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Title page

Harmonising Environmental Research and Monitoring of Priority Pollutants and Impurities in the Svalbard Atmosphere

HERMOSA

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46

47 **Keywords**

48 aerosol, atmospheric pollution, monitoring coordination, aerobiology, dust deposition, contaminants of
49 emerging Arctic concern (CEACs)

50

51 **Popular science summary**

52 **Highlights**

- 53 • Air impurities were measured in Svalbard, from sulphur to pollen, already before 1980s
- 54 • Air quality monitoring is spatially uneven – the Ny-Ålesund hub needs to be supported by
55 other regular sites
- 56 • Methods of impurity measurement show similarities which can be exploited for better problem
57 solving

58 **Summary**

59 Many characteristics of atmospheric air are measured in Svalbard, including levels of chemical
60 pollution, dark dust connected to soot, and living organisms, but most of these studies happen in Ny-
61 Ålesund. First air monitoring was initiated as early as 1970s, and multiple atmospheric components
62 have been added to the monitoring over time (especially since 2010; in early 2000s a few parameters
63 from Hornsund have joined the regular programme). Newer types of contaminants are being
64 discovered and measured in Svalbard. Methods for detecting simpler substances and particles have
65 been established for a long time, while certain complex chemicals and small living organisms are more
66 difficult to capture and study. Laboratory and field equipment upgrades help improve understanding of
67 the Svalbard environment. In this chapter, we find that collecting information on many characteristics
68 of the air at the same time helps solve long-standing scientific questions in Svalbard, such as the
69 origins of pollution in the Arctic air and the future of Arctic atmosphere in the changing world. This is
70 especially important since the Arctic is changing fast, both due to the planet warming and the shift in
71 local people's activity from mining to services, e.g. tourism.

72 **Recommendations**

- 73 • Researchers should agree on important parameters of the atmospheric composition to be
74 measured in at least three places across Svalbard (we propose Ny-Ålesund, Longyearbyen
75 and Hornsund, and parameters: black carbon (soot), the greenhouse gas methane, inorganic
76 ions, pollen and novel organic chemicals).
- 77 • Change in time (between seasons and years) of a few of such parameters should be
78 measured simultaneously, to better study the influence of human activity and climate change.
79 This would be easier to study in the future if organic chemical analysis was saved for future
80 searches of novel chemicals (that is, an electronic sample bank was founded).
- 81 • Ny-Ålesund is the best place to study how such parameters change between sea level and
82 mountain tops, but in other places it should be tested, too, with shorter experiments. Methods
83 at various locations need to be harmonised and laboratories compared for robust results.

84 **Photos or popular science graphics/figures**



85

86 **Caption 1:** A collection of instruments monitoring air composition (and pollution) atop Gruvebadet
87 laboratory roof in Ny-Ålesund. Ny-Ålesund is the main place in Svalbard for air monitoring, with two
88 main stations – Gruvebadet near sea level and Zeppelin mountain top. (Photo: Marco Casula)



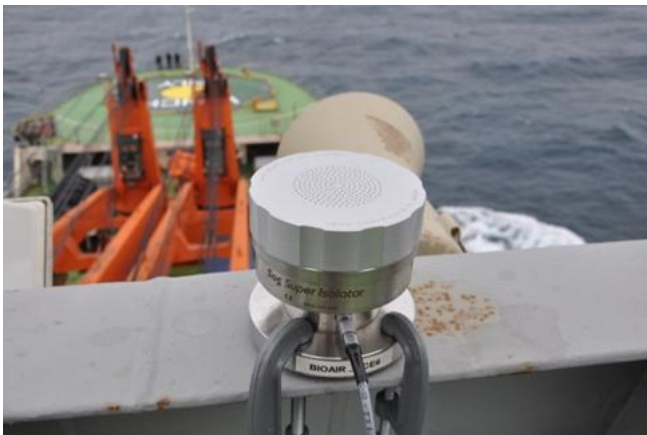
89

90 **Caption 2:** The environmental chamber of the Polish Polar Station Hornsund, also with a few
91 instruments sampling the air on its roof. Regular measurements of aerosol in Hornsund started in 2002
92 (Photo: Krystyna Koziol)



93

94 **Caption 3:** One of the air-sampling instruments, used for persistent and newly discovered pollutants
95 (Photo: Roland Kallenborn)



96

97 **Caption 4:** For air sampling for microorganisms, there are a number of instruments available. Key
98 questions for a researcher are: a) a filter size which captures bacteria, b) relatively high flow through
99 the instrument to study DNA, c) the ability of the instrument to cope with the Arctic environment, d) a
100 convenient power source (e.g. a battery) and e) best if there are other users in the scientific world.
101 Pictured is one such example, the SAS (Surface Air System) Air Sampler, aboard a ship. (Photo:
102 David Pearce)

103

104 **Main text**105 **Abbreviations:**

Abbreviation	Meaning	Abbrev.	Meaning	Abbrev.	Meaning
AARI	Arctic and Antarctic Research Institute	HCFCs	hydrochlorofluorocarbons	PCR	polymerase chain reaction
AMAP	Arctic Monitoring and Assessment Programme	HDPE	high-density polyethylene	PE	polyethylene
AOD	aerosol optical depth	HFCs	hydrofluorocarbons	PFAS	per- and polyfluoroalkyl substances
APS	Aerodynamic Particle Sizer	Hg-P	mercury associated with airborne particulate matter	PFR	Precision-Filter-Radiometer
AWI	Alfred Wegener Institute	HPLC	high performance liquid chromatography	PIXE	Proton Induced X-ray Emission
BC	black carbon	HR-MS	High Resolution Mass Spectrometry	PM (e.g. PM10)	particulate matter; the number following after PM signifies the maximum diameter (in μm) of particles included in the category
BFRs	brominated flame retardants	HVS	high-volume air sampler	POPs	persistent organic pollutants
BTX	benzene, xylene and toluene	IG PAS	Institute of Geophysics, Polish Academy of Sciences	PPSH	Polish Polar Station Hornsund
CCN	cloud condensation nuclei	INAR	Institute for Atmospheric and Earth System Research	PSAP	particle soot absorption photometer
CEACs	chemicals of emerging Arctic concern	INP	Ice Nucleating Particles	PTFE	polytetrafluoroethylene
CFCs	chlorofluorocarbons	IOPAN	Institute of Oceanology Polish Academy of Sciences	PUF	polyurethane foam
CFRs	chlorinated flame retardants	KOPRI	Korean Polar Research Institute	QA/QC	quality assurance/quality control
CFUs	colony forming units	LC	liquid chromatography	QFF	quartz fiber filter
CNR-ISP	Italian National Research Council Institute of Polar Sciences	MAAP	Multi Angle Absorption Photometer	RAS	Russian Academy of Sciences
CNRS	French National Research Council	MgO-UV	magnesium oxide	rBC	refractory black carbon
CPC	Condensation Particle Counter	MOSAIC	Multidisciplinary drifting Observatory for the Study of Arctic Climate	RGM	reactive gaseous mercury
CRDS	cavity ring-down spectroscopy	MS	mass spectrometer	RNA	ribonucleic acid
CUPs	current-use pesticides	MSA	methanesulfonic acid	RV	research vessel
CVAFS	Cold Vapor-Atomic Fluorescence Spectrophotometry	NanoSIMS	nanoscale secondary ion mass spectrometer	SAS	Surface Air System

cVMS	cyclic volatile methyl siloxanes	NILU	Norwegian Institute for Air Research	SEM-EDX	Scanning Electron Microscopy / Energy Dispersive X-Ray Spectroscopy
DAPI	4',6-diamidino-2-phenylindole	NOAA/CMDL	National Oceanic and Atmospheric Administration's (in the USA) Climate Monitoring and Diagnostics Laboratory (currently ESRL)	SMPS	Scanning Mobility Particle Sizer
DFPC	Dynamic Filter Processing Chamber	NCSR	National Center for Scientific Research (Greek)	SP2	single-particle soot photometers
DNA	deoxyribonucleic acid	NPI	Norwegian Polar Institute	SpC	specific electric conductivity
EANET	Acid Deposition Monitoring Network in East Asia	OC	organic carbon	SPMDs	semipermeable membrane devices
eBC	equivalent black carbon	OCPs	organochlorine pesticides	TFA	trifluoroacetate
EC	elemental carbon	OPC	optical particle counter	TFMS	trifluoromethane sulfonic acid
EMEP	European Monitoring and Evaluation Programme	OPEs	organophosphate esters	TSP	Total Suspended Particulate
FID	flame ionisation detector	OPS	optical particle sizer	UAVs	Unmanned Aerial Vehicles (a.k.a. drones)
GC	gas chromatograph	PACs	polycyclic aromatic compounds	UNIMIB	University of Milan Bicocca
GC-ECD	gas chromatography with electron capture detection	PAHs	polycyclic aromatic hydrocarbons	UNIS	University Centre in Svalbard
GEM	gaseous elemental mercury	PAS	passive air sampler	US EPA	United States Environmental Protection Agency
GFF	glass fiber filter	PBDEs	polybrominated diphenyl ethers	VOCs	volatile organic compounds
GVB	Gruvebadet	PCBs	polychlorinated biphenyls	WSOC	water-soluble organic carbon
HCBD	hexachlorobutadiene	PCNs	polychlorinated naphthalenes	XRF	X-ray fluorescence spectroscopy

106 1 Introduction

107 Atmospheric pollution research and monitoring in Svalbard occupies a significant position in pan-Arctic
 108 research on priority pollutants (AMAP 2016, 2017), providing observations of their long-range
 109 atmospheric transport (Iversen and Joranger 1985; Hung et al. 2010). Atmospheric research in
 110 Svalbard has been increasing in diversity and magnitude in the recent years, with more
 111 comprehensive long-term observational efforts and numerous short-term intensive field experiments.
 112 Coordination of the research and scientific exchange in terms of common sampling and analytical
 113 protocols, joint data analysis, publications, and related planning of future research has growing
 114 potential. It presents two advantages: lowers the environmental footprint of researchers coming to
 115 Svalbard (by reducing the numbers of people necessary to collect samples for various impurities) and
 116 allows to see a bigger, interconnected picture of environmental processes.

117 In this chapter, we collect information from various sources on the state of the research and monitoring
118 of priority pollutants and other impurities in the atmosphere over Svalbard, bridging the chemical,
119 biological and supportingly physical monitoring efforts. By atmospheric impurity we consider any kind
120 of substance that is dispersed in the atmosphere, whether in gaseous or particulate form. The
121 definition encompasses molecules of various sizes and chemical composition, to biological cells and
122 small organisms, referred to as aerial plankton. Among physical properties of the atmospheric aerosol,
123 we mention mainly the AOD as a basic parameter monitored in Svalbard, however it is elaborated on
124 elsewhere (e.g. in the LOAD-RiS chapter). Unfortunately, it is impossible to list every short-term
125 dataset from a campaign conducted in Svalbard, hence we only strive for a representative overview
126 with a focus on long-term monitoring programmes. The opportunities for harmonising several types of
127 measurements are sought in this work, and the distribution of measurements across Svalbard is both
128 an opportunity and a hindrance, hence the first iteration of the problem is divided by geographical
129 locations. Direct monitoring of the atmospheric impurities is also closely connected to their deposition
130 in precipitation, and hence we mention here the efforts in precipitation sampling which may lead to
131 synergy with aerosol or air sampling, yet we have to restrict considerations of the topic to such cases
132 alone (excluding, for example, the literature on ice cores collected in Svalbard).

133 In the past, there have been a few chapters of SESS Reports showing a particular fraction of the vast
134 topic of atmospheric impurities (Gallet et al. 2019; Malard et al. 2019; Petkov et al. 2019; Viola et al.
135 2019; Gilardoni et al. 2020; Mazzola et al. 2020; Sipilä et al. 2020; Singh et al. 2021; Traversi et al.
136 2021; Petkov et al. 2022). In the interest of efficient information processing, we will only refer to topics
137 previously described in SESS reports to the extent which is necessary to understand the potential for
138 harmonisation between the already described and other atmospheric components. The same
139 approach is taken with the parallel chapters in this report on mineral dust (SVALDUST) and AOD
140 measurements (LOAD-RiS). Due to the focus on measurement harmonisation and the best potential to
141 do so for lower tropospheric, ground-based measurements, we will narrow our focus to this kind of
142 experiments and monitoring programmes.

143 **2 Overview of existing knowledge**

144 **2.1 Existing monitoring and available datasets**

145 **2.1.1 Atmospheric impurity monitoring in Ny Ålesund**

146 Ny Ålesund has an unparalleled position in the Arctic and Svalbard atmospheric impurity monitoring,
147 holding two main facilities with an elevation difference of 425 m (Gruvebadet at 50 m and Mt. Zeppelin
148 at 475 m asl), and several facilities dispersed in its vicinity (Figure A1). It offers a unique opportunity
149 for harmonised studies of atmospheric impurity differences with elevation (within and beyond the
150 boundary layer) and between multiple impurities. For example, a recent study (Song et al. 2022) has
151 explored the sources of atmospheric particles in Ny-Ålesund with machine learning, showing the
152 importance of secondary aerosol in cloud condensation processes and predicting non-linear changes
153 in aerosol composition with temperature changes (resulting from climate change).

