

## Project Proposal

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### POLARCAT-Norway – the Norwegian part of POLARCAT

**Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, of Climate, Chemistry, Aerosols, and Transport**

An International Polar Year Project (#32)

#### Proposed by:

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<http://zardozi.nilu.no/~andreas/POLARCAT/>



*POLARCAT is endorsed / supported by these organizations*



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## 1 Introduction

This application proposes a **strong Norwegian contribution to and coordination of** the International Polar Year (IPY) project POLARCAT (Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, of Climate, Chemistry, Aerosols, and Transport). POLARCAT has received full endorsement from the IPY ICSU/WMO Joint Committee and is also endorsed, supported and overseen by four long-term international programs (IGAC: International Global Atmospheric Chemistry Project; SPARC: Stratospheric Processes and their Role in Climate; iLEAPS: Integrated Land Ecosystem – Atmosphere Processes Study; AMAP: Arctic Monitoring and Assessment Programme). POLARCAT is described in detail in a so-called White Paper that reflects the status as of June 2005 (updates are given below). Because of the 10-page space limit for this proposal, the reader is referred to the White Paper and the project's webpage (<http://zardoz.nilu.no/~andreas/POLARCAT/>) for the scientific background, references, and a description of planned activities. Andreas Stohl is also involved in other fully endorsed IPY projects (20, 140, 171, 196, 443), contributions to which will be made through POLARCAT-Norway.

### 1.1 POLARCAT goals

The overall goal of POLARCAT is to study the *role of long-range poleward transport of aerosols and trace gases for climate change in the Arctic*. Some particular objectives are to

- better characterize the transport pathways and sources of pollution entering the Arctic troposphere, including quantification of the residence times of polluted air masses in the polar dome.
- determine the vertical layering of Arctic pollution and the associated optical properties of Arctic aerosol particles and estimate how source regions change with altitude.
- study the seasonal and interannual variability of transport pathways and removal processes for aerosols and pollutants, and investigate likely changes in a future climate.
- characterize the direct radiative effects (solar and terrestrial) of pollution layers in the Arctic.
- investigate the interactions of aerosols with clouds (e.g., their role as ice nuclei), and the associated indirect radiative forcing.
- study the impact of boreal forest fire emissions on the chemical composition of the Arctic troposphere and radiative transfer.
- quantify the albedo changes of snow and ice surfaces and resulting radiative effects due to the deposition of black carbon (BC) from anthropogenic fossil fuel and biomass burning sources.
- determine the fate and effects of aerosols and chemical compounds injected into the stratosphere by pyro-convection, including their role for ozone formation and ozone depletion in the polar stratosphere.
- validate aerosol, trace gas, and cloud products from satellite observations.

### 1.2 Major POLARCAT activities

POLARCAT will carry out three major (and a few smaller) co-ordinated measurement campaigns in the Arctic, two in later winter/early spring 2007 and 2008, and one in summer 2008. The main objectives for the winter/spring campaigns are to revisit the Arctic Haze phenomenon and study its climate impact by performing air- and shipborne measurements with modern instrumentation, and to explore the transition from the dark winter to the photochemically active spring. The summer campaign will explore transport of boreal forest fire pollution plumes into the Arctic to characterize their radiative effects in the atmosphere and via changes in snow/ice albedo. Asian, European and North American anthropogenic contributions to gaseous pollutants and aerosols shall also be determined. The campaigns will involve about 10 aircraft, a ship, and Arctic surface stations, for which long-term studies will also be made. In addition, data from a large suite of satellite platforms will be analyzed and new satellite products developed, and a suite of models will be used to interpret the data.

