remote sensing

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Perspective

SIOS's Earth Observation (EO), Remote Sensing (RS), and operational activities in response to COVID-19

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Abstract: Svalbard Integrated Arctic Earth Observing System (SIOS) is an international partnership of research institutions studying the environment and climate in and around Svalbard. SIOS is developing an efficient observing system, where researchers share technology, experience, and data, work together to close knowledge gaps, and decrease the environmental footprint of science. SIOS maintains and facilitates various scientific activities such as the State of the Environmental Science in Svalbard (SESS) report, international access to research infrastructure in Svalbard, Earth observation and remote sensing services, training courses for the Arctic science community, and open access to data. This perspective paper highlights the activities of SIOS Knowledge Centre, the central hub of SIOS, and the SIOS Remote Sensing Working Group (RSWG) in response to the unprecedented situation imposed by the global pandemic coronavirus (SARS-CoV-2) disease 2019 (COVID-19). The pandemic has affected Svalbard research in several ways. When Norway declared a nationwide lockdown to decrease the rate of spread of the COVID-19 in the community, even more strict measures were taken to protect the Svalbard community from the potential spread of the disease. Due to the lockdown, travel restrictions, and quarantine regulations declared by many nations, most physical meetings, training courses, conferences, and workshops worldwide were cancelled by the first week of March 2020. The resumption of physical scientific meetings is still uncertain in the foreseeable future. Additionally, field campaigns to polar regions, including Svalbard, were and remain severely affected. In response to this changing situation, SIOS initiated several operational activities suitable to mitigate the new challenges resulting from the pandemic. This article provides an extensive overview of SIOS's Earth observation (EO), remote sensing (RS) and other operational activities strengthened and developed in response to COVID-19 to support the Svalbard scientific community in times of cancelled/postponed field campaigns in Svalbard. These include (1) an initiative to patch up field data (in situ) with RS observations, (2) a logistics sharing notice board for effective coordinating field activities in the pandemic times, (3) a monthly webinar series and panel discussion on EO talks, (4) an online conference on EO and RS, (5) the SIOS's special issue in the Remote Sensing (MDPI) journal, (6) the conversion of a terrestrial remote sensing training course into an online edition, and (7) the announcement of opportunity (AO) in airborne remote sensing for filling the data gaps using aerial imagery and hyperspectral data. As SIOS is a consortium of 24 research institutions from 9 nations, this paper also presents an extensive overview of the activities from a few research institutes in pandemic times and highlights our upcoming activities for the next year 2021. Finally, we provide a critical perspective on our overall response, possible broader impacts, relevance to other observing systems, and future directions. We hope that our practical services, experiences, and activities implemented in these difficult times will motivate other similar monitoring programs and observing systems when responding to future challenging situations. With a broad scientific audience in mind, we present our perspective paper on activities in Svalbard as a case study.

Keywords: Earth observation; Remote sensing; COVID-19; Svalbard; Earth System Science; SIOS

1. Introduction

Svalbard Integrated Arctic Earth Observing System (SIOS) [1] is a Norwegian initiated international consortium of 24 research institutes from 9 nations building and optimising a sustained regional multidomain distributed Arctic observing system of long-term measurements in and around the High-Arctic archipelago of Svalbard. The observing system consists of long-term in situ and remotely sensed measurements in and around Svalbard addressing Earth System Science (ESS) questions. SIOS research infrastructures (RI) can be used for various current and future satellite missions for calibration and validation (Cal/Val) activities. Eventually, integration of in situ and satellite-based measurements will benefit the entire ESS community to address broad scientific questions. Within SIOS, researchers can cooperate to access instruments, acquire remotely sensed and in situ data, and address questions that would not be practical or cost effective for a single institution or nation alone. SIOS focuses on cross-disciplinary processes and their interactions between the different spheres, i.e. biosphere, geosphere, atmosphere, cryosphere, and hydrosphere. The observing system strives to provide the members with systematic high-quality observations in a cost-efficient and environment friendly way. Other networks such as the Sustaining Arctic Observing Networks (SAON)/Arctic GEOSS, stakeholders, and users outside the SIOS consortium also benefit from these data series. The SIOS Knowledge Centre (SIOS-KC), located in the Svalbard Science Centre in Longyearbyen, is the central hub of SIOS. SIOS-KC coordinates the services provided by SIOS for the international research community and ensures sustainability and maintenance of the network. The services offered include: (1) integration of the distributed research infrastructure and data to optimise the observing system, (2) access to the research infrastructure (SIOS ACCESS programme), (3) data management including storing and curating of scientific data (ground-based, airborne and spaceborne), (4) tools and support for scientists to make use of the extensive Earth observation (EO) and remote sensing (RS) resources available, (5) coordination of logistical services, (6) training and education programmes, and (7) information and outreach. EO and RS activities are important parts of the observing system as certain key data can be measured with satellite-based observations. Over the past three decades, tremendous developments in EO satellite missions have made significant contributions to spatial-spectral-temporal sampling and subsequent extraction of geoinformation (GI) from the Arctic. Due to the harsh and remote Arctic environment, there is a lack of basic in situ observations that can support scientific understanding of key processes and support operational services. Most of the existing data are collected via time limited research projects, and many of these via manual and on-site work [2]. Svalbard is probably one of those regions in the Arctic with the most in situ measurements spanning across various spheres; still, there are massive gaps spatially distributed in various regions. Such data gaps can be filled using frequent satellite-based acquisitions, new product generation using EO/RS/GI, and integration of ground-based, airborne, and satellite-based measurements.

The novel coronavirus SARS-CoV-2 caused the current global pandemic of Coronavirus disease 2019 (COVID-19), resulting in massive infection and mortality around the world [3]. Besides, situations like the pandemic have the potential to contribute to issues related to exacerbating personal mental health and socio-economic inequalities. The virus is still surging across the world in multiple waves of outbreaks in different countries, causing considerable societal and global economic impacts. Many national governments implemented lockdowns of various forms, including prohibition on large gatherings, travel restrictions, and implementing or encouraging social distancing, to decrease virus spread and reduce pressure on healthcare systems [4]. International researchers, including those from SIOS member institutions, carry out field campaigns annually in different parts of Svalbard and associated waters, especially focussing on Ny-Ålesund, Longyearbyen, and Hornsund. However, due to the sudden and rapid outbreak of the COVID-19, the World Health Organization (WHO) declared a global pandemic on 11th March 2020 and most nations closed their borders. Norway was locked down from the 13th of March 2020. Because of the small community and limited health services in Longyearbyen, even stricter measures were taken in Svalbard in comparison to mainland Norway. The worldwide lockdown in the beginning of the Arctic spring season has affected many field campaigns to Svalbard. Glaciologists and snow scientists (including those associated with biosciences) were initially worst affected as spring is a crucial period to monitor changes in glaciers and amount of snow stored in the catchments. Most of the scientists in the countries with active Svalbard research activities, including Norway, were grounded. Some of RIs (e.g. Polish Polar research facility at Hornsund) were temporarily closed for visitors. By the time Norway initiated the lockdown, also most of the planned conferences were already cancelled (Figure 1), postponed, or converted to online mode. This was a completely new situation and needed special attention.

COVID-19 has impacted the polar research in many ways since the beginning of the year and it continues to affect future programmes. These include cancellation of field campaigns, cancellation and/or postponement of important conferences, workshops, and training courses, delays in delivery of scientific outputs because of shutdown of campuses, cancellations and/or delay in funding and many more. Several transnational access projects in the Arctic supported by EU-INTERACT (https://eu-interact.org/) have been affected during the field season in 2020 with around 120 scientists had to cancel their field campaigns. Frame and Hemmings [5] reviewed the potential impact of COVID-19 in Antarctica through tourism and scientific research over three (short-term, mid-term, and long-term) time periods. According to these authors, Antarctic tourism and field-based research will be severely reduced in the short term. We believe that this conclusion is also applicable to the impact on Svalbard field-based research in a short term. In response to this situation, a few activities have been started by leading networks such as Scientific Committee on Antarctic Research (SCAR) and International Centre for Integrated Mountain Development (ICIMOD) on studying social aspects and impact on communities due to COVID-19. ICIMOD has published a comprehensive report on COVID-19 impact and policy responses in the Hindu Kush Himalaya [6]. COVID-19 has also heavily impacted scientific and logistical activities in Antarctica [7]. The Antarctic COVID-19 Research Group of SCAR has conducted a survey [8] to learn more about the impact of pandemic on the Antarctic research community. Outcomes of this survey are expected to understand effects of the COVID-19 situation on the Antarctic science community to inform strategic decisions to mitigate impacts. On the other hand, SIOS focused more on mitigating short term impacts of COVID-19 during the core field season in Svalbard. The Rapid Action on Coronavirus and EO (RACE) [9] platform launched by joint cooperation between European Space Agency (ESA) and the European Commission demonstrates the use of wide range of EO data from Copernicus Sentinels and third-party missions to track societal, economic, and environmental changes in times of COVID-19 pandemic. Recent publications and services in literature highlight the contribution of EO and RS in tracking the spread of virus and monitoring the pandemic events or the effect of the lockdown on the environment [10–12]. Our study, however, is probably the first attempt of highlighting the role of EO and RS for mitigating the damage in terms of possible data gaps in long time data series of scientific observations in one of the most remote places on planet Earth.

Figure 1. Most conferences were either cancelled, postponed, or converted to online versions due to the global COVID-19 pandemic.

SIOS-KC provides services including logistics, remote sensing, communication, online events, training courses, data access, observation facility catalogue, and satellite data visualisation on the website and provide support via online tools. In the beginning of the pandemic (January–February 2020) in mainland China and Italy, regular activities were not yet affected but SIOS-KC was alert and developed a pandemic plan of action. When the Norwegian lockdown began on 13th March 2020, SIOS-KC quickly initiated several activities to adapt to the new situation. The Remote Sensing Working Group (RSWG) of SIOS took an active part in developing new activities to keep the scientific community engaged in these difficult times. SIOS responded with several initiatives: to keep international research community up-to-date about the fast-changing regulations concerning travel restrictions to Svalbard and to the different research facilities, a compilation of all relevant information resources was made available on the SIOS web page; a logistics sharing notice board was launched as a platform to offer and request help with issues related to cancelled field activities during the lockdown; the SIOS remote sensing service published an offer to patch up field data gaps with RS techniques, and a monthly webinar mini-series was started in March 2020 to provide a social experience and keep the Svalbard research community engaged. SIOS also approached the situation with a general attitude of flexibility and service mindedness, for example being generous with extensions to deadlines and trying to find solutions to logistical problems in field campaigns. Detailed descriptions of these activities are presented in this article.

2. SIOS's Response to the COVID-19 Pandemic

In the following sections, we present our key activities conducted in the period March–December 2020 in response to changes in travel restrictions in Svalbard in chronological order (Figure 2).

