

# Arctic haze in a climate changing world: the 2010-2020 trend (HAZECLIC)



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## 1. Introduction

Rapid changes in the Arctic environment including increasing temperatures, extending warm seasons, depleting sea ice, reducing surface albedo and changing long-range transport patterns of air pollutants (IPCC 2013) have become and will continue to be the focus of intense research efforts to better understand the processes that control Arctic climate (Arctic Monitoring and Assessment Programme [AMAP] 2011).

Since high-latitude climate variability has been shown to be an early indicator of global climate changes, unravelling the processes leading to Arctic amplification of radiative forcing becomes particularly relevant (Serreze and Barry 2011).

During winter–spring, the combination of intense isentropic transport from mid-latitudes to the Arctic and strong surface-based temperature inversions leads to significant increase of tropospheric aerosol concentration known as Arctic Haze (Quinn et al. 2007). The most relevant contributions to Arctic pollution in mid-winter is of SO<sub>2</sub>, which is oxidized to sulphate by both particle (aqueous phase) processes in winter (Wang et al. 2020) and photochemical processes in spring (Ye et al. 2018) through a number of inorganic and organic drivers and intermediates. The synergetic effect of the increased residence time in wintertime and springtime sunlight makes the polar atmosphere act like a large chemical reactor, increasing the number of particles that can scatter solar radiation (Russell and Shaw 2015).

In contrast to the Arctic Haze period, pollutant concentrations during summer are much lower owing to their limited long-range transport into the Arctic from the lower latitudes, as the polar front retreats to the High Arctic (Stone et al. 2014).

Arctic Haze is mainly anthropogenic in origin due to emissions from mid-latitude areas (Europe, former Soviet Union and North America) that are transported to and trapped in the Arctic air mass during winter and early spring (between January and April). These long-range emissions add up to

the inputs from remote Arctic locations, which are minor during the Haze period. Concerning the source areas, sources from Europe and North America become significant at an altitude > 2km, while at higher elevations (> 3km) emissions from deserts, biomass burning regions and Asia play a role (Sharma et al. 2013; Shindell et al. 2008).

The Haze is mostly made of particles belonging to the accumulation mode, which are very efficient at scattering visible solar radiation; however, they also become weakly absorbing particles due to the presence of black carbon (BC; AMAP 2011; Zhao and Garrett 2015).

The net result of the strong scattering and weak absorption is a marked reduction in visibility up to a few km or less. This “weak” absorption exerts large climatic influences when the “dark” Haze expands over the highly reflective Arctic snow cover, since the highly reflective surface amplifies aerosol-radiative interactions due to multiple scattering between the surface and the Haze (Aoki 2013).

In particles mostly belonging to the accumulation mode (Tunved et al. 2013), the Arctic Haze mainly comprises a varying mixture of sulphate and organic particulate matter and, to a lesser extent, ammonium, nitrate, dust, BC and heavy metals (Li and Barrie 1993; Quinn et al. 2007).

Based on the measurements of sulphate and optical properties (light scattering and extinction) of the aerosol, the amount of the Haze reaching the Arctic was found to be either relatively constant or decreasing between the 1980s and early 1990s (Quinn et al. 2007). Moreover, based on data from many sites in the High Arctic, it appears that sulphate has continued to decrease during the first decade of the 21st century from North America and Greenland (Alert, Barrow, Station Nord) to Svalbard Islands (Zeppelin), Northern Norway (Karasjok, Svanvik), Finland (Oulanka) and western Russia (Janiskoski) such as Barrow and Alert (Quinn et al. 2007). This decreasing trend has been confirmed by recent works, such as Sharma et al.

(2019), that show a consistent drop (about 52%) in sulphate concentration at Alert over a 34-year-long period (1980–2013). In particular, at Zeppelin site, non-sea salt sulphate was found to decrease by 21.5% on average between 1990 and 2008, with the most remarkable decline occurring during the early 1990s (AMAP 2015).

Regarding Svalbard Islands, a drop of 21.5% during the period 1998–2008 was found at Zeppelin by Hirdman et al. (2010) by applying a trend analysis based on annual mean geometric concentrations. Similarly, Zeppelin shows the steepest decrease during the early 1990s.

By combining measurement data with calculations using a Lagrangian particle dispersion model (flexible particle dispersion model [FLEXPART]), Hirdman et al. (2010) identified high-latitude Eurasia (mainly Eastern Europe and the metal smelting complexes at Norilsk) as the dominant source region for sulphate at Zeppelin.

Such a trend can be particularly relevant in terms of climate owing to multiple reasons. Among these, recent studies based on present simulations with an Earth system model including comprehensive aerosol physics and chemistry (Acosta Navarro et

al. 2016) suggest that sulphate aerosol reductions in Europe since the 1980s can explain a significant part of Arctic warming over that period.

Moreover, although Arctic warming increases mainly in cold seasons (fall and winter), it is actually triggered in spring/summer by the increase in incoming solar radiation together with a more efficient poleward oceanic and atmospheric heat transport. The summertime energy surplus can reduce sea ice-cover, possibly leading to a heat transfer from the Arctic Ocean to the atmosphere (Acosta Navarro et al. 2016). Thus, it would be important to establish if air quality regulations in the Northern Hemisphere, the ocean and atmospheric circulation, and Arctic climate are related and to what extent.

Thus, a thorough investigation on the chemical markers of the Haze in different areas of the High Arctic can help monitor the temporal evolution of this process in the medium and long run as well as its potential impact on the radiative balance and atmospheric reactivity, with a special attention to possible de-acidification of the atmosphere due to a decreasing content of sulphuric acid and a relatively constant content of ammonia.

