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The Expedition TRITON2021 of Hendes Dansk Majestæt Skib TRITON to the Greenland Sea in 2021

Edited by

Rebecca McPherson, Carina Engicht and Torsten Kanzow

HELMHOLTZ

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Titel: AWI-Wissenschaftlerin Carina Engicht befestigt den Kranhaken an einem Verankerungselement, um es sicher von der Verankerungsleine vor dem 79 North Glacier in Nordostgrönland zu lösen.
(Foto: Rebecca McPherson, AWI)
Title: AWI scientist Carina Engicht attaches the crane hook to a mooring element in order to safely disconnect it from the mooring line in front of the 79 North Glacier in Northeast Greenland.
(Photo: Rebecca McPherson, AWI)

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TRITON2021

30 August 2021 – 19 September 2021

Runavik (Faroe Islands) – Rejkyavik (Iceland)

Chief scientist
Torsten Kanzow

Coordinator
Rebecca McPherson

Contents

APPENDIX

1. ÜBERBLICK UND FAHRTVERLAUF

Torsten Kanzow[1,2], Rebecca McPherson[1]
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Wir haben uns dem dänischen Inspektionsschiff HDMS *Triton* angeschlossen, das am 30. August in Runavik (Färöer Inseln) auslief. Ziel der Expedition war es, zwei Verankerungen in der Nähe des Nioghalvfjerdsfjorden (79-Nord-Gletscher) in Nordostgrönland zu bergen. Am 07. September erreichten wir den 79N-Gletscher bei fast eisfreien Bedingungen. Am 08. September konnten wir die beiden Verankerungen 79N2-2 (ausgebracht während PS109 im Jahr 2017) und 79N6-2 (ausgebracht während MSM-76 im Jahr 2018) bergen. Die Arbeiten verliefen reibungslos, allerdings fehlten die oberen Elemente (Schwachstellensegment) von 79N2-2. Diese Arbeiten wurden durch vier hydrographische Stationen in der Nähe des Gletschers ergänzt, bei denen das CTD-System mit Angelrute eingesetzt wurde. Am 19. September 2021 erreichten wir Reykjavik (Island).

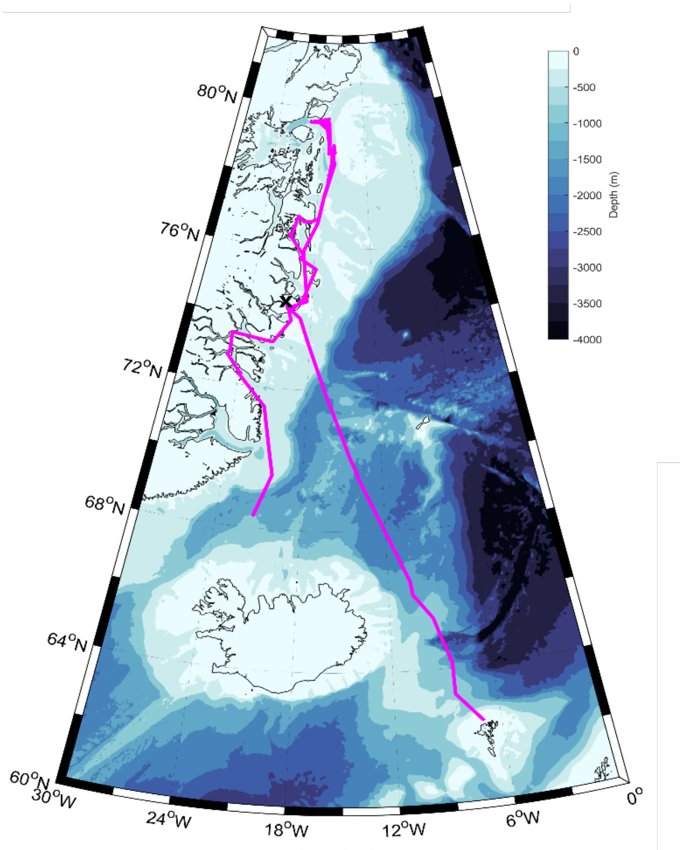

Abb. 1.1: Verlauf der Patrouille der Küstenwache an Bord der HDMS TRITON vom 30. August bis zum 17. September von den Färöern nach Island. Die Station Daneborg im Jungen Sund ist mit einem schwarzen Kreuz markiert.

Fig. 1.1: Track of the coastguard patrol aboard HDMS TRITON from 30 August to 17 September from the Faroe Islands to Iceland. The station of Daneborg in Young Sund is marked with a black cross.

SUMMARY AND ITINERARY

We joined the Danish inspection vessel HDMS *Triton* leaving Runavik (Faroe Islands) on 30 August. Our aim for the expedition was to recover two moorings near the Nioghalvfjerdsfjorden (79 North Glacier) in Northeast Greenland. On 07 September we arrived at the 79N Glacier during almost ice-free conditions. On 08 September we were able to recover both moorings 79N2-2 (deployed during PS109 in 2017) and 79N6-2 (deployed during MSM-76 in 2018). The operations went smoothly, but the top elements (weak link segment) of 79N2-2 were missing. This work was complemented by four hydrographic stations close to the glacier using the fishing rod CTD system. On 19 September 2021 we arrived in Reykjavik (Iceland).

Itinerary in detail

In the afternoon of 30 August 2021, HDMS *Triton* left the port of Runavik (Faroe Islands). Going around the eastern coast of Iceland we arrived in Young Sund and anchored off Daneborg (Danish military station) at 01 September (see cruise map in Figure 1.1).

During the anchorage, we stayed on board as anti-COVID measures demanded the avoidance of contact between personnel in Daneborg and on the ship. *Triton's* helicopter was used for logistical operations (delivering goods from Daneborg to other sites related to the sled dog Sirius Patrol and ancient hut conservation (National Museum Nuuk; Inge Bisgaard & Nanok; Peter Schmidt Mikkelsen). Using small boat shuttles, cargo was brought on board from Daneborg (mainly materials for depots of the Sirius Patrol such as sled dog food, gasoline, other supplies).

On 03 September, we carried out a successful test of the CTD (fishing rod) and our mobile echosounder (Fig. 2.11) from the lower starboard deck of *Triton*. On 04 September, we went out with the zodiac in Young Sund and conducted a smooth measurement programme at 3 sites (near outer sill, close to anchorage position at Daneborg and a bit further inside the fjord, Fig 2.12).

On 05 September, we left Daneborg in the afternoon, heading northward. During the journey north, the helicopter was used to bring supplies of depots from the ship to land and to deploy 3 small teams who were charged with different tasks (e.g. building a runway, repairing a shelter hut). Our route took us along Hofstetter Foreland (Fig. 1.2), Germania Land, west of Store Koldewey, Dove Bugt, Store Belt, then into Norske Trough and passing Ile-de-France, Franske Oer and Norske Ø.

Fig.1.2: Impression from our voyage along Hofstetter Foreland

On 06 September, a pre-briefing was carried out with the deck crew where Carina Engicht explained theoretically how the mooring recovery operations should be conducted. This was followed later in the day by a practical exercise where the crew practiced both the crane and capstan handling.

We arrived at the mooring site of 79N6-2 on 07 September in the evening (off the southeast corner of Hovgaards Ø, Fig 2.13), reaching the northernmost position of the expedition. The sea ice conditions this year turned out to be highly favorable for our purposes, with hardly any sea ice found both in our work area (Fig. 1.3) and during the transit from the south. This situation is highly unusual when compared with summertime conditions in the past decade. Half a mile south of the position of site 79N6-2 we conducted a CTD cast, which revealed significantly lower bottom temperatures than were found at this site in 2018 during the MSM76 expedition. *Triton* moved to mooring position 79N2-2 at the calving front in the night with medium visibility and returned to 79N6-2. On the morning of 08 September, we worked on the recovery of the mooring 79N6-2. Two icebergs were in the vicinity and isolated small sea ice floes. Visibility had considerably improved compared to the previous day. In somewhat windy conditions (from northerly directions), the mooring was released and a line from *Triton* was attached to the surface float using a Zodiac (Fig. 2.2). The mooring was then brought on board smoothly over the port side (upper deck) of *Triton*, working with the ship's crane and capstan.

