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The Lower Atmosphere above Svalbard (LAS): Observed long term trends, small scale processes and the surface exchange

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Introduction

All the components of the Arctic System must be observed across time and space to understand the scope and evolution of change. Understanding how the system functions and projecting future changes requires models developed or initialised using data. For the Svalbard region, these data should primarily come from the core Earth System Science (ESS) observations within SIOS. Long-term records of lower atmospheric variables are primarily available from six permanent observations sites in Svalbard: Longyearbyen, Barentsburg, Ny-Ålesund, Hornsund, Hopen and Bjørnøya. Bjørnøya has a climate distinct from the rest of Svalbard, and Hopen is not representative of large parts of the archipelago, either. The remaining sites are all at sea level, on or near the west coast of Spitsbergen, limiting our ability to understand spatial variability across the main parts of Svalbard. Among the long-term stations, by far the most extensive atmospheric observations are made in Ny-Ålesund. This report therefore focuses on the observations, results and needs in Ny-Ålesund, while also highlighting the challenges coming from the lack of broader geographical coverage.

One of the core aims of SIOS is to *combine model and observing strategies to achieve the most rapid and cost effective development of both and to maximize the understanding gained from the available information*. Data are limited in time and space, and a good way to fill the gaps is by means of theoretical and numerical models at different time and space scales. Data can then support tests and verify models, and models can identify areas where new measurements would most contribute to better understanding and predictability.

The present report addresses some of the major themes concerning atmospheric research in Svalbard: long-term measurements, the boundary layer and its interaction with snow, aerosols and clouds. The first topic is obviously important to link atmospheric research with programs in other disciplines, as both biology and glaciology are strongly influenced by climate change. Moreover, the long-term recording of key meteorological parameters is needed to constrain climate models running on a long time scale and to understand the pronounced warming in the European Arctic in a global context. The atmospheric boundary layer, especially under thermally stable conditions, is not fully understood. Hence climate models usually show the largest spread in the boundary layer. Aerosol, clouds, their feedbacks and the hydrological cycle remain the largest sources of uncertainty in climate models. The error bars in the radiative forcing by aerosol and clouds, according to the IPCC reports, are of the same magnitude as the anthropogenic CO_2 forcing. Therefore, it is not surprising that the different institutes performing research in Svalbard, while having slightly different perspectives on their own, all contribute to several of these four topics. Hence the atmospheric research in Svalbard and its international cooperation is most advanced in these topics. The four themes interact significantly with each other and are presented separately merely for convenience. Further studies and analysis should attempt to better understand these interactions, in addition to working within the individual themes.

Long-term trends in the lower atmosphere

Keywords: Temperature, humidity, wind field, atmospheric pressure, radiation budget, cloudiness

Observations of numerous parameters describing the basic thermodynamic state and composition of the atmosphere, meteorology, radiation, aerosols, clouds, greenhouse and trace gases, have been collected in Svalbard, with varying degrees of detail, for decades now. However, many aspects of multi-decadal trends and inter-annual, annual and seasonal variability of atmospheric conditions have not yet been well examined in the region. Important studies have been made based on the long-term observations performed at Ny-Ålesund, but much still needs be done to give a complete overview of Svalbard's environment and ongoing changes and a better interpretation of small-scale local processes and their interaction with large-scale conditions. A common sampling strategy between different research groups should produce more valuable, temporal and spatial, integrated data sets useful to reduce the measurement gaps and get a better data coverage over Svalbard.

Recent results

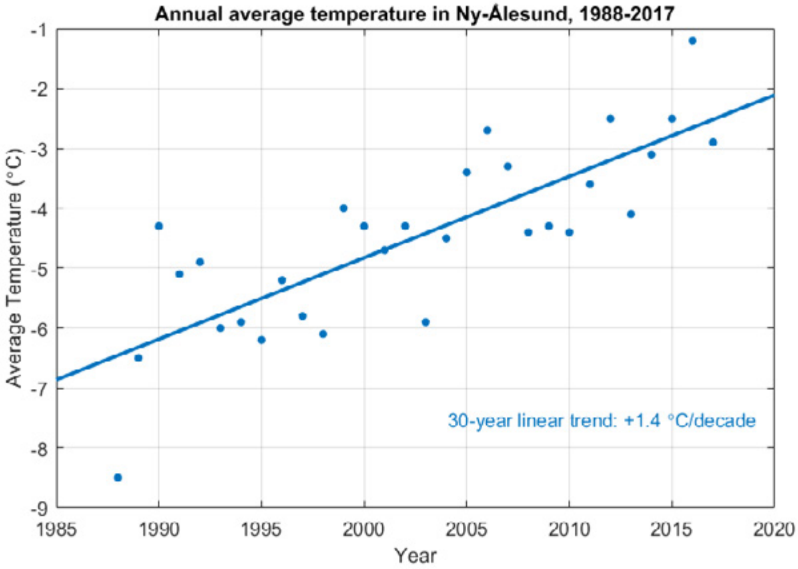

Figure 1: Annual mean air temperature measured at 2 m in Ny-Ålesund from 1988 to 2017 (dots). The linear regression (line) shows a trend of air temperature increase (+1.4 °C/decade) corresponding to about + 4.2 °C in 30 years.

