Arctic Fe and Atlantic fixed N regulates summer primary production in the North Greenland Sea

Stephan Krisch[1Ŧ], Thomas J. Browning[1Ŧ], Pablo Lodeiro[1], Mark James Hopwood[1], Martin Graeve[2], Kai-Uwe Ludwichowski[2], Stephane Roig[1], Eric P. Achterberg[1Ŧ]

[1] Marine Biogeochemistry Department, GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany.
[2] Alfred-Wegener-Institute for Polar and Marine Research, Bremerhaven, Germany.

Fram Strait Region – GEOTRACES cruise GN05

- Dominated by (i) the **West Spitsbergen Current** (WSC) that contains warm and saline Atlantic Water (4 °C, >35.10 PSU) at its core, directed northwards from the Greenland Sea towards the Arctic Ocean;[1] and (ii) the southward-directed **East Greenland Current** (EGC), which originates from the Arctic Ocean but includes a contribution of NE Greenland Shelf waters, and comprises low-salinity polar surface water (<31.40 PSU) and more-saline sub-surface waters (<34.80 PSU).[2]
- Extent of Arctic sea ice has diminished ~40% since 1970s,[3] giving rise to the possibility of an extended growth season.[4]
- While high latitude North Atlantic (>50°N) is host to spring-summer Fe limited phytoplankton growth,[5] and
- Arctic Ocean primarily limited by availability of fixed N:[6,7]

What factors regulate phytoplankton growth in the sub-Arctic Fram Strait region?

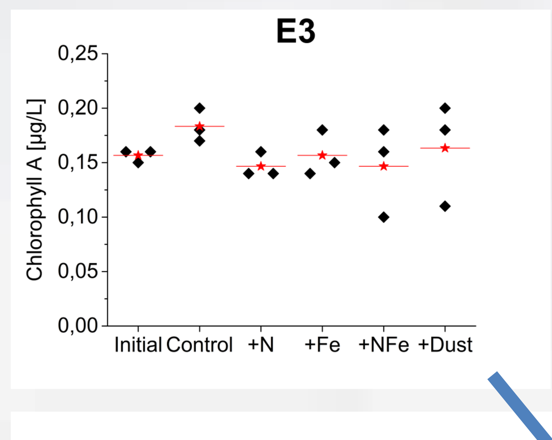
- Dissolved trace metal analyses (dFe, dMn, dCo, dNi, dCu, dZn) via Offline-SeaFAST preconcentration and HR-SF-ICPMS;[8] QuAAtro auto-analyzer-system for PO_4, NO_2^-, NO_3^-, $Si(OH)_4$, and OPA-Fluorescence method for NH_4.[9]

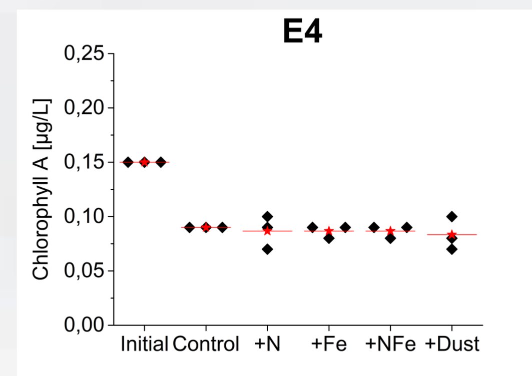
Table 1: Initial conditions of bioassay experiments.

