Report on iCUPE impacts

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WP6 Dissemination and strategic development

Task 6.3 ***Research impact assessment****, Del. 6.3.1*

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Introduction

The Horizon-2020 iCUPE (Integrative and Comprehensive Understanding on Polar Environments; https://www.atm.helsinki.fi/icupe) is a science driven the ERA-PLANET (http://www.era-planet.eu) Programme Strand-4 project, which science approach provided the necessary basis for developing the different data products.

The overall aim of the iCUPE was to evaluate and present a holistic understanding of the impacts of various increasing human activities on the polar areas, and especially in the Arctic. The main scientific impact of the iCUPE is related to improved understanding and new knowledge about local and remote sources of Arctic air pollutants, including Short-Lived Climate Forcers (SLCFs) and their precursors as well as their sinks, and improved quantification of the life cycle of mercury, heavy metals, black carbon and persistent organic pollutants (POPs). In addition, iCUPE examined changes in the Arctic snow and ice surfaces, vegetation, biomass characteristics, mapped out the development of natural resources extraction and delivered the new first impact assessments of the future exposure scenarios of pollutants in the Arctic regions.

iCUPE delivered new data products and developed novel observables, state-of-the-art methods and algorithms. The new iCUPE data products filled current observational gaps in key variables of POPs, Chemicals of Emerging Concern (CECs), SLCFs, and trace gases in the polar context. New data (products) on ice sheet and glacier surface structures, on vegetation biochemical characterization and on night light mapping, on atmospheric mercury, on persistent chemicals of Emerging Global Concern in the Arctic and on POPs in polar regions were delivered. iCUPE merged satellite images with ground truth data that had already been collected by different Arctic Observatories, thus creating a new interdisciplinary network of continuous monitoring of the Arctic environment. These new data

products made an important contribution to the development of sustainable and interoperable observational and prediction systems of the polar areas and enhanced the European leadership in the Arctic monitoring and provision of data-related services to key stakeholders. The remote sensing efforts within iCUPE extended current capabilities of monitoring of snow and ice surfaces significantly. In addition, iCUPE provided a blueprint on the capabilities of planned and future satellite missions for Earth's Observations (EO) of polar regions and introduced a concept for in-situ measurements, which is capable of complementing the satellite based observations of the polar regions.

iCUPE used specific deliverables as a primary source for the "quantified indicators and targets". The "technical readiness levels" (TRLs) of selected iCUPE activities, datasets and services, are the main tools for estimating the impact during the project lifetime and beyond.

European leadership in GEO and European participation to COPERNICUS

The iCUPE contributed to integration of the on-going observations and filling observational gaps in ground-based and remote sensing observations of the polar/ Arctic regions. The project analyzed the existing data pools and provided new data products that improve the accuracy, temporal and spatial resolution of the SLCFs and other EO data in the polar regions.

iCUPE provided new information out of EO observations by using generic big data statistical methods on EO data (WP3). iCUPE also advanced beyond recent retrieval of satellite remote sensing data and developed novel approaches and provided guidance for a strategic development of satellite remote sensing (Polar EO needs & opportunities, WP3). As an outcome of this work iCUPE described the common in-situ data interface with the Polar EO data, the capabilities and limitations of advanced optical satellite missions for snow/ vegetation/ gas flaring mapping applications in Arctic areas. Novel in depth analysis enabled also the estimations of the supraglacial lake volumes in a key region in northeast of the Arctic and ice sheets and glacier surface structures.

Contribution to the development of sustainable and interoperable observational, modelling, data assimilation and prediction systems

The horizontal tasks within ERA-PLANET facilitated data provision keeping in mind interoperability (WP 5). Within iCUPE, the data interoperability was carried out by the evaluating the interoperability interfaces and tests with GEOSS Common Infrastructure (GCI), TEPs and Copernicus Data Integration and Analysis System (DIAS) in collaboration with the ERA-PLANET Strands 1-3. This work contributed to the GEOSS and utilizes the GEOSS GCI and the "GEO Discovery and Access Broker - Application Program Interface" (DAB APIs) (Task 5.2).

