In a sea of crumbling icebergs (SUPPLEMENTARY MATERIAL)

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ABSTRACT.

SUPPLEMENTARY MATERIAL

(A) Hardy's observations from 1926

"The iceberg before us had this typical flat top which was now somewhat inclined, no doubt due to irregular melting; and its edges were broken into peaks and turrets reminding one of some Norman fortress. Since ice floats with nearly eight times as much of its mass below water as above it, we can imagine how great was the thickness of the barrier that gave it birth. Its sides were beautifully sculptured and there were deep caverns and clefts in them; in these was seen that most remarkable, almost luminous, ice-blue; so different from the blue of the sea or the sky. For a mile or more around it the water was dotted with little fragments of ice which had broken from its sides; they are known as 'bergy bits', an expression of the old whalers. We steamed so close that at one time it was impossible to get the whole iceberg into my camera's field of view. The captain steered the ship among the bergy bits to give us the first time the sound of broken ice upon her bows and sides: a musical scrunching sound, a little like the shovelling of broken glass.
Just as we were directly opposite the iceberg, there came a roar like thunder. For a moment we expected to see the whole castle crack from top to bottom or heel over; but no, this seemingly portentous sound was just some minor cracking on another side. Such icebergs break up by flat pieces carving from their side to form the dangerous submerged icebergs called 'growlers'.
...
We were to have a station at 8.30 but put it off till a few miles past the berg on account of the abnormal local conditions, the colder and less saline surface layer, due to the melting ice."
Sir Alister Hardy: Great Waters (Hardy, 1967); the iceberg was encountered on 16th February 1926 near 50°S, 30°W.

(B) How much ice is required to cool 1 kg of seawater by 1°C?

We estimate how much ice (kg) is required to cool one kilogram of seawater by 1°C, say from 6°C to 5°C, solving the energy balance (Eq. 5 in main text) for x while setting $y = 1$ kg. Assuming $T_{\mathrm{ice,i}} = -20$°C and setting $T_{\mathrm{sw,i}} = 6$°C, $T_{\mathrm{sw,f}} = 5$°C one obtains

$$x = \frac{y\, c_{\mathrm{p,sw}} \left(T_{\mathrm{sw,i}} - T_{\mathrm{sw,f}}\right)}{L_m - c_{\mathrm{p,ice}} T_{\mathrm{ice,i}} + c_{\mathrm{p,sw}} T_{\mathrm{sw,f}}} \approx 0.01 \text{ kg} \tag{1}$$

i.e. 1/100 kg of ice could cool 1 kg of seawater by 1°C.