## 2. Overview of existing data and analysis of new data

This report presents an analysis of both existing and new data of sulphate and ammonium concentration in PM<sub>10</sub> aerosol from Gruebadet Observatory (GVB; 78.918°N, 11.895°E) and Mt. Zeppelin Observatory (ZEP; 78.908°N, 11.881°E). Both sites are located in Ny-Ålesund (78°55' N, 11°56' E); they are close (about 1.5 km as the crow flies) but have different elevations (about 50 m and 474 m a.s.l., respectively) and distance from Ny-Ålesund research village (about 700 m for GVB). The ZEP is owned and managed by the Norwegian Polar Institute and is part of the Global Atmospheric Watch network.

The monitoring of aerosol (PM<sub>10</sub>) chemical composition at GVB began in 2010 and is still

ongoing; aerosol samples were collected during the spring–summer period at different resolutions (1–2 days) by several sampling devices, including PM<sub>10</sub> samplers and multi-stage impactors. Since winter 2018/2019, all-year-round samplings have started.

The dataset presented here refers to one-to-two-day PM<sub>10</sub> aerosol samples collected on 47 mm diameter PTFE filters (Pall Corporation and Cobetter Filtration Group) using a low-volume sampler (TECORA Skypost). The sample filters were prepared under a laminar flow hood in Florence and shipped to Ny-Ålesund; after sampling, the filters were stored in a freezer at “Dirigibile Italia” Station and then shipped back to Florence together with field blanks. The filters were cut into two parts; one

half was analyzed for metals (Giardi et al. 2018) or archived. The PM<sub>10</sub> mass was determined by weighing the filter before and after the sampling by means of a five-digit microbalance (Sartorius ME235P). The filters were conditioned for 48 h (25°C and 50% RH) before weighing.

The portion of the filter devoted for chemical analysis was diluted with 10 mL of ultrapure water (18 MΩ·cm, Millipore MilliQ grade) and extracted in ultrasonic bath for 20 minutes. Sulphate and ammonium were measured by two Ion Chromatographic systems performing the analysis of inorganic anions and inorganic cations, respectively. The detailed procedure is described in Becagli et al. (2011).

For both the parameters, reproducibility on real samples was better than 5%, and filter blanks were found to be lower than the detection limit. As reported by Giardi et al. (2016), detection limits for sulphate and ammonium are 0.08 and 0.09 ng m<sup>-3</sup>, respectively, considering the most conservative conditions of sampled volume (i.e. 55 m<sup>3</sup> for daily resolution).

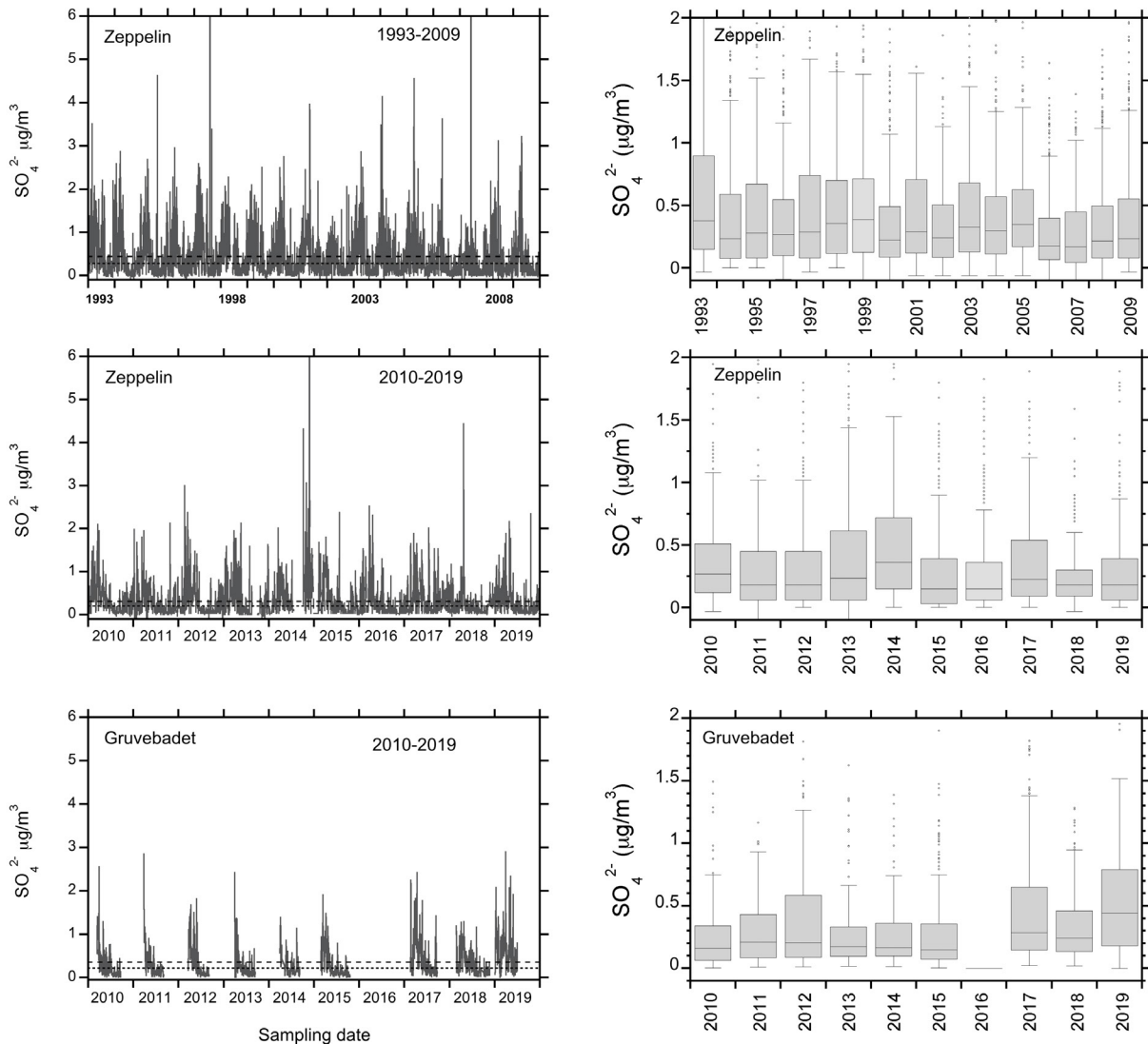
Regarding measurements at Zeppelin site, sampling and analytical determination were accomplished by using the methods described in the EMEP Manual v1996, as reported in the EBAS NILU website.