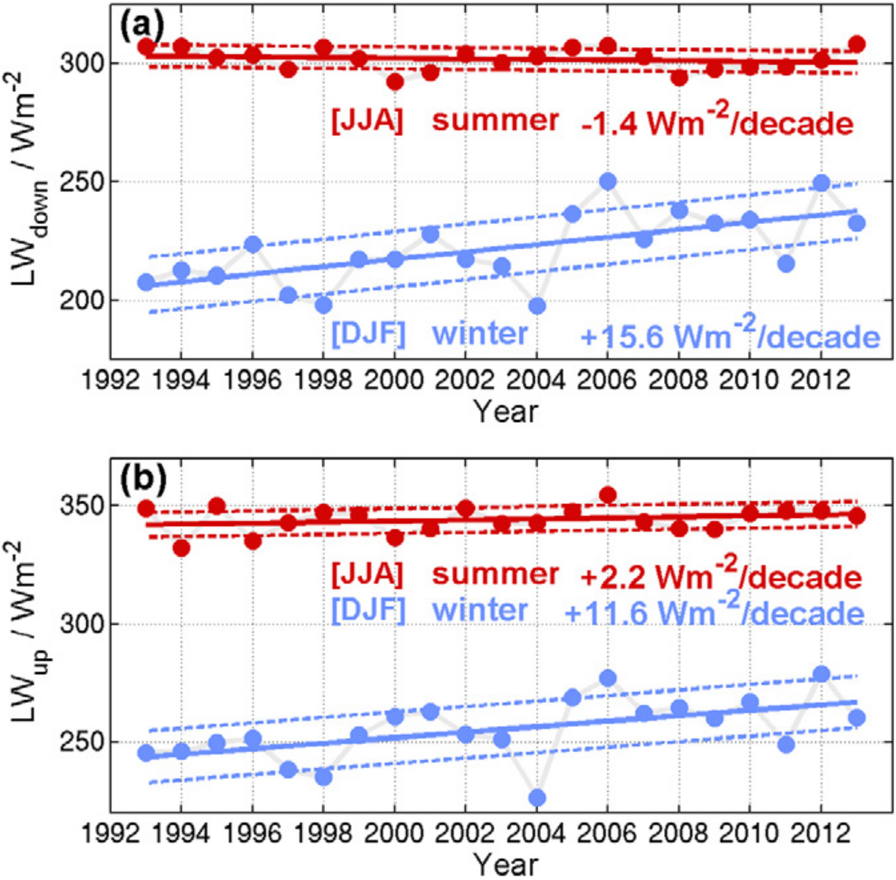

Figure 2: Seasonal mean downward (a) and upward (b) longwave radiation for summer (red dots) and winter (blue dots) in Ny-Ålesund. The continuous and dashed lines are the linear regression and regression uncertainty, respectively. No relevant changes are observed in the summer months (JJA) for downward and for upward longwave radiation. A considerable increase in winter months (DJF) is observed for downward and upward longwave radiation.

Maturilli et al. (2013, 2015) present long-term observations of meteorological and atmospheric radiation data. The annual mean temperature at Ny-Ålesund has risen by +1.3 ± 0.7 K per decade, with a maximum seasonal increase during the winter months of +3.1 ± 2.6 K per decade. Dahlke and Maturilli (2017) attempt to quantify the advective contribution to the observed atmospheric warming in the Svalbard area. Based on radiosonde measurements from Ny-Ålesund, a strong dependence of the tropospheric temperature on the synoptic flow direction was revealed. Kayser et al. (2017) provided statistics of temperature inversion characteristics, static stability, and boundary layer extent. During winter, when radiative cooling is most effective, they found the strongest impact of synoptic cyclones. Maturilli and Kayser (2017) showed that the humidity in the whole troposphere is rising. They indicate a strong seasonality of atmospheric surface layer warming and relate the changes to different radiation parameters. Winter is the season with the largest long-term changes in radiation, with an increase of +15.6 ± 11.6 W m^2 per decade in the downward longwave radiation. Mazzola et al. (2016) confirm these trends, discussing monthly and seasonal behaviour of meteorological parameters and radiation data that characterize the site as basic information to study the small scale processes, and their interaction with the other components of the system.

Unanswered questions

The reason for the rapid winter warming seen in Ny-Ålesund is not clearly understood. It cannot yet be addressed to what extent anthropogenic greenhouse gases, changing circulation patterns with more Atlantic impact (both from the atmosphere itself and the oceanic circulation), differences in cloud frequencies and properties and other factors have contributed. Furthermore, the representativeness of Ny-Ålesund, both for the rest of Svalbard and the wider Arctic, needs to be addressed in the future. By comparing data from Ny-Ålesund to those from other Arctic sites, the relative importance to the observed warming of long-lived greenhouse gases versus circulation or cloud changes, which probably act more on a regional scale, will become clearer.

Summary of existing data

Surface radiation measurements of up- and downward short- and longwave radiation have been made in Ny-Ålesund since August 1992 in the frame of the Baseline Surface Radiation Network (BSRN), complemented with surface and upper air meteorology since August 1993. The long-term radiation data set in Ny-Ålesund is available at https://doi.org/10.1594/PANGAEA.150000. The supplementary data set contains the basic BSRN radiation and surface meteorological data and is available at https://doi.org/10.1594/PANGAEA.854326. In addition, standard synoptic meteorological observations are available from the Norwegian

Meteorological Institute since 1969 (http://eklima.met.no), and non-BSRN radiation measurements are available from the Norwegian Polar Institute from 1974 until 2000 (https://data.npolar.no). Long-term vertical profile measurements of the atmospheric parameters are collected since September 2009 at the Climate Change Tower, between the surface and 34 m. Data are stored in the IADC database (http://mainnode.src.cnr.it/cnr/data.php). An overview of the existence, interoperability and accessibility of relevant databases and datasets should be provided for measurements at stations in Svalbard beyond Ny-Ålesund; the Research in Svalbard (RIS) portal will be starting point for this task.

