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Polar data sets and data streams of SLCFs: characteristics, availability and challenges for long-term sustainability and operational use.

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WP 1 - Ground-based component for SLCFs

Task 1.1 - Integration of observations provided by Research Infrastructures and networks

Version 1.0

Index

1 Abstract

This report aims to provide a synthetic but comprehensive description of the status of aerosol and other SLCFs measurements in polar regions, and current perspectives for coordinated efforts and development of a sustainable year-round observation network. In this context we use the word network to indicate that robust methodologies and standards have been developed and are used routinely by all research groups operating in polar regions for both in-situ as well as columnar measurements. The actual status of measurements is inserted in the historical context of the last 40 years. Given the extreme difficulty of being univocal in providing this figure, different sources are reported so as to allow the reader to make crossings and comparisons between them. The aspect of data availability and accessibility, and the challenge it still represents today, is highlighted. This problem that seemed unsolvable until a few years ago is rapidly progressing with the ever increasing development of platforms and software to manage efficiently and automatically (machine to machine - M2M, approach) the services that are linked to interoperability and the principles of FAIRness: discovery, curation, download, virtual analysis.

The set of information collected and presented leads to the extraction and determination of the challenges and opportunities that arise in order to finally arrive at an integrated monitoring network in the polar regions, and in particular in the Arctic, of the SLCFs (BC, methane, tropospheric ozone, aerosols of different origin) able to operate with the same force both when the sun is above the horizon and when the sun is found below the horizon (polar night). The economic development that increasingly characterizes the Arctic and that draws strength and thrust precisely from climate change, makes this goal increasingly urgent and necessary, given that this economic development, however sustainable, will bring with it a significant increase in the local sources of SLCFs.

2 The historical perspective

In the last 40-50 years activities related to SLCFs in polar regions were always connected with time-limited research programmes and specific interests of research groups. Harsh environmental conditions and lack of interest, considering main pollution sources external to the Arctic, limited expansion of global networks to high latitudes and interest of meteo- and environmental services for operational activities.

Despite low concentration of SLCFs with respect lower latitudes, the continued presence of ice and snow, the extreme radiation regime with a very long polar night, the persistent thermal inversion at the surface and high stable Boundary layer (ABL) largely affect all processes involving aerosol and SLCFs in polar regions, increasing their relevance in the climate system and role in climate change and its amplification in the Arctic. More than this, polar regions represent a very interesting laboratory to investigate aerosol related processes in a till pristine environment.

Historical perspective of aerosol measurements in the Arctic (and Antarctica) can be acquired from what was reported by several review papers realized thanks to the information gathered in the POLAR-

AOD network (e.g. Tomasi et al, 2007, 2012, 2015). A very relevant source of information about measurements, as well as sources and impacts, of SLCFs are several assessment reports that the Arctic Monitoring and Assessment Programme (AMAP) released from 2006 till 2015 (AMAP, 2006, 2008, 2008, 2011, 2015). Using large part of these measurements and results of POLAR-AOD, a characterization of Arctic aerosols have been provided by Stone et al. (2014) and Tomasi et al. (2015). on the basis of aerosol optical depth and black carbon measurements. A synthesis of actual knowledge on Processes Controlling the Composition and Abundance of Arctic Aerosol can be found in the paper of Willis at al. (2018). A last relevant peer review publication to complete this historical perspective is for sure the paper about SLCFs effects on climate published by Quinn et al. (2008). Even if IPCC reports, many publications and the new AMAP assessment report on SLCFs recently released (AMAP, 2021) provide estimates of direct and indirect effects, this paper is fundamental in indicating the correct approach and methodology.

POLAR-AOD-IPY was one of the 17 projects included in the "Atmosphere" domain by IPY 2007-2009 programme (ID. 171 - Vitale et al. 2007) Integrated regular measurements of aerosol physical and radiative properties at a number of polar stations were planned in order to (i) evaluate the seasonal background concentrations inferred from AOD measurements, (ii) define the spectral characteristics and patterns of the radiative processes induced by both natural and anthropogenic aerosols, and (iii) ameliorate the knowledge of physical, chemical and radiative properties of polar aerosols, and of their horizontal and vertical distributions and temporal variability, for better evaluating the role of polar aerosols in the climate system. During IPY, field data were recorded at 15 stations in the Arctic and 16 stations in Antarctica (Figure 1).

