

Assembly of the CarboPerm WebGIS for the Laptev Sea Region, Arctic Siberia – Data Visualisation as a WebGIS Service

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Abstract: Permafrost regions are highly sensitive to climate change. Bringing research data and metadata from diverse sources together and visualising them within a publicly available worldwide system would have an enormous impact on data accessibility and availability and would significantly promote scientific work. The CarboPerm WebGIS, a case study focusing on the Lena River Delta in the Laptev Sea Region (Siberia), shows how a WebGIS infrastructure can support scientific work, data management, data visualisation, and data publication. CarboPerm is an interdisciplinary German project with Russian cooperation, investigating the formation, turnover and release of carbon in Siberian permafrost landscapes. There, the Lena River formed the largest delta in the Arctic and is place of long-term Russian-German scientific cooperation in permafrost research. The CarboPerm WebGIS is being set up to visualise and emphasise the spatial context of local samples, measurements, and analyses versus the thematic background information (e.g., geomorphology, pedology, geology and vegetation), using the WebGIS infrastructure “maps@awi” at the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI). The CarboPerm WebGIS database includes historical data from long-term Russian-German cooperation and recent field campaigns as well as environmental datasets that are freely available via the internet or research data repositories.

Zusammenfassung: Permafrost-Landschaften reagieren sehr sensibel auf den Klimawandel. Die Synthese von Forschungsdaten und Metadaten über diese Gebiete und deren Visualisierung in einem interoperablen, weltweit zugänglichen System ist von hohem Nutzen für Wissenschaft und Gesellschaft. Innerhalb des Permafrost-Forschungsprojektes CarboPerm wird für das Lena-Delta und die Laptevmeer-Region ein WebGIS-Projekt entwickelt, welches die wissenschaftliche Forschertätigkeit durch Datenmanagement, Datenvisualisierung und Datenpublikation unterstützt. CarboPerm ist ein interdisziplinäres deutsch-russisches Kooperationsprojekt, das die Bildung, den Umsatz und die Freisetzung von Kohlenstoff in sibirischen Permafrost-Landschaften untersucht. Der Fluss Lena hat das größte Delta in der Arktis ausgebildet und ist gleichzeitig ein Kerngebiet langjähriger russisch-deutscher Kooperation in der Permafrost-Forschung. Das CarboPerm WebGIS wurde ins Leben gerufen, um den räumlichen Bezug von lokalen Probenahmen, Messergebnissen und Analysen mit thematischen Hintergrundinformationen, wie z.B. Geomorphologie, Pedologie, Geologie und Vegetation zu visualisieren. Die CarboPerm-WebGIS-Datenbank entstand unter Nutzung der WebGIS-Infrastruktur „maps@awi“ am Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung (AWI). Sie beinhaltet sowohl historische Daten aus der langjährigen russisch-deutschen Kooperation als auch von aktuellen Geländekampagnen, sowie umweltrelevante räumliche Datensätze, die aus öffentlich zugänglichen Datenquellen und Daten-Repositorien stammen.

MOTIVATION AND CHALLENGES

Permafrost research in Siberia has been carried out by Russian scientists for centuries, and for decades, Russian-German collaboration has initiated joint expeditions and established long-term measurements, specifically in the Laptev Sea region. The research subjects are diverse and range from specific permafrost-related to paleoclimate or environmental studies, to measurements of vertical and lateral fluxes of carbon, energy, and water, or assessing the permafrost landscape stocks of carbon and nutrients. Geophysical, geomorphological, pedological, geobotanical, cryological, hydrological, geochemical, biogeochemical, and biological data have been collected on the land, along the coast, and in the sea. In the central Lena Delta, a multi-parameter, long-term measurement field for permafrost-related parameters has been installed on the Island Samoylov. Here, long-term time series have been published (BOIKE et al. 2013, 2015). Supported by bilateral and international programmes and by the modern research basis “Samoylov Station” (Fig. 1) in the Lena Delta since 2013 (operated by the Trofimuk Institute for Petroleum Geology and Geophysics, Siberian Branch, Russian Academy of Sciences), the data collection by interdisciplinary international teams in the Lena Delta Region has intensified.