154 The earliest regular monitoring work at Ny Ålesund has been conducted by NILU, starting as early as
155 1989 (for SO₂ and SO₄²⁻ measurements), although earlier short-term studies have been conducted
156 there, e.g. in 1980-83 on organochlorine POPs by Oehme and Ottar (1984). Their main facility is
157 located on top of Mt. Zeppelin (joined since by other institutions), a unique site with much smaller
158 influence of the local contamination factors than any other land-based station in Svalbard due to its
159 elevation. NILU is collecting data on a wide range of variables there, from inorganic ions and gaseous

160 compounds (oxides of carbon, sulphur and nitrogen, also H₂ and NH₃), through various forms of
161 mercury in atmospheric air, to metals and metalloids in precipitation. Carbon dioxide concentrations
162 are monitored there by Stockholm University; in parallel, weekly flask samples have been analysed for
163 trace gas concentrations by NOAA/CMDL. The monitoring programme at Zeppelin spans also organic
164 compounds: greenhouse gases (CH₄, fluorinated gases), POPs and selected CEACs (AMAP 2011,
165 2016; Carlsson et al. 2016; AMAP 2017; Platt et al. 2022; Xie et al. 2022b), saccharides, VOCs and
166 more (ebas-data.nilu.no/; see also section 6. *Data availability*). Furthermore, selected POPs and
167 CEACs have been detected in air samples from Ny-Ålesund (as well as Longyearbyen, Barentsburg
168 and Hornsund) via diverse national research projects (Table A1 & section 6. *Data availability*). The
169 concentrations of most POPs listed for control under the Stockholm Convention, e.g. PBDEs, PCBs
170 and OCPs, showed clearly seasonal variation and declining trends over the year from 1990s to 2021
171 (AMAP, 2016; Wong et al. 2021). Given the advances of sampling and analytical techniques, more
172 and more novel CEACs have been identified and quantitatively detected in Arctic air (see Appendix
173 Table A1; Xie et al. 2015; Wong et al. 2021). Unfortunately, the time trends of CEACs are not as clear
174 as those for classic POPs, and the relatively high concentrations of CEACs in Arctic summer imply the
175 impact of local sources or reemission from cryosphere (AMAP 2017; Xie et al. 2022a).
176 Studies of CEACs from Svalbard testify also to the transport, persistence and impacts of these
177 chemicals in the Arctic (Hao et al. 2021; Li et al. 2022).

178 A large part of the atmospheric impurity research at Ny-Ålesund is nowadays located also in the
179 Gruvebadet atmospheric laboratory (GVB), about 1 km away from the main settlement. The GVB is
180 dedicated to the study of the atmospheric composition and the atmosphere-cryosphere interaction.
181 The laboratory is equipped with several instruments dedicated to aerosol studies (see positions 12 -
182 29 in *section 6 table / Table A2 in Appendix*). The accessible roof holds an installation of both
183 sampling heads and full samplers (Figure 1). Several continuous measurements are performed at
184 GVB to fully characterise the aerosol composition within the planetary boundary layer during the entire
185 year and with dedicated experimental campaigns. Specialty areas of GVB laboratory include size-
186 segregated chemical and optical analyses of particulate matter (PM₁₀), including trace elements,
187 WSOC, and BC forms, microplastics, additives, plasticizers and other CEACs, as well as INP
188 properties, all performed with state-of-the-art analytical techniques. Multi-decadal results of eBC (see
189 section 2.2 for a definition of eBC) are available in Svalbard from Zeppelin; since 2010, these data
190 have been integrated into the measurements at the Gruvebadet laboratory (cf. Gilardoni et al. 2020).
191 Continuous monitoring of the optical (scattering and absorption) and physical (dimensional distribution)
192 properties of the in-situ aerosol using semi-automatic instrumentation (nephelometer and SMPS and
193 APS absorption photometer) are conducted in collaboration between Italian institutions running GVB
194 and AWI (Germany), INAR (Finland), the University of Stockholm (Sweden), the NCSR "Demokritos"
195 (Greece) and KOPRI (Republic of South Korea). Recently (in 2021), a measurement campaign of
196 particle fluxes using the eddy covariance technique was conducted, collecting measurements of
197 momentum flows and ultrafine particles with a sonic anemometer and a condensation meter CPC.
198 Flow measurements of dimensionally segregated particles were conducted through the use of an
199 optical counter OPC. A passive sampler for dry deposition of aerosol, and a "Cyclone" sampler
200 collecting spores and pollen, compliment the programme at this supersite.

201 The GVB facility is also used to study the atmosphere-cryosphere interaction (in tune with a SESS
202 Report recommendation by Gallet et al., 2019), through a parallel programme of snow monitoring (for
203 wet and dry deposition), showing the role of snowpack as a chemical sink of emissions from rock
204 weathering, forest fire, marine and biogenic emissions, and anthropogenic contaminants, such as BC,

205 secondary aerosols (e.g., SO_x, NO_x), complex organic pollutants (e.g. POPs) and heavy metals (e.g.,
206 As, Cd, Pb). Quantifying the concentrations of those impurities in the seasonal snowpack allows to
207 understand the accumulation and depletion mechanisms, and in consequence to assess the total load
208 of contaminants potentially released by spring melt into the local food chain. Furthermore, air-snow
209 exchange may significantly interfere with atmospheric concentrations of PFASs at Ny-Ålesund,
210 showing strong snow to air evaporation for fluorotelomer alcohol and fluorotelomer acrylates (Xie et al.
211 2015). For atmosphere-cryosphere interaction studies, a weekly sampling of the entire snowpack has
212 been adopted – by snow pit approach, with a vertical resolution of 10 cm. Snow is then analysed to
213 quantify the concentration of the elements and compounds (at CNR-ISP), the BC loading (at NPI) and
214 to characterise the microbial community (at Universite De Lyon\CNRS). Snow density and stratigraphy
215 data support the chemical data interpretation, and an automated nivometric station works near the
216 GVB site since 2020.

217



218

219 **Figure 1:** Overview of the instruments placed atop Gruvebadet atmospheric laboratory roof. (Photo:
220 Marco Casula)

222 It is worth mentioning that at GVB, several measurements have been intergrated into one sampling
223 protocol, described partially in the studies using the data collected there (Scalabrin et al. 2012;
224 Zangrando et al. 2013; Turetta et al. 2016, 2021; Feltracco et al. 2019, 2020, 2021b, a). The currently
225 developing project BETHA-NyÅ (RiS ID 11924) aims to further harmonise aerosol measurements at
226 GVB and Zeppelin, as has been postulated in a SESS Report by Traversi et al. (2021).

227 **2.1.2 Other land-based atmospheric impurity research in Svalbard**

228 Besides the atmospheric measurement hub at Ny Ålesund, the main air impurity screening sites in
229 Svalbard are located in Longyearbyen, Barentsburg, and Hornsund, however studies on specific
230 topics may be encountered in other locations, such as Petuniabukta. One of the earliest monitoring
231 sites in the Norwegian Arctic (including Svalbard) was Bjørnøya – the inorganic compounds in
232 atmospheric air and aerosol have been measured there since 1977 (SO₂ in atmospheric air,
233 <http://ebas.nilu.no/>). Important discoveries at the time have been based on this station functioning, e.g.
234 Iversen (1989) showing the meteorological mechanism of long-range atmospheric transport causing
235 winter/spring pollution maxima. The measurements in Bjørnøya were phased out in 1989.

236 In Longyearbyen, a strong focus of atmospheric impurity research was on local and regional pollution.
237 A fully equipped sampling observatory has been established on the roof of UNIS, with several high
238 volume air samplers (TISCH, Cleves, OH, USA, Type TE-1000BL, US EPA TO-A4, TO-9A). Further
239 campaign-based studies were conducted at the former Aurora observatory in Adventdalen, and in
240 collaboration with SvalSat on the adjacent Plateau mountain. During the past years, in Longyearbyen,
241 POPs and novel CEACs have been detected in gaseous and/or particle phase during research
242 projects (including novel PFAS, PCBs and PAHs and their major transformation products).

243 The research conducted in Longyearbyen has been instrumental in documenting the transition from a
244 coal-mining-based community to a settlement relying mostly on services as an income source, with
245 both sources contributing to local air pollution. Coal mining has been present in Longyearbyen (and
246 Svalbard in general) since the early 1900s when John Munro Longyear established the first mining
247 infrastructures in Adventdalen (Westby & Amundsen, 2003; Kvello, 2004). Since then, five major
248 locations across Svalbard had large coal mining infrastructures established and operated (Table A3 in
249 Appendix). After the Norwegian government decided to abandon coal mining on Svalbard (in 2017),
250 other business activities like services, municipality, research, education, building and maintenance, as
251 well as international tourism, have replaced coal mining as professional areas in Svalbard (Avango
252 2020).

253 Today, around 3000 inhabitants are living and working in Svalbard, mainly in Longyearbyen (2400)
254 and Barentsburg (400). All settlements in Svalbard are isolated infrastructures: life-supporting services
255 such as heating, electric power, water supply and waste handling need to be provided on-site. In
256 addition to high costs of infrastructure operation, settlements in Svalbard have a significantly higher
257 ecological footprint per inhabitant compared to mid-latitude locations, where infrastructure is shared.
258 An earlier report by the Norwegian Environmental Agency concluded that Svalbard man-made CO₂
259 emissions (produced by ca 3000 people = 0.06% of the total population) accounted for ca 1% of the
260 total Norwegian CO₂ emissions in 2009 (Vestreng et al., 2009). Hence, the local emissions are
261 important to control - also to minimize exposure risk for local populations (e.g. to CEACs).

262 For two decades now, Svalbard settlements were comprehensively investigated for local pollution.
263 Transportation and emissions from gasoline-fuelled engines are an important local contamination
264 source on Svalbard. Shipping, the operation of heavy-fossil-fuel-driven vehicles (e.g. lorries), and
265 private transportation (cars, snowmobiles) contribute significantly to the local pollution profile. Reimann
266 et al. (2009) reported on the emission of VOCs in Longyearbyen, especially BTX, from snowmobile
267 exhaust. Elevated BTX levels were attributed to the extensive use of two-stroke engine snowmobiles
268 in November – June. Those BTX emission levels were similar as in a medium size European city, like
269 Zürich (400 000 inhabitants). Also for PAHs, elevated air concentrations were confirmed to come from
270 fossil-fuel-driven engines, both in and around Longyearbyen. A variety of local sources such as a local
271 fuel station, the coal power plant and various municipal installations were confirmed. Unlike BTX,
272 PAHs are environmentally stable contaminants and hence were subsequently found in surface soil
273 along major snowmobile tracks near Longyearbyen.

274 PAHs are relevant local pollutants, and coal-fired power plants both in Longyearbyen and Barentsburg
275 are identified as their major local source. A recent comprehensive study investigated the emission
276 profile and the rapid atmospheric transformation process for PAHs (Marquès et al. 2017; Drotikova et
277 al. 2020, 2021). Air samples from three locations, at increasing distances from the source (0 – 8 km
278 from the power plant), were investigated for PAHs and their major transformation products (oxy- and

279 nitro-PAHs). Seasonal profiles have thus been described for the PACs: during polar day, rapid
280 photochemical transformation eliminates nitro-PAHs, while oxy-PAHs are less affected.

281 In the past years, a variety of new organic pollutants were identified as local contaminants in Svalbard
282 (AMAP 2017; Kallenborn et al. 2018). Among CEACs, PFASs were found to be directly emitted from
283 Svalbard installations, mainly at the local airports (Longyearbyen, Ny-Ålesund, Svea – the fire fighting
284 training locations) and local waste dumps (Skaar et al. 2019; Ali et al. 2021). Elevated levels of PFAS
285 in the local food webs were confirmed both in Ny-Ålesund and Longyearbyen. Recently, a study on
286 surface snow revealed the presence of novel ultra-short PFASs in the vicinity of Longyearbyen
287 (Foxfonna glacier). Here, the photochemical transformation of long-chain precursor PFAS led to
288 elevated levels of TFA and TFMS in surface snow. TFA was also identified in drinking water in
289 Longyearbyen (Nödler, pers. comm.), proving the importance of PFAS emission screening.

290 In Barentsburg, aerosol measurements started in 2011 (Sakerin et al 2012; Golobokova et al 2013).
291 Since 2016 systematic measurements of optical, microphysical and chemical aerosol properties have
292 been conducted by researchers from RAS and AARI (Chernov et al 2016, Sakerin et al 2018; Sakerin
293 et al 2019). AOD, and other physical properties including eBC concentration, were measured by sun
294 photometer (since 2015), aetholometer, integrating nephelometer and a photoelectric particle counter
295 (Sakerin et al 2012; Chernov et al 2016; Sakerin et al 2019). Aerosol was sampled for further
296 measurements of chemical composition, for example the concentration of major inorganic ions and
297 trace metals (Chernov et al 2016, Sakerin et al 2018, Golobokova et al 2020). The sampling was
298 performed according to EANET and EMEP guidelines (EMEP 2001). Alternating daily and weekly
299 modes, 14 – 18 m³ of air was pumped through a four-stage filter holder at 2 m above the ground on
300 the south side of Barentsburg Meteorological Observatory (V. Radionov, pers. comm). Seventeen
301 PAHs concentrations were also measured there in aerosol (Sep -Oct 2017; Golobokova et al 2020).

302 Chemical composition of the atmospheric boundary layer was observed daily in April – September in
303 2011-2015, monthly from April 2016 to 2018. Since 2016, atmospheric gases (CO₂, CO, SO₂, H₂S,
304 NO_x, O₃ and gaseous Hg) have been automatically monitored, maintained by AARI, and data was
305 occasionally used for comparisons with other sites in Svalbard. Since 2019, aerosol is sampled
306 weekly. The highest ion concentrations were measured in 2011-2012 during the renovation of
307 Barentsburg. After the introduction of filter system on Barentsburg power plant in 2012, the total ion
308 concentrations were halved by 2016, and slightly increased after (Sakerin et al 2018). Generally,
309 concentrations increase in winter-spring period and slightly drop in May-June, with sea spray as a
310 main source of aerosol throughout the year and the local influence of coal mining and power plant
311 exhaust more prominent during the polar night (Golobokova et al 2020).

312 RPA “Typhoon”, North-West branch (Saint-Petersburg) ground-based monitoring programme includes
313 the analysis of atmospheric aerosol for 16 PAHs, PCBs and trace metals, since 2002 (Demin et al.,
314 2011). Apart from direct measurements, method development and intercalibration exercises with NILU
315 were conducted. Samples have been collected twice a year in spring (March) and late summer
316 (August) by a multichannel sampler PU-4EP (Russia) simultaneously on three filters AFA-HA-20
317 (acetate cellulose fibrous material with electrostatic effect, 20 cm²) at three sites in Barentsburg and
318 outside the settlement (Demin et al., 2011, E. Yaeski, pers comm). The methods of sampling and
319 analysis remain unaltered for the whole period of observations.

320 The Governor of Svalbard, in collaboration with the Norwegian Environmental Protection Agency
321 (Miljødirektoratet), commissioned a Svalbard-wide survey on potential local sources of PCBs in 2007
322 (Lundkvist et al., 2008). Virtually in all settlements on Svalbard, elevated PCB concentrations were

323 found in the local environment; decommissioned and defect technical equipment (like transformers)
324 was identified and removed for proper destruction. This first survey noted the paucity of information on
325 PCB contamination from Russian settlements and hence a dedicated campaign for mapping PCB
326 contamination in Barentsburg and Pyramiden was initiated (Evenset et al., 2009). The authors
327 concluded that although local emissions were considered high, the majority of Svalbard PCB pollution
328 stems from decades of atmospheric long-range transport.

