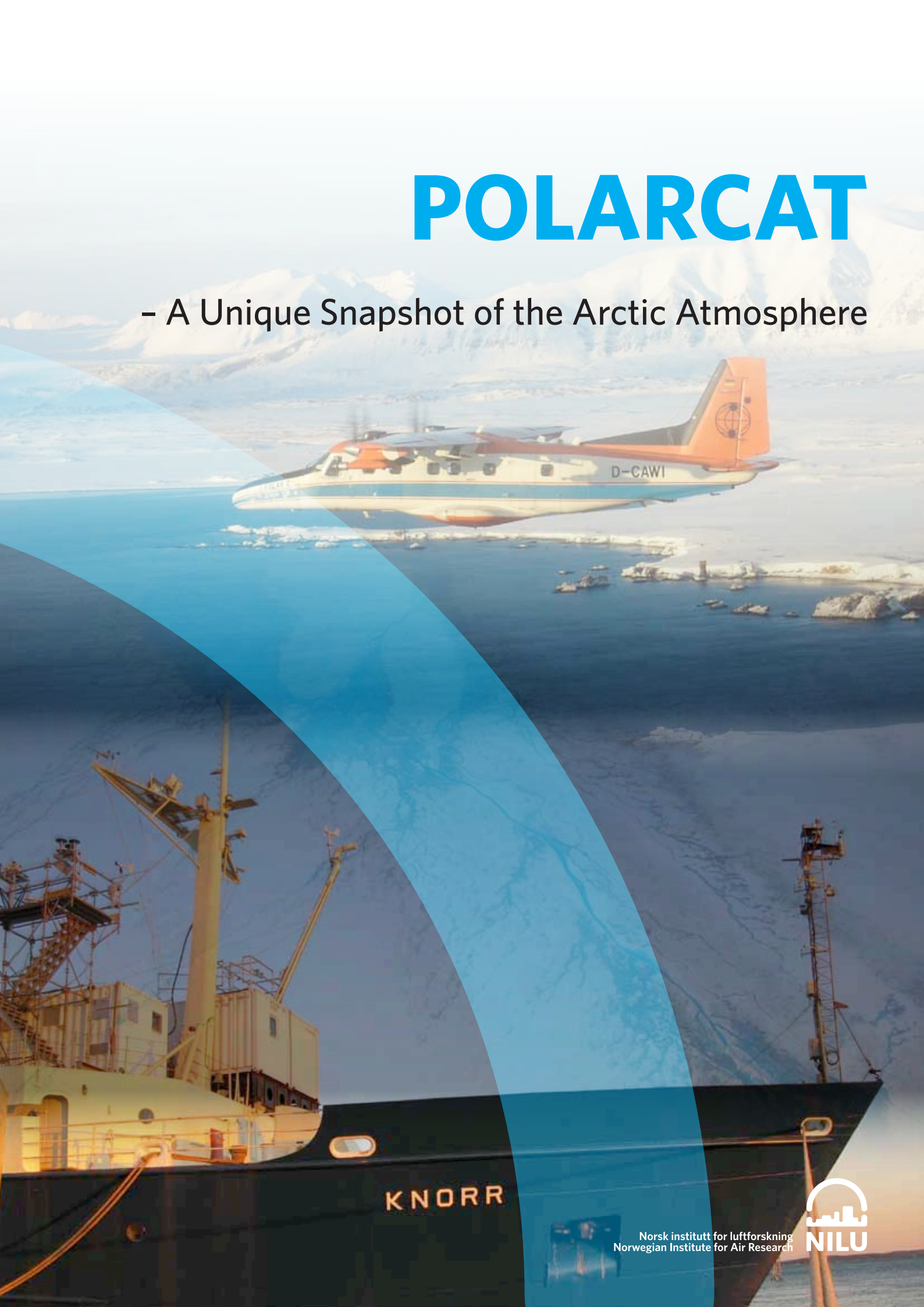
POLARCAT

– A Unique Snapshot of the Arctic Atmosphere



Norsk institutt for luftforskning
Norwegian Institute for Air Research
NILU

Content

POLARCAT

POLARCAT is an extensive research project under the International Polar Year (IPY), studying the transport of pollutants and climate forcing agents into the Arctic.