### 1.3 Current status of POLARCAT-International

The POLARCAT community has during the last 18 months put significant efforts into the planning for the IPY. This includes two international workshops: one at NILU in May 2005 (supported by the EU ACCENT Network of Excellence) and one in San Francisco in December 2005. Other meetings will be held in Vienna in April 2006 and in Capetown in September 2006. An international steering committee was elected, the White Paper was written and a project webpage was set up. To date, close to 100 institutes have joined POLARCAT and important progress has been made to secure funding of core activities. The first campaign, headed by two German institutes (Alfred-Wegener Institute, AWI, and Deutsches Zentrum für Luft-und Raumfahrt, DLR), will be the largest experiment so far of the ASTAR (Arctic Study on Tropospheric Aerosol and Radiation) series. Except for the Norwegian contribution, it is funded and scheduled for 19 March-19 April 2007 (see letters from A. Herber and A. Minikin). Since it will involve two aircraft based in Longyearbyen, Svalbard, it is of special relevance for this proposal. A Canadian aircraft study (J. Whiteway, personal communication) of pyro-cumulonimbus clouds is also already funded. NOAA (U.S.A. National Oceanic and Atmospheric Administration) will take 32 scientists on the research vessel R.H. Brown to the Greenland, Norwegian and Barents Sea in March 2008 (see letter) and will contribute also with smaller aircraft campaigns. NASA (U.S.A. National Aeronautics and Space Administration) is planning aircraft campaigns in winter/spring and summer 2008 (see their ARCTAS White Paper, which is directly linked to POLARCAT). Chances are very good (H. Schlager, personal communication) that DLR will also participate in the summer 2008 campaign (Svalbard is a possible base). A French aircraft campaign is funded, another one proposed; a Finnish study using station measurements in the Finnish Arctic is funded already. Canadian aircraft campaigns are being proposed at the time of this writing. In addition to these efforts to secure the necessary infrastructure, a large number of proposed studies are under consideration by various national agencies (e.g., several in Canada, France, Germany, Russia, U.S.A., etc.). Some of them plan to use aircraft, others propose model studies, measurements at surface stations (Alert, Barrow, Summit, Zeppelin), satellite data analyses, or analyses of existing data. **In summary, several of the rather expensive platforms for executing POLARCAT have been secured already and others will very likely be available. POLARCAT, at an international level, is proceeding very well!**

### 1.4 Relevance for Norway, legacy

NILU was among the pioneers in Arctic pollution research, and the legacy of the activities undertaken in the 1970s and 1980s (see the special issue of Atmospheric Environment (Rahn, 1989), dedicated to Brynjulf Ottar, the first director of NILU) has later been succeeded by lead contributions to the Arctic Monitoring and Assessment Programme (AMAP, 1998; AMAP 2006). A major asset of POLARCAT-Norway is to sustain and further develop the national competence related to Arctic air pollution. It will make strong use of Norwegian (including historical) data and will expose these data to a large international scientific community. It will build legacy by starting new measurements at Andøya and Svalbard, by providing a 40-year record of highest-quality model analyses of transport to Svalbard, and by giving a complete snapshot of the current state of the troposphere around Svalbard and other parts of the Arctic for future reference. It will bring at least one major aircraft campaign and a very well equipped research vessel to Svalbard. The airborne measurements will add value to the surface measurements at Svalbard by extending them into the vertical. POLARCAT-Norway also has a strong Russian participation, thus strengthening the links between the two scientific communities. Norway has an excellent expertise in atmospheric chemistry and aerosol modeling and the POLARCAT dataset will allow further developing this expertise.

POLARCAT addresses questions (aerosols, long-range pollution transport, climate change processes, time series analyses) that are considered critical for Norway (e.g., Miljøverndepartement, 2005: Katalog over Miljøverndepartementets viktigste kunnskapsbehov 2005-2009; Forskningsråd, 2003: Lange tidsserier for miljøovervåking og forskning). POLARCAT will, thus, enable Norwegian researchers and national authorities to play a lead role in Arctic pollution and climate research, assessments, and development of abatement measures in the decades to come. POLARCAT is also

a very effective enterprise for Norway because the high costs of the aircraft operations will be covered mainly by the international partners.

POLARCAT-Norway will target the education of the next generation of researchers by giving Norwegian students the opportunity of participating in an international campaign by helping with the release of highly sophisticated Lagrangian balloons. It will also develop an e-learning module, integrated with related activities undertaken by the ACCENT Network of Excellence, to introduce undergraduate students as well as policy makers to Arctic meteorology and air pollution problems.

### 1.5 Data policy

POLARCAT-Norway will follow the IPY data policy.

## 2 Work plan

The work planned for POLARCAT-Norway is organized in nine connected work packages (WP): Coordination (WP 1), historical, current and new measurements at Svalbard (WP 2), balloon launches from Svalbard (WP 3), the role of boreal forest fires (WP 4), studies in the Russian Arctic (WP 5), optical characterization of Arctic aerosols (WP 6), climate influence of Arctic aerosols (WP 7), e-learning (WP 8), and synthesis of the international POLARCAT findings (WP 9).