The work in iCUPE explored ways to deliver open data in near real time seamlessly to different end-users, such as Earth System modeling community (WP 1). The new data products were stored and made available in the integrated iCUPE virtual platform (Task 5.2, 5.3, 5.4, 5.5). Data-Pilot's utilizing Platform as a Service (PaaS) techniques have been realized and made available (Task 5.5). Different concepts of automated meta-data generation and data quality assessments to allow cloud platform

based workflow chains utilizing machine learning techniques have been tested and implemented. In addition, iCUPE provided recommendations for future research strategy for the next 30 years including the assessment of the quality of the current methods and data and suggesting improvements for both observations and analysis of the SLCFs, POPs, heavy metals and CECs.

As a part of the strategy work iCUPE introduced a concept for flagship stations for the coherent, coordinated, comprehensive in-situ measurements in the polar areas and for future satellite mission planning (Task 3.4). In this task iCUPE will focus on two different approaches. First of all, iCUPE has introduced "Stations Measuring the Earth surface – Atmosphere Relationships" (SMEAR) concept and will explore its interoperability with GEOSS and Copernicus structures. This concept is based on integrated observation of the land-atmosphere interface describing different energy flows. The concept has been developed at the SMEAR- II station in Hyytiälä, Finland since 1995. Today it represents the most advanced in-situ ecosystem- atmospheric station in the world measuring over 1200 variables on a continuous basis, 24/7. Furthermore, it is contributing to several European ESFRIs (ACTRIS, ICOS, LTER, ANAEE). In GEO flagship activities, the SMEAR concept is relevant for Global Observation System for Mercury (GOS4M), Geo Carbon and GHG Initiative and GEO Cold Regions Initiative (GEO CRI).

The modelling toolbox of iCUPE covers different data analysis tools such ME-2, COREM, FLEXPART, PSCF (WP1,4), 3D atmospheric chemical-aerosol transport models PMCAMx, WRF-Chem and Multimedia contaminant fate & transport model MCFTM - BETR Global, which is a geographically-explicit global-scale multimedia contaminant fate model (WP4), and emission scenario model (GAINS) together with the Earth System Model (ESM) ECHAM6-HAMMOZ (WP4). iCUPE developed integrative modeling tools and tested the interoperability of modeling and observational data. For example, the aerosol composition and concentration fields calculated with PMCAMx can be used for improving the multimedia contaminant fate and transport model (MCFTM) BETR Global, which currently includes only one generic aerosol type (Task 4.3).

Improvement and selection of effective environmental indicators for end-users

In order to enable science-based decision-making both locally and regionally, the comprehensive and harmonized data produced within iCUPE was applied for improving the modeling capacity for future exposure and impact scenarios in the Arctic. Within the project, such scenarios representing alternative possible resource development paths were developed for scientific and policy use. The project used the BETR Global model, which has earlier supported the implementation of the Stockholm Convention and the Convention on Long- Range Transboundary Air Pollution (CLRTAP). The model has also been applied for scenario analysis and impact assessment of POP emissions. iCUPE applied emission scenario model (GAINS) together with the ESM ECHAM6-HAMMOZ and documented national plans on extracting natural resources in polar areas (e.g. Yamal MegaProject in Russia), for generating specific scenarios on changes in polar emissions and their impacts on pollutant concentrations (e.g. BC, OC, SO2, CH4). The scenarios provided insights to the extensive multi- and

interdisciplinary assessments on the alternative future scenarios for the Arctic environment (Task 4.4). Results from WP4 aiming to evaluate and improve emission estimates of SLCFs (BC, CH4) are relevant for the work of the AMAP SLCF Expert Group (EG) which assesses the impacts of SLCFs on climate and health in the Arctic. iCUPE partner CNRS participates in the AMAP SLCF EG and contributed to the recent AMAP SLCF assessment and summary for policy makers.