Recommendations for SIOS

As all existing research sites are located at or close to the West coast of Spitsbergen, they probably share similar synoptic conditions but different micro-meteorology characteristics. Sites at the east coast of Spitsbergen and in northeast Svalbard would be influenced by a different (more Arctic) synoptic regime and hence be useful to separate local from regional and continental influences. Additionally, better observations from sites away from the coasts, especially on glaciers, would provide a more thorough understanding of the climate of Svalbard, considering its varied terrain and extensive glacier cover. An improvement of spatial distribution of measurement stations within Svalbard should be addressed and supported by SIOS.

Boundary layer meteorology

Keywords: Vertical profiles, turbulent fluxes, wind, air temperature, radiation budget

The atmospheric boundary layer (ABL) in the Arctic is one of the elements in the climate system that needs to be well understood to obtain a quantitative understanding of the exchange processes at the interfaces and to test the parameterization schemes for numerical modelling of weather, climate and chemical composition of the atmosphere. Due to the complicated orography of Svalbard, micrometeorological phenomena as well as the heterogeneity of the surface (type, albedo, and moisture) the measured fluxes of turbulence or trace gases that typically vary on scales of 100 m are normally not resolvable in climate models. The turbulent processes in the ABL drive the fluxes of energy and mass between the surface and the free atmosphere. The exchange of water vapour, aerosols and trace gases, in particular CH_4 and CO_2, are also controlled by such processes, as well as the long-range transfer of pollutants. The availability of long-lasting time series of turbulence measurements (first- and second-order moments of velocity and temperature) is allowing new and reliable re-evaluations of some classical expressions, mostly related to the application of Monin-Obukhov Similarity Theory (MOST), to identify critical aspects where the similarity theory fails, and in general to extend our knowledge of the ABL.

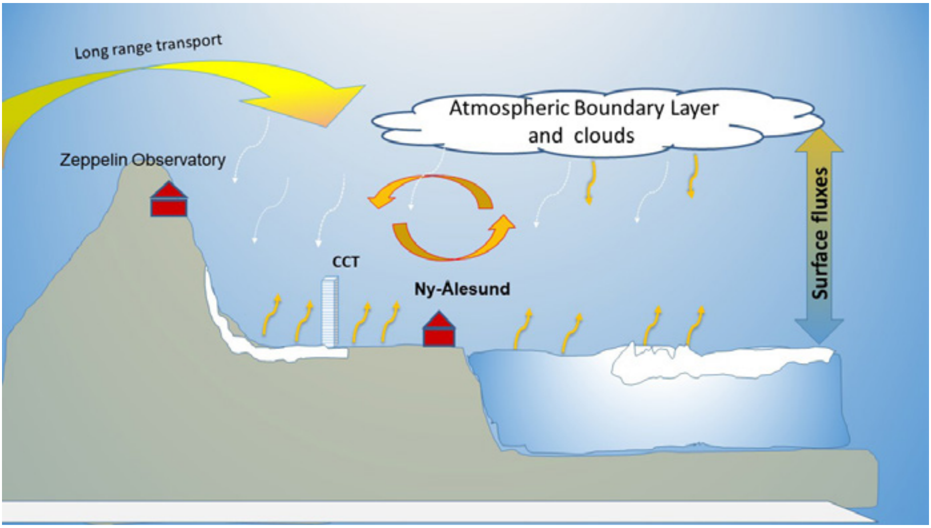

Figure 3: Conceptual model of the lower atmosphere above the fjord at Ny-Ålesund, Svalbard. All the components of the climatic system (sea, atmosphere, ice, snow, soil) interact, transferring energy and mass through the interfaces. The local conditions are also influenced by large-scale processes and long-range transport of mass and energy that contribute to amplifying the variability of the climatic system.

Recent results

The long time series of atmospheric measurements together with focused field experiments have allowed research into several aspects of the ABL structure, from the interaction of the local processes with synoptic circulation, to case studies of singular events like the solar eclipse. They have also provided good statistics on the behaviour of the ABL in different stability conditions, and allowed for evaluating and improving the parameterizations for modelling. Schiavon (2015) described the wind profiles in the lowest tens of metres of the stably stratified atmospheric boundary layer using the data collected at the Climate Change Tower in Ny-Ålesund. Investigation into the vertical structure of the atmospheric stable boundary layer (SBL) is presented by Mazzola et al. (2016) using sonic anemometers and low-frequency thermo-hygrometers and anemometers deployed in a vertical array on the Climate Change Tower in Ny-Ålesund. They show that both the traditional and upside-down SBL cases can occur. The general turbulent characteristics of the boundary layer in Ny-Ålesund under different stability conditions are analysed by Tampieri et al. (2016). They highlight the behaviour of the vertical mixing in quasi-neutral, low-wind conditions, examine the properties of the similarity scaling in unstable conditions and analyse the vertical profiles of the mean velocity and momentum and heat fluxes, also for stable cases. Observations of the ABL over larger areas using controlled meteorological (CMET) balloons have been shown to be valuable in Svalbard (Roberts et al. 2016).

