Del. 6.4.2 Report on future plans for iCUPE

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1. Introduction

The iCUPE project answers to ”European network for observing our changing planet” (ERA-PLANET) thematic strand 4 (Polar areas and natural resources). During project’s lifetime consortium worked on combining integrated in-situ and satellite EO with a modelling platform by 1) synthesizing data from comprehensive long-term measurements, intensive campaigns and satellites, collected during the project or provided by on-going international initiatives 2) relating the observed parameters to impacts, and 3) delivering novel data products, metrics and indicators to the stakeholders concerning the environmental status, availability and extraction of natural resources in the polar areas. See Petäjä et al. (2020) for further information.

Overall, iCUPE collected a significant body of knowledge, including novel datasets, methods, algorithms and published more than 100 research papers. Already during the project's duration beneficiaries started working on implementing and planning actions aimed at extending the achieved results beyond the project’s timeline and utilizing an established network of scientists and knowledge in various projects.

Aim of this deliverable is to report on the plans of iCUPE beyond the project lifetime and activities already taking place to prepare the next steps of the iCUPE consortium.

2. The iCUPE Datasets and their future refinements

The iCUPE project produced and delivered, starting from Dec 2018, in total more than 20 datasets (DSs), which are the main end product and forms the basis for the legacy of iCUPE. The teasers of DSs (https://www.atm.helsinki.fi/icupe/index.php/datasets/submitted-datasets and the delivered DSs (https://www.atm.helsinki.fi/icupe/index.php/datasets/delivered-datasets) as well as DSs metadata will be preserved for the long-term and openly available for the end users. The datasets are linked at

the iCUPE website as well as available from national (i.e. Partners' countries) and international data repositories (e.g. Zenodo, etc.). Supported by the The ERA-PLANET (http://www.era-planet.eu umbrella since the iCUPE project is the 4th Strand of ERA-PLANET project, the data sets are listed also in their online catalogue (http://www.icc.uab.cat/geonetwork), which include information and metadata for the iCUPE datasets. As a summary, the iCUPE data sets are summarized in Table 1 below.

Table 1. A summary of iCUPE datasets, model results and applications with their respective connections to Sustainable Development Goals (SDG), see also Noe et al. (2021) for additional details.

	iCUPE Datasets, model results and applications	Relevant SDGs
1	Aerosol physical and optical characteristics including equivalent black carbon at Ny-Alesund, Svalbard (with 3 datasets for aerosol ultrafine particle size distribution, aerosol large particle size distribution, scattering, absorption)	13, 3, 4
2	Anthropogenic contaminants from polar regions (with 2 datasets for ice cores and snow)	13, 3, 4
3	Arctic atmospheric mercury observations (with 2 datasets for Hg(0) isotope and Hg(II))	13, 3, 4, 14, 15, 17
4	Artificial light sources in the Yamal Peninsula, Western Siberia	13, 3, 4, 11, 17
5	Blueprint for novel proxy variables integrating in-situ and satellite remote sensing data (with 2 datasets on condensation sink and mixing layer height)	13, 3, 4
6	Emerging organic contaminants from the Arctic (with 3 datasets for air, snow, and water)	13, 3, 4, 14, 17
7	Fractional snow cover area in selected sites of Svalbard islands, Norway, and associated Vlab application	13, 4
8	Ground-validation of precipitation measurements in high-latitudes	13, 4
9	Long-term monitoring of gaseous elementary mercury in background air at the polar station Amderma, Russian Arctic, and associated mercury visualization pilot	13, 3, 4, 14, 15
10	Near-Real-Time aerosol absorption measurements from Zeppelin Station, Ny Ålesund, Svalbard	13, 3, 4
11	Organic aerosol composition in the circumpolar Arctic environments	13, 3, 4

12	Small-scale vertical and horizontal variability of the atmospheric boundary layer aerosol using unmanned aerial systems	13, 3, 4
13	Snow spectral reflectance measurements at Ny-Alesund, Svalbard	13, 4
14	Time-series of lakes' size changes in Northeast Greenland	13, 9, 4, 17, 6, 7
15	Validated aerosol vertical profiles from ground-based and satellite observations above selected sites (with 2 datasets for Finland and Siberia)	13, 3, 4
16	Vertical profiles of equivalent black carbon in the Arctic boundary layer at Ny-Ålesund, Svalbard	13, 3, 4
17	Visible Near Infrared airborne and simulated EnMAP satellite hyperspectral imagery of Toolik Lake, Alaska	13, 14, 15, 6, 4

All these iCUPE Datasets can be used in various applications, and first of all, by the research community for studying physical, chemical, ecosystem, processes and interactions in the Arctic regions, and for model validation and sensitivity studies.