POLARCAT is one of the largest projects in the International Polar Year. More than 20 countries have been participating in the study, and all available methods such as aircraft, remote sensing, surface measurements and modeling have been used.

Katherine Law, Service d'Aeronomie CNRS, and Andreas Stohl, NILU – Norwegian Institute for Air Research, are the project coordinators of POLARCAT.
www.polarcat.no

NILU – Norwegian Institute for Air Research is an independent, non-profit institution established in 1969.

Through its research NILU increases the understanding of processes and effects of climate change, of the composition of the atmosphere, of air quality and of hazardous substances.

Based on its research, NILU markets integrated services and products within the analytical, monitoring and consulting sectors. NILU is concerned with increasing public awareness about climate change and environmental pollution.
www.nilu.no

POLARCAT was an international effort funded by many different agencies. The Norwegian component of POLARCAT was funded by the Norwegian Research Council.

The Research Council of Norway

A Climate for New Policies

During the International Polar Year (IPY), a number of international partnerships were formed to establish the Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, of Climate, Chemistry, Aerosols, and Transport (POLARCAT).

Under the umbrella of POLARCAT, projects have cooperated with national funding to undertake the most comprehensive assessment of air pollution impacts on the Arctic to date. In the spring and summer of 2008, more than 20 institutes from ten nations participated in coordinated intensive aircraft, ship, and station-based campaigns with accompanying efforts from the satellite and modelling communities to provide near real time products for mission planning and analysis.

Targeting Black Carbon

Notable warming trends have been observed in the Arctic. Reductions in the atmospheric burden of CO2 are the backbone of any meaningful effort to mitigate climate forcing. But, even if swift and deep reductions were made, given the long lifetime of CO2, the reductions may not be achieved in time to delay a rapid melting of the Arctic.

Hence, the goal of constraining the length of the melt season and, in particular, delaying the onset of spring melt, may best be achieved by also targeting shorter-lived climate forcing agents which impact Arctic climate, too.

These are agents such as methane, tropospheric ozone and black carbon (BC), all of which are strongly influenced by human activity. They are all potent but short-lived. While uncertainties are large, some calculations attribute an Arctic warming to black carbon that is comparable to the warming caused by CO2. However, whereas CO2 stays in the atmosphere for almost a hundred years, black carbon has a lifetime of only a few days to weeks.

Targeting these climate agents would help reducing the ice melt in the Arctic while effective measures to reduce CO2 emissions are still under discussion.

Increased Activity in the High North

With the increased activity in the High North, we also have to take into account that these activities is likely to also increase the emissions of black carbon. This may pose significant threats to the vulnerable arctic environment.

It may be hard to quantify, but it is clear that sources of pollution in the High North have a greater climate impact - probably much greater - than sources of equal strength further south.

The Role of POLARCAT

The data sets produced by POLARCAT are unique as they provide a detailed snapshot of the Arctic atmosphere in spring and summer 2008. For the first time, we have a three-dimensional picture of the chemical composition and the aerosol content of the Arctic atmosphere, from Europe to Siberia, over North America and Greenland, and up to the North Pole. These data sets have already changed our view of the Arctic troposphere that traditionally has been built mainly upon the measurements available at a few surface measurement stations: It has become clear that the air aloft is chemically very different from the air encountered near the surface. Furthermore, the sources of the air pollution encountered aloft are very different from the sources contributing to near-surface pollution.

Not only has POLARCAT extended our view of the Arctic into the third dimension, it has also added a large number of new measurements that were so far unavailable from the main Arctic observatories. These measurements allow, for instance, a separation of pollution into biomass burning and fossil fuel combustion contributions. They are being used to develop better retrieval algorithms for satellite measurements in the Arctic, and they allow a validation and subsequent improvement of atmospheric chemistry transport and climate models.