Schulz et al. (2017) discussed the response of fluxes and temperature to the variation of the sunlight during a total solar eclipse that occurred in spring 2015 at Ny-Ålesund with stable atmospheric conditions and a snow covered surface. Kral et al. (2014) analysed, for seasonal variability and differing fetch conditions, measurements of turbulent fluxes of momentum and sensible heat using only a sonic anemometer and slow-response instruments on a tower on the coast of Isfjorden. Jocher at al. (2015) analysed the fluxes of a one-year data set from 3 different eddy sites around Kongsfjorden. The eddy covariance method and a hydrodynamic model approach (HMA) were compared and analysed with respect to season and mean wind direction. They found a clear distinction between 3 prevailing regimes (which have influence on the flux behavior), mainly caused by the topography at the measurement site. Concerning the fluxes, they found a good agreement between the methods in cases of turbulent mixing in summer but deviations are found for stable conditions. Less recently, Di Liberto et al. (2012) showed the possibility to estimate the PBL height by using lidar observations, radiosoundings, and a zero-order one-dimensional model. Jocher et al. (2012) presented the impact of gravity waves on eddy covariance measurements at a site on Kongsvegen glacier and the impact of the main wind direction on the observed fluxes.

The surface energy balance at the Svalbard Archipelago was simulated at high resolution with the Weather Research and Forecasting (WRF) Model by Aas et al. (2015) and compared with measurements of energy fluxes from a site near Ny-Ålesund and several other sites around Svalbard with more limited observations. For surface air temperature, a good agreement between model and observations was found at all locations, but the model overestimated both sensible and latent heat fluxes in most seasons. An interesting work by Schulz et al. (2017) shows the interaction between synoptic and local influences on the ABL height and stability over Ny-Ålesund using a combination of measured conditions during an intensive observational campaign and conditions simulated by a WRF model. Kilpeläinen et al. (2012) compared the vertical structure of the ABL, simulated with the mesoscale model WRF and with its optimized version Polar WRF, to tethered balloon soundings and mast observations taken in March and April 2009 from two Arctic fjords in Svalbard.

Summary of existing data

The Climate Change Tower is an important piece of scientific infrastructure in Ny-Ålesund that has been contributing to the long-term observations of meteorological parameters, turbulent fluxes at different levels and snow layer physical characteristics since November 2009. Due to the different sampling rate of the different sensors, mean values were computed based on a 30-minute average for low response (thermo-hygrometers and propeller anemometers) and fast response (sonic anemometers) sensors. Collected data are stored in the Italian Arctic Data Centre digital infrastructure (http://mainnode.src.cnr.it/cnr/data.php) and can be visualized and downloaded upon request. Since 2012 at the Atmospheric Observatory, a Microwave Radiometer has been running to provide atmospheric profiles of temperature and relative humidity, along with column values of liquid water path and integrated water vapour every 20 minutes. Moreover, a wind lidar has been running to provide 3D wind field profiles every 10 minutes. Data are stored at AWI Potsdam and are available upon request. Three Eddy Covariance (EC) systems set up at different times have been deployed at different sites within the Ny-Ålesund area. The first “Bayelva” is located 2 km W of the Atmospheric Observatory, in Bayelva valley, and has run continuously since 2008, measuring turbulent fluxes, surface temperature and soil temperature profiles (cfr. glaciology flagship). The second “Ny-Ålesund” is located 300 m SSW of the observatory and has run continuously since 2012, measuring turbulent fluxes, temperature and wind profiles in the lowest 2m, surface temperature, snow height and radiation. The third “old pier” is 100 m N of the observatory, just off the coastline at the end of old pier, and has run continuously since 2016, measuring turbulent fluxes and sea surface temperature. Data are stored at AWI Potsdam and currently under evaluation. Vertical profiles of meteorological parameters (pressure, wind, temperature and humidity) by tethered balloon system have been collected on a campaign basis, mostly in spring, since 2009 at the Atmospheric Observatory site. Data are stored at AWI in Potsdam and are available upon request.

Unanswered questions

The local features of the surface layer (the first few metres of the atmosphere) are not systematically related to the features of the upper part of the ABL and/or the free troposphere. Integration of conventional soundings, tower data and covariance measurements near the ground is necessary to fully observe the system. Ground-based remote sensing techniques with sodar to depict the thermal structure of the boundary layer depth or with lidars to estimate the aerosol stratification in the boundary layer could improve the observation of the vertical structure of the boundary layer, though not for all conditions. A rational approach (based on measurements and models) to link all these evaluations could lead to a substantial increase of understanding. A closure of exchange processes should include measurements at the air-sea/sea-ice interface.

Recommendations for SIOS

Evaluate the state of scientific infrastructure and data collection in Svalbard, beyond Ny-Ålesund, and provide support for new installation and/or repositioning of meteorological stations, EC systems and remote sensing systems at other sites outside Ny-Ålesund to build a distributed observation network on land, glaciers and sea. In particular, support should be provided by SIOS to establish and improve the network of measurements at the sea surface. Finally an effort should be devoted to increase the links between all the scientific components present in Svalbard for sharing information, data and facilities.