329 In southern Spitsbergen, long-term monitoring of several atmospheric pollution parameters is carried
330 out in the PPSH (at Hornsund). PPSH is the longest operating site in the AERONET network in
331 Svalbard, providing, i.a., continuous cloud-screened observations of spectral AOD since 2004. Aerosol
332 studies have been complemented with ceilometer data since 2017. Extended measurements of
333 aerosols in the atmosphere were conducted there in the years 2009-2015, when Raman lidar was
334 operational (Pietruczuk and Karasiński 2010), detecting the impact of volcanic ash (Karasiński et al.
335 2013) or wildfires (Markowicz et al. 2016) on the atmosphere of Svalbard. In the spring of 2021, more
336 detailed data on the concentration of the aerosol and its size distribution were collected using the OPS
337 3330 and NanoScan SMPS 3910 TSI spectrometers.

338 Chemical composition of aerosol is also monitored at PPSH, however less comprehensively. PPSH is
339 one of the northernmost continuous monitoring sites of radionuclides in the ground-level atmosphere
340 since 2002 (Mysiek-Laurikainen et al. 2006), recently expanded to include EcoGamma environmental
341 gamma radiation monitor. This monitoring additionally provides information on the concentration of
342 dust deposited on the Petrianov filters replaced in AZA-1000 at weekly intervals (Burakowska et al.
343 2021). The measurements have confirmed an influx of radioactive isotopes into Svalbard after the
344 Fukushima nuclear power plant disaster (Burakowska et al. 2021), which was visible also in Ny-
345 Ålesund (Paatero et al. 2012). Besides this ongoing programme, recent measurements have been
346 made in Hornsund within the scope of short-term projects Sea-snow POPs (RiS ID 11108) and HiLDA
347 (RiS ID 11195) since 2019 (Figure 2), to determine organic compounds concentration in the
348 atmospheric air at PPSH and to characterise mineral and antropogenic compounds in atmospheric
349 particulate matter.

350 Since 2004, monitoring of the chemical composition of precipitation (rain and snow) has been carried
351 out in Hornsund (Figure A1, see also section 6). Samples are collected: 1) ~500 m north of PPSH
352 (from a HDPE precipitation collector, daily) after each rain or snowfall; 2) on glaciers (Hansbreen until
353 2019; Ariebreen since then) after each snowfall near the ablation poles (into PE bags); 3) in an
354 elevation transect from the seashore to the summit of Fugleberget, irregularly (into PE bags). All
355 physico-chemical analyses are carried out in the PPSH chemical laboratory. After pH, conductivity and
356 HCO_3^- titration measurements, samples are filtered (on 0.45 μm cellulose membrane filters) and
357 analysed for the major ion composition using ion chromatography (now a Methrom 930 Compact IC).
358 The precipitation composition data collected by PPSH, before and after 2004, allowed to characterise
359 rain and snow composition origins (e.g. Pulina, 1991; Głowacki, Leszkiewicz, 1994; Głowacki, Pulina,
360 2000; Burzyk et al. 2001; Krawczyk et al., 2002; Krawczyk and Skręt, 2005; Kozak et al. 2015), spatial
361 differences in precipitation chemistry (e.g. Krawczyk et al. 2008), and the impact of wild fires and long-
362 range transport (e.g. Bryś 2002; Głowacki and Krawczyk, 2002; Ruman et al. 2014; Kozak et al. 2015;
363 Nawrot et al. 2016).



364

365 **Figure 2:** The environmental chamber facility of the PPSH, with various sampling heads exposed on
366 the roof in the spring 2019; a rainfall collector is located 100 m eastwards from there (Photo: K. Koziol)

368 **2.1.3 Specific study topics with atypical or sparse spatial representation**

369 Aeolian dust studies in Svalbard, recently renewed after a dormant phase since the 1980s (e.g.
370 Pełkala 1980; Åkerman 1983; Gębica and Szczęsny 1988), are limited to a few sites. Direct
371 observational data exist only for Ny-Ålesund (Moroni et al. 2015, 2016, 2018; Gallet et al. 2018; Conca
372 et al. 2019; Jacobi et al. 2019) Hornsund (Migala and Sobik 1984; Kavan et al. 2020; Lewandowski et
373 al. 2020; Spolaor et al. 2021); and Longyearbyen (e.g. Khan et al. 2017; Kandler et al. 2020). Apart
374 from that, there are only two studies from Petuniabukta area, central Svalbard (Kavan et al. 2020;
375 Rymer et al. 2022). The studies at Ny Ålesund were conducted by ground level active filtering (Conca
376 et al. 2019), or vertical profiling (Moroni et al. 2015, 2016); the detailed mineralogical and chemical
377 composition of the aerosol was reported by Moroni et al. (2018). Aeolian processes are also monitored
378 as the deposition of material on snow (Khan et al. 2017; Gallet et al. 2018; Jacobi et al. 2019; Kavan
379 et al. 2020; Lewandowski et al. 2020; Spolaor et al. 2021). The only direct deposition of dust was
380 observed by Rymer et al. (2022) with the passive samplers in central Spitsbergen. Quantifying mineral
381 dust deposition remains a challenge due to its large spatial and temporal variability - the measured
382 deposition rates vary, are site-specific, and depend on the method used.

383 Another sparsely distributed type of measurement across Svalbard is aerobiological sampling.
384 Aerobiology research is a relatively nascent field in Svalbard - few studies have been published from
385 the archipelago on aerial microbiology and aerial plankton, the transport of pollen and eukaryotic
386 spores, both of local and long-range origin (cf. Figure A1). Johansen and Hafsten (1988) revealed
387 pollen, bryophyte and fungal spores in Burkard trap at Ny-Alesund, most of them of local origin.
388 However, Polunin (1955) found mostly exotic pollen species for Svalbard including *Pinus* pollen
389 highlighting the role of long-range transport. In a study on bacterial diversity in the air over Svalbard,
390 biodiversity was found to be similar to other, both polar and non-polar environments. The identification
391 of viable bacteria suggests that living bacteria are ubiquitous in the air around Svalbard (Cuthbertson
392 et al. 2017). In a 6-month study on the bacterial community composition in the atmosphere at
393 Ny-Ålesund, community structure exhibited seasonal dynamics that mimicked the different stages of
394 bacterial colonization of algal blooms in the surrounding fjords. This highlights the importance of open
395 water as a source of airborne microorganisms (Feltracco et al. 2021a). In a cultivation-dependent
396 study (likely to underestimate the number of live air-borne microorganisms), fifteen fungal taxa were
397 isolated from the air of Longyearbyen (Pusz and Urbaniak 2021). Currently, no long-term monitoring
398 programmes focus on aeromicrobiology in Svalbard, although the project ArcticBioAir (RiS: 11752) is

399 generating pilot data to determine the potential of such monitoring. Finally, despite the
400 microinvertebrates predominating in faunal diversity of polar regions and playing a pivotal role in
401 matter flow, the majority of studies investigate microinvertebrate transport only by migratory birds,
402 humans or imported soils (Coulson et al. 2013; Pilskog et al. 2014). Few studies discuss passive
403 transport of invertebrates by wind at all (Hodkinson et al. 2001; Coulson et al. 2002, 2003; Coulson
404 2015), and among them, only two test aerial transport empirically (Coulson et al. 2002, 2003).

405 **2.1.4 Atmospheric impurities research from the seas surrounding Svalbard**

406 A complimentary element of atmospheric impurity monitoring in Svalbard is its presence in the
407 seas around the archipelago. While sampling techniques and protocols match those used on land,
408 marine research is tied geographically to cruise routes and thus repeated measurements concern a
409 wider area instead of an exact location of the sampling site. Challenging atmospheric conditions at sea
410 introduce potential measurement hindrance, e.g. the dense fog, strong wind and breaking wave.

411 Since 2004, AOD instruments have been deployed periodically on various ships on waters around
412 Svalbard Island: RV Oceania (2007, 2009-2020, e.g. Leck et al. 2001; Tjernström et al. 2014;
413 Heintzenberg et al. 2015), the Swedish ice-breaker *Oden* (2008; ASCOS campaign - Chang et al.
414 2011; Sierau et al. 2014), RV Polarstern (2012, 2015, 2017, 2020), RV Jan Mayen (2009); RV
415 Akademik Mstislav Keldysh (2016; Terpugova et al. 2018) and RV Alliance (2021). The IOPAN RV
416 Oceania participates in the Maritime Aerosol Network, the component of AERONET network, and
417 provides ship-borne AOD measurement since 2007 in the Norwegian and Greenland Seas. Since
418 1987, IOPAN has been conducting a regular, annual AREX Arctic Expedition (Węśławski and Sagan
419 2020), performing meteorological surveys, measuring aerosol fluxes, physical and optical properties of
420 aerosols from the start. Those cruises were conducted year by year with almost the same research
421 plan, with continuity and repeatability both in time and space, covering about 90 days in the Arctic
422 each summer (Ferrero et al. 2019; Pakszys et al. 2020). The RV Oceania's annual summer cruise is
423 one of the longest monitoring programmes conducted in the Svalbard seas. Recently, in collaboration
424 with the UNIMIB, also PAHs, n-alkanes, organic matter and trace elements have been added,
425 irregularly.

426 The German research icebreaker RV Polarstern (of AWI) has a longer history with the Arctic than RV
427 Oceania, initiated in 1991, continuing between 2001 and 2021 (2009, 2012, 2015, 2017, 2020, 2021),
428 crowned with the longest, over one-year cruise of the MOSAiC expedition across the Arctic. MOSAiC
429 was the first year-round expedition into the central Arctic exploring the Arctic climate system drifting
430 with the sea ice across the central Arctic from September 2019 to October 2020, for example
431 launching radiosondes onboard. AWI's polar research aircraft and UAVs played an important part in
432 atmospheric investigations throughout MOSAiC (Mazzola et al. 2020; Griesche et al. 2020).

433 Air quality monitoring on the sea is especially important in the context of sea-air exchange
434 phenomena. Substantial evidence from observations and modelling shows the impact of climate
435 change on the biogeochemical cycle of POPs and CEACs in the Arctic, pertinent to both the seas and
436 the atmosphere (Ma et al. 2016). For instance, many legacy POPs have revolatilized into air from
437 water, snow or ice as a consequence of sea ice retreat and rising temperatures (Ma et al. 2011).
438 Besides, many CEACs were likely transported with ocean currents and waves from the low and
439 medium latitudes to the High Arctic. The warm Atlantic seawater may bring CEACs such as ionic
440 PFASs, OPEs and PPCPs into the waters surrounding Svalbard and influence their atmospheric levels
441 through air-water gas exchange or sea spray (Li et al. 2017; Sha et al. 2022). Both ship-based and

442 stationary observations in Svalbard have shown that air-water/snow gas exchange alters the
443 atmospheric concentrations of chemicals (Yu et al. 2019; Araujo et al. 2022; Dastoor et al. 2022).

444

445 **2.2 Sampling techniques and data collection protocols**

446 The liquids and solids dispersed in the atmospheric air (i.e. aerosols, PM) encompass both inorganic
447 and organic chemicals, frequently in mixed particles, particles of specific optical properties, such as
448 BC, and more complex and larger airborne impurities, such as pollen, microplastics, and small living
449 organisms. Some of these substances have closely related aerosol and gaseous forms, e.g. sulphate
450 in aerosol which comes from the dissolution of gaseous SO₂. With such a variety of analytes, a suite of
451 analytical approaches needs to be employed for their qualitative and quantitative characterisation.
452 However, since the mode of transport is similar for multiple species of similar molecular or particle
453 size, there can be also found similarities in sample collection approach – which allow for
454 harmonisation of several measurement types in one monitoring protocol. In harmonisation attempts,
455 key variables to consider are sampling consumables type (e.g. filter material or pore size), exposure
456 time (or sampled air volume), and the analytical steps leading to final results.

457 The first group of chemicals with harmonised sampling regimes in the Svalbard monitoring is gaseous
458 constituents measured on-line, such as the greenhouse gases (CH₄, CO₂, HFCs, SF₆), O₃ and several
459 ozone-depleting chemicals (CFCs, HCFCs, halones, and other halogenated organic gases). The on-
460 line measurements offer quick access to analytical results and high sampling frequencies, e.g. NILU
461 monitors 23 gases at Zeppelin at least once per 4 hours (every 5 minutes for O₃). Most of these
462 measurements are provided by automated GC systems with different detectors: FID for methane,
463 MgO-UV for carbon monoxide, and MS for halogenated compounds (Myhre et al. 2010). CH₄
464 concentrations may also be measured with CRDS (ebas-data.nilu.no/). For longer-term averages,
465 weekly flask sampling has also been used in trace gas analysis by NOAA CMDL.

466 Inorganic ionic species in atmospheric aerosol play an important role as source indices (Giardi et al.
467 2016; Udisti et al. 2016; Amore et al. 2022), for example, sodium and chloride are typically originating
468 from sea salt, bromide and iodide depend on the sea ice extent (Spolaor et al. 2013). Some of them
469 also play a role in climate forcing (Toon and Pollack 1980; Satheesh and Krishnamoorthy 2005),
470 exerting a cooling effect by light reflection and forming reflective clouds (especially sulphate). Their
471 role as CCN is also important (Merikanto et al. 2009). Since it is relatively easy to determine the
472 concentration of ions, they form a basis for further analyses and have been monitored in Svalbard for
473 a long time. The traditional method of sample collection for the analysis of inorganic ions in air and
474 aerosol includes a combination of denuders (glass and alkaline-carbon-coated) and filters (Beine et al.
475 2001). The filter pack captured both fine and coarse particulate matter (a Teflon filter, 1-µm pore size)
476 and acids evaporated from the front filter (a Nylon filter, 1-µm pore size). The analytical technique best
477 suited for the determination of inorganic ions collected by both denuders and filters is ion
478 chromatography. Collection times applied by Beine et al. (2001) were between 12 and 24 hours.
479 Nowadays, sampling and analysis of inorganic ions remains similar, yet with a large variety of modified
480 protocols. For example, Teinilä et al. (2003) used polycarbonate films and a sequence of membrane
481 filters with two types of impactors in their NICE campaign (at Ny-Ålesund). In Barentsburg, samples
482 were collected on a four-stage filter pack. The direct accumulation of aerosol took place at the first
483 PTFE filter (0.8 µm pore size; Golobokova et al 2013; Chernov et al 2016). Three other filters,
484 chemically pre-treated (EANET 2003), collected gases (filter 2: nitric acid, filter 3: sulphur dioxide,
485 hydrochloric acid, filter 4: ammonia). Similarly, Park et al. (2017), Becagli et al. (2019) and Jang et al.
486 (2021) used quartz filters to analyse sulphate and MSA concentration (at GVB). All the above studies

487 used a variation of 18 M Ω water extraction and ion chromatography as determination technique. The
488 variety of employed filter materials allows to harmonise ion analysis with a different particulate impurity
489 monitoring, using filterpapers dedicated to that purpose.