Large-scale research programmes focusing on the Laptev Sea region are for example: CarboPerm, the EU FP7 project PAGE21 and PETA-CARB “Rapid Permafrost Thaw in a Warming Arctic and Impacts on the Soil Organic Carbon Pool”. CarboPerm is funded by the German Federal Ministry of Education and Research (BMBF) 2013–2016 and combines multi-disciplinary investigations by Russian and German permafrost scientists, focusing on the formation, turnover and release of carbon and nutrients. PAGE21 is a large-scale international collaborative project within the research field “Vulnerability of Arctic permafrost to climate change and implications for global GHG emissions and future climate”, funded within the Seventh Framework Programme of the European Union between 2013 and 2015, co-ordinated by the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI). Results of PAGE21 were the optimisation of monitoring processes, process studies and modelling for permafrost landscapes. The European Research Council (ERC) is funding PETA-CARB from 2013–2018 to investigate and quantify the permafrost organic carbon pools and to build up the Arctic Permafrost Geospatial Centre (APGC), a data centre for the collection and visualisation of permafrost-related data. To strengthen the communication between all the partners, there is the need for data curation and, especially, data visualisation in the Laptev Sea region.

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Fig. 1: Approaching the Russian research station Samoylov on Samoylov Island, Lena River Delta by helicopter (photo A. Morgenstern AWI, June 2015). “Samoylov Station” is the logistic base for permafrost research in the Laptev Sea Region, operated by the Trofimuk Institute for Petroleum Geology and Geophysics, Siberian Branch, Russian Academy of Sciences.

Abb. 1: Schrägaufnahme aus dem Hubschrauber im Anflug auf die russische Forschungsstation „Samoylov Station“ auf der Samoylov-Insel im Lena-Delta (Foto A. Morgenstern, AWI, Juni 2015). Die „Samoylov Station“ ist die logistische Basis für Permafrostforschung in der Laptewmeer-Region, die durch das Trofimuk Institute for Petroleum Geology and Geophysics, Siberian Branch, Russian Academy of Sciences betrieben wird.

However, which technology/platform would support this intention? Geographic Information System (GIS) server technology has been improving greatly and web-based data visualisation has been expanding steadily. Furthermore, desktop GIS’ fundamental advantage is its feasibility to store and operate, besides raster data, three different feature data types (points, lines and polygons) that are put into relation by their geographic position. Regardless of their scientific source, data integration solely depends on its position. In environmental science, a large variety of data can be represented by these three feature types, and desktop GIS have become very popular during the last decade. Additionally, desktop GIS software is not only capable of data analysis and map creation, but also provides tools for data management, such as data catalogue functionalities and metadata editing. This implies that GIS server and desktop GIS technology support scientific work at all levels, from data collection and data processing to data management and data visualisation, by the publication of web services. Based on this, AWI has established a comprehensive GIS infrastructure. The GIS architecture offers an easy-to-use pathway from desktop GIS to GIS server, by sharing a data base management system and a specific folder system. Scientists may manage their data and layers either as a single data layer or as a collection of specific data layers, using desktop GIS. All data products are published as web services and embedded and displayed within a GIS viewer application.

In this case study, we illustrate the implementation of the CarboPerm WebGIS project, using the AWI GIS infrastructure and data originating from the long-term Russian-German cooperation, recent field campaigns as well as environmental datasets that are freely available via the internet or published via research data repositories (e.g., PANGAEA). Elger et al. (2016) give an overview on DOI-referenced data publication and selected data repositories.