### 2.1 WP 1: Coordination, including forecasting and transport analyses for all platforms

Leader: A. Stohl, NILU

**Coordination:** In order to make POLARCAT a success, the international activities must be coordinated. NILU has a long history of leading large international projects and the lead scientist of this proposal is familiar with the challenges of such a large international activity. He has coordinated aircraft activities for the so-called Lagrangian experiment in the framework of ICARTT (International Consortium for Atmospheric Research on Transport and Transformation; <http://www.al.noaa.gov/ICARTT/>) in summer 2004 and has worked with many POLARCAT partners in the past. POLARCAT coordination will include

- setting up an international project secretariate;
- reporting to and keeping contact with the endorsing organizations, the IPY IPO, and the media;
- e-mail contact with POLARCAT scientists (now 140 but more during IPY);
- organizing bi-annual meetings of the POLARCAT steering committee, and annual science meetings for the entire POLARCAT community;
- keeping contact with other IPY projects (coordinator is directly involved in 5 other projects);
- hosting all POLARCAT-relevant information on a webpage kept actual on a monthly basis. A “Field operations” website will be created that links together all available resources (e.g., forecast products, satellite imagery, data sets, etc.);
- setting up a meta-database with links to the data archives of participating organizations;
- provision of forecasts and analyses of pollution transport for all POLARCAT platforms;
- organizing special issues in major scientific journals for publication of POLARCAT results.

**Transport model forecasts:** Forecasts of pollution transport with the Lagrangian particle dispersion model FLEXPART have been provided for several major campaigns in the past (e.g., Stohl et al., 2003; Forster et al., 2004; Stohl et al., 2004; Methven et al., 2006) and are popular for flight planning, scheduling lidar measurements, etc. At the time of this writing, for instance, FLEXPART forecasts are being used in a major field mission exploring pollution export from Mexico City (<http://zardoz.nilu.no/~flexpart/forecasts/>). During POLARCAT field missions, NILU will provide forecasts four times a day. Several improvements to the current system will be made, especially a better real-time ingestion of biomass burning emission information.

**Transport model analyses:** The Lagrangian particle dispersion model FLEXPART will be run backward in time for 20 days from all POLARCAT stations and mobile platforms. For surface stations, these calculations will be made every 3 hours for a ten-year period; for mobile platforms,

they will be made for small segments along a platform's trajectory. Results will be made available on the internet and shall replace trajectory calculations as the primary resource for interpreting transport processes. Since the ICARTT campaign in summer 2004, these products ([http://www.al.noaa.gov/icartt\\_analysis/](http://www.al.noaa.gov/icartt_analysis/)) have already been used in 15 publications.

Providing transport model forecasts and analyses for all POLARCAT platforms will ensure a very high standard for both the flight planning and for the interpretation of the influence of transport processes on the measured data. From past experience, it is expected that several POLARCAT key players (e.g., AWI, DLR, CNRS, NOAA) will heavily use these products. Furthermore, through provision of these products, NILU will become involved in many different scientific studies during IPY whose full scope is currently impossible to know.

## **2.2 WP 2: Svalbard in-situ measurements: re-analysis and new measurements**

Leader: S. Solberg, NILU

Measurements of the chemical composition of the air and precipitation have been made at Svalbard for a long time. Sulphate concentrations in the air have been measured since 1977, first at Ny Ålesund and since 1989 at Mount Zeppelin. At Barrow, an equally long record exists for light scattering. As summarized in the White Paper, trends for most available species (e.g., light scattering and absorption at Barrow, sulphur at Zeppelin) at both stations are decreasing but a possible trend reversal has occurred since the end of the 1990s. Of interest are also light hydrocarbons, which can be used as markers for the different source categories contributing to pollution, and ozone, for which relatively long records exist from Svalbard.