490 Alternatively, copper grids coated with carbon film may be used, combined with a later analysis by
491 electron microscopy (as in Chinese Yellow River Station). NanoSIMS may be used to analyse the
492 composition of individual aerosol particles then (Chi et al. 2015). At GVB, the equivalent of this
493 approach is using nucleopore polycarbonate membrane filters with a 12-stage low volume impactor
494 and analysis by SEM (see also section 2.1.1), which is also a way to study mineral dust composition.

495 For mineral dust quantification, most sampling protocols are rather individual and depend on the
496 device used (for active sampling procedures). The passive sampling in Rymer et al. (2022) used the
497 standard Marble Dust Collector traps (Hall and Upton 1988). An alternative sample collection strategy
498 involves snow cover sampling as a carrier of mineral dust deposition. Usually only the upper layer of
499 snow is sampled to avoid contamination from the ground surface.

500 Sampling for the determination of metals and metalloids is very similar to sampling for the
501 determination of ions, and sometimes different parts of the same filter are used for both determinations
502 (Zhan et al. 2014; Golobokova et al. 2020), which is an excellent harmonisation example. Analytical
503 methods, invasive and non-invasive, are used to determine the content of metals and metalloids. The
504 invasive method requires wet digestion of the sample, using e.g. nitric acid and microwaves as an
505 energy source. Subsequently, the content determination is performed using inductively coupled
506 plasma mass spectrometry (Berg et al. 2004; Demin et al. 2011; Zhan et al. 2014; Bazzano et al.
507 2016; Conca et al. 2019, 2021; Golobokova et al. 2020; Turetta et al. 2021). This method can also be
508 used to determine the isotope content of e.g. lead (Bazzano et al. 2016). It is also possible to
509 determine the content of the radioisotope ²¹⁰Pb using the automatic alpha/beta analyser (Paatero et al.
510 2003). A non-invasive method is to use XRF (Anderson et al. 1992; Shpartko et al. 2021).

511 Among metals, mercury is of special importance due to its toxic effects. Hg is determined in the air in
512 three forms: GEM, RGM and Hg-P (Gauchard et al. 2005). The most popular GEM determination
513 device is a Tekran gas-phase mercury vapor analyser, which uses the CVAFS technique: the
514 atmospheric air is passed through a gold trap, the gold forms an amalgam with mercury, and after a
515 specified enrichment time of the sample, thermal mercury desorption and final detection as HgO by
516 atomic fluorescence spectrometry is performed. For the other two types of mercury, they must first be
517 isolated from the air stream: for RGM, KCl-coated annular denuder or soda lime trap is used, and for
518 Hg-P, quartz filters are used. The enriched samples can then be analysed using the CVAFS technique
519 (Ferrari et al. 2005; Osterwalder et al. 2021). A detailed description of the repeatability of the method
520 has been made by Aspino et al. (2005).

521 BC particles have a unique combination of properties, including strong visible light absorption, being
522 refractory with an aggregate morphology, and insoluble in water and common organic solvents
523 (Gilardoni et al. 2020). BC mass concentrations are measured directly by incandescent and thermal
524 techniques or indirectly from absorption measurements using appropriate mass absorption cross-
525 section values as the conversion factor (Petzold et al. 2013). Different terms are used depending on
526 the property being measured. While rBC refers to incandescent measurements, EC is used for thermal
527 techniques and eBC is the term for optical or photoacoustic techniques. Intercomparison of different
528 techniques agrees within a factor of two. The principal measurement technique for BC is based on
529 SP2, using an online laser-induced incandescent method for size distribution of rBC. Total mass
530 concentrations and information on the mixing state of BC (a ratio of BC to total particle diameters) can
531 also be derived (Schwarz et al. 2010; Kondo et al. 2011). Long-term monitoring of BC in the

532 atmosphere is based on two other techniques. The first is the thermal-optical methods, which measure
533 EC and OC at the same time (Caiazzo et al. 2021). Active research networks have adopted different
534 protocols to quantify EC (see WMO/GAW (2016) for details). EC measurements may differ by up to a
535 factor of two due to differences in protocols, instruments, laser signals, and corrections for the
536 chemical character of OC (Karanasiou et al. 2015). Filter-based optical methods are another approach
537 taken for long-term BC monitoring, providing outputs as eBC. Instrumentation available in Svalbard
538 include the PSAP, aethalometer or MAAP (Petzold and Schönlinner 2004). Uncertainties in the filter-
539 based absorption techniques are caused by non-BC aerosol compounds, which can either absorb or
540 scatter the light when deposited on the filter, and by light scattering of the filter itself. Correction
541 schemes have been developed for the Arctic to account for the effects mentioned above in the
542 aethalometer absorption conversion (Backman et al. 2017).

543 Atmospheric POPs monitoring at Zeppelin is a key component of AMAP (e.g., AMAP 2016), and its
544 collection and analysis method are therefore well established. In order to generate high quality data
545 and comparable results, a standard operation protocol for air sampling and analysis has been
546 harmonised through the analytical laboratories working within AMAP for classic POPs including PCBs,
547 PBDEs, OCPs and PFASs. Standard operating procedures have been created on both active and
548 passive air sampling for POPs monitoring. Newer studies of POPs aspire to match the standard
549 techniques closely, e.g. at Barentsburg, PAHs and PCBs were determined in particulate matter
550 collected on GFF (14 m³ of air collected in 24 hours) (Golobokova et al, 2020). The concentrations of
551 PAHs were measured by a GC-MS (GC with MS detection) Triple Quadrupole system. In the RPA
552 “Typhoon” programme, less typically, 16 PAHs concentrations were determined with a HPLC with
553 fluorescence and diode array detectors. PCB analysis was performed with a GC-ECD (Demin et al.,
554 2011, E. Yaeski, pers comm).

555 A challenging topic for the sampling and analysis techniques is CEACs, due to variety of the
556 encountered substances, new substances being added to the catalogue, and their relatively low
557 concentration levels. As the concentrations of CEACs in Arctic air are usually at picograms to
558 nanograms per cubic meter (pg/m³ to ng/m³), suitable sampling and pre-concentration techniques are
559 essential to match the sensitivity of the analytical instruments. Active air sampling is performed with a
560 HVS equipped with a GFF or QFF for collecting atmospheric particles (cutoff points vary), and the
561 solid adsorbents, e.g. Amberlite XAD-2 resin, PUF or PUF-XAD-2 combination for the gaseous phase
562 (Röhler et al. 2020, 2021). Cellulose nitrate membrane filter (pore size: 1-5 µm) is used to trap
563 microplastics in the air. The sampling of CEACs is typically compatible with the former POPs collecting
564 programmes.

565 Passive samplers (PAS) have been also deployed to monitor the background level and annual trends
566 of POPs and CEACs in Svalbard (Li et al. 2022). Sampling media include PUF discs, XAD-2 resin and
567 SPMDs. The PASs are cost-effective, simple in operation, and could be deployed anywhere, e.g., on a
568 glacier or in remote sites without power supply. The application of PAS provides additional data - from
569 more locations.

570 Many other organic compounds are also screened in Svalbard by NILU, as can be ascertained from
571 the <http://ebas-data.nilu.no> database. Such compounds were collected by a HVS (besides selected
572 POPs, including PFAS, also carbohydrates such as levoglucosan, mannitol or sucrose, and other
573 substances, e.g. bisphenol A or triclosan; also total OC), PAS – a PUF plug (PAHs, OCPs, PCBs – a
574 campaign in 2006), steel canister (chosen alkanes and alkenes), glass flask (selected alkanes), and
575 adsorbent tube (selected aldehydes and ketones).

576 Given the diverse techniques and configurations developed for monitoring POPs and CEACs in Arctic
 577 air, sampling artifacts often occur along with the technique design, sampling material, and air-sampling
 578 interval, in particular: breakthrough, microbial and photo degradation, and equilibrium or non-
 579 equilibrium states regarding passive sampling (Bohlin-Nizzetto et al. 2020; Li and Wania 2021; Hao et
 580 al. 2021). The concentrations of certain POPs and CEACs could be underestimated by 30-95%
 581 (Melymuk et al. 2014), which might override their seasonal variations and mislead the assessment of
 582 their environmental fate and related risk. Therefore, the current challenge is to validate sampling
 583 approaches with a focus on the POPs and CEACs through interlaboratory comparison to achieve
 584 comparability of air impurity measurements in the Arctic. The detailed information on methodologies
 585 for air sampling, chemical analysis, data management and QA/QC were described in the literature and
 586 annual reports (NILU 2021).

587 A distinct set of methods is dedicated to aerobiology, while the basic collection mechanism resembles
 588 that for other particulates (Feltracco et al. 2021a). Aerobiological sampling methods involve impaction,
 589 impingement, membrane filtration (Figure 3) or drop plate mechanisms, which have been extensively
 590 reviewed in Griffin et al. (2011). Although efforts have been made to establish standard methodologies
 591 (Pearce et al. 2016; Dommergue et al. 2019; Jensen et al. 2022), no single ideal method exists. For
 592 example, microinvertebrates passively transported by wind are still collected by classical techniques,
 593 unchanged in decades. Each methodology has advantages and disadvantages (Table 1) – selecting
 594 the right one will depend on the research question. Recent developments in this regard include work
 595 by Ferguson et al. (2019), who evaluated airborne recovery efficiencies using filtration and liquid
 596 impingement and found filtration using polycarbonate filters to give the best recovery, with
 597 impingement recommended for shorter duration of sampling. Luhung et al. (2021) investigated DNA
 598 extraction efficiencies from filters and found direct extraction (by placing sampling filter into extraction
 599 kit) to result in underestimating total cell numbers. Instead, they suggested a two-stage approach: first
 600 removing biomass from the filter, then re-filtering onto a smaller, thinner membrane. Total bacterial
 601 count can be measured by growing cells on agar and counting the total number of CFUs and
 602 fluorescence microscopy on filters (combined with staining via a universal DNA stain such as DAPI, or
 603 a 16S-rRNA-specific probe such as EUB338) and molecular methods (Mayol et al. 2014; Cuthbertson
 604 et al. 2017). With the development of molecular sequencing methods (PCR, Sanger resp. Illumina
 605 sequencing), with improvements in microscopy, cell culture, and sampling methodology, along with
 606 modern sensitive sensors detecting changes in air composition – new possibilities opened up in
 607 quantifying the abundance, diversity and composition of several biological constituents in the air.

608 **Table 1:** Typical aerobiology sampling methods.

Method	Advantages	Disadvantages
Membrane filtration	Low expense, easy to use, high capture rate, possibility of combining biological and chemical analysis	desiccation of the microorganisms on the filter surface, filter size can impact particle loading, inefficient extraction of nucleic acids
Impingement	efficient for culture- and non-culture-based analyses, the liquid matrix can be split for various analyses	low-capture rates, loss of collection fluid to evaporation and violent bubbling, loss of viability, liquid incompatible with chemical analysis
Impaction	cell death from impaction is insignificant, efficient means of obtaining total counts of fungal spores, ease of use, portability, assessment of culturable populations of bacteria and fungi per volume of air	restricted use in the analysis of other microbial types (bacteria and viruses), loss of viability due to impact stress, loss of recovery efficiency, low sample volumes due to low flow rates

Sticky traps	Low expense, easy to use and install, perfect for counting of animals and plants directly on the trap.	Dedicated to invertebrates and plant particles, often destroy invertebrate specimens; cannot be used for quantifying bacteria and fungi
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609



610

611 **Figure 3:** For air sampling for microorganisms, there are a number of commercial options available.
 612 Key considerations are: a) direct collection or a filter size of 0.2 μm to capture bacteria, b) maximum
 613 flow rates for DNA yield, c) the ability ability to cope with the Arctic environment, d) a convenient
 614 power source (battery or generator) to enable long sample runs and e) preferably many users to
 615 provide data for comparison elsewhere. Pictured is one such example, the SAS Air Sampler as
 616 deployed in the field. (Photo: David Pearce)

617

618 3 Contributions to interdisciplinarity

619 An integral part of this chapter is connecting the chemical, biological and supportingly physical
 620 measures of atmospheric impurity loading, and certainly more work at this interface is warranted. The
 621 analysis of geographical distribution of atmospheric impurity measurements in Svalbard shows the
 622 most likely location for interdisciplinary studies in the Ny-Ålesund hub, as co-siting multiple
 623 measurements offers vast opportunities for the improved understanding of the Arctic environment as a
 624 whole. The internal harmonisation of measurements at Ny-Ålesund is already underway. Emerging
 625 disciplines, such as aerobiology or CEACs is likely to be enhanced there in the future. However, other
 626 locations offer a further insight into interdisciplinary problems, for example Longyearbyen – into
 627 screening the human impact during the change of predominant activity type in the area. Furthermore,
 628 climate-induced changes in spatial patterns and seasonality in air-impurity-related parameters need to
 629 be studied at more than one site to be comprehensively understood, and the Arctic is likely to face
 630 multiple non-linear changes (e.g. Song et al., 2022). The air impurity interactions with climate are likely
 631 to be at the forefront of interdisciplinary issues in Svalbard since multiple components of the
 632 atmospheric aerosol – of various origins, and both chemical and biological – can act as CCN and INPs
 633 (Varutbangkul et al. 2006; Möhler et al. 2008; King et al. 2012; Abbatt et al. 2019). Furthermore, both
 634 direct and indirect impact of aerosol upon radiation and precipitation components of climate has been
 635 noted (Toon and Pollack 1980; Satheesh and Krishnamoorthy 2005; Merikanto et al. 2009; Burgos et
 636 al. 2020; J. Allen et al. 2020), and the climate properties change air quality. Interdisciplinary aspects,
 637 such as impacts on cryosphere and ecosystems, are inherent in atmospheric impurity studies (Boy et
 638 al. 2019), as are the well-known connections to human health, social science and economy (IPCC
 639 2021, 2022a, b).

