EDEN ISS

D5.1 – Initial System Test Report

prepared for

WP 5.1 – Transportation and Setup

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Executive summary

This document describes the overall deployment of the EDEN ISS Mobile Test Facility to Antarctica. It builds upon the EDEN ISS-DLR-WP4.4-D4.4-Overall System Test Report which described the assembly, integration and test phase of the project as well as the preparation and transport of the facility to Antarctica. This Initial System Test Report commences with the offloading of the Mobile Test Facility from the S.A. Agulhas II research vessel in the vicinity of the Neumayer Station III. It then describes the installation activities, results of initial on-site tests, issues encountered during the installation, as well as particular design modifications incorporated into the facility.

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Acronyms

Acronym	Explanation	Acronym	Explanation
AMS	Atmosphere Management System	MTF	Mobile Test Facility
AWI	Alfred Wegener Institute	NDS	Nutrient Delivery System
FEG	Future Exploration Greenhouse	NM-III	Neumayer Station III
ISPR	International Standard Payload Rack		
ISS	International Space Station		
MCC	Mission Control Center		

1 Deployment Mission

1.1 Deployment at Neumayer Station III

The 2016-2017 Neumayer Station III summer field season was utilized to install the EDEN ISS elevated platform and install the large power cable and fiber optic cable running from NM-III to the platform. Having completed these activities the previous summer field season helped accelerate the actual EDEN ISS deployment schedule during the 2017-2018 NM-III field season. The deployment team arrived at the station via aircraft on December 20, 2017. The original planned date of the EDEN ISS containers arrival was ca. December 26, 2017 but due to weather and ice conditions, this was pushed back to January 3, 2018, when the S.A. Agulhas II arrived in the NM-III vicinity and dropped off the EDEN ISS containers. The offloading location, as well as the path used by the tracked vehicles that transported the containers to NM-III, are shown in Figure 1.