The legacy

The legacy of POLARCAT is twofold: Firstly, POLARCAT has directly improved our understanding of the Arctic atmosphere. The POLARCAT data now help to improve satellite retrieval algorithms as well as models of the Arctic atmosphere, which will be of lasting value. Secondly, the snapshot of the Arctic atmosphere obtained in 2008 is an important point of reference for future changes. Already now we can foresee that in another International Polar Year in the future, new measurements will be made and they will be compared to ours. The changes that will be seen will be of interest not only to scientists but will be of great importance to all that are concerned about the Arctic environment.

The following pages will give you some insight into a small selection of the ground breaking POLARCAT activities that has taken place during the International Polar Year.

Andreas Stohl Katherine Law

Coordinators of POLARCAT

Crossing the Polar Dome

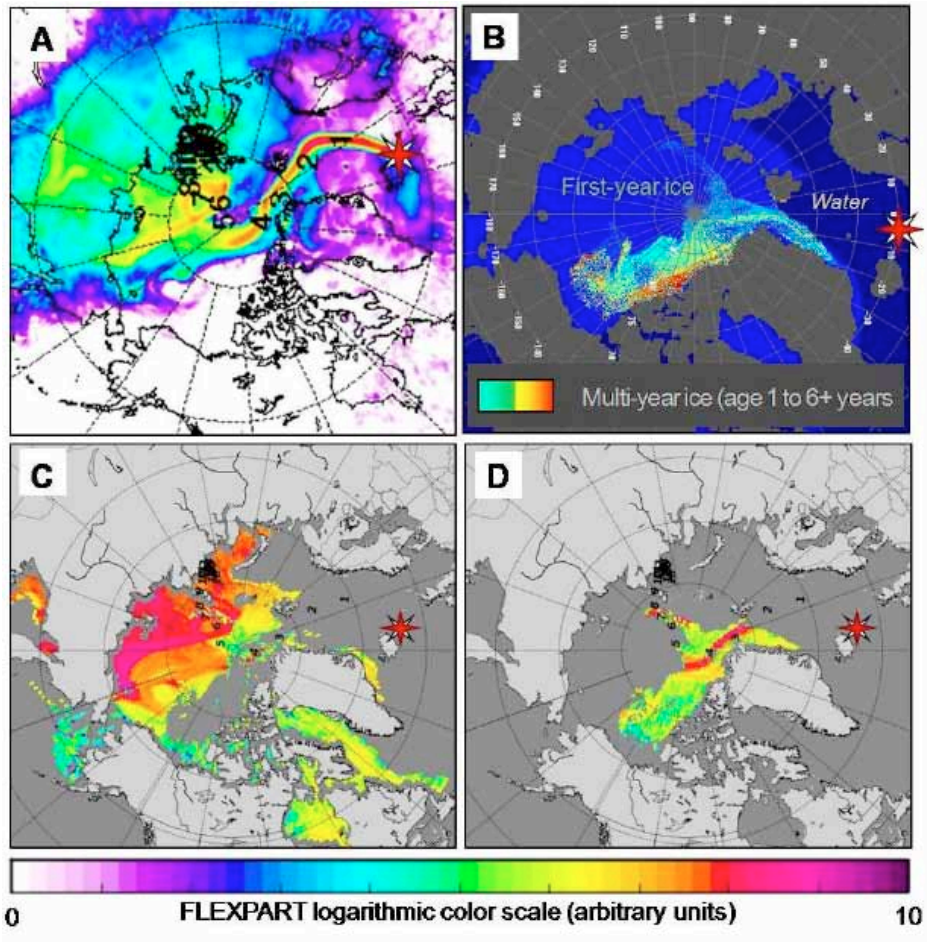
One of the POLARCAT goals has been to provide synoptic measurements; those which occur at the same time across large spatial extents. In the Spring of 2008 a series of campaigns were initiated across the Arctic.