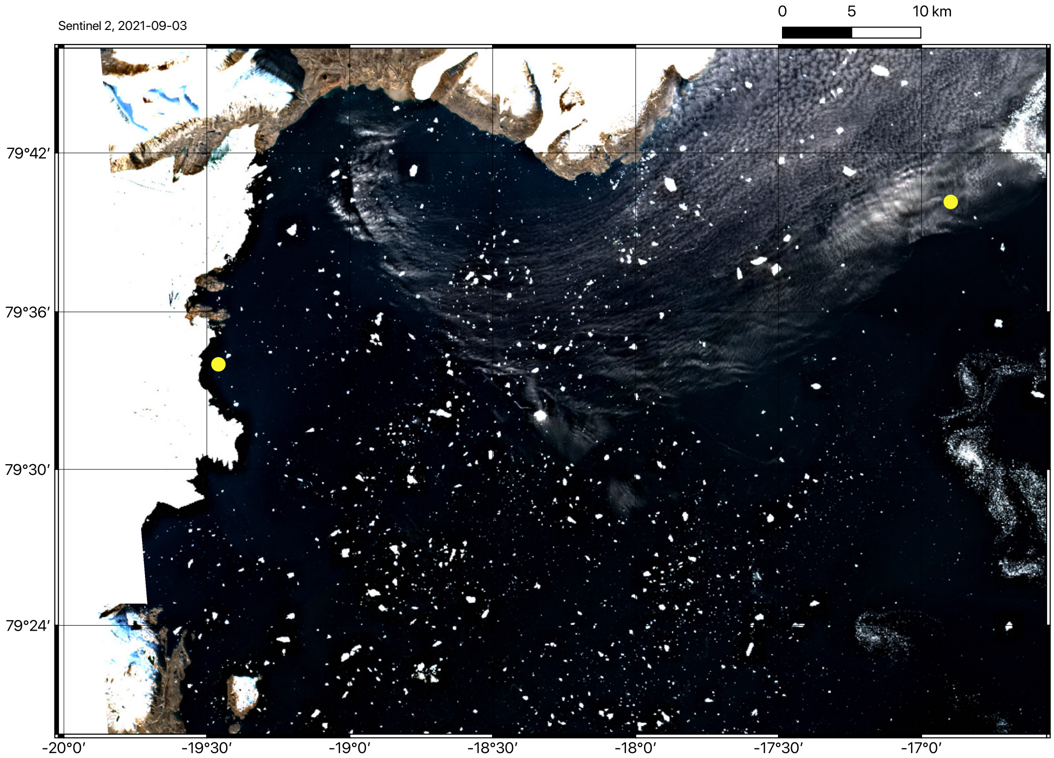

Fig. 1.3: Satellite image (Sentinal 2) of the ice situation in the work area near the 79N Glacier taken quasi cloud-free conditions on 03 September, 2021. The calving front of the 79N North Glacier is seen on the left, and the southern coast of the island of Hovgaards Ø at the top. Yellow dots mark the mooring positions of 79N2-2 (near the calving front) and 79N6-2 (off Hovgaards Ø). Image provided by Janin Schaffer (AWI).

In the afternoon of 08 September, we moved west to mooring 79N2-2. Winds were very calm and visibility had improved even further. Compared to 2017, a glacier ice tongue had developed south of site 79N2-2, extending eastward into the bay from the calving front. At the site 79N2-2 there was basically no sea sea ice present and icebergs were seen at a safe distance.

Mooring 79N2-2 was successfully released and surfaced. A Zodiac was again deployed to attach a line and recover the instruments in the inductive loop above weak link on board. Upon surfacing however, it was clear that the entire inductive loop and all instruments attached to it were missing. The data logger was still attached to the main mooring line, as were all instrumentation below it. The rest of the mooring recovery went smoothly. After the recovery, three CTD profiles were taken with the fishing rod: one at the 79N2 position, one at the sill upstream of the 79N2 position, and another one upstream of the sill in the bay (Fig 2.13). The purpose of these measurements was to follow up on the results by Schaffer et al. (2020) regarding hydraulic control of the warm Atlantic Water inflow into the cavity below the floating ice tongue of the 79N glacier. Upon completion of the task in the evening of 08 September, we moved south along Norske Trough.

On 09 September during low visibility, the 3 teams which had been deployed at the huts on land during the transit north were taken back on board by helicopter while *Triton* was traveling in Norske Trough east of Norske Oer and Franske Oer. Winds picked up strongly overnight (20 m/s) when *Triton* sailed south, arriving in Dove Bugt in the morning of 10 September. The plan to anchor off Denmarks Havn was abandoned despite its protected location due to too high winds. After a small exchange by zodiac, *Triton* relocated to Godfred Hansen Ø, an island further inshore. Here *Triton* anchored, facing Ålborghus, an ancient trapper hut. Very strong winds and low visibility on 11 September did not allow many of the planned logistics to be accomplished. The plan had been to sling a storage shed next to the trapper hut onto *Triton* by helicopter to bring it to Ella Ø.

On 12 September, when still anchoring off Godfred Hansen Ø, the visibility improved . The following morning, as winds had calmed down significantly, the helicopter operation was successfully carried out and *Triton* left Dove Bugt later in the day, heading south along the coast.

On the evening of 13 September, in calm conditions, *Triton* anchored overnight in the sheltered natural harbour at Haystack. The next day, a helicopter flight to Alabama Hut brought supplies over for the coming Sirius Patrol winter campaign. Bringing out further supplies to Germania Havn (invisible to us due to low visibility), *Triton* arrived back in Daneborg in the early morning hours of 15 September. Here we had the opportunity to get a guided tour of the housings, workshops and sled dog yards of the Sirius Patrol.

In the evening of 15 September, *Triton* left Daneborg to move into Kejser Franz Joseph Fjord. The anchorage at Ella Ø facing the scientific station was reached near noon. The hut from Ålborghus was slung over to the island in the morning. The afternoon was used as an opportunity to visit the station, which was just being shut down for the winter by Sören Rysgaard whom we met for a few minutes before he and his colleagues were picked up by Twin Otter. In the evening, the oceanography team carried out a calibration cast between the Sea&Sun CTD sensor used on the fishing rod and a MicroCAT (#13489 from 79N2-2) down to 300 m using the Zodiac in conditions of snowfall and light fog. Unfortunately, due to technical issues, the CTD was not recording during this cast.

In the morning of 16 September *Triton* left Ella Ø for Kong Oscar Fjord, arriving at the meteorological Station Mestervik (close to the exit of the fjord) later that day. The next day, we took on board around 30 Danish civilians, that had visited their relatives at the Sirius Patrol in Daneborg earlier and had stranded at Mestersvik on their way by plane back home to Denmark. In the following *Triton* headed straight south along the Greenlandic coast and reached the port of Reykjavik (Iceland) on 19 September.

WEATHER CONDITIONS DURING TRITON2021

Torsten Kanzow[1,2], Rebecca McPherson[1]

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On 30 August 2021 at 3pm, HDMS *Triton* left the port of Runavik (Faroe Islands) and set sail towards Young Sund in the North. *Triton* anchored off Daneborg on 1 September. During the transit, the swell was between 1.5 – 2-5 m. In Young Sund. weather conditions were bright and clear with little wind. Additionally, due to the sheltered location of the fjord, the sea state was calm.

We remained in Young Sund until 5 September during which time there was little wind or cloud cover, and the sea state in the fjord was calm.

For several days, the good weather conditions prevailed with low winds and a swell of < 1m as we transited north towards 79N Glacier. Low clouds appeared as we moved farther north and visibility decreased to less than 20 m as we arrived on 07 September at the first mooring site (79N6-2). Though visibility was poor, the ice conditions were excellent as hardly any ice was seen at either mooring site or during the transit north.

On the morning of 08 September, visibility had improved considerably and the 79N6-2 mooring was recovered in relatively windy conditions from a northerly direction. The sea state was calm. Visibility improved over the day, with calmer winds and an almost mirror sea state as moved to the second mooring site at the glacier front. At this site (79N2-2) there was basically no sea sea ice present and icebergs were seen at a safe distance.

Visibility decreased and winds increased on 09 September as we transited south. Winds picked up strongly overnight (20 m/s) as the *Triton* arrived in the Dove Bugt in the morning of 10 September. Very strong winds and low visibility continued on 11 September, preventing the planned logistics from taking place depsite the shelted location.

On 12 September, the visibility improved during the day while strong winds persisted. Good visibility maintained on the following morning, and winds calmed down significantly when still anchoring off Godfred Hansen Ø on 13 September. In calm conditions on the evening of 13 September, *Triton* anchored overnight in the sheltered natural harbour at Haystack.

There were calm conditions and excellent visibility on the evening of 15 September as the *Triton* moved into Kejser Franz Joseph Fjord. Conditions deteriorated over the next day, with fog and snowfall and larger wind-driven swells despite the shelted setting.

On 16 September, visibility had improved and the sea state was calmer in Kong Oscar Fjord. Cloud cover was low but winds lessened. From 17 September, on the way back to Iceland, the sea state was relatively calm with swells of between 1 – 2 m and light winds. The *Triton* arrived in the evening of 19 September in dry and calm conditions.

2. PHYSICAL OCEANOGRAPHY

Torsten Kanzow[1,2], Rebecca McPherson[1], Carina Engicht[1]
[1]DE.AWI
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Grant-No. AWI_TRITON_01

In order to be able to join the HDMS *Triton* voyage, the oceanography team of AWI had applied for support by the Joint Arctic Command (JACO) of the research project *"Access of Atlantic Water to Greenland Glaciers"*, which had been submitted via the ISAAFFIK web site and was finally approved on 23 March, 2021.

Background and objectives

More than 25% of the current global mean sea level rise is caused by mass loss of the Greenland Ice Sheet, with a substantial increase of the mass loss rate in recent decades. The strongest increase in mass loss has been observed at the margins and lower elevations of the Greenland Ice Sheet where glaciers are retreating, accompanied by strongly accelerating glacier flow speeds and thinning. Observations of individual glaciers show that their acceleration and thinning during the recent past is related to a warming of Greenland's fjord waters, which is caused by an inflow of warmer Atlantic Water (AW) from the subtropical Atlantic. In the last decade, the warming of the North Atlantic has proceeded into the Nordic Seas and the Arctic Ocean, amounting to almost 1°C in the West Spitsbergen Current (WSC). One prominent example of rapid glacier retreat in Northeast Greenland has been the collapse of the floating ice tongue of Zachariæ Isstrøm (ZI, Fig. 2.1).