Beyond the academia, the iCUPE datasets are suitable to be used to evaluate impacts on social-economical activities in the Arctic, and well-linked to Sustainable Development Goals (SDGs, Noe et al. 2021) such as #3, 4, 11, 13, 14, 15, and 17. In particular, DSs (on aerosols, including black carbon, physico-chemical properties and spatio-temporal variability based on ground-based, satellite and unmanned aerial systems observations) show links to atmospheric pollution and climate change, which allow to evaluate impact on environment and population (especially, indigenous people) health for the Arctic States as well as long-range transport/ deposition of pollution to remote populated regions. Hence, the evaluation results will be useful for the climate adaptation and changing social life-style and economic activities in Arctic regions. The DSs (on atmospheric mercury observations) show links to atmospheric pollution and deposition on underlying surfaces, and hence, the contamination of seas/lands. This helps to estimate impact on fishery and reindeer economical activities, and hence, impact on environment and population health through food chains. The DSs (emerging organic contaminants in water) show a situation on contamination of seas, which is important for evaluation of impact on fishery industry, and hence, impact on population health through food chains. The DSs (on emerging organic and anthropogenic contaminants in snow) underline contamination of food supply for reindeers, which is valuable for evaluating impact on economic activities and style of the life of indigenous people as well as impact on population health through food chains. The DSs (time series of lake size changes in Northeast Greenland) show changes in water resources availability, which can influence the hydropower plans of the Greenlandic government to foster economic development in Greenland.

Selected iCUPE DSs had been and will continue to be promoted through the knowledge transfer for the University science education (including/ referencing in lectures and used in practice), utilized in online Hackathons (for example: "Hack-the-Arctic"; Mar 2021; https://hackthearctic.com); intensive research training events (Jun 2019, Tyumen, Russia) and young scientist schools (expected: online during 15 Nov - 3 Dec 2021; https://megapolis2021.ru & face-to-face in Aug-Sep 2022, St.Petersburg, Russia) with focus on multi-scales and -processes integrated modelling, observations, and assessments for environmental applications.

The use of iCUPE datasets will continue beyond the project lifetime and acts as a legacy for the project enabling building up the next steps of the collaboration. The open data format allows updates for the DSs.

3. Scientific projects initiated by the iCUPE community

3.1 iARCDEV, the next generation iCUPE project

During spring-summer 2020 all iCUPE partners together with 20 more partners from EU, USA and Russia teamed up and wrote a proposal for a project "**i**ntegrated **ARC**tic change observations and services for sustainable Arctic **DEV**elopment (iARCDEV)". The project's planned goal was to provide interoperable services for science-based policy making at regional to national and international levels, in support of sustainable Arctic development. To do this, the team planned to utilize the full capacity of integrative in-situ observations, satellite remote sensing, community-based observations and supporting modeling frameworks. One of the objectives was to deliver novel pilot services relevant to local communities and stakeholders assisting Arctic people and nations to adapt to climate change, specifically: based on co-design processes, to incorporate crucial contributions from community-based observation systems, citizen science activities, and indigenous perspectives of e.g. reindeer herders; facilitating a bidirectional transfer of knowledge to provide relevant data products and information key to a peaceful and sustainable Arctic development, in sync with the EU Green Deal. The project was not funded, but seven service pilots were developed and will serve as a basis for the future proposals, together or separately.

The iARCDEV-proposal was submitted to Horizon 2020 call: H2020-LC-CLA-2018-2019-2020, Building a low-carbon, climate resilient future: climate action in support of the Paris Agreement. Although well evaluated, the project was not selected for funding. However, the concepts and the individual pilots developed during the writing process have already facilitated subsequent scientific collaboration and will continue to act as a stepping stone for the future scientific collaborations in the Arctic context.

Below are brief descriptions of the iARCDEV pilots.

1 ARCLAND (Comprehensive ARCtic LANDscape observations and forecasting) is a multifaceted permafrost observing system that will improve Arctic-wide landscape change detection, scaling of GHG emissions and carbon cycling related to permafrost thaw, hydrological regimes and associated feedbacks. The observing system will be based on in-situ and satellite data and will also provide historical (100+ years) context for landscape change by harnessing local historical knowledge. The pilot

will fill observation gaps on GHG emissions and C cycling from actively thawing permafrost locations, lakes, wetlands, peatlands, and streams. Additionally, a citizen science project sharing, georeferencing, and archiving recent and historical optical remote sensing data, photographs, paintings, and written records of permafrost landscapes will be undertaken to develop a historical anchor for understanding current and ongoing observations as well as model outputs.

Addressed Arctic challenge: A warming climate is destabilizing all facets of northern life driven by warming soils, degrading permafrost and changing ground thermal regimes. This has direct implications for access to subsistence activities, northern infrastructure including buildings, roads, and industrial development. Landscape warming also has indirect implications for ecosystem functioning influencing primary productivity, water quality, biogeochemical, pollutant and GHG cycling.

Pilot sustainability and vision beyond iARCDEV: The pilot is developed around existing circumpolar INTERACT infrastructure, modelling efforts are open sourced and will be operationalized and updated beyond the project time frame. The contributions to upgrading and modernising existing observational networks will increase their longevity and therefore provide tools for the sustainability of the ARCLAND pilot.