As part of the work, iCUPE provided a discussion platform to exchange best practices in the ground sites and to foster collaboration between the consortium partners and the end-users (Task 6.2). The project also involved representatives from EMEP, WMO-GAW, Arctic Council AMAP, SAON, INTAROS, POLARNET, IASC and the Russian and Chinese research communities via PEEX.

Contribution to accurate, comprehensive information to policy and decision-makers

iCUPE provided multidisciplinary information and novel data on the current status of the polar environment (WP 1-5). It delivered quantified data on the relative contributions of local and long-range transported pollutants affecting the atmospheric composition in the Arctic, on emission and deposition of pollution affecting the properties of snow and ice, on the effects of changes in atmospheric composition and surface properties that are essential required for science-based decision-making.

We reported data on long range transported pollutants, their deposition and accumulation in the snow cap and release dynamics during the Arctic spring. We investigated POPs, heavy metals, mercury and emerging pollutants from deposition to their entry into the hydrosphere and eventually into the food chain. In connection to the iCUPE modeling framework, we were able to identify their sources and provide insights into the decision-making processes.

iCUPE provided novel insights into POP transport and processing (Task 4.4) in the cold climates and integrates the multidisciplinary information to an impact assessment of pollution in terms of POPs and CECs. This assessment is suitable to address openly environmental issues at local and regional scales for a science- based decision making and support. The main policy making stakeholders of iCUPE are the Arctic Council and United Nations' Environment Programme (UNEP) and United Nations' Economic Commission for Europe (UNECE). iCUPE provided an update of the POPs list of the Stockholm Convention and delivered evidence of transboundary transport, sources and sinks of SLCFs, POPs, CECs and mercury in the Arctic in synergy with CLRTAP convention (Task 2.2). iCUPE supported the Minamata Convention on mercury by providing data on a quality controlled and consistent GMOS atmospheric Hg data set and improving Hg exposure estimates (Task 2.2, 2.4). Scenarios on specific changes in polar emissions and their impacts on pollutant concentrations (e.g. BC, OC, SO2, CH4) are made available for the policy and decision making (Task 4.4).

Exploitation and use of EO derived data for the benefit of citizens' daily life

The increased level of understanding on the pollution transport and source in the Arctic as well as POP exposure assessments (WP 4) provided data that is valuable and relevant for the general public. Snow coverage (WP3) cycle and its changes affect the life of Arctic communities considerably. Avenues to exploit this data in a way that it benefits and affects the daily life of the selected local communities in the Arctic was considered in collaboration with the stakeholder engagement as a part of dissemination activities (WP 6).

Reinforcement of the interface with user communities in GEOSS framework

iCUPE collaborated with existing European ESFRI infrastructures and national facilities as well as INTAROS, APPLICATE (coordinator AWI, also an iCUPE beneficiary) by filling the observational and data gaps of POPs, CECs and SLCFs in the polar areas with the special focus on utilization and integration of observational data with iCUPE modeling tools. The project assessed the parameter variability (WP 1,4) based in well identified supersites (Svalbard, Värriö & Hyytiälä (SMEAR-I & II), Pallas-Sodankylä, Ny-Ålesund, Villum measurements, Antarctic: Mario Zucchelli, Dumont Durville, Dome C research bases) along quasi-longitudinal transects from east to west at high latitudes. iCUPE provided a spatial expansion of the dataset that is quality controlled around the ground-based sites needed for the validation of the satellite datasets.

iCUPE impact on innovation capacity

In collaboration with the active and innovative beneficiaries, the iCUPE project formed an innovative and inspiring framework for joint work. The outlined during proposal stage potential for innovation related to in-situ instruments (WP 1, WP 2, particularly reactive mercury) and satellite techniques was utilized in the project. Other innovation envisioned and delivered by iCUPE is in laboratory analysis methods for POPs, CECs and heavy metals, to push the instruments to lower detection limits for these analytes in water, snow and ice. This benefited the community as the methods can be formalized and transferred to laboratories that carry out controls under the European water framework directive.

iCUPE impact on scientific outcomes from the polar regions

Our scientific outcomes contributed to improved understanding about the drivers and consequences of Arctic and boreal climate change, and fundamental mechanisms associated with cryosphere-atmosphere-biosphere interactions in particular related to pollutants and contaminants in polar regions (WP2).