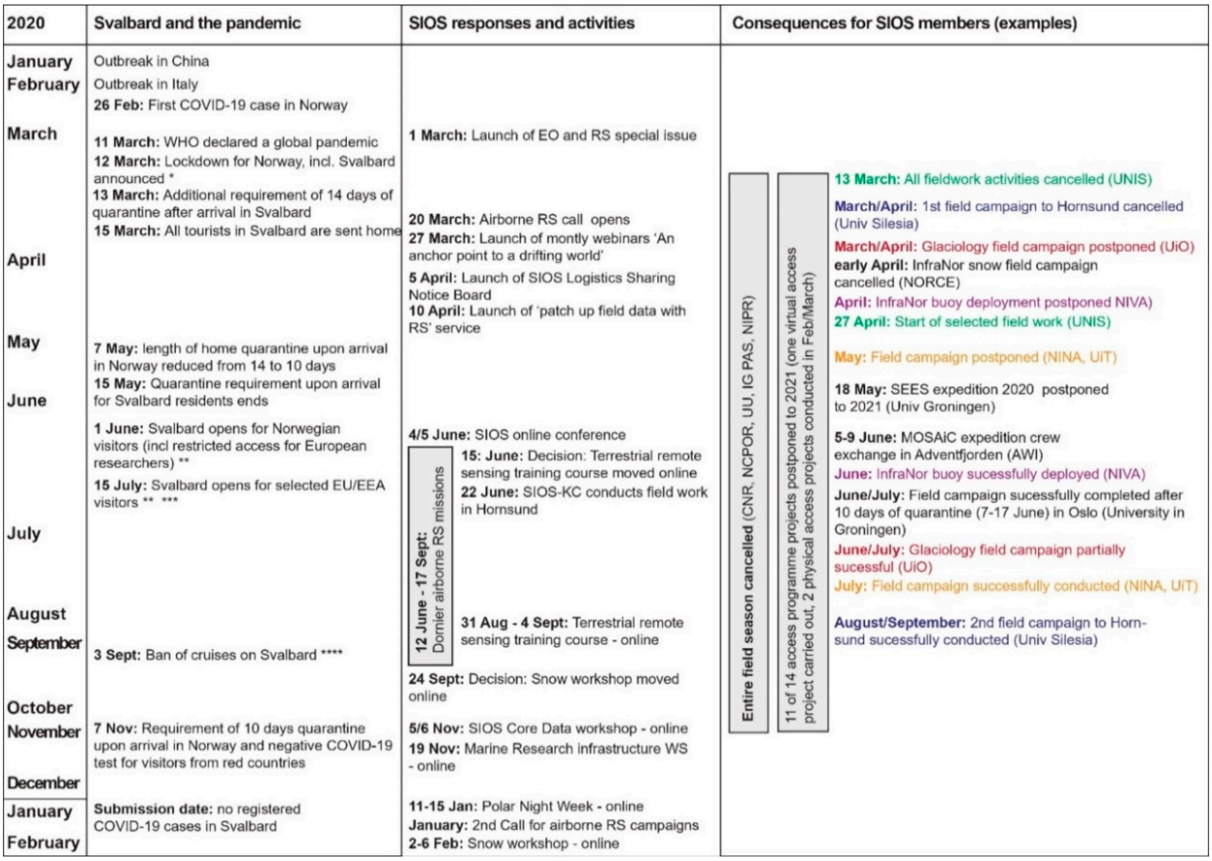

Figure 2. Timeline of events since outbreak of the pandemic, including travel restrictions related to Svalbard, Svalbard Integrated Arctic Earth Observing System (SIOS) responses and activities and some examples of consequences for SIOS member institutions. CNR: National Research Council of Italy; NCPOR: National Centre for Polar and Ocean Research, India; UU: Uppsala University, Sweden; IG PAS: Institute for Geophysics Polish Academy of Sciences, Poland; NIPR: National Institute of Polar Research, Japan; UNIS: University Centre in Svalbard, Norway; UiO: University of Oslo,

Norway; NORCE: Norwegian Research Institute, Norway; NINA: Norwegian Institute for Nature Research, Norway; UiT: UiT The Arctic University of Norway; AWI: Alfred Wegener Institute, Germany. [*14 days of quarantine after arrival in Norway required, ** except EU/EEA countries with high infection risk ('red countries'), *** no longer 10 days quarantine after arrival in Svalbard required, ****For cruises with more than 30 people (crew and passenger), except day cruises].

2.1. Special Issue in an International Journal to Facilitate Publications from the International Scientific Community

An unintended consequence of fortuitous timing of an already planned activity was the launch of a special issue to facilitate publications from the international scientific community in Svalbard. Since the beginning of March 2020, SIOS has hosted the special issue "Earth Observation (EO), Remote Sensing (RS), and Geoinformation (GI) Applications in Svalbard" [13] in the Remote Sensing (https://www.mdpi.com/journal/remotesensing) journal. This special issue is being edited by 12 experts from SIOS member institutions and SIOS-KC with a strong RS, GI and EO background. This activity was not started in response to COVID-19 but was already planned at the beginning of the year. However, this activity has since provided a platform for researchers to publish their EO and RS based studies in Svalbard during a time when many are confined to home offices. It also helps scientists to expedite their pending publications during lockdown time.

2.2. SIOS Webinar Series: an Anchor Point to a Drifting World

This activity was SIOS's first response specifically to the new situation, when the RSWG launched the first of the SIOS webinar series on EO and RS. We aimed to provide a social experience to the Svalbard research community to remedy the lack of a social environment because of cancelled field campaigns and conferences by launching a webinar series. The SIOS webinar series "an anchor point to a drifting world!" includes talks on EO and RS [14] with expert scientists working on different environments of Svalbard, followed by panel discussions (Figure 3). In our experience, keeping the community together in times of chaos was a wise decision. All the talks of this webinar series are available online as PDF and video files, which are open for the entire scientific community. This constitutes an excellent learning resource for the research community, especially early career researchers. Other online seminar series and events were announced subsequent to the launch of the SIOS webinar series. The International glaciological society launched an IGS global seminar series [15] on 15th April 2020. Polar Geospatial Centre (PGC) webinars [16] also gained attention during the lockdown period. All these online events were a means to bring the scientific community together and share their scientific results with the community in these challenging times.

Figure 3. In March 2020, SIOS launched a monthly webinar series to keep the SIOS community engaged with each other and to provide a social experience. This webinar series acts as a symbolic anchor point to a drifting Svalbard science community.

2.3. SIOS's Online Conference on Earth Observation (EO), Remote Sensing (RS), and Geoinformation (GI) Applications in Svalbard

Encouraged by the success of the SIOS webinar series and lessons learned from the online version of the International Arctic Science Committee's (IASC's) Arctic Science Summit Week (ASSW) in the beginning of lockdown (March 2020), SIOS decided to host its own online conference in June 2020 [17]. The conference aimed to (1) promote the opportunity for PhD students, postdocs, researchers, scientists, and academicians to contribute actively to SIOS's special issue in Remote Sensing journal (MDPI), (2) review the state-of-the-art EO/RS/GI applications in Svalbard and (3) provide a social experience to the Svalbard scientific community. The conference was hosted on 04-05th June 2020. A total of 53 talks were delivered, including 3 keynote talks and 3 invited talks, by presenters from 24 institutions from 12 countries. Out of these talks, 14 talks were delivered by early career researchers. A special session was hosted on the airborne remote sensing applications in Svalbard, in which project investigators from the "SIOS announcement of opportunity in airborne remote sensing" delivered short presentations on the planned activities. Additionally, a special session on EO and RS activities supported by SIOS was conducted. We also conducted open remote sensing dialogue for the first time to receive inputs from the EO and RS community on further developments on COVID-19 related activities. The participation in the conference was wide, with more than 370 registered participants (around 140 attendees on the first day and around 90 attendees on the second day). A very positive response was observed on feedback polls with an average score of 9 out of 10 for all the presentations (Table 1). Most of the presentations and an abstract book are available on the SIOS website (https://sios-svalbard.org/RS_OnlineConference2020) and is an important knowledge resource in the pandemic times.

2.4. Shifting from Physical to the Virtual Mode of Terrestrial Remote Sensing Training Course

After the successful and interactive online conference organised in June 2020, we were still not confident that travel restrictions would be lifted in September 2020 when our annual remote sensing training was planned to take place in Longyearbyen. Therefore, on 15th June 2020, we decided to convert the training course to a fully online mode. With this decision, SIOS wanted to ensure that applicants from all countries can participate in the training course, independent of the current travel restrictions. SIOS held this online training course [18] during 31st August–4th September 2020. The course covered topics on how to effectively use EO and RS data acquired from satellites, from the air or from the ground, and their associated tools and software in the context of terrestrial research in Svalbard. The course was intended for field scientists, PhD students, and technicians with no or little experience with EO and RS techniques. The training was delivered by ten EO and RS experts and international academicians. A virtual field excursion activity and hands-on sessions were developed to make this training course to include practical exercises. This was our first experience of hosting a fully online training course and the feedback from this activity provided us with valuable insight into how to deliver future online courses. Apart from providing training to selected participants, we also decided to open the course lectures for anyone interested to join, as a special edition of our SIOS webinar series. This essentially provided a free opportunity for many budding scientists to learn new EO and RS skills necessary for Svalbard research. Around 150 registered participants attended different lectures during the whole training course.

2.5. Patch up your Field Data with Remote Sensing Observations

Continuous long-term data is essential for modellers and other scientists for interpreting and tracking long term changes and is an essential component of the SIOS observing system. However, the pandemic situation posed a new challenge in measuring in situ parameters due to travel restrictions and quarantine regulations in Svalbard. EO and RS are thus more relevant in the current times than ever. While in the beginning we focused more on online events and carrying out discussions with scientists, in the next step, we started working on practical suggestions from the community to respond to their needs. The first step was mapping the needs of researchers and evaluating the possibilities to provide RS observations in the absence of field campaigns in Svalbard. Since we had no generic solution, in the first stage, we wanted to understand the anticipated damage to data series within the Svalbard scientific community. With the launch of the service "patch up your field data with remote sensing observations" [19], we tried to help those scientists who were unable to conduct field campaigns in Svalbard this year to fill the gaps in observations using RS (Figure 4). The data collected from this tool would provide a summary of data and logistics requirements from researchers, role of EO and RS observations in absence of field campaigns, and mitigation measures that can be considered in the future similar situations to save or fill the long-term time series of data and the continuous operation of instruments in Svalbard. This strategy would probably be applicable to many cryospheric regions including Antarctica and Himalayas, where field campaigns often need to be cancelled or postponed. We believe that our initiative can be expanded to other regions to map requirements from scientists to avoid gaps in essential data in the future.

Table 1. Overview of virtual activities conducted by SIOS to bring the community together.

No.	Webinar Theme	Date	No. of Talks	No. of Registrations	No. of Attendees	Feedback (out of 10)
1	An anchor point to a drifting world: EO and RS applications in Svalbard and panel discussion on COVID-19 driven damage mitigation in Svalbard	27 March 2020	5	Registration was not required	55	≈8
2	An anchor point to a drifting world: EO and RS applications in Svalbard and panel discussion on data management	24 April 2020	3	Registration was not required	48	≈8
3	SIOS Online Conference on EO, RS, and GI	4–5 June 2020	53	372	≈90–140	≈9
4	SIOS Terrestrial Remote Sensing Training Course-Lecture series	31 Aug.–4 Sept. 2020	12	163	≈40–50	≈8
5	An anchor point to a drifting world: Grand Challenge Initiative (GCI) cusp rocket missions in Svalbard and their relevance to atmospheric studies	23 October 2020	4	55	30	≈9
6	SIOS Core data workshop	5–6 Nov. 2020	4	58	43	≈7

7	SIOS Marine research infrastructure workshop	19 Nov. 2020	16	67	60	≈9
8	An anchor point to a drifting world: Marine science in Svalbard - global to local perspective and panel on the outcomes of the SIOS marine infrastructure network workshop	27 Nov. 2020	4	124	65	≈9

2.6. Logistics Sharing Notice Board

One problem that arose during the onset of COVID-19 was by scientists that were scheduled to maintain and download data from various installations, both as permanent infrastructures in research facilities, but also temporary installations in the field. In addition, field parties usually collect various data during the maintenance of the installations, essential to complement data collected by various stationary instruments. In response to this tricky situation, SIOS came forward to provide a helping hand to look after essential instruments in the field when scientists were not able to travel to Svalbard. Although we had started providing EO and RS based solutions, we realised that there were many scientific observations for which it was not possible to fill the gap using only RS. As such, our next level of response to the changing situation was more hands-on. In response to cancelled fieldwork in Svalbard, Svalbard Science Forum (SSF) (https://www.forskningsradet.no/en/svalbard-science-forum/) stepped forward at the very beginning of lockdown to help connect researchers in need of support for field logistics by facilitating dialogues on a social media platform [20]. Since SIOS had already started developing the "Logistics Sharing Notice Board" for regular sharing of information on logistics and resources, we decided to expand this activity to meet the new challenge. The most significant issue at the beginning of the lockdown was that most of the glaciologists who are visiting Svalbard every year at the beginning of March 2020 were now unable to travel and carry out fieldwork. In these special times, SIOS offered to assist where possible to avoid gaps in long-term data series. SIOS introduced the Logistics Sharing Notice Board [21] in April 2020, which gives an overview of the planned fieldwork in Svalbard with the possibility to offer or request spare capacity (Table 2).

Figure 4. Overview of SIOS's Earth observation (EO), Remote Sensing (RS) and operational activities in response to COVID-19 pandemic including (**a**) Platform for publishing studies: SIOS's special issue in an international journal motivate scientists to consider submitting manuscripts in indoor times. (**b**) EO and RS activities: Patch up missing data with remote sensing observations in times of lockdown and travel restrictions. (**c**) Social experience and networking platform: SIOS online conference as a platform to connect the Svalbard research community when physical meetings are not feasible, and (**d**) Logistics Sharing Notice Board: a tool to help scientists in times of lockdown to maintain their field instruments for the season.