640 **4 Unanswered questions**

641 Within each field of atmospheric impurity research, there remain unanswered questions. For example,
642 researchers investigating mineral dust still ponder the origin of the deposited material, especially
643 whether it is local or long-range transported (e.g., Moroni et al. 2016, 2018; Conca et al. 2019; Kavan
644 et al. 2020; Lewandowski et al. 2020). Shrinking glaciers are expected to expose more mineral dust
645 sources locally (Zawierucha et al. 2019; Schuler et al. 2020; Geyman et al. 2022; Rymer et al. 2022).
646 Altitude effects are also of concern, as are seasonal changes. These concerns and open questions
647 are shared on a principal level with other atmospheric impurities, and they can be summarised as: the
648 question of changing origin (what is the proportion of local to long-range sources?), changing
649 seasonality (how do seasonal patterns in impurity concentrations change?), and unknown effects of
650 altitude. Additional concern is a question of climate impact of atmospheric impurities in such changed
651 conditions, through light scattering in the atmosphere, precipitation changes and albedo (surface
652 reflectivity) effects. In aerobiology, increasing temperatures in the Arctic along with an increasing
653 number of tourists spur a question about invasion of Svalbard by non-native pollen and spores.
654 Specifically for CEACs, questions arise about their degradation products and their environmental fate.
655 We believe that the parallel monitoring of multiple impurities would accelerate research progress
656 towards solving such questions, since information provided by various impurity contents will be more
657 comprehensive and thus more likely conclusive.

658 **5 Recommendations for the future**

659 **For a harmonised picture of spatial distribution of key atmospheric impurities across Svalbard,**
660 we recommend to establish regular measurements of a basic set of variables at ground-based
661 stations, which are logistically available and represent a different level of local human impact
662 (proposed here: Longyearbyen, as the main settlement, and Hornsund, as a relatively remote site with
663 year-round staff). These are also AERONET sites, already measuring AOD. The proposed set of key
664 impurities includes: BC (due to its climate impacts and a large uncertainty in deposition patterns; cf.
665 Zdanowicz et al. 2021); CH₄ (due to climate effects and potential local sources), inorganic ions (simple
666 aerosol source markers), pollen (to track the colonisation of Svalbard by new plants), and finally
667 chosen CEACs (e.g. PFAS due to known sources in Svalbard). Such measurements should be
668 performed with consistent methods and be subject to interlaboratory checks. Co-timing of
669 measurements (and matching their time resolutions) at these stations will also be necessary. Regular
670 measurements will allow detecting also the changes in **seasonal phenomena** due to climate change.
671 For several atmospheric impurities, three sites across Svalbard are insufficient to **detect the spatial**
672 **differences**, especially in bulk atmospheric deposition, which is both more varied and more relevant to
673 the impact on the terrestrial system than pure atmospheric concentrations. For such variables, field
674 campaigns can be used to supplement the existing data, be it with the use of PAS or snow as a
675 natural deposition medium. Impurities we recommend here are: mineral dust, CEACs with an
676 established negative impact on the terrestrial ecosystem, BC and aerobiological parameters (the
677 deposition of pollen, and DNA studies of microbial communities).
678 **The altitudinal transect in Ny Ålesund between Mt. Zeppelin and Gruvebadet** should remain in
679 operation, if possible with unified protocols – consistent with SESS recommendations by Sipilä et al.,
680 (2020) and Traversi et al., (2021); shorter-term experiments on altitude differences in impurities
681 concentration in the atmosphere and their deposition would be beneficial elsewhere (Viola et al. 2019).
682 **Unified or highly comparable measurement methods** are desired, which has already been
683 postulated for BC (Gilardoni et al. 2020) or microplastics (Singh et al. 2021), or harmonised Svalbard-

684 wide sampling strategies (consistent with the conclusions of Petkov et al., 2022). Therefore, a long-
 685 term experiment with parallel collection with different sampling protocols at one site is proposed here.
 686 **A sample bank should be designed for CEACs**, in the form of non-targeted chemical analysis
 687 recording (with high resolution GC or LC-MS techniques), since there is a possibility of discovering
 688 further chemicals in a future re-analysis of such data and thus detecting in past samples the CEACs
 689 only discovered in the future – and studying their temporal trends, testifying to the changing human
 690 impact in the Arctic, resulting e.g. from the diversion of shipping routes or increased tourism.
 691 **Broadening the spectrum of measured properties** also applies as a prospective research area in
 692 **aerobiology** as more in-depth characterisation of the gene pool in the aerial microbiome becomes
 693 possible. Functional links with the environment are also an important concern for future aerobiology
 694 studies (new recommendations compared to Malard et al., 2019).
 695 Finally, the breadth of existing data, not all of which is fully available (FAIR-compliant), drives the last
 696 recommendation to **make the existing and future datasets findable, accessible, interoperable**
 697 **and reusable** to facilitate solving complex scientific problems connected to atmospheric impurities
 698 through collaboration.

699 6 Data availability

No. on the map (Fig. A1)	Dataset (impurity type + method in brief)	Parameter (Air/Aerosol = A; Snow/Rain = P) + temporal resolution of measurement (if known)	Period	Location (BAR = Barentsburg; GVB = Gruvebadet; HRN = Hornsund; LYB = Longyearbyen; NyA = Ny-Ålesund; ZEP = Mt. Zeppelin)	Metadata access (URL)	Dataset provider
1	POPs (mainly organochlorine pesticides and PCBs) by high-volume sampler	A	1980-1983	NyA	article: (Oehme & Ottar, 1984)	NILU
2	black carbon by aethelometer	A; every 5 or 10 mins (two devices)	2011	NyA, Chinese Yellow River Station, and three other locations	article doi: 10.3402/polar.v33.21821	J. Zhan & Y. Gao (Rutgers University)
3	black carbon by aethelometer	A, every 10 mins	2005-2008	NyA, Chinese Yellow River Station	article doi: 10.1175/JAS-D-15-0009.1	L. Chen (State Oceanic Administration, Xiamen, China) et al.

4	trace gases (O ₄ , BrO, OClO, NO ₂) by MAX-DOAS	A , continuous (every 2000 ms)	2017	NyA, Chinese Yellow River Station	article doi: 10.1016/j.scitotenv.2022.156335	D. Chen (Chinese Academy of Sciences, Hefei) et al.
5	mineral dust by copper TEM grids coated with carbon film	A , 20 min - 2 h	2012	NyA, Chinese Yellow River Station	article dois: 10.5194/acp-19-10433-2019; 10.5194/acp-15-11341-2015	J. W. Chi (Shandong University, Jinan) et al.; H. Yu (Hangzhou Normal University) et al.
6	inorganic ions, conductivity (EC) and pH by bulk sampler	P , daily in 1980-83, then weekly	1980-2021, EC only in 1984-85, gaps for particular parameters	Ny-Alesund	http://thredds.nilu.no/thredds/fileServer/ebas/NO0057R.198401010700.00.20210512110343.bulk_sampler.conductivity.precip.2y.1w.NO01L_bs_w_0057.NO01L_cond_meter.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0057R.199301010000.00.20181210133000.bulk_sampler.precipitation_amount.precip.5y.1w.NO01L_precip_bulk_UK.NO01L_BW.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0057R.198209070000.00.20210512133009.bulk_sampler.precip.4mo.1w.NO01L_bs_w_0057..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0057R.198209070000.00.20210512133009.bulk_sampler.precip.4mo.1w.NO01L_bs_w_0057..lev2.nc	NILU

					bas/NO0057R.198401010700.00.20210512133009.bulk_sampler..precip.2y.1w.NO01Lbs_w_0057..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/e bas/NO0057R.198301010000.00.20210512133009.bulk_sampler..precip.1y.1w.NO01Lbs_w_0057..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/e bas/NO0057R.198601010700.00.20210512133009.bulk_sampler..precip.2y.1w.NO01Lbs_w_0057..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/e bas/NO0057R.198301010700.00.20181210133000.bulk_sampler..precip.1y.1d.NO01Lbs_d_0057..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/e bas/NO0057R.198801010700.00.20210512133009.bulk_sampler..precip.3y.1w.NO01Lbs_w_0057..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/e
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					v2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0057R.19800901070000.20181210133000.bulk_sampler..precip.16mo.1d.NO01L_bs_d_0057..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0057R.19820101070000.20181210133000.bulk_sampler..precip.1y.1d.NO01L_bs_d_0057..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0057R.19910101070000.20220405123422.bulk_sampler..precip.31y.1w.NO01L_bs_w_0057..lev2.nc	
7	inorganic ions by filter pack	A, weekly	2019-2021	NyA, Tranform atorbua	http://thredds.nilu.no/thredds/fileServer/ebas/NO1154R.20181203070000.20220405125351.filter_3pack...5w.1w.NO01L_f3p_w_1154.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO1154R.20190107070000.202204051	NILU

					25351.filter_3pack...3y.1w.NO01L_f3p_w1154.NO01L_IC.lev2.nc	
8	inorganic ions by filter pack	A, daily or weekly, depending on the period	mid-2008-2018	NyA, Nordpolh otellet	http://thredds.nilu.no/thredds/fileServer/ebas/NO1665R.200807010700.00.20180529103658.filter_3pack.magnesium.aerosol.6y.1d.NO01L_f3p_d_1665.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO1665R.200807200700.00.20180817000000.filter_3pack..aerosol.18mo.1d.NO01L_f3p_d_1665.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO1665R.200807200700.00.20181024000000.filter_3pack..aerosol.17mo.1d.NO01L_f3p_d_1665.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO1665R.201406090700.00.20190328142000.filter_3pack..aerosol.4y.1w.NO01L_f3p_d_1665.N	NILU

					O01L_IC.lev2.nc	
9	trace gases (e.g. CO, CH ₄ , O ₃) by FTIR spectroscopy			NyA, AWIPEV station	Data not directly available	project website: https://www.iup.uni-bremen.de/ftir/cms/
10	pollen	A, weekly	1986	NyA	https://doi.org/10.3402/polar.v6i1.6842	S. Johansen & U. Hafsten
11	Atmospheric optical depth (AOD) / water vapour in the air column / inversion aerosol products	A, depending on cloud cover	Since 2017 (& March-April 2006)	NyA	https://aeronet.gsfc.nasa.gov/new_web/data.html ; https://aeronet.gsfc.nasa.gov/cgi-bin/data_display_aod_v3?site=Ny_Alesund_AWI	C. Ritter (AWI), AERONET
12	bacteria	A	2018	NyA, GVB	https://doi.org/10.1016/j.atmosenv.2021.118458	M. Fetracco (CNR-ISP)
13	WSOC, phenolic compounds, trace elements and rare earths; in 6 dimensional classes of aerosol \ Andersen High volume cascade impactor	A, weekly	Since 2010	NyA, GVB	https://doi.org/10.1594/PANGAEA.928238 https://doi.org/10.1016/j.atmosenv.2021.118458 https://doi.org/10.3390/atmos12060694 https://doi.org/10.1016/j.scitotenv.2020.142954 https://doi.org/10.1016/j.chemosphere.2018.12.147 https://doi.org/10.1016/j.scitotenv.2019.136089 https://doi.org/10.1007/s12210-016-0518-6 https://doi.org/10.1021/es400125r ²	E. Barbaro (CNR-ISP, UNIVE)

² Dataset could be request to E. Barbaro (CNR-ISP, UNIVE) partial dataset are available on PANGAEA <https://doi.org/10.1594/PANGAEA.928238>

14	EC/OC \ 2 TECORA low volume	A, weekly	Since 2010	NyA, GVB	https://doi.org/10.3390/atmos12030320	R. Traversi (UniFI) & G. Calzolai (INFN)
15	PM10 for elementary composition (PIXE) \ Sequential TECORA Skypost	A, weekly	Since 2010	NyA, GVB	Upon request to R. Traversi	R. Traversi (UniFI)
16	PM10 sampling for ionic compounds determination \ Sequential TECORA Skypost	A, weekly	Since 2010	NyA, GVB	(Traversi et al. 2021) https://doi.org/10.3390/atmos10070349 https://doi.org/10.1016/j.atmosenv.2021.118890 https://doi.org/10.1007/s12210-016-0517-7	R. Traversi (UniFI)
17	Sampling of PM10 - determination of trace elements and lead isotopes \ TECORA High-Volume	A, four days - now weekly	Since 2010	NyA, GVB	https://doi.org/10.3390/atmos12091152 https://doi.org/10.3390/atmos12030388 https://doi.org/10.1071/EN19227	M. Malandrino (UniTO) & M. Grotti (UniGE)
18	Aerosol sampling in 4 dimensional classes for distribution of ions \ Dekati 4-stage impactor	A, weekly	From 2010 to 2018	NyA, GVB	https://doi.org/10.1007/s12210-016-0529-3	R. Traversi (UniFI)
19	Spore and pollen sampling \ Cyclone	A, weekly	From 2018	NyA, GVB	Upon request	L. P. D'Acqui (CNR-IRET)
20	Ice Nucleating Particles (INP) \ TECORA PM10/PM1	A, campaign based	From 2018 to 2020	NyA, GVB	https://doi.org/10.5194/acp-21-14725-2021	M. Rinaldi et al.
21	Characterisation of WSOC in sub-micrometric aerosol with H-NMR & HR-TOF-AMS (all offline) \ TECORA Echo HVS PM1	A, weekly	From 2018 - ongoing	NyA, GVB	https://sios-svalbard.org/metsis/metadata/urn_uid_it-cnr-dta-iadc-101	M. Rinaldi, M. Paglione (CNR-ISAC)
22	Microplastics, CEACs, PAHs \ TSP Tisch HVS	A, weekly	From 2021 - ongoing	NyA, GVB	upon request	F. Corami, M. Vecchiato (CNR-ISP)
23	Optical properties of the aerosol \ Nephelometer, Radiance Res.	A, weekly	From 2010 - ongoing	NyA, GVB	upon request	M. Mazzola (CNR-ISP)
24	Optical properties of the aerosol (including eBC) \ Radiance Res. (PSAP)	A, daily to weekly	From 2010 - ongoing	NyA, GVB	https://metadata.a.iadc.cnr.it/geonetwork/srv/eng/catalog.search#/metadata/ee3fb49e-c3e2-4572-95b8-	M. Mazzola, S. Gilardoni (CNR-ISP)