We used novel ground-based techniques to monitor arctic atmospheric Hg speciation and dynamics, along with PBDE, PAH, PCB, Persistent Chemicals of Emerging Global Concern, heavy metals (Cr, Pb, Cd), and black carbon (BC) in the snow, air and ice. This has led to an improved integrated understanding of the lifecycles of these persistent pollutants in the Polar regions as well as their dynamic in the Arctic environment once deposited. The comprehensive source apportionment based

on detailed in-situ characterization and novel approaches with a combination of modeling, remote sensing, innovative field experiments and advanced analysis tools provided novel insights into the sources of atmospheric pollution in the Arctic. Thanks to iCUPE (WP2) we improve the capability to observe and evaluate the presence of contaminants in the snow pack not only during a specific season but during the entire year strongly improving our comprehension of the processes that drive and cause their presence in the Polar Regions. Moreover, thanks to the available environmental archive (ice core) it was possible to evaluate the anthropogenic impact before and during the industrial revolution and during the recent decades with particular focusing on the Arctic amplification period.

A large number of Arctic aerosol samples from different stations was provided in WP1 and chemically investigated by re-aerosolization and subsequent offline analysis by aerosol mass spectrometry. This dataset is absolutely unique and has been used for source apportionment to understand the different contributions of organic aerosols to the mass load at the Arctic stations originating from natural as well as from anthropogenic sources. This study has significantly contributed to the understanding of Arctic aerosols, their chemical nature and corresponding fingerprint linking them to different sources.

The EO activities that were carried out within iCUPE helped to understand and predict snow-cover changes and their multiple consequences in the polar environment, such as the contaminant release during the snow melting . The scientific outcomes were fostered by open data availability and interoperability enforced by iCUPE. Generally, this facilitated higher visibility and reusability of scientific outcomes. Especially iCUPE scientific outcomes contributed to data and services of GEOSS and Copernicus but also the ERA-PLANET community as a whole will increase awareness of the environmental impacts and status in the fragile polar regions of the public audience.

Impact exploitation after the project

iCUPE as a part of the EU Polar Cluster, is involved and participating in the development of joint dissemination efforts, aiding and ensuring impact exploitation beyond the lifetime of the project. iCUPE partners have taken onboard iCUPE communication and dissemination approach and pledged to maintain old and actively seek new ways to maximize project's impacts.

iCUPE's final products will be introduced to the wider community of Arctic stakeholders in the 2nd AASCO event on 9.Dec.2021. The iCUPE outcome will also be issued as a part of the AASCO White paper, which will be targeted to the Arctic policy making processes https://www.atm.helsinki.fi/peex/index.php/aasco/.

Appendix summarizing the scientific output of iCUPE.

List of iCUPE publications

iCUPE partners have written more than 105 research articles published in 52 different journals, books and reports. Publications include 2 papers in Nature, 1 in Nature Geosciences, 1 in Science and 2 in PNAS.

Two cornerstone publications on iCUPE concept, results and examples were prepared as well:

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2. Steffen M. Noe, Ksenia Tabakova, Alexander Mahura, Hanna K. Lappalainen, Miriam Kosmale, Jyri Heilimo, Roberto Salzano, Mattia Santoro, Rosamaria Salvatori, Andrea Spolaor, Warren Cairns, Carlo Barbante, Fidel Pankratov, Angelika Humbert, Jeroen E. Sonke, Kathy S. Law, Tatsuo Onishi, Jean-Daniel Paris, Henrik Skov, Andreas Massling, Aurélien Dommergue, Mikhail Arshinov, Denis Davydov, Boris Belan, and Tuukka Petäjä, 2021 (under review). Arctic observations and Sustainable Development Goals - Contributions and examples from ERA-PLANET iCUPE data. Environmental Science and Policy.