Table 2. Fieldwork assistance requested via SIOS's Logistics Sharing Notice Board (More details: https://sios-svalbard.org/logistic-notice-board#). Those highlighted with grey coloured background were not fulfilled because of logistics and technical constraints. *Research in Svalbard, RiS Id (https://www.researchinsvalbard.no/).

No.	Project Name/Brief Description	RiS ID*	Location in Svalbard
1	Lomonosovfonna Firn Aquifers and mass balance	3395	Lomonosovfonna / Nordenskiöldbreen
2	Hydro-condition of Werenskioldbreen 2020	11198	Werenskioldbreen, Hornsund
3	Plant stable isotopes	N.A	Longyearbyen
4	Antibiotic resistance genes and integrons as indicators of biotic pollution and resistance load of Arctic ecosystems	11563	Longyearbyen
5	Bogerbreen mass balance	N.A	Bogerbreen in Endalen (Longyearbyen)
6	Hydro-meteorological condition of the Hornsund area 2020	11198	Catchments of the Hornsund fjord region including Werenskioldbreen, Brateggbreen, Ariebreen, and Fuglebekken

SIOS-KC is staffed by professionals with fieldwork experience in a range of disciplines including biology, environmental science, atmospheric sciences, glaciology, and EO/RS. Therefore, we decided to make use of the SIOS-KC's expertise by offering to conduct campaigns to carry out field measurements, collect and/or deploy equipment in the field and carry out basic maintenance. This was also an opportunity for us to support local businesses by cooperating with local logistics providers to solve such tasks alongside the expertise of SIOS partners and SIOS-KC. This is significant for the current situation because the tourist industry, including local tourist guides with extensive field experience, is suffering heavily with loss of income due to dwindling numbers of tourists.

The first request entered on the notice board was from a glaciologist from Uppsala University, who has been monitoring glaciological and meteorological parameters on the Lomonosovfonna icefield since 2006. The team was hopeful in mid-March that they could make it to Svalbard, but the travel restrictions to Svalbard made it impossible for them to carry out their field campaign. The research group wanted to recover data and remove instruments from the glacier before the sensors installed last year would be buried by snow and eventually lost, and likely hard to recover after next winter. This would be a huge loss in terms of funding and resources and create more than a year-long gap in the data that has been monitored since 2006. They requested a rescue mission to save these instruments, which SIOS-KC planned and was almost ready to execute. Unfortunately, when a different scientific field party had an accident on another glacier, all activities on glaciers were stopped to minimise the pressure on the limited search and rescue resources in Svalbard and the plan to rescue the instruments was cancelled. This example highlights the uncertainty in carrying out field observations in polar regions. More successful uses of the notice board are described in Section 3.

2.7. SIOS's Announcement of Opportunity (AO) in Airborne Remote Sensing—2020

In parallel to the efforts based on satellite data gap filling and ground-based logistics support to scientists, we channelised dedicated funding for scientists to use aircraft and unmanned aerial vehicles (UAVs) to collect data in Svalbard (https://sios-svalbard.org/AirborneRS). This is one of the best ways to fill the data gap in the current situation as it is practically possible to conduct field campaigns using airborne platforms despite travel restrictions with minimal resources. SIOS allocated 1 million Norwegian kroner to cover 25 hours of flight time in the field season of 2020 in collaboration with its member institutions NORCE Norwegian Research Centre and University Centre in Svalbard (UNIS). The available platforms offered aerial images, UAV images, and hyperspectral data which will be freely available to scientists [22]. In total, 10 scientific research projects (Table 3 and Figure 5) were able to acquire aerial images and hyperspectral data from various locations in Svalbard through this initiative. The aircraft Dornier DO228 aircraft operated by the local company Lufttransport is permanently stationed on Svalbard and used regularly for transporting personnel and cargo to the science community in Ny-Ålesund and mining community in Svea. The aircraft has recently been fitted with a camera (Phasone IXU-150, Schneider LS 55mm f/2.8) and a hyperspectral imager (VNIR-1800, Norsk elektrooptikk) (Figure 6). The hyperspectral sensor images the ground in 186 spectral bands covering the range 400–1000 nm. Hyperspectral data can be used to map minerals, vegetation, and the presence of animals. In addition, aerial photos have many uses in Svalbard, such as mapping snow, sea ice, and glaciers, counting seals, and making 3D models of the terrain. The cameras installed on the Dornier aircraft can acquire images with a ground resolution of 10 cm from flight altitude of 1000 meter. A big advantage for this platform is that we can acquire images when it is cloudy above the airplane, unlike satellites that depend on cloudless conditions—something which can be a rare sight on a typical Svalbard summer. This is a well-timed activity which coincided with scientists who usually travel to Svalbard every year to continue their scientific measurements being grounded in their home countries. Data collected from the SIOS funded airborne missions will not only help to fill a few of the data gaps resulting from the lockdown, and will be used by glaciologists, biologists, hydrologists, and other Earth system scientists to understand the state of the environment of Svalbard during these times.

Table 3. Airborne remote sensing projects from SIOS's announcement of opportunity (More details: https://sios-svalbard.org/AirborneRS). Those highlighted with grey coloured background were not implemented because of logistics and technical constraints.

No.	Project Name/Brief Description	RiS ID	Location in Svalbard
1	Mapping surface properties on Lomonosovfonna (SurfPro)	3395; 3231	Lomonosovfonna
2	Kongsvegen surge: Digital Elevation Model 2020 (KING_SURGE_DEM2020)	11431	Kongsvegen
3	Airborne Remote Sensing in South of Spitsbergen (current evolution of polar environment) (AirborneSOS)	10511, 11411, 10218, 6823, 11500	Wedel-Jarlsberg Land (Southwestern Spitsbergen)
4	Hindcasting and projections of hydro-climatic conditions of Southern Spitsbergen (HyMote)	11198	Southern Spitsbergen
5	The Vanishing White (VANWHITE)-Airborne Remote Sensing campaign Svalbard 2020.	11411	Coraholmen and Flintholmen
6	Automatic system for monitoring vegetation and environmental seasonal changes on Svalbard using hyperspectral data (ASMoVEn).	11063	Adventdalen
7	Long term changes in vegetation and permafrost in Rosenbergdalen (Rosenbergdalen)	11497	Rosenbergdalen
8	Barnacle Goose Ecology: interactions with a changing environment (GOOSE)	6359	Ny-Ålesund and surroundings
9	De-icing of Arctic Coasts: Critical or new opportunities for marine biodiversity and Ecosystem Services?	N/A	Adventdalen and Agardhfjorden
10	Icebergs study by Centre for Integrated Remote sensing and Forecasting for Arctic Operations (CIRFA)	10373	Icebergs around Nordaustlandet
11	Mapping of perennial firn aquifers and firn characteristics on Svalbard ice fields (PFA)	3395; 3231	Holtedahlfonna to Lomonosovfonna
12	Sea ice observations using aerial imagery from the Dornier during the Coordinated Arctic Acoustic Thermometry Experiment (CAATEX) cruise to 84N with KV Svalbard (CAATEX-DORNIER)	N/A	Sea ice areas north of Svalbard

The call for access to aerial photos opened at about the same time as Norway closed down in March 2020, scientific review and logistics feasibility was done during May, and we began aircraft missions at the beginning of June 2020. In September 2019, NORCE had already conducted pilot missions to test sensor performance, and while planning these flight campaigns researchers were invited to request data from their area of interest. These test flights helped us to rapidly plan and execute this first operational activity in the time of the pandemic when it is most relevant for the scientific community. Researchers will be able to analyse the data from the aerial photographs by comparing them with satellite data and their own measurement series from previous fieldwork. Such comparisons are important both for researchers working on Svalbard and for owners of Earth observation satellites for validation of satellite data.

One of the major goals of SIOS is to work towards reducing the environmental footprint of scientific observations. Therefore, SIOS strongly supports and coordinates the usage of UAVs and aircraft platforms to acquire aerial imageries and hyperspectral data for the Svalbard research community. The most significant advantage of this activity is that the Dornier is always stationed in Longyearbyen. With its regular flights to Ny-Ålesund and Svea, it makes it even more economical to collect data from the regions that are covered by the flight route. Flights to Villum Research Station at Station Nord, Greenland expands the applicability of these missions outside Svalbard. All the data collected during these missions will follow the FAIR principles [23]. The huge volume of airborne data being collected during these missions will make Svalbard one of the richest regions on the Earth in terms of the amount of hyperspectral data available. This years' flight missions continued until mid-September and currently we are planning our next call of opportunity to use the aircraft and UAVs for flight operations in 2021. This call would add more value to fill the gaps for consecutively two years as we are still not sure whether scientists would be able to carry out field activities next year yet.

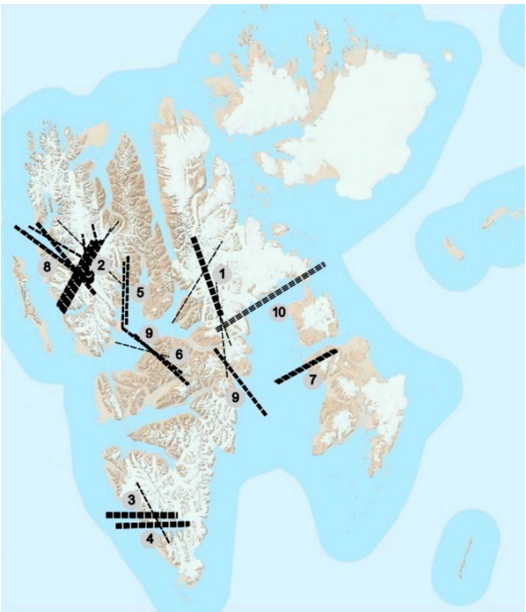

Figure 5. All flight lines covering an area of approximately 700 sq. km in the period 09.06.2020–20.09.2020. Ground resolution varies between 10–30 cm for the RGB images and 20–50 cm for the hyperspectral data.

(**a**) (**b**)

Figure 6. SIOS-NORCE aircraft-based sample imagery and hyperspectral data over Svalbard. (**a**) A RGB (460 nm, 550 nm and 640 nm) composition of three hyperspectral lines at the bottom of Kongsvegen glacier and (**b**) an image of the coastline at Agardhbukta.

2.7.1. Possible Use of Dornier Based Image Acquisition to Fill the Data Gap in Various Fields of Science in Svalbard during Pandemic Times

The successfully completed flight campaigns in 2020 have been indicated as a flight map (Figure 5). SIOS hopes to attract more researchers and anticipates an increase in the number of requests in 2021. This effort can be continued even after the pandemic to reduce the environmental footprint of observations. The flights over Lomonosovfonna will be used to reconstruct mass changes for the mass balance years

2019–20 and 2020–21 by using high resolution RGB photography from the aerial missions in September 2020 to create a digital elevation model and compare the airborne digital elevation model (DEM) with the DEMs created from mobile differential global positioning system (dGPS) campaigns in spring 2019 and planned in 2021. The high resolution DEMs will also be used to identify newly opened crevasses and utilise safer routes along the glaciers for the spring 2021 to minimise the risk of accidents. The flights over Flintholmen and Coraholmen will be used for mapping of lichen vegetation extent and health in the region using different combinations of spectral bands and indices from hyperspectral data. Acquisition of hyperspectral data is critical to accurately detect and map lichen and biological soil crust dominated vegetation communities. Complementary on-site fieldwork was conducted (carbon flux, carbon economy, albedo, species abundance, and other relevant vegetation features) by NINA/UiT in the same week as the acquisition of hyperspectral data in July 2020.

2.7.2. Applications of Unmanned Aerial Vehicles (UAVs) in Svalbard during the Pandemic

During recent years, the use of UAVs has become an important element for earth observation activities—especially in Svalbard [24]. Typically, UAV-based fieldwork is conducted during spring and summer in Svalbard. In spring, cryosphere studies in remote locations can be reached with snowmobiles. In summer, most sites are accessed by boats or by foot. UAV fieldwork in the summer is conducted in a wide range of disciplines, most of which require snow-free ground conditions (e.g. biology, geology). The impact of the pandemic on UAV applications in Svalbard is hard to assess because no complete overview of planned field activities exists. However, we have a good overview of UAV-based field applications that were conducted in cooperation with SIOS and UNIS—although only on an anecdotal basis. For example, campaigns have been conducted by various groups in UNIS, NTNU, NIVA, the Nicolaus Copernicus University in Torun. Other campaigns have been cancelled by NORCE, Czech Academy of Sciences, University of Silesia in Katowice, and UNIS.

