VRSvalbard – a photosphere-based atlas of a high Arctic geo-landscape

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Abstract

Recent technological advances provide opportunities to enhance students' learning. Field-based geoscience education is no exception. Traditional pedagogy of field teaching, although invaluable, sometimes struggles to provide students with the depth and breadth of real-world examples to foster a deep understanding of geoscientific landforms and processes. These methods rely on complex landscape features examined in a field activity to exemplify the learning content, while teaching staff typically ground students' understanding with supplementary printouts of figures, diagrams, and sketches.

In this paper we present VRSvalbard, an interactive web-GIS platform currently populated with 129 virtual field tours of the High Arctic Archipelago of Svalbard. The virtual field tours are built around 1481 aerial photospheres, systematically acquired largely during drone-based data acquisition campaigns as part of the overarching Svalbox project including a database of digital outcrop models. The virtual field tours offer interactive digital field experiences in desktop and virtual reality mode. Selected tours also integrate 3D datasets, digital outcrop models, digital elevation models, interactive map layers, satellite imagery, published figures, photos, audios, videos, and text resources. These elements are presented within a detailed and realistic 3D digital globe that allows students to virtually explore field sites before and after field excursions. In addition, we provide an overview of the motivation behind VRSvalbard, the technical framework of the platform and a summary of using the VRSvalbard platform during education, research and field excursions for the petroleum industry.

Keywords. Svalbard; field-based education; digital learning; drones; digital twin

Introduction

Geoscience education plays a pivotal role in shaping students' understanding of the Earth's complex and dynamic processes. It is a field that inherently demands field-based education, where students step out of the traditional classroom and into the natural environment to directly observe and interpret geoscientific phenomena.

In the Norwegian high Arctic Archipelago of Svalbard (Figure 1), with its remote and extreme environments, the University Centre in Svalbard (UNIS) conducts year-round field-based geoscience education. The field conditions are often challenging, including sub-zero temperatures, high winds, snowdrift, and limited or no daylight during the polar night from October to February. Additionally, the fragile Arctic environment demands adherence to strict environmental regulations to minimise human impact and reduce the environmental footprint of fieldwork. Logistic complexities related to planning, permit acquisition, and necessary safety measures also need to be considered (Senger et al., 2021; Horota et al., 2023). At the same time, Svalbard's geological diversity and the complex weather variations in the circum-Arctic offer valuable learning opportunities for field-based geoscience education.

Svalbard comprises all islands between 15-35°E and 74-81°N, including the largest island Spitsbergen. Geologically, Svalbard is the emergent part of the Barents Shelf and offers a nearly continuous sedimentary record from the Devonian to the Paleogene (Olaussen et al., 2024). The diverse lithologies along with recorded tectono-thermal events including compressional and extensional tectonics and large-scale magmatism make Svalbard an invaluable place to study and teach a wide variety of geoscience courses. Importantly, recent global climate change is more pronounced in the high Arctic (Rantanen et al., 2022), and Svalbard is one of the world's most rapidly warming places (Isaksen et al., 2022) where students can experience it and therefore gain a deeper understanding of this process.

As technology continues to reshape the educational landscape, there is a pressing need for innovative solutions to bridge the gap between traditional field-based learning and contemporary pedagogical methods (Cliffe, 2017). In this context, virtual field experiences and digital outcrop models of field environments emerge as powerful tools which address these field educational