(C) Figures

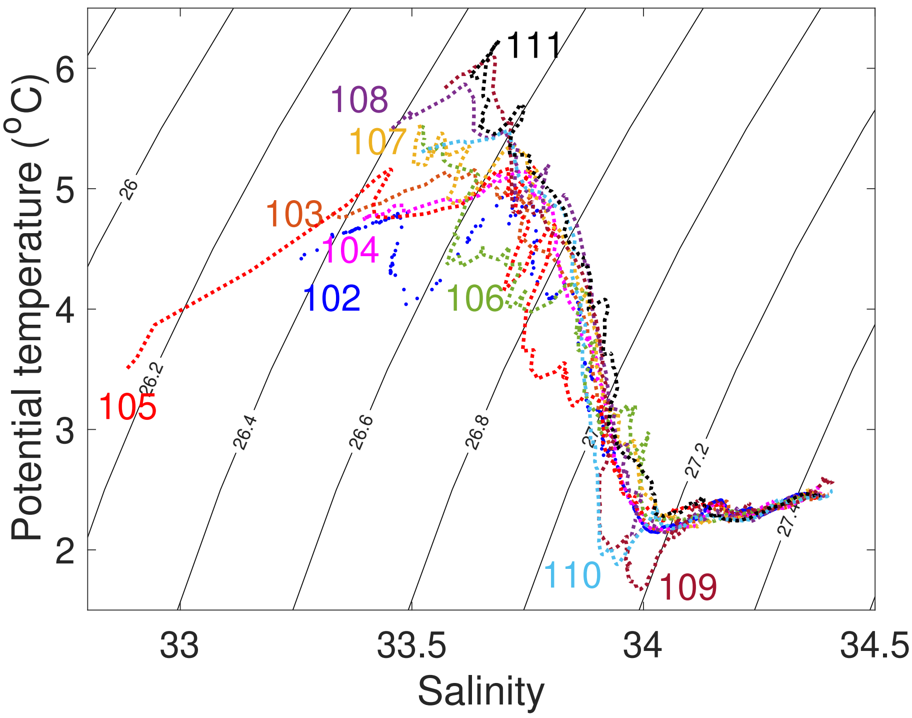

Figure S1 Potential temperature, θ, versus salinity, S, – or θ-S diagram for short – based on CTD data (0 – 500 m depth) of Stations 102 to 111. Plotted numbers refer to stations. Isocontours show potential densities σ_0. Please note the temperature minima below 2°C for stations 109 and 110 indicating the northern nose of Winter Water and thus location south of the APF. The temperature minima of all other stations are above 2°C indicating location north of the APF. The upper layers of stations 102-105 are much fresher and less dense compare to the unperturbed station 111. Stations 106-108 show weaker perturbation.

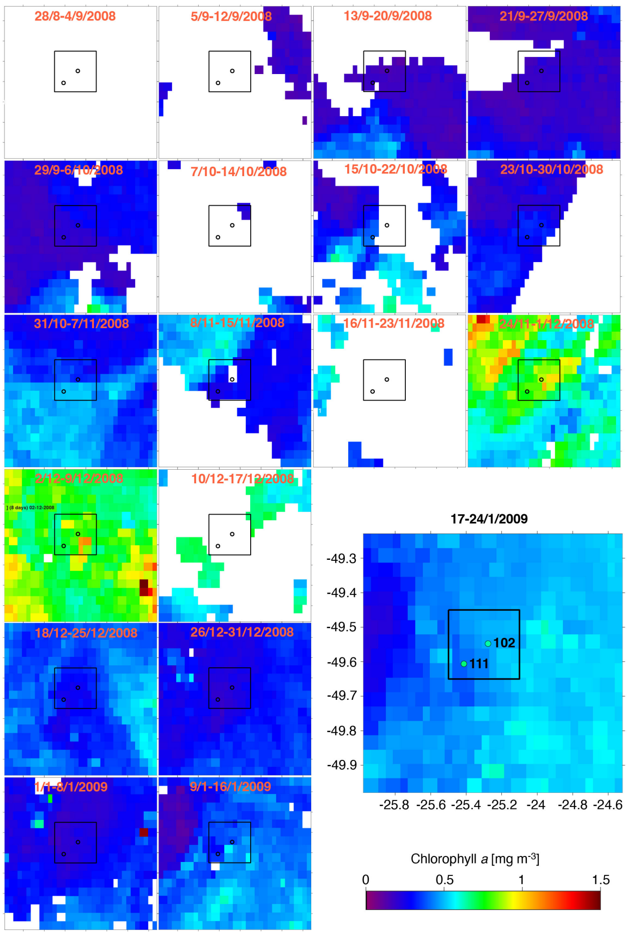

Figure S2 Weekly (8 days) composite chlorophyll *a* from 28.8.2008 to 24.1.2009 from the ESA Ocean Color Climate Change Initiative/Ocean_Colour_cci version 6.0 (Sathyendranath et al., 2019). The black box corresponds to the area shown in Fig. 3a. Stations 102 and 111 are indicated by the black circles. The Larger bottom right panel correspond to the value for our study period. Note that the color for stations 102 and 111 in this panel correspond to the values measured on board (slightly higher than the satellite values and similar for both stations).