2 ArcSEA (Pan-Arctic SEA water circulation and sea ice extent, thickness and volume: survey, forecast and tendencies) combines improved sea level, sea ice thickness and snow depth satellite observations over the Arctic Ocean to provide innovative short- and long-term sea ice extent and concentration estimates for operational forecasting purposes and climatic studies. Data from three climate models are used: ECMWF for sub-seasonal (meteorological applications), HadGEM for short-range and seasonal (sea water and sea ice properties) and EC-Earth for decadal climate forecasting. Pack ice plays a central role in the development of phytoplankton and the upper food chain. We connect this to new AI methodologies for Chlorophyll-a retrieval from optical satellites.

Addressed Arctic challenge: We address Arctic Amplification, local and remote impacts and the underlying mechanisms. We contribute to socioeconomic blue growth, in regards to sustainable exploitation of Arctic natural resources and the new marine routes made accessible by current and future sea ice loss.

Pilot sustainability and vision beyond iARCDEV: The European Sentinel Missions Programme is a long-term project linked to several Copernicus operational services that will ensure the sustainability of the new methods and products to be developed within the framework of ArcSEA. A new Sentinel-Extension mission should be operational by 2026/27 to extend the observation of the ice pack thickness. The model assimilation will make good use of the data from the upcoming CRISTAL and CIMR missions, a capability that is intended to be eventually integrated and used in their respective operational systems.

MERCURY (Pan-Arctic MERCURY cycling and human exposure) aims to fill data gaps on Arctic mercury pollutant cycling in the land-air-ocean continuum, and to address human health risk. We will use iARCDEV and Arctic GOS4M observations in a state-of-the-art 3D Earth system model to predict how IPCC climate and UNEP Minamata Convention emission trajectories will affect mercury cycling and marine food-web pollution. The model assimilates ArcSEA, MELT-WATCH and ARCLAND products to provide pilot services that include ecosystem mercury predictions for Arctic national health agencies and fisheries supporting sustainable fishing practices, blue growth and human fish consumption advisories.

Addressed Arctic challenge: Both UNEP and AMAP identified that scientists need to investigate the role of climate change on mercury cycling and human exposure because climate effects are expected to be particularly severe in the Arctic. The MERCURY pilot service will quantify permafrost mercury loss to rivers and air, and model the impact on Arctic marine food web mercury levels. We will also determine mercury fluxes from the cryosphere, from snowfall, un-melted sections of glaciers and glacial melt waters, to estimate increased fluxes due to climate change and glacial retreat. Observations will be used to constrain and validate models, make new parameterisations, and forecast ecosystem mercury levels.
Pilot sustainability and vision beyond iARCDEV: Arctic mercury monitoring (under GOS4M) is planned to continue beyond iARCDEV as part of Arctic-GEOSS. The model development is necessary to assure accuracy in longer-term Arctic risk assessment needed for sustainable development of the Arctic. Modeling-based human mercury exposure assessments beyond iARCDEV will be done by an engineer funded through GEOSS and CNRS.

REINDEER (Copernicus EO based snow information service to REINDEER herding community) will develop a one-stop-shop mobile web app that provides easy access to Arctic weather data, Copernicus satellite and webcam-based remote sensed snow and soil products and hydrological forecasts. We will improve the services with novel cryospheric products via an easily accessible and user-friendly application. This needs direct feedback from the indigenous community to optimize visualization and tailored presentation of data. Optimized data handling, incl. Big Data satellite products will be established to allow fast loading of information in the Arctic remote areas. Primary users and co-designers will be reindeer husbandry communities (Reindeer Herders' Association in Finland). It will support traditional reindeer herding and will address changing environmental conditions, such as the increased necessity of supplementary feeding and corralling under difficult winter snow conditions.
Addressed Arctic challenge: Part of the livelihood and particularly the traditions of the local communities and indigenous population in Scandinavia rely on the well-being of their reindeers. This pilot supports sustainable development of the reindeer herding. The pilot will specifically promote scientific cryosphere data application to the public and indigenous population. It will connect various Arctic data products (satellite, model and webcam) in a one-stop-shop that will be easy to use. The co-design will adjust the pilot that it matches the needs and requirements of the local Arctic population.
Pilot sustainability and vision beyond iARCDEV: At the end of iARCDEV we envision that the service will be transferred to the operational services within FMI and sustainability beyond the project is ensured.