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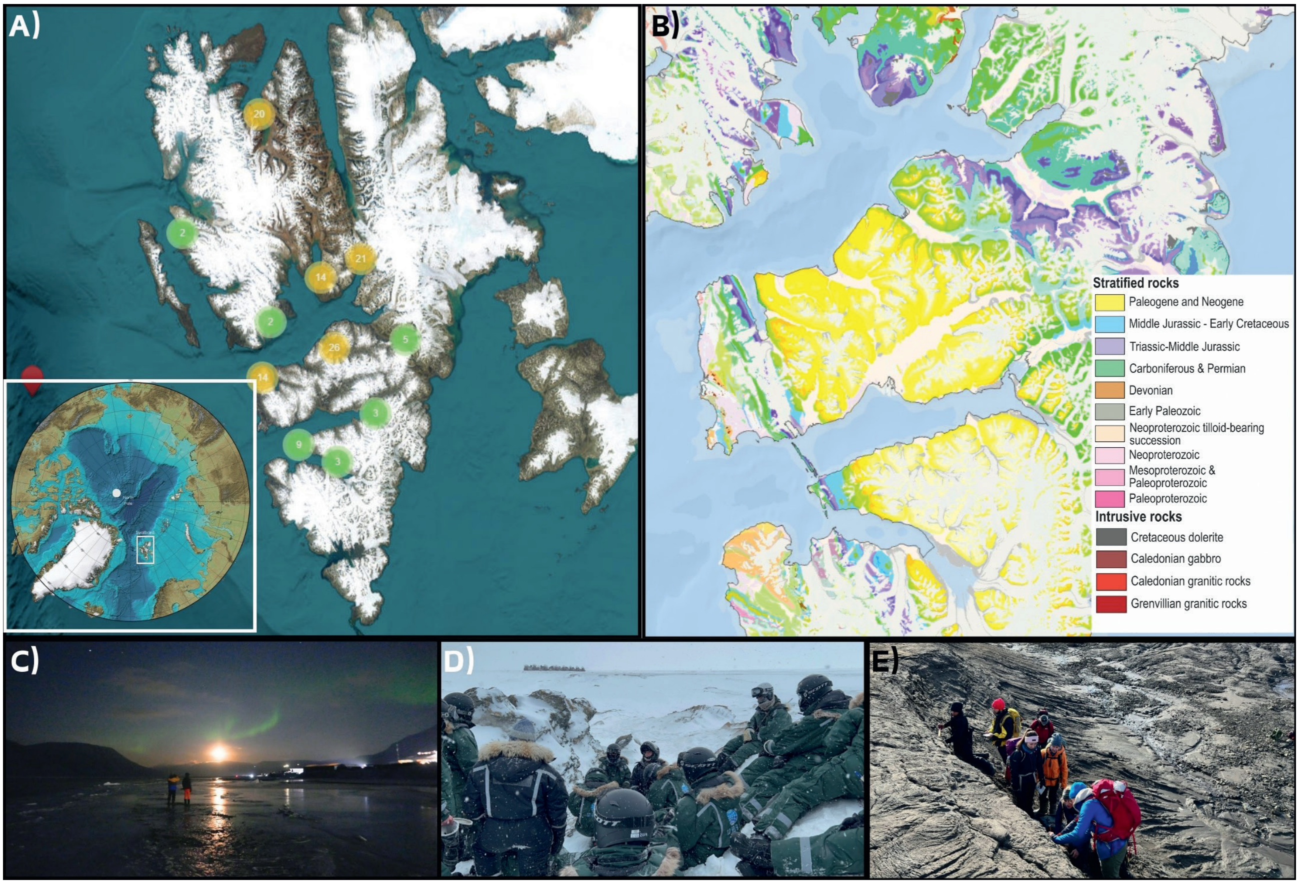


Figure 1 A) Location of the Svalbard archipelago (inset map, based on IBCAO; Jakobsson et al, 2008) and the available Virtual Field Tours on www.vrsvalbard.com/map. B) Geological map from Dallmann, (2015) and the Norwegian Polar Institute (2016). C) Meteorology fieldwork in Adventdalen (January 2021). D) Geology fieldwork at Kapp Linne (April 2023). E) Geology fieldwork at Borebukta (September 2022).

challenges and offer educators the means to create immersive and engaging learning experiences (Horota et al., 2023). Virtual field experiences improve 3D thinking and the positive perceptions of learning (Pugsley et al., 2022). While digital outcrops have been around for the past 30 years (Buckley et al., 2008), it was during the global Covid-19 pandemic when their usefulness became apparent to a larger teaching community (Bond & Cawood, 2020; Senger et al., 2021).

In this paper we introduce VRSvalbard (https://vrsvalbard.com/), a tool to support field-based learning experiences for students, researchers and industry professionals. We present the technical framework of VRSvalbard and our strategy for systematic and sustainable data acquisition. Finally, we provide case studies of how VRSvalbard is used in several UNIS courses and outline how such digital tools complement traditional field teaching.

VRSvalbard: motivation, technical framework, and data acquisition

Motivation

The development of VRSvalbard commenced with an analysis of the educational needs and goals related to UNIS geoscience courses' field components. UNIS offers courses in Arctic Geology, Arctic Geophysics, Arctic Biology and Arctic Technology and all courses include a mandatory field component utilising the natural laboratory offered by Svalbard. The harsh and extremely seasonally dependent field conditions often require adjustments to planned field activities. In this context, digital tools like VRSvalbard and Svalbox (www.svalbox.no/map; Betlem et al., 2023) offer an opportunity to support students' learning if an actual field experience must be adapted and to make more efficient use of fieldwork that is undertaken as planned. Since 2016 UNIS has been systematically acquiring digital outcrop models (DOMs) and openly sharing them through the Svalbox database (Senger et al., 2022; Betlem et al., 2023). While DOMs allow quantitative geoscientific work, they only cover single outcrops/mountainsides and their acquisition and processing take time. In recent years DOMs are almost exclusively acquired using drones, many of which are also capable of taking photospheres (i.e. 360° panoramic images derived from automatically stitching together multiple photographs taken around a single nodal point) as a complementary qualitative dataset. Photospheres are ideal for placing DOMs in a regional context and providing different perspectives of the field sites. As photospheres can be acquired very quickly, they can be taken in parallel with field activities and thus provide a digital representation of the specific conditions (snow cover, weather etc.) of the field day.