During the early phase of the pandemic in the spring, all fieldwork activities including UAV operations were stopped due to the lockdown. The local situation relaxed after Easter and field excursions with low risk were permitted. In practice, this meant that day trips around Longyearbyen were made possible again. During this time, strict international travel restrictions were in place in Europe, which meant that only researchers located in Svalbard had the opportunity to conduct fieldwork. This left a window of less than a month for snowmobile fieldwork until the snow cover disappeared in mid-May. This was a severe limitation, especially to cryospheric studies.

During the summer, international travel restrictions were relaxed which allowed researchers to travel to Svalbard for fieldwork. A 10-day quarantine had to be fulfilled on the Norwegian mainland before onward travel to Svalbard, resulting in it being mostly Norwegian scientists making the journey. However, some other nationalities, especially German, Polish, and Czech are also known to have come to Svalbard. To our knowledge, several UAV-based field activities have been conducted based in Longyearbyen, Ny-Ålesund, and Hornsund. UAVs were used for fieldwork in wide range of disciplines, including glaciology (glacier mapping), biology (vegetation index mapping), geology (outcrops mapping), cultural heritage preservation (mapping), and meteorology (atmospheric measurements). Most of these activities were conducted with simple, off-the-shelf UAVs and to our knowledge no advanced UAV operations occurred. It should be noted that field activities usually require a good amount of planning and preparation. As a result, several summer campaigns were cancelled in March and April because the confusing and unpredictable pandemic situation prevented proper planning.

In summary, the assessment of the impact of the pandemic on UAV-based fieldwork is difficult and must remain incomplete. To our knowledge, most UAV fieldworks during the springtime (March-June) were cancelled or postponed. Fieldwork in the summer and thereafter seemed to be conducted more successfully. This means that the largest knowledge gaps due to the pandemic are occurred in long-term studies in the cryospheric sciences. We know of at least one case where long-term monitoring of crevassed glaciers with UAVs was substantially affected by the lockdown, severely limiting their scope [25].

2.8. Ongoing and Upcoming Activities in Times of Pandemic

Our regular activities such as the ACCESS programme [26], that provides an opportunity to scientists from around the globe to utilise research infrastructure in Svalbard, have been affected badly by the current crisis. Due to COVID-19, 11 of the 14 projects that were funded in the 2019 call were postponed until 2021. The SIOS ACCESS programme supported the lunar aerosol optical depth (AOD) intercomparison campaign carried out in Ny-Ålesund in February 2020 (https://sios-svalbard.org/AOD_intercomparison_2020). The NY-alesund TurbulencE Fiber-Optic eXperiment (NYTEFOX, https://sios-svalbard.org/NYTEFOX_2020) is a project led by the University of Bayreuth and supported by SIOS. This project was also fortunate enough to complete fieldwork before the lockdown in Norway started. These are the only planned projects supported by SIOS that successfully completed their field campaigns in Svalbard in 2020. In addition, a virtual access project was completed (https://sios-svalbard.org/SWESOS_2020). It was anticipated that SIOS partners would have reduced capacity to accept new projects in the 2020 call because their research facilities/infrastructure were underutilised in 2020 and are expected to be under pressure in 2021 by national programmes. It was also considered likely that fewer applications would be received due to the uncertainty for researchers when planning field campaigns. We did not anticipate that virtual (access to data) or remote (sample collection by local operators) access will be affected by COVID-19 and saw the current situation as an opportunity to promote these options and increase remote support to scientists. When the call for access closed on 30th September 2020, 17 applications had been submitted, down from 29 in the 2019 call. For the first time we received applications for remote access to the research infrastructure, 3 in total. This shows how researchers are changing their behaviour in response to the current crisis.

Another regular activity of SIOS is the annual State of Environmental Science in Svalbard (SESS) [27] report. The report involves collaborative writing of a chapter by a team of authors but planned meetings and writing workshops have had to quickly move online in response to the pandemic. Despite this, the writing teams have worked hard and managed to deliver their contributions to the report in time. The report will be released in January 2021 and contains 11 chapters and a joint statement with topics ranging from the upper and lower atmosphere, pollution, coastal ecosystems, hydrology to snow cover and permafrost (Figure 7). Several chapters are focussing on remote sensing methodologies and almost all have remote sensing sections included.

3. Success Stories from SIOS Initiatives

The academic response of COVID-19 [28] shows that writing papers for scientific publication has been the most common task during the pandemic as this task can readily be performed remotely. The SIOS special issue which was launched in the beginning of the March-2020 proved to be an effective platform for researchers to publish their research. At the time of writing, we have 3 submissions [29,30] in this special issue. The top-five presentations by early career researchers from the SIOS online conference have been selected and the authors have been invited to submit full manuscripts to the special issue. In addition, SIOS's regular activity of SESS report provided an additional platform for scientists to write a collaborative report on Svalbard science.

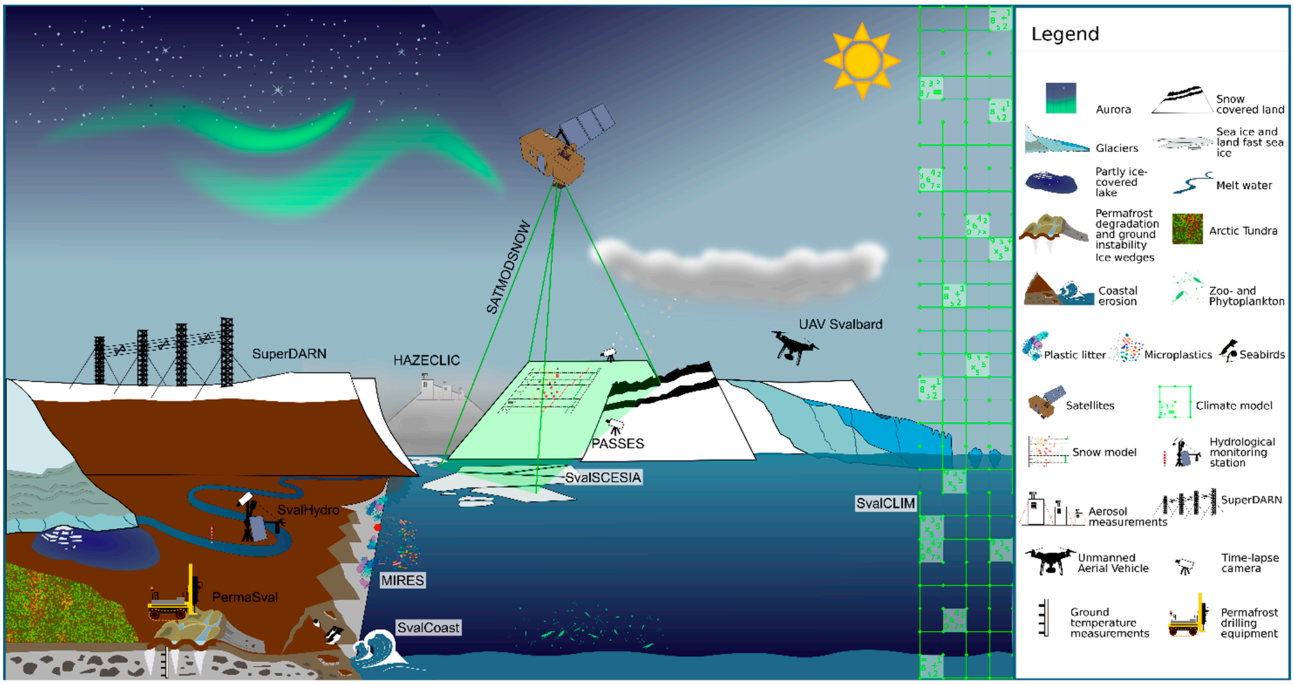

Figure 7. The State of Environmental Science in Svalbard (SESS) report 2020 includes chapters on the use of satellite images and in situ cameras to estimate snow cover, a review on unmanned aerial vehicle (UAV) activities and many more. The report can be downloaded from the SIOS website: https://sios-svalbard.org/SESS_Issue3 (Illustration: Floor van den Heuvel).

We have received a few inputs on our mapping of the requirements from researchers and how SIOS can help fill data gaps using EO under "patch up your field data with RS observation" service. A group of researchers are trying to investigate the aerodynamic roughness length of crevassed glaciers, which influences the rate at which the glacier is exchanging heat with the atmosphere. With globally rising air temperatures, this mechanism is likely to lead to an accelerated warming and melting of highly crevassed glaciers. During this project they aimed to conduct UAV-based RS on crevassed glaciers on Svalbard. UAV flights were planned to map the glaciers and then the aerodynamic roughness length would be estimated based on the high-resolution digital elevation models (DEMs). However, the researchers were unable to conduct most of the spring and summer fieldwork. This means that they lack data for several glaciers (e.g. Nordenskiöldbreen, Wahlenbergbreen, Tunabreen, Mohnbukta), as well as a time-series that they planned to build (e.g. on Tunabreen). Researchers hoped to conduct as much fieldwork as possible in the summer, but it was not possible to fulfil all missions during the spring and early summer because of restrictions on field activities and lack of field personnel. Researchers are now investigating the possibility to use some satellite-based RS to estimate aerodynamic surface roughness on glaciers. UAV based data collected using limited flights in summer can be used for validation of the results retrieved from satellites.

A PhD student had planned her field campaigns in April and August 2020 to undertake ground penetrating radar (GPR) measurements to study the bedrock of glaciers and subglacial landforms, e.g. overpassed moraines. The spring campaign and GPR measurements were cancelled because of travel restrictions. Due to the lack of aerial images from the southern part of Wedel Jarlsberg Land, she would instead have to work on an older DEM which might affect the results of the study. Without her field campaigns she would not be able to understand the morphological changes in the glacier and estimate the relative age of glacial landforms. Further, without this data it will be difficult for her in working with her doctoral research without prolongation of her schedule. However, the team conducted geomorphological analysis over one glacial moraine with the use of UAV during August/September 2020. With the acquired aerial images and hyperspectral data she is able generate a DEM for geomorphological analysis and vegetation analysis for estimating the relative age of glacial landforms. Photos from UAV collected during summer will be used to validate data generated from photos collected by Dornier aircraft. In this example, it is evident that the SIOS support to acquire airborne data was very important to fill the data gap.

Another researcher had planned to conduct continuous velocity measurements of Hansbreen using dGPS over the period August-September 2020, operating mainly from on the Polish Polar Station Hornsund. This project was designed to expand current glacial monitoring and integrate it with oceanographic monitoring. The research group collected dGPS measurements, atmospheric and marine observations on the Hansbreen and in the Hornsund fjord during summer 2020. Additionally, terrestrial laser scanning was used to collect data over the Hansbreen front. The ground control points (GCP) measured with dGPS technique will serve to generate DEM from aerial imagery captured by Dornier aircraft in June 2020. Field data together with the aerial imageries will allow them to estimate the velocity of Hansbreen in the period July-August 2020.

A team of researchers had planned a series of activities including acquiring aerophotogrammetry data by UAV in order to generate a digital elevation model, radio-echo soundings on Werenskioldbreen and Hansbreen, digging snowpits, and collecting snow cores. However, because the field campaign was cancelled, they were left with a gap in the perennial continuity of geophysical data collection (radio-echo soundings), and lack of data from manual snowpits for data validation, causing a lot of damage to this scientific study to understand glacier behaviour. In order to fill the data gaps and mitigate the damage this season, the team has requested to use the Dornier to acquire airborne remote sensing data to process and obtain a DEM of Werenskioldbreen and Hansbreen, southwestern Spitsbergen. The DEM will be used to determine the internal structure of the glacier as a response to glacial processes and complex environmental conditions. The DEM will be combined and compared with other data from this region (e.g., geophysical).

The SIOS team received a few requests on the Logistics Sharing Notice Board. One of these requests was from the University of Silesia in Poland, who needed help to install instruments and collect samples in Wedel Jarlsberg Land. We were able to organise a short fieldwork campaign in the vicinity of the Polish Polar Station Hornsund in close cooperation with the University Centre in Svalbard (UNIS). Our team spent three days at the Baranowski Station (University of Wroclaw) next to the Werenskioldbreen maintaining automatic weather stations, time-lapse cameras, water gauge station, collecting water samples and measuring the water runoff in two catchments. More information on the fieldwork conducted in June 2020 as available online: https://sios-svalbard.org/News_20200703. At this point we have fulfilled a few supporting campaigns to help scientists collect essential data and save instruments in these difficult times. The number of tourists visiting Svalbard is at a record low and this is accompanied by record high unemployment in Longyearbyen, especially among tourist guides. In this difficult situation, SIOS has tried to involve local skilled guides in scientific measurements which is a need of the hour. These activities will surely make a difference in paying back to our society in these challenging times.