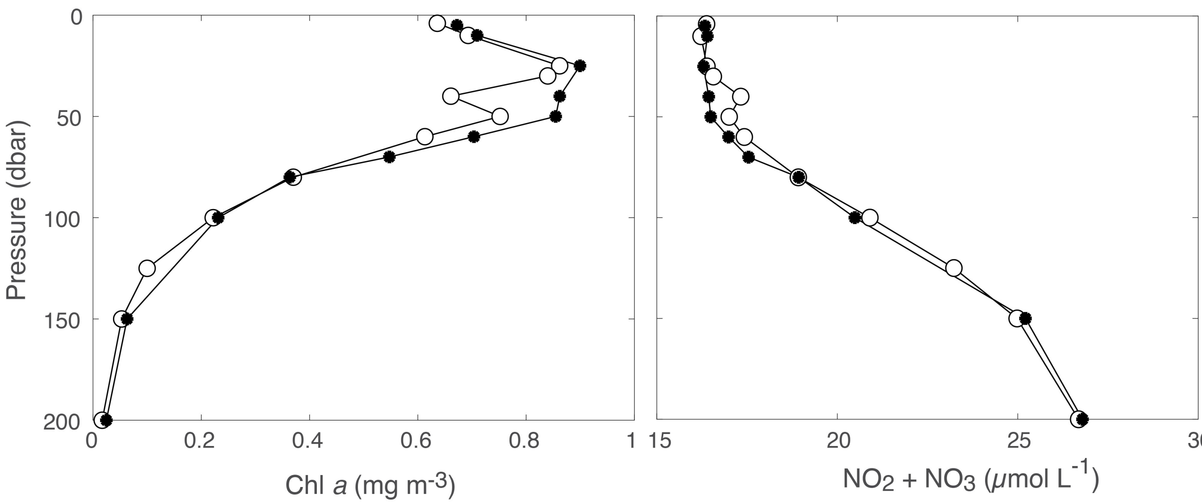

Figure S3 Vertical profiles of chlorophyll *a* (left panel) and $NO_2 + NO_3$ (right panel) concentrations at stations 102 (white circles, inner core) and the unperturbed reference station 111 (black circles).