CARBOPERM WEBGIS AT MAPS@AWI

The CarboPerm WebGIS is continuously developed within the AWI GIS infrastructure, which enables the development of WebGIS services for project-specific data. The core components are ArcGIS for Server, a PostgreSQL database including Spatial Database Engine (SDE), and desktop GIS software. Data uptake, editing and manipulation can be accomplished by using the ArcGIS desktop application. An intuitive editor

ensures that metadata and project descriptions follow ISO standards. Published WebGIS projects and related descriptions are added to “maps@awi”, the openly accessible unit for searching and displaying WebGIS projects at AWI. Here, data can be actively visualised by zooming, panning or enabling/disabling layers on appropriate background maps. The CarboPerm WebGIS can be accessed from “maps.awi.de” or via the respective project website.

In 2015, the CarboPerm WebGIS database contained nine feature layers focusing on three major subjects:

- (I) Field data from joint Russian-German investigations,
- (II) regional datasets from joint Russian-German investigations,
- (III) circumpolar or large-scale publicly available spatial datasets.

In addition to the project-specific data, a high-resolution world imagery web service was implemented as background map (World Imagery). At present, multi-point vector-data layers are displayed to visualise the locations of samples or measurements, such as, “discharge measurements” (FEDOROVA et al. 2013) and “sediment cores (carbon, nitrogen)” (ZUBRZYCKI et al. 2013b). Additionally, line and polygon vector-layers represent features related to geomorphology, geology, cryology, or botany, including “Lena Delta terraces” (MORGENSTERN et al. 2011) and “Yedoma” (GROSSE et al. 2013).

In what follows, we give an overview on the visualized GIS layers that have been implemented:

- I Field data from joint Russian-German investigations (Fig. 2):
 - a) Geochemical data from sediment cores (ZUBRZYCKI et al. 2013b) published as a data supplement to ZUBRZYCKI et al. (2013a) in PANGAEA.
 - b) Long-term time series of hydrographic measurements (e.g., discharge) measured in different Lena River branches and published in PANGAEA (FEDOROVA et al. 2013), and later linked as a data supplement to FEDOROVA et al. (2015).
- II Regional datasets from joint Russian-German investigations:
 - Second and third geomorphological main terraces of the Lena Delta published in PANGAEA as GIS-compatible vector layers (MORGENSTERN et al. 2011). Detailed lithology and overview on the main geomor-



Fig. 2: Regular water sampling of meltwater from the Yedoma cliffs in the Lena Delta in late summer 2014 during maximum of ground-ice thaw and run-off of melt waters. Water samples will be analysed for dissolved organic carbon (DOC), coloured dissolved organic matter (cDOM), water isotopes (hydrogen and oxygen) and anorganic hydrochemistry (cations and anions) (photo B. Heim, AWI, 2014).

Abb. 2: Regelmäßige Beprobung des Schmelzwassers der Yedoma-Klippen im Lena-Delta im Spätsommer 2014 zur Zeit des maximalen Tauens des Yedoma-Grundeises und stärksten Schmelzwasserabflusses. Untersucht wird auf gelösten organischen Kohlenstoff (DOC), Gelbstoff (cDOM), Wasserisotope (Wasserstoff und Sauerstoff) und anorganische Hydrochemie (Kationen, Anionen) (Foto B. Heim, AWI, 2014).

phological terraces of the Lena Delta is described in SCHWAMBORN et al. (2002b) with sedimentological data published in PANGAEA (SCHWAMBORN et al. 2002a) that are being prepared for CarboPerm WebGIS visualisation in group I.

- Lena Delta lakes (>20 ha) published in PANGAEA as GIS-compatible vector layers (MORGENSTERN et al. 2011).

These regional geomorphological and hydrographic GIS data layers are frequently downloaded from PANGAEA and already widely used within the research groups working in the Laptev Sea region.

III Freely available environmental data from the World Wide Web:

Feature layers with geomorphological, pedological, land cover, and permafrost units were selected due to beneficial aspects in visualising environmental data. These datasets are publicly available, but not well known outside the actively working communities.