Here, we report the record of sulphate and ammonium concentrations and sulphate/ammonium ratio measured at GVB during the 2010–2019 time period. These data series are compared with the corresponding longer time series from Mt. Zeppelin and all the publicly available data covering the 1993–2019 time period at daily resolution ([www.ebas.nilu.no](http://www.ebas.nilu.no)). These are reported to highlight trend similarities and differences.

Figure 1 shows the temporal profile of sulphate concentrations at ZEP and GVB sites; the temporal profile from ZEP is split into two plots (1993–2009 and 2010–2019) to better appreciate the temporal pattern at both seasonal and interannual scale.

Considering the entire investigated period, concentration levels are quite similar at the two sites. Regarding the 2010–2019 time period, mean values are quite close (0.338 mg m<sup>-3</sup> at ZEP and 0.350 mg m<sup>-3</sup> at GVB), and median values are practically coincident (0.210 mg m<sup>-3</sup>) at the two sites. Such a similarity can also be observed clearly in the box plots given in Figure 1, which shows that the 50% of the values range between 0.1 and 0.8 mg m<sup>-3</sup> at both the sites in the 2010–2019 decade. By analyzing a longer trend at Zeppelin, i.e. covering the previous 17 years, higher background and mean values can be observed yielding an average of 0.434 mg m<sup>-3</sup> and a median value of 0.270 mg m<sup>-3</sup>. Moreover, distribution plots show a higher occurrence of larger values, causing a clear widening of the box containing the 50% of the data.

As stated in the Introduction section, such a result is consistent with the reduction of sulphur emissions from the former Soviet Union and Europe during the 1990s (Quinn et al. 2007; Sirois and Barrie 1999). Sulphate has been shown to continue its declining trend into the 21<sup>st</sup> century, as well, but at a slower rate (Quinn et al. 2007). In Ny-Ålesund, non-sea salt sulphate was found to decrease at ZEP by 21.5% on average between 1990 and 2008, with the most remarkable decline occurring during the early 1990s (AMAP 2015). In particular, during the Haze season, concentrations decreased at a rate of about 2 % yearly (Udisti et al. 2020).



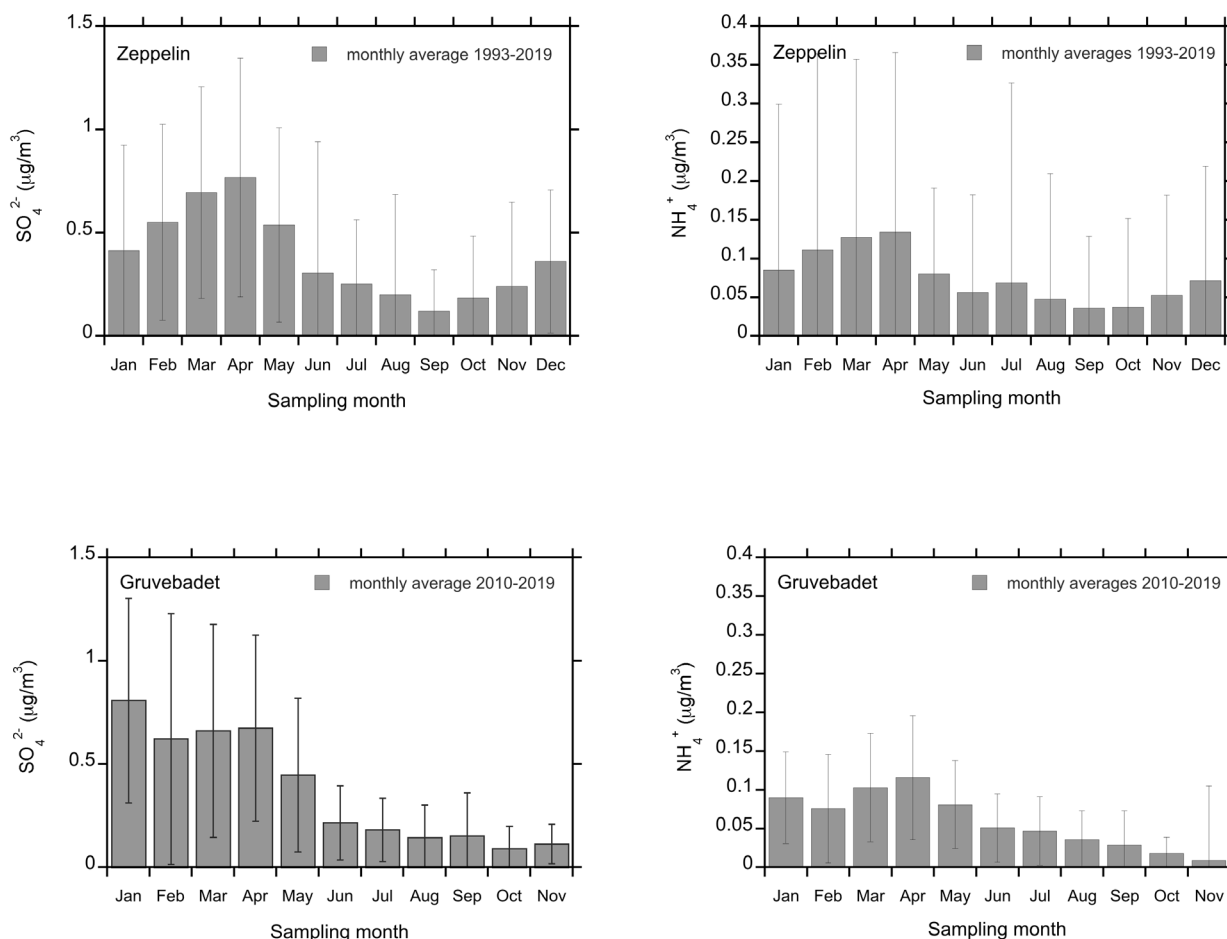
**Figure 1:** Sulphate concentration trends at Zeppelin (top and mid plot) and Gruvebadet (bottom plot) for the entire investigated period. The plots on the left display raw data at full resolution, while plots on the right show the data distribution as annual box plots separately for different years. Dashed and dotted lines represent mean and median values, respectively, over the investigated period.