We suggest a complete re-analysis of the data from Svalbard with regard to pollution sources. For this, FLEXPART will be run in backward mode every 3 hours and 20 days backward in time over the entire period of more than 30 years with available data, using ECMWF input data (re-analyses and operational analyses for the last few years). The results of these calculations will be made available via websites similar to <http://zardozi.nilu.no/~andreas/STATIONS/ZEPPELIN/> (results for the years 1999-2005 are already available). Using Bayesian inversion, the source regions of sulphur and BC in particular will be determined for different periods of the record to analyze how the source regions have changed over the past few decades. It is expected that large changes in pollution source regions will be found, for instance a strong decrease of sulphur pollution transported from western Europe in the 1980s and an abrupt drop of pollution from eastern European countries and the former U.S.S.R around the year 1989. Yet, to date these changes have not been documented fully on a source region basis (but see Sharma et al., 2004), partly because trajectory analyses are not accurate for the long transport distances involved, and partly because variability in air transport masks effects of emission changes. Also of interest will be how the source regions of sulphur, BC, and other species (e.g., carbon monoxide as a tracer) have changed more recently (since about 2000 and into the IPY period), as the economies in eastern European countries are now growing. Southeast Asia is now the dominant source of BC worldwide. Koch and Hansen (2005), in a model study, recently suggested that it is also the largest source of BC for the Arctic. This was questioned by Stohl (2006) in another model study. The light absorption measurements from Zeppelin, in combination with the backward calculations and results from a 3-D aerosol transport model and a global climate model (see WP 7), will hopefully allow a clarification.

Levoglucosan is the most recognized marker for tracing emissions of particulate matter from biomass burning. It is emitted in high concentrations, not present in the vapor phase, associated with fine aerosols exclusively, and is not selectively removed from the atmosphere. These qualities enable detection of biomass burning plumes far from their sources. For POLARCAT, daily levoglucosan measurements for about 14 months will be made to study the influence of North American and Siberian wildfires in summer (see WP 4), as well as of domestic wood burning in winter, on aerosol concentrations at Svalbard. Aerosols will be collected at Zeppelin using a high-volume sampler and levoglucosan analysis will be performed using HPLC/HRMS (Dye et al., 2005; Yttri et

al., 2005). Collaboration with Johan Ström, Stockholm University (BC and aerosol size distributions) will allow constructing detailed aerosol and ozone budgets for Zeppelin.

### **2.3 WP 3: Deployment of controlled meteorological balloons from Svalbard**

Leader: L. Hole, NILU

Six Controlled Meteorological (CMET) balloons will be supplied by researchers from Smith College and the University of Massachusetts (<http://www.science.smith.edu/cmet/main.html>) and released from Longyearbyen during the spring 2007 campaign. These small and lightweight balloons (payload ~ 400 grams) can be commanded via the internet and satellite link to change altitudes, perform repeated soundings, or follow constant-potential temperature surfaces. Data from the balloons (position, altitude, winds, temperature, pressure, and humidity) will be available in real time. CMET balloons can remain airborne for several days.

The strategy for using the balloons is as follows: A starting research aircraft will profile the atmosphere above Longyearbyen to find a polluted layer. Its altitude will be reported to the ground in real time and two balloons will be launched into that layer immediately. One balloon will strictly follow this polluted air mass by staying at constant potential temperature (corrected for slow diabatic cooling). The other balloon will occasionally perform vertical soundings to explore the variability of the meteorological parameters and aerosol backscatter around this layer. The returning aircraft will visit the balloons to sample again the polluted layer “tagged” by the balloons. The aircraft will start again on the next day (and possibly on a third day) to repeat the measurements in the balloon’s vicinity. Through this Lagrangian experiment, information is obtained about important processes that otherwise cannot be observed directly. The measurement data taken repeatedly in the same volume of air will allow inferring changes in the aerosol size distribution and the chemical composition (e.g., ozone formation or destruction), thus yielding important constraints for the models used in WP 7. The meteorological conditions will be ideal for this experiment, as turbulence, hence mixing with surrounding air masses, is almost negligible in the Arctic in early spring.

### **2.4 WP 4: Boreal forest fires as a pollution source and climate agent for the Arctic**

Leader: A. Stohl, NILU

Traditionally, most studies of Arctic air pollution concentrated on the winter/spring period when pollution levels generally are highest, producing the so-called Arctic Haze. In summer, deposition is more efficient, transport is slower and, thus, pollution levels are lower – therefore, less attention was paid to this season. However, since more efficient deposition is an important reason why concentrations are lower in summer than in winter, this also means that the deposition load itself is relatively less reduced from winter to summer. For the radiative forcing of the Arctic climate, it is also important that in winter solar radiation is largely absent in the Arctic whereas in summer the sun is constantly above the horizon. Furthermore, highly reflective stratus cloud decks, above which absorption is enhanced, are frequent in summer.