- The “Yedoma” GIS layer displays a geomorphological, organic-rich (about 2 % carbon by mass), Pleistocene-age permafrost layer with an average ice content of 50-90 % by volume. The data for the Siberian “Yedoma” areas was made publicly available by the USGS (GROSSE et al. 2013).
- The “Soil Organic Carbon Content” GIS layer is derived from the NORTHERN CIRCUMPOLAR SOIL CARBON DATABASE produced by HUGELIUS et al. (2013).
- The Land Cover unit (“Soil Types”, “Vegetation Ecosystems” and “Wetland Ecosystems”) GIS layers are derived from the Land Resources of Russia (STOLBOVOI & SAVIN 2002). This resource, first published in 2002, houses a collection of geo-referenced databases for socio-economics, environmental conditions and land endowment of the Russian territory, compiled by the International Institute for Applied Systems Analyses (IIASA).
- The “Permafrost Zones” (continuous, discontinuous and sporadic) GIS layer is derived from the circumpolar

permafrost and ground ice unified international data based on the original 1:10,000,000 paper map called “Circum-Arctic map of permafrost and ground-ice conditions”. The corresponding GIS data are published as revised digital datasets by the National Snow and Ice Data Center (NSDIC) (BROWN et al. 2001).

- The Data User Element (DUE) Permafrost Digital Elevation Model (DEM) (SANTORO & STROZZI 2012) with a high spatial resolution of 100×100 m cell size published in PANGAEA as (DUE PERMAFROST PROJECT CONSORTIUM 2012). Up to date, there exists no global DEM data north of 60° with such high resolution, the default spatial resolution of available global DEM data sets being 1 km x 1 km cell size.

Figure 3 shows the WebGIS visualisation with selected datasets for the major themes: I) field data II) regional data sets and III) global data sets.

DISCUSSION

Environmental researchers, especially those working in remote locations, have become increasingly aware of the vast potential of GIS and WebGIS technologies. Hence, it is no surprise that the number of datasets in GIS-specific formats and the availability of GIS data are raising continuously. Several data repositories, such as PANGAEA or data portals like the EMODnet central portal, make research data freely accessible in usable formats for GIS applications.

Publishing research data as WebGIS services offers several advantages. GIS focuses on well-designed, highly informative maps and data layers, and not on written text. Subsequently, WebGIS layers of any scale and information density transport information through visualisation. This not only promotes the attractiveness of the data products but allows displaying the data and information in an environment that is often very interdisciplinary and, in varying degrees, technically interactive.