The dataset reported here allows extending the trend to the 2010–2020 decade and assessing the extent of the drop. Considering ZEP site, by providing the longer dataset, a continuous sulphate decrease can be observed throughout the 27-year-long period. By dividing the time interval in three periods and applying a linear regression, we can observe a different decreasing rate for the last decade: The drop rate is around 20% during the 1993–1999 and 2000–2009 timeframes, while a steeper decrease is assessed for the 2010–2019 period (around 30%).

Conversely, possibly due to the shorter time period, no significant evidence of a decrease in sulphate at

GVB can be observed through a preliminary data analysis.

Similar decreases were also observed for equivalent black carbon (eBC) in various Arctic sites for 2000–2008 (Hirdman et al. 2010) and 1980–2013 (Sharma et al. 2019). Moreover, a strong correlation was also observed between Zeppelin and two other Arctic sites (Pallas and Alert) by Eckhardt et al. (2015) and captured by models belonging to different classes. This confirms earlier evidence of a common source region for sulphate and eBC and common mixing and removal processes for these aerosol components (Quinn et al. 2007).



**Figure 2:** Monthly average of sulphate (left) and ammonium (right) concentrations at Zeppelin and Gruvebadet Observatories (top and bottom plot, respectively) over the time period covered by the available data. Vertical bars refer to the standard deviation of the measurements.

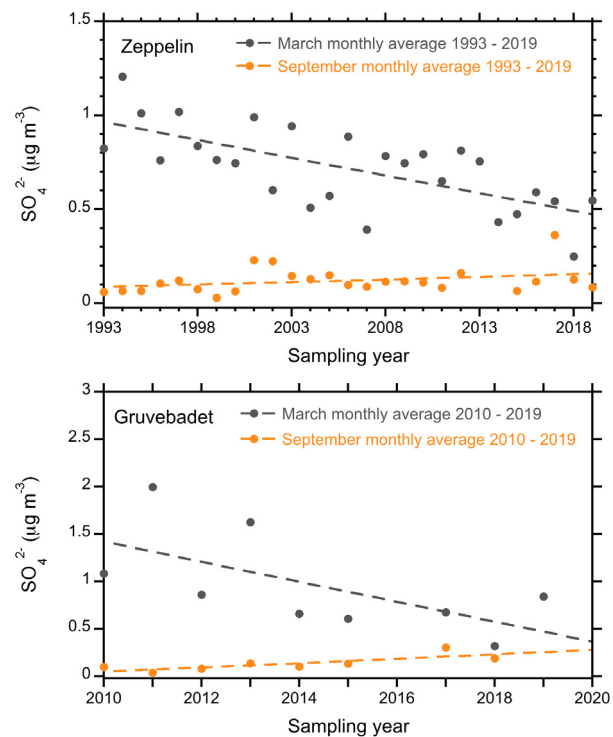
The seasonal pattern of sulphate that can only be barely spotted in Figure 1 can be clearly observed in Figure 2, which shows monthly averages for the entire periods covered by available data at the two sites. Temporal pattern of sulphate as well as ammonium is mainly controlled by the Arctic Haze, with concentrations maximizing during late winter–early spring due to build-up of Haze and then declining and minimizing during summer. The shape of sulphate’s winter maximum at GVB is different from the one at ZEP. At the latter site, one can observe the highest values in April, whereas at GVB a larger maximum is shown during the late winter–early spring period (i.e. February and March). Given that the sampling coverage is different for GVB and Zeppelin (i.e. November and January were sampled only during 2018/2019 field season), this has to be taken only as a preliminary hint; therefore, the difference between the two sites needs to be confirmed through further measurements.

By combining the evidence given by Figures 1 and 2, it is reasonable to assume that a change in sulphate emissions is connected to a change in the chemical composition (or at least sulphate content) in the Haze. Indeed, by analyzing the pattern of sulphate’s monthly averages of different years, it comes out that the months affected by the Haze are driving the sulphate drop along the years.