BC is a particularly important agent for the radiative forcing of the Arctic. It absorbs radiation both in the atmosphere, as well as after deposition on snow/ice surfaces and might be of similar importance for the forcing of the Arctic climate as greenhouse gases (Hansen and Nazarenko, 2004). Stohl (2006) recently suggested that in summer BC from boreal forest fires, especially fires in Siberia, has a larger potential of being transported into the Arctic than BC from anthropogenic fossil fuel combustion. In a study of the boreal forest fires burning in Alaska and Canada in the summer of 2004, Stohl et al. (2006) indeed found that the concentrations of light absorbing aerosols and aerosol optical depths (AOD) at Barrow, Alert, Summit and Svalbard were strongly enhanced in fire plumes. At Barrow spectacularly high values were measured, higher than the largest values recorded during Arctic Haze conditions. At Summit, all AOD values over a 2-month period were above the normal background, due to continuous passages of forest fire plumes. It is also of interest that most of the Barrow data during fire episodes were removed from the official record by data screening algorithms actually designed for eliminating periods with local contamination. If that has occurred also during other years, the long-term Barrow data set may be significantly biased.

Here it is suggested to analyze aerosol light absorption, aerosol scattering, AOD, aerosol size distribution, levoglucosan (see WP 2) and carbon monoxide concentrations and other data from as many Arctic stations as possible and for several years. This will be done in a collaborative effort with the data producers, as in the Stohl et al. (2006) study and will include this time an additional analysis for selected years with the EMEP chemical transport model that can provide complementary information on the different aerosol components (see WP 7). Through a collaboration with Canadian colleagues (D. Lavoue, S. Sharma) we will get access to high-quality forest fire BC emission data with a resolution of better than  $0.5^\circ$ , hourly time resolution, and estimates of the fire energy and injection heights into the atmosphere, allowing FLEXPART forest fire plume transport simulations of unprecedented quality. Siberian forest fires emit even more BC than North American ones. Thus, it will also be important to investigate years with strong burning in Siberia (e.g., 2003). It is anticipated that this study may lead to a re-thinking of pollution and aerosol sources for the Arctic in summer. In another collaborative effort, carbon monoxide, aerosol light absorption and albedo data from Summit shall be analyzed in order to determine how strong an imprint the forest fire plumes left in the snow/ice. Summit is ideal for that purpose because forest fire plumes tend to be more pronounced at these high altitudes.

An interdisciplinary community, involving fire ecologists, meteorologists specialized in fire weather forecasts and satellite data experts, has come together in POLARCAT to specifically target forest fire plumes with research aircraft in summer 2008. This will allow, for the first time, to fully characterize forest fire plumes, including their microphysical properties and radiative effects, as they are transported into the Arctic, and to study the pyro-cumulonimbus phenomenon (Fromm and Servranckx, 2003). We will contribute to this community effort with analyses of the aircraft data.

## **2.5 WP 5: Studies in the Russian Arctic and sub-Arctic**

Leaders: B. Belan, IAO, Tomsk; N. Elansky, OIAP, Moscow

The Russian boreal zone/Arctic is an interesting region both in winter and in summer. In winter, pollution enters the Arctic lower troposphere primarily in western and central Russia. In summer, Siberia is the region where most of the boreal forest fires occur – for instance, 21 million hectare burned in 2003. There is a lack of measurement data from this vast region. POLARCAT shall improve this situation both by analyzing existing data, and by making new measurements during IPY. Using the FLEXPART transport calculations in a collaborative work between OIAP and NILU, we will analyze measurement data from Lovozero ( $68^\circ\text{N}$ ,  $35^\circ\text{E}$ ), Kislovodsk ( $44^\circ\text{N}$ ,  $43^\circ\text{E}$ ), Zotino ( $61^\circ\text{N}$ ,  $89^\circ\text{E}$ ), and existing data from the TROICA experiments along the Transsiberian Railroad (Elansky et al., 2001; Oberlander et al., 2002). For all these stations/platforms, relatively comprehensive gas phase/aerosol data sets exist. Furthermore, one more experiment with the TROICA carriage shall be made, likely in summer 2008 to characterize the situation during a time of the year when boreal forest fires are frequent. Alternatively, early spring 2008 during the Arctic Haze season is also an option.