By John Faulkner Burkhart, NILU – Norwegian Institute for Air Research

The Arctic has been a topic of significant research interest, dating back to the first International Polar Year (IPY) from 1881-1884, when the inspiration of Austrian Carl Weyprecht was realized as "the largest coordinated series of scientific expeditions ever undertaken in the Arctic during the 19th century". The purpose of these observations were to provide a comprehensive, synoptic series of measurements of geophysical variables across the Arctic. Since then two other International Polar/Geophysical Years (1932–33/1957-58) have been conducted.

A series of campaigns

The latest IPY was conducted from March 2007 to March 2009. A common goal of the efforts are to provide synoptic measurements; those which occur at the same time across large spatial extents. This, too, was a goal of the POLARCAT campaigns. In the Spring of 2008, a series of campaigns were initiated across the Arctic. During March and April National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA) stationed aircraft out of Fairbanks, Alaska while The French National Center for Scientific Research (CNRS) sent a plane to Kiruna, Sweden. During this time I was aboard the R/V Knorr sailing from Wood's Hole, Massachusetts to Svalbard via Tromsø, ultimately terminating our cruise in Reykjavik, Iceland as part of the NOAA-ICEALOT campaign.



A) Circumpolar map of the FLEXPART modeled footprint emission sensitivity for the air mass sampled on 2 April 2008 at 00:00 UTC. The numbers represent the days of transport backward in time.

B) Map of the Arctic sea ice coverage colored by the calculated sea ice age for 1-7 April 2008. FLEXPART source contribution maps for

C) First Year Ice and

D) Multi Year Ice. These maps identify the geographic regions where the modeled air mass spent the most amount of time in contact with FYI or MYI over the whole of its 20 day history. The red star indicates the position of the R/V Knorr (62.9°N,12.3°E). The logarithmic color scale at the bottom is applicable to panels a, c, and d.

Elevated toxin levels

Understanding, and quantifying, the various pathways for pollutants into the Arctic is an ongoing research topic. Dating back to Nansen's first expeditions into the Arctic, the 'pristine' nature was already called into question. Today, we know numerous toxins bioaccumulate in the Arctic fauna, and measurements of several compounds clearly show elevated levels inside the 'polar dome', a region with constant potential temperature layers over the Arctic. The geophysical processes which create such a unique and unusual environment - long polar days, polar night, and bright snow and ice covered surfaces - also compound the impacts of these pollutants, often having a different behavior than what may be observed at lower latitudes.

New evidence

Sea ice, abundant in the Arctic, is one such geophysical process. During the ICEALOT cruise measurements of ozone and volatile organic compounds (VOC) were investigated to understand the influence of halogen oxidation on their chemistry [1]. Continuous measurements aboard the R/V Knorr and measurements from NOAA aircraft were analysed using the FLEXPART transport model and special sea ice products. These sea ice products provide quantification of the residence time the measured air masses have had in contact with sea ice; a source of halogens. Using VOC ratios, periods of intense halogen oxidation can be identified, and their source clearly identified from the model (Figure 1). Our measurements confirmed the unique environment within the polar dome, but provided new evidence that halogen oxidation occurring within the Arctic can impact air masses in the sub-Arctic, despite dilution and mixing during transport.

John Faulkner Burkhart

REFERENCES

http://www.arctic.noaa.gov/aro/ipy-1/

Gilman et al., Ozone variability and halogen oxidation within the Arctic and sub-Arctic springtime boundary layer. In preparation. 2010.

Smoke signs at the North Pole

What smoke plumes from Siberian forest fires can tell about Arctic air pollution

Many pollutants reach the Arctic through the atmosphere. During the GRACE summer campaign, researchers observed from aircrafts and satellites how large pollution plumes from Siberian forest fires crossed over the pole.