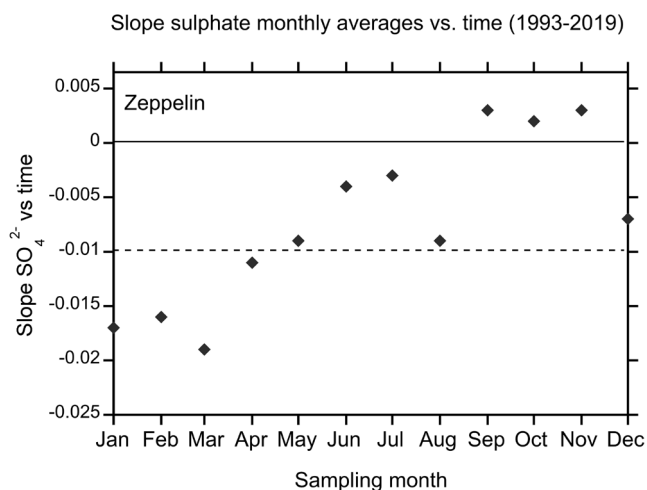
Indeed, few studies have estimated the contribution of various sulphate sources in Ny-Ålesund, and anthropogenic sources were confirmed to be dominant during winter/spring in terms of crustal, sea-salt and biogenic sources (Udisti et al. 2016; Yang et al. 2018). For instance, according to a source apportionment performed by Udisti et al. (2016) on the basis of aerosol chemical composition at GVB in 2014, biogenic sulphate fraction reached up to 70% in summer, becoming dominant as the anthropogenic component decreases in this season.

Figure 3 shows the temporal profile of sulphate concentration in March and September for the entire range of available datasets at the two sites; the two months were chosen as representative of “Haze” and “no-Haze” periods. In March, sulphate average shows a progressive decrease with time, while September average remains either constant or increases both at ZEP and GVB. These trends show statistically significant linear correlation coefficients (> 95%); the slope of the corresponding regression line is shown for ZEP in Figure 4. From the figure, it appears that there is a seasonal pattern in sign and extent of sulphate trends along the year; substantial decreasing trends can be observed for late winter–early spring (January–April), slightly declining trend is seen during late spring–summer (May–August) and then again in December, and slightly positive trends are observed in Autumn (September – November). This pattern is in line with the dominance of the Haze in the first part of the year and its changing through last decades, but the constant or slightly increasing levels during summer and autumn at both ZEP and GVB sites does not have a straightforward interpretation. Given that marine biogenic source dominates sulphate emissions during late spring–summer, the data shown in Figure 4 may hint towards a progressive increase of intensity or transport processes related to this source along the last decades at Ny-Ålesund even though it is unclear why this could affect autumn months.

The decrease of sulphate concentration in aerosol mainly reflects a decrease in sulphuric acid, it being the main component of the Arctic Haze and particularly of the aerosol accumulation mode (Udisti et al. 2016, 2020) dominating the Haze size distribution. Such a change may have a relevant influence on the chemistry of the Arctic atmosphere in terms of neutralization capacity. According to Sharma et al. (2019), there has been a shift from a generally acidic particulate (sulphuric acid) to a more neutral one (mainly due to ammonium sulphate) due to the larger decline in  $\text{SO}_2$  emissions with respect to ammonia emissions in the source regions. The analysis of ammonium concentration and  $\text{SO}_4^{2-}/\text{NH}_4^+$  ratio in the aerosol can provide useful information about this likely evolution of the chemistry of the atmosphere along the last decades.



**Figure 3:** Temporal trend of monthly averages of sulphate concentrations for two selected months (March and September) from the entire sampling period at Zeppelin and Gruvebadet sites.