During our analyses of UNIS' field activities, we identified that field sites frequently had to be changed on short notice due to harsh weather conditions or polar bear encounters. Keeping the site and changing fieldwork dates and/or rearranging bookings of transport (typically boats or snowmobiles) would in many cases have been preferable but were often not possible due to logistical constraints. Changing field sites, or cancelling the field day, were frequently the only viable options. These factors led us to acquire visual datasets with a better overview of Svalbard's landscape (in the sunlight and/or with less snow cover) and the frequent rescheduling and cancelling of fieldwork gave us the idea to develop virtual field tours (VFT) for key field sites around the archipelago.

Technical framework

VRSvalbard comprises seven backend and six front end user-interface components hosted externally using a web-hosting provider (Figure 2; Table 1). It is developed in WordPress, where the HTML5 package output from the Pano2VR software is uploaded via the Garden Gnome Package plugin for each of the localities in individual webpages. These pages are linked to markers displayed over an interactive map, that is built using the open-source Leaflet Map Plugin JavaScript library in the VRSvalbard.com/map tab. Geographical coordinates are attributed to each marker which automatically gets placed and clustered over the interactive map through shortcodes, small code snippets that display a specific function or content in WordPress.

VRSvalbard currently hosts 129 VFTs from localities all over Svalbard (Figure 1A). They are also shown in separate interactive maps in the VRSvalbard.com/courses tab displaying field teaching localities for specific UNIS courses.

The HTML5 packages output for the VFT were built using Garden Gnome's Pano2VR - Panorama Tour Builder software to upload, orient and link photospheres and Sketchfab 3D models links, photos, videos, and text as supplementary content. The software exports it as an HTML5 package for each project field location. The whole customisation and export process takes up to 30 minutes for each VFT (± 10 photospheres) to be ready for upload to VRSvalbard (Figure 3).

The platform also hosts interactive 3D geospatial presentations as thematic virtual field guides (VFGs) of Svalbard's geology (Figure 4). VFGs are developed using the Cesium ion 3D geospatial platform that creates and hosts 3D content in the cloud. It allows 3D data upload to create 3D tiles that can be combined with high-resolution terrain, satellite imagery, and map layers for

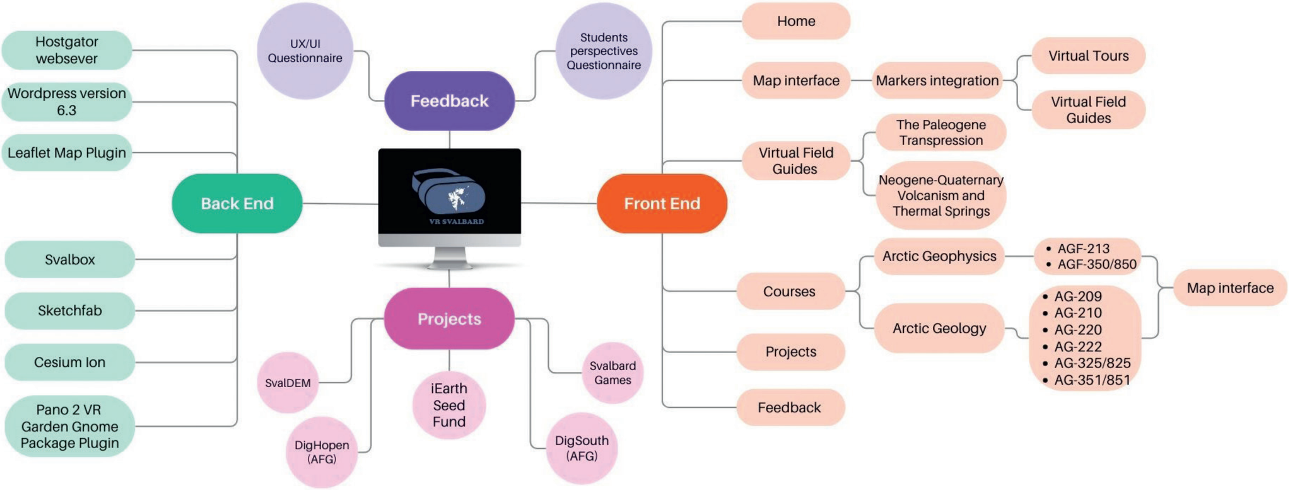


Figure 2 Technical framework – Back-end and front-end, map and marker implementation, funding projects and feedback questionnaires.