SIOS has also taken the opportunity when many of our collaborators are confined to their offices and home offices to discuss new initiatives. One examples of such is the developing marine infrastructure network, which will be a forum for discussing all aspects of marine observational infrastructure (technical solutions, data sharing, measurement gaps, logistical cooperation). The inaugural workshop of this network was held online in November 2020. Networks such as these are extremely important to SIOS, as it helps the scientific community to be more robust in response to future disruptions such as pandemics. It is envisioned that should a similar situation occur, it may be possible for partners to cooperate to ensure the most essential mooring maintenance is carried out. By creating an integrated mooring network within which data are shared we can also ensure greater spatial coverage of essential variables, which makes the loss of data from one mooring less critical than it would otherwise be.

4. Response of SIOS Member Institutions to Mitigate Damage Caused by COVID-19

In this section, we focus on examples of activities conducted by SIOS member institutions in response to the COVID-19 pandemic.

Cancellation of the spring expedition of University of Silesia to Hornsund affected many researchers and students. Students of the International Environmental Doctoral School [31] could not conduct field work of their projects. The service and maintenance of automatic weather stations (AWS) was also suspended. As the Dornier aircraft collected data over Hornsund only once, scientists were not able to realise plans such as: analysis of geometry changes of Hansbreen glacier, dynamics of the glacier, evolution of glacial zones of Hansbreen and Werenskiolbreen, producing vegetation health maps, analysis of snow cover extent in the coastal zone of Hornsund fjord and continuation of a sedimentological study of a glacio-marginal landform and glacio-fluvial deposit at Werenskioldbreen. However, after relaxation of lockdown in July 2020, the team was able to conduct a summer field campaign in August/September 2020 to partly fill the gaps with the fieldworks such as measurements of Hansbreen surface by terrestrial laser scanning, dGPS measurements of mass balance stakes on Hansbreen and collecting imagery with UAV over the glacial moraine. This limited field data will be used as validation data for Dornier based aerial imagery. Aerial images from Dornier aircraft in connection with field data will enable the team to fill certain gaps, e.g. orthophotos together with laser scanning data will be used to estimate glacier velocity, DEMs from aerial photos will be used in geomorphological and glaciological analysis and hyperspectral data will be used for assessment of age of glacial landforms based on succession of vegetation.

Major parts of the annual field campaign of the Institute of Geophysics Polish Academy of Sciences (IG PAS) in Hornsund during the spring - autumn 2020 were affected by the pandemic. In Spring, the research facility in Hornsund closed to visitors of any origin, while in the late Autumn the disruption was mainly due to travel restrictions to Svalbard. A longstanding Hansbreen glacier mass balance monitoring programme was heavily affected, as glaciologists failed to reach the research facility in Hornsund. For safety reasons, crew from the research facility only managed to conduct limited snow depth measurements at the accessible mass balance stakes installed on the glacier. The lack of a specialised team in the field lead to gaps in measurements of glacier velocity and snow stratigraphy. In the autumn, ablation was measured at only 3 stakes. Most of the stakes melted out, as maintenance of the stake network planned for Spring 2020 failed. IG PAS plans an extensive field campaign in Spring 2021, to rebuild the stake network and estimate mass balance of Hansbreen glacier. It is planned to use EO and RS products provided within the SIOS framework to establish new mass balance monitoring network.

The Norwegian Institute for Nature Research (NINA) and UiT The Arctic University of Norway field campaigns (ASMoVEn) (https://www.researchinsvalbard.no/project/8922) were delayed due to travel restrictions from late April / beginning of May to beginning of June 2020. The plan was to set up near-surface remote sensing racks and a spectrometer in Adventdalen as a part of the SIOS-InfraNor project. Apart from the early setbacks, fieldwork was conducted smoothly with a new visit to Adventdalen carried out during 19-26 July 2020. Description of vegetation (species cover/frequency) was conducted (by UiT) on the sites where the instruments are situated. The racks and instruments were taken down for maintenance and retrieval of data in the last week of September 2020. Data gaps that exist during spring and some of dates in summer can be replaced by available cloud-free satellite data from Moderate Resolution Imaging Spectroradiometer (MODIS Terra and Aqua) and Sentinel-2A/2B if they exist. The collection of data from the rack-sites and the FLoX-spectrometer was successfully accomplished and the team will begin analysis of the spectrometer data in order to assess them against carbon-flux data from the eddy covariance tower situated nearby. SIOS airborne campaigns in Adventdalen were carried in three periods, and the instruments on the racks and spectrometer act as controls/calibration on the ground. Especially, the early acquisition airborne campaign during May-June may fill a gap during spring when the team was not able to monitor the vegetation properly due to travel restrictions.

A team of scientists from Uppsala University cancelled their whole field campaign in 2020, but a few essential tasks of maintenance and replacement of instruments were taken care of by engagement of residents in Svalbard. The research team is hopeful to make best use of aerial images and hyperspectral data acquired by Dornier aircraft-based sensors. Even after relaxation of lockdown in July 2020, it was too late to organize helicopter-based operations in the field site. The team worked indoors during the lockdown period to fill missing observations using EO and RS and also organise maintenance of instruments with the help of local residents in Svalbard. Around 75% of field data has been lost during the field season and we spent only a fraction of the budgeted costs. Organising a field campaign by involving residents has been emerged as an effective alternative for field activities, even after pandemic times.

Researchers from NORCE Norwegian Research Centre cancelled a 10-day field campaign involving UAV, GPR, and snow science satellite validation in March 2020, the week after lockdown was announced, while equipment was already shipped to Longyearbyen. To fill the data gap, the team ordered satellite acquisitions by TerraSAR-X but in situ observations could not be carried out. Parts of the scientific objectives related to measuring snow water equivalent with a UAV borne ground penetrating radar was performed in Tromsø in late April. Accordingly, some of the scientific objectives of time series of snow product development were met, but without Cal/Val activities with in situ measurements as this needed to be done in the spring season before the snowmelt. Further, NORCE chose to cancel a field trip to the Longyearbyen area in the last half of May. The purpose of the trip was to place time-lapse cameras (trail cameras) for phenological observations. These cameras have been used since 2014 and capture photos each hour between 10am and 3pm every day from late May to mid-September, and the images then show the plant development. These images are then used as validation data for MODIS and Sentinel-2 data in mapping onset, peak, and end of the growth season.

The Japanese biological field campaign of National Institute of Polar Research (NIPR) was postponed, and maintenance of field equipment was not completed in 2020. The team is looking into the availability of hyperspectral cameras for considering possible future monitoring remotely. Japanese researchers left Svalbard in the critical period of middle of March when the lockdown period started. In the middle of October, they could revisit the field, however the ground was already frozen and no maintenance of ground sensors was possible.

The University of Oslo (UiO) had to cancel or postpone many of the planned field campaigns but managed to conduct three on short notice: installation and replacement of autonomous instruments on Kongsvegen glacier related to glacier hydrology and glacier dynamics; test and application of novel miniature loggers to explore subglacial drainage systems; exploration of ice-filled permafrost cases around Ny-Ålesund to assess soil dynamics and sorting in them. Whereas the two last ones cannot be supported much or even replaced by RS, the team will use high-resolution satellite radar and optical images to supplement the glaciological ground measurements on Kongsvegen.

The Pandora spectrometer instrument was installed by the Norwegian Institute for Air Research (NILU) at Sverdrup research facility in Ny-Ålesund in 2019 and calibrated in March 2020. This acts as a fiducial reference measurement for the Sentinel-5P mission. Being permanently mounted at the Sverdrup station and self-calibrated and remote-controlled, the Pandora spectrometer is relatively invulnerable to general travel cancellations and postponed campaigns during the Covid-19 outbreak. However, manual, and physical inspection of the instrument is required on a regular basis, especially in the winter season when there is a need to remove snow and ice on the sensor head and cables. The manual inspection is performed by local operators in Ny-Ålesund, and there is thus a risk for less maintenance, or worst-case scenario critical damage, of the instrument linked to a COVID-19 disease outbreak affecting the daily operations at the station.

The characterisation of the snow optical behaviour is usually performed during field surveys that require efforts in terms of preparation. Accordingly, one field campaign scheduled by National Research Council of Italy (CNR) during April - May 2020 in the framework of the iCUPE H2020 project [32] was cancelled due to the COVID-19 related restrictions and the relaxation of travel restrictions announced right at the end of the snow-melting season. The need for ground observations during the pandemic times has been attempted to be met by using in situ facilities such as time-lapse cameras and the Continuous Reflectance Monitor (CReM) that are continuously operating in the Ny-Ålesund area. While time-lapse cameras are facilities already operating in the area for decades, the continuous detection of the snow spectral reflectance is an innovative tool based on different setups [33,34]. The CReM setup and time-lapse cameras are operating at the Amundsen-Nobile Climate Change Tower in Ny-Ålesund and provide detailed information about the spectral behaviour of snow in the visible and in the short-wave infrared wavelength domains. The use of the Zeppelin webcam image time-series [35] processed using the automatic classification algorithm described by [36], provided information about the snow cover at different spatial scales. The ground-truth data collected by these instruments provides a quick solution for studying the melting season even if fieldwork is limited by the pandemic situation. The heavy impact of travel restrictions forced the team to use time-lapse cameras and the development of terrestrial photography applications in order to substitute field campaign. All the collected images, even if they do not replace direct snow reflectance measurements, can be integrated with the continuous data taken from the CReM and with those remotely sensed. The combination of different data sources could represent a valid approach for reconstructing the seasonality of the snowpack and the vegetation phenology. In spring 2021, the team is planning to install updated instruments and to evaluate drifts in old devices. Possibilities of making easy-to-install devices are being considered so that in the unfortunate case of cancelled field campaigns in future, they can be substituted by involving local residents in installing and maintaining instruments. This example shows the need of the development of innovative technology to make future field instruments in the Arctic which can be handled easily by indigenous people and residents. For broader relevance in the future, the team created strong synergies with international partners aimed at creating a network and harmonising the different procedures related to terrestrial camera infrastructure operations. Furthermore, the creation of a network focused on "terrestrial Photography ApplicationS on Snow covEr in Svalbard" (PASSES) [37] could be a seed for the growth of a camera network useful to the research community for compensating, at least partially, the lack of field observations in future.

As is the case with most of the in situ observational programmes around Svalbard from different organisations, the Indian Arctic Programme (IAP) of the National Centre for Polar and Ocean Research (ESSO-NCPOR) has been significantly affected by the restrictions imposed due to the COVID-19 pandemic resulting in cancelling all the field activities in Svalbard for the year 2020. The field visits which start around the same time as the national lockdown (March) by glaciologists, atmospheric scientists, and oceanographers were completely hampered by international travel restrictions. All such field campaigns for the current year, and probably for next year as well, had to be cancelled. This creates significant discontinuity for the in situ observations that are systematically recorded every year around the same time. Unlike the neighbouring countries in Europe, international travel restrictions imposed in India did not allow for field campaigns even after the first phase of lockdown in Svalbard was relaxed around mid-July. This has particularly affected the projects dealing with mass balance studies of targeted glaciers around Svalbard (e.g., Vester Broggerbreen, Feiringbreen), permafrost health monitoring, terrestrial, and marine biodiversity projects. However, the automated instruments used for observation of different multi-disciplinary parameters of the fjord and atmosphere have produced valuable information uninterrupted. Furthermore, with the help of the local company Kings Bay AS, a few planned CTD castings could also be conducted in the fjords. The major effect on these automated instruments was in terms of their routine physical check-up and calibrations, particularly when they remain unattended during a long period of time in winter. However, the observations from these instruments could be very crucial to decipher the effect of the pandemic and associated restrictions on different environmental parameters in Svalbard.

At the beginning of lockdown, the Norwegian Institute for Water Research (NIVA) had to postpone the annual deployment of the SIOS-InfraNor buoy in Adventfjorden until June 2020 when the travel restrictions were relaxed. Additionally, NIVA cancelled a few cruises with the cargo ship M/S Norbjørn. All the field sampling activities and laboratory experiments of the FreshFrate project (funded by the FRAM centre), addressing effects of freshwater runoff on Svalbard's coastal ecosystems, have been postponed to 2021 due to travel restrictions. The relaxation of lockdown did not help NIVA researchers as the sampling strategy was focused on seasonal variations which cannot be captured when there are gaps in sampling. In response, NIVA tried to mitigate data gaps with the help of local scientists from UNIS to collect water samples, in addition to the SIOS-InfraNor buoy deployment for example. Data collected from the buoy was intended for the Cal/Val activities of satellites but the delay in deployment affected this activity. NIVA will actively participate in training local researchers in buoy deployment experiments and to collaborate with UNIS to prepare for similar situations in the future. Besides that, the M/S Norbjørn cargo ship sailing plan has not been impacted by the COVID-19 situation, so the NIVA ferrybox installation on board has been measuring continuously and picked up discrete water samples.