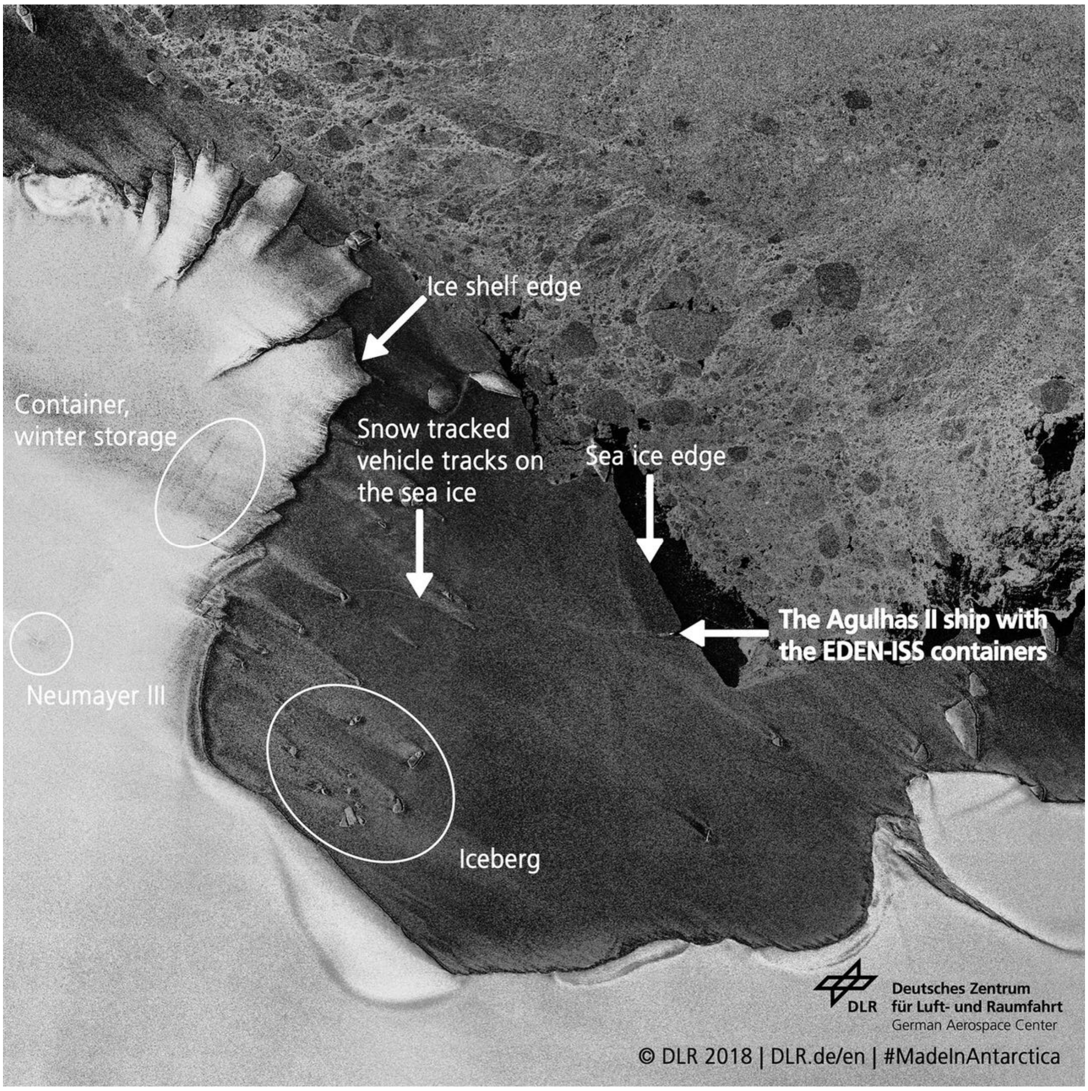

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Figure 1: Offloading location of the S.A. Agulhas II research vessel. The EDEN ISS containers were offloaded onto the sea ice and driven on sled pulled by tracked vehicles to Neumayer Station III.

Transportation of the EDEN ISS containers to the NM-III took approximately two hours. The Pistenbully vehicles and employed sleds are illustrated in Figure 2.

Figure 2: The tracked vehicles used to transport the EDEN ISS containers across the ice to NM-III.

The initial deployment activities of the EDEN ISS containers involved the following:

- Parking of the containers in the direct vicinity of NM-III to empty a wide range of project supplies into NM-III (e.g., laboratory supplies, dangerous goods, temperature sensitive supplies).
- Transport of the containers ca. 400 m to the EDEN ISS elevated platform. The Service Section container and FEG container were parked directly beside the platform while the blue transport container was parked ca. 20 m from the platform.
- Organizing supplies and setup of the blue transport container as a temporarily work space.
- Removal of the container transport walls.
- In conjunction with the AWI construction team, the Service Section container was temporarily installed onto the elevated platform and then removed so that the container twist locks could be welded to the platform.
- Reinstallation of the Service Section container.
- Installation of several pieces of container to container interface hardware that were required to be installed prior to the final placement of the containers together (install subfloor air ducts, free up FEG to Service Section container interface area, prepare four container to container interface bolts).
- Placement of FEG container onto platform to ensure the container to container fit is appropriate.
- Removing FEG container from platform in order to weld the FEG container twist locks.
- Reinstallation of FEG container onto platform and tightening the bolts connecting the two containers.

Although perfect alignment of the containers was not possible, following several attempts of readjusting the FEG container with respect to the Service Section container, a suitable container to container interface/alignment was achieved. The completion of the installation of the containers onto the platform also allowed the large NM-III crane to be used to install the free cooler and roof ladder onto the top of the Service Section container. This was followed by the installation of a wide array of external hardware and removal of some final transport hardware (e.g., window covers, covers for cable/pipe pass-throughs).