The largest remaining floating ice tongue of Greenland is the neighboring 79 North Glacier (79NG, Fig. 2.1). Together, ZI and 79NG drain the Northeast Greenland Ice Stream (NEGIS) - encompassing 15% of the total area of the Greenland ice sheet. Continuous thinning of the 79NG tongue by up to 30% has occurred over the past 20 years, caused by a mass imbalance due to increased melting along the ice tongue base, driven by ocean heat fluxes. There exists a pathway of warm AW recirculating in Fram Strait across the Northeast Greenland shelf towards the 79NG (depicted by a dashed, red arrow in Fig 2.1). We have demonstrated, based on observations acquired aboard *RV Polarstern* in 2016 and 2017 (PS100 and PS109), that ocean heat transport toward the 79NG is accomplished by a continuous, year-round inflow of warm AW, with the inflow into the cavity of the 79NG being hydraulically controlled by a local bathymetric sill-system.

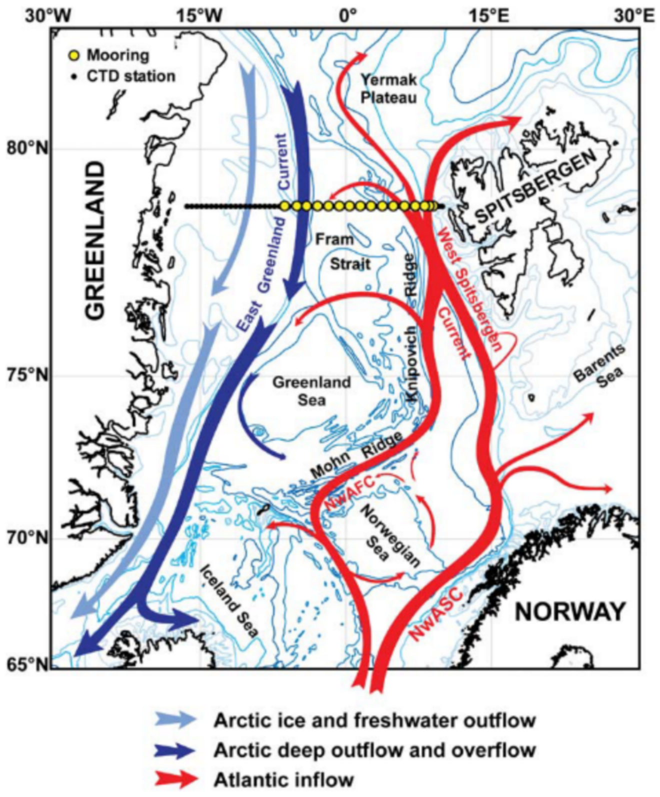


Figure 2.1: General ocean circulation in the wider areas of interest (Fram Strait, Northeast Greenland Shelf, Western Nansen Basin). Red arrows represent the circulation of warm Atlantic Water (the dashed one has been added based on results by Schaffer et al., (2017), while light blue ones show the surface Polar water. Also shown are the locations of the 79N Glacier (79NG, red cross) and Zachariæ Isstrøm (ZI, green cross). Adapted from Beszczynska-Möller (2012).

The North-East Greenland Ice Stream (NEGIS) system shows signs of significant ocean-driven thinning of its major outlet glaciers, the 79NG and ZI. We aim to implement sustained monitoring capacities for investigating ocean-driven melt of the 79NG and ZI. This shall enable us to answer what the sensitivities of present-day ocean-driven melt are to changing environmental conditions at 79NG and ZI.

In order to address this, the aim of this field work was to recover two moorings at the 79NG; one located in the inflow channel at the glacier's calving front (mooring 79N2-2 deployed during PS109 in September 2017) and the other residing further to the east, off Hovgaard Ø (mooring 79N6-2 deployed during MSM76 in September 2018). We posit that the variability of melting of the 79NG and ZI glaciers is predominantly remotely forced: based on far-field advection of AW from Fram Strait and modification of AW on the continental shelf, we will use e.g., wind stress and sea ice climatologies and far field mooring data (WSC) to establish these connections. The data collected near the 79NG and ZI will also be used to validate a coupled ocean-ice sheet model of the NEGIS-ocean system that is being newly developed at AWI, and will be used to develop an advanced prognostic capacity at the regional scale.

Work at sea

2.1 Mooring Programme

Both moorings 79N2-2 and 79N6-2 were successfully recovered during the expedition. In the following, the general procedure is described (Chapter 2.1), followed by recovery overview tables (Chapter 2.2) and a visualization of some of the data sets retrieved (Chapter 2.3).

General Procedure and setup

Recoveries began by establishing an acoustic communication to the mooring releasers. At the mooring position, an acoustic command was sent from the vessel to the releasers to obtain information about the slant distance from the ship to the releaser and the status of the releaser itself. The quality of the acoustic reply was very high in comparison to other vessels and we instantly received clear replies from the releasers. After receiving a status that the releasers were vertical and at the correct distance, the ship moved approximately two cables away from the mooring position. This was followed by another acoustic signal sent to estimate the distance. Once confirmed, we sent the release command. In both cases, the confirmation of a successful release was received after the first release command was sent, and acoustic ranging confirmed the moorings were rising.

After the flotation had surfaced, mooring technician Carina Engicht went with the zodiac to connect a rope from the vessel to the mooring (Fig 2.2). The zodiac then returned to the vessel. For mooring 79N2-2, we had a backup zodiac in the water because it had a longer rope than 79N2-6 and more flotation packs on the surface. In case the mooring would have drifted around the vessel, the zodiac could have grabbed a pack of floats and straightened the mooring line out (away from the hull).

Fig. 2.2: Zodiac established line connection to top floatation of mooring 79N-6, so the mooring can be pulled to the vessel

The recovery setup and procedures on deck are now explained. As you see in Figure 2.3 (right panel; showing the floats on the crane) a block was mounted to the crane. The line comes from the cable drum over the capstan (Fig. 2.3, left panel) and through the block at the crane, with the capstan holding the weight of the mooring. The first step to retrieve the floatation pack is to attach the crane hook (Fig. 2.3, right panel and Fig. 2.4, left panel) to the top of the floatation pack. Now the crane can lift the pack by the hook until the load is taken over by the crane hook. The recovery line (white line in Fig. 2.3) gets manually disconnected and is subsequently re-connected below the floatation. The capstan then lifts the mooring from below the flotation (thus taking over the load from the crane) and the floatation lower connection is now loose and manually disconnected. It is lowered on deck by the crane hook.

Fig. 2.3: The left image shows the setup of the capstan and cable drum during a recovery. The right image displays the crane on the starboard side, which was used for the recovery. Mooring technician Carina Engicht is the person standing on the right.

Now the load is back on the capstan, so the mooring line can be wound onto the cable drum until another mooring element comes on board which needs to be taken out (for flotation and ADCPs, etc). Then the procedure is repeated. Note that we replaced all iron shackles connection (which were originally installed during the mooring deployments) by rope shackles before spooling the connection over the capstan drum. This was to make the line handling easier and safer, given the small diameter of the drum.

Fig. 2.4: left image: Carina Engicht attaches the crane hook to a mooring element in order to safely disconnect it from the mooring line. Right image: Heavy corrosion is visible on the ring in the release hook of mooring 79N6-2.

We had two people at the reeling taking the instruments off the mooring line, with the lead being Carina Engicht, who also gave the commands to the deck crew. Three crew members were in charge of the capstan; one behind (holding the line tight), one in front (guiding the line) and one operator who also switched the power between crane and capstan. Two people were on the cable drum, with one winding and the other one guiding the line onto the drum. The deck officer was present to help with communication. There was also a crane operator and one person in charge of the protocol (Rebecca McPherson). Two persons - one scientist (Torsten Kanzow) and one officer from *Triton* - were observing the mooring arrangement in the water and gave advice regarding orientation of the vessel relative to the mooring. The officer was also in charge of the security on deck.

In terms of operations, the recoveries went smoothly and without any interruptions. Yet several points should be noted. Though all instruments were recovered from mooring 79N6-2 (Tab. 2.1) the rings in the hooks of both releasers had significantly suffered from corrosion, to the point that the mooring would not have survived another year connected to the anchor (see right panel in Fig. 2.4). Many of the recovered instruments were also covered by biological growth (see ADCP in Fig. 2.5).

Fig. 2.5: The ADCP (top element) and the dual release unit (lower element) of mooring 79N6-2 are lowered onto the deck. Biological growth has covered both elements.

From the second recovered mooring (79N2-2), all instruments above the data logger were missing. These were several inductive SBE-39 (T, P) and one SBE-37 (T,C,P) (see Table 2.2 and Figure 2.7 for details). They had been placed on a wire for inductive data transmission to the data logger, above which a series of weak link connections had been placed in order to break at defined positions should an iceberg get hold of the mooring. We cannot judge (yet) whether the loss of the inductive loop (including all instruments at depths shallower than 228 m) was cause by an iceberg encounter or by corrosion of the weak (electrically conductive) links. What should be noted is that the data logger experienced strong corrosion on the lid. It was decided not to open the data logger in the ship to retrieve the data storage card as the logger contains lithium batteries, which in case the pressure case is flooded, might explode.