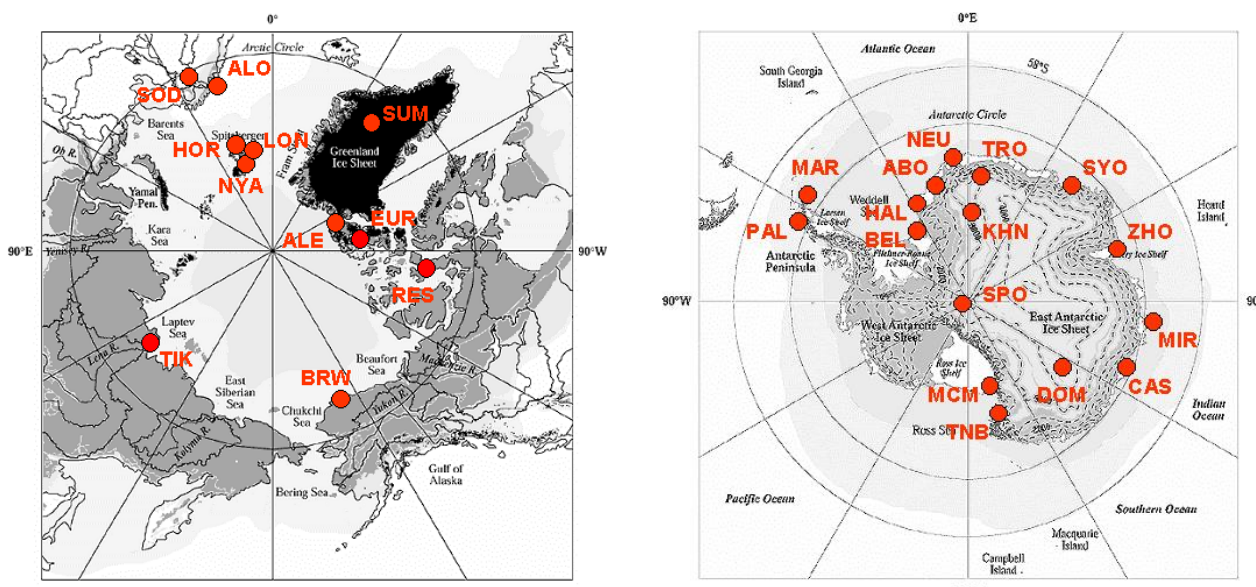

Figure 1 - *Arctic and Antarctic stations that will carry out aerosol measurements during IPY.*

In any case, if we focus on long-term systematic observations in the Arctic of surface aerosol characteristics, as pointed out in the AMAP Technical Report N. 4 (AMAP, 2011) only 5-7 stations above 60 °N latitude carry out activities and provide observations. Meanwhile a large programme gave the possibility to perform a relatively large amount of BC snow sampling campaigns across the Arctic.

Then, the picture that emerges from these sources, is that the level of standardization of atmospheric observations along the Arctic were quite week. The need to adapt commercial instruments and field procedures to environmental conditions are the main reason for that, emphasised by the historical absence of consolidated global network that can provide motivation and support for better harmonization at least of procedures and analysis procedures. POLAR-AOD since beginning of 2000, was an attempt to overpass this intrinsic weakness of the observing system related to SLCFs, but the network up to now have been mainly based on a voluntary effort of participants, and after IPY 2007-2009 lack of resources for a specific support, was not able to fully develop. IPY 2007-2009 was the opportunity also for start another atmospheric networking effort, devoted to many atmospheric measurements not only to SLCFs. International Arctic Systems for Observing the Atmosphere (IASOA), is a networking effort supported by US Agencies. The mission to advance Arctic system research, through (i) Observations, (ii) Data access; (iii) Synergistic science, to develop understanding and services, is implemented focusing on activities performed in 10 stations all around the Arctic and developing harmonization and upgrade of measurements in different areas of atmospheric sciences through dedicated working groups (Uttal et al, 2016). For the context of iCUPE, two of the 6 established, aerosols and Methane ozone and other trace gases, are relevant (source IASOA web site https://psl.noaa.gov/iasoa/home2) . Along the time, despite better support with respect POLR-AOD, also IASOA experienced several difficulties. But is in any case a precious source of data for several station for the period from 2005-2015.

3 The current status of SLCFs observations in polar regions

Figure 2 shows the current situation of aerosol and SLCFs measurements that are carried out throughout the year in the Arctic. We have 14 stations across the Arctic with a clear prevalence of western longitudes. the length and breadth of monitoring programs vary greatly from site to site. There are sites that have been operating for more than 30 years now, measuring a large number of parameters, while others, such as Capo Baranova, have only been opened in the last 2-3 years. The detail for the measurements in the atmospheric column (remote sensing observations from the ground), as recently photographed by the POLAR-AOD network, is provided in Figure 3.