Atmosphere-snow interactions

Keywords: Snow depth, precipitation, aerosol deposition, snow reflectivity, heat transfer

The role of snow in the interactions between atmosphere, land and ice is a key question in understanding Arctic variability, but snow is particularly difficult to quantify and monitor over time, so again the models are currently not effectively simulating snow in all its aspects. Part of the problem is the technical challenge of using isolated point measurements to assess snow depth distribution on appropriate horizontal scales to fit into current models. On the other hand, from a local point of view, the variability of the snow characteristics are hard to parameterize. There is a need to understand snow structure and composition in relation to the atmosphere, so new technical approaches, new technologies and more extensive networks of measurements are required to better evaluate and understand this critical variable and its relevance to other variables. Snow cannot be considered an independent variable and the study of the physico-chemical characteristics of the snow must integrate knowledge with the atmospheric conditions, aerosol characteristics, energy fluxes, albedo and radiation budget at the surface.

Recent results

Most of the recent works concerning snow are still far from considering the role of snow in the interactions with atmosphere, land and ice as key questions in understanding Arctic variability. Merkouriadi et al. (2017) show that snow depth is a major uncertainty in predicting ice thickness, using remote sensing algorithms. They examined the winter spatial and temporal evolution of snow physical properties on first-year and second-year ice during the Norwegian young sea ICE (N-ICE2015) expedition. To our knowledge, in Svalbard not many studies have been analysing the impact of snow on the climate system variability. Most of the important studies on snow relay what the snow contains and not how it contributes to such variability. Snow is mainly considered as medium where the emissions of natural and anthropogenic activity transported by the atmosphere are collected. In this frame, size distribution of black carbon (soot, BC) in the snowpack has been measured by Sinha et al. (2018) at two sites at Ny-Ålesund in April 2013. The BC size distributions did not show significant variations with depth in the snowpack, suggesting stable size distributions in falling snow. Nawrot et al. (2016) analysed the chemical properties of precipitation, monitoring snow cover and fresh snow at the Hornsund Polish Polar Station and in an elevation profile on the Hans Glacier. Meteorological data from the coast and the glacier helped to examine in detail the impact of atmospheric processes on snow cover contamination. Ianniello et al. (2016) performed measurements of atmospheric concentrations and fluxes of reactive nitrogen above the snow surface at Ny-Ålesund, where significant emission fluxes of NO and NO_2 were observed. Deposition fluxes of HNO_3 and fine and coarse particulate NO_3^- were also observed, reaching peak values during snowfall events. Measurements of surface snow provided experimental data of dry deposition. However, wet deposition in falling snow seemed to be the major contribution to the nitrate input to the snow.

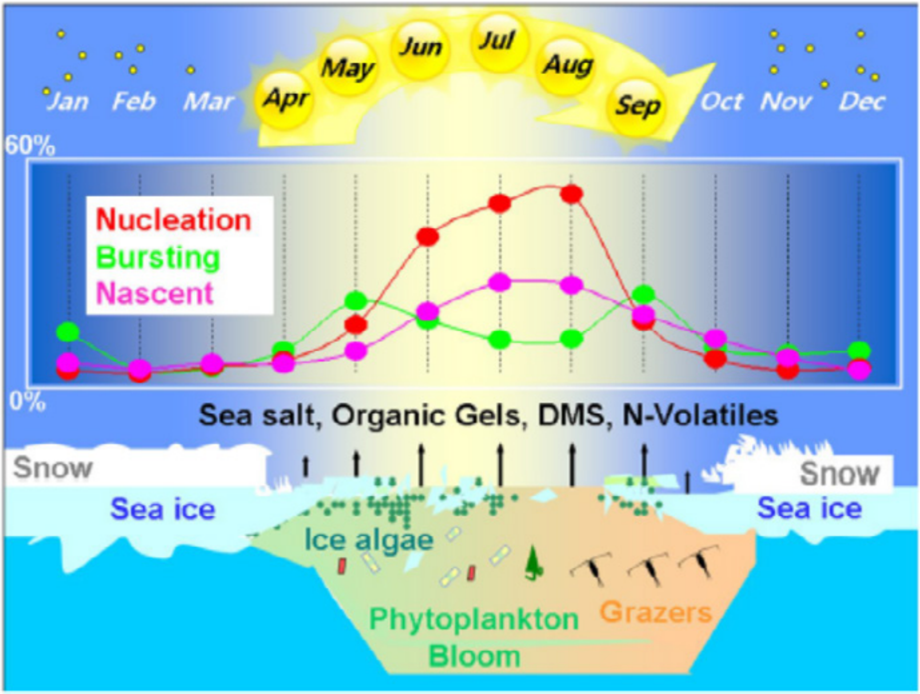

Figure 4: Schematic illustration of seasonal cycle of sea-ice, microbiota, sea-to-air emission and ultrafine aerosols in the Arctic. Aerosol size ranges are 10 ± 2 nm (nucleation aerosols), 32 ± 12 nm (bursting aerosols) and 50 ± 11 (nascent ultrafine aerosols). Both bursting and nucleation aerosol categories contribute to new particle formation events.