2.1.2 Recovery Tables

Below is a series of tables which summarise the mooring recoveries, including their metadata and location (Tab. 2.1), the status of the instruments (Tab. 2.2, Tab. 2.3) and their recovery protocols (Fig. 2.6, Fig. 2.7).

Tab 2.1: Overview of the mooring recoveries during TRITON2021 including latitude, longitude, the time at which the acoustic release was triggered and the time of the last instrument on deck.

Mooring	Date released	Time released	Latitude	Longitude	Time on deck
79N6-2	08.09.2021	09:51	79° 39.9 N	16° 54.7 W	11:06
79N2-2	08.09.2021	14:35	79° 34.22 N	19° 28.67 W	16:04

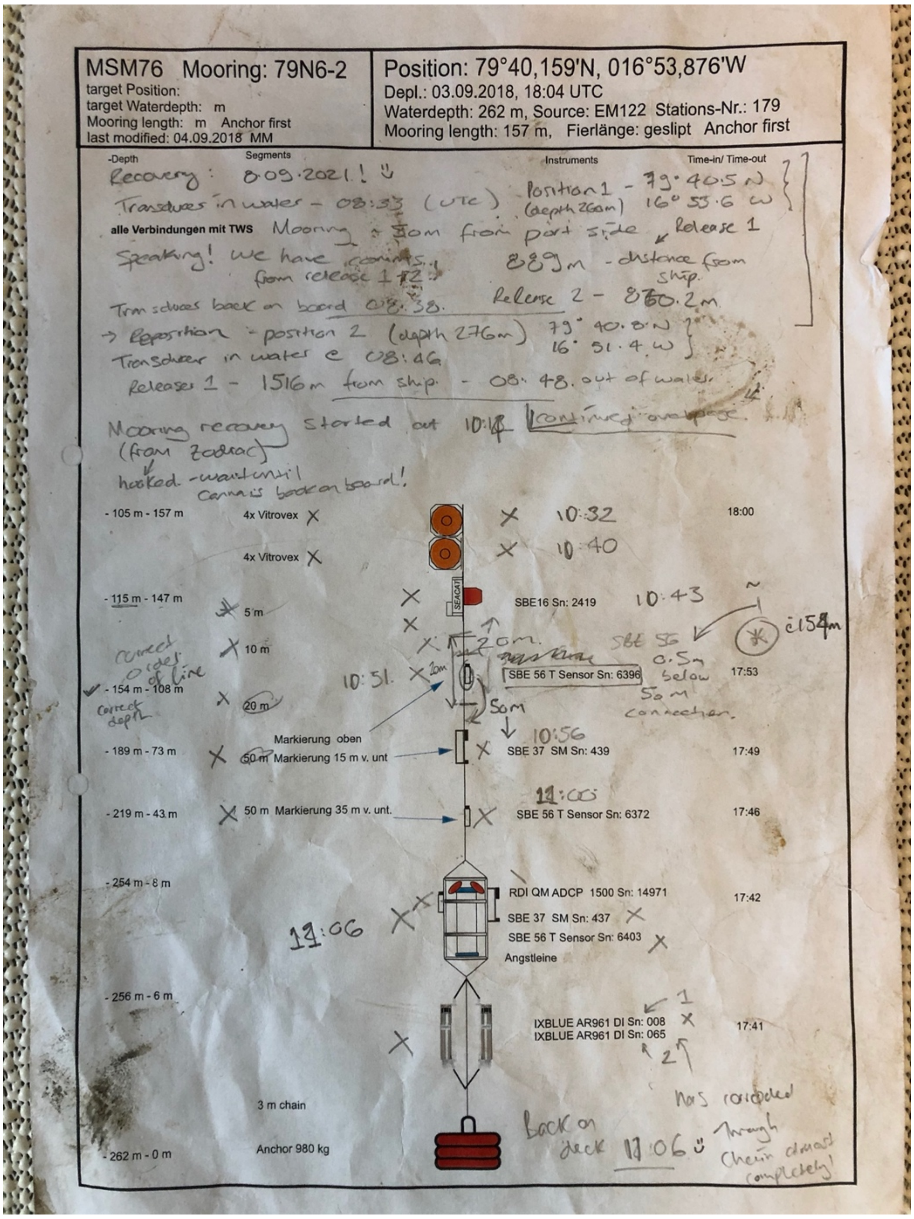
Tab 2.2: Overview of the instruments and data sets from mooring 79N2-2. Also given are the serial numbers of the instruments, and whether they were recovered or not. Initial comments on the quality of the data recovered are provided.

Instrument	s/n	Recovered?	Download complete	End of record	Data quality	Comment
SBE-37	15723	Lost	no	tbd	tbd	data logger might have data
SBE-39	8419	Lost	no	tbd	tbd	data logger might have data
SBE-39	8416	Lost	no	tbd	tbd	data logger might have data
SBE-39	8420	Lost	no	tbd	tbd	data logger might have data
SBE-39	8418	Lost	no	tbd	tbd	data logger might have data
Develogic Data Logger	12084	yes	no	tbd	tbd	Strong corrosion on lid
SBE-37	13489	Yes	Yes	08/09/21	good; S drift?	--
SBE-56	7078	Yes	Yes	23/04/21	good	--
SBE-56	7079	Yes	Yes	12/04/21	good	--
SBE-56	7080	Yes	Yes	26/03/21	good	--
SBE-37	13488	Yes	Yes	08/09/21	good; S drift?	--
RDI ADCP 1200	22753	Yes	no	tbd	tbd	--
SBE-37	0229	Yes	Yes	14/12/20	good	--
SBE-56	7081	Yes	Yes		good	--
RDI ADCP-LR	23977	Yes	no	tbd	tbd	--
SBE-56	7082	Yes	Yes	tbd	good	--

Instrument	**s/n**	**Recovered?**	**Download complete**	**End of record**	**Data quality**	**Comment**
IXSea RT2500	951	Yes	n/a	n/a	n/a	--
IXSea RT2500	739	Yes	n/a	n/a	n/a	--

Tab 2.3: Instrument and data sets recovered from mooring 79N6-2

Instrument	**s/n**	**Recovered?**	**Download complete**	**End of record**	**Data quality**	**Comment**
SBE-16	2419	Yes	Yes	08/09/21	T & C severely corrupted! Not usable.	Sensor should be disposed
SBE-56	6396	Yes	Yes	08/09/21	good	--
SBE-37	439	Yes	Yes	08/09/21	good	--
SBE-56	6372	Yes	Yes	08/09/21	good	--
RDI ADCP 150	14972	Yes	Yes	tbd	tbd	--
SBE-37	437	Yes	Yes	08/09/21	T ok; few jumps in S	Periods with jumps need to be removed
SBE-56	6403	Yes	Yes	08/09/21	good	--
IXblue AR 961	008	Yes	Yes	n/a	n/a	Strong corrosion on releaser ring
IXblue AR 961	065	Yes	Yes	n/a	n/a	Strong corrosion on releaser ring



MSM76 Mooring: 79N6-2
target Position:
target Waterdepth: m
Mooring length: m Anchor first
last modified: 04.09.2018 MM

Position: 79°40,159'N, 016°53,876'W
Depl.: 03.09.2018, 18:04 UTC
Waterdepth: 262 m, Source: EM122 Stations-Nr.: 179
Mooring length: 157 m, Fierlänge: geslipt Anchor first