MELT-WATCH (MELTing glaciers in Greenland and Svalbard and WATCHing changes) combines remote sensing and modelling techniques in order to provide a service focused on melting glaciers and snow, with a connection to ground-based observations. The visualization of seasonal time-series on glacier melt characteristics, supraglacial lakes, ice/snow albedo and water/ice parameters in coastal areas will provide a crucial tool for investigating the melt cycle, freshwater input into the ocean and the seasonal variability of coastal areas in relation to climate change. We will provide gap-filling services that complete existing knowledge and transform scientific datasets into societal relevant information. This pilot service will feed further into modelling communities and iARCDEV pilots (incl. MERCURY and

ARCPOP), and raise awareness concerning climate change to the public and will support decision makers on actions that can adapt human activities to environmental changes.
Addressed Arctic challenge: Melting glaciers are associated with different economic prospects and several environmental challenges. The latter connects to both the terrestrial and marine ecosystems. While terrestrial issues are based on infrastructure and accessibility to remote areas, the second components are focused on maritime safety and on the environment (search and rescue, pollution).
Pilot sustainability and vision beyond iARCDEV: The integration with virtual laboratory environments (e.g. VLAB-IIA) and the preparation of wms that can be connected to already-existing platforms such as WMGS or GLIMS are envisioned to provide sustainability beyond the project.

SArcUD (Sustainable Arctic Urban Development) will deliver evidence-based Arctic urban indices for immediate response and long-term decision-making to local and regional Arctic governments. The indices will be co-designed with stakeholders and will address amongst other impacts of energy use, urban development, fires and dust storms on the terrestrial ecosystem and human health, and how these impacts can be sustainably mitigated under a range of climate change scenarios. The pilot uses local in-situ data (e.g. air quality, meteorology, ship traffic for coastal cities), ECMWF re-analysis and satellite data as an input for numerical weather prediction, atmospheric chemistry and receptor modeling. The results will be validated with satellite products (e.g. TROPOMI, CALIPSO, MODIS) and in-situ observations. The short- and long-term decisions are evaluated with WMO Global Atmospheric Watch (GAW) Urban Research Meteorology and Environment (GURME) concept for sustainable cities.
Addressed Arctic challenge: Understanding the social and economic drivers of Arctic change as well as assessing vulnerability and building resilience of Arctic environments and societies were identified at the 2018 Science Ministerial as two out of three major challenges. Key challenges that are addressed with this pilot include natural hazards (dust storms, forest fires, avalanches, floods, thawing permafrost) and extreme weather events.
Pilot sustainability and vision beyond iARCDEV: Recommendations on how to further develop and establish integrated urban services in Arctic cities will be made for future implementation in connection with the WMO Integrated Urban Services program. The experience from the pilot cities can be applied to other Arctic cities.

ARCPOP (ARCtic observations and modeling for legacy and emerging Persistent Organic Pollutants) integrates observations and creates a unique database for POPs and EOCs in the Arctic Ocean basin. The EOCs in the Arctic ecosystem will be identified and quantified. Multicompartment models using ArcSEA and MELT-WATCH products will elucidate biogeochemical cycling. Integrated assessments will provide a foundation for the development of European and global chemical management policies to protect health and the environment in the Arctic.
Addressed Arctic challenge: UNEP and AMAP underscore the need to investigate the role of climate change on POPs cycling and human exposure in the Arctic. We will determine emerging POPs influxes from continents to the Arctic via long-range oceanic/atmospheric transport. Re-emission of legacy POPs from cryosphere and permafrost under the condition of climate change and glacial retreat will be quantitatively evaluated. Observations will be assimilated in models to forecast ecosystem POPs levels and human exposure.
Pilot sustainability and vision beyond iARCDEV: Within this pilot, both monitoring stations and research expeditions will be integrated for POPs observations, which are supported by national and

international research programs. Beyond iARCDEV, the relevance of this pilot to the Arctic ecosystem research, the health of local people, chemical industry, and stakeholders will increase the sustainability of the ARCPOP service, and observations and forecasting efforts will therefore be continued.

APROVE-ARC (Aerosol in-situ PROperties, VErtical distribution, and source apportionment in the ARCtic) takes a full advantage of integration of physico-chemical aerosol parameters from stations across the Arctic by improving these with vertical resolution and seasonality. With validated in-situ, model and satellite data we will provide local and global stakeholders with decision making and long-term environmental assessment tools. We target the influence and impact of anthropogenic fossil fuel combustion and biomass burning emission sources in the Arctic.
Addressed Arctic challenge: Environmental quality in the Arctic is deteriorating both due to local and long-range transported pollution. Novel services are needed to ensure safety of the local population. We will disseminate data on environmental changes and their forecasts to local Arctic communities.
Pilot sustainability and vision beyond iARCDEV: The pilot is co-designed with local authorities, teaching staff, national policy makers and the general public. In the future, European and International Research infrastructures could continue to provide data and support e.g. Copernicus to adopt the pilot.