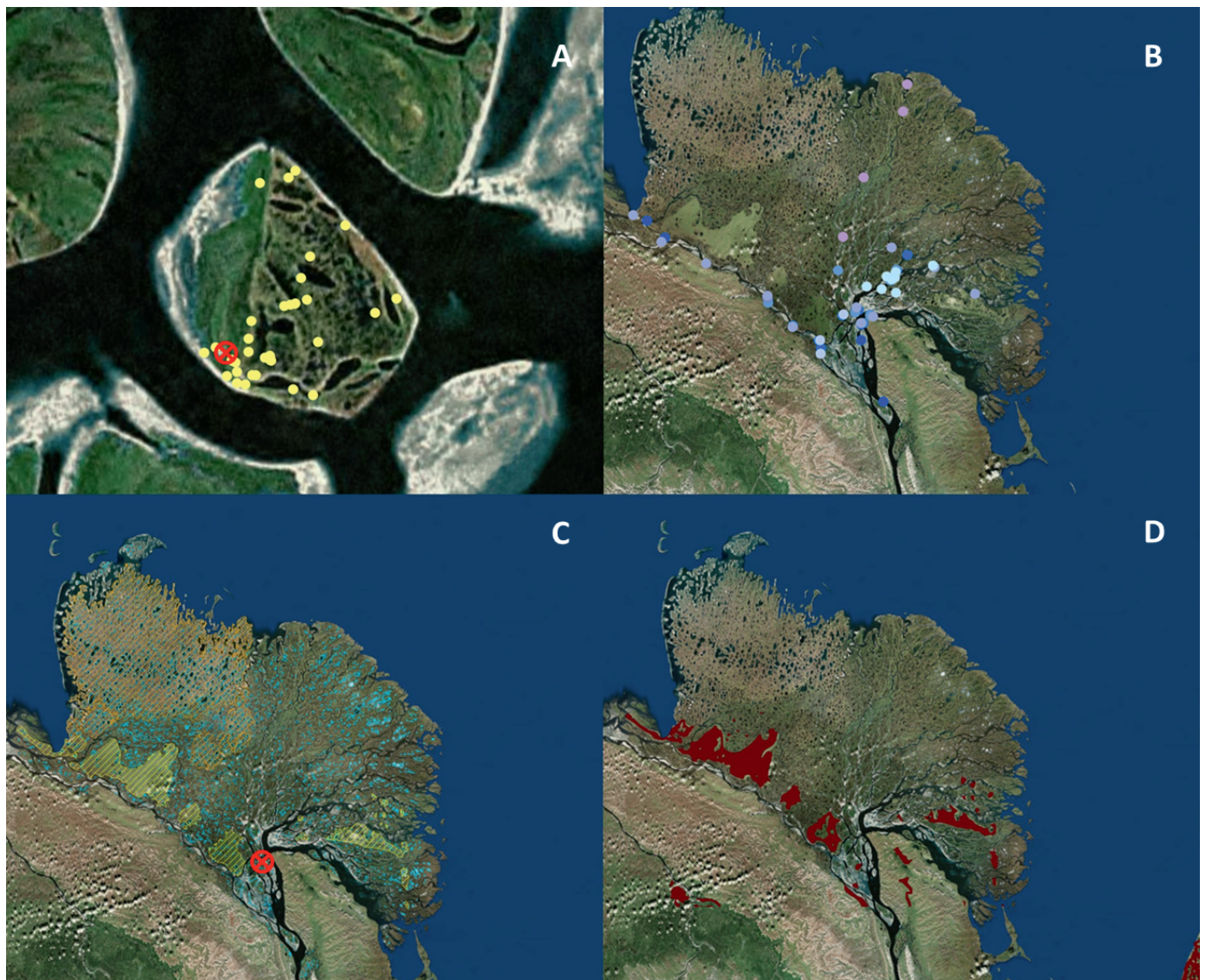


Fig. 3: CarboPerm WebGIS features overlay the background map (World Imagery) focusing on the Lena River Delta. A: Samoylov Island (horizontal scale about 2.3 km), yellow symbols show soil geochemical sampling locations (ZUBRZYCKI et al. 2013b); red-crossed circle indicates location of “Samoylov Station”. B-D: Lena River Delta (horizontal scale about 250 km); B: blue symbols show discharge measurement sites for different years (FEDOROVA et al. 2013); C: yellow and orange hatched polygons display geomorphological terraces and blue polygons display lakes (MORGENSTERN et al. 2011); D: brown polygons display Yedoma units (GROSSE et al. 2013).

Abb. 3: Verschiedene CarboPerm WebGIS Informationsebenen für den Bereich Lena-Delta, dargestellt auf der WebGIS Hintergrundkarte (World Imagery). A: Insel Samoylov (horizontaler Maßstab ca. 2,3 km), gelbe Punkte zeigen die Probenahmestellen für geochemische Bodendaten (ZUBRZYCKI et al. 2013b); roter Kreis mit Kreuz zeigt die Position „Samoylov-Station“. B-D: Übersichten über das Lena-Delta (horizontaler Maßstab ca. 250 km); B: blaue Symbole zeigen die Messstellen für Durchfluss-Messungen über verschiedene Jahre (FEDOROVA et al. 2013); C: gelb und orange schraffierte Polygone zeigen geomorphologische Terrassen und blaue Polygone die Seen (MORGENSTERN et al. 2011); D: rot-braune Polygone beschreiben die Yedoma-Einheiten (GROSSE et al. 2013).