Component (software, element)	Purpose	License/cost	Export format	Reference / Version
Hostgator	Web Hosting platform	Shared webhosting / 04 USD per month	N/A	N/A
Wordpress	Open-source content management system	GPlv2 - Free	N/A	Version 6.3
Leaflet Map JavaScript Library	Implement interactive map	Free	N/A	Leaflet 1.9.4
Pano2VR	Generate VFT	Educational / 175USD one-off fee	HTML5 Package	7.0.6 64bit
Sketchfab	Web platform that hosts 3D Models	Pro / 15USD per month	.obj, .blend, .fbx, .gltf, .glb, .las, .ply, .stl, etcs.	2023
Cesium ION	3D geospatial platform	Free	Url link (iFrame)	N/A
Svalbox	Major data and equipment provider	Free	.jpeg, .obj,	Senger et al., (2021), Betlem et al., (2023)

Table 1 Back end components of VRSvalbard.

global coverage and shows where data fits in the digital world. The 3D geospatial assets and presentations are stored in a Cesium ion account and are imported to a VFG page in VRSvalbard as an iFrame embedded link.

Data acquisition

The images of the field sites were collected to provide a virtual 3D perspective of the learning sites. We acquired both overlapping images for Structure-from-Motion (SfM) reconstruction (Westoby et al., 2012; Betlem et al., 2023), and photospheres. We used consumer drones, particularly DJI's Mavic 2 Pro (Hasselblad 1" CMOS sensor 20 Mp) and Mavic 3 (Hasselblad 4/3" CMOS sensor 20 Mp) models. Systematic acquisition was conducted during dedicated Svalbox field campaigns, but also carried out as opportunistic field activities (field excursions as part of UNIS courses, near-town day trips around Longyearbyen, or on multi-day expeditions farther afield; Table 2).

Some preexisting data, including photospheres (Betlem et al., 2022) and DOMs from the Svalbox database (Senger et al., 2021; Betlem et al., 2023) were integrated in the VRSvalbard.

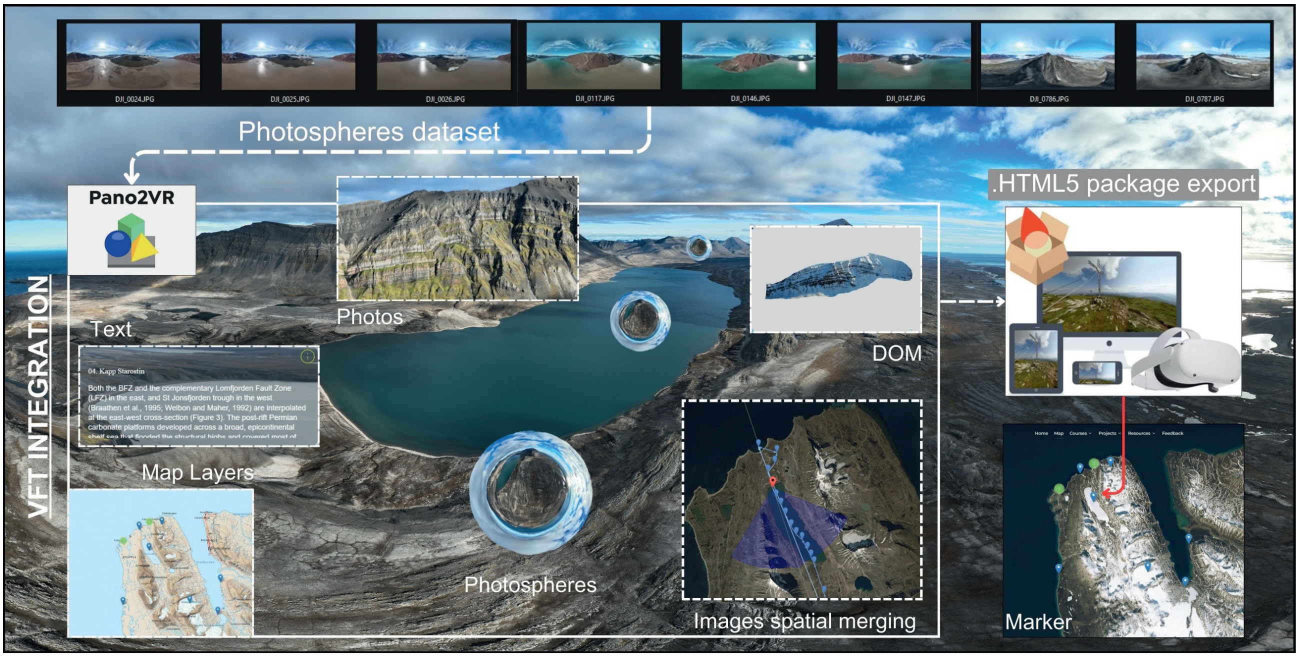
VRSvalbard: visualisation, data integration, and case studies

In the platform, the VFTs are a sequence of panoramic images that are spatially merged to create a virtual experience. Once created, the viewer can virtually experience local and remote field sites. VFTs can be experienced through desktop computers, laptops, tablets, mobile devices, and even in an immersive view mode with head-mounted displays.