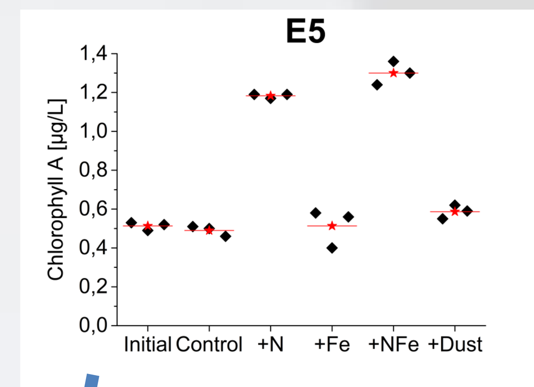
		E1	E2	E3	E4	E5
$T_{pot.}$	°C	-1.3	0.1	-1.6	2.3Ŧ	8.8
Sal	PSU	29.97	30.62	30.03	32.51 Ŧ	35.07
MLD§	m	12	10	14	/	14
NO_3		<0.02	<0.02	0.5	12.3	0.3
PO_4	µM	0.4	0.3	0.3	1.0	0.1
Si		4.4	1.1	4.4	7.4	<0.03
NH_4		<0.05	<0.05	0.5	1.6	<0.05
dCo	pM	202	148	164	114*	40
dFe		1.3	0.8	1.8	1.3*	0.4
dMn	nM	5.0	4.2	5.6	2.8*	1.5
dNi		6.2	4.7	5.9	4.4*	3.1
dCu		4.8	3.7	4.5	2.9*	1.3
dZn		1.8	/	1.8	0.9*	0.8
Fe_N*	nM	1.3	0.8	1.3	-5.3*	0.3

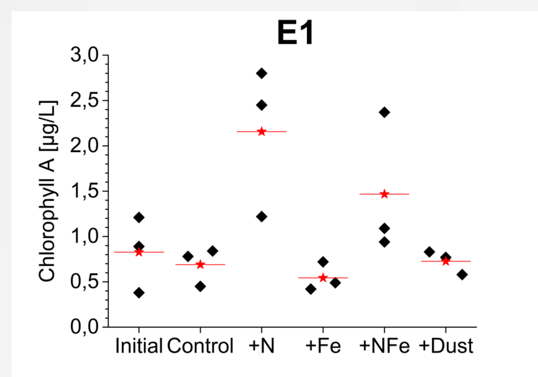
§Surface mixed layer depth (MLD) defined by threshold value of 0.03 kg/m³ difference to surface reference density (10 m depth); ŦValues obtained from ship-based thermosalinograph (11 m depth); *Trace metal concentrations taken from station S8.

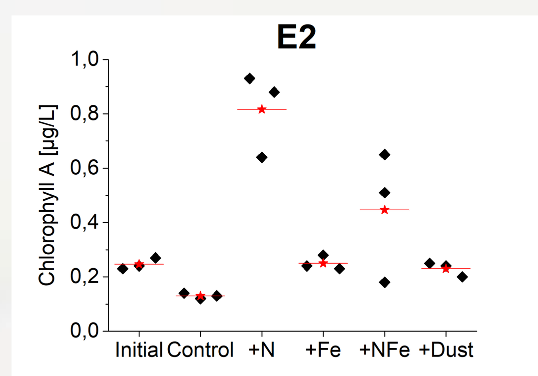
↓→ Figs E1-E5: Chlorophyll-a responses to nutrient supply after 72h incubation following Browning *et al.* (2017). Red symbols show the mean chlorophyll concentration and black symbols indicate the individual replicates. Surface WSC and EGC shows fixed N limited phytoplankton community growth.