Unanswered questions

Snow is an important medium to measure the quantity and the property of atmospheric constituents falling at the surface. However, many aspects of its interaction with the overlying atmospheric layer, in terms of radiation and mass, chemical and energy fluxes, are still poorly understood. There is a need to find better parameterizations for representing snow and its role in the broader climate system in numerical models. Modelling of the ABL should aim to include the mass fluxes into and from the snow, which would provide a better simulation of both atmospheric and snow properties. However, deposition and exchange processes are not yet well enough understood to develop reliable parameterizations, so there is a need for more detailed coincident observations of atmospheric constituents, turbulent fluxes and the concentrations of the same constituents in precipitation and in snow on the ground.

Clouds and Atmospheric Aerosol

Keywords: Microphysics, clouds, aerosol, nucleation, long range transport

Arctic clouds are critical in influencing energy exchange between ocean and cryosphere surfaces. Water vapour is a major greenhouse gas, and changes in the moisture content of the global atmosphere modifies Arctic climate through transport of water vapour into the Arctic from mid-latitudes, causing changes in cloudiness and thus the radiation balance. The individual cloud droplets started their lives as aerosol particles. At the most fundamental level, understanding the processes that determine cloud properties from microscale to global scale requires understanding which particles actually form cloud droplets under various different conditions. These aerosol particles are mostly transported to Svalbard over long distances in the atmosphere. The resulting atmospheric aerosol concentration, size distribution, chemical and optical properties in the Arctic show a very strong repeating seasonal cycle controlled by seasonal variations in the general circulation, by varying strength of natural and distant anthropogenic sources, and last but not least, by changing efficiency of aerosol removal by clouds and precipitation. The seasonal variation in aerosol properties is not only a boundary layer phenomenon, but also occurs throughout most of the troposphere. Understanding aerosol-cloud interactions and the role of atmospheric dynamics and circulation is among the most important scientific challenges. Many pollutants and atmospheric constituents that are transported over long distances to the Arctic have been monitored for many years in Ny-Ålesund, including aerosol, greenhouse gases and short-lived climate forcers such as black carbon (soot). These influence snow albedo and cloud properties. Ny-Ålesund is well equipped with state-of-the-art aerosol measuring systems, both in-situ and from remote sensing. For this reason, the site should be a key validation point for climate models with interactive aerosol and trace gases to analyse the questions: what are the pollution pathways, the aerosol secondary formation processes, sources and sinks and the interaction between aerosol and clouds in the European Arctic. To answer these important, general questions the different aerosol measurements need to be combined, also considering vertical profiling, the interaction between aerosol and the boundary layer and the combination between in-situ and remote sensing information. Some of the recent work already points into this direction.

Recent results

Markowicz et al. (2017) used a combination of aethalometer measurements on a tethered balloon and lidar measurements to show that BC concentrations are normally low and their vertical concentration is not related to the backscatter in the lidar. Ritter et al. (2016) provided a statistics for the Haze season 2014 from a lidar perspective and height-resolved optical properties of aerosol during the iAREA campaign on aerosol in Spitsbergen. Tomasi et al. (2015) described an overview of photometer measurements at different polar sites and typical, lidar-based optical properties from Ny-Ålesund. In the paper of Stock et al. (2014) long-term aerosol optical depth (AOD) data are presented and interpreted via air back-trajectories and EOF patterns of surface pressure, and they found high AOD loads over Ny-Ålesund for air masses from the central Arctic, with less aerosol from Europe. Hoffmann et al. (2012) showed how lidar data from an Arctic haze event has been inverted to obtain a size distribution that showed reasonable agreement to a size distribution by SMPS at the Zeppelin Observatory. However, experiments like this need to be repeated for various aerosol conditions, as sometimes remote sensing instruments seem to overestimate and in-situ aerosol measurements to underestimate extinction (e.g. Tesche et al. 2014). Stock et al. (2011) showed that lidar and photometer data collected during an Arctic Haze event and a biomass burning case showed similar optical properties. Hence the maximum information content from remote sensing data needs to be revised. Hoffmann et al. (2012) analysed an aerosol layer of volcanic origin in the lower troposphere, which sporadically and unpredictably can enter the Arctic. Udisti et al. (2016) evaluated the seasonal pattern of sulfate, as a key component of the Arctic haze that presents a strong seasonality, with mean spring concentration about 1.5 times higher than that measured in summer. Giardi et al. (2018) presented, at high temporal resolution, a large atmospheric concentrations dataset of metals in Arctic particulate matter and used this to distinguish between local and long-range transported dust. Ferrero et al. (2016) and Cappelletti et al. (2016) demonstrated the possibility to measure vertical profiles of atmospheric BC and aerosol properties by tethered balloon. In particular Cappelletti et al. (2016) improved the capability of measuring at the same time aerosol light scattering, absorption coefficients and size distribution, which is very promising for deducing the aerosol optical properties as a function of height along the probed atmospheric column. Important results related to source apportionment, annual cycle and hygroscopic properties have been achieved using data from the Zeppelin Observatory. Strong evidence of role of marginal ice zone and biogenic sources in new aerosol particle formation in the Arctic was shown (Dall'Osto, 2017). Microphysical aerosol properties observed at Ny-Ålesund were studied together with 4 other sites in the Arctic and all sites show that similar processes and seasonal cycle is present on pan-Arctic scale (Freud et al., 2017). Seven years of observations of cloud condensation nuclei also show a repeating annual cycle closely linked to atmospheric aerosol and interplay between natural and anthropogenic sources of CCN (Jung et al., 2018). Specific to cloud research, among other types of measurements, cloud radars have been employed within the last 3 years by groups from Japan and Germany. Currently the cloud net algorithm is tested for Arctic clouds. Research that analyses cloud properties in relation to the synoptic wind is currently being performed. Further, a radiative transfer model to better understand the forcing of clouds and aerosol is currently being applied, but this important work will need to continue into the future as well.