As a collaboration between IAO and a French group led by P. Ciais (involving also K. Law, co-coordinator of POLARCAT), an Antonov-30 aircraft is currently being equipped with modern in-situ chemical, aerosol, and remote sensing instrumentation (see attachment). The first few flights were recently completed. The data from these flights will be shared with NILU. Furthermore, as part of this proposal, one more long flight (likely to Yakutsk) shall be made. This flight will target a forest fire plume traveling towards the Arctic. The French partners will make their instrumentation available to IAO for this flight. The flight will be coordinated with the TROICA campaign and with other aircraft missions, especially the NASA campaign.

The Russian partners are now also seeking support from Russian funding agencies to extend their POLARCAT contribution beyond that described here. Furthermore, K. Law, co-coordinator of POLARCAT, has received French funding for Antonov-30 flights.

## 2.6 WP 6: Optical and microphysical characterization of aerosols in the European Arctic

Leader: J. E. Kristjánsson, UiO; co-leaders: K. Stebel and C. L. Myhre, NILU

Optical and microphysical properties of Arctic aerosols have been studied at single sites, like Barrow, Alaska (Bodhaine and Dutton, 1993; Polissar et al., 1999), Ny-Ålesund, Svalbard (Herber et al., 2002), at several Russian Arctic sites (Shahgedanova and Lamakin, 2005), and during international campaigns, like ASTER (Treffeisen, 2004, Yamanouchi et al., 2005). Over the last decade, data from a large number of satellite sensors suitable for aerosol studies (e.g., MODIS, MISR) have become available. Due to the special conditions with high surface albedo, large solar zenith angle, long path through the atmosphere, and low background aerosol concentrations, the determination of aerosol properties from satellites is still a challenge in the Arctic region. Only limited knowledge of the vertical structure of aerosol properties in the European Arctic is available. A real step forward can be expected from a lidar on the CALIPSO satellite (launched in April 2006), which will provide high-resolution vertical profiles of aerosols and clouds (Winker et al., 2002). Nevertheless, more advanced ground-based Raman lidars are required for CALIPSO validation. Due to mesoscale variability of tropospheric aerosols (Anderson et al., 2003), a combination of quasi-continuously operating ground-based and satellite born instruments is needed to study their optical and microphysical properties.

Vertically integrated optical and microphysical properties will be studied from observations at four sites located on Svalbard (Ny-Ålesund and Hornsund), and in Northern Scandinavia (ALOMAR, Sodankylä). The work will be performed in close collaboration with AWI and NIPR, who operate photometer/lidar in Ny-Ålesund, FMI, who run a PFR in Sodankylä, and AERONET (instrument at Hornsund). Through participation in the IPY project POLAR-AOD homogenized AOD measurements from other Arctic sites will be available for joined interpretation of the results. By comparison with ground-based measurements we will determine the best suitable satellite data for the European Arctic. The synthesized data set will be used to classify aerosol properties on Svalbard and Northern Scandinavia. Vertical aerosol profiles will be retrieved from ground-based lidar at ALOMAR (on the island of Andøya) and compared to results from Ny-Ålesund. Intercomparison of measurements from the ground-based Raman lidars and the CALIPSO lidar will help narrow down uncertainties in the description of the aerosol profiles. In collaboration with the outcomes from transport models (WP 1), the potential impacts of natural and anthropogenic contributions to the aerosol concentration will be estimated. Another aim of our study is to improve the knowledge of the ageing processes of the aerosols. During the spring 2007 campaign, closure studies will combine ground-based measurements with aircraft and satellite observations. During the 2008 summer campaign data obtained within WP 6 will contribute to the study of long-range transported aerosols from boreal fires (WP 4). Our studies will be complemented with data from the EARLINET-ASOS project, which is useful for tracking aerosols from central Europe. An important issue is, not only to observe the polluted Arctic, but also to determine the background aerosol concentrations and properties.