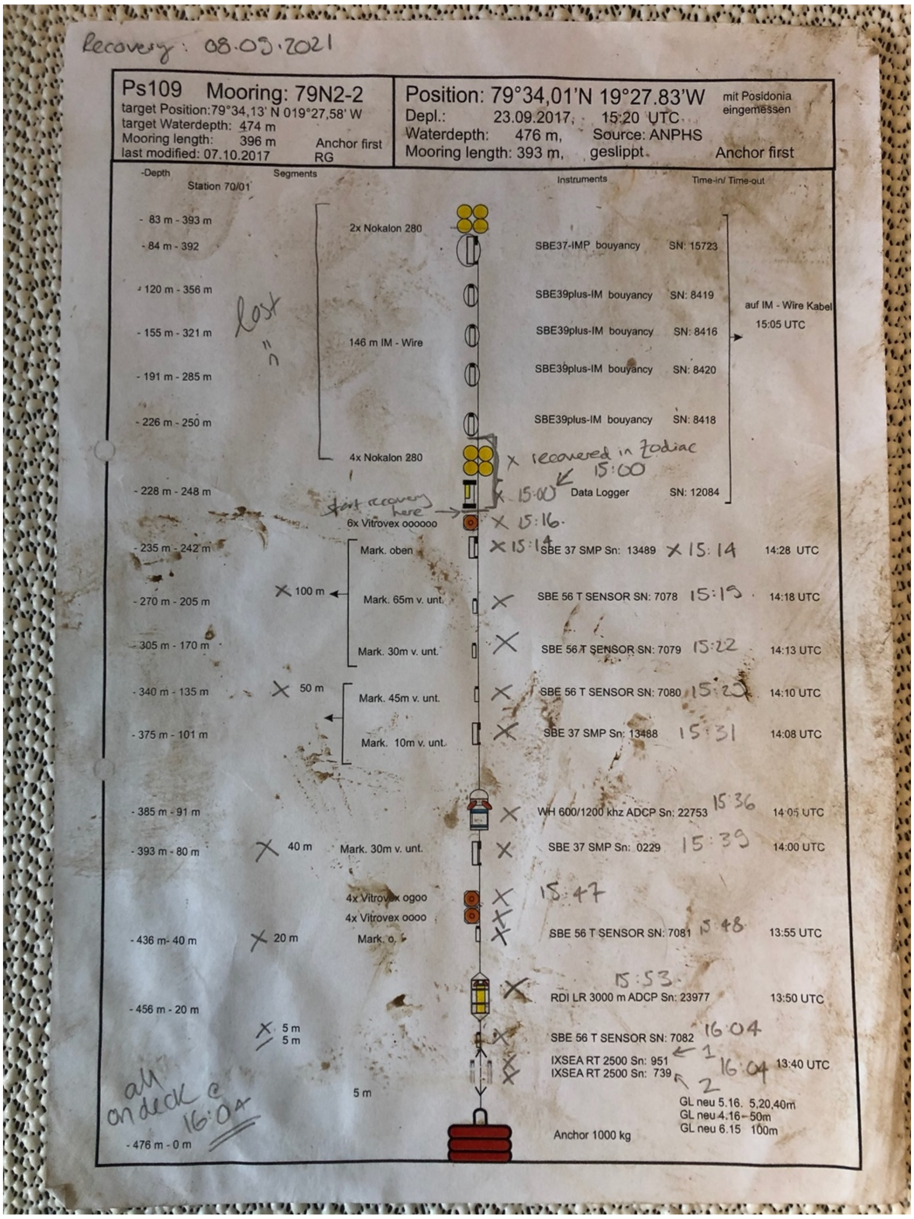
-Depth Segments Instruments Time-in/ Time-out

Recovery: 8.09.2021! :)
Transducers in water – 08:33 (UTC)
Position 1 – 79° 40.5 N, 16° 53.6 W (depth 260m)
alle Verbindungen mit TWS
Mooring ~ 30m from port side
Speaking! we have comms.. from release 1 + 2 :)
Release 1 889m – distance from ship.
Release 2 – 860.2m
Transducers back on board 08:38.
→ Reposition – position 2 (depth 276m) 79° 40.8 N, 16° 51.4 W
Transducer in water @ 08:46
Releases 1 – 1516m from ship – 08:48. out of water.

Mooring recovery started at 10:14 (from Zodiac) continued over page.
hooked – wait until Carina is back on board!

- 105 m - 157 m 4x Vitrovex X X 10:32 18:00
4x Vitrovex X X 10:40
- 115 m - 147 m 5 m X SBE16 Sn: 2419 10:43
X
10 m X 20m.
correct order of line
✓ - 154 m - 108 m 20 m X 10:51. X 2m SBE 56 T Sensor Sn: 6396 17:53
correct depth
SBE 56 0.5m below 50m connection.
c154m
50m
Markierung oben
- 189 m - 73 m X 50 m Markierung 15 m v. unt X SBE 37 SM Sn: 439 10:56 17:49
- 219 m - 43 m X 50 m Markierung 35 m v. unt. X SBE 56 T Sensor Sn: 6372 11:00 17:46
- 254 m - 8 m X X 11:06 RDI QM ADCP 1500 Sn: 14971 17:42
SBE 37 SM Sn: 437 X
SBE 56 T Sensor Sn: 6403 X
Angstleine
- 256 m - 6 m X IXBLUE AR961 DI Sn: 008 1 X 17:41
IXBLUE AR961 DI Sn: 065 2
has corroded through chain almost completely!
3 m chain
- 262 m - 0 m Anchor 980 kg Back on deck 11:06 :)

Fig. 2.6: Recovery protocol of mooring 79N6-2



Recovery: 08.09.2021

Ps109 Mooring: 79N2-2
target Position: 79°34,13' N 019°27,58' W
target Waterdepth: 474 m
Mooring length: 396 m Anchor first
last modified: 07.10.2017 RG

Position: 79°34,01'N 19°27.83'W mit Posidonia eingemessen
Depl.: 23.09.2017; 15:20 UTC
Waterdepth: 476 m, Source: ANPHS
Mooring length: 393 m, geslippt Anchor first

-Depth Station 70/01 | Segments | Instruments | Time-in/ Time-out

- 83 m - 393 m 2x Nokalon 280
- 84 m - 392 SBE37-IMP bouyancy SN: 15723
- 120 m - 356 m SBE39plus-IM bouyancy SN: 8419 lost
- 155 m - 321 m 146 m IM - Wire SBE39plus-IM bouyancy SN: 8416 "
- 191 m - 285 m SBE39plus-IM bouyancy SN: 8420
- 226 m - 250 m SBE39plus-IM bouyancy SN: 8418
4x Nokalon 280 x recovered in Zodiac 15:00
- 228 m - 248 m x 15:00 Data Logger SN: 12084
auf IM - Wire Kabel 15:05 UTC
start recovery here
6x Vitrovex oooooo x 15:16.
- 235 m - 242 m Mark. oben x 15:14 SBE 37 SMP Sn: 13489 x 15:14 14:28 UTC
- 270 m - 205 m x 100 m Mark. 65m v. unt. x SBE 56 T SENSOR SN: 7078 15:19 14:18 UTC
- 305 m - 170 m Mark. 30m v. unt. x SBE 56 T SENSOR SN: 7079 15:22 14:13 UTC
- 340 m - 135 m x 50 m Mark. 45m v. unt. x SBE 56 T SENSOR SN: 7080 15:25 14:10 UTC
- 375 m - 101 m Mark. 10m v. unt. x SBE 37 SMP Sn: 13488 15:31 14:08 UTC
- 385 m - 91 m x WH 600/1200 khz ADCP Sn: 22753 15:36 14:05 UTC
- 393 m - 80 m x 40 m Mark. 30m v. unt. x SBE 37 SMP Sn: 0229 15:39 14:00 UTC
4x Vitrovex ogoo x 15:47
4x Vitrovex oooo x
- 436 m- 40 m x 20 m Mark. o. x SBE 56 T SENSOR SN: 7081 15:48 13:55 UTC
- 456 m - 20 m x RDI LR 3000 m ADCP Sn: 23977 15:53 13:50 UTC
x 5 m
5 m x SBE 56 T SENSOR SN: 7082 16:04
x IXSEA RT 2500 Sn: 951 ← 1
x IXSEA RT 2500 Sn: 739 ← 2 16:04 13:40 UTC
5 m
GL neu 5.16. 5,20,40m
GL neu 4.16 - 50m
GL neu 6.15 100m
- 476 m - 0 m Anchor 1000 kg
all on deck @ 16:04

Fig. 2.7: Recovery protocol of mooring 79N2-2

Preliminary (expected) results

Overall, the data quality from the hydrographic sensors (SBE37 and SB56) was good. It can be seen from Fig. 2.8 that all records from the SBE-56 sensors of mooring 79N2-2 ended around April 2021 (left image), thus after 3.5 years (roughly 5 months prior to recovery). See also Table 2.2. This is probably due to the high sampling rate chosen (30 seconds), which lead to empty batteries in the end. There is no suspicion of any malfunction of any of these sensors. The SBE-56 records of mooring 79N6-2 (deployed one year after 79N2-2) are all complete (right panel), despite having used a sampling frequency of 10 seconds.

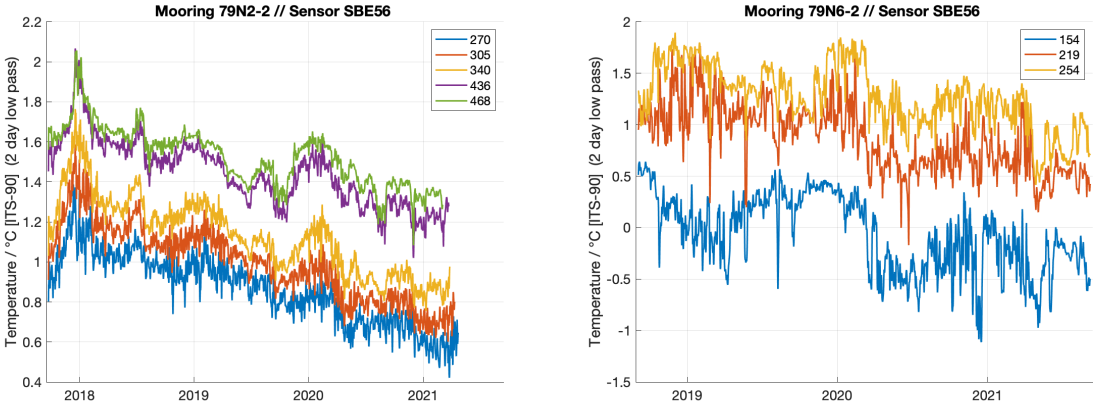
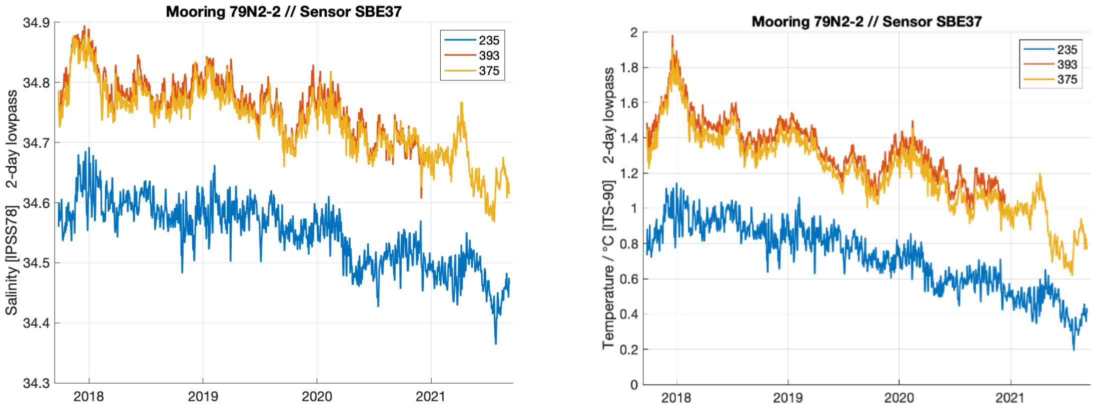


