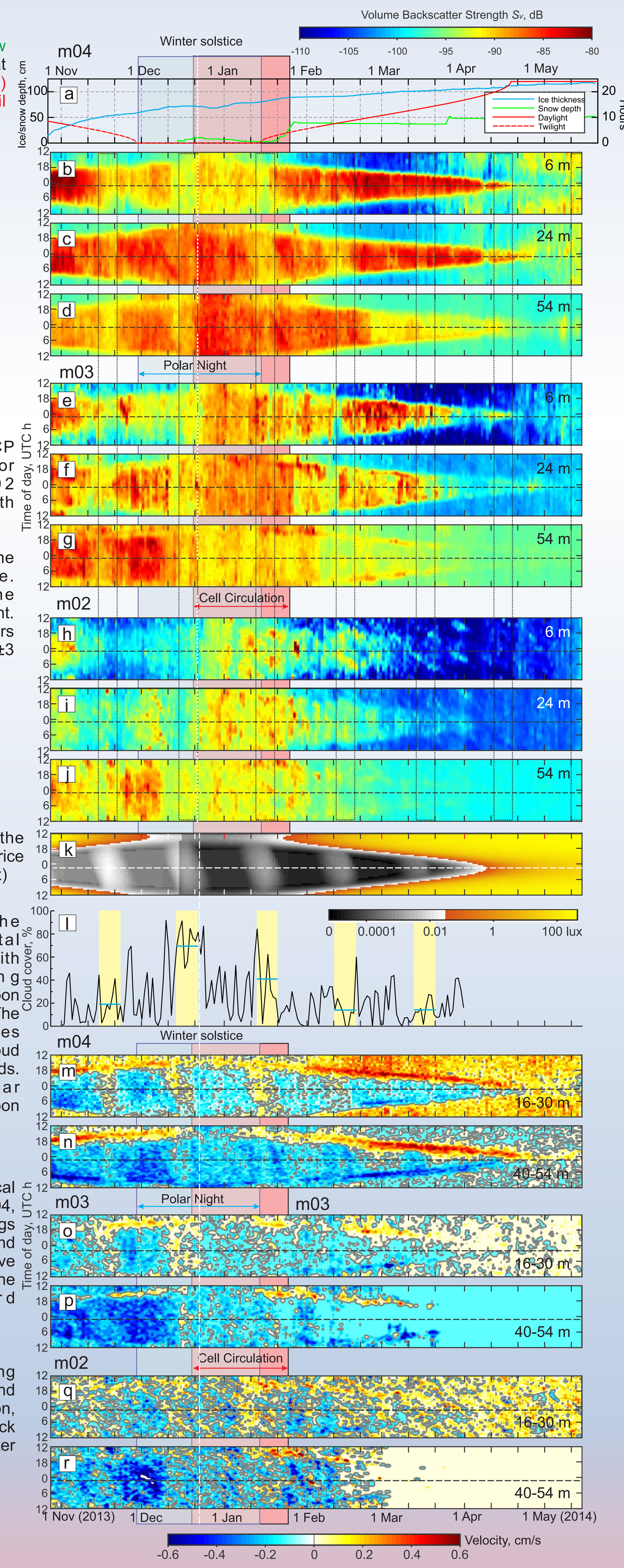
Dashed horizontal lines represent the astronomical midnight.

YS-M01-M04. Young Sound fjord. North-East Greenland, 2013-2014



Schematic depiction of polynya impact on the YS circulation adapted from Dmitrenko et al. [2015]. The first map insert shows Young Sound (YS) on the Greenland map and the second map shows positions of landfast ice-tethered oceanographic moorings (red circles) deployed in YS from October 2013 to May 2014 and position of time lapsed camera (purple square) facing mooring m3. (b) Vertical distribution of temperature (red, 8C) and

The time series of snow and ice thickness (cm) at m04 and duration of (solid) sunlight + (dashed) civil twilight (h);



Actograms of the ADCP acoustic backscatter for m04, m03, and m02 moorings at three depth levels: 6 m, 24 m and 54 m.

Vertical white dashed line depicts winter solstice. Horizontal dashed line shows astronomic midnight. Dotted rectangular contours the full moon occurrence ±3 days.

Actogram of the modeled underice illuminance (lux)

Time series of the NCEP-derived total cloud cover (%) with yellow shading highlighting the full moon occurrence ±4 days. The blue horizontal lines indicate the mean cloud cover for these periods. Dotted rectangular contours the full moon occurrence ±3 days.

ADCP-measured vertical velocity (cm/s) for m04, m03, and m02 moorings averaged for 16-30 m and 40-54m. Positive/negative values correspond to the upward/downward displacement.

Blue and pink shading highlights polar night and enhanced cell circulation, respectively. Vertical black dashed line depicts winter solstice.

Summary:

- Diel vertical migration (DVM) of zooplankton is deviated by the seasonal and inter-annual variability in sea-ice;
- Along-slope flow dominates the DVM disruptions by wind-driven upwelling and downwelling at the shelf break;
- The midnight sun DVM was observed in the Pacific Water layer during summer 2004, a signal masked by suspended particles in the next summer.

Dmitrenko, I.A., Petrusevich, V.Y., Darnis, G., Kirillov, S.A., Komarov, A.S., Ehn, J.K., Forest, A., Fortier, L., Rysgaard, S and Barber, D.G. (2019) Sea-ice and water dynamics and moonlight impact the acoustic backscatter diurnal signal over the eastern Beaufort Sea continental slope. Subm. to J. Geophys. Res. Oceans

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Summary:

- Unlike other ice-covered and ice-free Arctic and sub-Arctic locationsm, DVM in Hudson Bay is controlled by solar illumination throughout the whole year, not by moonlight.
- Seasonal variations in zooplankton migration and distribution in the water column were observed throughout the entire time series.
- The observed response of zooplankton to spring tide is consistent with the zooplankton tendency to stay away from the layers with enhanced water dynamics and to adjust its DVM accordingly.

Petrusevich, V.Y., Dmitrenko, Niemi, A., Kirillov, S.A., Kamula, C. M., Barber, D. G., and Ehn, J. K. (2019) Impact of tidal dynamics on diel vertical migration of zooplankton in Hudson Bay. Prep. for subm. to Ocean Science.

Summary:

- DVM in Young Sound persisted throughout the entire winter including the period of polar night;
- Polynya-enhanced circulation disrupted DVM favouring zooplankton to occupy the surface layer;
- Weaker intensity of DVM beneath ice during polar night was observed when the moon was in full phase.

Petrusevich, V., I. A. Dmitrenko, S. A. Kirillov, S. Rysgaard, S. Falk-Petersen, D. G. Barber, W. Boone, and J. K. Ehn (2016), Wintertime water dynamics and moonlight disruption of the acoustic backscatter diurnal signal in an ice-covered Northeast Greenland fjord, J. Geophys. Res. Oceans, 121, 4804–4818, doi:10.1002/2016JC011703.