## 2.7 WP 7: Climate influence of Arctic aerosols

Leader: T. Iversen, Met.no; Co-leader J. E. Kristjánsson, MetOs, UiO

Direct Arctic aerosol effects. Anthropogenic aerosols cause a brownish Arctic haze during late winter / early spring (AMAP, 1998, Ch. 9) with sulphate and soot aerosols also containing light-absorbing BC. In Arctic haze, BC is frequently internally mixed with scattering particles in a size-range which efficiently influence solar radiation (e.g. Rosen et al. 1981; Heintzenberg, 1982; Valero et al, 1983; Rosen and Hansen, 1984). Absorption is important relative to scattering in the Arctic due to a high surface albedo, with measured heating rates of 0.1-0.2 K/day during Arctic haze (Valero et al., 1989). Sunlight absorbed by soot deposited on snow may furthermore speed up melting of Arctic ice and snow, with a risk of positive feed-back. Clarke and Noone's (1985) chemically and optically analysed Arctic snow-samples indicated considerable effects. Grennfell et al.

(2002), however, estimated small albedo effects during SHEBA, but recent model-calculations give large climate effects (Hansen and Nazarenko; 2004; Koch and Hansen; 2005). The latter paper emphasizes soot-sources in south-east Asia – a conclusion which is challenged by others (Stohl, 2006).

Indirect Arctic aerosol effects. The indirect aerosol effect on global climate is regarded to only be exceeded in absolute value by greenhouse gas forcing (Lohmann and Feichter, 2005). Interactions between aerosols and clouds are very uncertain. Ice clouds are particularly uncertain and ice-nuclei poorly understood. Observations analyzed by Garrett et al. (2004) indicate that Arctic clouds are more sensitive to anthropogenic pollution than clouds in other regions, and there are strong indications that clouds in the Arctic have different microphysical and radiative properties than clouds elsewhere. Longwave radiative effects of clouds tend to dominate, and result in a positive radiative forcing at the surface (Intrieri et al., 2002a). On the other hand, Girard et al. (2005) presented evidence of dehydration caused by sulfate aerosols in Arctic air masses. Ice nuclei and humidity are reduced from the air and leads to a negative radiative forcing. In the SHEBA experiment (e.g., Curry et al., 1996), it was found that supercooled cloud droplets are common in the Arctic, even at temperatures lower than  $-20^{\circ}\text{C}$ . They often occur in between layers containing ice crystals (Intrieri et al., 2002b). These remarkable conditions are poorly understood, but are probably related to the very stable troposphere in the Arctic winter. It is known from Arctic haze studies that this pollution from different remote source regions (North America, Europe, Siberia, East-Asia) can be vertically separated by intrusions of cleaner air of maritime origins (North Atlantic). Soot and mineral dust can be effective ice nuclei, but it is not known how the ice nuclei concentrations vary depending on pathways to the Arctic. It is of great interest to explain the observed cloud microphysical conditions through a careful characterization of the aerosols in the different layers, as well as their origin.

Model tools. The main model tool for studying climate effects of Arctic aerosols is the Oslo-version of the Community Atmosphere Model (*CAM-Oslo*) of the National Center for Atmospheric Research in U.S.A. Also its 1-dimensional single column version (SCAM) is available. CAM-Oslo calculates aerosol lifecycles and links aerosol number, size, and composition to radiation and clouds. Iversen and Seland (2003), Kirkevåg and Iversen (2002), and Kristjánsson (2002) describe earlier versions Updated descriptions are underway (Kirkevåg et al, 2005). The model presently calculates sea-salt, mineral dust, sulphate, BC, and organic carbon aerosols, and parameterizes optical properties and water activity by tabulations. CAM-Oslo will be used stand-alone for detailed Arctic aerosol-cloud-radiation studies, and for a small selection of climate equilibria response calculations when coupled to a “slab-ocean” model. CAM-Oslo calculations can also be controlled by observed meteorological data through “nudging”.

CAM-Oslo tends to underestimate Arctic aerosol concentrations in the cold seasons, and potential reasons for this will be investigated in this project. Remedies have been proposed, including SO<sub>2</sub>-oxidation on ice-crystals (Rotstavn and Lohmann, 2002), and improved fog and stratus at low temperatures. Model tests (Seland, 2006, Pers. Comm.) also show sensitivity of remote anthropogenic aerosols w.r.t. processes such as below-cloud scavenging.