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List of iCUPE theses (BSc, MSc, Phd)

- MSc thesis by Aino Ovaska, to be finalized by September 2021.
- MSc thesis by Robin Zindler (supervisor A. Humbert): Supraglaziale Hydrologie am 79°N Gletscher Nordost-Grönland, 2020

List of iCUPE data sets

The iCUPE delivered datasets (DS) are publicly available (including “read-me” files with metadata and references) at: https://www.atm.helsinki.fi/icupe/index.php/datasets/delivered-datasets

- DS on emerging organic contaminants in air from the Arctic (HZG; D 2.4.1; T 2.4)
- DS on emerging organic contaminants in snow in the Arctic (HZG; D 2.4.1; T 2.4)
- DS on anthropogenic contaminants in snow from polar regions (CNR-IDPA; D 2.1.1; T2.1)
- DS on anthropogenic contaminants in ice cores from polar regions (CNR-IDPA; D 2.1.2; T2.1)
- Dataset on emerging organic contaminants in water from the Arctic (HZG; D 2.4.1; T 2.4)
- DS on Near-Real-Time aerosol absorption measurements from Zeppelin Station, Ny Ålesund, Svalbard (NSCR; D 1.2.1; T 1.2)
- DS on Arctic atmospheric Hg(II) observations (CNRS; from D 2.2.1; T 2.2)
- DS on long-term monitoring of gaseous elementary mercury in background air at the polar station Amderma, Russian Arctic (INEP KSC RAS; from iCUPE collaborators)
- DS on classification of artificial light sources in the Yamal Peninsula, Western Siberia (GFZ; from D 3.2.2; T 3.2)
- DS on fractional snow cover area in selected sites of Svalbard islands (Norway) (CNR; from D 3.2.2; T 3.2)
- DS on small-scale vertical and horizontal variability of the atmospheric boundary layer aerosol using unmanned aerial systems (TROPOS; from D 1.3.2; T 1.3)
- DS on time series of lake size changes in Northeast Greenland (AWI; from D 3.3.2; T 3.3)

- DS of validated aerosol vertical profiles from ground-based and satellite observations above selected sites in Finland and Siberia, Russia (CNRS & UHEL; from D 4.3.1; T 4.3)
- DS on Visible Near Infrared airborne and simulated EnMAP satellite hyperspectral imagery of Toolik Lake, Alaska (GFZ; from D 3.2.2; T 3.2)
- DS on aerosol physical and optical characteristics including equivalent black carbon (subsets on aerosol ultrafine particle size distribution, aerosol large particle size distribution, scattering, absorption and equivalent black carbon) at Ny-Alesund, Svalbard (CNR; from D1.1.2; T1.1)
- DS on snow spectral reflectance measurements at Ny-Alesund, Svalbard (CNR; from D1.1.3; T1.1)
- DS on vertical profiles of equivalent black carbon in the Arctic boundary layer at Ny-Ålesund, Svalbard (CNR; from D1.3.2; T1.3)
- DS for ground-validation of precipitation measurements in high-latitudes (UHEL; from D 4.2.1; T 4.2)
- DS on Arctic atmospheric Hg(0) isotope observations (CNRS; from D 2.2.3; T 2.2)
- DS on organic aerosols in the Arctic (PSI; from D 1.4.2; T 1.4)
- A blueprint for novel proxy variables integrating in-situ and satellite remote sensing data with an exemplary DS (subset on condensation sink and mixing layer height) (UHEL; from D 4.1.1; T 4.1)
- Monthly GlobSnow v3.0 Northern Hemisphere snow water equivalent dataset through PANGAEA: https://doi.org/10.1594/PANGAEA.911944

Other outputs:

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