Fig. 2.8: Temperature time series of all recovered SBE-56 sensors from moorings 79N2-2 (left) and 79N6-2 (right). The legends state the nominal depths of the sensors.

It can be seen from Figure 2.9. that two records of the SBE-37 sensors of mooring 79N2-2 are complete while one (the sensor #229 placed at 393 m) ends in December 2020 (see also Table 2), thus after 3 years and 3 months of operation. This is probably due to empty batteries. There is no malfunction visible.



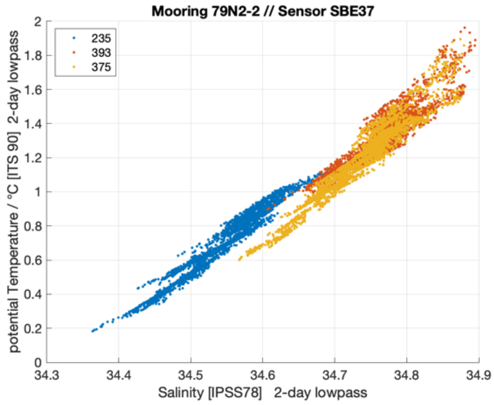


Fig. 2.9: Time series of salinity (upper left), temperature (upper right) and a temperature-salinity diagramme (lower left) based on the SBE-37 Sensors (MicroCATS) of mooring 79N2-2. The legends state the nominal depths of the sensors.

It can be seen from Figure. 2.10 that both records from the SBE-37 sensors of mooring 79N6-2 are complete. A few “jumps” can be seen in salinity of the sensor #437 placed at 254 m depth which become quite apparent in the T-S diagram (lower left panel) as secondary clusters of data points. These data points should be carefully removed/flagged in the processing.

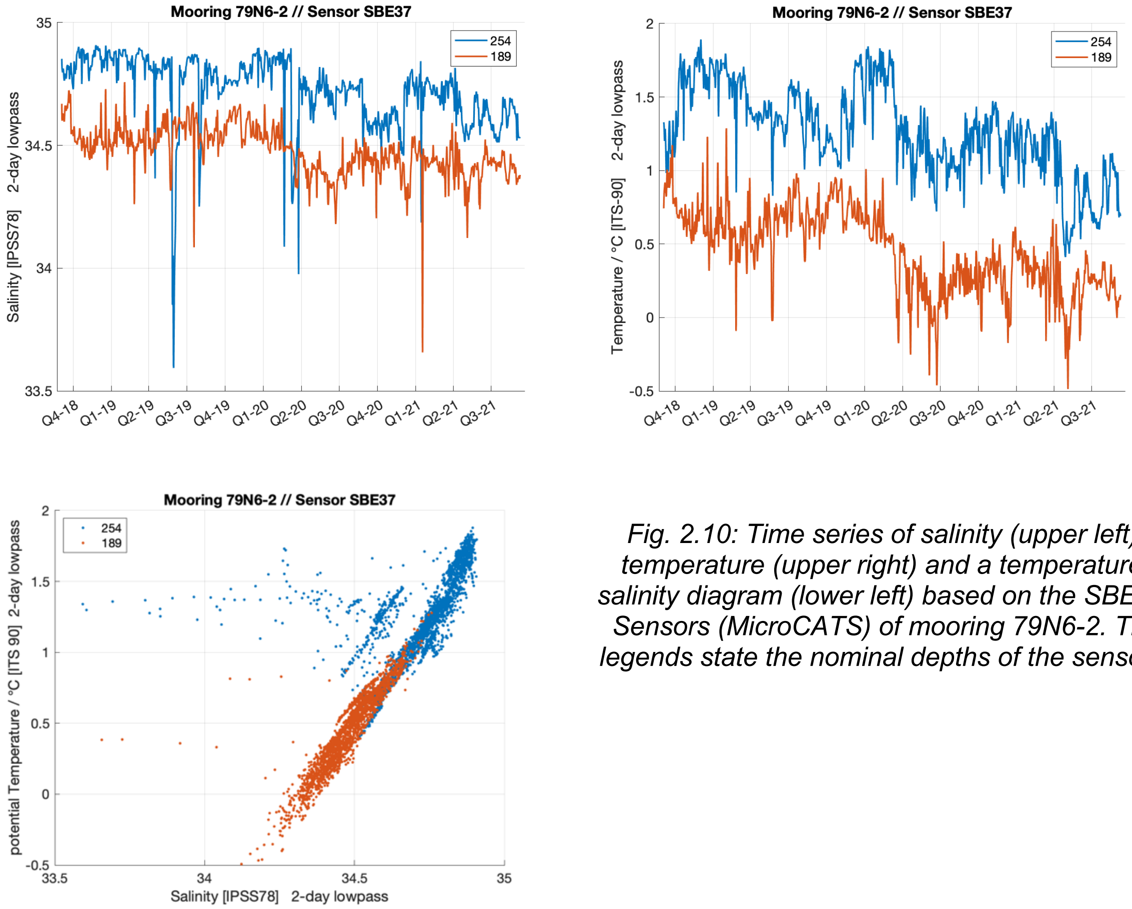


Fig. 2.10: Time series of salinity (upper left), temperature (upper right) and a temperature-salinity diagram (lower left) based on the SBE-37 Sensors (MicroCATS) of mooring 79N6-2. The legends state the nominal depths of the sensors.

Overall, the temperature records at both moorings sites show significant downward trends over time. At 79N2-2, a remarkable temperature/salinity peak is found in December 2017/January 2018, peaking near 2.0°C in the Atlantic Water layer (79N6-2 does not show this because it was only deployed in September 2018). The downwards temperature trends are accompanied by downward trends in salinity. Additionally, the T/S properties at mooring 79N2-2 are suggestive of slight water masses changes over the 4 years of observations (Fig. 2.9, lower left panel), the origin of which remains to be understood. It will be of high interest to establish whether the changes we observe will be accompanied by changes in the circulation, which the analysis of the recovered ADCP records might be able to reveal.

2.2 Hydrographic programme (including echosounder)

Hydrographic programme set-up

Hydrographic measurements during the TRITON2021 cruise were conducted using a CTD (conductivity-temperature-depth sensor). The CTD (Sn. 1459, Sea and Sun) measured temperature, salinity and pressure continuously as it was profiled through the water column. The instrument was connected to a fishing rod with electronic reel, powered by an external power source (Fig. 2.11). The CTD was operated either from the port side of the ship on a lower deck or from a Zodiac. A total of 10 CTD profiles were conducted in North East Greenland, the details of which are provided in Table 2.4 and mapped in Figures 2.12 and 2.13.

Tab. 2.4. List of CTD stations during TRITON2021 expedition including their latitude, longitude and water depth, and on which platform the CTD was deployed from.

Station	Cast	Date	Latitude	Longitude	Max depth [m]	Water depth	Platform
1	1	04.09.2021	74.2972	-20.2687	86	99.6	Zodiac
1	2	04.09.2021	74.2963	-20.2658	86	99.6	Zodiac
2	1	04.09.2021	74.2460	-20.1877	56	79.4	Zodiac
2	2	04.09.2021	74.2438	-20.1823	41	79.4	Zodiac
3	1	04.09.2021	74.3218	-20.3125	163	164	Zodiac
4	1	07.09.2021	79.6683	-16.8717	242	278	Triton
5	1	08.09.2021	79.5650	-19.4730	470	487	Triton
6	1	08.09.2021	79.6027	-19.3220	327	340	Triton
7	1	08.09.2021	79.6417	-19.0483	420	428	Triton
8	1	17.09.2021	72.3820	-24.1600	187	377	Zodiac

Before each profile, a depth sounding was taken either using the ship's echosounder or, on the Zodiac, a portable externally powered system (S2009 Fish Finder, Simrad) which was suspended in the upper 2m of the water column. The sounder has a range of 2,000 m. If the water depth was below 200 m, the depth reading was compared to the Zodiac's echosounder (range accurate up to 200 m). The pay-out of fishing line required for the depth of the desired profile could then be estimated. The aim of each profile was to capture the full water column. GPS coordinates of the profiling location were also noted, either from the ship or using a handheld GPS device (Garmin).