Unanswered questions

As mentioned by Tesche et al. (2014), the combination of different aerosol measurements can lead to inconsistent results. More indications for this exist (L. Ferrero, private communication based on 2011 data and J. Lisok, private communication based on 2014 data). Combined aerosol measurements from the sites at Gruvebadet and Zeppelin, together with those from a tethered balloon and a lidar can be used to systematically improve our understanding of the aerosol properties. Aerosol properties in relation to relative humidity have already been studied on Mt. Zeppelin. However, due to the broad variety of the chemical composition of aerosol and the complex boundary layer structure in Kongsfjorden, this will probably remain an open topic for the near future. One of the challenges in future research is to understand the impact of changing atmospheric dynamics, water vapour distribution and aerosol properties on tropospheric cloud formation. The ultimate question we would like to answer is: To what extent are the changes in tropospheric cloudiness linked to perturbations in atmospheric dynamics and to aerosol effect on clouds?

Summary of existing data

Sun-photometers are very important sensors to estimate the AOD: one is located at the BSRN site and runs continuously (mid-March to early Oct) since 2003, and another runs continuously (mid-March to early Oct) since 2010 at Zeppelin Observatory. Both work at 10 wavelengths with 1-minute resolution. A Star-photometer at the Atmospheric Observatory works with 10 wavelengths and 6-minute resolution; it runs sporadically (mid Oct to end March) since 1996. To measure backscatter, extinction, depolarization and water vapour (night time) profiles from a Raman Lidar "KARL" with 7.5-m / 2-minute (maximal) resolution, runs on clear sky days since 2000. Data are stored at AWI Potsdam and are available upon request. Ground based measurements of aerosol are provided at Zeppelin Observatory and at Gruvebadet Aerosol laboratory. To observe cloud height and microphysical properties, a micropulse lidar has measured backscatter from clouds since 2002, with depolarization data since 2013, and a cloud radar has measured cloud reflectivity since 2013, with all data stored at NIPR. More recently, in-situ observations of cloud phase and droplet size distribution (data stored at U. Tokyo) and cloud condensation nuclei (data stored at KOPRI) have been made at Zeppelin Observatory.

Science Summary

Svalbard is located in a region in which North Atlantic and high Arctic conditions are mixing, and even though it is not representative of the whole Arctic it is a very important region in the Arctic where rapid warming has occurred. Moreover the region provides particular opportunities to tackle major questions, such as vertical and horizontal coupling of relevant variables, that are not easily addressed elsewhere. With the help of appropriate modelling, these results could be extended within and around the archipelago. The geographical position and the geomorphological structure allow Svalbard to be considered a natural laboratory for studies concerning climate change in polar regions as well as feedbacks on the other areas of the planet. *What occurs in the arctic does not remain in the Arctic!*

The low atmosphere is the part of the atmosphere directly influenced by processes occurring at the surface. The incoming solar energy is distributed to all the components of the climate system: atmosphere, cryosphere, land and sea, and the themes concerning the low atmosphere are strongly interconnected with all components of the climate system.

Long-term trends in Svalbard indicate that the climatology of wind, temperature, precipitation and cloudiness has changed during the last decades and that these changes can be attributed to the global increase of greenhouse gases, but also to the variation of the atmospheric composition and dynamics. Focusing more on the lower atmosphere, it is widely acknowledged that global climate change is substantially anthropogenically driven, but it is far from clear how much the remarkable changes observed in the Arctic are driven primarily by external processes (including Sun-Earth connections) or due to internal Arctic System processes, such as local and regional variations and feedbacks.

For example, melting of sea ice due to global warming causes an accumulation of heat into the sea contributing to the so-called Arctic amplification and driving an increase of evaporation, aerosol production, nucleation processes and, consequently, cloud formation. These processes are not independent from each other as they interact with other components of the climate system. Long-range transport, from mid- and low latitudes, contributes to the high variability of atmospheric conditions in the Svalbard region.

Some “hot current questions” are currently studied in Svalbard, and in particular in Ny-Ålesund, by several research groups from different scientific institutions, but definite answers have not been yet achieved.

Important results have been obtained in the atmospheric boundary layer studies. These results are mainly based on observations, and a huge amount of data has been collected over several years by the observatories and during specific field campaigns. The AWI observatory, the Zeppelin Observatory, the Gruvebadet laboratory, and the numerous other infrastructures have contributed to building such a database. For long-term trends in the lower atmosphere, the questions concern the dramatic increase of temperature, in particular in wintertime, and the trends in trace gases. Study of atmosphere-snow interactions is providing accurate precipitation measurements, estimation of the trends, measurements of Black Carbon and accurate measurements of physical and chemical properties of snow. Clouds and atmospheric aerosol studies focus primarily on the stability and occurrence of mixed-phase clouds, the hygroscopic growth of aerosol and aerosol-cloud interactions. An important study is attempting to achieve aerosol closure and to identify the forcing constraints of aerosol and clouds.