VFGs, on the other hand, are interactive, digital experiences that provide users with a thematic storytelling exploration of a field area. In essence, they capture the real-world environment of a specific location or region through a variety of multimedia content, including images, videos, maps, and 3D models to teach. VFG experiences are only visualised via desktop or mobile devices.

Field campaign type / name	Dates	Number of field days	Type of base camp	Number of photospheres	Reference/Comment
Research					
HALIP_V2 2023	14-19.09.2023	6	Small boat	39	
HALIP 2023	04-21.08.2023	18	Small boat	22	
Woodfjorden	17-31.07.2023	14	Medium boat	458	http://tinyurl.com/y273vsbh
Bjørnøya	01-22.09.2022	22	Tent / Cabin	190	
Petuniabukta	23-28.06.2022	5	Field station	123	
Dicksonland	08-21.07.2021	14	Small boat	11	
Dedicated data acquisition					
Svalbox GoNorth	Spring 2023	6	Cabin	79	Betlem et al., 2023; http://tinyurl.com/4y8wjdvn
Near-Longyearbyen	Summer 2022 – 2023	10	UNIS	130	
Svalbox 2023	17-21.04.2023	5	Cabin	55	
Festningen 2022	27-31.08.2022	4	Hotel	111	
Svalbox/AG222 scouting – 2022	4-6.4.2022	3	Hotel		
Svalbox 2021	21-30.07.2021	10	Small boat	49	Betlem et al., 2021; http://tinyurl.com/2anepx6e
Courses					
AG-209/222 – 2023	03.03.2023, 21-25.03.2023	6	Hotel / Day Trips	85	
AG-351/851 – 2022	03-10.10.2022	8	Big Boat	29	
AG-210 - 2022	25-26.08.2022	2	Day trips	32	
AG-209/222 – 2022	09-10.03.2022	2	Day trips	36	
AGF-213 – 2021	07-10.09.2021	4	Hotel	9	
AG-210 - 2021	18-23.08.2021	6	Hotel	16	
AG-340 -2021	12-16.08.2021	5	Hotel	7	
Total		**150**		**1481**	

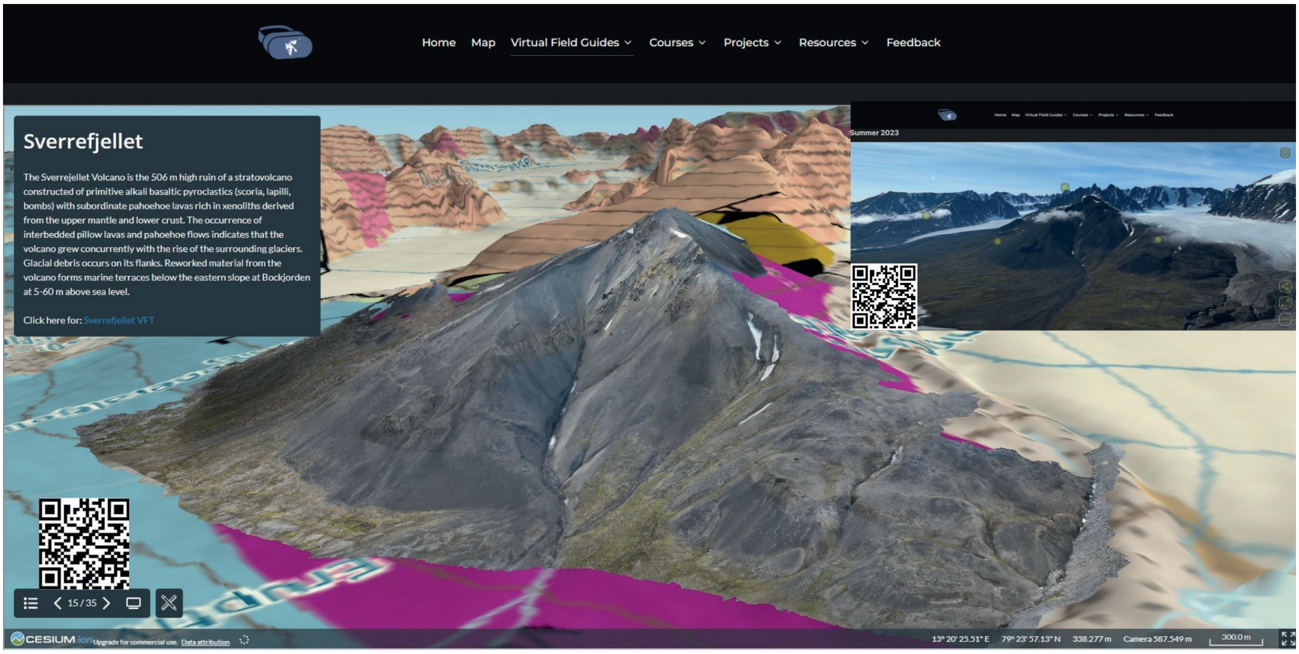
Table 2 Synthesis of major field campaigns contributing data to VRSvalbard. Small boat is *RV Clione* with four scientists onboard. Medium boat is *Ulla Rinmann* with 11 scientists onboard.