The operational instrumentation that the Norwegian Meteorological Institute (MET Norway) maintains in Svalbard is designed to operate on its own for long periods. Due to weather and ice conditions, yearly maintenance is not always possible, implying that all automatic weather stations are designed for sustained standalone operation. A consequence of this thinking is that extension of the observation programme at the automatic weather stations is done in a manner not affecting the operational capability of the stations, meaning that the importance of sensors and their geophysical output is prioritised. As a consequence, the power supply is split between critical and non-critical sensors which may be shut down if power supply issues arise. The primary consequence of the COVID-19 lockdown on the institute’s activities in Svalbard was on the planned upgrade of several stations. Originally the institute planned to establish a borehole for permafrost measurements co-located with the automatic weather station at Edgeøya–Kapp Heuglin, and to extend the sensor suite at Verlegenhuken with measurements of permafrost, snow, and surface irradiance. These activities were planned as part of the yearly maintenance for the automatic weather stations with transportation support from the Norwegian Coast Guard. Installations at Verlegenhuken were successfully completed and the flow of data established, but preparation of the borehole at Edgeøya–Kapp Heuglin had to be postponed due to the number of personnel involved. Furthermore, construction of the foundation for two inland automatic weather stations, in Nedre Sassendalen and Klauva, was cancelled due to COVID-19 and work is postponed until 2021. Operation of the manned stations of the institute has continued as planned, but with stronger restrictions on personnel exchange.

The Norwegian Polar Institute (NPI) is responsible for a large set of long-term observational programmes in Svalbard. These are related to climate, ecotoxicology, and biodiversity. NPI also has a geological mapping programme in Svalbard. Many of these activities overlap and are merged into the SIOS observations and priorities. The COVID-19 lockdown hampered some programmes severely. Notably the polar bear monitoring programme was unable to perform any activities during the essential spring field season. This was partially compensated for with a fortified activity in the autumn. Oceanographic observations around Svalbard have been hampered with several cruises planned for 2020 being cancelled. Other important programmes (ptarmigan and reindeer population studies as well as botanical inventories) were able to adapt and perform full programmes with field groups where key scientists had trained local personnel (mainly laid-off field adept individuals from the tourist industry). COVID-19 has thus opened a new perspective on how to manage some programmes within NPI which probably will both benefit local employment, lower total costs and decrease the environmental footprint (e.g. less travel). In Ny-Ålesund NPI has had a modified rotation of personnel (some individuals have spent longer periods in Ny-Ålesund than previously) and been able to run all long-term observational programmes. NPI has also supported several of the international institutions such that some of their programmes have been able to be maintained despite the institutions' inability to send their own personnel to Ny-Ålesund. This may also lead to new approaches to collaboration well beyond COVID-19 that are viewed as a positive outcome of the 2020 ordeal.

The Arctic Geophysics department (AGF) of the University Centre in Svalbard (UNIS) has two research groups—one in space physics and one in air–ice–sea interaction. For space physics, all fieldwork takes place in the dark season. Thus, the space physics group has not had cancellations of fieldwork due to COVID-19 related issues, as at the start of the outbreak, all fieldwork had already been done. For the dark season 2020/21 there has been cancellations of sounding rocket launches which the group participates in, and these have been postponed until the 2021/22 dark season. Apart from this, the space physics group will be able to maintain its standard observational programme at the Kjell Henriksen Observatory. The oceanographers usually use academic course related fieldwork cruises to collect research data from buoys. Due to COVID-19 the planned cruise was cancelled; thus the oceanographers were not able to collect data in April 2020 (winter) as has been done every year since 1999. However, they were able to obtain two days on a research vessel in order to secure the September data (summer) of the hydrography in Isfjorden and the shelf outside, thus maintaining the long time series for the Isfjorden transect. The meteorologists also use course fieldwork to collect data for ongoing research projects. Due to COVID-19, fieldwork was cancelled in autumn 2020, and data could not be collected. The data is used for e.g. validation of weather models in the Arctic. This has not been mitigated.

It is essential to mention that other institutions (including those not listed in this article) also planned to conduct measurement campaigns during the pandemic as part of the already developed procedures and due precautions. Unfortunately, the biggest obstacle that caused the campaigns to be cancelled was rapidly changing regulations on the border control to Norway and quarantine rules. In the absence of stable international traffic regulation in times of a pandemic, research activities in the following months may be subject to significant risk, despite appropriate measures being taken.

5. Discussion

Arctic regions are particularly vulnerable to situations like the pandemic [38]. Therefore, Arctic science has been significantly influenced by COVID-19. Even during the absence of pandemic, field research in the Arctic regions including Svalbard is relatively limited, with scarce scientific observations for studying Earth System Science [39]. Therefore, the effects of the persistent gap in field activities will reverberate for decades across scientific disciplines of Svalbard research.

At the time of writing this manuscript, Svalbard is still officially one of those regions on the planet that has escaped the first few waves of the COVID-19 pandemic. This was aided by the island's relative isolation, relatively low population (approx. 2800 across an area of 61,022 km^2, population density: 0.044/km^2), highly restrictive travel and quarantine measures adopted during the beginning of the pandemic, and relatively lower number of visits of tourists and tourist ships during 2020. However, based on our current knowledge of the variety of known and unknown modes of spread of the virus and looking at the speed of its spread, it is difficult to prevent the entry of virus to Svalbard even if strict travel and quarantine measures are still in place since the beginning of the pandemic.

The global pandemic has resulted in significantly decreased field activity in Svalbard leading to reduction in environmental impacts for a brief period at the expense of gaps in long-term data series and monitoring programmes. International cooperation through networks/consortia is necessary to save the essential scientific data and infrastructure in Svalbard. Norway started relaxing the lockdown slowly and Svalbard was open for Norwegian researchers and tourists on 1st June 2020, while it reopened to a few EU/EEA countries on 15th July. Currently travel from most countries is banned with restrictions and exemptions. With the temporary reopening of Svalbard during summer 2020, a few researchers could conduct their field campaigns during the rest of the period of summer and autumn, but the reopening came too late for those exclusively interested in the spring season. Even after the reopening of Svalbard, there was limited field activity. Since the beginning, the COVID-19 pandemic forced us to develop alternative activities for the utterly new, unforeseen, and unique situation. In the beginning, the trickiest part was none of us were prepared for such a working style and nobody was sure about the success of these activities. However, we wasted no time in starting these activities in response to the continuously changing situation. Our resources and activities have been listed in the GEO repository (https://www.earthobservations.org/covid19.php) of COVID-19 response activities and tools developed by various organisations in the world. Here you can find many more relevant activities in response to COVID-19, but SIOS's activities are the only ones highlighting practical services to field scientists in the Arctic.

5.1. Perspectives on Impact of Data Loss in Long Term Monitoring and Science

Our knowledge of gradually more dramatic impacts of continuously changing climate will be held back if critical long-term monitoring work is interrupted [40,41]. It is foreseen that the pandemic will cause delays of up to or exceeding one year in planned field activities. The loss of data for the Svalbard related science for a year or more may have very differing implications on different projects. The impact is clearly highest for the experiments where the lack of regular maintenance can lead to loss of the instruments as well as the yearly data (e.g. glaciers mass balance and burial of AWSs). Cancelled fieldwork could affect not only a single campaign but also the possibility to maintain instruments and observation sites including drifts in field instruments during the whole season. This can cause large data gaps spanning over long periods during years with rapid environmental changes. For some measurement series, especially long-term monitoring, data gaps are immensely problematic in terms of missing important data in particular seasons or years and may complicate the statistical analysis.

5.2. Suggested Mitigation Measures

The pandemic lockdown has shown that it is beneficial to expand the engagement of local residents, research infrastructure providers, logistics operators, and collaborators to carry out joint research activities on mutual terms. This will require some local capacity building, with particular focus on training, equipment, and funding to cover fair pay. In a funding perspective, a coordinated and flexible response to delays and changes in field activities is required by funding agencies and responsible institutions. It is necessary to reserve funding for emergency mitigation to ensure sustained support for researchers and covering losses of local logistics and/or infrastructure providers.

It is also clear that the negative impact could partly have been mitigated if the scientific and logistics groups had prepared for this situation beforehand. However, such prior preparations or backup plans are not common for all kinds of scientific activities. For instance, AWSs are generally installed to work for years without major maintenance but glacier stakes and other instruments may need entirely different approach to prepare for similar situations in future.

In a situation where scientists suddenly are cut off from their field area—as the Svalbard research community experiences now—it would be favourable to have well planned or established citizen science projects that can be conducted by the local community. This could include collection of both ground truth data for validation of satellite-based products and collecting samples for scientific experiments. Current citizen science projects are often closely related to tourism activities, e.g., cruises, which also were halted during 2020. However, the lockdown left most tourist guides without work and a Svalbard specific citizen science model could be developed to involve these and others from the local community. The field expertise of local tourist guides, students, and parts of the general public would facilitate their involvement in scientific data collection activities. By developing easy-to-understand standard field data protocols and documents on regular maintenance of instruments, in combination with regular courses, a pool of potential citizen science contributors could be built. This would be a strong resource in general and especially in a situation like now to back-up scientific research in remote places like Svalbard.

It is imperative to establish a holistic perspective of the observing system with prioritisation of the importance of various observing efforts and their sensitivity to data gaps. This can result in specialised efforts to avoid gaps in top-priority data series in future situations. Some observing efforts already have mitigation plans for such circumstances (e.g. automatic weather stations that can operate for years without maintenance) with sufficiently scaled power supply (large batteries with additional solar panels and wind turbines) and communication capabilities (online access with delayed mode data dump locally) to compensate for weather and ice conditions preventing the scheduled maintenance. Such approaches have proven handy in the current situation, although not originally designed for a pandemic situation. For other activities alternative approaches relying on remote sensing applications (satellites, airplanes, UAVs) and to increase the cooperation between scientists and organisations in the areas of logistics, maintenance support and data sharing could be more appropriate in filling data gaps.

5.3. Earth Observation and Remote Sensing Perspective

Satellite coverage from polar orbiting satellites is good in the Arctic and Svalbard is probably one of those areas in the High Arctic that has the best potential coverage for satellite data. Utilisation of optical sensors is challenged by the Arctic night and extensive cloud cover. The latter is partly compensated by the high repeat cycle at high latitudes, but the Arctic night leaves imagers in the visible part of the electromagnetic spectrum useless parts of the year. Microwave sensors on the other hand do not have issues with the Arctic night or clouds, but have challenges related to spatial resolution (passive microwave), surface emissivity and/or weather (atmospheric column, wind effects etc.). Challenges vary depending on the application area and whether the study area is terrestrial or marine. Applications requiring high temporal resolution depend on the repeat cycle (specified by the inclination and footprint of the satellite/sensor) of the satellite platform and instrument considered. For studying glacial movements and spring thaw of permafrost shifts, Synthetic Aperture Radar (SAR) measurements can cover most of the requirements using proven algorithms, albeit, with the lack of ground verification or limited verification. For these applications, the impact will clearly be the lowest while better preparation for the pandemic situation could have reduced the impact even further. However, for other application areas, remote sensing algorithms are still under development and development of these will stall due to a lack of in situ validation data. In the future, it is necessary to critically assess the requirements of scientific projects in Svalbard aligned with preparation to reduce potential impacts of pandemic situations.

Space agencies have major roles to play in such circumstances where EO is highly relevant to fill data gaps. Proprietary or commercial satellite owners should take an active role in collecting frequent data in Svalbard and Arctic during pandemic times to help scientists filling the data gaps. One of such initiatives include Maxar's Open Data Program that has released an initial set of high-resolution satellite imagery in support of the COVID-19 response efforts. However, such efforts are limited to those systems where data collection and mode specification for satellite acquisitions are actively controlled.