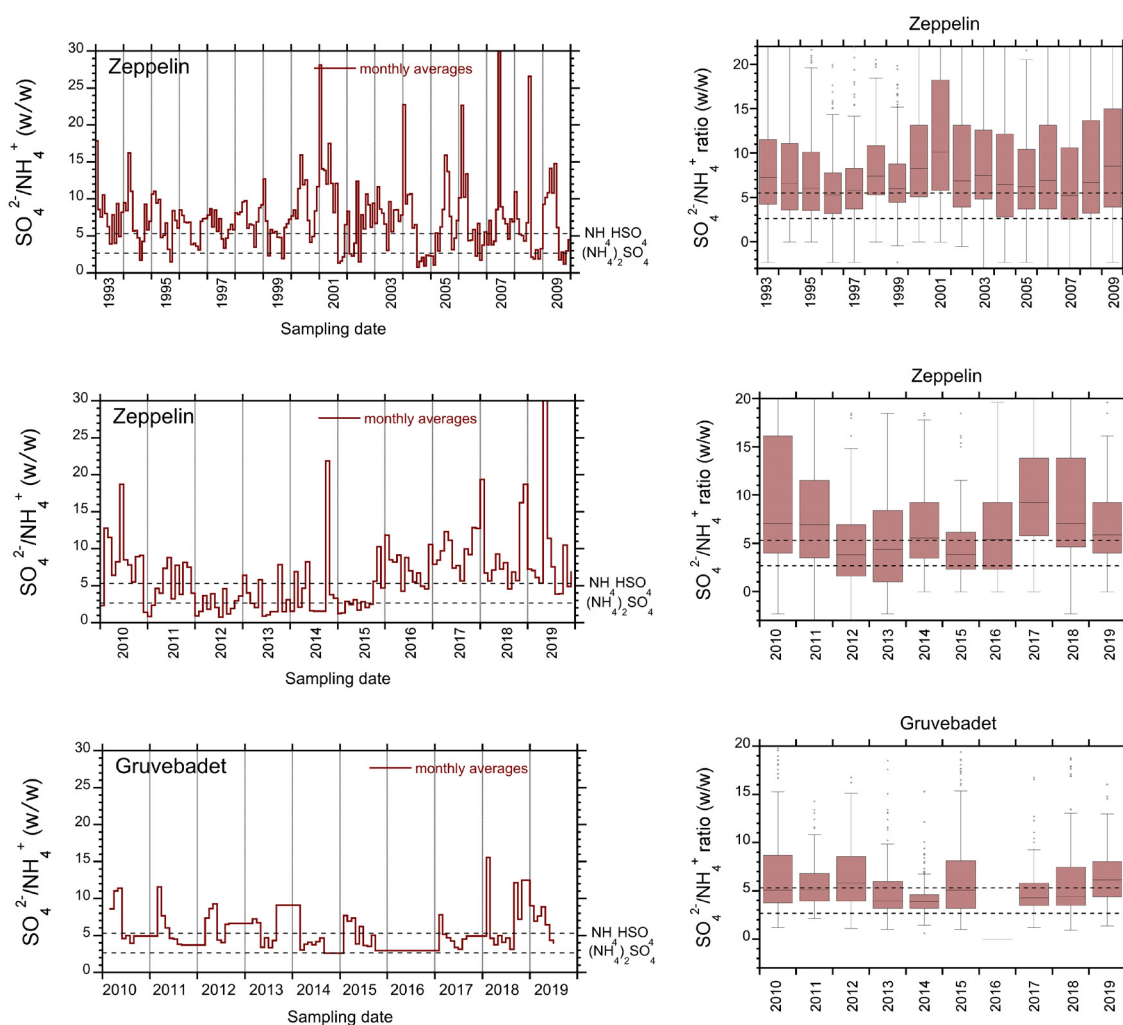


**Figure 4:** Decreasing/increasing rate of sulphate in the long run (1993–2019) at Zeppelin for each month of the year. Dotted and continuous lines separate the season, showing different trends.



Figure 5 shows  $\text{SO}_4^{2-}/\text{NH}_4^+$  ratio (w/w) at monthly (plots on the left) and yearly (plots on the right) resolution at ZEP and GVB over the entire period covered by available data. Previous works already showed that sulphate is present in the aerosol found in Ny-Ålesund mainly as ammonium salt, often both as  $(\text{NH}_4)_2\text{SO}_4$  and  $(\text{NH}_4)\text{HSO}_4$  during spring–summer (Giardi et al. 2016; Udisti et al. 2016, 2020). Both monthly and yearly averages exhibit a general excess of sulphuric acid with respect to  $(\text{NH}_4)_2\text{SO}_4$  and  $(\text{NH}_4)\text{HSO}_4$  ratios, with usually higher values at ZEP than GVB indicating an overall dominance of sulphuric acid over neutralized salts. By looking into details at a seasonal scale (see Figure 6), it appears that sulphate/ammonium ratios are particularly high, ranging between 11.6 and 12.2 at ZEP and between 6.7 and

9.7 at GVB as monthly mean during the Haze period (January–April; see Figure 5). These values are much higher than 5.33 – the ratio marking the formation of  $\text{NH}_4\text{HSO}_4$  salt during the Haze period; however, in summer, the values are found to be around 5.33. These results indicate the presence of an excess of sulphate with respect to the stoichiometric amount needed to neutralize ammonia, confirming that during the Arctic haze months, a significant fraction of sulphuric acid is present together with the most acidic form of sulphate salts (i.e.  $\text{NH}_4\text{HSO}_4$ ). The minima of the ratios get slightly shifted during August and September at ZEP and during July and August at GVB, but the general seasonal trend remains quite similar.



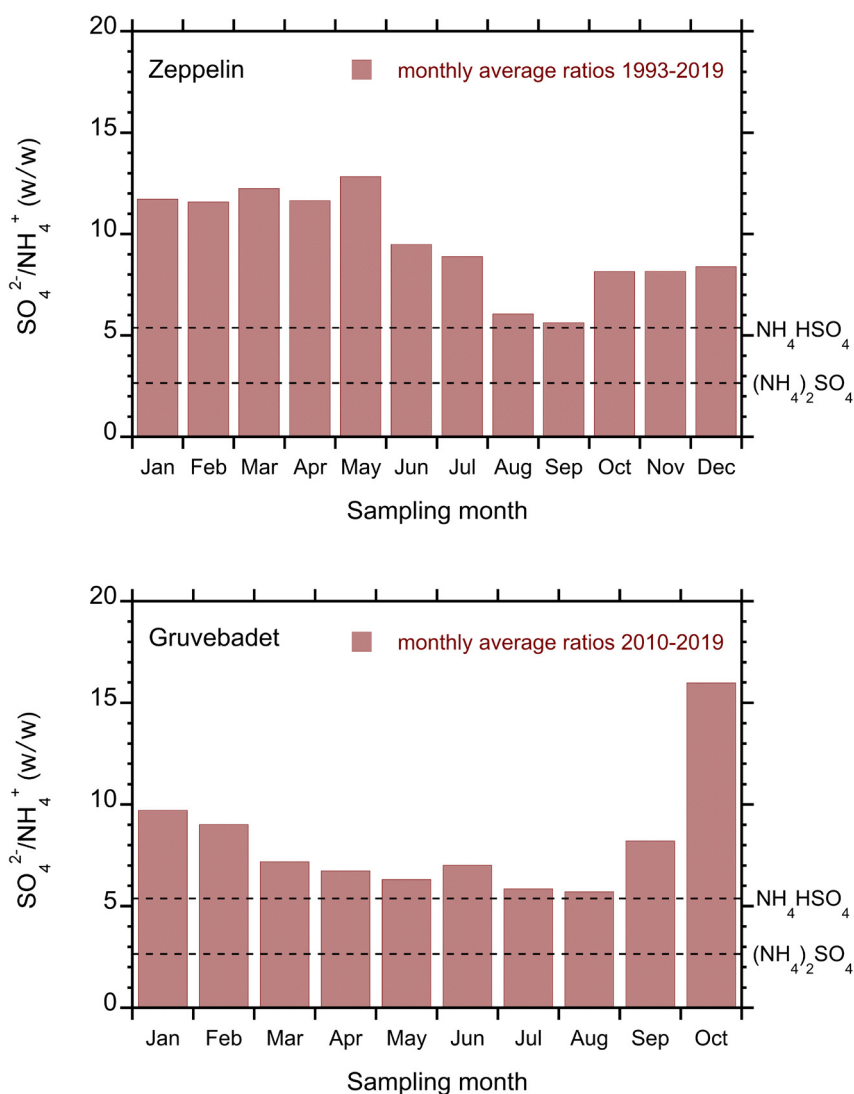
**Figure 5:** Sulphate/ammonium ratio at monthly resolution and distribution box plot at Zeppelin and Gruebadet Observatories (top plots and bottom plot, respectively) over the entire time period covered by the available data. Dotted lines mark the value of the sulphate/ammonium ratio (w/w) in  $\text{NH}_4\text{HSO}_4$  (5.33) and  $(\text{NH}_4)_2\text{SO}_4$  (2.66)