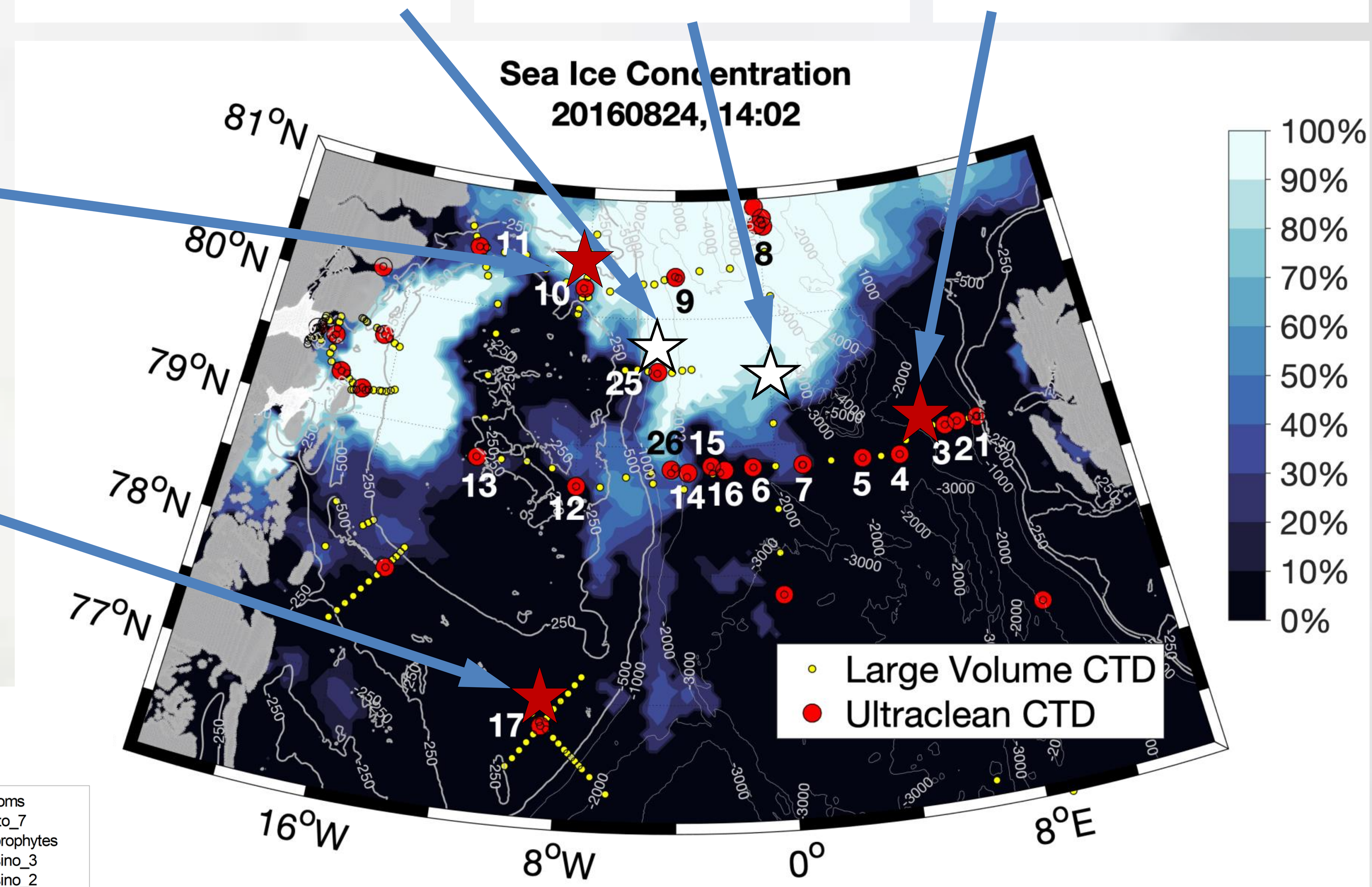




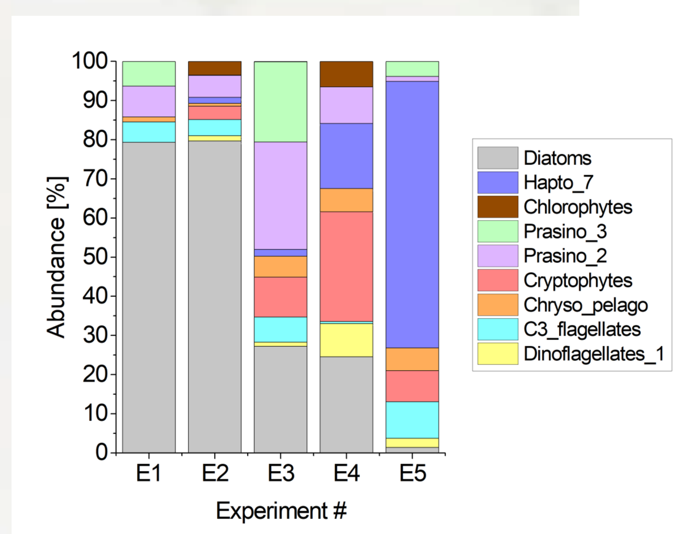






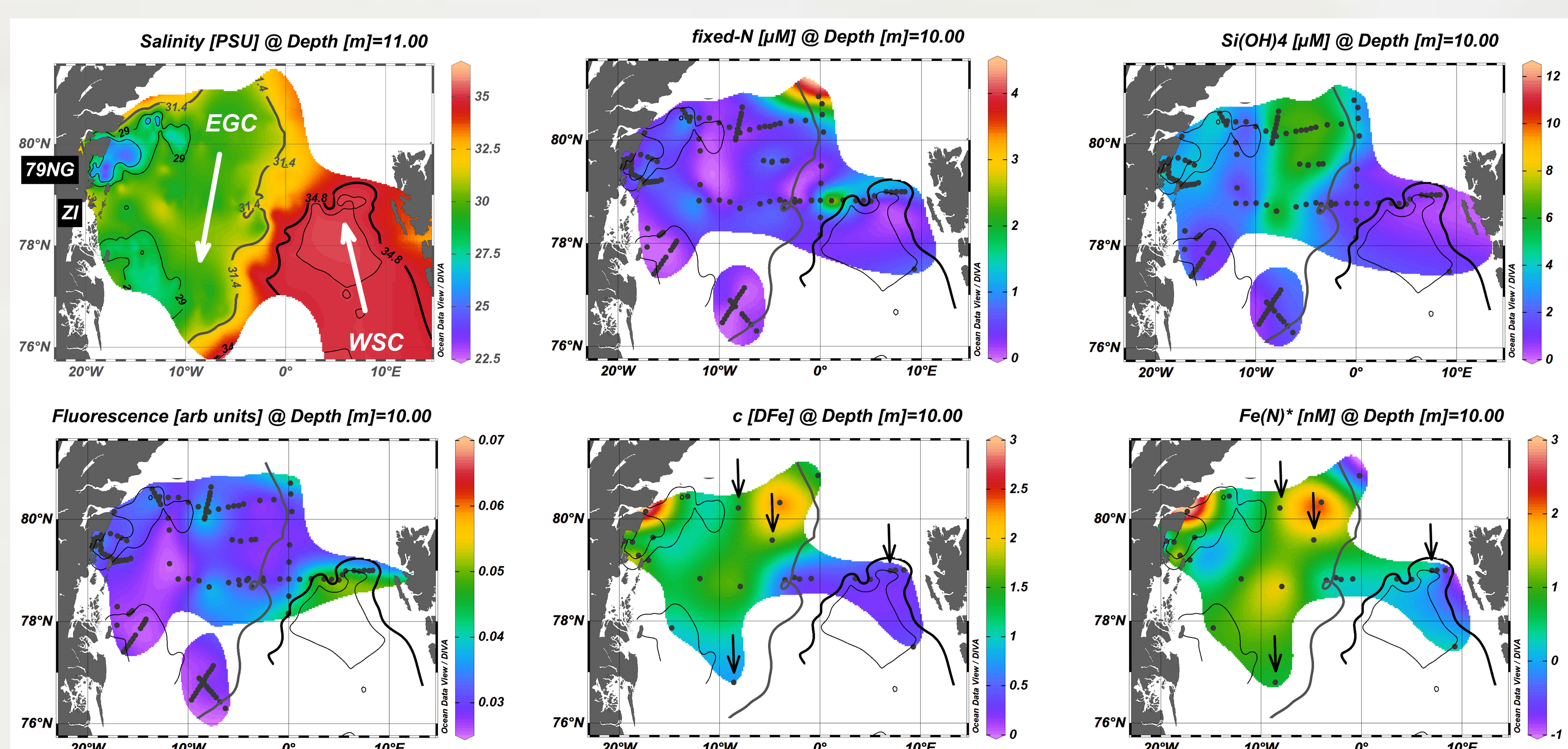


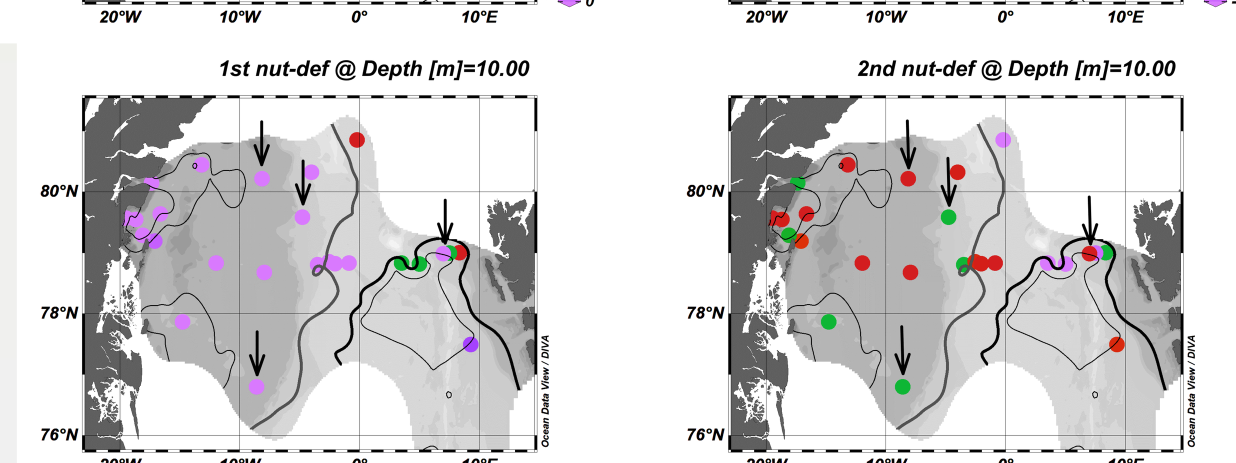
↑ Fig. 1: Bathymetry and location (1a) of ucCTD stations sampled in Fram Strait (1-9, 14-16, 25) and on the NE Greenland Shelf (10-13, 17-24). Star symbols indicate the location and outcome from the nutrient-spiked bio-assay studies (E1-E5):
Red (N limitation), and white (no response to N, Fe or dust addition). Approx. 50% of Fram Strait region (76-82°N, 20°W-15°E) is covered by seasonal sea ice.



↑ Fig. 2: Phytoplankton composition at bioassay experiment water collection sites as determined by pigment analysis and CHEMTAX.