ARCNITE (ARCtic citizen-science to monNITor Effect of air and light pollution on Arctic nights) utilizes co-designed community-based measurements of air and light pollution in Arctic urban areas, real time and campaign in-situ data and satellite observations of night-lights and skyglow. We will deliver mobile and web app(s) for impact assessment of night-time lights (skyglow) on Arctic ecosystems and aurora observations by merging the satellite and in-situ data with modeling. Night light products can monitor urbanization and gas flaring in the Arctic, which are sources of air pollution (black carbon).
Addressed Arctic challenge: Reduction of emission and energy consumption is key to sustainability of Arctic communities. We address pollution transport, biodiversity, and environmental impacts of economic development. Light pollution (artificial light at night) is a novel stressor and occurs in combination with other pollutants affecting ecosystems during winter. We address conflict of interest among industries (e.g. tourism vs. mining).
Pilot sustainability and vision beyond iARCDEV: The integration of the light pollution and night sky data into existing databases like GlobeAtNight and MySkyAtNight both supported by IDA (International Dark Sky Association) and Stars4ALL (H2020) will provide sustainability beyond iARCDEV.

3.2 CONTAINER, a project plan stemming from the MELTWATCH pilot

The iCUPE consortium continued to explore joint projects initiated by the planning of iARCDEV. One of the pilots, MELTWATCH, was reformulated into a European Space Agency (ESA) ITT call under the name “CONcept of an integrated Toolbox on Atmosphere-cryosphere INtERactions” (CONTAINER) prepared by Roberto Salzano (CNR) and a team of iCUPE scientists in 2020. The main idea of the project was to connect the complementary expertise built in iCUPE. The objective is to utilize satellite remote sensing to characterize the ice surface properties of Greenland, estimate the accumulated amount of aerosol impurities on the ice surface altering the albedo, quantify the impacts of the impurities to melt process, use modeling tools to constrain depth of the melt water percolation and

sub-surface impurity transport and quantify the timelines pertinent for the Greenland ice sheet melt processes. The consortium is currently exploring other avenues for funding the work.

The CONTAINER project is a very practical future plan originating from iCUPE as within the project we were able to bring together complementary Arctic research teams as underlined by our joint scientific publications, e.g. Petäjä et al. 2020 and Humbert et al. 2020.

3.3 CRiceS, a successful Arctic project under Horizon-2020 Call

iCUPE contributed to proposal writing approved with EU funding - the Horizon-2020 project "*Climate Relevant interactions and feedbacks: the key role of sea ice and Snow in the polar and global climate system*" (CRiceS; 2021-2025; http://www.crices-h2020.eu). It is coordinated by Prof. Risto Makkonen (Finnish Meteorological Institute FMI, Finland) and Prof. Jennie Thomas (Centre National de la Recherche Scientifique, CNRS, France). The project, started in September 2021 (with kick-off-meeting on 12-14 October 2021), will contribute to better understanding of the ocean-ice-snow-atmosphere system and polar processes in a global context in the Arctic and Antarctic regions through observations (in-situ, remote sensing, community), modelling (process, regional, global) and knowledge exchange (outreach, stakeholders engagement, improved climate projections, risks, impacts, knowledge of feedbacks). The CRiceS core themes are: CT1 – Heat, mass and momentum exchanges; CT2 – Aerosols and clouds; CT3 – Biogeochemical cycles, greenhouse gas exchange; and CT4 – Integrated system understanding.

The CRiceS consortium includes 21 partners – Universities and research organizations – from Europe, Africa, Asia and North America (Finland, France, Norway, Sweden, Italy, South Africa, Germany, Spain, UK, Switzerland, The Netherlands, Canada, India, and Russia). The Horizon-2020 PolarRES (*Polar Regions in the Earth System: the Role of Local and Regional Polar Processes in Changing the Polar Climate and the Global Climate System*) project is the sister project to the CRiceS. It is coordinated by Dr. Priscilla Mooney (NORCE Norwegian Research Centre). The Russian Sister project to CRiceS, coordinated by Dr. Gennady Platov (Institute of the Computational Mathematics and Mathematical Geophysics, ICMMG, Novosibirsk, Russia) will contribute with global and regional modelling for the Arctic and the Russian Arctic seas (details at: https://peexhq.home.blog/2021/10/22/russian-sister-project-to-the-horizon-2020-crices). Similarly, the Canadian Partners (University of Victoria Canada and University of Calgary) and Indian Partner (National Centre for Polar and Ocean Research India) will join with national funding as the Sister Projects to the CRiceS.

3.4 AASCO, a successful outreach and interaction platform from the iCUPE project

The Arena for the gap analysis of the existing Arctic Science Co-Operations (AASCO) is an initiative headed by the Institute for Atmospheric and Earth System Research (INAR) at the University of Helsinki and sponsored by the Prince Albert II of Monaco Foundation for the years 2020-2021. It is in collaboration with the Universities of Arctic (U-Arctic), WMO, SAON, SIOS, the Institute of Remote Sensing and Digital Earth - Chinese Academy of Sciences (RADI - CAS), Moscow State University (MSU) and The Harvard Law School. AASCO is working to bridge the scientific research communities to chart

a path towards a comprehensive practice of science and is enhancing public attention to the scientific message in a frame of Arctic-boreal research and Arctic futures. It strengthens the collaboration and concept planning of the Arctic Ocean and terrestrial research at large scales and the implementation of the Agreement on Enhancing International Arctic Scientific Cooperation. It also supports the development of the observation network delivering novel ground-based ocean-land-atmosphere data for the Earth system modeling and for the future early warning systems.

iCUPE contributed by active participation in AASCO events, presenting results from iCUPE as well as planning of the White Paper that aims to synthesize the scientific understanding and state-of-the-art for cryosphere, hydrosphere, atmosphere, biosphere feedbacks and interactions, discuss the research infrastructure (RI) and data needs to answer the key scientific questions related to these feedbacks & interactions. Many iCUPE participants aim to be involved in the successive to AASCO projects and activities, continuing towards developing a strong pan-Arctic network of research.