					1e7ff6361ac5	
25	Optical properties of the aerosol and BC \ Aethalometer	A, daily to weekly	From 2021 - ongoing	NyA, GVB	upon request	M. Mazzola, S. Gilardoni (CNR-ISP)
26	Aerosol size distribution, 523 nm-20 µm range \ Aerodynamic Particle Sizer	A, daily to weekly	From 2010 to 2020	NyA, GVB	https://doi.org/10.3390/atmos12020271	M. Mazzola (CNR-ISP); R. Traversi (UniFI)
27	Aerosol size distribution, 10-487 nm range \ SMPS	A, daily to weekly	From 2010 - ongoing	NyA, GVB	upon request	M. Mazzola (CNR-ISP); R. Traversi (UniFI)
28	Passive sampler for dry deposition – SEM analysis (dimensional & chemical particle characterisation) \ Sigma-2	A, month	From 2020 - ongoing	NyA, GVB	upon request	P. Ielpo (CNR-ISAC); F. Scoto (CNR-ISAC)
29	Multiparametric optical characterisation of airborne dust with single particle extinction and scattering \ OPTAER	A, days	From 2022 - ongoing	NyA, GVB	upon request	Marco Potenza (UniMib)
30	CO ₂ , CH ₄ , N ₂ O, SF ₆ and O ₂ /N ₂ ratio and stable isotope ratio of CO ₂	A, weekly	03/2015-03/2019	NyA	https://ads.nipr.ac.jp/dataset/A20191217-006	D. Goto (NIPR) et al.
31	inorganic ions by filter pack	A, daily	1989-2021, with breaks	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.19930101070000.20210420142507.filter_3pack...8y.1d.NO01L_f3p_d_0042.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20010101070000.20210420142507.filter_3pack...10y.1d.NO01L_f3p_d_0042.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.	NILU

					19930101070000.20210421112338.filter_3pack.aerosol.18y.1d.NO01L_f3p_d_0042.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20110101070000.20210420142507.filter_3pack...1y.1d.NO01L_f3p_d_0042.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.19891101070000.20210420142507.filter_3pack.sulphur dioxide.air.28y.1d.NO01L_f3p_d_0042.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20180101070000.20220405123416.filter_3pack...4y.1d.NO01L_f3p_d_0042.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20120101070000.20210421112338.filter_3pack...6y.1d.N
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					001L_f3p_d_0042.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.19891101070000.20210420142507.filter_3pack.sulphate_total.aerosol.3y.1d.NO01L_f3p_d_0042.N001L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20110101070000.20210421112338.filter_3pack.sulphate_corrected.aerosol.1y.1d.NO01L_f3p_d_0042.NO01L_IC.lev2.nc	
32	"heavy metals" (As, Cd, Co, Cr, Cu, Fe, Pb, Mn, Ni, Ti, V, Zn) by high volume sampler	A, weekly	1994-2021, with breaks	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.19970101000000.20181210133000.high_volume_sampler..aerosol.1y.1w.NO01L_fphv42.N001L_icp_ms.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.19950104070000.20181210133000.high_volume_sampler..aerosol.1y.1w.NO01L_fphv42.N001L_icp_ms.lev2.nc	NILU

					001L_icp_ms.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.19940105070000.20181210133000.high_volume_sampler..aerosol.23y.1w.NO01L_fphv42.NO01L_icp_ms.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20170102000000.20210415105909.high_volume_sampler..aerosol.2y.1w.NO01L_NILU_hvs_2d_0042.NO01L_icp_ms.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20190107070000.20220420100159.high_volume_sampler..aerosol.3y.1w.NO01L_NILU_hvs_2d_0042.NO01L_icp_ms.lev2.nc	
33	cloud condensation nuclei (CCN) number concentration by a CCN counter	A, hourly	2007-2015; 2018-2019	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20180101000000.20200218000000.CCNC.cloud_condensation_nuclei_number_concentration.aerosol.1y.1h.KR03L_DMT_CCN-100-	KOPRI

					KOPRI.KR03L CCNC 2018. lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20070101000000.20191003114100.CCNC.cloud_condensation_nuclei_number_concentration.aerosol.9y.1h.KR03L_DMT_CCN-100-KOPRI.KR03L_CCNC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20190101000000.20201216000000.CCNC.cloud_condensation_nuclei_number_concentration.aerosol.1y.1h.KR03L_DMT_CCN-100-KOPRI.KR03L_CCNC 2019.lev2.nc	
34	ozone by UV absorption	A, hourly	1989-2022	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.19890831230000.20220407000000.uv_abs.ozone.air.32y.1h.NO01L_uv_abs_uk_0042.NO01L_uv_abs.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20200108000000.20220821210510.uv_abs.ozone.air.3y.1h.NO01L_uv_abs_uk_0042_NRT.NO01L_uv_abs.lev1.5.nc	NILU

35	mercury by Tekran (flue gas CEM), a gold trap denuder, high-volume sampler or mini-trap	A, hourly (in 2021 - every 3 hours)	1994-2016; 2021	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20100101000000.20110120000000.Hg_mon.mercury.air.1y.1h.NO01L_tekran_42_dup.NO01L_afs.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20000208090000.20170320000000.Hg_mon.mercury.air.17y.1h.NO01L_tekran_42.NO01L_afs.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20030412132300.20141121112113.mini_trap.mercury.aerosol.25mo.1h.NO01L_tpm_42.NO01L_mini_trap.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20010101080000.20181210133000.high_vol_sampler.mercury.aerosol.2y.1d.NO01L_tpm_42.NO01L_cv_afs.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20021230000000.20181210133000.high_vol_sampler.mercury.aerosol.12mo.1w.NO01L_hvs_42.NO01L_mini_trap.lev2.nc ;	NILU
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					http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20210101000000.20220317000000.Hg_mon.gaseous_elemental_mercury.air.1y.1h.NO01L_tekran_42.NO01L_afs.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20030412144500.20140501000000.ann_denuder.reactive_gaseous_mercury.air.25mo.1d.NO01L_rgm_42.NO01L_tekran.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20010413080000.20021030000000.ann_denuder.reactive_gaseous_mercury.air.13mo.1d.NO01L_rgm_42.NO01L_gardis_monitor.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20170101000000.20180115000000.Hg_mon.gaseous_elemental_mercury.air.1y.1h.NO01L_tekran_42.NO01L_afs.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20180101000000.20220502083209.Hg_mon.g
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					seous_elemental_mercury.air.y.1h.NO01L_tekran_42.NO01L_afs.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20210701013000.20220324000000.Hg_mon...6mo.3h.NO01L_tekran_42_modified.NO01L_afs.lev2.nc	
36	halogenated greenhouse gases (CFCs; halons, HCFCs, HFCs, SF ₆ and other halogenated compounds) by an online gas chromatograph (GC)	A, daily; since 2010 every 2 hours	2001-2021	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20020101000000.20120717000000.online_gc..air.9y.1d.NO01L_HP5973_ADS_no42.NO01L_automat ic_desorption_system..nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20100901000000.20130831000000.online_gc..air.28mo.1d.NO01L_Agile nt_GC-MS_5973_ME DUSA_19_ZEP.NO01L_NILU_MEDUSA..nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20010101000000.20110112000000.online_gc..air.1y.1d.NO01L_HP5973	NILU

					_ADS_no42.N001L_automat ic_desorption system..nc ; http://thredds .nilu.no/thred ds/fileServer/e bas/NO0042G. 201009011421 00.202205160 000000.online gc..air.11y.2h. NO01L_Medus a- 19.NO01L_AG AGE.lev0.nc	
37	H ₂ by GC-HgO	A, every 2 h	2006-2009	NyA, ZEP	http://thredds .nilu.no/thred ds/fileServer/e bas/NO0042G. 200601010000 00.200909070 000000.GC- HgO.hydrogen .air.3y.2h.NO0 1L_RGA3_no4 2.NO01L_RGA 3_MPI2009..n c	
38	CO (carbon monoxide) by GC-HgO	A, at least daily (every 2 h 2006-2008; hourly 2009-2012)	2001-2012	NyA, ZEP	http://thredds .nilu.no/thred ds/fileServer/e bas/NO0042G. 200601010000 00.200909070 000000.GC- HgO.carbon monoxide.air. 3y.2h.NO01L RGA3_no42.N 001L_RGA3..n c ; http://thredds .nilu.no/thred ds/fileServer/e bas/NO0042G. 200901010000 00.202205090 000000.GC- HgO.carbon monoxide.air.	NILU

					4y.1h.NO01L_RGA3_no42.NO01L_RGA3.le v2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20010101000000.20130719000000.GC-HgO.carbon_monoxide.air.11y.1d.NO01L_RGA3_no42.NO01L_RGA3..nc	
39	CO (carbon monoxide) by online CRDS	A, hourly (daily in 2013)	2013-2022	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20130101000000.20140811122844.online_crds.carbon_monoxide.air.19mo.1d.NO01L_picarro1_G2401.NO01L_picarro..nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20190101000000.20220718083023.online_crds.carbon_monoxide.air.3y.1h.NO01L_picarro2_G2401_ICOS.NO01L_picarro.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20200101000000.20220228210212.online_crds.carbon_m	NILU

					onoxide.air.1y.1h.NO01L_picarro_G5310_NRT.NO01L_picarro.lev1.5.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.202001010000.20220822010220.online_crds.carbon_monoxide.air.1y.1h.NO01L_picarro4_G2401_NRT.NO01L_picarro.lev1.5.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.202001010000.20220822160216.online_crds.carbon_monoxide.air.1y.1h.NO01L_picarro4_G2401_NRT.NO01L_picarro.lev1.5.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.201801010000.20220718083023.online_crds..air.1y.1h.NO01L_picarro2_G2401_ICOS.NO01L_picarro.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.201301010000.201909111
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					22545.online_crds..air.2y.1h.NO01L_picarro1_G2401..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20210101000000.20220718083023.online_crds..air.1y.1h.NO01L_picarro2_G2401_ICOS.NO01L_picarro.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20170801000000.20220718083023.online_crds..air.3y.1h.NO01L_picarro2_G2401_ICOS.NO01L_picarro.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20190527000000.20220228213456.online_crds...3y.1h.NO01L_picarroG5310_NRT.NO01L_picarro.lev1.5.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20220624080000.20220822010220.online_crds...59d.1h.NO01L_picarro4_G2401_NR
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					T.NO01L_picarro.lev1.5.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.201404302200.00.20220822160216.online.crds...8y.1h.NO01L_picarro4_G2401_NRT.NO01L_picarro.lev1.5_dup1.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.201404302200.00.20220822010220.online.crds...8y.1h.NO01L_picarro4_G2401_NRT.NO01L_picarro.lev1.5_dup1.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.202206240800.00.20220822160618.online.crds...59d.1h.NO01L_picarro4_G2401_NRT.NO01L_picarro.lev1.5.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.201707241000.00.20180911081359.online.crds..air.59w.1h.NO01L_picarro_G2401_temp_2017_NRT
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					.NO01L_picarro.lev1.5.nc	
40	CO ₂ and CH ₄ , N ₂ O by online CRDS	A, hourly	2012-2022	NyA, ZEP	https://sios-svalbard.org/metsis/search?search_api_fulltext_op=or&fulltext=Zeppelin+online-CRDS&start_date=&end_date=&is_parent=All&platform_ancillary_cloud_coverage=All&f%5B0%5D=dataset_level%3Alevel-1	NILU
41	PAHs by high-volume sampler	A, weekly	2008	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20080107075300.20181210133000.high_volume_sampler...1y.1w.NO01L_fpu_f_42a..lev2.nc	
42	POPs (mainly organochlorine pesticides and PCBs) by passive PUF samplers	A, single sample	2006	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20060714000000.20181210133000.passive_puf..air.74d.3mo.NO01L_puf_42.NO01L_gc_ms.lev2.nc	
43	POPs (mainly organochlorine pesticides and PCBs) by high-volume sampler	A, weekly samples, representing 48-72 h	pesticides regularly since 1994, PCBs since 1998; early measurements in 1984	NyA, ZEP	article doi: 10.1016/j.envpol.2016.01.079 ; 1984 data in article: http://www.jstor.org/stable/4313848 ;	NILU
44	PFAS by high-volume sampler	A, weekly samples, representing 48 h	2006-2014	NyA, ZEP	article doi: 10.1016/j.atmosenv.2017.10.028	P. Bohlin-Nizzetto (NILU)

³ Search link provided here as an exception to save space – it covers 134 datasets.

