SUMMARY

PS122-1 (or Leg 1) was the first leg of the International Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC). From September 20 to October 4, it started with about two weeks of transit of RV Polarstern to the start area of the transpolar drift in the northern Laptev Sea and the search for an ice floe as the basis for the year-long drift expedition. This was followed by the setup of a network of autonomous stations and buoys in the wider area (mostly by partner vessel Akademik Fedorov) and a central research camp on the ice next to RV Polarstern. During Leg 1 RV Polarstern drifted with the transpolar ice drift system toward the North Pole until mid-December 2019 when the arrival of the MOSAiC partner vessel Kapitan Dranitsyn marked the transition into MOSAiC Leg 2. During the drift of the Polarstern a comprehensive, interdisciplinary measurement program of atmosphere, ice, ocean, and ecosystem properties and processes was started above, in, and under the ice. The unprecedented observational program was very successful and reached the goals of the expedition. Together with the continued measurements during all other legs these observations will lay the foundation for adequately improving climate models to pave the way for a better understanding and prediction of Arctic and global climate change.

ZUSAMMENFASSUNG

PS122-1 (oder Leg 1) war die erste Etappe des internationalen multidisziplinären driftenden Observatoriums zur Erforschung des arktischen Klimas (MOSAiC). Vom 20. September bis zum 4. Oktober begann sie mit einem etwa zweiwöchigen Transit von RV Polarstern zum Startgebiet der transpolaren Drift in der nördlichen Laptewsee und der Suche nach einer Eisscholle als Basis für die einjährige Drift-Expedition. Es folgte der Aufbau eines Netzes von autonomen Stationen und Bojen in der weiteren Umgebung (hauptsächlich durch das Partnerschiff Akademik Fedorov) und eines zentralen Forschungscamp auf dem Eis neben RV Polarstern. Während Leg 1 driftete RV Polarstern mit dem transpolaren Eisdrift-System bis Mitte Dezember 2019 in Richtung Nordpol, als die Ankunft des MOSAiC-Partnerschiffs Kapitan Dranitsyn den Übergang zu MOSAiC Leg 2 markierte. Während der Drift der Polarstern wurde ein umfassendes, interdisziplinäres Messprogramm der Eigenschaften und Prozesse in Atmosphäre, Eis, Ozean, Biogeochemie und Ökosystem über, im und unter dem Eis gestartet. Das beispiellose Beobachtungsprogramm war sehr erfolgreich und hat die Ziele der Expedition voll erreicht. Zusammen mit den fortgesetzten Messungen während aller anderen Fahrtabschnitte werden diese Beobachtungen die Grundlage für eine angemessene Verbesserung der Klimamodelle bilden, um den Weg für ein besseres Verständnis und eine bessere Vorhersage des arktischen und globalen Klimawandels zu ebnen.

1 INTRODUCTION

Markus Rex[1] and Marcel Nicolaus[1] [1]DE.AWI

1.1 MOSAiC introduction and objectives

The Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) is an international Arctic Research initiative that is broadly motivated by the dramatic changes in the Arctic climate system over the last few decades, highlighted by significant losses of sea ice, and generally deficient model representations of the important processes responsible for, and responding to, these changes. The ultimate goal of the initiative is to enhance understanding of central Arctic coupled atmosphere-ice-ocean-ecosystem processes to improve numerical models for sea ice forecasting, extended-range weather forecasting, climate projections, and climate change assessment. This goal is achieved by carrying out the most comprehensive, most accurate, most continuous, and most systematic interdisciplinary in-situ and airborne observations in the Arctic Ocean to date, and by obtaining these over a full seasonal cycle including the winter freezing and summer melting seasons.

At the core of MOSAiC the German research icebreaker Polarstern was frozen into the ice for a full year, during which it drifted passively with the natural drift of the sea ice. MOSAiC took place in five Legs (PS122-1 to PS122-5), which are each summarized in separate cruise reports, the current document representing the report for Leg 1 (PS122-1).

The MOSAiC expedition started on September 20, 2019 in Tromso, Norway. After the transit through the Barents and the Kara Sea to the drift starting area an in the northern Laptev Sea Polarstern drifted with the Transpolar Drift during Legs 1 to 4 (PS122-1 to PS122-4) until reaching the ice edge in the Fram Strait End of July 2020. After relocating Polarstern to a new position close the the North Pole a second drift section started during Leg 5 (PS122-5).

Throughout the expedition Polarstern served as a high-tech, comfortable research base from which the surrounding ice, water, and air was explored. Only with such a base the demanding scientific activities could be realized, in contrast to, e.g., ice camps which provide less capable infrastructure and which can only support somewhat limited research agendas.

The general timeline of Leg 1 of the expedition (PS122-1) is summarized in table 1.1.

Tab.1.1: Key dates of the expedition PS122/1

Date	Description
20 Sep 2019	Departure in Tromsø, Start of PS122/1A1
02 to 04 Oct 2019	First exchange with Akademik Fedorov, Start of PS122/1A2
04 Oct 2019	Arrival at floe and start of drift
17 Oct 2019	Second exchange with Akademik Fedorov, Start of PS122/1B
13 Dec 2019	Arrival of Kapitan Dranitsyn at ice floe
15 Dec 2019	End of PS122/1 and start of PS122/2
18 Dec 2019	Departure of Kapitan Dranitsyn from ice floe
	Arrival of Kapitan Dranitsyn in Tromsø

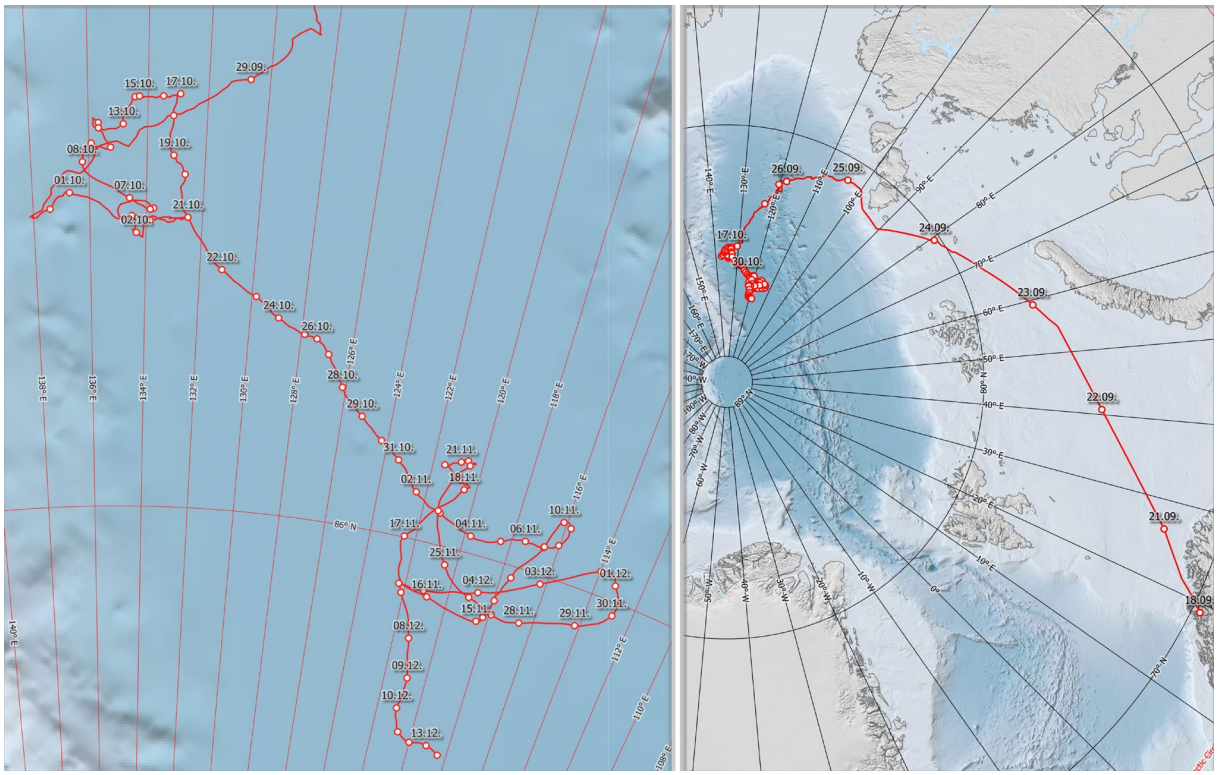

Fig.1.1: a) Over all cruise track of PS122/1, including the transit of Kapitan Dranitsyn to/from the floe from/to Tromsø. b) drift track of PS122/1. The track of Akademik Fedorov is shown in the cruise report Krumpen, T. and Sokolov, V., 2020

1.2 Leg 1A: Transit from Tromsø to Ice Camp

During the first four weeks of PS122-1 Polarstern was supported by the operations of Akademik Fedorov, which helped selecting a suitable ice floe, setting up the distributed network of autonomous research sites and provided fuel to Polarstern at the beginning of the passive drift phase, replacing the consumption during transit. The activities of Akademik Fedorov are summarized in a separate cruise report.

Polarstern left Tromso at 20:00 on September 20, 2019 and started its transit to the Laptev Sea. Akademik Fedorov left Tromso one day later to wait for the late arrival of key expedition equipment. Both vessels proceeded independently toward the starting area of the drift. Progress along the North East Passage was quick in the ice-free Barents and Kara Seas. The ice edge was met just east of the Severnaya Zemlya. From there Polarstern first went to the area of the Gackel Deep to retrieve four Ocean Bottom Seismometers, which had been deployed there during previous cruises. The retrieval of these instruments was successfully completed during 27 and 28 September and Polarstern transited through thin ice towards the area 135degE / 85degN.

After a thorough selection of the most suitable ice floe Polarstern took over fuel from Akademik Fedorov, proceeded to its final position in the selected floe and shut down the main engines on October 4. Immediately the setup of the central research camp next to Polarstern and of the distributed network up to several dozends of kilometres away started. The central research camp is introduced in section 1.4 and described in detail in section 4 of this document. Additionally, in the distributed network 125 buoys where set up in the wider area, which served as autonomous monitoring systems and transmitted their data directly by satellite, have been deployed, most of them during Leg 1A from Akademik Fedorov (c.f. Krumpen, T. and Sokolov, V., 2020). These buoys included 70 Position buoys, 8 mainly atmospheric buoys (O-buoys) plus different automatic weather stations, 35 snow and ice buoys (12xSnow, 16x Thermistor

stings, 4x S-IMB, 3x multi-sensor buoys), 14 ocean buoys (4x flux, 5x DTOP, 3x ITP, 2x Uptempo).

1.3 General ice conditions and drift of the floe

The main ice floe consisted of 3 different ice regimes (Areas) at the start of the drift in early October:

- Area 1:

  The northernmost part consisted of new sea ice that formed during the previous weeks and had thicknesses around 0.40 m. It was comparably flat and smooth ice.
- Area 2:

  The so called 'Fortress' was the solid and strong core of the floe. This feature was tracked in satellite images through the entire last summer and survived the melt period. It was strongly deformed with thicknesses often well beyond 3 meters, but also including re-frozen melt ponds of only 0.3 to 0.4 m thickness.
- Area 3:

  The southern part consisted of a honeycomb structure of sea ice that survived the last summer and some new ice forming in between. The ice was level with thickness of 1.0 to 1.5 m for the older and 0.3 to 0.4 m for the younger ice.

At the beginning of the drift, the floe had no major cracks or broken pieces and new ice formed in the deformation zones around it. A larger area of new ice was at the port side of *Polarstern* only some 0.1 m thick. The first cracks appeared at the bow and the port side of *Polarstern* on 8 October. They developed into a major lead with new ice formation until 15 October. On 16 and 17 October this new ice was piled up into pressure ridges of several meters height as a result of divergent ice movements. Afterwards, the ice of the MOSAiC floe was comparably stable and grew thermodynamically as a function of air temperatures. The surrounding remained quite dynamic (see Chapter 4).

Between 16 and 19 November, a low-pressure system (see Chapter 2) passed the ice camp and caused major changes in the snow and ice conditions. The resulting cracks, leads, and pressure ridges were part of a deformation zone that stretched tens of kilometres across the entire area. A deformation zone of 100 to 200 m width stretched though the ice camp off the bow of *Polarstern*. As a result, the ice floe lost most of its level parts and became much more deformed and rougher. Snow accumulated around the pressure ridges and all deformation zones. On 17 November, a main shear event (see below) split the floe into two parts with a strong deformation zone. At this time also the core part of the floe (the Fortress) got separated into two parts, but remained stable otherwise.

Over the period of PS122/1, the snow and sea ice conditions changed in a way that

- The thickness of new (first year) ice increased from 0.30 to 0.75 m. This holds for most regions of Area 1, but also other places with thin new ice at the beginning of the drift
- The thickness of thicker level (second year) ice increased from 0.50 to 0.90 m, while results for the more deformed and previously thicker ice are not yet available
- The snow depth of level ice was rather constant, while the deformed ice areas accumulated significant amounts of additional snow. Details are not yet available.

For more details, please find the sea ice mass balance measurements and transect data in chapter 4.3 and 4.4.

On 3 December, a massive ridge piled up in front of the bow of *Polarstern*, deforming the very dynamic zone ahead of the vessel once more. More smaller ridges build from former cracks in the Met City and Remote Sensing parts of the floe. Airborne surveys and radar images showed a lot of wider leads in within the distributed Network, indicating ice divergence.

During the 70 days of drift, the ice moved a distance of 400 nm (720 km) along the track (based on 1h positions, Figure 1.1). Average speed was 0.23 kn, mostly ranging between 0.1 and 0.5 kn. The highest drift speed of 0.8 kn was reached on 16 November 2019. On this single day, the ship drifted more than 12 nm (20 km). The net distance between the starting position (04 October 13:50 UTC, 85.08°N, 134.41°E) and the end position (13 December 10:00 UTC, 86.59°N 119.20°E) was 120 nm (216 km) and brought us 1.5 degrees (165 km) closer to the North Pole.

During the first 12 days, the net drift direction was south with the southernmost point at 84.752°N on 17 October. Afterwards, a phase with rather persistent drift to the north-west followed until 07 November. The following 4 weeks, until 06 December, were characterized by repeated circles across the 86°N latitude with a northernmost point at 86.196°N on 15 November. The last week of this leg brought the Ice Camp norward with steadily increasing latitudes until 13 December.

1.4 Ice Camp set up and evolution

All installations and sites on the ice on the main floe around *Polarstern* are called the 'Ice Camp'. By the end of Leg 1, the ice camp consisted of 5 Cities, 15 larger sampling and measurement sites and some 150 individual instruments and installations. These elements were connected through a network of flagged walkways and roads, including approx. 5 km of power and data cables on tripods. All off road areas were considered 'no go' zones, except the logistics and common leisure area with a diameter of roughly 200 m right next to *Polarstern*.

The original setup of the ice camp (early November) is shown in Figure 1.2 and the final setup in (mid December) in Figure 1.3. The central observatory (CO) with the main fraction of sites was installed to the bow and starboard side of *Polarstern* and extended some 500 m to these sides. Parts of the CO were secured by a trip wire installation against polar bears, but due to the ongoing changes in the ice conditions, this was only completed to some 50% at its maximum extent (see Chapter 8.1). The main installation of the power/network lines along the main road connected *Polarstern* with Ocean City, Balloon Town, Remote Sensing Site, and Met City. This was called the 'spine'. The spine went along an old ridge (the 'outer wall') surrounding the Fortress. As such it was the most stable part of the Ice Camp and provided most safety and reliability to the installations. Also skidoos, sleds and all main logistics components were parked and stored along the spine, when on the ice. The ROV Oasis was installed straight ahead of *Polarstern* and connected with an individual road.

By the end of Leg 1, the ice camp consisted of

- Five main cities:
    - Met City (MET) with >20 installations for mostly atmospheric observations (Chapter 3.X)
    - Ocean City (OC) with a tent covering a 1.2 m diameter hole to access the ocean under the sea ice (Chapter 5.X)

    - Remote Sensing (RS) with >10 installations of remote sensing instruments observing snow and ice properties (Chapter 4.9)
    - Balloon Town (BT) with two tents to perform measurements with a tethered balloon (Chapter 3.1)
    - ROV Oasis (ROV) with installations to operate a Remotely Operated Vehicle under the sea ice (Chapter 4.7)
- Sampling plots for
    - Ice coring on different ice types (Chapters 4.5 and 8.4)
    - Snow measurements and sampling on different ice types (Chapter 4.2)
- Distributed installations for
    - Ice and snow mass balance measurements (Chapter 4.3)
    - Sea ice dynamics (Chapter 4.6)
    - Seismological measurements (Chapter 4.6)
    - Other autonomous measurement devices / buoys (Chapter 4.3)
- Routes for measurements along transects over the ice (Chapter 4.4)

Please find more detailed descriptions of all sites and installations in the according chapters.

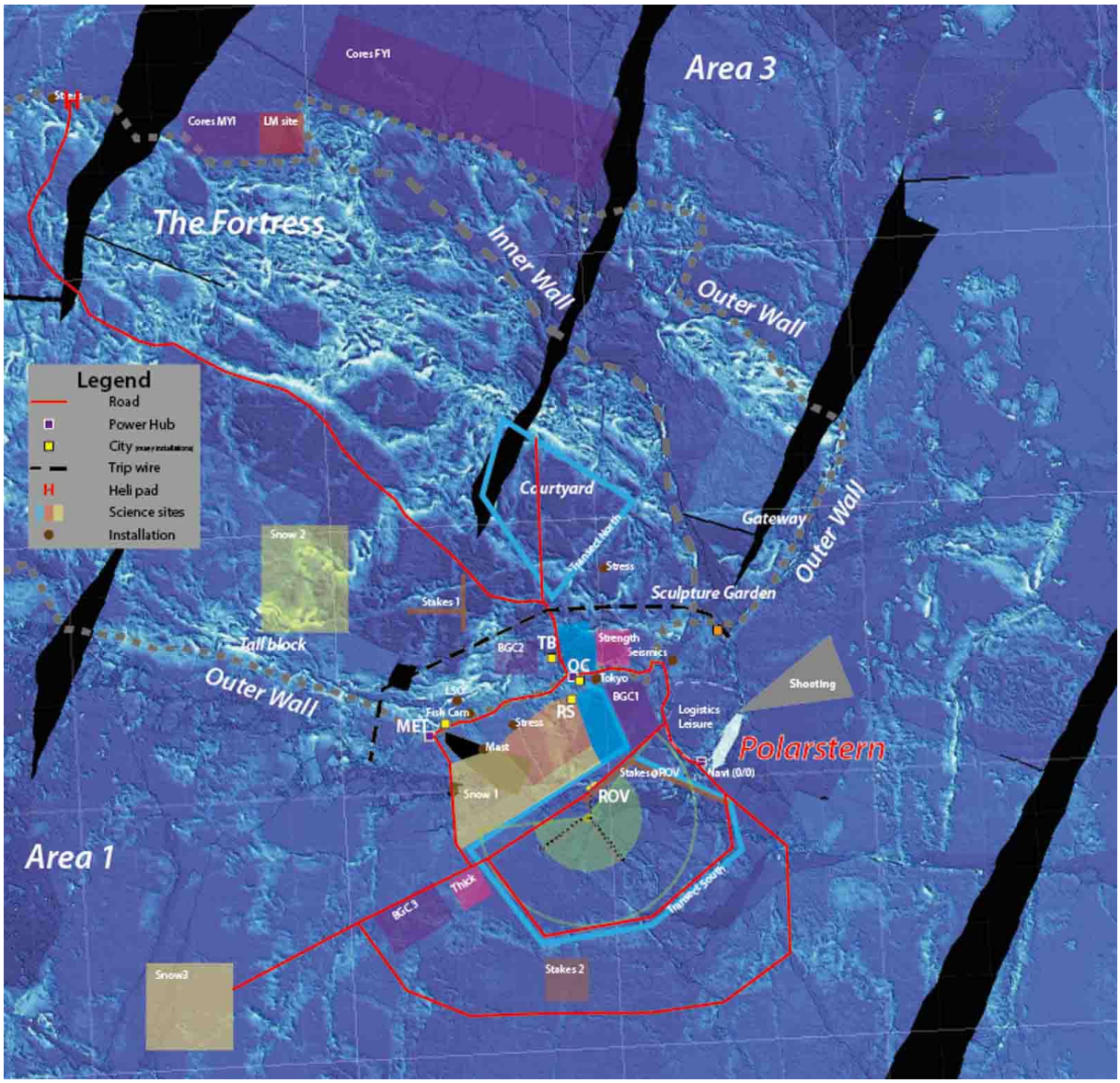

Fig.1.2: Ice camp map as realized by 11 November 2019. The background image shows surface elevations derived from the airborne laser scanner (flight on 20 October 2019, see Section 4.X). The grid shows mesh sizes of 500 x 500 m.

The layout of the ice camp changed over time as a result of the very dynamic ice conditions. After anchoring to the floe, a first design of the Ice Camp was decided and stepwise implemented. Over the first month, the Ice Camp grew to the status as shown in Figure 1.2. Already during this phase, the ROV Oasis had to be relocated once, after a main fraction of the floe shifted in front of the bow towards port side by approx. 600 m. The ROV recovered from its first location between 19 and 26 October and set up on the site as shown in Figure 1.2 afterwards again (see Chapter 4.X). Until early November several small cracks appeared on the floe, including one through the logistics area on 23 October, extending to up to 2 m. Otherwise the ice conditions were stable enough not to affect the Ice Camp installations until 16 November, except some relocation of power lines in response to cracks or smaller ridges.

On 17 November, large parts of the ice camp (including ROV Oasis, Remote Sensing Site and Met City) broke off the floe part to which also *Polarstern* was anchored. The ice became mobile and broke into various smaller floes, which moved up to 600m to the side and later some 150m

back. At that time, also the power connections to the sites had to be interrupted. Ocean City and Balloon Town were also temporarily disconnected from the power and data lines, although their installations were not directly affected by the ice dynamics. Besides the shift of the floes, the ice of RS broke into many small pieces such that all instruments and the hut had to be recovered on 16 November. After conditions stabilized, the RS site was set up at its new location during the first week of December (Figure 1.3). Also OC was affected by the large shear event. Although it remained on the stable side of the facture zone, a pressure ridge formed right next to the tent and also impacted the ice hole. Hence OC was relocated some 100 m away from the ridge between 20 and 25 November.

Beyond these main re-locations, various individual installations suffered from cracks and new ridges. Most obvious was the fall of the 30m high tower (the ‘noodle’) on XXX, which could only be re-installed on XXX some 100m away from the original position (see Chapter XXX). Many smaller installations, such as thermistor strings or ablation stakes, ended in pressure ridges or leads and could not be recovered. Also, the road and cable network had to be re-configured several times and maintained regularly over the 10 weeks of drift.

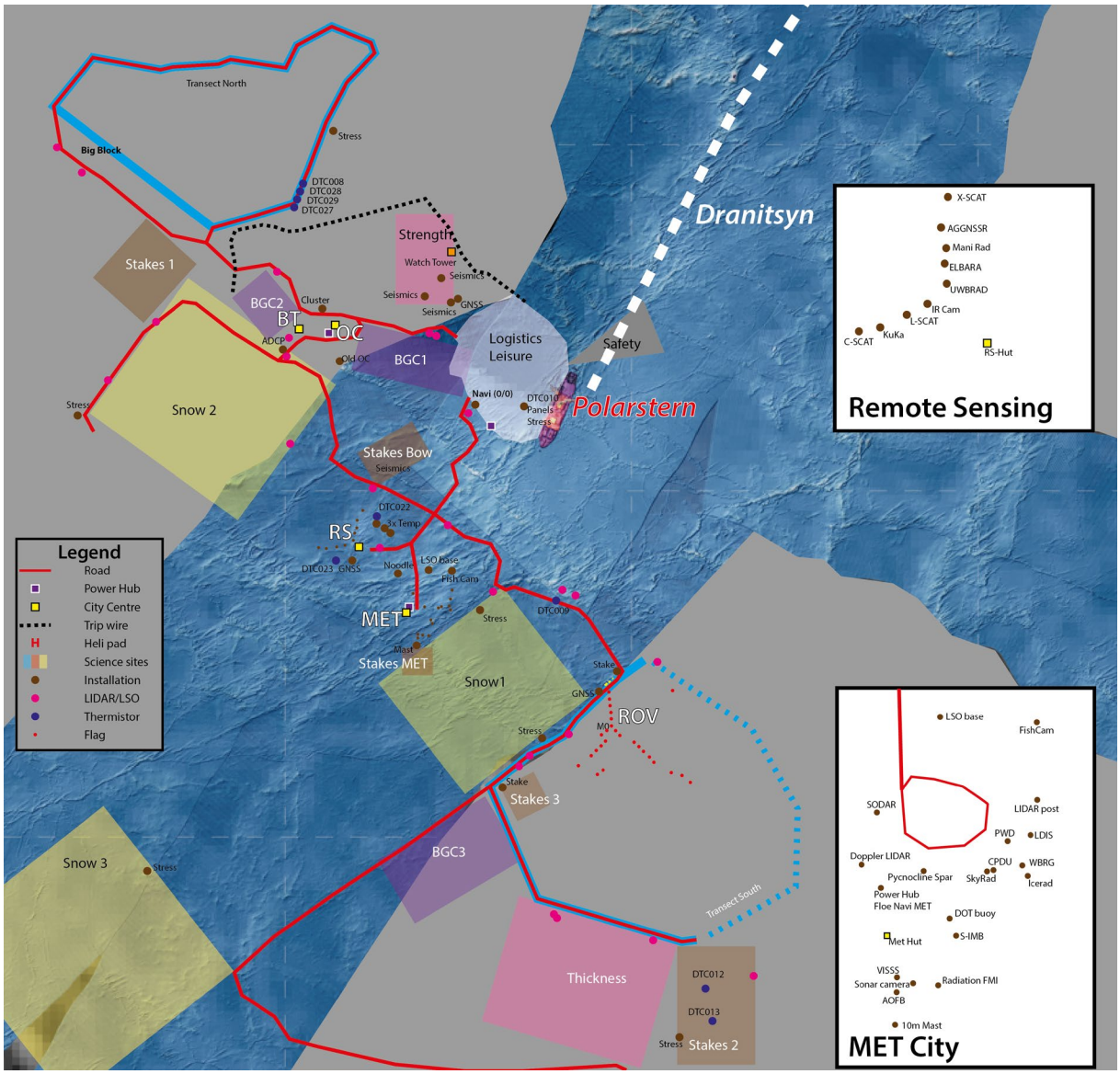

Fig.1.3: Ice camp map as handed over to PS122/2 on 13 December 2019. Note that this map is missing the northernmost part, as shown in Figure 1.2. The background image shows surface elevations derived from the airborne laser scanner (flight on 06 December 2019, see Section 4.8).

References

Krumpen, T. and Sokolov, V. (2020): The Expedition AF122/1: Setting up the MOSAiC Distributed Network in October 2019 with Research Vessel AKADEMIK FEDOROV, Berichte zur Polar- und Meeresforschung = Reports on polar and marine research, Bremerhaven, Alfred Wegener Institute for Polar and Marine Research, 744, 119 p., doi:10.2312/BzPM_0744_2020, hdl:10013/epic.16bc0ab7-fe46-4fb5-ae69-3edc93a72356