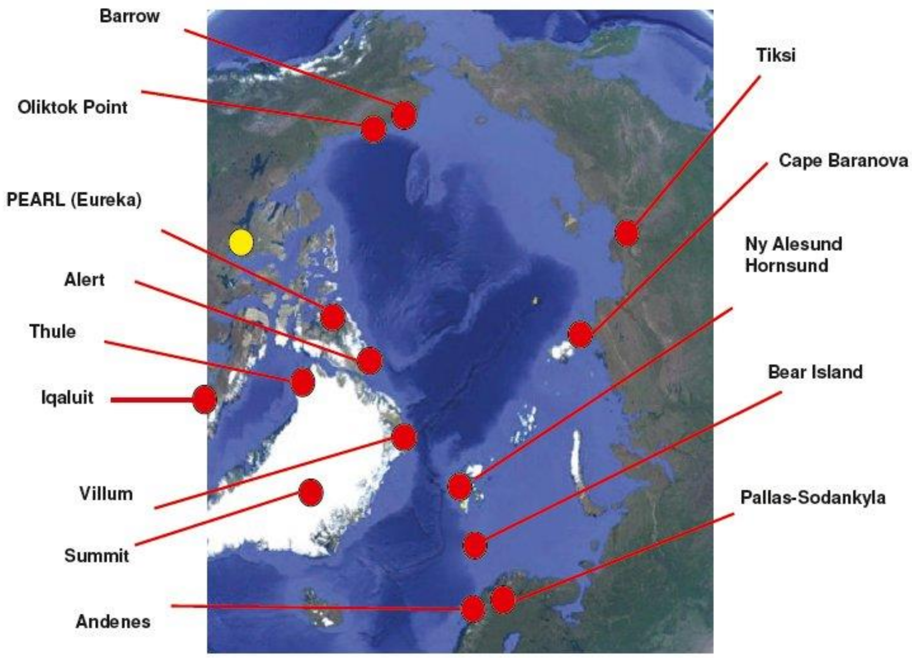

Figure 2 - *Map of stations carrying out aerosol measures throughout the year.*

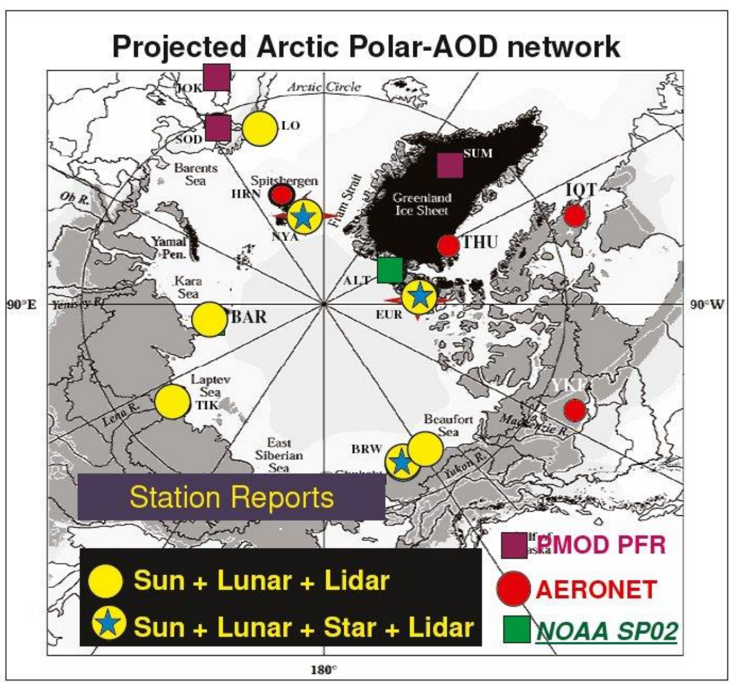

Figure 3 - *Actual situation for ground-based remote sensing of atmospheric column*

The picture of actual measurements was made also to support MOSAIC year-round experiment and field campaign (https://mosaic-expedition.org/), and provide information to T-MOSAIC initiative (https://www.t-mosaic.com/), in which both POLAR-AOD and IASOA have been involved. The map and list of stations in Figure 2 and 3 are coherent with those we can found/read consulting other relevant sources., but not coincident. Meanwhile around 8-10 stations are constantly reported, depending on sources of information and parameters considered other 5-10 stations can be included. A clear example of that is provided in Figure 4, where the Arctic sites hosting monitoring activities of black carbon and co-emitted compounds are reported together with measured parameters (Tørseth et al., 2020).