However, scientists prepare their data products to comply with their own or scientific standards. Data products intended to be visualised and published as WebGIS services have also to satisfy specific technical requirements, including standardised metadata and are primarily operated by experienced GIS and administrative personnel. The development of specific WebGIS services like CarboPerm by a broader community, therefore, requires predefined data-management structures and how-to-use/preparation information. At AWI, a user manual was created to guide scientists through the data preparation and editing process, to provide insights into internal data structuring and related layout requirements. Additionally, a GIS-viewer template, including test data, was published to demonstrate GIS-viewer functionalities and show existing

data-manipulation tools that may be plugged into the respective GIS project. Both, the user manual and the GIS-viewer template are easy-to-use services that shall encourage even colleagues who are less experienced in GIS to visualise and publish their data as WebGIS services. To guarantee sufficient metadata for re-use, scientists are encouraged to archive their (GIS) datasets in a data repository such as PANGAEA, preferably with a product guide to ensure documentation and sustainability, before adding them to the WebGIS. Most data repositories are attaching digital object identifier (DOI) to their dataset, thereby guaranteeing their long-term availability and citability. For more than a year now, the citation of dataset DOIs and their integration in reference lists of journal articles are widely accepted by most publishers and data centers. A

major step for this development that is also described in Elger et al. (2016), was the “Statement of Commitment by the Coalition for Publishing Data in the Earth and Space Sciences” (COPDESS, HANSON et al. 2015) and the FORCE11 initiative that developed a set of principles for data citation that is widely endorsed (DATA CITATION SYNTHESIS GROUP 2014).

Once all GIS data layers are prepared, scientists just have to drop their project descriptions into a specific folder, which is shared with the GIS administrator, who subsequently operates the GIS data layer publishing process and creates the WebGIS project. Finally, the newly established WebGIS project and its description are added to “maps@awi” and made publicly accessible.

In addition to the CarboPerm WebGIS project, WebGIS projects for the Southern Ocean, Antarctica, the North and the Baltic Seas are available at “maps@awi”. Some WebGIS projects have already been completed, whereas others are going on. The CarboPerm WebGIS is an ongoing project for which data preparation has recently started. It is an initial starting point to demonstrate the capabilities and benefits of such systems in a practical way while targeting a specific scientific community. It subsequently encourages scientists to contribute their own data. Despite being a project-related WebGIS, selected GIS layers in the CarboPerm WebGIS are already accessible via data portals of the United States Geological Survey (USGS), the National Snow and Ice Data Center (NSDIC), the International Institute for Applied System

Analysis (IIASA) or published through data repositories or described in journal articles like, e.g., Earth Systems Science Data (ESSD).

The data assembly of the CarboPerm WebGIS follows the strategy of a previous international-Russian WebGIS project, the EU CONTINENT Baikal WebGIS (HEIM et al. 2008). Within the EU CONTINENT Baikal WebGIS, a variety of already openly accessible data were preselected to provide mesoscale environmental background information together with the project-specific field data. Within the CONTINENT Baikal WebGIS data assembly, datasets from the Land Resources of Russia (IIASA; STOLBOVOI & SAVIN 2002) provided relevant environmental background information.

Within the CarboPerm WebGIS data assembly activities, AWI is currently assessing the usability of various openly accessible datasets whose thematic content is reliable and usable, since they are reviewed by our user communities or have even been produced by collaborating research teams. GROSSE et al. (2013) mapped the Yedoma areas and HUGELIUES et al. (2013) compiled the Circum-Arctic map of organic soil content. MORGENSTERN et al. (2011) derived the lake water objects of the Lena Delta and mapped in cooperation with Russian scientists the extent of the Lena Delta terraces. Bringing these already published data together within a broader spatial and thematic context provides an added-value to the interdisciplinary scientific communities. However, data visualisation and compilation sometimes exposes artefacts and inconformi-



Fig. 4: “Maps@awi” – Web access to all AWI WebGIS projects including CarboPerm and Yamal WebGIS projects.