The following overview timeline presents the main on-site activities that were conducted during the EDEN ISS deployment phase:

Week 1 (January 4 - 10)

- Installation of containers on platform (Figure 3)
- Setup of communications hardware in NM-III multipurpose laboratory
- Installation of external hardware including: roof ladder, free cooler, free cooler cooling fluid pipes, cable channels, CO_2 distribution system, external lights, door bumpers, small stairs, chimney H-cowl, roof safety rails, cable and piping pass-throughs (rubber) in external walls
- Connection of the NM-III to MTF power cable to the Power Control and Distribution system
- Setup of the energy monitoring system sensors in the power box
- Unpacking of tools in the MTF
- Activation of internal heaters
- Connection of air duct, NDS and thermal control system piping interfaces
- Insulation of the container to container interface

Figure 3: Installation of the EDEN ISS containers onto the previously installed elevated platform.

Week 2 (January 11 – 17)

- Installation of patch antennas on MTF and on the NM-III station
- Connection of Argus sensor wiring
- Filling of the thermal control system with cooling fluids
- Complete Atmosphere Management System (AMS) setup, including filter installation
- Illumination system setup
- NDS tray installation, fill NDS with fresh water and perform leak check (Figure 4)
- Complete basic setup of multipurpose laboratory in NM-III (e.g., reverse osmosis system running)
- Command and Data Handling System setup and testing
- Testing of gas safety system
- Arrival of the second part of EDEN ISS deployment team (January 13)

Figure 4: NDS hardware located in the FEG subfloor area as shown during the early on-site setup of the EDEN ISS greenhouse in Antarctica (several cameras and sensors remain covered with hand gloves so as to protect them from TransMADD-sprayed hydrogen peroxide).

Week 3 (January 18 – 25)

- Completion of CO_2 distribution system connections
- Installation of CO_2 flowmeter
- Testing of AMS and thermal control system via software
- (ISS rack-like) International Standard Payload Rack (ISPR) plant growth system setup
- Improve FEG atmospheric closure (tape air ducts, insulate/better seal connections)
- Insulate external cable and piping pass-throughs
- Raising of the platform and installation of primary platform stairs
- Improve the structural rigidity of the free cooler electronics box against wind by installing a metal brace
- Install multi wavelength imagers for plant health monitoring

Figure 5: EDEN ISS facility following the elevation of the platform and installation of the platform stairs.

Week 4 (January 26 – February 1)

- Employ the TransMADD system in the FEG for disinfection of the grow area
- Antarctica to Europe communication troubleshooting
- First planting in the MTF (Figure 6)
- Troubleshooting of various MTF subsystems (external lighting, CO_2 delivery)
- Continued ISPR plant growth system setup and testing
- Calibration and final testing of various sensors (pH, electrical conductivity, condensate collection, CO_2 flowmeter, leak sensors)
- Installation of protection for the fiber optic cable as it runs along the external platform
- Prepare the FEG nursery
- Final setup and check-out of NDS

Figure 6: Initial planting activities in the FEG.

1.2 *Initiation Phase of the MTF*

Although troubleshooting of various subsystems continued into early February, increased focus was placed on testing and readying the MTF for overwinter operations. During this phase, seeds were germinated within the dedicated nursery of the FEG. Further MTF initiation directed activities included:

Week 5 & 6 (February 3 - 14)

- Initiation of control system/enabling all system alarms and appropriate thresholds
- CO_2 leak test within FEG and ISPR growth chambers
- Planting of first crops in the nursery (start of germination)
- Final teach-in of EDEN ISS overwintering crew member (Paul Zabel) on various systems
- Last sensor calibration within the AMS
- Solving of additional Argus control problems
- Inventory and final reorganization of spares and supplies within the station and the MTF
- Start of germination process within the ISPR
- Test of multi wavelength imagers with maturing plants
- Test of communication lines between MTF and NM-III as well as to the Mission Control Center (MCC) in Bremen, Germany
- Troubleshooting with microbial contamination within the nutrient solution during ramp-up phase

Figure 7: A view of the EDEN ISS MTF from the NM-III lounge looking southward. Also shown are the additional summer field season sleeping huts and further southward the NM-III Air Chemistry Laboratory (SPUSO).

1.3 EDEN ISS Infrastructure in Neumayer Station III

In support of the nominal experiment phase, a dedicated laboratory (multi-purpose lab) within the NM-III station was outfitted (See Figure 8). The laboratory is equipped with tools for microbial investigations, food quality and safety measurements and general equipment for post-harvest analysis. The lab is also used for sample preparation and stabilization. All samples (food quality- and safety related as well as microbial samples) are stored in a mobile freezer at -40°C. A dedicated sample-return strategy was worked out in order to transport the samples back to Europe for further analysis after the experiment phase ends (~end of November 2018).

Figure 8: Multipurpose laboratory within the NM-III station, which was outfitted with dedicated EDEN ISS equipment in order to support the post-harvest analysis and sample preparation.

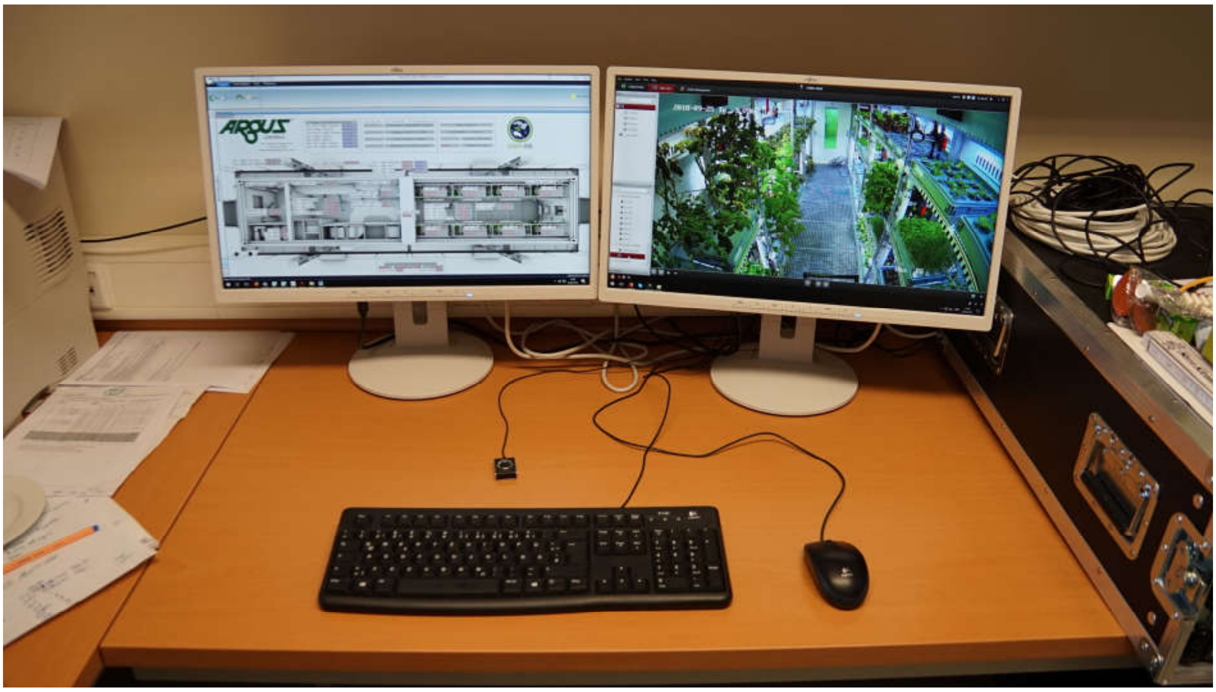

Figure 9: EDEN ISS computers in multipurpose lab.

Figure 10: Storage area of EDEN ISS Spares and consumables, located on the gallery of NM-III.

2 Results of Initial Subsystem and Systems Tests

2.1 *FEG Leakage Test*

During the initiation phase of the MTF, an air exchange test, with CO_2 as tracer gas, was performed. The results of this test can be used to estimate the air exchange between the internal environment of the FEG and the surrounding environment (in particular, the greatest amount of leakage is expected to be through the FEG and the Service Section separation wall). The FEG atmosphere has an elevated concentration of CO_2 in order to increase plant growth rate. For future project calculations such as CO_2 uptake by the crop, it is important to quantify the atmospheric closure/leakage rate of the FEG.

The air exchange rate test was conducted by first increasing the CO_2 concentration well above the level of the surrounding environment. The concentration in the FEG was raised to 2000 ppm, while the surrounding environment has an average concentration of around 400 ppm. As test results can be influenced by the metabolism of plants or humans, it was conducted before plants were planted in the FEG and without anyone in the facility. The concentration decay of CO_2 can then be used to calculate the air exchange rate. Figure 11 shows the results of the test conducted during the initiation phase of the MTF. The CO_2 concentration was logged for a period of almost 24 hours. Over this period the concentration dropped from 2000 ppm to 1550 ppm. The calculated air exchange rate is lower than 50% air volume per day. For comparison, the maximum permitted leakage requirement defined at the beginning of the project was 500% air volumes per day. In the case of FEG leakage rates, a more accurate value could be obtained with a longer duration test (i.e., allowing the FEG CO_2 concentration to drop to values closure than actual ambient values). This was, however, not possible during the MTF initiation phase as the deployment team members needed to work in the facility to complete their tasks before the end of the field season. A longer duration test is thus planned for the next MTF maintenance period between November 2018 and January 2019.

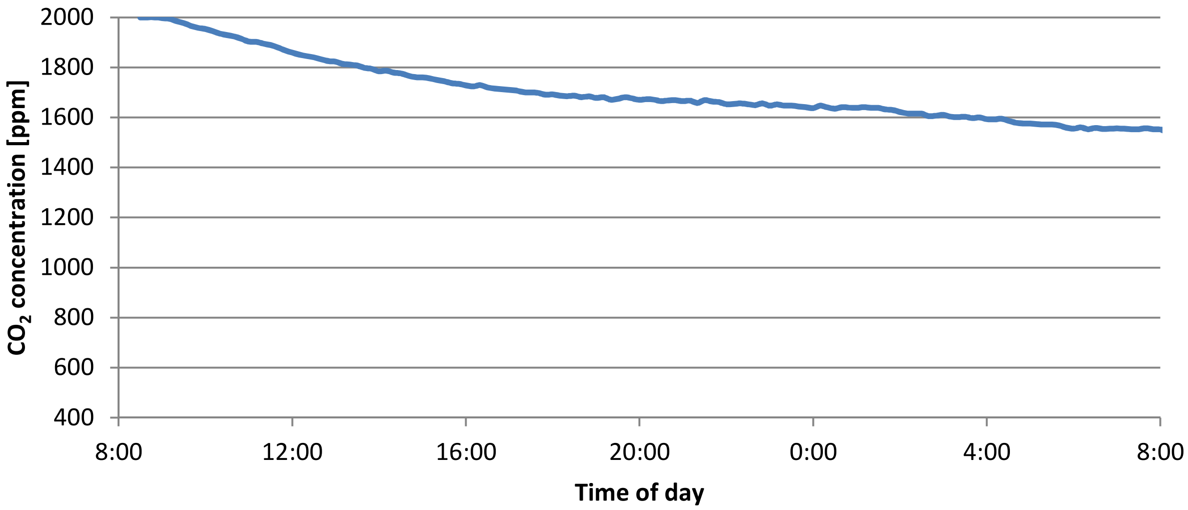

Figure 11: CO_2 concentration inside the FEG during the air exchange test with carbon dioxide as tracer gas.

2.2 *MTF Power Consumption*

An energy measurement system was installed within the MTF power box to monitor subsystem power draws. The measurement system is called Diris Digiware and is sold by the company Socomec. Diris Digiware is a modular system with different modules for voltage and current measurements. The system implemented in the EDEN ISS MTF consists of a voltage measurement module which constantly measures the electrical voltage of the 3-phase main power supply, seven current measurement modules which measure the electrical current of 19 different subsystems or components, a liquid-crystal display in the power box and a communications module to transmit the data to the MTF computer network. Preliminary results taken from the energy measurement system during the early phase of Antarctic operations are presented in Table 1.

Table 1: MTF Measured Power Draws over the period of one week from February 26 to March 4, 2018.

Subsystem	Energy used over one week (kWh)	Average Power (kW)	% of Over-all Draw
Overall MTF	1445	8.60	N/A
CDHS	93	0.55	6.5%
ILS	437	2.60	30.4%
NDS	22	0.13	1.5%
AMS	470	2.80	32.7%
ISPR	48	0.29	3.3%
Thermal	291	1.73	20.2%
Common equipment	77	0.46	5.4%

The values in Table 1 demonstrate that the MTF draws an average of 8.6 kW. It also illustrates that, as would be expected, the ILS and AMS represent the major power draws of the greenhouse. It should be noted that the “Overall MTF” energy in kWh is a measured value and does not perfectly equate to the sum of the energy use measured for the other subsystems (difference only ca. 7 kWh). Also, it should be noted that the presented values represent what is expected to be an average week of MTF operations, but that measurements will be continued throughout the entire Antarctic operational phase and that some variation in these values is to be expected.

3 Issues Encountered and Incorporated Design Updates

Although the EDEN ISS containers were delivered later than planned, the actual on-site deployment activities followed the timeline and the actual activities that were included in the field plan developed in the lead-up to the field season. Although the MTF facility was in the anticipated/planned state at the time of departure of the deployment team, there were several unexpected events that occurred during the field season and a subset of these off-nominal issues are described here:

- *Service Section to FEG door not opening fully*. As described previously, great effort was placed on getting the Service Section and FEG containers to line up properly on the elevated platform. The result was that the containers were approximately 1 to 1.5 cm further separated from each other than they were in Bremen (where the containers were installed directly on the ground) and that one container was angled slightly with respect to the other. The latter was apparent from the perspective that the Service Section to FEG door (installed on the frame of the FEG container) could not be fully opened, as it would bump directly into the Service Section floor. Several adjustments had to be made to the door, the first is that it was moved up as much as possible on its hinges and the rubber installed on the underside of the door was removed. As removing the rubber insulation on the bottom of the door reduced the atmospheric closure of the FEG, a permanently installed bar including a band of rubber insulation was installed directly onto the floor of the FEG. When the door was closed it would push up against the rubber and seal the door connection (Figure 12, left).
- *External damage to the underside of the containers during transport*. Although only first noticed following the installation of the containers onto the elevated platform, it was evident that the Service Section and FEG container bottoms had been pierced during transport to Antarctica. Although one of the two damage locations was significantly deeper, both were insulated with spray foam and then taped over with aluminum tape.
- *Leaks in the thermal control system and NDS piping*. Several leaks in the plastic piping of the thermal control system and NDS were found during early testing/leak checks of these systems with water. It is obvious that the transport to Antarctica was the primary reason for these leaks but as they were somewhat minimal, the project would not have taken any additional measures pre-shipment to reduce the number of leaks that were apparent. These leaks were fixed either by removing a section of piping and installing a freshly glued section or applying additional glue to the connection in question. That said, as one of the leaks of the thermal control system occurred from a union connection, it is suggested that following long duration transport, such as occurred with the EDEN ISS containers, that all union connections should be checked/re-tightened prior to system initiation. Although this was already a known issue with the tightly compact thermal system rack, a lesson learned that should be carried over to future greenhouse system designs is that all connections should be better accessible and systems rack should not be built in such a compact manner if they limit access to all installed components. Thus in addition to providing better access to all connections following shipment, this would simplify repairs and maintenance activities on the thermal control system (on-site maintenance and repair should always be considered a high priority in subsystem design).
- *Removing air from the thermal control system*. Several issues arose in the initial operation of the thermal control system in which the appropriate cooling fluid temperatures in the thermal system could not be maintained. Although considerable time was spent manually releasing air via the various thermal system air release valves, it was obvious that further air was trapped within the roof-top free cooler and this was resulting in less optimal heat transfer. As the free cooler was only used for several hours in Bremen (due to the summer weather during the Bremen test phase) and a large standalone electric cooler was used, such issues were not observed during the AIT phase. The opening and closing of the various air release valves during the Antarctic deployment phase resulted in one of the air release valves breaking. In particular, although the valve could be reclosed it could not be reopened to release air

as otherwise a leak of the Tyfoxit F50 cooling fluid would permanently occur. A project decision was made to change the air release valve while the full deployment team was on-site to reduce the possible heavy workload for the single overwintering operator should this air release valve be further required. Additionally a solid protocol for getting the air out of the free cooler loop was developed, which involved adjusting thermal control system pump settings and manually opening and closing the various other valves in the system, both of which helped force further fluid though the system and further dislodging any remaining air bubbles.

Figure 12: (Left) Floor installed door bar with insulating rubber. (Right) CO_2 distribution system with installed secondary regulator heater.

- *Blockage of flow through the secondary CO_2 regulator*. Although detailed analysis showed that problems due to low temperature were not likely to arise with the CO_2 distribution system even if it were to be placed outside the MTF, on several of the cold days of the deployment phase it was observed that even with the internal CO_2 solenoid valve open, no CO_2 would flow into the FEG. Following leak checks, testing and additional observations, it was concluded that this was a result of CO_2 freezing up within the secondary regulator of the CO_2 distribution system (Linde W20/B regulator with 0.5 to 10.5 bar output, part number: 7616606). When a small amount of heat was applied to the regulator a small grain of CO_2 ice could be heard as it was dislodged and CO_2 could then flow again. To combat this problem, a small electric heater was installed directly onto the regulator body and a minor amount of insulation added (see top regulator in Figure 12, right). Control logic was built into the Argus control system to activate the heater on a set schedule and no additional blockages in the CO_2 delivery system were observed.
- *Microbial contamination in the NDS*. Early in the deployment the NDS was filled with nominal NM-III water to test the system for leaks. This water was later drained and the system refilled with reverse osmosis water and concentrated hydroponic stock solutions added to their respective NDS tanks. Several NDS check-out tests were conducted to ensure that the system could maintain the desired pH, electrical conductivity, tank level set-points while testing NDS hardware in the lead-up to plants being added to the FEG. Plants were added approximately a week later and approximately two days later the team remarked that the solution in NDS tank 1 (salad crop hydroponic solution) was cloudy, had a small amount of foam buildup floating on the surface and was emitting a moderately foul odor. This was followed by the observation of a white/pinkish fungus on the surface of the rockwool plugs that some of the plants were growing in. Images of both the growth tray fungus and state of the hydroponic solution were taken and sent along to the EDEN ISS science team in Europe. Samples were also collected for later analysis. Although the on-site team reacted initially by increasing the

duty cycle of the ozone generators feeding the NDS tanks, which resulted in some improvement over the period of a day, considering input from the remote science team and the fact that the deployment team would be departing in less than a week, leaving the on-site operator alone, the deployment team decided that proceeding with a full-system clean-out was the preferred option prior to their departure. The team proceeded in removing all plants from the MTF, draining the entire NDS, cleaning all accessible surfaces (e.g. plant trays, inside of NDS tanks) with appropriate disinfectants, filling the NDS with a concentrated bleach solution and operating all pumps and components for a period of 5 hours. The system was then drained, filled with water, re-drained and left to dry. In conjunction, additional seeds were germinated in the station and the ozone generator settings reassessed and further increased. The results and analysis of the samples returned will be reported upon in a later publication.

- The external communication lines to the MTF control PC (Argus) were not stable and remote access to this control PC (through personnel from Argus or other members of the EDEN ISS project remote operations team) was not possible. This situation lasted several days and the planned upgrades and improvements could not be made to the CDHS. Eventually the situation was resolved by the AWI information technology department by readjusting the firewall settings within the server architecture in Bremerhaven.

Another key element of the EDEN ISS MTF is the International Space Station rack-like plant growth system (ISPR). Although several of the top-level on-site activities with the rack-like system have been described here, a full description of its deployment and early operations are described in ISPR/RUCOLA project documentation.