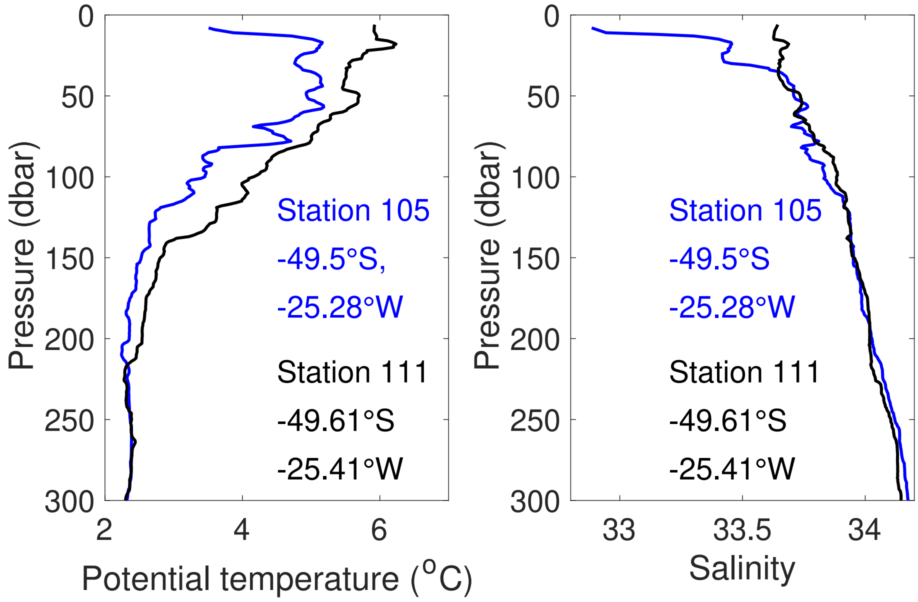

Figure S4 Potential temperature (left panel) and salinity (right panel) profiles of CTD stations 105 (blue lines) in the region perturbed by icebergs and melting glacial ice, and unperturbed reference station 111 (black lines), respectively. The differences in temperature are up to 2.4°C (near the surface) and are clearly recognizable down to 200 dbar (≈ 200 m). The differences in salinity are up to 0.7 psu (near the surface) and reach down to at least 30 dbar. Estimates of mixed layer depths based on density criteria would give only a quite limited view of the rather complex profiles in the perturbed region.

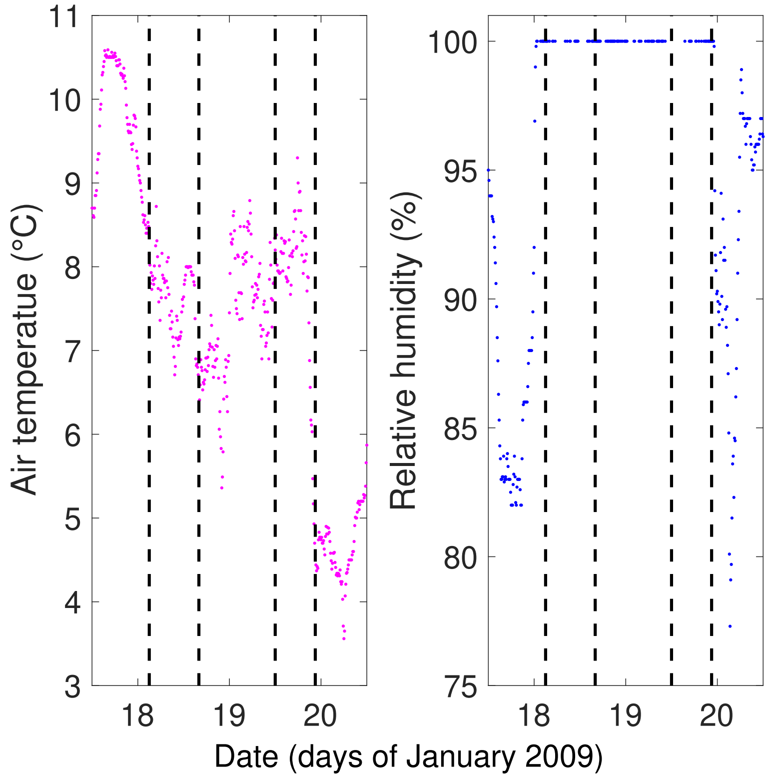

Figure S5 Underway observations of air temperature (left panel) and relative humidity (right panel). Data source: https://dship.awi.de