The validity of theories being applied to the observations still needs to be verified. In such a complex region, theory can fail and modelling cannot correctly reproduce the observations. This can be particularly true for the boundary layer vertical structure, atmospheric stability, stratification, fluxes of energy and mass, aerosol characterization and vertical distribution, cloud formation and cloud coverage. Moreover, the local observations must be coupled and integrated with the large-scale atmospheric and oceanic processes to get a complete overview of the phenomenology.

Main scientific gaps

From the open scientific questions, it can be seen that processes linking aerosol, clouds, boundary layer, and how they interact are still not sufficiently understood. In this respect, atmospheric research in Ny-Ålesund is not isolated but faces the same challenges as elsewhere e.g. Gimeno (2013), Boucher et al. (2013). Once some scientific progress is achieved, a state-of-the-art Large Eddy Simulation (LES) model for the Kongsfjord region could potentially bring all the existing measurements on aerosol, clouds, ABL and snow together for a closer look at the deficits or peculiarity of individual measurements, the micrometeorology of the complex terrain and deficits and shortcomings in the model. Generally, Ny-Ålesund is handicapped by a complicated orography. Moreover, the West coast of Spitsbergen is influenced by the interaction between the water and air masses of Atlantic and Arctic origin. On the long term, even with a better understanding of the micrometeorology in Kongsfjorden and closer cooperation with other existing stations in Svalbard, it might be necessary to consider permanent measurements at least of some key variables in the eastern part of the archipelago and at elevation, away from the coasts. The advantages of Ny-Ålesund are the relatively cheap and quick travel conditions and the comfort it provides. Moreover, more and more existing data sets will become “long-term” in the near future. Further, Ny-Ålesund is located in the region of most dramatic temperature increase. In fact, during the next decade the annual average temperature may rise above 0°C which will cause dramatic effects on the glaciers and the ecosystem. Nevertheless, its dramatic orographic influence poses a challenge in the interpretation and representativeness of the observations. However, a combination of LES modelling and different data sets of key meteorological quantities at different locations in Kongsfjorden and Svalbard may provide a strategy to differentiate between local and synoptic conditions. In this respect the measurements in Ny-Ålesund can also contribute to ESM modelling, as each meteorological profile from each site will be influenced by unique small scale disturbances.

Cross cutting themes

The seasonal variation in aerosol properties is not only a boundary layer phenomenon, but also occurs throughout most of the troposphere. Understanding aerosol-cloud interactions in a frame of atmospheric dynamics and circulation is among the most important scientific challenges. Aerosol research in Svalbard has a very long tradition, both in-situ and by remote sensing. In Ny-Ålesund, the cooperation between the different research groups is already strong. Research on boundary layer and clouds has been evolving quickly over about the last 7 years. So far, as stated above in the current research questions, each topic has its own, well-defined questions. Naturally, with evolving knowledge, in the end those topics will merge together. The communities have been gaining good experience by performing joint measurement campaigns. A common calibration facility is on the way, and it will be improved. Upcoming projects like the EARTHCare satellite mission will surely intensify the cooperation among the atmospheric community.

The Ny-Ålesund atmospheric community is already represented prominently in many high-level scientific organizations. Data are regularly uploaded in databases like BSRN, GRUAN, Fluxnet, to name just a few. SIOS promotes an open data policy and the natural exchange and external use of the data collected in Ny-Ålesund and in Svalbard data should be improved by a higher transparency through which each institution stores the data in in a well-documented, interoperable format. In this sense, common and interoperable systems should be supported to increase the data discovery and access. Open Data Policy should also sustain common procedures for maintenance of instruments and data processing information. Everyone knows that data management is complicated, also because of gaps when changing of the recording instrument occurs. Each scientific community has its own history in managing the data. In some case this can hard to modify, but a common procedure to access the data information (Metadata) should be achieved. Procedures must be user friendly, reducing the administrative requirements. A list of which PI is responsible for which data might introduce hardly any new administrative work, but would strengthen the cooperation among the research institutions. The Ny-Ålesund Atmosphere Flagship works to maintain such a list for relevant datasets there, and Research in Svalbard is a start towards that goal for the whole of Svalbard.

Summary of recommendations for SIOS

- Evaluate the state of scientific infrastructure and data collection in Svalbard beyond Ny-Ålesund
- Better coordinate the observations at existing sites between the different research fields
- Improve of spatial distribution of measurement stations within Svalbard
- Establish high quality, long-term observations at geographically diverse sites around Svalbard
- Build a distributed observation network on land, glaciers and sea
- Make the information on data (metadata) and data available, exchangeable and accessible.
- Improve the modelling to guide, improve and expand observations in the region

Data accessibility

Institution	Metadata and data URL
PANGEA – GERMANY	http://dx.doi.org/10.1594/PANGAEA. 150000/ 854326
IADC- ITALY	http://mainnode.src.cnr.it/cnr/data.php
NMI – NORWAY	http://eklima.met.no
NPDC–NORWAY	https://data.npolar.no
NILU – NORWAY	https://www.nilu.no/Miljoovervakning/tabid/186/language/en-B/Default.aspx
NIPR – JAPAN	https://scidbase.nipr.ac.jp/modules/metadata/index.php?cat=arctic
KOPRI – KOREA	https://kpdc.kopri.re.kr/metadata/?rid=KPDC_2018_0162

Table 1: List of data centres which host data for atmospheric studies in the Svalbard region.

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