It is interesting to notice that previous works at GVB (Giardi et al. 2016; Udisti et al. 2016) that focused on single years (2013 and 2014, respectively) found different results from that of the summer sulphate/ammonium ratio, with smaller values, around 2.66, corresponding to the complete neutralization of  $\text{H}_2\text{SO}_4$  with ammonia to yield  $(\text{NH}_4)_2\text{SO}_4$ . Nevertheless, comparing the ratios at the two sites for the time period of 2010–2019, both monthly averages and distribution plots at yearly resolution show generally higher values for ZEP. Since sulphate levels are basically similar at the two sites and measured ammonium concentrations are lower at ZEP, the latter drives the ratio. It is likely that differences in the analytical determination and

detection limits of the methods used for ZEP and GVB can explain different values of the ratios at the two sites.

Regarding the long-term trend of the ratio, it appears to be highly variable. Moreover, in this case also, it is possible that a relatively large uncertainty on low ammonium concentrations prevents from observing trends over the years. Sticking to the available data, it appears that there is no clear trend towards a more neutralized atmosphere, but to ascribe it to increasing ammonia emission and compensating decreasing sulphate, further measurements and harmonized protocols are needed.



**Figure 6:** Monthly averages of sulphate/ammonium ratios at Zeppelin and Gruevbadet Observatories (top and bottom plot, respectively) over the entire time period covered by the available data.

### 3. Connections and synergies with other SESS report chapters

This report is in synergy with the SESS Report 2019 chapter “Atmospheric black carbon in Svalbard (ABC Svalbard)” (Gilardoni et al. 2020), which presents an overview of existing data on BC from the same sites as investigated here (ZEP and GVB). BC being another relevant marker of the Arctic Haze, the merger of the datasets presented here and of “ABC Svalbard” would yield a more comprehensive view of the changes in the Haze in Ny-Ålesund.

The datasets and results presented here also fit some of the recommendations in the SESS Report 2019 chapter “Multidisciplinary research on biogenically driven new particle formation in Svalbard (SVALBAEROSOL)” (Sipilä et al. 2020). In the chapter, the authors strongly suggest the continuation of current dimethylsulfide (DMS) and aerosol measurements at Gruvebadet and Zeppelin stations, possibly simultaneously, to better understand the present and predict the

future CCN concentration and optical properties. For this purpose, a more detailed knowledge of the secondary aerosol formation pathways must be achieved. Both sulphuric acid and ammonia have been proven to work as triggers of new particle formation processes in different continental environments (Kirkby et al. 2011; Kulmala et al. 2013); however, the exact mix of reagents which is responsible for such processes in the Arctic is not known yet (Sipilä et al. 2020).

Possible connections can be found with SESS Report 2020 chapter “How representative is Svalbard for future Arctic climate evolution? An Earth system modelling perspective (SvalCLIM)” (Gjermundsen et al. 2021) by using the long-term data reported here to feed predictive models, which pays special attention to the changing features of the Arctic Haze and its impact on overall Arctic climate.

### 4. Unanswered Questions

Although not completely satisfactory, our current knowledge of the chemical and physical features of the Arctic Haze can be considered as promising.

Long-term and permanent observatories measure aerosol species, including particularly sulphate and other chemical proxies of the Haze (e.g. ammonium, nitrate, BC, organic carbon), as well as size distribution and optical properties of the aerosol that can be related to such process.

A large dataset on the surface concentrations of this kind of aerosol and their seasonal/annual variability is now available, and long-term trends have shown that sulphate has decreased and aerosol has become less acidic.

Nevertheless, the available datasets cover different temporal ranges (from the last few years to the last four decades) at the different sites and with different temporal resolutions so that the merging

of all the datasets to draw significant conclusions on the trends in the Arctic is not straightforward and needs to be accomplished accurately not to be misleading.

In addition, the same datasets have been obtained by applying different protocols of sampling (low- and high-volume samples, sampling medium), sample storage and treatment and, especially, chemical analysis (different analytical performances, blank levels, numbers and kinds of measured analytes), possibly compromising the reliability of a comparison.