04. Kapp Starostin

Both the BFZ and the complementary Lomfjorden Fault Zone (LFZ) in the east, and St Jonsfjorden trough in the west (Braathen et al., 1995; Welbon and Maher, 1992) are interpolated at the east-west cross-section (Figure 3). The post-rift Permian carbonate platforms developed across a broad, epicontinental shelf sea that flooded the structural highs and covered most of

Figure 3 Schematic figure displaying how visual photospheres are spatially merged and how dataset is integrated in selected photospheres in the Pano2VR software. Data is exported as .html packages and uploaded to a VRSvalbard page accessible through a marker in an interactive map.



Sverrefjellet

The Sverrejellet Volcano is the 506 m high ruin of a stratovolcano constructed of primitive alkali basaltic pyroclastics (scoria, lapilli, bombs) with subordinate pahoehoe lavas rich in xenoliths derived from the upper mantle and lower crust. The occurrence of interbedded pillow lavas and pahoehoe flows indicates that the volcano grew concurrently with the rise of the surrounding glaciers. Glacial debris occurs on its flanks. Reworked material from the volcano forms marine terraces below the eastern slope at Bockjorden at 5-60 m above sea level.

Click here for: Sverrefjellet VFT

Figure 4 Data integration and storytelling as a virtual field guide QRcode to URL https://vrsvalbard.com/neogene-quaternary-volcanism-and-thermal-springs/). Integration of ArcticDEM, Bing Satellite, Sverrefjellet DOM, geological map layer of Svalbard, text box and clickable link to the virtual field trip of Sverrefjellet displayed in the upper-right corner, accessible through the QRcode to URL https://vrsvalbard.com/Sverrefjellet/.

Data integration and storytelling

The photosphere selection provides a virtual experience of motion by approaching a given landscape feature of study in the digital space. Interactive elements like popups, photo hotspots, directional sound, images, video, and text can be added as informational content to selected photospheres to highlight landscape features, and display 3D model pop-up windows from the Svalbox.no web portal. The datasets are linked together in Pano2VR software while developing the VFT (Figure 3).

The photosphere image transitions are limited to illustrate details over a specific real-like landscape location. To facilitate the integration of photospheres with complementary data like digital outcrop models, geological maps and regional terrain models, a full 3D visualisation platform is required. These are provided by VRSvalbard's thematic virtual field guides (VFGs; Figure 4).

To complement storytelling for teaching, 3D datasets were also added to Cesium Ion as assets and displayed in VRSvalbard as a Cesium story presentation. One example is the VFG of the Neogene-Quaternary Volcanism and Thermal Springs that seamlessly integrates map layers, digital outcrop models, digital elevation models and geological maps that facilitate storytelling by being all in the same context. The VFGs are supplemented with text, figures, and clickable links that bridge this fully digital 3D learning tool with the VFT on a side bar to provide context (Figure 4).

Case studies

VRSvalbard has been implemented as a teaching tool in several Arctic Geophysics (AGF), and Arctic Geology (AG) courses at UNIS: AGF-213, AGF-351/851, AG-209, AG-210, AG-220, AG-222, AG-336/836, and AG-351/851 (Figure 5; Table 2). It has been used for various purposes in the courses including:

- as a demonstration tool in lectures and in-class activities (All courses),
- fieldwork planning (All courses),
- orientation and navigation (AGF-213, AGF-351/851, AG-210),
- health and safety briefings (All courses),
- detecting changes in the landscape (AG-210, AG-220),
- guaranteed virtual access to field sites in daylight and good visibility (AG-209, AG-222),
- post-fieldwork analysis (All courses),
- students' term projects (AG-209, AG-210, AG-222, AG-351/851),
- as a resource for course assessments and activities (All courses),

The use of VRSvalbard in UNIS courses has provided invaluable feedback on the experiences of instructors and students; this feedback is being actively and continuously collected through short informal interviews (with instructional staff) and in-class discussion and surveys (with students). The full extent of each course field component highlighting the unique use of VRSvalbard and feedback related to specific courses can be found at https://vrsvalbard.com/purposes-of-use/.