45	OC/EC (organic carbon/elemental carbon) by high-volume sampler (in PM10)	A, weekly	2017-2021	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.201901160700.00.20220406124026.high_volume_sampler..pm10.3y.1w.NO01L_hvs_week_no42_pm10.N001L_NILU_sunset_002.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.201701050700.00.20220406124026.high_volume_sampler..pm10.23mo.1w.N001L_hvs_week_no42_pm10.lev2.nc	NILU
46	Saccharides by high-volume sampler	A, weekly	2017-2021	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.201701050700.00.20220406124026.high_volume_sampler.cellulose.pm10.4y.1w.NO01L_hvs_week_no42_pm10.AT05L_spectrophotometric_uv_340nm.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.202101110700.00.20220317000000.high_volume_sampler..pm10.12mo.1w.N001L_hvs_week_no42_pm10.lev2.nc	NILU

					ek no42 pm10.NO01L UHPLC 50249.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.201901160700.00.20220406124026.high_vol_sampler..pm10.2y.1w.NO01L_hvs_weekno42_pm10.NO01L_UHPLC_50249.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.201701050700.00.20220406124026.high_vol_sampler..pm10.23mo.1w.NO01L_hvs_weekno42_pm10.lev2.nc	
47	VOCs (volatile organic compounds) by adsorbent tube	A, daily	1994-1998	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.199404140800.00.20181210133000.ads_tube.air.5y.1d.NO01L_DNPH_silica_tube_waters37500_no42.NO01L_HPLC_UV.lev2.nc	
48	alkanes by glass flask	A, weekly	2003-2016	NyA, ZEP	http://thredds.nilu.no/thredds/fileServer/ebas/NO0042G.20030313135500.20210831200407.glass_flask.air.14y.1w	

					.US13L_glass_f_lask_NO0042G_US13L_GC_FI_D_v1.lev2.nc	
49	organic gaseous compounds by steel canister	A , daily	1989-1999 (various periods for various gases)	NyA, ZEP	NOT HARVESTED INTO SIOS DATABASE - link unknown	NILU
50	black carbon, number and mass concentrations by SP2	P , daily	09/2012-03/2018	NyA	https://ads.nipr.ac.jp/dataset/A20191018-008	K. Goto-Azuma (NIPR) et al.
51	black carbon, mass concentration, by SP2	A , hourly	03.2017	NyA	https://ads.nipr.ac.jp/dataset/A20191217-011	S. Ohata (Univ. of Nagoya) et al.
52	POPs and CEACs by high-volume sampler	A , weekly	2011	NyA, AWIPEV Station (HEREON)	article doi: 10.1038/srep08912; more data in the process of obtaining dois at https://pangaea.de	HEREON (Z. Xie)
53	black carbon, mass concentration, by COSMOS	A , hourly (at least the first link, which is a dataset starting in 10/2012)	04/2009-10/2019	NyA	https://ads.nipr.ac.jp/data/metadata/A20180402-008/record ; http://doi.org/10.17592/001.2020112001	M. Koike (Univ. of Tokyo) et al.
54	microfauna	A , weekly	2000, 2001	NyA	https://doi.org/10.1007/s00300-003-0516-x	S. Coulson (UNIS) et al.
55	pollen, bryophyte spores	A , daily	1950	Sarsbukta	https://doi.org/10.1139/b55-03	N. Polunin
56	dust deposition	A+P , yearly	2012-2022	Petuniabukta	https://doi.org/10.1016/j.cate.2021.105974	Krzysztof G. Rymer (UAM Poznan)
57	dust deposition	P , campaign based	2019	Petuniabukta	https://doi.org/10.5281/zenodo.6790470	J. Kavan (Uni. Wroclaw & Masaryk University, Czech Rep.)
58	bacteria	A , once	2015	Billefjorden	doi:10.3390/biology602002	L. Cuthbertson (University of Northumbria at Newcastle) et al.
59	bacteria	A , once	2015	Gipsdalen	doi:10.3390/biology602002	L. Cuthbertson (University of Northumbria at Newcastle) et al.
60	bacteria	A , once	2015	Sassenfjorden	doi:10.3390/biology602002	L. Cuthbertson (University of

						Northumbria at Newcastle) et al.
61	bacteria	A , once	2015	Deltanese t	doi:10.3390/biology602002	L. Cuthbertson (University of Northumbria at Newcastle) et al.
62	bacteria	A , once	2015	Adventfjorden	doi:10.3390/biology602002	L. Cuthbertson (University of Northumbria at Newcastle) et al.
63	bacteria	A , once	2015	Isfjorden	doi:10.3390/biology602002	L. Cuthbertson (University of Northumbria at Newcastle) et al.
64	fungi	A , daily	2019	Area of LYB	https://doi.org/10.1007/s10661-021-09090-2	W. Pusz & J. Urbaniak
65	Atmospheric optical depth (AOD) / water vapour in the air column / inversion aerosol products	A , depending on cloud cover	2003-2004; 2018	LYB	https://aeronet.gsfc.nasa.gov/new_web/data.html ; https://aeronet.gsfc.nasa.gov/cgi-bin/data_display_aod_v3?site=Longyearbyen	B. Holben (NASA), AERONET
66	PAHs, oxy- and nitro-PAHs, by high-volume sampler	A , on days with predicted NW wind direction	28 August - 28 September 2018	LYB (UNIS roof)	article doi: 10.5194/acp-20-9997-2020	T. Drotikova (UNIS) et al.
67	PAHs, oxy- and nitro-PAHs, by high-volume sampler	A , 31 samples in total, 24 h each (~weekly)	Nov 2017 - Jun 2018	LYB (UNIS roof)	article doi: 10.5194/acp-21-14351-2021	T. Drotikova (UNIS) et al.
68	BTEX (aromatic VOCs) by GC-FID	A , every 15 mins	2007	LYB	article doi: 10.1021/es900449x	S. Reimann (Empa, Switzerland) et al.
69	bacteria	A , four	2015	LYB	doi:10.3390/biology602002	L. Cuthbertson (University of Northumbria at Newcastle) et al.
70	bacteria	A , once	2015	Bjørndalen	doi:10.3390/biology602002	L. Cuthbertson (University of Northumbria at Newcastle) et al.
71	fungi	A , daily	2019	Area of LYB	https://doi.org/10.1007/s10661-021-09090-2	W. Pusz & J. Urbaniak
72	PAHs, oxy- and nitro-PAHs, by high-volume sampler	A , on days with predicted NW wind direction	28 August - 28 September 2018	LYB (Aurora station Adventdalen)	article doi: 10.5194/acp-20-9997-2020	T. Drotikova (UNIS) et al.
73	fungi	A , daily	2019	Area of LYB	https://doi.org/10.1007/s10661-021-09090-2	W. Pusz & J. Urbaniak

74	fungi	A, daily	2019	Area of LYB	https://doi.org/10.1007/s10661-021-09090-2	W. Pusz & J. Urbaniak
75	bacteria	A, once	2015	Mine (Gruve) 7	doi:10.3390/biology602002	L. Cuthbertson (University of Northumbria at Newcastle) et al.
76	fungi	A, daily	2019	Area of LYB	https://doi.org/10.1007/s10661-021-09090-2	W. Pusz & J. Urbaniak
77	pollen by sticky trap	A, weekly	2022	BAR CALM site	data available by request; RiS projects 11316 and 10855	AARI paleo reconstruction group
78	PAHs, PCBs and trace metals, by multichannel sampler PU-4EP	A, twice a year	since 2002	BAR	data available by request at RPA "Typhoon", North-West branch	RPA "Typhoon"
79	trace gases (NO _x , NO ₂ , NO, NH ₃ , SO ₂ , H ₂ S, CO ₂ , CO, O ₃) + PM10 + mercury by Lumex AAS	A, continuous, 10 min (Hg)	2017-2021	BAR mountain	data stored at AARI, currently not online; RiS ID 10863	AARI
80	pollen by sticky trap	A, weekly	2017-2019; 2022	BAR	data available by request; RiS projects 11316 and 10855	AARI paleo reconstruction group
81	pollen by sticky trap	A, weekly	2017-2019; 2022	BAR	data available by request; RiS projects 11316 and 10855	AARI paleo reconstruction group
82	trace gases (NO _x , NO ₂ , NO, NH ₃ , SO ₂ , H ₂ S, CO ₂ , CO, O ₃) + PM10 + mercury by Lumex AAS	A, continuous, 10 min (Hg)	2017-2022	BAR town	data stored at AARI, currently not online; RiS ID 10863	AARI
83	AOD, water vapor content, aerosol concentration and size distribution, BC concentration by sun photometer, photoelectric particle counter, aetholometer	A, continuous	2011-2022	BAR	article dois: 10.1117/12.2248456; 10.1134/S1024856019010147	D. G. Chernov (V.E. Zuev Institute of Atmospheric Optics SB RAS, Tomsk) et al.; S. Sakerin et al.
84	inorganic ions (ion chromatography) and dissolved trace metals (ICP-MS) by low-volume sampler	A, weekly	2011-2022	BAR	article dois: 10.15356/2076-6734-2013-2-129-136; 10.31857/S2076673420010025	L. P. Golobokova (Limnology Institute, Siberian Branch, Russian Academy of Sciences) et al.
85	PAHs by GC/MS TripleQuad, low volume	A, campaign based	2017	BAR	article doi: 10.31857/S20	L. P. Golobokova

	sampler				76673420010025	(Limnology Institute, Siberian Branch, Russian Academy of Sciences) et al.
86	pollen by sticky trap	A , weekly	2017-2019; 2022	BAR	data available by request; RiS projects 11316 and 10855	AARI paleo reconstruction group
87	snow chemical composition: major ions, HCO ₃ ⁻ , pH, conductivity	P , every fresh snow episode > 5 mm	2005 - 2019	Hansbreen glacier (HRN)	data available: https://monitoring-hornsund.igf.edu.pl/index.php/login	IG PAS (A. Nawrot)
88	snow chemical composition: major ions, HCO ₃ ⁻ , pH, conductivity	P , every fresh snow episode > 5 mm	Since 2020 - ongoing	Ariebreen glacier (HRN)	data available: https://monitoring-hornsund.igf.edu.pl/index.php/login	IG PAS (A. Nawrot)
89	metals and metalloids in precipitation, by ICP-MS, and TOC by a Shimadzu TOC Analyser	P , every event	2010-2012	HRN precipitation gauge	Summary data in supplementary to the article doi: 10.3402/polar.v34.24207	K. Kozak (Gdansk Tech) et al.
90	POPs (organochlorine pesticides and PCBs) in snow	P , every event during 1 month; weekly surface snow at environmental chamber	2019	HRN area	doi: 10.34808/2cd8-pk41	K. Koziol (Gdansk Tech)
91	precipitation chemistry: major ions, HCO ₃ ⁻ , pH, conductivity; sum of the precipitation	P , daily	Since 2005 - ongoing	HRN	data available: https://monitoring-hornsund.igf.edu.pl/index.php/login	IG PAS (A. Nawrot)
92	aerosol concentration, aerosol size distribution (0.01-10 µm), aerosol vertical distribution	A , 1 min (concentration) ; 10 min (size distribution)	2021	HRN	https://doi.org/10.25171/InstGeoph_PAS_I_GData_AVSE_EFI_2021_008 : https://doi.org/10.25171/InstGeoph_PAS_I_GData_AVSE_EFI_2021_009 : https://doi.org/10.25171/InstGeoph_PAS_I_GData_AVSE	D. Kępski, M. Posyniak (IG PAS)

					EFI 2021_010 10.25171/Inst Geoph_PAS_I GData_AVSE EFI 2021_011 https://doi.org/10.25171/InstGeoph_PAS_I GData_AVSE EFI 2021_012 ⁴	
93	radionuclides: Concentration of: ⁷ Be, ²¹⁰ Pb, ⁴⁰ K, ¹³⁷ Cs, ¹³⁴ Cs [$\mu\text{Bq}/\text{m}^3$] PM (dust) [$\mu\text{g}/\text{m}^3$]	A , weekly	Since 2002	HRN	https://doi.org/10.1016/j.jenvrad.2021.106739	A. Burakowska, M. Kubicki (IG PAS)
94	Atmospheric optical depth (AOD) / water vapour in the air column / inversion aerosol products	A , depending on cloud cover	Since March 2005	HRN	https://aeronet.gsfc.nasa.gov/new_web/data.html ; https://aeronet.gsfc.nasa.gov/cgi-bin/data_display_aod_v3?site=Hornsund	P. Sobolewski (IG PAS), AERONET network
95	POPs (mainly organochlorine pesticides and PCBs) by high-volume sampler	A	1980-1983	Hopen	article: Oehme & Ottar, GEOPHYSICAL RESEARCH LETTERS, VOL. 11, NO. 11, PAGES 1133-1136, 1984	NILU
96	sulphate and sulphur dioxide concentrations by a filter pack	A , daily	1978-1989	Bjørnøya	http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.198901010700.00.20181210133000.filter_3pack...7mo.1d.NO01L_f3p_2d_0037.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/e	NILU

⁴ Entire dataset available on the project subpage <https://dataportal.igf.edu.pl/group/avseefi>; registration on the website is required to download the data; field data were collected inside a polygon defined by the coordinates in Fig. 1; basic measurements in a fixed position are continued with the SPS30 micro sensor

					bas/NO0037R.198501010700.00.20181210133000.filter_2pack...3y.1d.N001L_f2p_37.NO01L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/e bas/NO0037R.198801010700.00.20181210133000.filter_3pack...1y.1d.N001L_f3p37.N001L_IC.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/e bas/NO0037R.198001010700.00.20181210133000.filter_2pack...5y.1d.N001L_f2p_37..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/e bas/NO0037R.197801010700.00.20181210133000.filter_2pack...2y.1d.N001L_f2p_37.NO01L_thorin.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/e bas/NO0037R.197701010700.00.20181210133000.filter_2pack.sulphur_dioxide.air.1y.1d.NO01L_f2p_37.NO01L_th
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					orin.lev2.nc	
97	metal concentrations (Cd, Pb, Zn) by bulk sampler	P, monthly	1980-1987	Bjørnøya	http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.19800101000000.20181210133000.bulk_sampler..precip.8y.1mo.NO01L_Nbs_37.NO01L_icp_ms.lev2.nc	NILU
98	ion concentrations (NH ₄ ⁺ , Ca ²⁺ , Cl ⁻ , Mg ²⁺ , K ⁺ , Na ⁺ , NO ₃ ⁻ , SO ₄ ²⁻) by bulk sampler; conductivity and pH	P, daily	1977-1985 (various periods within that timespan)	Bjørnøya	http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.19790101070000.20181210133000.bulk_sampler..precip.1y.1d.NO01L_bs_d_0037..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.19770101070000.20181210133000.bulk_sampler..precip.1y.1d.NO01L_bs_37..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.19800101000000.20181210133000.bulk_sampler..precip.8y.1mo.NO01L_Nbs_37.NO01L_icp_ms.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.19770101070000.20181210133000.bulk_sampler..precip.1y.1d.NO01L_bs_37..lev2.nc	NILU