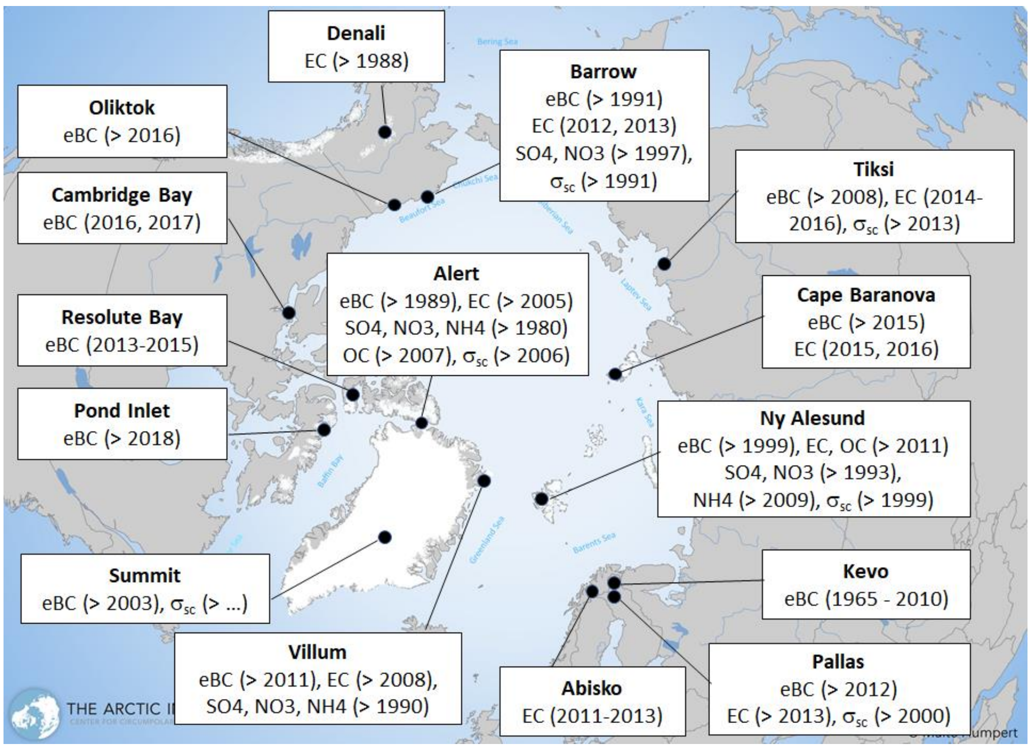

Figure 4 - *Arctic sites hosting monitoring activities of black carbon and co-emitted compounds (source of information Tørseth et al., 2020).*

Authoritative source of information about the status of SLCFs long-term measurements in polar regions we can list include:

- IASOA web site and in particular IASOA data portal (https://psl.noaa.gov/iasoa/dataataglance)
- AMAP assessment reports (in addition to those reported above we can add Assessment 2015 on Methane and the Assessment 2021 on Impacts of Short-lived Climate Forcers on Arctic Climate in preparation).
- the web page of the EU Initiative to Support International Policy to Reduce Black Carbon (EU-BCA) and deliverables/publications released, with a particular attention on the Technical report by Tørseth, cited yet (https://eua-bca.amap.no/). This web page also provide a very

comprehensive list of publications, websites and other resources related to BC, in particular documents of the Expert Group on Black Carbon and Methane (EGBCM) of the Arctic Council

None of this source, with the exception of the report of Tørseth et al. realised in the frame of EU-BCA actions, made an attempt to obtain a complete list of stations and activities, due to the great uncertainty in be sure to have access to all information. For this reason the attempt made in connection with MOSAIC expedition with the contribute of iCUPE, and the results presented in this report, are relevant. Confidence on the general picture we can obtain integrating this report and other authoritative sources, can arise by the work that Grid Arendal made during IPY 2007-2009 for mapping the Locations of major research stations in the Arctic (Figure 5). If we add on the map the few stations opened after 2010, Villum station in N-E Greenland, CHARS in Cambridge Bay, Canada, Cape Baranova, Russia, we can find and locate on the map in Figure 5 all stations that are performing long-term activities related to SLCFs. Is important to note that map in Figure 5 include also stations that are not connected with Atmospheric composition activities.

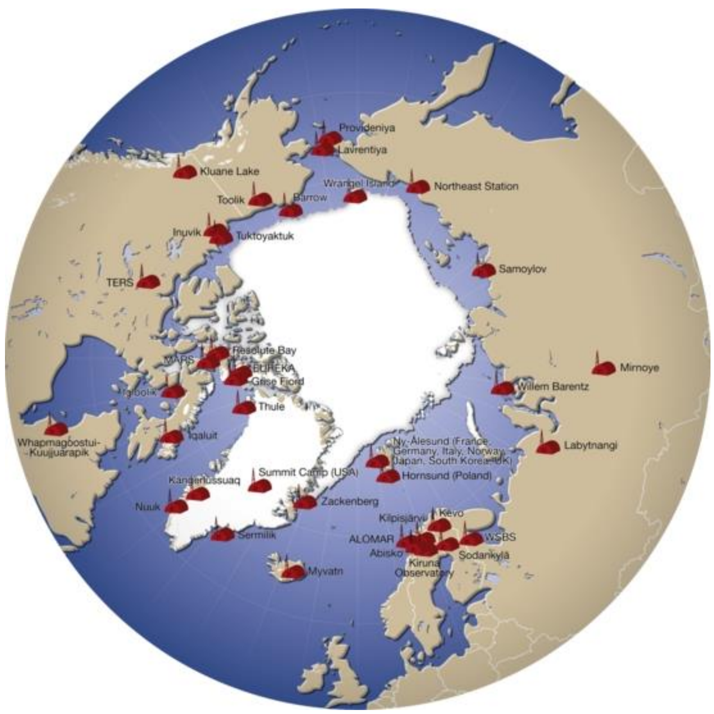

Figura 5 - *Locations of major research stations in the Arctic. Most sites depicted focus on research fields other than atmospheric composition. Credit:* Hugo Ahlenius, UNEP/GRID-Arendal: http://www.grida.no/resources/7141