Upon deployment, the instrument was lowered into the surface layer and held at 0.5 m for approximately one minute before the profile began, in order for the sensors to acclimatise to the surface water conditions. Then released, a constant fall-rate (~ - 0.6 m/s) was controlled using the electronic reel on the fishing rod.

The instrument was turned on before each profile using a magnet and recording was stopped at the end of each profile. Only the downcast was used on which to conduct analysis as the sensors are at the head of the instrument; during the upcast, the water column is first disturbed by the movement of the body of the instrument through the water.

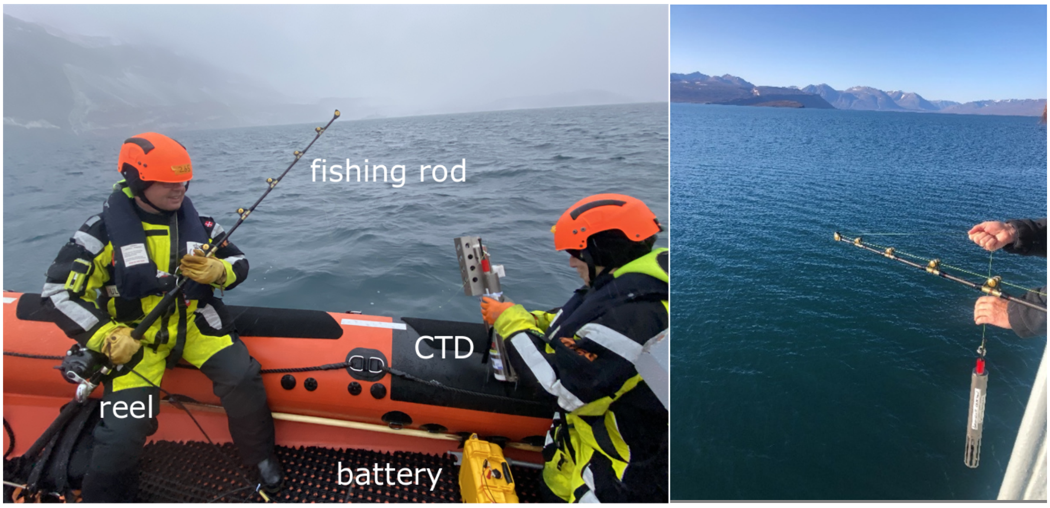


Fig. 2.11: (left) The CTD profiling set-up in the Zodiac, with fishing rod and electric reel connected to the battery. The CTD here is also attached to a Microcat. (right) The CTD attached to the fishing rod, about to be deployed from the lower deck of the Triton in Young Sund.

A second CTD (Sn. 1495, Sea and Sun) was also tested and results of the temperature and salinity profiles compared well to the first instrument. A pressure offset of approximately 1.5 m existed for both instruments and was adjusted for in the subsequent data processing. Due to this excellent agreement of the measurements between both sensors, only Sn. 1459 was used for profiling at later locations.

Preliminary (expected) results

Young Sund (Daneborg)

Three stations were profiled in Young Sund: at the mouth of the fjord, by the Danish military post of Daneborg (home of the Sirius Patrol), and further up-fjord (Fig. 2.12). Each profile was taken towards the southern part of the fjord where the channel was deepest. The Zodiac was used to reach these locations and conditions were excellent: there was no wind and the ocean was flat and calm. The profiles were compared to results from the extensive sampling conducted by Boone, 2018 (PhD Thesis) and Boone et al., (2018), and were in good agreement. The profiles in this fjord were also used to test the set-up of the fishing rod and CTD, and echosounder, and hone the sampling technique.

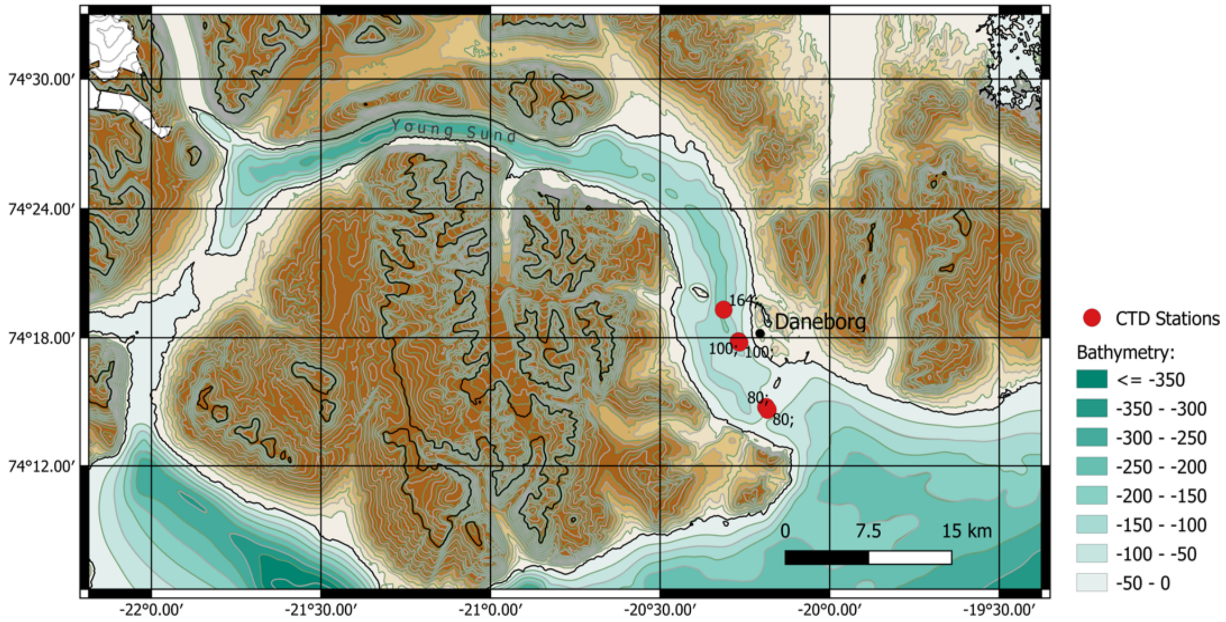


Fig. 2.12: Map of Young Sund and the CTD stations (red circles) with their water depth. The camp of Daneborg is noted.

79North Glacier

A total of four CTD profiles were taken in the vicinity of the 79N Glacier. Before the recovery of mooring 79N6-2, a profile was taken near the mooring location on 07.08.2021. A further three full-depth CTD profiles were taken after the recovery of mooring 79N2-2 (on 08.09.2021), located at the mooring position, at the shallow sill near the calving front, and upstream of the sill (details in Table 4 and Figure 2.13). All four profiles showed a similar water column structure, with a 20m thick warm (> 1.5°C) and fresh (< 28) surface layer (meltwater), overlaying a cold (< -1.5°C) and saline (32) layer between 50 – 100 m (Polar Water, PW). Below 150 m to the bottom of each profile, temperatures increased with depth from 0°C up to ~1°C, with a salinity of 34.5 (Atlantic Water, AW).

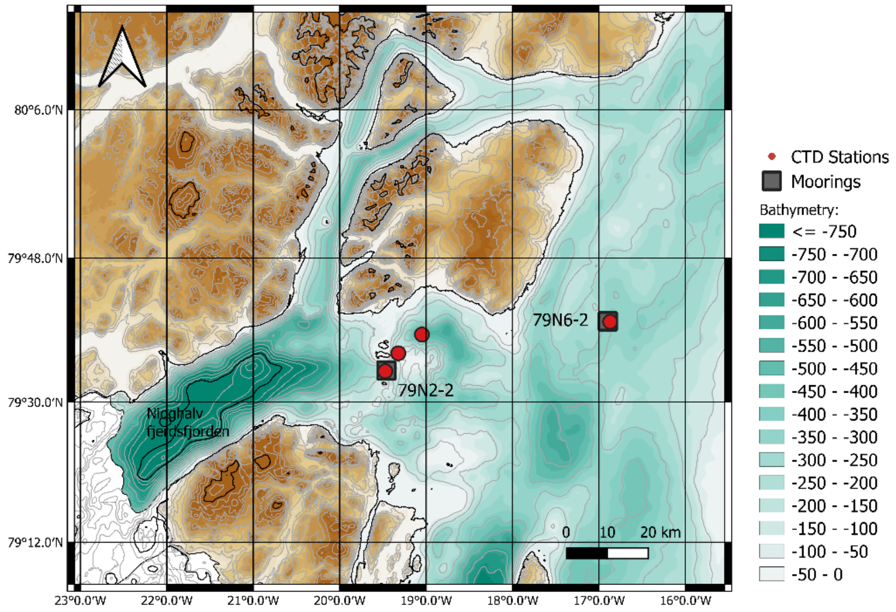


Fig. 2.13: Map of Nioghalvfjerdsfjorden (79N Glacier) and location of the recovered moorings (grey circles) and CTD stations (red circles).