3.5 Pan-Eurasian EXperiment (PEEX) Programme support

The PEEX provided very efficient connections and links for beneficial collaboration of EU iCUPE partners with the Russian partners, which were interested in the iCUPE project activities and carried out research in the Arctic and Sub-Arctic regions as well as having operational capacities and observational infrastructure in these geographical regions. In particular, **4 PEEX collaborating Russian partners** - *Institute of Northern Environmental Problem, Kola Science Centre, Russian Academy of Sciences (INEP KSC RAS), Shirshov Institute RAS (SIO RAS), Institute Atmospheric Optics Siberian Branch RAS (IAO SB RAS), and Moscow State University (MSU)* - actively participated in the iCUPE project and contributed with long-term dataset on mercury measurements at the Amderma station in Russian Arctic, elemental and organic carbon measurements over the northwestern coast of the Kandalaksha Bay of the White Sea, atmospheric composition at Fonovaya Observatory of the West Siberia, and micro-climatic features and urban heat island intensity in cities of Arctic region, respectively.
The iCUPE project related activities and results obtained (especially the delivering of datasets) were and will be further actively **disseminated** through the **PEEX Blog** (https://peexhq.home.blog), included in the **PEEX News** (https://www.atm.helsinki.fi/peex) and **PEEX quarterly newsletters** (https://www.atm.helsinki.fi/peex/index.php/portfolio-items/peex-newsletter-blog). Among these, the latest important news delivered: iCUPE project final science workshop (Jun 2021; https://peexhq.home.blog/2021/06/14/icupe-project-final-science-workshop); iCUPE Datasets for Polar Regions (https://peexhq.home.blog/2020/10/04/icupe-datasets-for-polar-regions/ (Oct 2020); etc. Moreover, the iCUPE project results were also actively disseminated and promoted through the PEEX Special Sessions arranged at the European Geosciences Union EGU-2020, 2021 (& also planned at EGU-2022; https://meetingorganizer.copernicus.org/EGU22/session/43890) General Assemblies (Vienna, Austria).

The mentioned above **4 PEEX collaborating Russian partners** also contributed to the **iARCDEV proposal** "*integrated ARCtic change observations and services for sustainable Arctic DEVelopment*".
In particular, the **KSC team** plan to contribute to co-design of the SArcUD (Sustainable Arctic Urban Development) pilot with focus on the Apatity city of the Kola Peninsula (Russia) bordering with Nordic

countries; analysis of black carbon origins and effects including usage such data for improvement emission inventories in Arctic regions and models verification; atmospheric mercury monitoring and assessment impact on the Arctic environment. The KSC also planned to utilize the centre for collective access to physico-chemical methods of analysis (which allows chemical-analytical studies of natural and industrial waters, bottom sediments and biotic components) and a unique network of biogeochemical environmental monitoring in Russia in the zones of influence of copper-nickel plants.

The **IAO team** plan to contribute to studies of physical and chemical processes in the atmosphere and at the surface; atmospheric aerosol properties; with sharing experience in organizing and carrying out ground-based and airborne measurements/ campaigns, satellite image processing and analysis; data (in-situ and airborne) analysis and observations (which can be tested in selected iARCDEV pilots, and used for models verification) in selected Siberian, Sub-Arcic and Arctic regions. The IAO also planned to carry out a comprehensive monitoring of the atmosphere: (i) at the Fonovaya Observatory station (West Siberia, Russia), which is equipped with a mast of 44 m (selected meteorology, gases, soil-atmosphere exchange, aerosols, solar radiation, etc. measurements). – particle count and size distribution, neutral cluster and air ion size distribution; (ii) with TU-134 aircraft laboratory (in-situ measurements of selected gases, black carbon, aerosol scattering coefficient, aerosol size distribution, meteorology, etc.; and (iii) lidar station (simultaneously measuring aerosol, ozone, and temperature profiles in the troposphere-stratosphere).

The **SIO team** plan to contribute to studies of modern geochemical processes in the atmosphere in marine boundary layer and over the catchment areas; atmospheric aerosol properties; with sharing experience in organizing and carrying out airborne measurements onboard research vessels and at adjacent land in selected Sub-Arctic and Arctic regions, river discharge of particulate and dissolved matter to the White Sea, suspended particulate matter studies in Arctic seas and long-term studies of vertical particle fluxes in selected areas. Special attention will be paid to study relations between climate change and biogeochemical processes in the Arctic and Sub-Arctic. The SIO also planned to use selected research vessels (such as “Akademik Mstislav, “Akademik Ioffe”, “Akademik Sergey Vavilov”, “Akademik Nikolay Strakhov”) with equipment necessary for sampling and analysis of aerosols, suspended particulate matter and sediments - in order to study aerosols of marine boundary layer, suspended particulate matter and deploy and recover buoy stations with sediment traps.