As a short summary of the above discussion we can indicate that the number of stations that carry our long-term activities related to SLCFs are not more than 20, less than 10 with a robust programme that include several parameters as well as in-situ observations and observations of the vertical atmospheric column. To this stations we need to add information can arise for satellite observations.

the latter, if still limited, are destined to assume an increasingly important role thanks to the development of sensors mounted on satellites and in particular to the increasing use of multi and hyper-spectral sensors

While it is relatively easy to identify measurement sites that currently run monitoring programs with good regularity, getting an accurate picture of the measured parameters and the instrumentation / methods used is much more difficult. This information is essential if we are to integrate the information we collect and not just try to build an aerosol climatology in the Arctic, but try to formulate a budget. Thanks to MOSAIC and the POLAR-AOD network, as explained in the second year report, thanks also to the contribution of iCUPE some actions have been carried out with the aim of improving our information about the current state of measures in the polar areas and especially in Arctic:

1 - POLAR-AOD organized a retreat workshop in May 2019 to take stock of atmospheric column measurements (Stone, O'Neill, Toledano, Vitale, 2019) and discuss actions to harmonize measurements, push implementation of measurements lunar, strengthen the synergies between active and passive techniques and strengthen network activities (for example, organize a common database).

2. - A workshop, organized in Aarhus at the end of January 2019 (Stove, Massling, 2019), made it possible to take stock of the overall in situ measurements of the SLCFs and also of all the measures that can help to interpret chemical processes well -physics affecting atmospheric aerosol in the Arctic region. This work of identifying parameters and methodologies is still ongoing.

To these, during the second half of 2019 and early 2020, work was added to collect detailed information about the instruments installed and the parameters measured in the various stations. Tables 1-4 below, compiled through a cooperative work coordinated by Marco Zanatta (at that time at AWI), summarize the result of this survey divided into 4 categories. in-situ measurements, gas measurements (both of trace gases and of possible aerosol precursors), vertical sounding measurements, measurements of the atmospheric column with remote sensing techniques from the ground.

	POLARSTERN	AWI-A	ALR	COM	PAL	VRS	ZEP	NYA	OLI	BRW	CBA	TIK	HOR	ERK	SUM	RV MIRAI
AEROSOL BASIC																
Total number concetration																
Total mass concetration																
Number size distribution																
Scattering																
Absorption																
Exinction (direct measurement)																
Cloud condensation nuclei																
ChemistryOnline																
ChemistryOffLine																
EC/OC																
OTHER																
Refractory black carbon																
Hygroscopicity (HTDMA)																
In siu cloud activation (CVI or interstitial)																
INP (online-offline)	on					on-off	off								off	off
Wet scattering																
Cloud residual size distribution																
Cloud resiudal BC																
Cloud residual composition																
Cloud liquid water content																
Droplet size distribution																
CCN in cloud residuals																
Aerosol ion spectrometer (NAIS)																
Single particle BC both in aerosol and cloud residuals																
Bioaerosol single particle (MBS) botn in aerosols and cloud residuals																

Legend	
	Observed
	Not observed
	To be confirmed
	No ifo

Platforms	
AWI-A	AWI-Aircfrafts (Apr and Sept)
ALR	Alert
COM	COMBLE (Andenes+Bear Island)
PAL	Pallas
VRS	Villum
ZEP	Zeppelin
NYA	Ny-Alesund
OLI	Oliktok
BRW	Barrow
CBA	Cape Baranova
TIK	Tiksi
HOR	Homesund
ERK	Eureka
SUM	Summit
RV MIRAI	Bering strait - Beaufort Sea Otober 2019

Table 1 - *Actual status of in-situ aerosol measurements at stations carrying out activities all year-round*

	POLARSTERN	AWI-A	ALR	COM	PAL	VRS	ZEP	NYA	OLI	BRW	CBA	TIK	HOR	ERK	SUM	RV MIRAI
GAS BASIC																
CO2																
CO																
CH4																
H2O																
H2O isotopes																
NO2																
NOx																
NOy																
SO2																
SOx																
O3																
OTHER																
Halocarbons																
Mercury																
VOC																
BrI																
CH4 isotopes																