These profiles were then compared to measurements taken at the same locations on previous expeditions (2017, PS109; 2018, PS114). A marked decrease in temperature over time is observed at all locations, in both the PW (50 – 100 m) and AW (> 150 m). Near the 79N Glacier, the mean difference in subsurface (> 50 m) temperatures was a decrease of 0.5°C from 2017 to 2021 (Fig. 2.14 a,b,c). At 79N6-2, the difference in subsurface temperature maximum between 2021 and 2018 reached over 0.8°C (Fig 2.14 d).

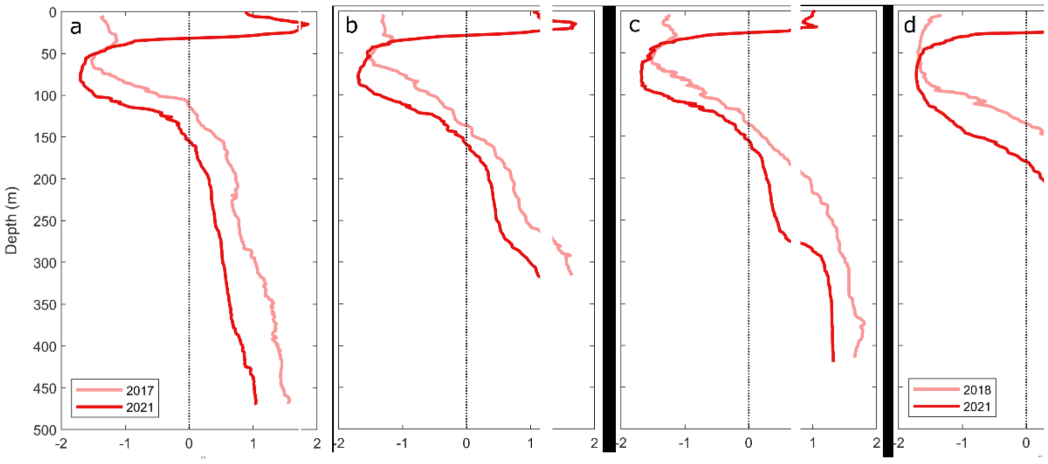


Fig. 2.14: Temperature profiles at (a) 79N2-2, (b) the sill at the 79NG calving front, (c) upstream of the sill, and (d) 79N6-2, from the TRITON2021 cruise (2021, dark) and from previous expeditions (2017, PS109; 2018, PS114).

There were changes in the water properties of the water column with distance from the calving front at 79N Glacier, highlighted in T-S diagrams of the four profiles. Near the calving front, the outflow of glacier-modified water can be seen being warmer and fresher than at other locations. Further offshore at 79N6-2, the cold and saline 'knee water' (< -0.5°C, > 32) is somewhat better preserved than near the glacier where is it mixed with glacially-modified water (Fig. 2.15 a). The AW also modified with distance from the glacier, increasing in both temperature and salinity from the calving front (Figs. 2.14c and 2.15b). Maximum temperatures increased from 1.03°C at 79N2-2 to 1.2°C at the sill, and 1.3°C upstream of the sill. However, at 79N6-2 maximum AW temperatures reached only 0.5°C (though the whole water column was not sampled at this location and the water depth was shallower than at the other sites).

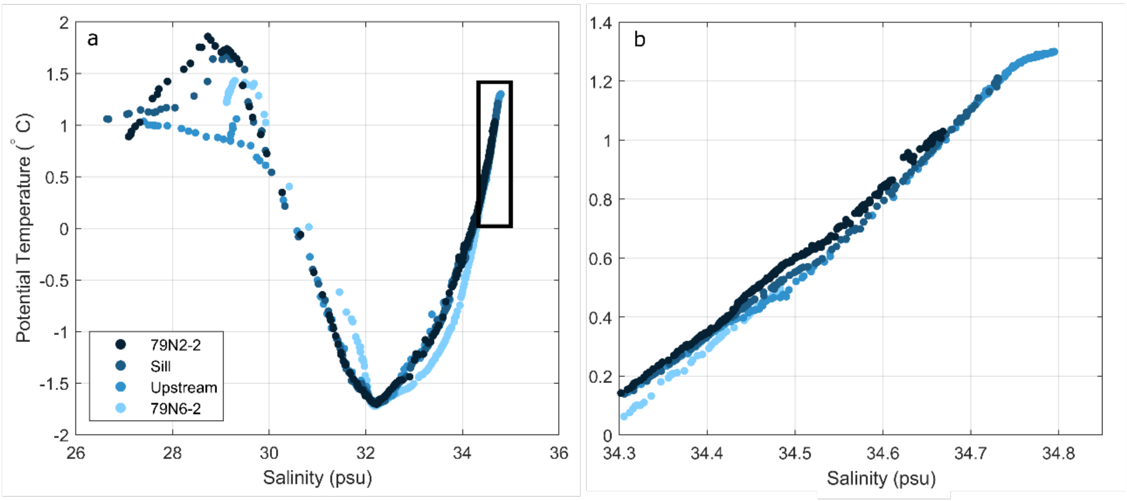


Fig. 2.15: Temperature-salinity diagram of all four CTD profiles taken near the 79N Glacier in 2021 (cf. Fig. 2.13). (a) the whole profile, with the portion in the black box shown in (b). The colours lighten with distance from the calving front.

It will be pertinent to examine if the pronounced cooling of AW illustrated by both the CTD profiles and the moorings is related to changes in the circulation near 79NG, and if this cooling is also observed on the wider NE Greenland continental shelf and even into Fram Strait.

Data management

Our aim is to compile data from the different devices in a single file once individual data sets have been retrieved, quality controlled and analysed. All data collected and generated by this project will be made publicly available via the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de).

This expedition was supported by the Helmholtz Research Programme “Changing Earth – Sustaining our Future” Topic 2, Subtopic 2.3.

In all publications based on this expedition, the **Grant No. AWI_TRITON_01** will be quoted.

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Boone W (2018) Seasonal and interannual variability of oceanographic conditions in a Northeast Greenland Fjord. PhD Thesis, Department of Environment and Geography Centre for Earth Observation Science, University of Manitoba.

Schaffer J, von Appen W-J, Dodd PA, Hofstede C, Mayer C, de Steur L & Kanzow T (2017) Warm water pathways toward Nioghalvfjerdsfjorden Glacier, Northeast Greenland. Journal of Geophysical Research: Oceans, 122(5):4004–4020. https://doi.org/10.1002/2016JC012462.

Schaffer J, Kanzow T, von Appen W-J, von Albedyll L, Arndt JE & Roberts DH (2020) Bathymetry constrains ocean heat supply to Greenland’s largest glacier tongue. Nature Geoscience. https://doi.org/10.1038/s41561-019-0529-x.

APPENDIX

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTIONS

A.2 FAHRTTEILNEHMER / CRUISE PARTICIPANTS

A.3 SCHIFFSBESATZUNG / SHIP'S CREW

A.4. STATIONSLISTE / STATION LIST

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTIONS

Affiliation	Address
DE.AWI	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung Postfach 120161 27515 Bremerhaven Germany
DE.UNI-Bremen	Universität Bremen Bibliothekstraße 1 27359 Bremen Germany

A.2 FAHRTTEILNEHMER / CRUISE PARTICIPANTS

Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
Kanzow	Torsten	AWI, Uni Bremen	Scientist	Physical Oceanography
McPherson	Rebecca	AWI	Scientist	Physical Oceanography
Engicht	Carina	AWI	Technician	Physical Oceanography

A.3 SCHIFFSBESATZUNG / SHIP'S CREW

<table>
<tr><td colspan="4">As <i>HDMS TRITON</i> is a Danish military ship, a full list of the crew cannot be included.</td></tr>
<tr><th>Rang /
Rank</th><th>Nachname /
Last Name</th><th>Vorname /
First Name</th><th>Position</th></tr>
<tr><td>Commander Senior Grade</td><td>Pind</td><td>Niels</td><td>Commanding officer</td></tr>
<tr><td>Lieutenant Commander</td><td>Fischer Petersen</td><td>Rasmus Christian</td><td>Operations officer</td></tr>
<tr><td>Lieutenant</td><td>Randrup Wagner</td><td>Annsofie</td><td>Deck officer</td></tr>
</table>

A.4 STATIONSLISTE / STATION LIST

Station	**Date**	**Time**	**Latitude**	**Longitude**	**Depth [m]**	**Gear**	**Comment**
TRITON_01	04.09.2021	13:30	74.2972	-20.2687	99.6	S&S CTD	
TRITON_02	04.09.2021	14:10	74.2460	-20.1877	79.4	S&S CTD	
TRITON_03	04.09.2021	14:45	74.3218	-20.3125	164.0	S&S CTD	
TRITON_04	07.09.2021	19:42	79.6683	-16.8717	278.0	S&S CTD	
TRITON_05	08.09.2021	09:51	79.6650	-16.1167	262.0	Mooring	Recovery 79N6-2
TRITON_06	08.09.2021	14:35	79.5703	-19.4778	476.0	Mooring	Recovery 79N2-2
TRITON_07	08.09.2021	18:20	79.5650	-19.4730	487.0	S&S CTD	
TRITON_08	08.09.2021	20:05	79.6027	-19.3220	340.0	S&S CTD	
TRITON_09	08.09.2021	21:05	79.6417	-19.0483	428.0	S&S CTD	
TRITON_10	17.09.2021	15:48	72.3820	-24.1600	377.0	S&S CTD	

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