By Dr. Harald Sodemann, NILU – Norwegian Institute for Air Research

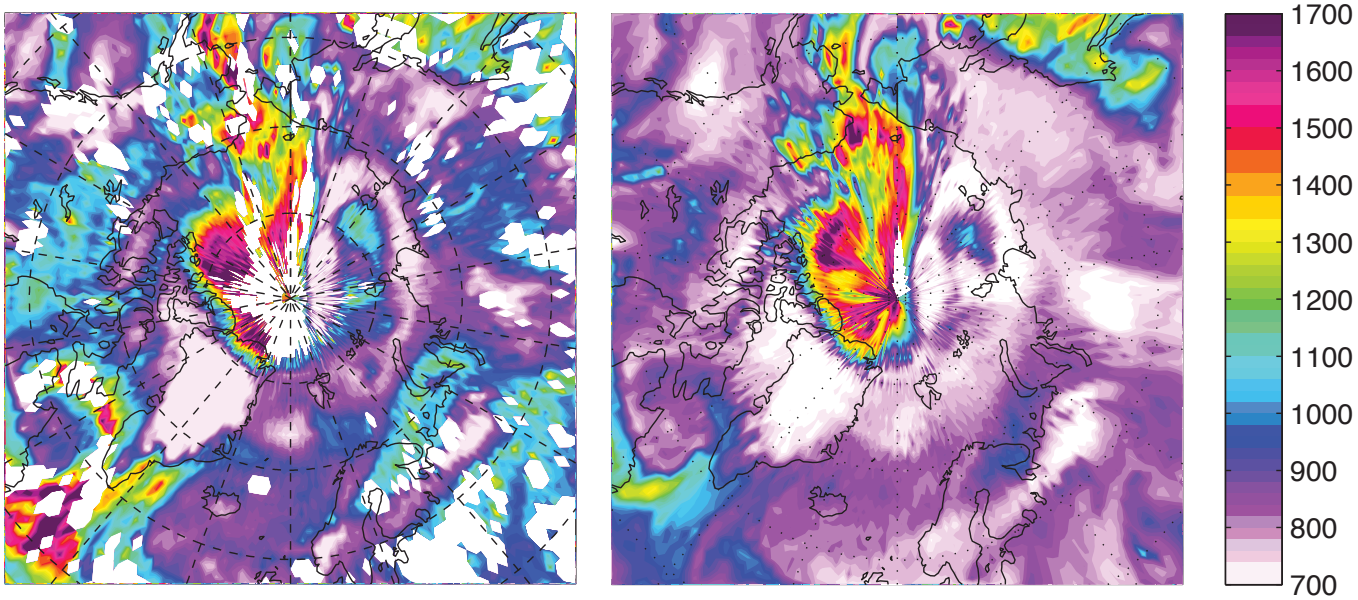
The Arctic is often perceived as a cold, pure, crisp and icy landscape, with the occational polar bear walking about. It has, however, been known for quite some time that the Arctic is in fact an area where man-made pollutants accumulate over time.

Crucial knowledge on black carbon

One such pollutant, which is released to the atmosphere through industrial processes and fossil fuel combustion, is black carbon, or soot. Soot is also a natural pollutant that is emitted to the atmosphere as part of the huge smoke plumes rising from the seasonal forest fires in Canada and Siberia. Both, man-made and natural black carbon emissions play a role in setting Arctic pollution levels. But how exactly is this pollution transported into the Arctic, where are the sources and what are the transport mechanisms? Answering these questions is not only scientifically interesting. It is also crucial knowledge to policy makers when making regulations are to control Arctic pollution levels.

Air masses on the move

People have long thought that the pollution would slowly seep into the Arctic. The picture has been one of the Arctic atmosphere as a large "bathtub" that is slowly filled as from a dripping faucet. However, ongoing research has shown that quite the opposite is the case. In fact, during summer for example, large excursions of air masses from the mid-latitudes are moved across the Arctic as part of storm systems. While the storms develop and move towards the north,



A large smoke plume from Siberian forest fires is traveling across the North Pole towards Greenland on July 8., 2008. The simulated smoke plume from the atmospheric transport model FLEXPART (right) matches well with the satellite observations of carbon monoxide from the IASI instrument (left).