Legend	
	Observed
	Not observed
	To be confirmed
	No ifo

Platforms	
AWI-A	AWI-Aircfrafts (Apr and Sept)
ALR	Alert
COM	COMBLE (Andenes+Bear Island)
PAL	Pallas
VRS	Villum
ZEP	Zeppelin
NYA	Ny-Alesund
OLI	Oliktok
BRW	Barrow
CBA	Cape Baranova
TIK	Tiksi
HOR	Homesund
ERK	Eureka
SUM	Summit
RV MIR	Bering strait - Beaufort Sea Otober 2019

Table 2 - *Actual state of gas measurements at stations that carry out aerosol-related activities all year round*

Sonding	POLARSTERN	AWI-A	ALR	COM	PAL(SNK)	VRS	ZEP	NYA	OLI	BRW	CBA	TIK	HOR	ERK	SUM	RV MIRAI
#/week		drop/flight														
Temperature	28	1-2	14	28	7			7	14	28	7			14	14	28
Humidity	28	1-2	14	28	7			7	14	28	7			14	14	28
WSpeed	28	1-2	14	28	7			7	14	28	7			14	14	28
Wdirection	28	1-2	14	28	7			7	14	28	7			14	14	28
O3	1		1		1			1						1		

Legend	
(green)	Observed
(white)	Not observed
(yellow)	To be confirmed
(red)	No ifo

Platforms	
AWI-A	AWI-Aircfrafts (Apr and Sept)
ALR	Alert
COM	COMBLE (Andenes+Bear Island)
PAL	Pallas
VRS	Villum
ZEP	Zeppelin
NYA	Ny-Alesund
OLI	Oliktok
BRW	Barrow
CBA	Cape Baranova
TIK	Tiksi
HOR	Homesund
ERK	Eureka
SUM	Summit
RV MIR	Bering strait - Beaufort Sea October 2019

Table 3 - *Actual status of vertical sounding measures at stations carrying out aerosol-related activities all year round*

Intrument	POLAR STERN	AWI-A	ALR	COM	PAL	VRS	ZEP	NYA	OLI	BRW	CBA	TIK	HOR	ERK	SUM	RV MIRAI
Column integrated																
Aerosol optical tickness/turbidity parameters (Sun/Star photometer)	Sun	Sun	Sun	Sun	Sun	Sun		Sun	Sun	Sun	Sun		Sun	Sun-Star		
Trace gas	MAX - DOAS					MAX-DOAS								UV-Vis DOAS/FTIR		
Vertical profile																
Aerosolo vertical profiles (backscatter/raman lidars)	RL	BS		RL				RL/MPL	RL					BS		
Wind vertical profiles (doppler lidars/windcube)	DL			DL		WL		WL	DL	DL						
Clouds																
Cloud vertical profiles and characteristics/precipitation (Cloud radar)																C-band
Cloud height (Ceilometer)																
Water-vapour profiles (Microwave radiometer)																
Radiation																
Infrared downwelling radiation (Pyrgeometer)																
Global solar downwelling radiation (Pyranometer)																
Solar direct radiation (Pyrheliometer)																
Meteo																
Standard meteo (T,RH,Ws,Wd)																
Precipitation amount (Disdrometer or other precipitation sensor)																

Legend	
(green)	Observed
(white)	Not observed
(yellow)	To be confirmed
(red)	No ifo

Lidar	
DL	dopler
RL	raman
AL	aerosol
WL	wind

Platforms	
AWI-A	AWI-Aircfrafts (Apr and Sept)
ALR	Alert
COM	COMBLE (Andenes+Bear Island)
PAL	Pallas
VRS	Villum
ZEP	Zeppelin
CBA	Cape Baranova
TIK	Tiksi
HOR	Homesund
SUM	Summit
RV MIRAI	Bering strait - Beaufort Sea Otober 2019

Table 4 - *Actual status of the measurements of the vertical column using remote sensing techniques from the ground at the stations that carry out activities related to aerosol all year round*

4 Data Management issues, needs, current efforts

Actual levels of ICT platforms/possibilities in relation to Arctic observations have been investigated by EU-Polarnet project (https://eu-polarnet.eu/) through a survey, which results are presented and summarized in the deliverable D3.1, that can be collected at the web page https://eu-polarnet.eu/achievements-2015-2020/. Results clearly indicate that the data management landscape is till fragmented and far from apply common standards. As stated by the report at page 11

..... a large majority of the data systems analyzed implement a formalized data encoding specification, but only half of them make use of a standard specification; they do not implement any processing interface.
More than half of the systems implement a metadata scheme, but only half applies a standard specification. Fewer of them (i.e. half of the responders) make use of a metadata specification to underpin a discovery service/interface. The systems that implement discovery services also publish an access interface.......

As a consequence of this picture the main recommendation made by D3.1 was

To engage the Polar Research Community in defining and adopting a set of Data Management principles to enhance the current data descriptions and ensure an effective sharing and (re-)usability.
a. Provide these principles in a clear format;
b. Provide a set of implementation guidelines for the principles.