					bas/NO0037R.197801010700.00.20181210133000.bulk_sampler..precip.1y.1d.NO01L_bs_37..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.198101010700.00.20181210133000.bulk_sampler..precip.2y.1d.NO01L_bs_d_0037..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.197801010700.00.20181210133000.bulk_sampler..precip.1y.1d.NO01L_bs_d_0037..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.198001010700.00.20181210133000.bulk_sampler.potassium.precip.1y.1d.NO01L_bs_d_0037.NO01L_as_2.lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.198101010700.00.20181210133000.bulk_sampler..precip.2y.1d.NO01L_
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					bs 37..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.197701010700.00.20181210133000.bulk_sampler..precip.1y.1d.NO01L_bs_d_0037..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.197901010700.00.20181210133000.bulk_sampler..precip.1y.1d.NO01L_bs_37..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.198301010700.00.20181210133000.bulk_sampler..precip.2y.1d.NO01L_bs_37..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.198501010700.00.20181210133000.bulk_sampler..precip.1y.1d.NO01L_bs_37..lev2.nc ; http://thredds.nilu.no/thredds/fileServer/ebas/NO0037R.198001010700	
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					00.20181210133000.bulk_sampler..precip.1y.1d.NO01Lbs_37..lev2.nc	
99	POPs (mainly organochlorine pesticides and PCBs) by high-volume sampler	A	1980-1983	Bjornoya	article: Oehme & Ottar, GEOPHYSICAL RESEARCH LETTERS, VOL. 11, NO. 11, PAGES 1133-1136, 1984	NILU
100	POPs (mainly organochlorine pesticides and PCBs) by high-volume sampler	A	1980-1983	Jan Mayen	article: Oehme & Ottar, GEOPHYSICAL RESEARCH LETTERS, VOL. 11, NO. 11, PAGES 1133-1136, 1984	NILU
No marker on the map	AOD	depending on cloud cover (only during polar day)	2007-2022 (Oceania 2007, 2009-2020, no measurement in 2021); RV Polarstern (2009, 2012, 2015, 2017 2020 2021) RV Jan Mayen (2009); RV Akademik Fedorov (2013); USCGC Healy (2011 and 2015); RV Oden (2014); RV Araon (2020, 2021); RV Alliance (2021)	Arctic maritime aerosol optical properties (Arctic circle)	https://aeronet.gsfc.nasa.gov/new_web/KML/Oceania_Summer_07_daily_lev15.kml https://aeronet.gsfc.nasa.gov/new_web/KML/Oceania_Summer_09_daily_lev15.kml https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Oceania_Summer_10.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Oceania_11_4.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Oceania_12_3.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Oceania_13_1.html https://aeronet.gsfc.nasa.gov/new_web/cruises	Project MAN & AERONET

					<p>es_new/Oceania_14_2.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Oceania_15_3.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Oceania_16_3.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Oceania_17_1.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Oceania_18_3.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Oceania_19_5.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Oceania_20_2.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Polars_tern_Summer_09.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Polars_tern_Summer_12.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Polars_tern_15_1.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Polars_tern_17_1.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Polars_tern_20_0.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Polars_tern_20_0.html</p>	
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					gsfc.nasa.gov/new_web/cruises_new/Polars_tern_21_0.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Jan_Mayen_2009.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Ak_Fedorov_13.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Healy_11_0.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Healy_15.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Oden_14.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Araon_20_0.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Araon_20_1.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Araon_21_0.html https://aeronet.gsfc.nasa.gov/new_web/cruises_new/Alliance_21_0.html
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711 **Figures and tables**

712 ***Figures***

713



714

715 **Figure 1:** Overview of the instruments placed atop Gruvebadet atmospheric laboratory roof. (Photo:
716 Marco Casula)



717

718 **Figure 2:** The environmental chamber facility of the PPSH, with various sampling heads exposed on
719 the roof in the spring 2019; a rainfall collector is located 100 m eastwards from there (Photo: K. Koziol)

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721

722 **Figure 3:** For air sampling for microorganisms, there are a number of commercial options available.
 723 Key considerations are: a) direct collection or a filter size of 0.2 μm to capture bacteria, b) maximum
 724 flow rates for DNA yield, c) the ability ability to cope with the Arctic environment, d) a convenient
 725 power source (battery or generator) to enable long sample runs and e) preferably many users to
 726 provide data for comparison elsewhere. Pictured is one such example, the SAS (Surface Air System)
 727 Air Sampler as deployed in the field. (Photo: David Pearce)

728

729 **Tables**

734 **Table 1:** Typical aerobiology sampling methods.

Method	Advantages	Disadvantages
Membrane filtration	Low expense, easy to use, high capture rate, possibility of combining biological and chemical analysis	desiccation of the microorganisms on the filter surface, filter size can impact particle loading, inefficient extraction of nucleic acids
Impingement	efficient for culture- and non-culture-based analyses, the liquid matrix can be split for various analyses	low-capture rates, loss of collection fluid to evaporation and violent bubbling, loss of viability, liquid incompatible with chemical analysis
Impaction	cell death from impaction is insignificant, efficient means of obtaining total counts of fungal spores, ease of use, portability, assessment of culturable populations of bacteria and fungi per volume of air	restricted use in the analysis of other microbial types (bacteria and viruses), loss of viability due to impact stress, loss of recovery efficiency, low sample volumes due to low flow rates
Sticky traps	Low expense, easy to use and install, perfect for counting of animals and plants directly on the trap.	Dedicated to invertebrates and plant particles, often destroy invertebrate specimens; cannot be used for quantifying bacteria and fungi

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737 **References**

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1264 **Appendix**

1265 **Table A1:** Monitoring efforts for POPs and CEACs in the Svalbard atmosphere, undertaken at the Ny
 1266 Ålesund (NyÅ) hub, in chronological order (except Gruvebadet - see Table A2 for all Gruvebadet
 1267 datasets). Abbreviations: BFRs – brominated flame retardants, CFRs – chlorinated flame retardants,
 1268 CUPs – current use pesticides, cVMS – cyclic volatile methyl siloxanes, HCBd – hexachlorobutadiene,
 1269 HVS – high-volume air sampling, PAHs – polycyclic aromatic hydrocarbons, PAS – passive sampling,
 1270 OCPs – organochlorine pesticides, OPEs – organophosphate esters, PBDEs – polybrominated
 1271 diphenyl ethers, PCBs – polychlorinated biphenyls, PCNs – polychlorinated naphthalenes, PFAS –
 1272 per- and polyfluoroalkyl substances. Data availability: all data by NILU available at [http://ebas-](http://ebas-data.nilu.no)
 1273 [data.nilu.no](http://ebas-data.nilu.no) (specific dataset links only available through SIOS database), all data by Z. Xie (Hereon)
 1274 available at <https://pangaea.de> (awaiting dois).

Organic species	Sampling method	Location within NyÅ	Period of sampling	Research unit	Supervising person
OCPs, PCNs	HVS	Zeppelin	1993-present	NILU	P. Bohlin-Nizzetto
PAHs	HVS	Zeppelin	1994-present	NILU	P. Bohlin-Nizzetto
PCBs	HVS	Zeppelin	2001-present	NILU	P. Bohlin-Nizzetto
PBDEs, PFAS (ionic)	HVS	Zeppelin	2006-present	NILU	P. Bohlin-Nizzetto
OCPs, PCBs, PBDEs, OPEs	PAS (Gas phase)	Ny-Alesund	2011-2018	RCEES	Q. Zhang
PFAS (volatile)	HVS	Zeppelin	2011-present	Hereon	Z. Xie
OCPs, PBDEs, HCBd, CUPs, novel BFRs, CFRs	HVS	Ny-Alesund	2012-Present	Hereon	Z. Xie
cVMS	HVS (Gas phase)	Zeppelin	2013-present	NILU	P. Bohlin-Nizzetto
Chlorinated paraffins	HVS	Zeppelin	2013-present	NILU	P. Bohlin-Nizzetto
Phthalate esters, fragrance material, UV-filters, OPEs	HVS	Ny-Alesund	2014-present	Hereon	Z. Xie
cVMS	HVS (Gas phase)	Ny-Alesund	2015-Present	Hereon	Z. Xie
Chlorinated paraffins	HVS	Ny-Alesund	2015-Present	Hereon	Z. Xie
HCBd	HVS	Zeppelin	2020-present	NILU	P. Bohlin-Nizzetto
Novel BFRs	HVS	Zeppelin	2017-present	NILU	P. Bohlin-Nizzetto
CFRs	HVS	Zeppelin	2019-present	NILU	P. Bohlin-Nizzetto
PFAS (volatile)	HVS (Gas phase)	Zeppelin	2017-present	NILU	P. Bohlin-Nizzetto
PFAS (ionic)	HVS (Particle phase)	Ny-Alesund	2017-Present	Hereon	Z. Xie
OPEs, phthalate esters	HVS	Zeppelin	2017-present	NILU	P. Bohlin-Nizzetto
Alkylphenol	HVS	Ny-Alesund	2018-Present	Hereon	Z. Xie
Microplastics	HVS (Particle phase)	Ny-Alesund	2019-Present	Hereon	Z. Xie
Volatile fluorinated substances	HVS (Gas phase)	Zeppelin	2020-present	NILU	P. Bohlin-Nizzetto

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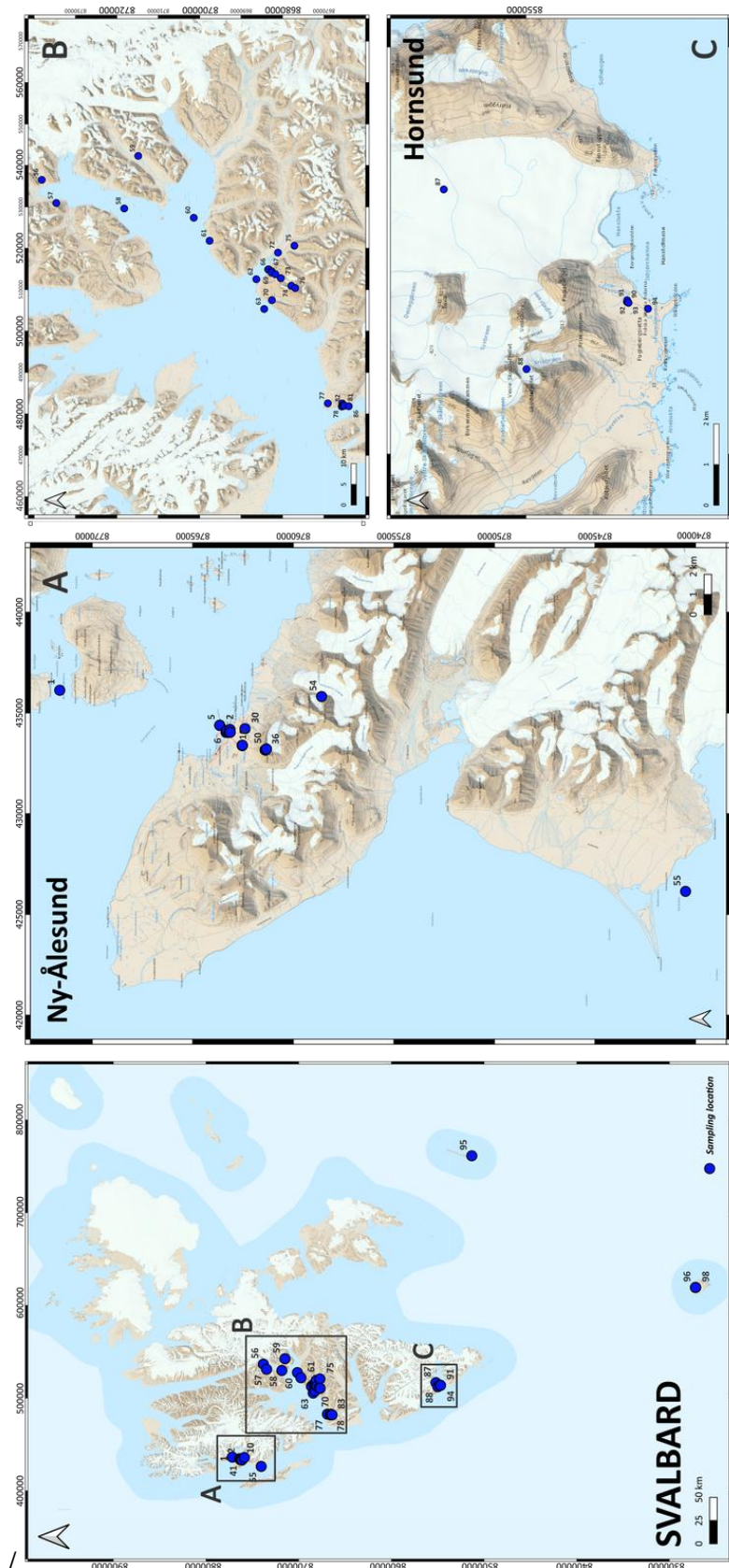


Figure A1: Distribution map, showing measurement sites relevant to the topic of atmospheric impurity monitoring and harmonisation across Svalbard. The numbered locations are described in section 6/Table A2. Data availability. Map source: Norwegian Polar Institute, toposvalbard.npolar.no.

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1279 **Table A2:** Data availability – and commentary to map in Figure A1.

1280 *Here, the whole section 6 should be placed in tandem with the map in Figure A1, and the section*

1281 *should be removed from the main manuscript, since it is not feasible for it to remain there with the*
 1282 *space constraint of 15 pages. The table would also fit better in landscape format.*

1283 **Table A3:** Coal mining in Svalbard as the long-term main source of local atmospheric pollution.

Site	Description of mining history	References
Long-yearbyen	1906-2018 – seven mines (Mine 1-7) established and operated by the Norwegian company Store Norske Spitsbergen Kulkompani (SNSK); 2028 - planned date to close the last one	(Westby and Amundsen, 2003; Kvello, 2004; Vågerö et al, 2021)
Barentsburg	1939 - mining operation in Grønnfjorden officially taken over by the USSR (from a Dutch operating company); currently, the mine is operated by the Russian governmental agency Trust Artikugol	(Pashkevich, 2018)
Grumant/ Coles Bay	1912-1961 - operated by the Soviet Union	(Samoïlovich and Adadurov, 1927; Kulikov, 1964; Portsel', 2011)
Pyramiden	1926 - mine facilities bought by the Soviet Union; in the 1960s -1970s it was the largest mine in Svalbard; in 1998 - closed and abandoned	(Andreassen et al, 2010)
Ny-Ålesund	1916 - coal mining established by the Kingbay mining company (Kings Bay Kulkompani); 1962 - a tragic mining accident led to closing mine operation, the facility – gradually transformed into an international research station	(Paglia 2020)

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