The **MSU team** plan to contribute to development of new studies of chemical physical and micro-climatological processes in the atmosphere and at the surface: Urban Heat Island (UHI) and deep stable boundary layers during wintertime in selected Arctic big cities rather than in islands in the Arctic ocean. Such contribution will enrich selected iARCDEV pilots. For the APROVE-ARC Pilot (on seasonality of black carbon (BC), chemical composition, BC in air) - to provide existing BC and aerosol chemical composition data for Tiksi (coast of Laptev sea) and Cape Baranova (high Russian Arctic); new observations on BC at new aerosol station (Yamal, Island Belyy); aerosol chemical composition, for arctic database, mapping, and source apportionment; extension of BC in snow by data from Arctic Yamal (the largest gas flaring region in the world). For the SArcUD Pilot (on estimation impacts on health from urban air emissions) - to provide observations in Russian Arctic cities Salekhard/Nadym; physics of Arctic urban boundary layer; air quality at Arctic urban conditions; existing atmospheric BC data near Salekhard city; urban emission data, fuel consumption.

All partners also contribute to development of new essential variables for the Arctic, knowledge transfer and dissemination of the iARCDEV project to research, universities, decision/policy-makers, stakeholders and end-user communities.

The **FutArcSoc** (Future Arctic Societies: Project On Feedbacks & System Understanding Of, Scenarios & Innovation Insights For, Future Development Of Arctic Societies) proposal aims to provide a holistic scientific understanding of impacts and feedbacks of Arctic futures. The project is aimed at enhancing the implementation of societal security and sustainability/ resilience in differently developed Arctic societies. FutArcSoc proposal introduces the following Arctic themes: logistics & infrastructures, natural resources & pollution, energy & economics, people & societies, natural resources & local communities, geopolitics & governance, perceptions & images, Arctic system & feedbacks together. These FutArcSoc themes are based on the recommendations of the Horizon 2020 Work Programme and Arctic policies in general. FutArcSoc concentrates on the most relevant issues and main opportunities for development as well as how research infrastructure could be used more effectively across national borders and programs. The added value of the project is the inter- and transdisciplinary approach combined with the holistic system analysis and currently missing aspects such as societal security to the analysis. FutArcSoc recognizes a complexity of the natural sciences' and economic (sub)models, social sciences' qualitative methods and aims to find synergy and "common nominators" between the methodological frameworks. The FutArcSoc consortium consists of partners from European countries as well as international academic collaborators and stakeholders from the Arctic and AC observer countries (Canada, China, Japan, Russia, USA).
The project has connections and partnerships to different communities in Russia (Universities and Russian Academy of Sciences, RAS), and in particular, **3 PEEX collaborating Russian partners** - *Saint-Petersburg State University (SPBU), Northern Arctic Federal University (NAFU), and Kola Science Center RAS (KSC RAS)*. As a fundamental part the FutArcSoc carries out regional case studies (geographical vis-à-vis issue/problem-based) made in collaboration with local partners on Northwestern Atlantic, Barents Sea Area, Svalbard, Yamal Peninsula, and Pacific Arctic (regions), where contribution of Russian partners to the Russian Arctic regions became essential and very valuable. The links between natural and socio-economical sciences in the Nordic and Arctic domains are crucially important and to be realised through data provision (results of ins-itu and remote-sensing observations and climate/regional/urban scales modelling) in support of socio-economic studies. FutArcSoc ideas for collaboration and research were further elaborated in seminar and discussions on holistic multi- and interdisciplinary approach in supporting the Arctic sustainable development (https://peexhq.home.blog/2021/03/16/seminar-on-holistic-multi-and-interdisciplinary-approach-in-supporting-the-arctic-sustainable-development) with plans for proposal preparation for a suitable Call the Horizon Europe programme.

Two online **science education** events were organized under the **PEEX Educational-Platform** umbrella in collaboration with the iCUPE project. In particular, the 48 hour Hackathon "Hack the Arctic" (https://hackthearctic.com; 12-14 March 2021) and the Young Scientist School (YSS) MEGAPOLIS-2021 "Multi-Scales and -Processes Integrated Modelling, Observations and Assessment for Environmental Applications" (https://megapolis2021.ru; 15 Nov - 3 Dec 2021) in Memory of Prof. Sergje Zilitinkevich - were carried out in 2021. In 2022, the iCUPE selected datasets will be also used for training events