Research campaigns

Photospheres are also acquired during research campaigns in both spring and summer (Table 2), providing an exponentially expanding photosphere database that also benefits teaching. In these campaigns the main aim is focused on more traditional geological field work, for instance collection of dolerites (intrusive igneous rock of basaltic composition) samples of the High Arctic Large Igneous Province (HALIP) for geochronology and geochemical analyses. Digital techniques are highly complementary and at UNIS we aim to include a two-person team dedicated to droning on all research campaigns to complement the more traditional scientific objectives. Data collected includes both digital outcrop models (for placing the sampled locations in context of the igneous plumbing system and quantitative analyses for the HALIP example) and photospheres (for seeing the overall setting and detailed examples of outcrops).

Industry campaigns

Svalbard has always attracted field excursions of petroleum companies interested in understanding the geological devel-

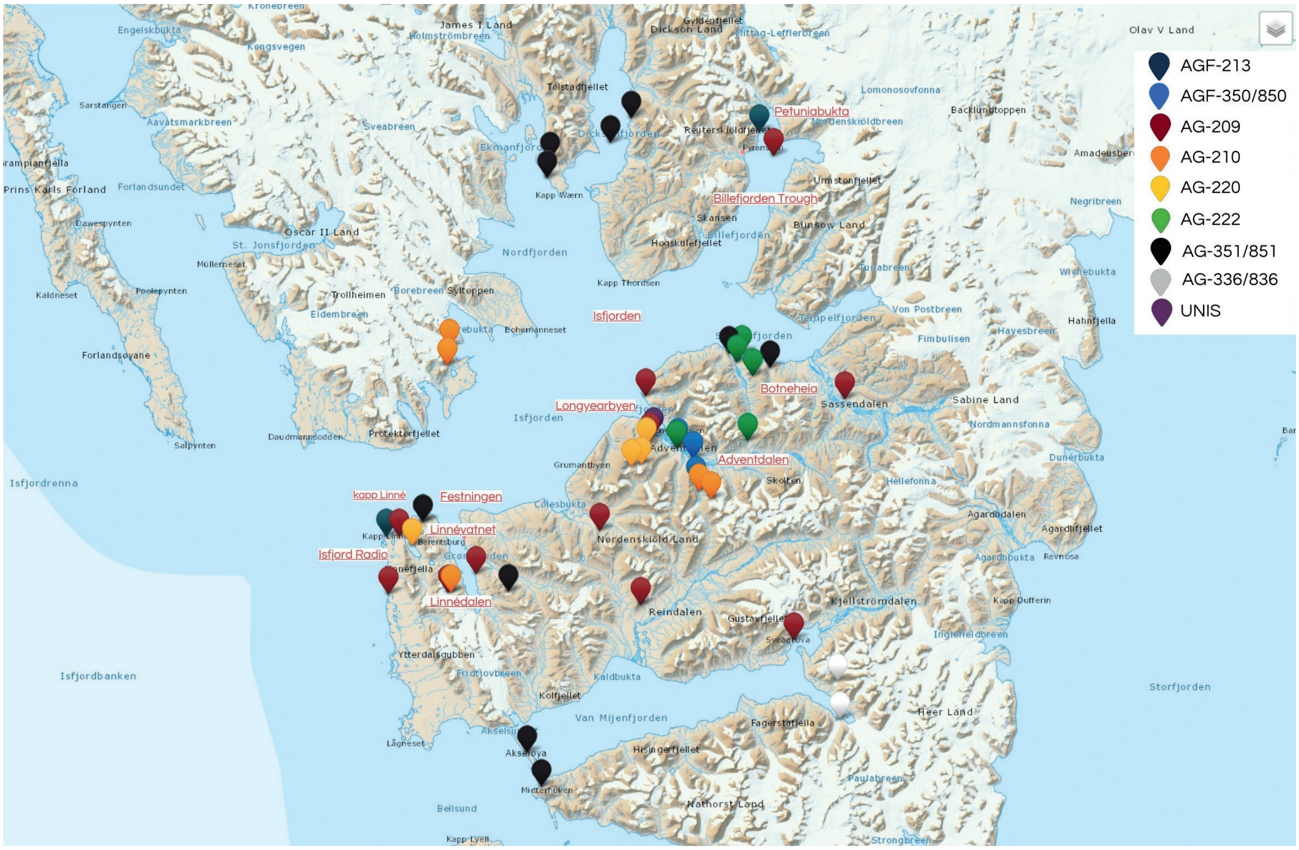


Figure 5 Field locations of all courses. BSc course = 200-level course code, MSc course = 300-level course code, PhD course = 800-level course code. Courses: AGF-213 (Polar Meteorology and Climate), AGF-350/850 (The Arctic Atmospheric Boundary Layer and Local Climate Processes), AG-209 (The Tectonic and Sedimentary History of Svalbard), AG-210 (Quaternary and Glacial Geology of Svalbard), AG-220 (Environmental Change in the high Arctic Landscape of Svalbard), AG-222 (Integrated Geological Methods: From Outcrop to Geomodel), AG-351/851 (Arctic Tectonics and Volcanism), AG-336/836 (Rift Basin Reservoir: From outcrop to model).