The DLR research aircraft FALCON measured atmospheric pollution levels directly in the air mass over Greenland.

they also drag along polluted air from areas where most of the world's industry is located.

Cyclones traveling from Siberia

During the POLARCAT summer campaign GRACE in July 2008, teams of several hundred scientists were deployed in the field in Canada and Greenland to observe and measure how smoke plumes from forest fires are transported into the Arctic. A particularly good opportunity to observe such an event occurred in the days between July 2. to 10, 2008 when two cyclones subsequently traveled from Siberia across the Pole towards Greenland, and brought along large plumes of smoke from Siberian forest fires as well as industrial and other pollution from Asia.

Several research aircraft were in the field to measure how much pollution was transported at what altitude. Satellites were measuring the total atmospheric burden of the smoke with almost complete hemispheric coverage. Targeting the pollution plumes with the aircraft would have been impossible without chemical weather predictions.

Reliable monitoring

The goal now will be working with the acquired data to bring together all available measurements and learn where the predictions were trustworthy and where they had deficiencies. The results from this work will contribute to better understand how model simulations should be interpreted, and how they can be used to reliably monitor and predict pollution levels in the Arctic atmosphere in the future.

Harald Sodeman.

An Icelandic dust storm observed from the air

While previous studies have been based mainly on data from meteorological stations, the first aircraft-based study of an Icelandic dust storm has now been presented.

By A. -M. Blechschmidt, J. E. Kristjánsson and Øivind Hodnebrog, Department of Geosciences, University of Oslo; H. Ólafsson, Department of Physics, University of Iceland; J. F. Burkhart, NILU – Norwegian Institute for Air Research

More than one third (40000 km2) of the area of Iceland is made up of black deserts. Dust storms occasionally occur, some of them even affecting the air quality of Great Britain, continental Europe and the higher latitudes.

Desert formation

Due to its location inside the North-Atlantic storm track, Iceland is frequently affected by intense low-pressure systems. This favours the development of strong winds in the vicinity of the deserts, which leads to sand storms. These are very effective in eroding and transporting soil material and contribute to Icelandic desertification. However, the biggest contribution to desert formation (apart from volcanic fly ash) comes from glacial outwash. In particular heat produced by volcanic eruptions below glaciers melts ice away. This can result in big flood events, leaving behind huge amounts of sandy materials.

Identifying the dust sources

The first aircraft measurements of an Icelandic dust storm were carried out during the Greenland Flow Distortion Experiment on February 22nd. 2007. This case is highly interesting as it occurred in conjunction with a low-level barrier jet which reached wind speeds of more than 30 m/s to the south of Iceland.

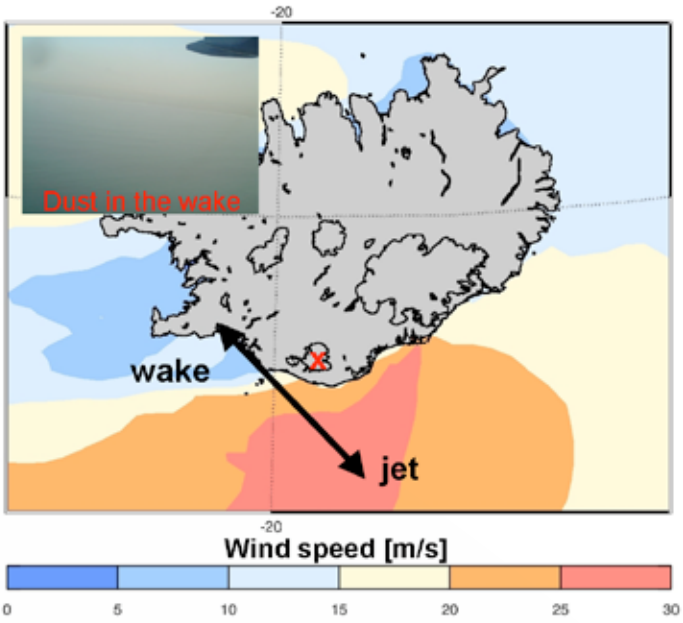
Anne-Marlene Blechschmidt

In this study, simulations with the Weather Research and Forecast model coupled with chemistry (WRF-Chem) are performed to identify the dust sources. Our results show that dust is lifted up by strong winds from sources near the Myrdalsjökull glacier and transported westwards into a region of low wind speeds on Iceland's west coast, termed the Icelandic wake. This agrees with the observations that show that the dust was confined to the wake.