such as intensive research training course (Aug-Sep 2022, St.Petersburg) and young scientist school (Autumn 2022, Moscow) connected with observational and modelling.
In the **Hackathon**, the iCUPE datasets as well as mentoring activities (from UHEL-INAR and EULS partners) were provided to the participants. Moreover, data was also provided by GlobalSMEAR, ACTRIS, SeaDataNet, SIOS, ICOS Portal, eLTER, Arctic SDI, and Arctic Data Center. More than 130 participants designed and submitted 27 final projects addressing the Hackathon different challenges such as Map the Arctic data, Science for policy-making, Services for citizens, Focus on Svalbard, Arctic Haze. The hackathon provided access to mentor scientists whom offered mentorship on both science and data handling, feasibility of implementation on projects. The invited keynote talks were streamed to serve as inspiration and information around topics of Arctic long-term observations, FAIR data, designing policy services with environmental data, data analysis, etc. Summary is available at: https://peexhq.home.blog/2021/03/25/hack-the-arctic-transforming-data-into-solutions-as-a-community.
The MEGAPOLIS-2021 **Schoo**l introduced a young generation of researchers to special topics in atmospheric and environmental sciences, Earth system modelling approaches and applications, especially considering transport and fate of small (micro) particles. During the school, participants learned about the current progress and challenges in Earth system research; meteorological, hydrological and atmospheric composition modelling and observations (including ground-based and remote-sensing); and modern technologies for environmental studies and assessments (including health impacts). The YSS programme consisted of theoretical lectures (24 in total) and practical exercises (with several INAR models and teachers) accomplished by groups of students as small-scale research projects (SSRPs) with final presentations/ defences of SSRPs, and awarded the School Certificates. More than 50 young researchers (advanced BSc, MSc and PhD students as well as PostDocs) from 22 Universities and research organizations/ institutions from Russia, China, Austria, Ethiopia, Switzerland, Ukraine, and UK participated in YSS. Summary is available at: https://peexhq.home.blog/2021/12/15/megapolis-2021-school.

The **Russian PEEX collaborating partner** – the Institute of Computational Mathematics and Mathematical Geophysics, Siberian Branch, Russian Academy of Sciences (ICMMG SB RAS) – is involved in **climate scale modelling tasks for the Arctic Ocean and the Russian Arctic seas** for new Horizon-2020 CRiceS (https://www.crices-h2020.eu; 2021-2025) project. The ICMMG applied for national funding and obtained financial support (about 30M Rubles; for 2021-2023) from the Ministry of Science and Higher Education of the Russian Federation. The Russian national project became the Sister project to the CRiceS. The ICMMG team (led by Dr. Gennady Platov) includes 14 scientists, experts in numerical modelling of climate system and its components with the focus on Arctic region, subaqueous permafrost and methane hydrates, inverse and ill-posed problems in socio-economical modelling. The ICMMG modelling results (for the Arctic and Arctic Russian seas) will contribute to the database for cross-comparison with results from other models; open data access policy and FAIR principles will be promoted to all generated data; and developed interface and services will allow direct and remote work with the modelling results. Summary is available at: https://peexhq.home.blog/2021/10/22/russian-sister-project-to-the-horizon-2020-crices.

3.6 iCUPE as part of EU Polar Cluster

iCUPE is a member of the The EU Polar Cluster (https://www.polarcluster.eu/) - a network of Horizon 2020 and a Framework Programme 7 funded polar projects. Its objective is to bring the insights from our various areas of expertise together in order to provide one entry point to EU funded Polar research, provide policy-relevant information and support the EU in implementing its integrated policy for the Arctic.

Through the various EU Polar Cluster activities, iCUPE will continue to participate in developing the European polar research, observation, infrastructure and/or modelling community network, as well as enhance sustainability and accessibility of outputs beyond project's official end date. Moreover, as a project that has ended, iCUPE can share advice and best practices with EU Polar Cluster Members projects, many of which have started only recently.

iCUPE participates in the following Task Groups (TG) and their activities:

- Communication TG - results dissemination;
- Data TG - collaboration within the area of data management, coordination of data management activities between cluster participants, coordination of cluster data management activities towards the SAON/IASC Arctic Data Committee, compilation of guidelines on data management for cluster projects;
- Education and Training TG - knowledge and experience exchange, networking, training activities, funding.

4. Legacy of the iCUPE project

The work within iCUPE has made its mark in the landscape of European and global Arctic research. The key outcomes of the iCUPE include the multidisciplinary, open and developing datasets. They will provide benchmarking data required to answer global grand challenges and contribute to answering to the sustainable development goals identified by the United Nations.

The preparatory work performed during the iCUPE project to develop new projects, such as iARCDEV has proved to be fruitful for cultivating new initiatives for comprehensive Arctic research projects. To this end, the iCUPE consortium is an active member of the EU polar cluster and openly seeking further funding opportunities to continue the work initiated within the iCUPE. We are already involved in a follow-up Arctic research project CRiseS and starting to collaborate with Arctic Passion EU-project. The collaboration and contribution from individual iCUPE consortium members in a suite of future science projects will continue beyond iCUPE.

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