A relevant open point of consideration that is connected to aerosol chemical composition and related sources is the vertical structure of boundary layer (BL) in Ny-Ålesund. A number of studies present consistent meteorological datasets on the long-term (e.g. 1993–2011, Maturilli et al. 2013) performed comparisons of eddy covariance measurements

with model results (Jocher et al. 2015) and derived vertical variations of momentum, heat fluxes and kinetic energy (Mazzola et al. 2016). However, although these datasets provide a good picture of the atmospheric variables in the area, they are still not sufficient to describe the vertical structure of the BL. A more detailed knowledge of this aspect would help in better interpreting the observed features in

chemical composition at GVB and ZEP.

In terms of environmental interpretation of the observed changes in the Arctic Haze, a challenging open point concerns the cause of the observed trends: Are they entirely due to changed emissions or does a changing atmospheric reactivity have a role to play?

## 5. Recommendations for the future

To discriminate between the contribution of sources (changing in terms of chemical composition and/or intensity and possibly different transport routes due to changes in atmospheric circulation patterns) and different chemistry of the atmosphere, continuous long-term measurements are required from strategic sites, such as GVB and ZEP; moreover, existing observations need to be continued and enlarged to further parameters.

In fact, since the two sites are located at different altitudes but at close distance, the differences in concentration levels and seasonal/interannual trends observed at the two sites can help to better understand the impact of local sources and long-range sources of sulphate and the other Haze proxies.

The measurement of other climatically relevant parameters (such as Cloud Condensation Nuclei [CCN and Ice-Nucleating Particle [INP]) and examination of specific studies (dealing with parameters such as single particle composition, mixing state of BC aerosol) has been performed during spot campaigns at both the observatories, but it is strongly suggested to continue it for the long term, in parallel with other ongoing observations.

In particular, regarding single particle size and composition analysis and INP properties of such particles, there is increasing evidence that such information is pivotal to understand the cloud-aerosol feedback in the Arctic, while the mixing state of BC with organic and inorganic aerosol species (including brown carbon) could provide relevant information to understand BC radiative forcing.

For this purpose, an accurate source apportionment by refined statistical tools (particularly Positive Matrix Factorization [PMF]) is mandatory. Hence, a broad spectrum of chemical and physical parameters measured at high and regular resolution is needed. Although data series for some of the mentioned parameters are available, there exists a lack of observation for some species, especially primary and secondary organic aerosols, needed for apportionment of particles to natural and anthropogenic sources.

Therefore, the measurement of methanesulphonic acid (MSA) would provide a valuable support in assessing the biogenic contribution to sulphate budget; this is because MSA is an univocal marker of marine biological activity (also related to sea-ice dynamics; Becagli et al. 2016, 2019) and sulphate/MSA ratio has already been used to reconstruct biogenic source in Ny-Ålesund (Udisti et al. 2016). Hence, there is a clear need to complement ongoing surface-based experimental observations.

GVB can be considered as a representative of ground-level concentrations of the investigated markers, and it is well within the BL. Conversely, Zeppelin observatory has a more dynamic relationship with BL (being often above the BL during winter season and sometimes within it during summer months); however, this phenomenon remains unanswered, and further meteorological and physical observations are needed. Hence, a thorough comparison between the datasets obtained at the two sites is needed to better constrain the impact of the Haze both at surface level and above the BL; this would help to have a

sort of both “local” and “long-range” signature in Svalbard Islands.

To improve the reliability and effectiveness of such a comparison, it is recommended to harmonize the protocols for aerosol sampling and measurements between the two sites. For instance, it would be helpful to set common cut off and/or to use multiple size classes, temporal resolutions, sampling material, extraction and analysis procedures. Later, data analysis tools could also be shared and used on the combined datasets. Moreover, periodic intercalibration exercises (e.g. round robin tests) on same samples are recommended to detect possible significant discrepancies and figure out the best

strategy to match the data series.

Future collaboration among the institutes and stations working on the topics discussed in this report should be solicited, with special attention to the research groups already working in Ny-Ålesund (Alfred Wegener Institut [AWI], Institut Polaire Français Paul-Émile Victor [IPEV], University of Helsinki and Finnish Meteorological Institute [FMI], Stockholm University, Korea Polar Research Institute [KOPRI]). These Institutes have already established collaboration over the past years. Other Institutes concerned with the research topics discussed here should also be encouraged to join efforts with existing collaborations.

## 6. Data availability

The data that will be collected and discussed in this report include

1. Long-term measurements of sulphate and ammonium concentration in atmospheric aerosol collected at GVB during the 2010–2020 period.

2. Long-term measurements of sulphate and ammonium concentration in atmospheric aerosol collected at ZEP during the 1993–2019 period.

| Dataset                    | Parameters  | Period    | Location/Area                             | Metadata/Data access (URL/DOI)   | Data provider   |
|----------------------------|---|-----------|---|--|---|
| PM10 chemistry at GVB      | Sulphate and ammonium concentration in PM10 aerosol | 2010–2019 | Gruvebadet Observatory (GVB) - Ny-Ålesund | <a href="http://ebas.nilu.no/">http://ebas.nilu.no/</a><br>SIOS data access portal: <a href="https://bit.ly/2HF8IDE">https://bit.ly/2HF8IDE</a> (click 'Search') | Rita Traversi<br><a href="mailto:rita.traversi@unif.it">rita.traversi@unif.it</a> |
| PM10 chemistry at Zeppelin | Sulphate and ammonium concentration in PM10 aerosol | 1993–2019 | Zeppelin Observatory (ZEP) - Ny-Ålesund   | <a href="http://ebas.nilu.no/">http://ebas.nilu.no/</a><br>SIOS data access portal: <a href="https://bit.ly/2HF8IDE">https://bit.ly/2HF8IDE</a> (click 'Search') | EBAS NILU   |

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Integrated Arctic Earth Observing System – Knowledge Centre, operational phase.

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