[11] Diatoms were the dominant phytoplankton group on the NE-Greenland Shelf (80%, E1, E2), moderately represented in Central and West Fram Strait (26%, E3, E4) and near-absent in surface WSC (1%, E5). There, haptophytes dominated (68%, E5), declined to central Fram Strait (E4, 17%) and were absent on the NE-Greenland Shelf.

↓ Fig. 3: Salinity, fluorescence, nutrient, and nutrient deficiency distributions in Fram Strait region. Primary and secondary nutrient deficiency (bottom row) ranked after Moore (2016): Fixed N (purple), dFe (red) and $Si(OH)_4$ (green).
Black dots indicate the sampling locations (all 10 m depth). Black arrows indicate sites of bioassay experiments (excl. E4). The location of Nioghalvfjerdsfjorden Glacier (79NG) and Zachariæ Isstrøm (ZI) are depicted in the salinity plot. Isohalines (contours) distinguish the polar surface water (S<31.4, bold grey) of the southward-directed East Greenland Current (S<34.8, <0°E) from Intermediate Water (34.8-35.1) and the Atlantic water (S>35.1, in black) of the northward-directed West Spitsbergen Current.





↓ Fig. 4: Surface chlorophyll a concentration in the Greenland Sea. MODIS satellite monthly average (Jul-Aug 2016); visualization produced with Giovanni online data system (NASA GES DISC). Maximum phytoplankton standing stocks observed within WSC surface water.