Modeling of the direct and indirect climate effects of aerosols with Oslo versions of NCAR GCMs, has been carried out for several years at MetOs-UiO (Kirkevåg and Iversen, 2002; Kristjánsson, 2002; Iversen et al., 2005; Kristjánsson et al, 2005; Storelvmo et al., 2005). The model and several aspects of the aerosol-cloud-radiation calculations have been subject to thorough scrutiny in the AEROCOM intercomparison project (<http://nansen.ipsl.jussieu.fr/AEROCOM/data.html>) (Kinne et al., 2005; Textor et al, 2005; Penner et al., 2006).

Calculations of Arctic aerosol burdens will be complemented with an off-line chemical transport model (CTM), the hemispheric *Unified EMEP model* (Simpson et al., 2003; Tarrason et al., 2003; Wind et al., 2003) with a higher spatial resolution (50 km vs. mainly T42 in CAM-Oslo). It is also particularly designed for source-allocation, and is suited for studying long term calculations of aerosols.

Experiments. Regular and campaign observations during IPY (e.g. the ASTAR-campaign in April 2007 and the summer 2008 campaign) will be used for model validation, in addition to more regular data in the Arctic and other regions. The ASTAR campaign is based in Longyearbyen and Ny Ålesund, and involves two well-equipped aircrafts making simultaneous measurements of aerosol properties and cloud physical properties. The aircraft measurements will be complemented by ground-based instruments (e.g. Barrow, Ny Ålesund, Alert) including a troposphere LIDAR, a spectrophotometer, and surface chemical measurements. Calculations will also be compared with satellite data when they become available (CALIPSO), and with transport calculations in WP1 and WP4.

Source regions for aerosol layers in the Arctic troposphere will mainly be studied with the Hemispheric EMEP model, after evaluation of this model in WP4. This will allow distinguishing the influence of natural sources (biomass burning and secondary organic aerosols), and the influence of anthropogenic aerosol sources from primary sources and precursor gases. Updates of emission data of BC (from e.g. D. Lavoue, Canada) will be investigated.

We will investigate the role of uncertain parameters in CAM-Oslo w.r.t modelling Arctic haze and Arctic aerosols. The calculation of surface albedo in CAM-Oslo will take into account soot deposition (e.g. Warren, S.G. and Wiscombe, W.J., 1980). In climate equilibria runs coupled with a slab ocean, impacts on snow- and ice-melt in the Arctic will be estimated and studied. Source-allocated soot deposited in the Arctic will mainly be made with the Hemispheric EMEP model as calculations of both anthropogenic and natural aerosols to the Arctic, with particular focus on carbonaceous particles.

In CAM-Oslo a parameterization of the indirect effect of ice clouds is being developed in collaboration with scientists at ETH in Zürich. The ASTAR campaign in March/April 2007, based in Longyearbyen and Ny Ålesund, will provide an excellent test-bed for the new parameterization. The campaign will involve two well-equipped aircraft making simultaneous measurements of aerosol properties and cloud physical properties. In particular the POLAR2 aircraft carries FSSP and 2D-C probes as well as a cloud particle imager (CPI), which together will provide detailed information on size distributions and shapes of cloud droplets and ice crystals. At the same time, the POLAR2 and Falcon aircraft will carry several instruments for characterizing the aerosols. These measurements will be complemented by ground-based instruments including a troposphere LIDAR, a spectrophotometer and surface chemical measurements. The ASTAR data set will be used to validate the model assumptions, especially concerning ice nuclei. One intriguing possibility, suggested by Bailey and Hallett (2002), is that ice crystal shape is related to the type of ice nuclei present. This will be explored, along with the implications for the cloud radiative forcing, which is strongly dependent on crystal shape (Kristjánsson et al., 2000).

## 2.8 WP 8: Synthesis

Leader: A. Stohl, NILU

During the last year of POLARCAT, the findings of the international program shall be published in at least one special issue of a major scientific journal (e.g., J. Geophys. Res.). In addition to the specialized papers on various topics, a synthesis paper shall be written that integrates all the POLARCAT findings and highlights what we have learned during IPY. This paper shall have a review character and will put the POLARCAT results into the proper historical perspective.

**Attachments:** *Endorsement letters from IPY IPO, IGAC, SPARC, iLEAPS, AMAP; POLARCAT White Paper; List of references; detailed work package budgets; description of the Antonov-30 instrumentation; letters of support from a few POLARCAT participants*