The major non-commercial space agencies already collect the maximum amount of data possible over Svalbard and surrounding waters. Integration of remote sensing data into the field scientist workflow is covered in many disciplines, however, it is still pending in some disciplines. For the commercially available systems, dominantly in the optical region, increased collection of data depends on the availability of funds to get specific images at given times. For historical data, several of the commercial providers have low-cost to free access for scientific use which can readily be used. In order to increase the utilisation of satellite remote sensing products by field scientists, training is required to increase the knowledge and closer collaboration between communities is required to identify best practises and gaps in the current product portfolio. SIOS is annually arranging courses for field scientists to increase their practical knowledge on how to utilise satellite remote sensing.

Airplane and UAV observations are promoted in SIOS to make scientists aware of the capabilities that airborne remote sensing offer to acquire the data for their studies. This will hopefully encourage scientists to explore the potential of remote sensing observations. Use of UAVs enables minimised environmental footprint research in and on sensitive Arctic ecosystems [42] and may be the only approach to near ground sensing. There are also some opportunities created by the pandemic in the fields of airborne remote sensing. For example, the substantial cut in air travel opens the airspace for increased UAV usage—an example for this can be found in the Nepal where UAVs were used for mapping during the pandemic [43]. Additionally, UAV application may replace or complement ground-based fieldwork in environments that are limited due to social distancing requirements (e.g., during transportation) or due to shortened campaign durations (e.g., due to quarantine). In such cases, advanced UAV operations (e.g. with fixed-wing UAVs) could be used to access a field sites that are not possible to access physically due to social distancing or time limitations. Simpler UAV operations (i.e. with off-the-shelf UAVs) may be able to accelerate field activities, for example by replacing ground-measurements.

Remotely sensed observations in combination with autonomous surface based remote sensing equipment like normalised difference vegetation index (NDVI)-sensors, cameras and spectrometers [44] can supplement missing field data for terrestrial projects (e.g. vegetation mapping) for scientists who lost access to Svalbard during the summer of 2020. Very high spatial and temporal resolutions RS data is one of the important characteristics needed by field scientists, especially terrestrial scientists and glaciologists. Data acquisition by very high resolution (VHR) satellites (WorldView-2/3, GeoEye, Pleiades) may also fill in specific gaps for a few fields of studies during pandemic situations as well as gaps due to environmental restrictions or other events. This is particularly dependent on application area, existence of robust and validated methods/algorithms for deriving information, and availability of specific modes of data at a given time. Frequent VHR satellite acquisitions would be valuable in case of lack of field data for glaciologists and geomorphologists. For instance, temporal acquisitions of such datasets can be used to derive glacier velocities, changes in frontal ablations, generating DEMs, and many more. However, the optical satellites exhibit large repeat cycles complicating the use in most of the applications. Frequent observation should especially cover dedicated areas where long term monitoring is being conducted. Determination of such areas of interest would need a contact between researchers and provider of RS data. Here, the role of SIOS as a platform for such communication is necessary. Critical assessment of satellite products derived from VHR data, proved in situ validation, and the usefulness of these products for various scientific communities working in Svalbard is necessary. Continuous availability of high-resolution satellite data with repetitive acquisitions are not feasible if not planned in advanced. Most of the high-resolution satellite datasets are acquired by commercial satellite owners making the acquisition expensive for projects with limited funding. On the other hand, most of the funds on travelling and field campaigns have been saved due to the pandemic and can be substituted for acquiring high resolution satellite images.

Concerning measurements that normally rely dominantly on satellite measurements, a single year without ground truthing will only have minor impact on the long-term measurements. The lack of ground reference measurements may increase the uncertainty of the satellite measurements. This uncertainty will increase if there are several consecutive years without ground measurements. This year, the capability of using VHR measurements to replace some of the in situ measurements has not been materialized, because of lack of planning and the unavailability of funds. Even if there may be larger possibilities, due to less air traffic, for local aircraft and UAV measurements the lack of locally available personnel has reduced the amount of these measurements during the pandemic.

Filling data gaps using EO observations in various applications is limited by the limited quantity of satellite and airborne (UAV and aircraft) observations and limited resources including funds for skilled personnel and data processing infrastructure. Therefore, quantitative assessment on the number of data gaps that can be filled using EO is not possible until geospatial products that can replace in situ measurements are generated using EO data.

Based on our case studies and examples provided in previous sections, a few of the long-term data monitoring programmes that have been affected and can be partially mitigated using EO include; (1) Glacier front monitoring measurements, which can be partially mitigated using satellite-based and UAV-based measurements. (2) Missing GNSS based glacier surface velocity measurements can be replaced by offset tracking repeat optical and radar satellite data. (3) Vegetation mapping projects are affected due to limited ground-truthing. (4) Snow cover extent data is being partially mitigated using EO observations.

There are of course serious limitations in filling data gaps using EO and RS (see for example UiO subglacial and cave measurements). Even if a process is observable from space at all, spatial and temporal resolution of the RS data often set clear limitations. The temporal resolution of optical data interferes with cloud cover which often renders data useless even if acquired successfully. A related question is if one can design field measurements in a different way, so that EO and RS can fill gaps. For instance, instead of relying on ground instruments directly design an observing-modelling framework where ground and satellite measurements are assimilated. Unavailability of ground measurements will then still hurt, but perhaps less than in a purely ground-based scheme. However, modelling and assimilation maturity for different fields of science in Svalbard are at different levels, which makes such efforts challenging. For example, modelling in oceanography and meteorological applications are well proved and practiced, while it is difficult to implement in biodiversity research.

It is also realised during this period that more efforts are required on accurately downscaling the resolution of remote sensing products to match with or substitute a few in situ datasets. Providing these downscaled products particularly over Svalbard can be useful for the studies affected due to in situ data gaps during the pandemic. In summary, there is a need to critically assess quantitatively how much data gaps can be filled with purely EO and RS activities in the absence of field data in future situations in Svalbard. Financial analysis is also needed to determine the break-even point to conduct costly long-term observations to fill the ground-based measurements gaps. Together with scientists, funding agencies should develop a realistic financing plan for substitute research for the coming years.

5.4. Data Management and Its Importance in Pandemic Times

One of the missions of SIOS is to provide free and open data sharing. The pandemic has again demonstrated the need for the scientific community to address sharing of scientific data and publications to facilitate open science, collaboration and cooperation, and rapid dissemination of scientific results to the community [45]. The SIOS Data Management System (SDMS) federates information on in-situ and remote sensing data from a number of data repositories. This is achieved through harvesting information about datasets into a unified catalogue. When scientists cannot perform fieldwork, such integration of information becomes increasingly important. In the beginning of November 2020, SIOS hosted the first online workshop on SIOS Core Data (SCD), which are Earth System Science data for Svalbard that fulfil the defined criteria of scientific requirements, data availability and collecting commitment. SIOS core data are connected to Essential Climate Variables (ECVs) as defined by The Global Climate Observing System (GCOS), the State of Environmental Science in Svalbard Report (SESS) and the needs of stakeholders and users. The SCD workshop engaged scientists in defining, standardising and harmonising observation protocols as well the related issues in data management when fieldwork was not possible. In a way, this activity brought the scientific community of SIOS together to work on various aspects of making scientific data in Svalbard easier to integrate and reuse. There are a lot of data, and this situation gives some time to discuss, learn, and explore best practises of metadata at discovery and use level, encoding formats to identify data management gaps that have to be addressed.

5.5. Importance of Bringing the Community Together in Pandemic Times

SIOS's activities to bring the community together such as webinars, online conference, and a training course have been proved to be good initiatives not only for the Svalbard community but the broader area of the Arctic. If not beforehand, participants from online activities and the different aid packages delivered by SIOS now understand the strengths of a regional observing system in Svalbard. SIOS played an important role on welding the Svalbard scientific community into a more united organisation by bringing scientists together via annual SESS report, ACCESS programme, workshops, and airborne remote sensing opportunities during the pandemic situation.

Nevertheless, due to the lack of personal conversation and cooperation during the fieldworks or exchanging of the crew in the research stations, the discussions on joint international projects and joint activities are challenging compared to the time before the pandemic. The fieldwork is an essential part to provide a learning experience for early career researchers (ECRs) on communicating with senior researchers and fieldwork management. The lack of fieldwork may also impact the level of interest of students in polar science-related disciplines because of training course without a practical part in the field. We must remember that all of this cannot be replaced solely by online meetings.

5.6. Perspectives on how Sudden Perturbations can Kindle Reforms in Our Approaches

Our case studies and practical examples have potential to enhance preparedness for future pandemic or similar situations. Examples and lessons learned from our experiences are probably transferrable to many fields of science and technology beyond their applications in polar regions. Many solutions were to some extent ad hoc choices on short notice but are here offered as a permanent resource for responding to future situations for international organizations, observing systems, and scientists in a more weighed manner.

For various reasons, the COVID-19 outbreak may have triggered a paradigm shift in the way we are conducting science studies in polar regions. This situation triggered a reduction of carbon footprint by reducing travels associated with meetings and fieldwork. This means that there is probably smarter way to maintain scientific installations using the assistance and expertise from local technicians and cut travel costs. All the same, scientists will of course prefer to manage the maintenance themselves, since this is a way to ensure best performance of data and resulting science questions. Our activities and examples show that there is a need of re-assessing our ways of conducting field campaigns in Svalbard.

5.7. Importance of International Networks Like SIOS in Pandemic Times

The pandemic yet again pointed out the need of international coordination to optimise the observational networks, particularly in key scientific regions like Svalbard. Certainly, many organisations involved in observation of different aspects in Svalbard have faced data gaps to some extent. The only way to fill this is through the use of remote sensing and sharing of data within organisations. SIOS has been instrumental in this, by not only promoting and making remote sensing products easily accessible, but also bringing a large number of international organisations under a common platform which makes researchers aware of the developments and provide required information to fill the data gaps due to the restrictions during the pandemic. This is also a great opportunity to boost interdisciplinary studies in Svalbard given that the restrictions implemented during the pandemic may allow studying more clear signals on changes in different environmental parameters. For example, the changes in the aerosol emissions in lower latitudes can be expected to be significantly altered due to the restrictions. These relatively large signals in a pristine environment can make their influence on the ecosystem more evident helping researches to understand and quantify their role more accurately. Overall, while the pandemic has halted progress in enhancing the observation networks around Svalbard, it has opened up new dimensions which help the scientific communities to realise the requirement of international cooperation, coordination, and usefulness of common platforms like SIOS in optimum use of observations around Svalbard. We stress that at this time the scientific community should connect more and open up for increased data and infrastructure sharing. Integrated observing systems, like SIOS, should play a key role in this setting. We have time to think about our results and our scientific needs: we can discuss inside the community and find areas for cooperation and interaction. It is important to learn from the past and to plan for the future. In future proposals and planning of field campaigns should include a contingency plan that discusses backups in case of pandemics, lockdowns, or travel restrictions. SIOS could become an important element for supporting such backup plans in and around Svalbard.

6. Conclusions

COVID-19 has posed a distinctive challenge to the scientific community working in Svalbard in terms of lockdown, remote working, cancelled social and networking events, cancelled fieldwork, changing working practices, and isolation and anxiety. Even though the pandemic has changed our regular activities for the unforeseeable time, the Svalbard research community continues in its resilience under the extraordinary and unparalleled current circumstances. In this study, we highlighted a bunch of EO, RS, and operational activities of SIOS and its member institutions to respond to COVID-19 related travel restrictions and resulting limited field activities in Svalbard. These activities were developed for the Svalbard research community, but we believe that similar activities can be expanded to the whole Arctic, Himalayas, or Antarctica or other remote places where field activities were affected during the COVID-19 situation. This set of activities will form a base for all such activities being implemented in other parts of the world and could significantly contribute to developing a long-term sustainable plan for responding to future similar situations. A few of these activities were developed for the new normal situation created by the pandemic, but we believe that these activities are transferable for the regular activities in future. Our efforts show that even after the lockdown of Svalbard due to the pandemic, scientific observations can be done using various means including EO, RS, and planning logistical activities using local skilled personnel. Laid off workers can be better utilised in conducting field campaigns in a future pandemic or similar situations. Times of crisis often result in innovation, new technology and new ways of working and thinking. Our experience and lessons learned during the pandemic would help to accelerate the development of remote sensing methods and solutions in order to reduce the environmental footprint of research in the fragile Arctic region. Our activities were successful in bringing the whole Svalbard science community together in pandemic times by facilitating collaboration via the SESS report, ACCESS programme, airborne measurements, webinars, online conference, training course, and finally documenting our response to COVID-19 in the form of a manuscript. The pandemic is not over yet, but these positive activities could stimulate more activities using EO and RS. Today, usage of satellites and other new technologies in RS such as UAVs, and aircraft-based data collection are more relevant than ever. It also gives the opportunity to carry out monitoring and research that minimises the environmental footprint of such activities in sensitive High Arctic ecosystems. It is not possible to observe all essential Svalbard variables (SIOS core data) using EO and RS, but we can secure a few of these variables when in situ measurement is not possible. This article attempts to share our experience, expertise, and activities for a broader audience in observing systems in Earth System Science. Overall, the results of these activities will be realised in the coming years when we move forward into a post-pandemic world. The pandemic situation is changing rapidly, and the relevance of this work would be realised at later stages. We have summarised all the activities at the time of writing this paper while we continue preparing for the next year. A more detailed analysis of the short term (next field season), mid-term (next 3 years), and long-term (7-10 years) effects of the pandemic on Svalbard research have not been analysed yet. We anticipate that our activities will provide a foundation to respond to future similar situations.