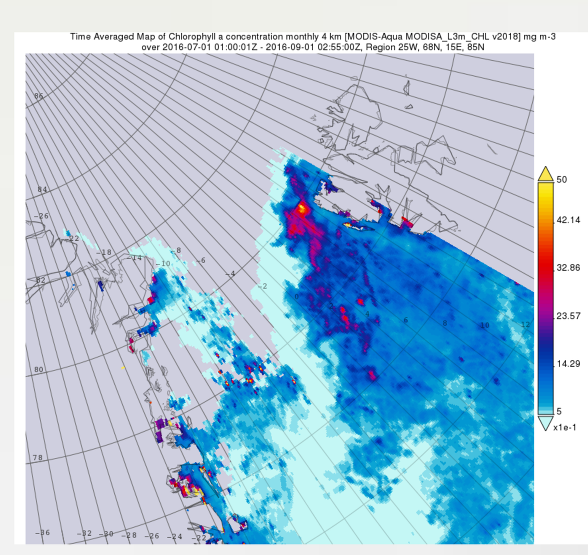


Table 2: Integrated physical characteristics and nutrient concentrations of the East Greenland Current (EGC), West Spitsbergen Current (WSC), and Intermediate (IW) surface (10 m) waters.

		EGC	WSC	IW
Sal	PSU	30.37 ± 0.78	35.02 ± 0.06	32.43 ± 1.97
$T_{pot.}$	°C	-0.5 ± 0.7	8.3 ± 0.7	-0.4 ± 2.2
Fixed N	µM	0.3 ± 0.5	0.7 ± 1.0	0.6 ± 0.6
dFe	nM	1.5 ± 0.8	0.4 ± 0.1	0.8 ± 0.5
$Si(OH)_4$	µM	3.5 ± 2.9	0.7 ± 0.7	2.3 ± 1.2

Conclusion

1. **WSC** and **EGC distinctly different** in physical characteristics, nutrient content, and thereby nutrient supply to surface waters (**Table 2**).
2. **Surface fixed N** essentially supplied by **WSC**; **dissolved Fe** supplied by local-derived glacier melt and via southward transport in the surface **Transpolar Drift**.[12]
3. **West-to-east** progression in **N/Fe-deficiency** evident from bioassay experiments, and relative Fe(N)* phytoplankton requirements[13].
4. **Phytoplankton** growth in the sub-Arctic North Greenland Sea **mostly N-limited**, but WSC potentially **approaching N+Fe co-limitation**.
5. **Convergence** of high N/low dFe (WSC) and high dFe/low N (EGC) waters **may enhance productivity**.
6. **Relief from light limitation unlikely raising primary productivity**, unless additional input of fixed N (and dFe) in post-bloom season.

Ŧ Author contact details

skrisch@geomar.de

tbrowning@geomar.de

eachterberg@geomar.de

References

[1] Rudels (2019) *Encyclopedia of Ocean Sciences*. 3rd Edition. Elsevier Inc., pp. 262–277. **[2]** Laukert *et al.* (2017) Geochim. Cosmochim. Acta, *202*, pp. 285–309. **[3]** Norwegian Polar Institute (2020) Sea ice extent in the Fram Strait in September, 1979-2018, http://www.mosj.no (01.2020). **[4]** Tremblay, Gagnon (2009) *Influence of Climate Change on the Changing Arctic and Sub-Arctic Conditions*. Springer Science + Business Media B.V., pp. 73–89. **[5]** Achterberg *et al.* (2013) Geophys. Res. Lett., *40(5)*, pp. 921–926. **[6]** Taylor *et al.* (2013) J Geophys Res-Oceans, *118*, pp. 3260–3277. **[7]** Mills *et al* (2018) Front Mar Sci, *5*, pp. 1–22. **[8]** Rapp *et al.* (2017), Anal Chim Acta, *976*, pp. 1–13. **[9]** PS100 (GN05) Macronutrient data, https://doi.pangaea.de/10.1594/PANGAEA.905347 (01.2020). **[10]** Browning *et al.* (2017) Nature, *551*, pp. 242–246. **[11]** Mackey *et al.* (1996) Mar. Ecol. Prog. Ser., *144,* pp. 265–283. **[12]** Krisch *et al.*, in preparation. **[13]** Moore (2016) Philos. Trans. R. Soc. A, *374:2081.* **[14]** Schlitzer (2019) Ocean Data View.

Acknowledgements

Special thanks to the crew and all collaborating scientists of GN05 (PS100).

OCEAN SCIENCES MEETING | 16–21 FEBRUARY 2020 SAN DIEGO, CA, USA

GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel
ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG