SUMMARY

PS122/4, or Leg 4, was the melt season leg of the international Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition. It followed the first three legs of MOSAiC, which observed the period from late September 2019 through early June 2020. This Leg 4 started on 6 June 2020 with an exchange of personnel in Isfjord Svalbard; incoming personnel had journeyed to that point on the *Maria S. Merian* and *Sonne* from Bremerhaven after completing a two-week quarantine. From this exchange *Polarstern* journeyed north into the pack ice where it again located the MOSAiC ice floe and drifted with it from 17 June 2020 through 31 July 2020. After the destruction of the floe near the ice edge on 31 July 2020, *Polarstern* recovered many other MOSAiC installations in the marginal ice zone and then had a rendezvous with *Akademik Tryoshnikov*, with the official end of the leg occurring on 12 August 2020. Leg 4 participants carried on with the *Akademik Tryoshnikov* to recover additional MOSAiC assets from the ice, and then returned to Bremerhaven on 24 August 2020. The core scientific component of Leg 4 was shorter than anticipated due to a late start as a result of Polarstern having to leave the pack ice to facilitate personnel exchange (a result of the international COVID-19 pandemic), as well as the total destruction of the MOSAiC floe in the marginal ice zone. In spite of this time limitation and the challenges posed by the global pandemic, Leg 4 was particularly successful in rapidly re-establishing the MOSAiC ice camp and conducting continuous measurements that maximized its ability to observe the evolution of the melt season in a comprehensive manner. All teams, including atmosphere, sea-ice, ocean, biogeochemistry, and ecosystem accomplished a great deal of science and fulfilled their research objectives, in addition to measuring on the MOSAiC ice floe until the end of its life cycle. During nearly four months together, the participants of Leg 4 developed a unique comradery and cohesion that contributed to its overall success and was recognised by all involved.

ZUSAMMENFASSUNG

PS122/4, oder Leg 4, war die Schmelzsaison-Etappe der internationalen Expedition Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC). Sie folgte auf die ersten drei Etappen von MOSAiC, die den Zeitraum von Ende September 2019 bis Anfang Juni 2020 beobachteten. Die vierte Etappe begann am 6. Juni 2020 mit einem Personalaustausch in Isfjord Svalbard; das ankommende Personal war nach einer zweiwöchigen Quarantäne mit der Maria S. Merian und der Sonne aus Bremerhaven dorthin gereist. Von diesem Austausch aus fuhr Polarstern nach Norden ins Meereis, wo sie erneut die MOSAiC-Eisscholle lokalisierte und vom 17. Juni 2020 bis zum 31. Juli 2020 mit ihr driftete. Nach der Zerstörung der Scholle in der Nähe der Eiskante am 31. Juli 2020 barg Polarstern viele weitere MOSAiC-Installationen in der Randeiszone und hatte dann ein Rendezvous mit der Akademik Tryoshnikov, wobei das offizielle Ende der Etappe am 12. August 2020 erfolgte. Die Teilnehmer von Fahrtabschnitt 4 fuhren mit der Akademik Tryoshnikov weiter, um weitere MOSAiC-Anlagen aus dem Eis zu bergen, und kehrten dann am 24. August 2020 nach Bremerhaven zurück. Die wissenschaftliche Kernkomponente von Leg 4 war kürzer als erwartet, da Polarstern das Packeis verlassen musste, um den Personalaustausch zu erleichtern (eine Folge der internationalen Pandemie COVID-19), und die MOSAiC-Scholle in der Randzone des Eises vollständig zerstört wurde. Trotz dieser

zeitlichen Beschränkung und der Herausforderungen durch die globale Pandemie war die vierte Etappe besonders erfolgreich, da das MOSAiC-Eislager schnell wieder aufgebaut und kontinuierliche Messungen durchgeführt werden konnten, um die Entwicklung der Schmelzsaison umfassend beobachten zu können. Alle Teams, einschließlich der Teams für Atmosphäre, Meereis, Ozean, Biogeochemie und Ökosystem, haben ihre Forschungsziele erreicht. Während der fast viermonatigen Zusammenarbeit entwickelten die Teilnehmer von Fahrt 4 einen einzigartigen Team-Spirit, ein Zusammenhalt, der zum Gesamterfolg beitrug und von allen Beteiligten anerkannt wurde.

1. OVERVIEW, DRIFT AND SET UP

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1.1. Introduction to Leg 4 and scientific 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 will be achieved by carrying out the a comprehensive, accurate, continuous, and systematic interdisciplinary study within the central Arctic Ocean over a full annual cycle.

At the core of MOSAiC, the German icebreaker *Polarstern* was frozen into the sea-ice of the northern Laptev Sea in October 2019, and then drifted with the Transpolar Drift across the central Arctic. This vessel has served as a high-tech yet comfortable base from which to measure and study the adjacent ice, water, and air. Together the vessel and the ice camp within a few kilometers of the vessel are referred to as the Central Observatory (CO). Surrounding this vessel, a Distributed Network (DN) of autonomous and semi-autonomous stations have been installed to provide measurements of spatial variability across the MOSAiC region and for use in upscaling MOSAiC measurements towards improved interfacing with models. Additionally, multiple aircraft campaigns have been planned for the MOSAiC year, offering a unique way to link regional-scale phenomena to the comprehensive observations made at the MOSAiC Central Observatory. The initial plan was for the full constellation of ground-based observations to drift across the Transpolar Drift for the full year, and for this year to be broken into six legs each with distinct on-site personnel. Continuity of observations from leg-to-leg is a foundational backbone to the MOSAiC concept, while each leg also has its own unique seasonal aspects. This report documents Leg 4 of MOSAiC, otherwise known as cruise PS122/4.

Prior to the start of PS122/4, MOSAiC had progressed through its first three legs. Leg 1 represented the installation period in late autumn, including identification of the MOSAiC floe, securing the *Polarstern* within the ice of that floe, establishing the Central Observatory with its many on-ice installations, and setting up the Distributed Network. Leg 1 started

approximately a month after the freeze onset, with about 30cm of newly frozen ice, and carried through until mid-December. MOSAiC's Leg 2, the mid-winter leg, focused on the heart of the Polar night, with extreme cold temperatures, rapid ice growth, and darkness for its full duration. In early March, Leg 3 started corresponding with the first annual rising of the sun and the evolution from winter into spring. This leg was characterized by its ice dynamics, which frequently interrupted the continuity of measurements and eventually resulted in the near destruction of the CO.

In early 2020 the COVID-19 pandemic griped the world and posed a great challenge for global travel and the MOSAiC expedition. As a result of closed borders and other travel restrictions, the originally planned aircraft-based crew change from Leg 3 to Leg 4 was no longer possible. After significant effort, and with few other options, a plan was developed to facilitate this crew rotation via Bremerhaven using the support of two German research vessels, the *Maria S. Merian* and *Sonne*. Due to delays and new requirements on quarantining, the rest of the expedition was re-formulated into two more legs instead of the originally planned three.

For MOSAiC to continue on in the age of COVID-19 required the development and implementation of strict protocols to ensure that the virus did not make it to *Polarstern* or any affiliated vessels. Accordingly, the participants (both scientific and *Polarstern* crew) of Leg 4 then assembled in Bremerhaven at the end of April 2020 to start a 2+ week quarantine period that involve initial isolation, and multiple virus tests to ensure that all participants were proven to be negative for the virus. After three rounds of negative tests for all participants, they boarded the *Maria S. Merian* and *Sonne* on 18 May 2020. These vessels sailed together up to Svalbard and awaited *Polarstern*, which was leaving the pack ice to facilitate this rotation of personnel and supplies. Due to high ice pressure, Polarstern did not arrive in Svalbard until early June 2020, at which point a rotation of cargo, fuel, and personnel was accomplished in Isfjord. On 6 June all Leg 4 personnel were moved onboard *Polarstern*, marking the official start to Leg 4. Other important dates during PS122/4 are noted in Table 1.1.

After leaving Svalbard on 8 June 2020, *Polarstern* made her way through the ice and back to the MOSAiC floe by 17 June, after which point a new Central Observatory was established on a remaining portion of the MOSAiC floe. Routine operations on this floe extended from 27 June to 30 July 2020. On 31 July 2020, the MOSAiC floe disintegrated. Leg 4 carried on after this period by recovering numerous MOSAiC installations that were part of the original set up as well as the DN. On 10 August *Polarstern* started a handover with the *Akademik Tryoshnikov* icebreaker. The rotation of personnel on 12 August 2020 marked the official end of Leg 4. Following this rotation, *Polarstern* ventured northward to continue operations at a new location in the ice, while *Akademik Tryoshnikov* continued to recover MOSAiC assets across the DN. The *Akademik Tryoshnikov* then arrived in Bremerhaven on 24 August 2020, at which point participants returned to shore.

Scientifically, Leg 4 fills an important role for MOSAiC. While the melt onset likely occurred in the last days of May, during the rotation activities, Leg 4 captured the early stages of the melt season and its evolution during the summer. It experienced a transformation of the surface, and followed the melt until the MOSAiC floe reached its natural demise in the marginal ice zone of the Fram Strait. These final stages of the ice life cycle, including destruction near the ice edge, were not initially planned but can be viewed as a scientific opportunity presented by the unique ice conditions of the MOSAiC year.

Tab. 1.1: Key dates of the expedition PS122/4

Date	Description
30 Apr 2020	Leg 4 starts quarantine in Bremerhaven
18 May 2020	Leg 4 leaves Bremerhaven on Maria S. Merian and Sonne

6 June 2020	Transfer of personnel near Longyearbyen, Start of PS122/4
8 June 2020	Departure of *Polarstern* north from Svalbard
17 June 2020	Arrival at original MOSAiC floe
19 June 2020	Final parking position on MOSAiC floe, start of new drift
20-27 June 2020	Establish ice camp adjacent to *Polarstern*
27 June 2020	Official start of routine observations
10-11 July 2020	24-hour sample cycle
29 July 2020	Start of camp take down
30 July 2020	End of camp take down, end of routine observations
31 July 2020	MOSAiC ice floe falls apart
31 July – 8 August 2020	Recovery of MOSAiC assets
10 August 2020	Rendezvous with Akademik Tryoshnikov
12 August 2020	Exchange of personnel, Official end of PS122/4
13 August 2020	Vessels part, Polarstern to the north for PS122/5.
13-18 August 2020	Akademik Tryoshnikov recovers M6, M4, M5, and L2 sites
24 August 2020	Akademik Tryoshnikov arrives in Bremerhaven

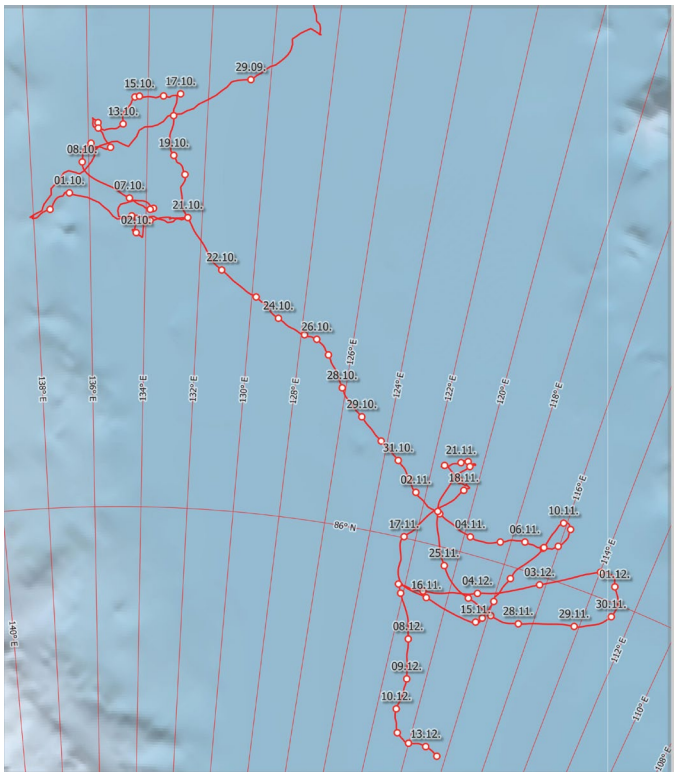

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Fig. 1.1: Over all cruise track of PS122/4 including the voyage into the ice, the drift, and the recovery activities.

1.2. Returning to the MOSAiC Floe

Polarstern's journey north from Svalbard started on 8 June 2020, reaching the ice edge within about a day and then proceeding north towards the MOSAiC floe. Progress was steady for the duration of the voyage, apart from a couple of days with increased ice pressure, during which time Polarstern stayed stationary with respect to the ice and waited for the pressure to release. During this period of waiting, a small ice floe was explored, offering some early opportunities to make measurements. The measurement included magnaprobe and GEM surveys of the surface and ice coring by an interdisciplinary team. While these measurements lack the temporal context from the MOSAiC floe, they were valuable for the Leg 4 team to start preparing and planning for later measurements in terms of equipment and protocols. It was also an opportunity to re-establish for the current team the protocols for safe scientific operations on the ice.

The transits out of, and back into, the ice pack to accommodate the turnover to Leg 4 also presented a unique, and unplanned, opportunity to make spatial measurements of key parameters along paired transects of the sea ice edge. Variability across the ice edge is of interested for numerous studies. During these transits, the 4-times daily sounding program continued un-interrupted, with enhancements to 8-times daily during the few days representing the immediate transition from ice to open ocean. Additionally, most instruments installed on the *Polarstern* bow containers and P-deck remained operational. These included the large suite of atmospheric instruments for measuring atmospheric structure, clouds, aerosols, precipitation, radiation, and trace gases (see Chapter 3). All of these measurements were made outside of Norwegian waters and no scientific data was obtained from within 12 miles of Svalbard.

The journey back to the MOSAiC floe was aided by high resolution visible and TerraSAR-X imagery, which helped with the initial identification of the MOSAiC floe area and offered insight into the conditions that awaited *Polarstern* upon return. From this imagery it was clear that the largest remaining piece of the MOSAiC floe was approximately round with a diameter of ~1 km. This floe contained much of the original floe's Fortress area, which consisted of a thick inner core with lots of ridging. Once within range, a helicopter recognisance flight helped to identify many of the key remaining assets around the area. This mission also allowed for visual surveys of surrounding floes, some of which were significantly larger and flatter than the remaining MOSAiC floe. Additionally, the helicopter conducted an ALS survey of the area on 16 June that enabled the first detailed mapping during Leg 4 (Fig. 1.X). The aerial mapping and survey provided the first clear documentation of the area, including the Fortress area, the original Central Observatory area with some installations still intact, the original Dark Site ice coring areas, the original Met Hut, a large pile of wood, and many other installations that had been left behind by Leg 3.

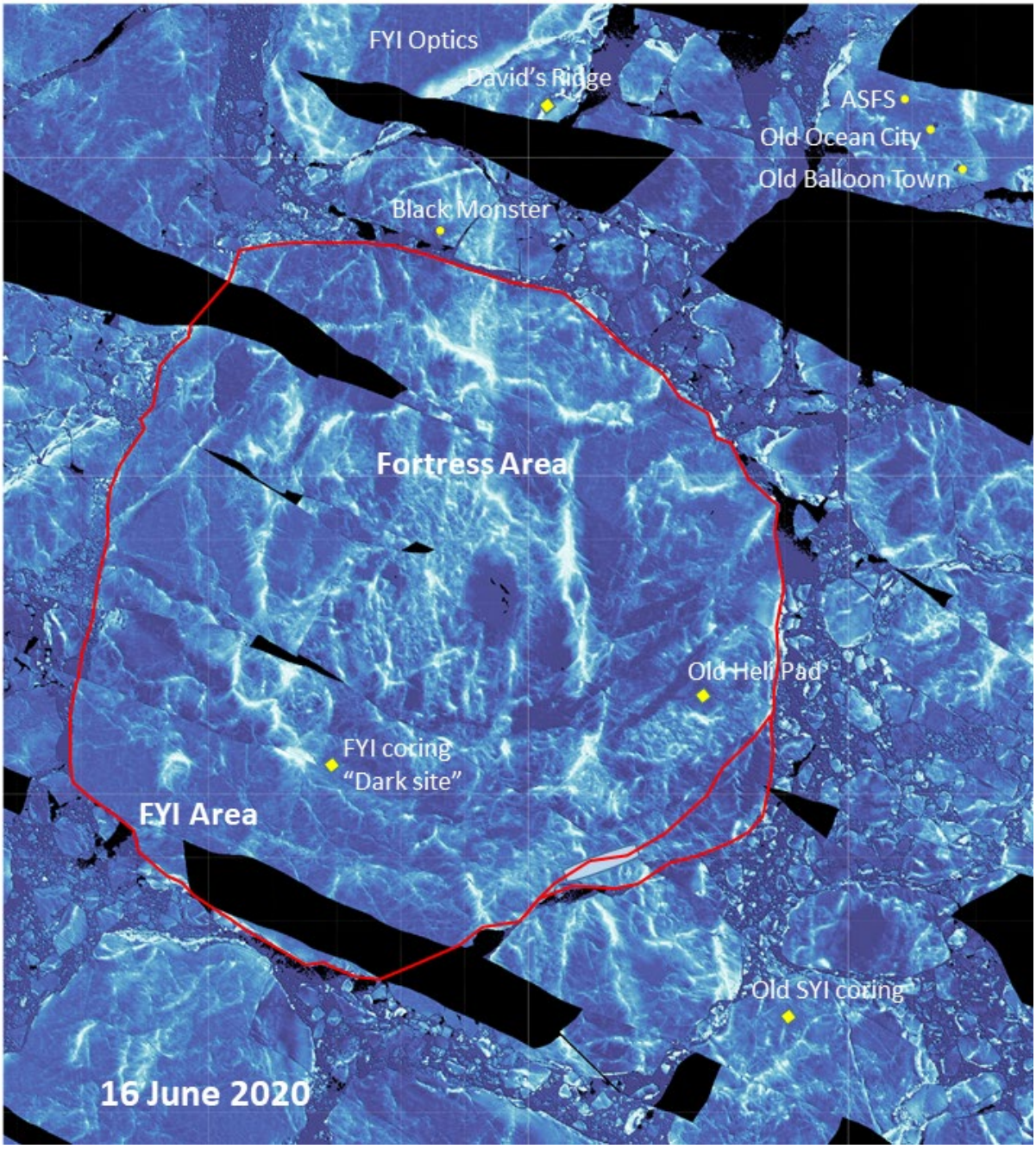

Fig. 1.2: ALS scan on 16 June 2020 with annotation of existing areas and installations around the MOSAiC floe.

On 17 June 2020 Polarstern came alongside the SW edge of the remaining MOSAiC floe (82.149N, 8.518E), and over the following two days the floe was explored and evaluated with the primary objective of determining the best location to establish the new Central Observatory. Multiple groups explored the floe, as well as an adjacent floe, conducting thickness mapping and drilling and developing a general survey of the options. It quickly became clear that this original part of the MOSAiC floe was the preferable option for two key reasons. First this floe offered the best continuity with previous measurements as it included the Dark Site where sea-ice coring had occurred during the first legs in addition to portions of other measurement areas such as ice transect work, ridge installations, and others. Second, the floe's characteristics were ideal. The Fortress area, as it did during the initial installation in October 2019, still represented some of the most stable ice in the local area. The floe was

well intact with numerous ridge systems and a thick inner core of second year ice (SYI). Importantly, the western and southern sides of the floe were wrapped in an extensive area of first year ice (FYI). This combination of SYI and FYI offered the best opportunity to support the MOSAiC science objectives while having a stable floe.

With the basic understanding of this floe, now called the Central Observatory (CO), it was clear that the vessel must be inserted into the southeast side of the floe, which offered a stable area of SYI that would best endure direct interactions with the ship itself and enable efficient access to the rest of the floe. The initial plan to install the ship directly into the ice did not appear to be viable as the ice in the region was quite thick. Thus, on 19 June 2020 (82.032N, 8.676E) a parking spot was developed along an uneven side of the floe, enabling the vessel to park with the floe along its starboard side and effectively trap an area of open water between it and the floe. This parking position addressed a couple of key objectives. First, the open water trapped between the vessel and the floe proved to be important for CTD operations off the starboard side. Second, the vessel was oriented with a southwestern heading, which according to wind roses from reanalysis should frequently be into the wind and thus supportive of clean air measurements for installations on the *Polarstern* bow. As with prior legs, this parking position also allowed for easy access to the ice from the starboard gangway position, and a good overview of the ice floe from the *Polarstern* bridge.

1.3. General ice conditions and drift of the floe

Over the course of PS122/4 the conditions of the ice floe developed over time. Many of the finer details are also described where appropriate within the relevant chapters of this report. Here a general description is provided as context for the overall evolution of the floe as it drifted along its southward trajectory towards the ice edge.

During the initial exploration period of PS122/4 on 17-19 June, the CO floe was an approximate circle with a 1 km diameter (Fig. 1.3). The main floe appeared to be continuous, without major cracks, and was divided by a few large, stable ridge systems. The thick inner core of the floe had accumulated deep snow in places. Surface melt had started across the floe, with a slushy melt layer accumulating near the bottom of the snow, particularly over the more rugged areas. At this time, a few large melt ponds were beginning to take shape, likely in the locations of large ponds from the previous melt season. These visible ponds had signs of re-freezing, suggesting that the melt process was playing out in stages. However, widespread differentiation of ponds had not yet occurred and standing water was limited. Rather, the whole surface of the floe was wet with snow melt.

Within a week, surface melt had progressed quickly with the snow largely being entirely melted from the flatter surfaces and extensive melt pond coverage (Fig. 1.4, 1.5). At this point most low, flat surfaces were covered with some amount of liquid water, with the only dry areas being those with deep snow and ridges. By the end of June, one key aspect of the floe had revealed itself: the sediment. The surface started to become browner and browner over time and started to expose numerous ‘Siberian treasures’ including stones, starfish, sea-floor plants, and others. Over time the accumulated sediment and other materials on the floe solidified the notion that this floe originated as fast ice on the Siberian shelf (see Krumpen et al.).

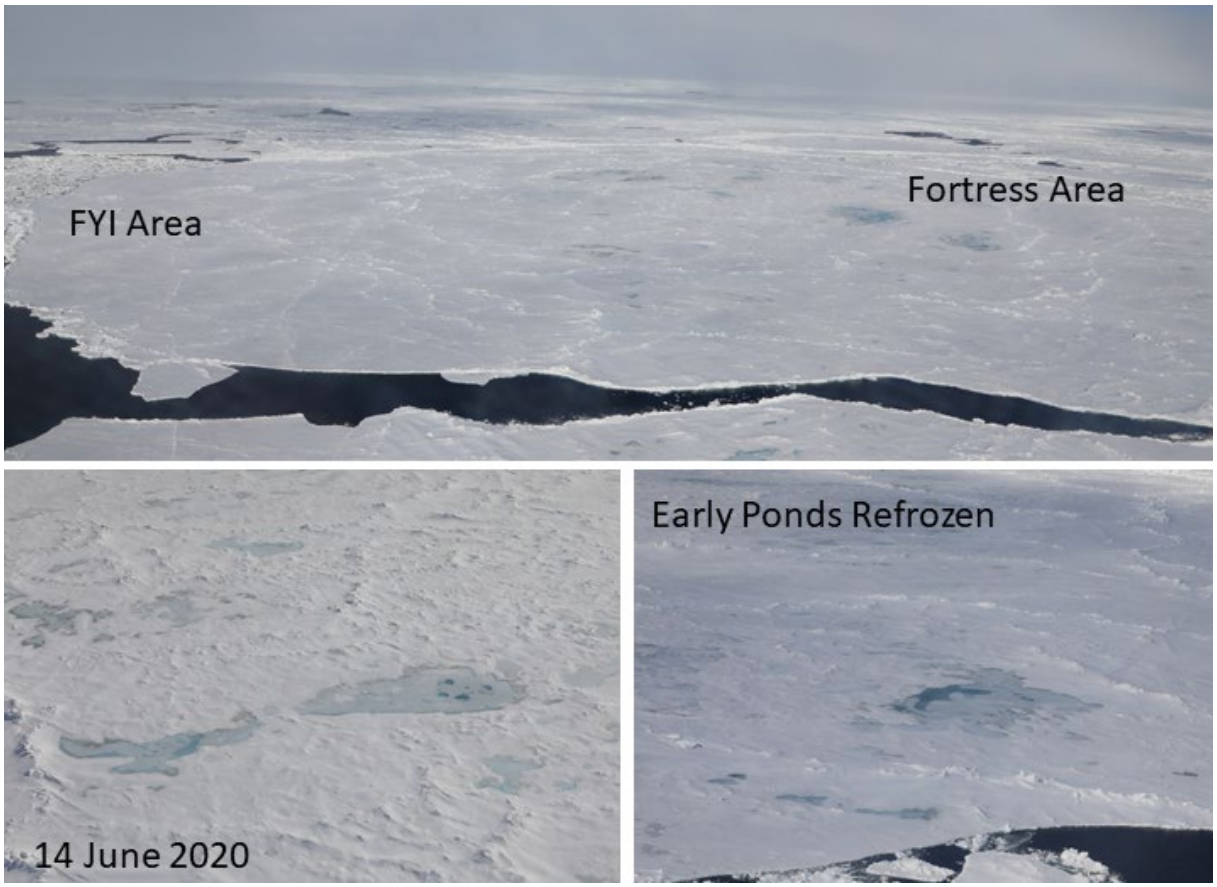

Fig. 1.3: Overflights of the MOSAiC floe on 14 June 2020 showing most of the remaining floe (top) and two close up views of melt ponds that have re-frozen (bottom). Photos: Matthew Shupe.

Fig. 1.4: Extensive pond coverage when looking towards Met City / Ocean City / Balloon Town from *Polarstern* on 25 June 2020. Photo: Matthew Shupe.

Fig. 1.5: Extensive pond coverage near ROV looking back towards *Polarstern* on 26 June 2020. Photo: Matthew Shupe.

By the last week of June, the melt ponds had started to consolidate and become better defined spatially. Moving into early July some ponds started to drain considerably, resulting in a significant decrease in melt pond fraction, which over time declined to approximately 30% (note: this number is for illustrative purposes while true values must be confirmed through scientific analysis). During this time, some drainage channels reached to the edge of the floe, allowing for extensive release of melt water from the floe. By mid-July, a few ponds near the edge of the floe in the FYI domain had also started to melt through. The extensive drainage contributed to a deepening fresh water lens under some parts of the floe, with a particularly thick layer of fresh water around key drainage points such as the Ocean City hydrohole. Additionally, as melt progressed and the sediment became concentrated over time, areas of FYI became readily apparent due to their lack of sediment. For example, a former lead through the middle of the floe from Leg 1 that had refrozen during the winter appeared as a clean white stripe amid otherwise brownish, sediment-laden ice.

During the second half of July ponds were well defined and growing rapidly in depth. Often the edges became overhung as the pond edges encroached below the surrounding hummocked areas. Drainage channels around the edges of the floe continued to widen such that ponds near the edge of the floe were effectively linked with open lead water and there were noticeable circulations of lead water inundating parts of the floe. During this period, the floe would occasionally lose small areas around its perimeter due to breakage. By the last week in July many ponds had melted through, including a few ponds towards the interior of the floe, although these were typically ponds that formed in FYI sections embedded in the larger SYI area.

A helicopter survey in late July out to the ice edge revealed that ice floes within about 10 nautical miles of the ice edge had a significantly different character, with a much smaller distribution of floe sizes. This spatial demarcation suggested the length scale over which penetration of waves and swell was causing mechanical breakup of the ice floes. On 28 July the CO drifted to within 20 nautical miles of the ice edge and was traveling at 5-7 nautical miles in a day. Over the following days melt progressed rapidly, with more ponds melting through. On 30 July, numerous cracks started to penetrate the flow, most remaining as simply cracks but not substantially opening until later in the evening. By the early morning of 31 July the MOSAiC floe had disintegrated in to small pieces of ice. The Met City piece of ice, still largely intact, drifted past the rear of the ship, representing a lateral move of more than 400m. At this point, the MOSAiC floe no longer existed in anything more than a

collection of small ice chunks that were rapidly melting and would approach the ice edge within a couple of days.

It is important to understand the MOSAiC floe within the context of the surrounding region of ice. Extensive satellite analysis will be required to develop this comprehensive context. However, helicopter flights provided a qualitative view and revealed a number of different ice types in the region. These included some extensive floes that were primarily composed of melt ponds (60-80%) with only thin skeletal structures of ice remaining above the melt water line, and little sign of sediment. These floes had a markedly different appearance relative to the MOSAiC floe. Additionally, there were a number of very dirty floes in the region, appearing somewhat more similar to the MOSAiC Fortress region. These floes at times had a gray or black appearance from above. Thus, the general ice in the region appears to contain floes, like the MOSAiC floe, which originated as fast ice from the Siberian Shelf, as well as intermingled FYI floes.

1.4. Ice Camp set up and evolution

After *Polarstern* took its final parking position next to the floe on 19 June (82.032N, 8.676E) the process of re-establishing the Central Observatory started. The first activities included developing the conceptual map and identifying the locations for core infrastructure such as huts, power lines, and sampling areas. Objectives guiding this process included: keeping a relatively compact camp that was easily maintained; taking advantage of stable ice to support longevity of the camp; optimizing the use of the limited spatial domain; deconflicting installations to minimize adverse impacts on sampling. The progression of camp installations and activities is captured in Figures 1.6-1.8.

By 20 June, a basic floe map was developed that served to coordinate installation activities on the floe for the following days (Fig. 1.6). A domain of about 100x100m was specified as the Logistics area directly adjacent to the vessel. A main spine of activity was identified heading north from *Polarstern* along a primary ridge structure associated with the Fortress. This ridge represented a stable route for running power lines and installing power hubs. Met City was established at the far end of this spine, approximately 400m from *Polarstern*. Its position on a ridge was less than ideal for many of the atmospheric measurements, but the ridge provided the stability required to install and maintain the necessary infrastructure. Ocean City was established to the southeast of Met City in an area of generally flatter SYI with a powerline tether to the Met City power hub. Balloon Town was identified about 100m back towards the ship along the spine, also sharing the same power hub. Eventually, an area for the Remote Sensing instruments was identified just to the north of the Logistics area near the spine. A second domain of activity extended forward of *Polarstern* with a pathway that headed along the floe edge to the southwest and then over to the west side of the floe, providing access to the extensive area of first year ice. A site was identified for the ROV approximately 200m from *Polarstern* near the floe edge, with an extensive area of FYI. Another 300m beyond that location was a site designated for the drone airport. Continuing along the pathway to the north along the west coast, sites were identified for ice optics work.

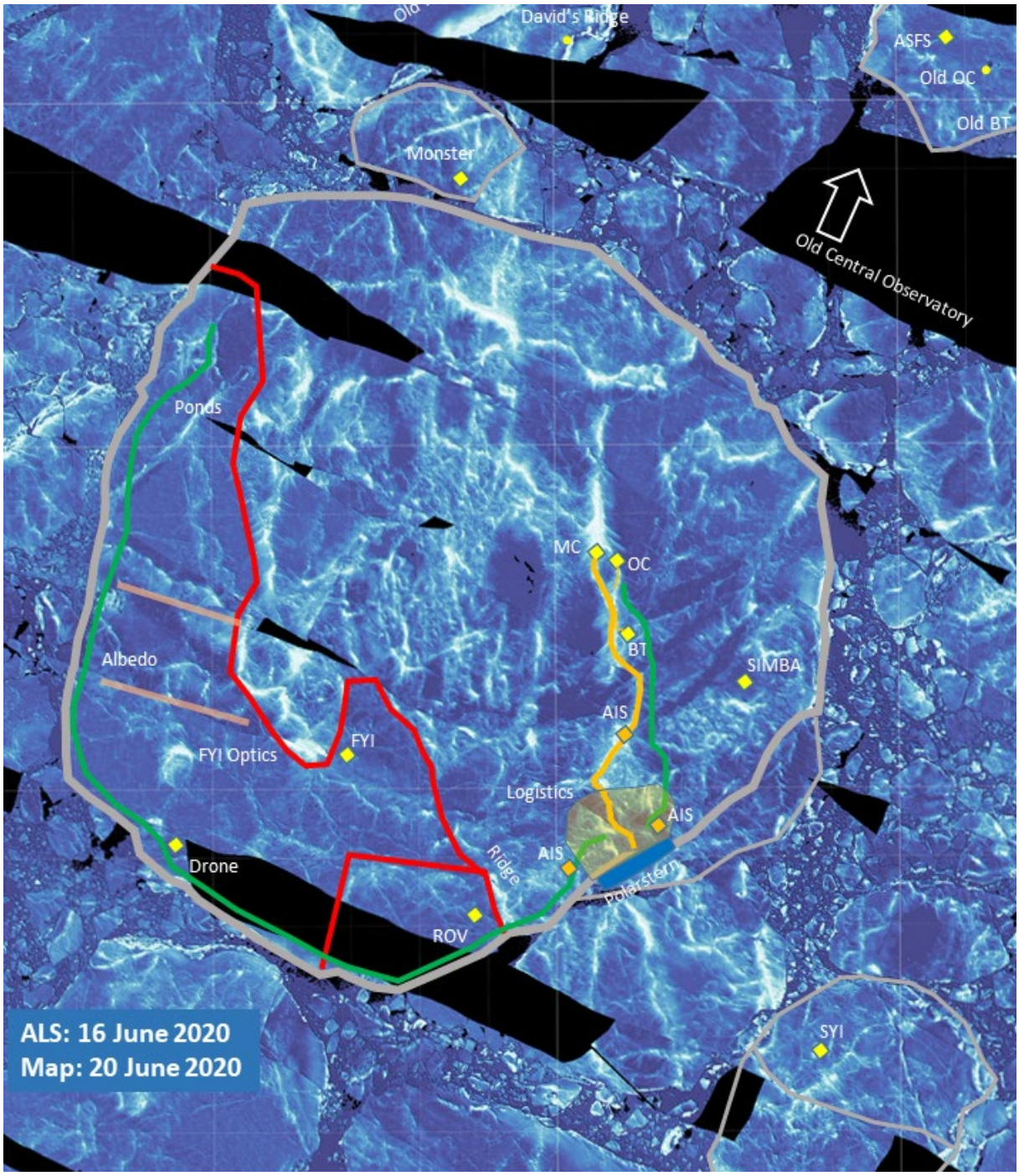

Fig. 1.6: Initial conceptual map of the new MOSAiC Central Observatory floe, with various features annotated. Underlying image is a helicopter-based ALS scan on 14 June 2020.

Over the course of about 1 week, this basic site plan was filled with an impressive collection of instruments, installations, and sampling activities. Routine operations started on 27 June (81.978N, 9.785E). The map in Figure 1.7 summarizes all installations in place by 7 July, while Figure 1.8 gives the final site map with all installations just prior to the end of operations on this floe. Initially, the primary pathways included the path to Met City, the path around the outer edge of the floe, and the path into the center of the floe which branched to the Seismic station and the ice optics area. Eventually the southern coastal pathway became impassable and was re-routed to connect with the path to the FYI optics areas. Additionally,

towards the end of July another pathway was established through the center of the floe to connect with the transect path. Other installations will be discussed by domain.

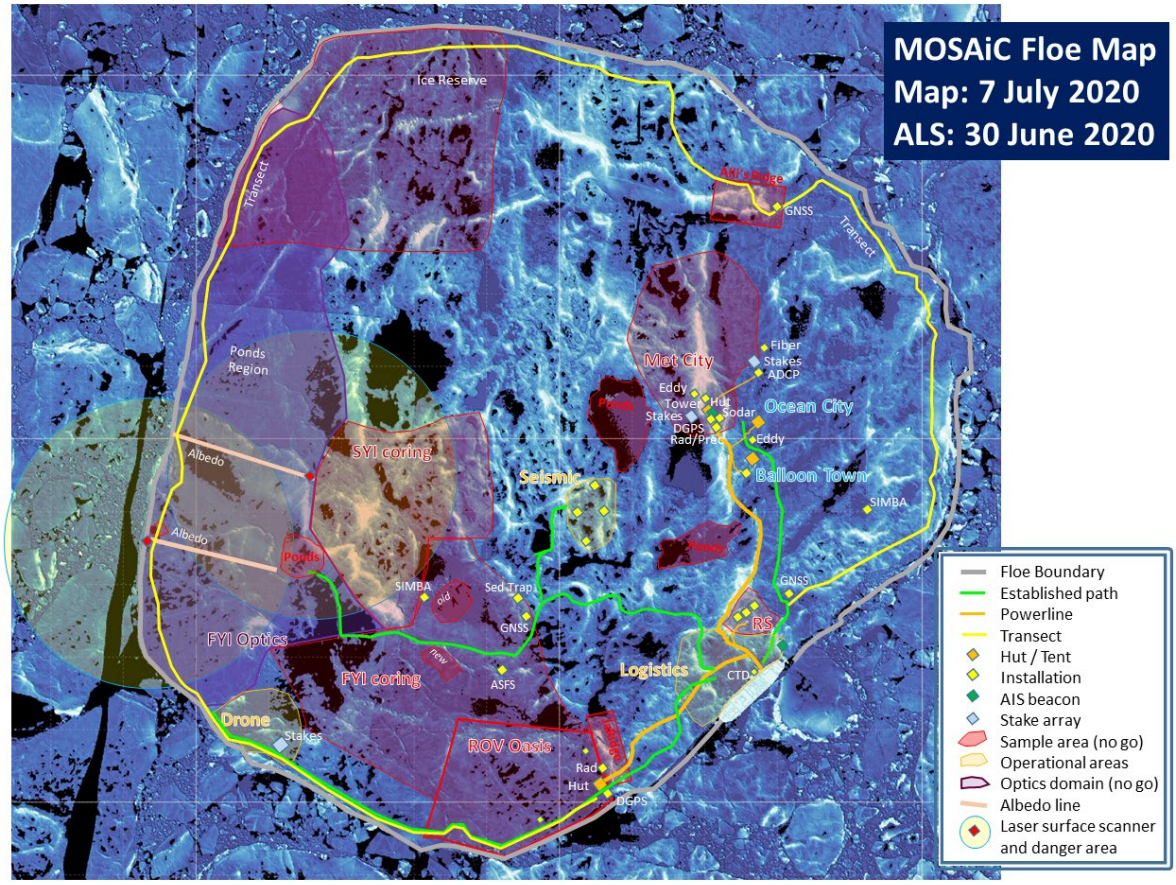

Fig. 1.7: MOSAiC Central Observatory floe map including all installations and sampling locations as of 7 July 2020. Underlying image is a helicopter-based ALS scan from 30 June 2020.

Met City Area. The original Remote Sensing hut was installed on top of the ridge at Met City as a local shelter and power distribution unit. The 11-m tower was installed just to the north of the hut, giving it a mostly unperturbed view of nearly 270 degrees. South of the hut were the radiation and precipitation measurements from the ARM program, plus a DGPS station. A sodar wind profiler was installed to the east, while a snow/ice stake array was set up directly to the west. A pair of eddy correlation sledges were installed in the region, and these would be moved according to the wind directions to allow for measurements of different surface times. Late in July an ice thickness drilling transect went through the middle of Met City. The general layout of Met City was fixed for most of the duration of the observational period of Leg 4. Two of the largest ponds on the floe were located just west of the city, with a smaller pond located immediately east. This second pond started to influence some of the local measurements towards the end of July. Ablation shielding was used to effectively limit ice melt from around the Met Hut and the met tower.

Ocean City Area. The central feature of Ocean City was the hydrohole and tent for ocean profiling. Nearby to the north an ADCP was installed as well as a fiber optic cable for continuous temperature measurements from 10m above the ice to 60m below the ice. This area also had a snow/ice stake array for thickness measurements. One distinctive feature

about Ocean City was its impact on local melt pond drainage. The large hydrohole immediately started draining the area and this drainage continued for an extended period and may have been influential in shaping the eastern flank of the floe by draining it earlier than it might have naturally drained. Additionally, this hole served as a major source of freshwater for the under ice domain.

Balloon Town. Leg 4 included the operation of two distinct tethered balloons. The larger Beluga was operated from a ridge near Ocean City. The smaller Miss Piggy was operated from a sledge about 80m south of the other balloon, but could in principle be moved if needed. A tent near the Beluga installation served as protection for some equipment and supplies.

Drone Operations. The initial drone airport was located at the southwest side of the floe in the FYI sector, allowing for overflights of the ice optics domain. Towards late July access to this location became more difficult and the pathway had to be relocated. A second drone airport was established in the last couple weeks of July to the east of Ocean City to enable intercomparisons with the tethered balloons operating in that area. Drone operations also occurred in the ROV area during a 24-hour sampling period on 10-11 July.

Remote Sensing. A small reserve located just north of the Logistics area accommodated a line of remote sensors with a view to the ice and snow surface. This area retained snow longer than most other parts of the floe, possibly because of its location amid a number of ridge structures. Local ponding became a factor in late July, with pond formation under still deep snow.

ROV Oasis. On the southern coast of the floe, the 150x200m ROV domain was established with a hole for deploying the ROV and a hut for operations. This hole primarily served the ROV operations, but was also periodically used for manual net tows and installation of long-lines for fishing by the ECO team. Directly adjacent to the ROV hut were two radiation stations and a DGPS. As a result of extensive melt and local inundation of lead water, the ROV hut and hole were relocated in the last week of July about 30 m towards the inside of the floe. Additionally, the original pathway through the ROV domain had to be re-routed in the latter half of July due to melt conditions.

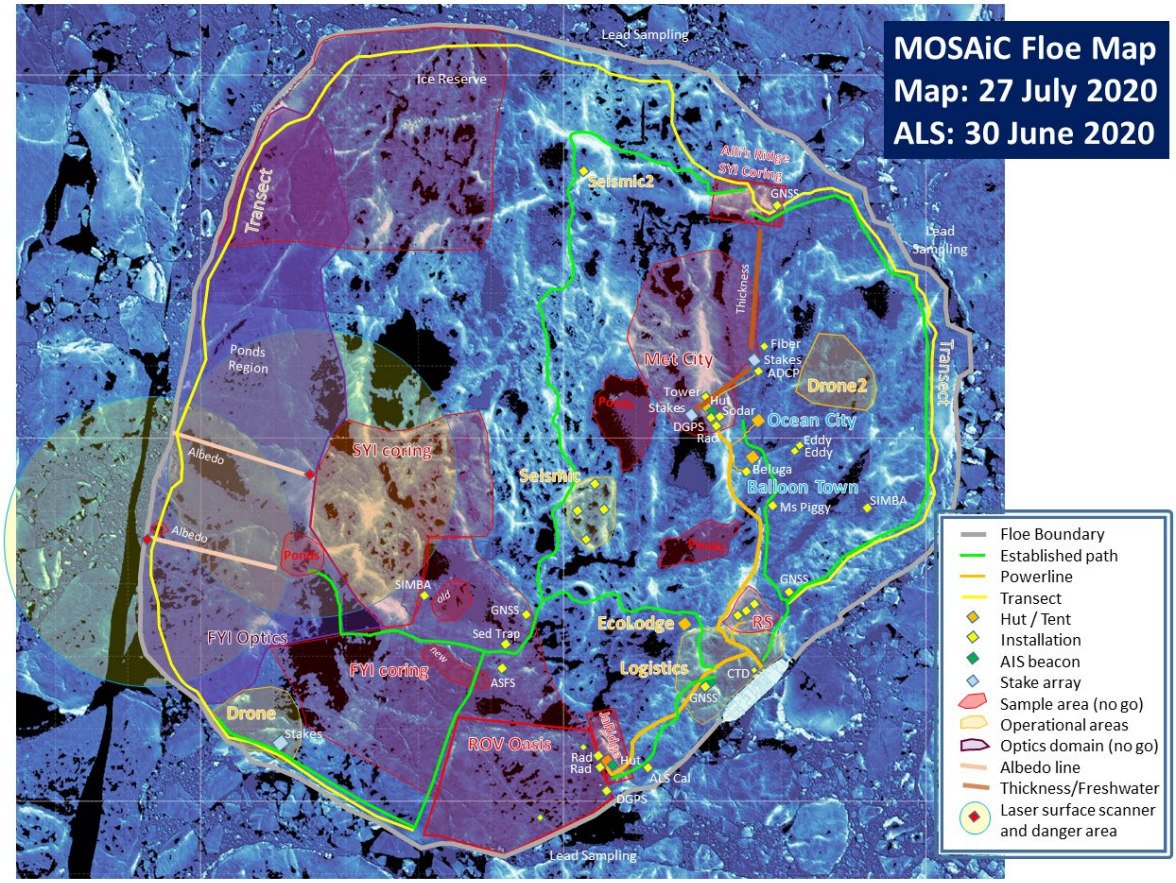

Fig. 1.8: MOSAiC Central Observatory floe map including all installations and sampling locations as of 27 July 2020. This map represents the final set of all installations as the camp was taken down over the following 2-3 days. Underlying image is a helicopter-based ALS scan from 30 June 2020.

Measurement and Sampling Domains. The floe included many different domains that focused on direct repeated measurements and/or sampling.

- FYI Coring: In the heart of the FYI domain was the FYI coring site, which was the same site used to take FYI cores during prior MOSAiC legs. The specific coring sites slowly migrated towards the east.
- SYI Coring: Since the previous SYI coring site was now isolated on its own distinct, but small, floe, a new SYI coring site was established on the northeast side of the floe. This site was in the area of Alli's Ridge. Towards the end of July this site became difficult to access due to degraded pathways.
- Albedo lines: In the FYI domain two lines for measurements of surface albedo, each 200m long, extended from the west coast of the floe in towards the first large ridge delineating the edge of the FYI domain. These lines transected a variety of surfaces including ponds.
- Transect: The primary sea ice transect was established around the outer edge of the floe. It started near the rear of *Polarstern*, circumnavigating the floe in the counter clock-wise direction. It passed through many different domains, including Alli's Ridge area, the full FYI domain, the albedo lines, the original drone airport, and the ROV Oasis. Initially this transect ended at the ROV hut, but eventually had to be terminated at the far edge of the ROV domain once the pathway through that area

degraded. The exact route of the transect remained as consistent as possible but had to be modified at times as the edges of the floe evolved.

- Pond work: Multiple ponds were studies, including a couple in the FYI area near the abledo lines and some ponds to the west and south of the Met City area. The largest pond, names Mystery Pond was directly west of Met City.
- Ridge work: Ridge work was primarily conducted at JaRidge, located directly east of the ROV Oasis, and Alli's Ridge, located in the northeast edge of the floe.
- Stakes: In addition to the ice/snow stake arrays at Met City and Ocean City, a third array was installed in the FYI domain near the first drone airport.
- Laser surface scanning: Two areas were established near the albedo lines for laser surface scans, each covering a circular area with diameter of about 400m.
- Seismics: A primary seismic station was re-established in the heart of the floe, with multiple stations. During the last week of July an additional station was installed in the northern area of the floe.
- EcoLodge: During the 24-hour sampling cycle, the ECO team established the EcoLodge just north of the Logistics area as a location to frequently sample near-surface water under the ice. This lodge consisted of two tents.
- Sediment Trap: A near-surface sediment trap area was established on the edge of the FYI domain just north of the ROV Oasis area for periodic sampling.
- Lead Sampling: General sampling of leads occurred in a number of areas around the edge of the floe depending on the contemporary ice conditions. More frequent lead sampling occurred near the ROV Oasis and off the northern coast of the floe.

In addition to these main sites and sampling areas there were a number of additional installations around the floe, including: GNSS stations near Alli's Ridge, near the rear and front of *Polarstern* and on the pathway to the FYI optics area; SIMBAs still installed from previous legs near the FYI coring area and east of Balloon Town; and an ASFS installed along the path to the FYI optics area.