Abb. 4: „Maps@awi“ – Webzugang zu allen AWI WebGIS-Projekten einschließlich der CarboPerm- und Yamal-WebGIS-Projekte.

ties, such as geometric misfits unrelated to coordinate system transformations. In these instances, further detailed investigations are required. Over time, these data revisions will help to maintain homogenous and interoperable datasets. Therefore, specific WebGIS projects can support these processes substantially.

OUTLOOK

A further mesoscale AWI-based WebGIS project, focusing on Russian-German permafrost research, is currently being implemented for the central Yamal Region in cooperation with the Earth Cryosphere Institute in Tyumen, Russia: the Yamal WebGIS (DVORNIKOV et al. 2016, see also Fig. 4). The Yamal and the CarboPerm WebGIS projects will be explored and further enhanced by our user communities.

Furthermore, both WebGIS projects highlight the Russian-German scientific activities in Siberia, raising the scientific and political awareness. At the moment, these WebGIS projects are in an initial state, but their scalability is guaranteed by the AWI-GIS infrastructure.

In the future, freely accessible data will be published in formats, complying with standards of the Open Geospatial Consortium (OGC), the OpenGIS® Web Map Service Interface Standard (WMS) or Web Feature Service (WFS), and therefore will further support data exchange. The integration of additional functionalities within the GIS-viewer is planned to include simple data manipulation tools (e.g., select, search and download) and links to data providers such as institutes, repositories and portals like the Arctic Permafrost Geospatial Centre (coordinated by the ERC PETA-CARB project) or Russian information websites.

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- COPDESS* <www.copdess.org> Coalition for Publishing Data in the Earth and Space Sciences (accessed 18 April 2016).
- EMODnet* <www.emodnet.eu> Central Portal of the European marine observation and data network (accessed 18 April 2016).
- maps@awi* <<http://maps.awi.de>> Alfred Wegener Institute GIS maps portal (accessed 18 April 2016).

List and Explanation of Acronyms

AARI	Arctic and Antarctic Research Institute
ArcGIS	Geographical information system for working with maps and geographical information developed by the Economic and Social Research Institute ESSRI
APGC	Arctic Permafrost Geospatial Centre
AWI	Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
BMBF	German Federal Ministry of Education and Research
COPDESS	Statement of Commitment by the Coalition for Publishing Data in the Earth and Space Sciences
CarboPerm	Interdisciplinary German project with Russian cooperation, investigating the formation, turnover and release of carbon in Siberian permafrost landscapes
DEM	Digital Elevation Model
DOI	Digital object identifier
DUE	Data User Element
EMODnet	Central portal of the European marine observation and data network
ERC	European Research Council
ESSD	Earth Systems Science Data
FORCE11	Future of research communication and e-scholarship
GHG	Greenhouse gas
GIS	Geographic Information System
IASA	International Institute for Applied Systems Analyses
USGS	United States Geological Survey
NSDIC	National Snow and Ice Data Center
OGC	Open Geospatial Consortium
PAGE21	Changing Permafrost in the Arctic and its Global Effects in the 21 st Century.
PANGAEA	Data Publisher for Earth & Environmental Science
PETA-Carb	Rapid Permafrost Thaw in a warming Arctic and Impacts on the Soil Organic Carbon Pool
PostgreSQL	Object-oriented database management system
SDE	Spatial Database Engine
USGS	United States Geological Service
WMS	OpenGIS® Web Map Service Interface Standard
WFS	Web Feature Service

- Northern Circumpolar Soil Carbon Database* <www.bolin.geo.su.se/data/nscsd/> Bolin Centre Database (accessed 18 April 2016).
- PAGE21* <www.page21.eu> Changing Permafrost in the Arctic and its Global Effects in the 21st Century (accessed 18 April 2016).
- PANGAEA* <www.pangaea.de> Data Publisher for Earth & Environmental Sciences (accessed 18 April 2016).
- World Imagery* <<http://services.arcgisonline.com/>> ArcGIS - Geographic information system of the Environmental Systems Research Institute (ESRI) (accessed 18 April 2016).
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