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References

1. Svalbard Integrated Arctic Earth Observing System (SIOS). Available online: https://sios-svalbard.org/ (accessed on 23 July 2020).
2. Buch, E.; Madsen, M.S.; She, J.; Stendel, M.; Leth, O.K.; Fjæraa, A.M.; Rattenborg, M. Arctic In Situ Data. Availability, Issue: 2.1 Date: 09/12/2019 EEA/IDM/15/026/LOT1. Available online: https://insitu.copernicus.eu/library/reports/CopernicusArcticDataReportFinalVersion2.1.pdf (accessed on 2 November 2020).
3. World Health Organisation (WHO). Coronavirus Disease (COVID-19) Situation Report—174. 2020. Available online: https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200712-covid-19-sitrep-174.pdf?sfvrsn=5d1c1b2c_2 (accessed on 21 December 2020).
4. Anderson, R.M.; Heesterbeek, H.; Klinkenberg, D.; Hollingsworth, T.D. How will country-based mitigation measures influence the course of the COVID-19 epidemic? *Lancet* **2020**, *395*, 931–934, doi:10.1016/S0140-6736(20)30567-5.
5. Frame, B.; Hemmings, A.D. Coronavirus at the end of the world: Antarctica matters. *Soc. Sci. Humanit. Open* **2020**, *2*, 100054, doi:10.1016/j.ssaho.2020.100054.
6. ICIMOD. *COVID-19 Impact and Policy Responses in the Hindu Kush Himalaya*; International Centre for Integrated Mountain Development: Kathmandu, Nepal, 2020. Available online: https://lib.icimod.org/record/34863 (accessed on 2 November 2020).
7. Hughes, K.; Convey, P. Implications of the COVID-19 pandemic for Antarctica. *Antarct. Sci.* **2020**, *32*, 426–439, doi:10.1017/S095410202000053X.
8. SCAR. Survey: The Impact of COVID-19 on the Antarctic Research Community. 2020. Available online: https://www.scar.org/scar-news/humanities-and-social-science-news/covid19-survey/ (accessed on 2 November 2020).
9. European Space Agency and European Commission. Rapid action on Coronavirus and EO (RACE). 2020. Available online: https://race.esa.int/ (accessed on 2 November 2020).
10. Nichol, J.E.; Bilal, M.; Ali, M.A.; Qiu, Z. Air Pollution Scenario over China during COVID-19. *Remote Sens.* **2020**, *12*, 2100.
11. Fan, C.; Li, Y.; Guang, J.; Li, Z.; Elnashar, A.; Allam, M.; de Leeuw, G. The Impact of the Control Measures during the COVID-19 Outbreak on Air Pollution in China. *Remote Sens*. **2020**, *12*, 1613.
12. Liu, Q.; Sha, D.; Liu, W.; Houser, P.; Zhang, L.; Hou, R.; Lan, H.; Flynn, C.; Lu, M.; Hu, T.; et al. Spatiotemporal Patterns of COVID-19 Impact on Human Activities and Environment in Mainland China Using Nighttime Light and Air Quality Data. *Remote Sens*. **2020**, *12*, 1576.
13. SIOS Special Issue on "Earth Observation (EO), Remote Sensing (RS), and Geoinformation (GI) Applications in Svalbard". Available online: https://sios-svalbard.org/SpecialIssueRemoteSensing (accessed on 23 July 2020).
14. SIOS Monthly Webinar Series on Earth Observation (EO) and Remote Sensing (RS) Talks. Available online: https://sios-svalbard.org/RSWebinarSeries (accessed on 23 July 2020).
15. International Glaciological Society Global Seminar Series. 2020. Available online: https://www.igsoc.org/igswebinar/ (accessed on 2 November 2020).
16. Polar Geospatial Centre-Webinar Series. Available online: https://www.pgc.umn.edu/tag/webinar/ (accessed on 2 November 2020).
17. SIOS's Online Conference on EO/RS/GI in Svalbard—4–5 June 2020. Available online: https://sios-svalbard.org/RS_OnlineConference2020 (accessed on 23 July 2020).
18. Training Course on Terrestrial Remote Sensing in Svalbard. Available online: https://sios-svalbard.org/TRST_2020 (accessed 20 July 2020).
19. Patch up Your Field Data Gaps with Remote Sensing. Available online: https://sios-svalbard.org/News_20200324a (accessed on 23 July 2020).
20. SSF Connecting Svalbard Researchers for Field Logistics. Available online: https://www.facebook.com/groups/139776787422274/ (accessed on 23 July 2020).
21. SIOS Logistics Sharing Notice Board. Available online: https://sios-svalbard.org/logistic-notice-board (accessed on 23 July 2020).

22. SIOS's Announcement of Opportunity (AO) in Airborne Remote Sensing-2020. Available online: https://sios-svalbard.org/AirborneRS (accessed on 23 July 2020).
23. Wilkinson, M.; Dumontier, M.; Aalbersberg, I.; Appleton, G.; Axton, M.; Baak, A.; Blomberg, N.; Boiten, J.-W.; da Silva Santos, L.B.; Bourne, P.E.; et al. The FAIR Guiding Principles for scientific data management and stewardship. *Sci. Data* **2016**, *3*, 160018, doi:10.1038/sdata.2016.18. Available online: https://www.nature.com/articles/sdata201618 (accessed on 07 January 2021).
24. Hann, R.; Altstädter, B.; Betlem, P.; Deja, K.; Dragańska-Deja, K.; Ewertowski, M.; Hartvic, F.; Jonassen, M.; Lampert, A.; Laska, M.; et al. *Scientific Applications of Unmanned Vehicles in Svalbard (UAV Svalbard)*; In: Moreno-Ibáñez et al (eds) State of Environmental Science in Svalbard (SESS) report 2020, Svalbard Integrated Arctic Earth Observing System (SIOS), Longyearbyen, Norway, 2021, https://doi.org/10.5281/zenodo.4293283.
25. Hodson, A.; Jonassen, M.O.; Hann, R.; Hess, C.; Garreau, A.; Dachauer, A. Using UAVs to Investigate Effects of Crevasses upon Glacier Surface Melting (Crevasse UAV), 2019–2020, RIS-ID 11148. Available online: https://www.researchinsvalbard.no/project/9044 (accessed on 23 November 2020).
26. SIOS ACCESS Programme. Available online: https://sios-svalbard.org/RIAccess (accessed on 24 July 2020).
27. SIOS State of Environmental Science in Svalbard (SESS) Report. Available online https://sios-svalbard.org/SESSreport (accessed on 20 July 2020).
28. Chantelle, R.; Frederick, F. The academic response to COVID-19. *Front. Public Health* **2020**, *8*, 621563, doi:10.3389/fpubh.2020.621563.
29. Nakoudi, K.; Ritter, C.; Böckmann, C.; Kunkel, D.; Eppers, O.; Rozanov, V.; Mei, L.; Pefanis, V.; Jäkel, E.; Herber, A.; et al. Does the Intra-Arctic Modification of Long-Range Transported Aerosol Affect the Local Radiative Budget? (A Case Study). *Remote Sens.* **2020**, *12*, 2112.
30. Vickers, H.; Karlsen, S.R.; Malnes, E. A 20-Year MODIS-Based Snow Cover Dataset for Svalbard and Its Link to Phenological Timing and Sea Ice Variability. *Remote Sens.* **2020**, *12*, 1123.
31. International Environmental Doctoral School. Available online: https://www.mssd.us.edu.pl/en/ (accessed on 23 July 2020).
32. Petäjä, T.; Duplissy, E.M.; Tabakova, K.; Schmale, J.; Altstädter, B.; Ancellet, G.; Arshinov, M.; Balin, Y.; Baltensperger, U.; Bange, J.; et al. Overview—Integrative and Comprehensive Understanding on Polar Environments (iCUPE): The concept and initial results, Environments (iCUPE). *Atmos. Chem. Phys*. **2020**, *20*, 8551–8592, doi:10.5194/acp-20-8551-2020.
33. Picard, G.; Libois, Q.; Arnaud, L.; Verin, G.; Dumont, M. Development and calibration of an automatic spectral albedometer to estimate near-surface snow SSA time series. *Cryosphere* **2016**, *10*, 1297–1316, doi:10.5194/tc-10-1297-2016.
34. Salzano, R.; Lanconelli, C.; Salvatori, R.; Esposito, G.; Vitale, V. Continuous monitoring of spectral albedo of snowed surfaces in Ny-Ålesund. *Rend. Lincei. Sci. Fis*. **2016**, *27*, 137–146, doi:10.1007/s12210-016-0513-y.
35. Pedersen, C. *Zeppelin Web Camera Time-Series, Dataset*; Norwegian Polar Institute: Tromsø, Norway, 2013; doi:10.21334/npolar.2013.9fd6dae0.
36. Salzano, R.; Salvatori, R.; Valt, M.; Giuliani, G.; Chatenoux, B.; Ioppi, L. Automated Classification of Terrestrial Images: The Contribution to the Remote Sensing of Snow Cover. *Geosciences* **2019**, *9*, 97, doi:10.3390/geosciences9020097.
37. Salzano, R.; Aalstad, K.; Boldrini, E.; Gallet, J.C.; Kępski, D.; Luks, B.; Nilsen, L.; Salvatori, R.; Westermann, S. Terrestrial Photography Applications on Snow Cover in Svalbard (PASSES). In: Moreno-Ibáñez et al (eds) State of Environmental Science in Svalbard (SESS) report 2020, Svalbard Integrated Arctic Earth Observing System (SIOS), Longyearbyen, Norway 2021. https://doi.org/10.5281/zenodo.4294084.
38. Petrov, A.N.; Hinzman, L.D.; Kullerud, L.; Degai, T.S.; Holmberg, L.; Pope, A.; Yefimenko, A. Building resilient Arctic science amid the COVID-19 pandemic. *Nat. Commun.* **2020**, *11*, 6278, doi:10.1038/s41467-020-19923-2.
39. Lee, C.; Eicken, H.; Jakobsson, M. Introduction: The Arctic Observing Summit 2013. *Arctic* **2015**, *68*, iii. Doi: 10.14430/arctic4456
40. IPCC. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. 2019. Available online: https://www.ipcc.ch/srocc/ (accessed on 20 December 2020).
41. Laing, A.; Garrison, C. 2020. 'Isolated within Isolation': Keeping out Coronavirus in the Frozen Antarctic. Available online: https://uk.reuters.com/article/uk-health-coronavirus-antarctica-feature/isolated-within-isolation-keeping-out-coronavirus-in-the-frozen-antarctic-idUKKCN21W2OE (accessed on 21 December 2020).
42. Tømmervik, H.; Karlsen, S.R.; Nilsen, L.; Johansen, B.; Storvold, R.; Zmarz, A.; Beck, P.S.; Johansen, K.S.; Høgda, K.A.; Goetz, S.; et al. Use of unmanned aircraft systems (UAS) in a multiscale vegetation index study of Arctic plant communities in Adventdalen on Svalbard. *EARSeL eProceedings* **2014**, *13*, 47–52.
43. Wight, A.J. COVID clears the skies for Earth-observing drones in Nepal. *EOS* **2020**, *101*, doi:10.1029/2020EO149765.
44. Anderson, H.B.; Nilsen, L.; Tømmervik, H.; Karlsen, S.R.; Nagai, S.; Cooper, E.J. Using Ordinary Digital Cameras in Place of Near-Infrared Sensors to Derive Vegetation Indices for Phenology Studies of High Arctic Vegetation. *Remote Sensing* **2016**, *8*, 847, doi:10.3390/rs8100847.
45. Data Together COVID-19 Appeal and Actions. Available online: https://codata.org/data-together-covid-19-appeal-and-actions/ (accessed on 21 December 2020).