The landscape however is making rapid progress towards greater integration and more efficient application of the FAIR principles: Findable, accessible, interoperable and reusable. We like to indicate here three actions, two of them specifically dedicated to polar regions, that are contributing to these development:
1 - the polar data forum initiative, promoted by the Arctic Data Committee (ADC) jointly established years ago by IASC and SAON. The polar data forum is providing a very powerful platform through which to involve a so fragmented community on joint and concrete targets connected to the FAIR principle. To regular meetings, the next planned in September 2021, the forum organize regularly Hackaton events dedicated to very specific issues/topics (https://polar-data-forum.org/)

2 - the Arctic PASSION EU project just started and engaged to continue the effort started by INTAROS project to provide an EU contribution to build an integrated Arctic observing system. Data management and data issues are a fundamental piece of its programme and in combination with the polar data forum this will be an important action through which to give reality to the recommendation made by EU-Polarnet coordination action in D3.1.

3 - The ENVRI-FAIR EU project, which overarching goal is is to advance the findability, accessibility, interoperability, and reusability (FAIRness) of the data and services offered by the ENVRI Cluster research infrastructures and to connect them to the emerging European Open Science Cloud. This project is important since connect the polar community with the whole European community devoted to environmental Research Infrastructures and to the developing cloud space for science in Europe.

To make a Data Management System (DMS) basically compliant with FAIR principles means to implement at least efficient discover and access functionalities based on standard and facilitating as much as possible machine to machine (M2M) interactions. Choices made on metadata and data encoding are fundamental from this point of view, as well as the development of discover and access interface easy, friendly and really helpful also for a not expert user. Include an application able to manage spatially referenced resources and/or provide data on a map viewer is an efficient solution, if combined with a good choice of search filters. However, a real step forward can be made only implementing in addition to **discovery** and **access** services, also **processing services**. Give to the user the possibility to handle the data is necessary if we like to extract the whole added value from a DMS. "Handling" can cover a very wide range, from simply allowing data to be downloaded up to allowing data processing and integration thanks to the availability of a more or less complex and performing virtual research Environment (VRE). A cost-effective effort can move along the line to allow the user to better understand the information made available (e.g. by visualisation) before to download the datasets. Standardization of data and metadata is an important issue, but the rapid development of multi-standard open source application for both (as example GEONETWORK for metadata and ERRDAP for data) make this less a problem. More relevant are issues related to data cataloging and semantics, mainly if we like not to develop DMS that even if dedicated to SLCFs are fully interoperable with broader disciplinary and multi-disciplinary data centers/repositories.

Moving more concretely on the actual status of SLCFs datasets at disposal, we can for sure indicate as main resources and repositories EBAS and IASOA databases:
(i) as stated on the home web page (http://ebas.nilu.no/) "*EBAS is a database hosting observation data of atmospheric chemical composition and physical properties. EBAS hosts data submitted by data originators in support of a number of national and international programs ranging from monitoring activities to research projects.....*". Being EBAS a data repository not dedicated to polar regions, despite a powerful interface that allow to explore the huge data mine of more than 120.000 available datasets through 6 possible point of view (project, country, station, instrument, observed parameter, matrix), to understand the information useful for a user/researcher interested to polar regions. Just as an example if we look for aerosol optical depth (AOD) and we select all stations located in Arctic and Antarctica we able to see that EBAS incorporate 129 datasets provided by only 4 stations, while if we limit to the Arctic datasets reduce to 75 arising only by Ny Alesund and Sodankyla.
(ii) the IASOA database entrance is through the web page https://www.esrl.noaa.gov/psd/iasoa/dataataglance. About 1000 records are at the moment stored there. IASOA is also working to define a standard format for data, the Merged Observatory Data Files (MODFs), suitable to help carrying out modelling comparisons (https://www.esrl.noaa.gov/psd/iasoa/node/311). Furthermore, IASOA also worked to realize a specific vocabulary for atmospheric measurements to increase standardization of metadata information and then help/improve search capability.

Despite this section and our interest has been dedicated to indicating the needs for FAIR compliant Data Management system, present the actual scenario and initiatives dedicated to improve it, we like to close the section with an example of a simple fully not standard repository to store, recover, explore data acquired by a single research group. Being this starting brick securing not only research activities of the group but also preparation of datasets for large and interoperable data centers and Data management systems (DMS).