Some minor design updates were also implemented during the initial deployment phase in the Antarctic. The following list gives an overview of these updates:

- NDS:
  - Trays were angled in order to allow better flow inside the trays.
  - Added visible labels to each tray; to be used as references on the images taken by the observation cameras.
  - Testing of the UV light, filter and pump in the fresh water tank

- AMS
  - Installed the CO2 flow meter, for more accurate measurement of CO2 usage in the MTF.
  - Added additional fans in the subfloor in both the SS and FEG to minimize ‘cold spots’ where condensation may occur.
  - Final taping of air ducts, plugging of leakage pathway in the cable channels between the two containers, to reduce leakage from FEG to Service Section.

Figure 13: The DLR EDEN ISS deployment team (Left to right: Paul Zabel, Conrad Zeidler, Matthew Bamsey, Daniel Schubert).

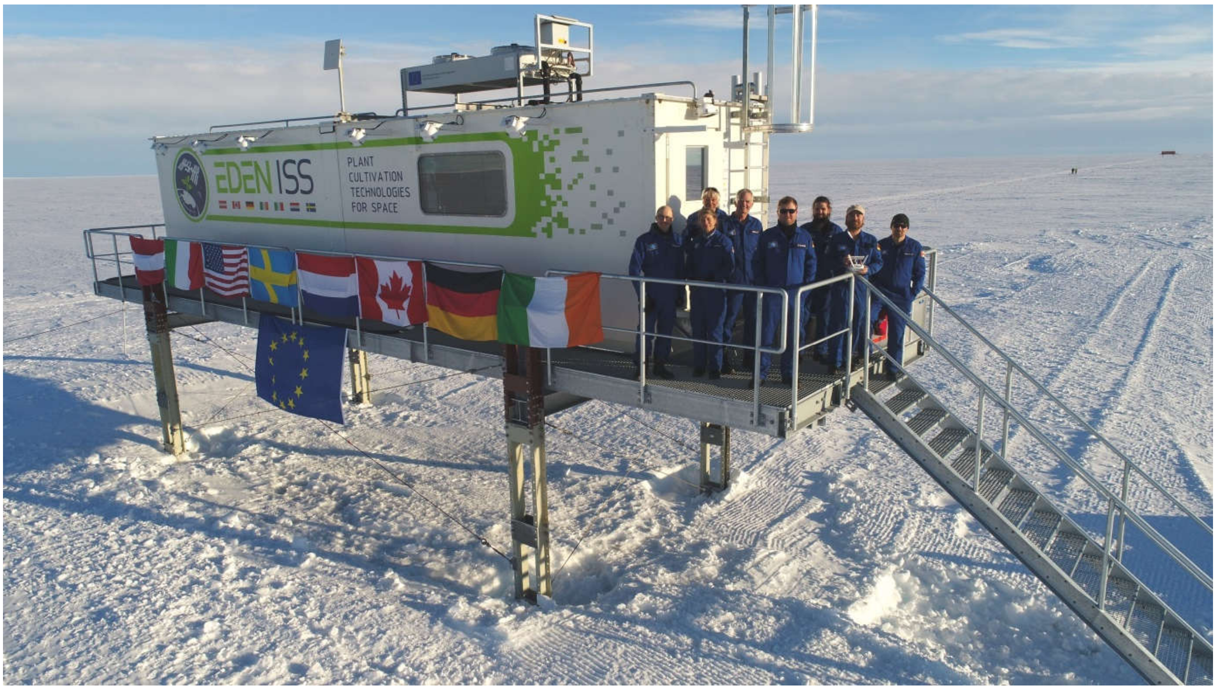

Figure 14: The full EDEN ISS deployment team (Left to Right: Giorgio Boscheri, Anna-Lisa Paul, Eberhard Kohlberg, Robert Ferl, Paul Zabel, Conrad Zeidler, Daniel Schubert, Matthew Bamsey).

Figure 15: The MTF observed around midnight nearing the departure of the EDEN ISS deployment team from Antarctica.

References

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