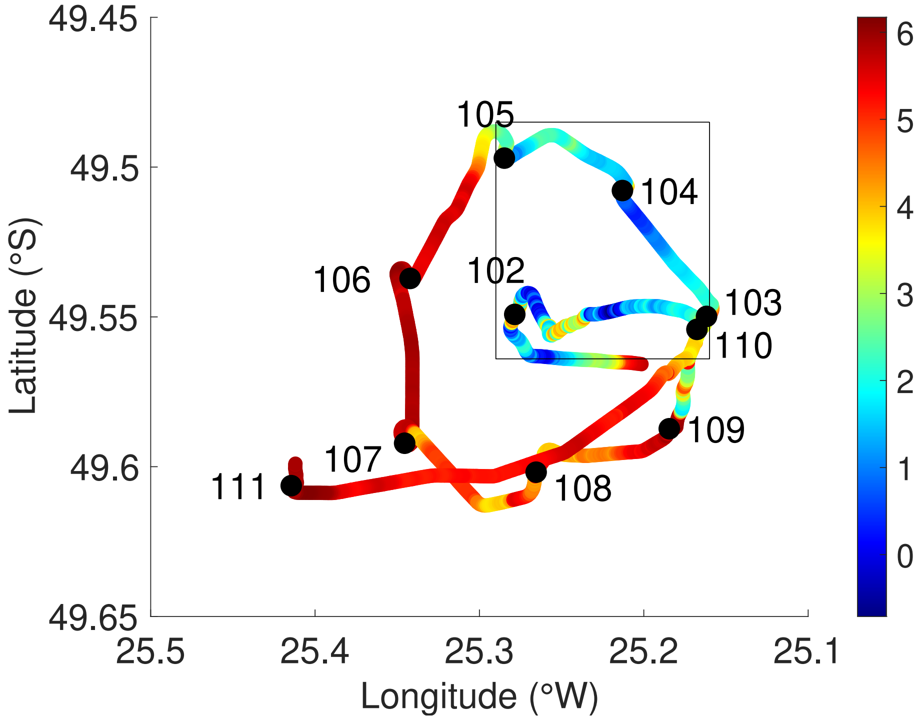

Figure S6 Location of CTD stations (102 to 111) between 18-19 January 2009 (black circles) and underway sea surface temperature (colored dots) from the bow thermosalinograph of *Polarstern*. The black rectangle (49.485°S to 49.564°S, 25.16°W to 25.29°W; size 9 km × 11 km, area about 100 km^2) indicates the area of largest temperature perturbation.

(D) DATA AVAILABILITY

Figure 2: Data for the track of iceberg A43f are from https://www.scp.byu.edu/data/iceberg/.

Figure 3: The positions of stations 102 to 111 can be found in the LOHAFEX/ANT-XXV/3 station book: Smetacek, Victor (2015): Station list and links to master tracks in different resolutions of POLARSTERN cruise ANT-XXV/3, Cape Town - Punta Arenas, 2009-01-07 - 2009-03-17. Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, PANGAEA, https://doi.org/10.1594/PANGAEA.847936. The sea surface temperatures and salinities from the thermosalinograph of POLARSTERN can be found under: Smetacek, Victor; Rohardt, Gerd (2009): Continuous thermosalinograph oceanography along POLARSTERN cruise track ANT-XXV/3 (LOHAFEX). Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, PANGAEA, https://doi.org/10.1594/PANGAEA.727472. Fugacity of CO_2, fCO_2, was calculated from mixing ratios, xCO_2, by standard operating procedures following Pierrot et al. (2009); compare supplementary files fCO2atm.xlsx & fCO2oce.xlsx.

Figure 4: The sea surface temperatures and salinities from the thermosalinograph of *Polarstern* (see above).

Figures S1, S4: CTD data: Wolf-Gladrow, Dieter A. (2010): Physical oceanography during POLARSTERN cruise ANT-XXV/3 (LOHAFEX), https://doi.pangaea.de/10.1594/PANGAEA.742652

Figure S3a: FigSChl102111.xlsx

Figure S3b: FigSNOx102111.xlsx

Figure S5: https://dship.awi.de

Figure S6: same as Fig. 3a

REFERENCES

Hardy, A (1967) *Great Waters - A Voyage of Natural History to study whales, plankton and the waters of the Southern Ocean in the old Royal Research Ship Discovery with the results brought up to date by the findings of the R.R.S. Discovery II.* Collins, London, 542 pp.

Pierrot, D and 9 others (2009) Recommendations for autonomous underway pCO_2 measuring systems and data-reduction routines. *Deep Sea Res. II*, **56**(8-10), 512–522 (doi: 10.1016/j.dsr2.2008.12.005)

Sathyendranath, S and 47 others (2019) An ocean-colour time series for use in climate studies: the experience of the ocean-colour climate change initiative (OC-CCI). *Sensors*, **19**, 4285 (doi: 10.3390/s19194285)