On 29 July the take down of camp started and progressed rapidly. The primary installations along the spine to Met City were all removed within a single day and brought back onboard *Polarstern*, including nearly everything from Met City, Ocean City, and Balloon Town. On this same day, much of the Remote Sensing area was brought back onboard as was the ROV equipment. On the 30 July the ROV hut and ASFS were dragged back to the ship and lifted onboard. Also on this day all power lines and power hubs were recovered and lifted onboard. By the end of 30 July, the only significant infrastructure remaining on the floe was the Met Hut (former Remote Sensing hut), still standing on its ridge location. This time effectively signified the end of operations on the MOSAiC floe at 79.085N, -2.463E. By the morning of 31 July the entire floe had disintegrated and the hut, still on its ridge but now on a small floe, drifted behind *Polarstern* and became lost in the fog. A few hours layer a short search pattern with the ship was used to eventually find the Met Hut and recover it onboard *Polarstern*.

1.5. Old Central Observatory and Distributed Network

When PS122/4 started in Svalbard on 6 June 2020 there were many MOSAiC assets that remained installed within the ice pack, including both installations from the original Central Observatory as well as the Distributed Network. In the middle of May near the end of Leg 3 there were many cracks and leads that threatened operations at the original CO. After much consideration, it was decided, based largely on the discretion of individual project PIs, that most non-autonomous installations would be brought back onboard *Polarstern*. Thus, the primary installations at Met City, Ocean City, Remote Sensing, and Balloon Town were all taken down and stored on *Polarstern*. The primary assets from the original Central Observatory left behind are listed in Table 1.2. Numerous position buoys were also left

behind to aid in the re-location process upon return to the ice. Once *Polarstern* did arrive back at the MOSAiC floe it was clear that most of the remaining installations were now on their own smaller floes detached from the largest remaining floe. During the course of Leg 4 these installations and their individual ice floes were visible from *Polarstern* for many weeks, with periodic relative movement of the individual floes. Towards the end of Leg 4 the dramatic movements of ice resulted in large changes in the surrounding ice floes from day to day, such that some of these other installations would be periodically visible but then drift away. Some, such as the old Met City floe, were not located again after they drifted away. As possible during Leg 4 many of these installations were recovered either during the Leg 4 drift using helicopters or kayaks, or after the completion of the drift using *Polarstern* (see Chapters 3-6 for more details).

Tab. 1.2: Primary installed assets remaining from the original Central Observatory floe. Note: Many of these installations were on isolated smaller floes at the beginning of PS122/4.

Type of Installation	**Name**	**Location**	**Recovered**
Digital Thermistor Strings	DTCx4	Isolated floe, part of Fort Ridge area	No
Radiation Station		Isolated floe, part of Fort Ridge area	No
AZFP POPE	Black Monster	Isolated floe, part of Fort Ridge area	Yes
AZFP POPE	White Monster	Old SYI floe / LM site	Yes
Sediment Trap	Sed Trap	Old SYI floe / LM site	Yes
Spectral Radiation Station	SRS_havoc	Old SYI floe / LM site	Yes
Radiation	Rad+LC	Old SYI floe / LM site	Yes
Ice mass balance	SIMBA IMB	Old SYI floe / LM site	Yes
Snow buoy	Snow	Old SYI floe / LM site	Yes
Seismics	Seismics	Old CO / Ocean City floe	Yes
Position	DGPS,GNSS (2)	Old CO / Ocean City floe	Yes
Ice deformation	LSO	Old CO / Ocean City floe	Yes
Ocean Profiling	UiB Cluster	Old CO / Ocean City floe	Yes
Atmospheric fluxes	ASFS30	Old CO / Ocean City (relocated from L2)	Yes*
Position	SVP/ISVP	Various	No/Yes

After being established during Leg 1, the MOSAiC Distributed Network suffered significant losses over the following eight months. These losses included major ice deformation events at both of the L1 and L3 sites that damaged or destroyed many of the installations at those two locations. Of the L-sites, L2 was the most intact by the start of Leg 4. The state of the L- and M-sites during Leg 4 is summarized in Table 1.3.

Tab. 1.3: Installations at the L- and M-sites in the Distributed Network, including lists of those that were operational and non-operational during PS122/44, as well as those installations that were recovered during PS122/4. *The L2 ASFS was initially operating at the old Central Observatory and was moved to L2 during PS122/4.

Site	**Operational**	**Not Operational**	**Recovered During Leg 4**
L1	SIMBA IMB,	AOFB, SIMB3, Snow	SIMBA IMB, ITP,

	IMB+bio+rad, ITP		IMB+bio+rad
L2	AOFB, SIMB3, ITP-bio SIMBA IMBx2, Snow, ASFS*	IMB+bio+rad	AOFB, SIMB3, ITP-bio, Snow, ASFS, IMB+bio+rad
L3	Snow, SIMBA IMB, Rad+LC	AOFB, SIMB3, IMB+bio, ITP, Ice station	Snow, SIMBA IMB, ITP, Rad+LC
M1	PG/CTD, SIMBA IMB	Snow, DTOP	PG/CTD, Snow, SIMBA IMB
M2	DTOP	PG/CTD, Snow, SIMBA IMB	(no communication during recovery)
M3	PG/CTD, Snow, SIMBA IMB, DTOP		PG/CTD, DTOP
M4	PG/CTD, SIMBA IMB	Snow	PG/CTD, SIMBA IMB
M5	PG/CTD, DTOP	Snow, SIMBA IMB	DTOP
M6	PG/CTD, Snow, SIMBA IMB		PG/CTD, Snow, SIMBA IMB
M7		PG/CTD, Snow, SIMBA IMB	(no communication during recovery)
M8	SIMBA IMB	PG/CTD, Snow, DTOP	(no communication during recovery)

During Leg 4 the Distributed Network was not visited much. L2 was the primary hub of action prior to the recovery phase. It was visited on 30 June to deliver an ASFS from the old CO back to L2 where it could join the other suite of buoys that had been continuously operating there since the beginning of MOSAiC. During this visit the radiation installation that had been damaged by a ridging event was recovered and the snow buoy was re-leveled. Most other installations on site were operational and appeared to be in good shape although the two SIMBA IMBs were on a distinct floe. The site was visited again on 14 July for servicing and maintenance of the ASFS. Additionally, this visit allowed for a fishing-rod CTD profile down to 200 m depth. Lastly, during Leg 4 a couple of L-site helicopter ALS scans were conducted.

From 31 July through 8 August, after the disintegration of the main floe, *Polarstern* was used to recover many of installations across the MOSAiC constellation, including those within the Distributed Network (see Table 1.3). Recoveries were successful at L2, L1, L3, M3, and M1. After a crew rotation on 12 August that signified official end of Leg 4 (80.05N, -6.117E), the Leg 4 participants going home on *Akademik Tryoshnikov* spend another week to further recover assets from the Distributed Network. These included the M6, M4, and M5 sites along with the ITP from L2.