At CNR-ISP tools have been developed and implemented to allow automatic storage of data arising from different stations and pertaining to a wide spectrum of measurements. Ancillary data as back-trajectories can be also automatically calculated and stored. Tools allow to visualize in graphical format, on a daily basis, data stored in a selected period. Tools have been developed in such a way to work also

with very limited resources to view and examine data. The only condition is to have an ICT infrastructure as fast internet connection and a laptop or a little server.
Routine algorithms transfer data from a single station and a single instrument at the end of the day to a server. If/when limited resources are at disposal, routine algorithms automatically elaborate and store graphs for each data stream. This approach allows to obtain a very fast answer to the user request. On the other end, the same approach limit our possibility to visualize data: the period of time need to be fixed by the procedure when developed and user cannot decide later with freedom on which interval would like to observe data. In our developed system, the natural choice is 1 day, that is the frequency with which data are collected and stored. If ICT resources are sufficient to guarantee fast elaboration, routines can easily be implemented to produce graphs when the user request is submitted. In this case, the user can select the time period from few hours to several days.
Another nice functionality is the possibility to visualize measurements performed by different instruments at the same station and/or in different stations. With the use of such developed tools we are able to have a very easy graphical comparison of measurements of the same parameter measured at the same time at two stations, and add, if/when necessary, to the comparison other graphs of co-related parameters.

5 Challenges and opportunities

The "*picture*" presented in Section 3, as indicated is the result of several programs and often the efforts of small research groups. There is certainly a need to strengthen and secure this framework through coordination actions. POLAR-AOD and IASOA, initiatives both promoted as part of IPY 2007-2009, provide tools for connecting and engaging the entire community working on atmospheric composition and SLCFs in the Arctic. POLAR-AOD duo-polar networking can became very important to transfer best practices and lesson learned to Antarctica.

POLAR-AOD network is well connected with industrial partners providing tools and with networks such as AERONET and SKYNET which cover medium and low latitudes, and is part of the T-MOSAIC initiative. The retreat meeting of May 2019 made it possible to agree on various coordination activities and inter-comparison campaigns:

In a short-term perspective:

- Carry out inter-comparison campaigns: (i) in winter 2020 in Ny-Alesund and (ii) in summer 2020 in Lyndenberg Despite pandemic situation, both campaigns were carried out including a day of workshops to discuss the results and experiences that emerged.

- Test new tools and techniques such as CLIDAR. This was made during the first inter-comparison campaign in Ny-Alesund

Support by iCUPE was important in respect to sustain this field activities

In a long-term perspective:

- Development of a website and a common repository for data
- Develop solid and specific QC / QA procedures,
- better integrate passive remote sensing (RS) observations with lidar and aerosol microphysics profiles

IASOA, relevant since connect 10 of the most important long-term observatories operating in the Arctic (https://psl.noaa.gov/iasoa/obs_tour), develop its science and coordination action through 6 thematic Working Groups (https://psl.noaa.gov/iasoa/science2) that were very active until 2018-2019, operating through regular virtual meetings in which to share information and discuss best way to coordinate activities and develop best practices/protocols.

If POLAR-AOD and IASOA represent networking activities (*OPPORTUNITIES*) that could be able to overpass fragmentation and connect research groups, the great challenge is to give them a robust and stable support in terms of economic and mainly human resources. Both (more POLAR-AOD, less IASOA) were largely based on a voluntary participation and engagement, and at more of ten years from IPY this represents a great weakness, a weakness, which must absolutely be resolved before the work done so far is irretrievably lost.

6 Concluding remarks and recommendations

Harmonizing protocols, methodologies and sometimes instruments established/used by global networks is quite often not the best solution for a harsh environment as conditions can be very individual, this turns into an intrinsic weakness of the Arctic observational system, and a need to develop a dedicated flexible strategies in establishing a sustainable long-term observing system in the Arctic related to SLCFs and connect it to large research infrastructures (e.g. ICOS, ACTRIS and IAGOS at EU level) and global network (e.g. AERONET, SKYNET, NDACC).

Looking to the overarching goal of a sustainable long-term observing system in the Arctic for SLCFs, the state of art, opportunities and challenges presented in this report bring us to formulate several recommendations:

- is necessary to provide regular support to POLAR-AOD and IASOA. In particular is important to establish a central office for both and well connect to ongoing projects devoted to organize a circum-arctic observing system: Arctic PASSION from EU side (https://arcticpassion.eu/) and CoObs RNA from US side (https://sites.google.com/alaska.edu/rna-observations/home);
- thematic working group approach should be reinforced and focused more on develop best practices, continuous observations, integration of different methods, best coverage of polar night, common or, if not possible (for example since instruments are different), synergic procedures for data sampling/acquisition and mainly QA/QC procedures;

- reinforce interaction with Research Infrastructures (RIs) like ACTRIS and ICOS and with global networks to assure that the Arctic observing system is well integrated and compliant with their approach for methodologies/procedures, without to forge the Arctic specificity:
- interact with initiatives like polar data forum to move toward the complete FAIRness of acquired data; and with ENVRI-FAIR to be compliant with the European landscape related to Environmental observations (ENVRI community)
- develop a better integration of ground-based measurements and satellite observations, thanks to POLAR-AOD and IASOA establish a validation programme for satellite measurements;
- promote development of new technologies with the aim to improve capabilities for continuous year-round observations, as well as simultaneous observations of many parameters so to be able to improve our knowledge on processes involving SLCFs and on the consequences of climate change.

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