opment of the greater Barents Shelf. Svalbard is its exposed part and offers insights into the petroleum systems of the hydrocarbon provinces in the SE Barents Sea (Olaussen et al., 2024). Such field excursions often include a multi-disciplinary team (geoscientists, petroleum engineers etc.) from either a single company or a licensed group, with a specific target in mind. Field excursions are most often organised with a chartered boat with overnight stay, ranging from a few days in the Isfjorden area to a week-long circumnavigation of Spitsbergen. UNIS leads these campaigns and provides both scientific and technical guides. Existing data on the Svalbox and VRSvalbard platforms facilitate pre-field work workshops with the field trip participants, highlighting the regional context of the sites that are planned to be visited. These data allow the participants to revisit the field locations back in the office, also allowing colleagues who were not able to attend the actual field trip to join geoscientific discussions.

Discussion

From the ground to the air: drone-based photospheres

Photospheres are used in many applications, for instance virtual tours of museums (Schulmeister and Edwards, 2020), the Global Seed Vault in Svalbard (https://seedvaultvirtualtour.com/), tourism (Sukardani et al., 2023), or in biology (Eidesen & Hjelle, 2023). Most people have been exposed to photospheres through Google Street View (Anguelov et al., 2010). The emergence of affordable small drones with high-quality cameras provides geoscientists with an aerial view of their field sites (e.g., Jordan 2015). Drones have proven instrumental in efficiently collecting a wide array of geospatial data, including high-resolution imagery and topographic information, even in remote and challenging terrains (Pina & Vieira., 2022). Leveraging the wealth of data obtained through drone-based surveys, researchers have begun to harness this information to construct immersive and non-immersive virtual field trips and exercises (Cheng & Tsai., 2019; Horota et al., 2022; Whitmeyer and Dordevic 2021). These guides offer a dynamic platform for students, scientists, and enthusiasts to virtually explore and analyse geological features and environmental changes (Pugsley et al., 2022).

Teaching and learning opportunities of photosphere-based platforms.

VRSvalbard is becoming an important instructional tool frequently used in numerous courses at UNIS. Unpredictable field conditions require use of supplementary resources to ensure that students have the possibility to achieve learning outcomes for field courses. In this context, the benefits of using VRSvalbard are clearly identified by both instructors and students alike. Instructors use VRSvalbard during the design of field activities (pre-fieldwork preparation tasks, field assessment, etc.) and students use VRSvalbard to support their learning in the course. Photosphere-based platforms may be key in addressing emerging needs in geoscience education including fostering greater accessibility (e.g., in relation to expense, obstacles to travel, physical accessibility for students or teachers with disabilities; Carabajal et al., 2017; Carabajal & Atchison, 2020; Kingsbury et al., 2020), enhancing design for online and blended virtual field learning (Pugsley et al., 2022) and responding to needs for emergency remote teaching. The photosphere-based platforms provide high-quality materials with useable data rather than static and limited digital resources (e.g., image banks on websites) that have been critiqued as inadequate substitutes for field learning (Carabajal et al., 2020). The uses of VRSvalbard in teaching at UNIS suggests that use of photosphere-based platforms do not risk reducing the quality of field work but strengthens and expands what has been traditionally possible. We anticipate that web-GIS platforms like VRSvalbard, along with other similarly designed materials could be used in collaborative online international learning programs in geoscience education to support open higher education broadly.

Conclusions

In this contribution we have presented the VRSvalbard web-GIS platform offering photosphere-based access to field sites in the High Arctic archipelago of Svalbard. VRSvalbard leverages the use of bird's-eye view photospheres and SfM-based digital outcrop models to provide geoscience students and researchers with photorealistic virtual field experiences. The platform is freely and openly available to everyone but is mostly used in courses at UNIS. We conclude by summarising the advantages of the platform:

- A growing number of photospheres from Svalbard are freely available.
- Photospheres are thematically linked to field campaigns visited as part of UNIS courses (virtual field tours).
- Photospheres are integrated with digital outcrop model and complementary geoscientific data in thematic virtual field guides.
- The platform makes fieldwork more efficient by facilitating pre-fieldwork planning and post-field work analyses.
- In cases where field sites cannot be visited the platform allows an alternative and engaging way of accessing field sites digitally.

Data availability

Photospheres are available through the Svalbox platform, hosted on the Zenodo repository (Betlem et al., 2022a; Betlem et al., 2022b; Betlem et al., 2022c; Betlem et al., 2023a).

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Academic licences for developing virtual field guides and 3D geospatial data visualisation were made available by GardenGnome (Pano2VR) and Cesium ion, respectively.

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