Improving the dust parameterization

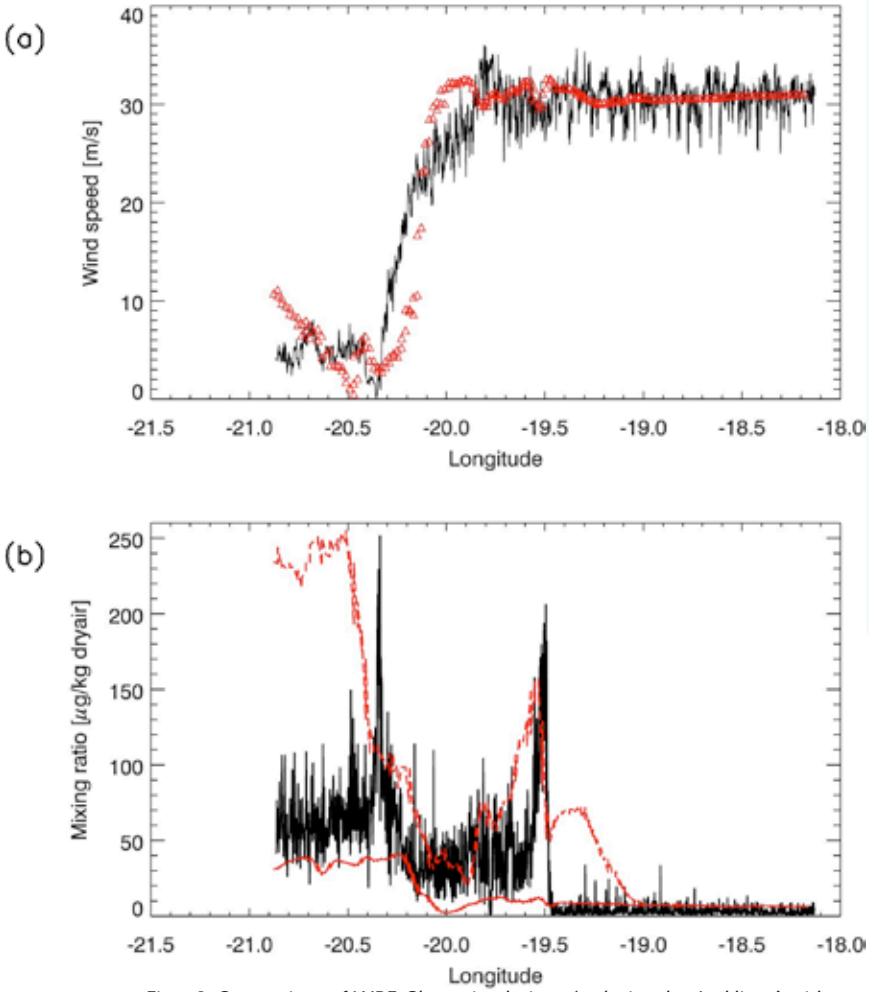
We are currently working on improving the dust parameterization used in WRF-Chem, which is based on a wind erosion module by Shaw et al. (2008). The module calculates total mass of wind-blown dust based on vegetation type, soil moisture and wind speed. In the present study, model wind speed (see Figure 2(a)) and wind direction, which are important parameters for simulating the magnitude of dust emissions and dust transport, agree very well with the measurements.

However, there are rather large differences between the measured and simulated amount of dust. Figure 2 (b) shows mass mixing ratio from the aircraft and WRF-Chem at a height of 400 m. The solid red line represents a run performed with the original dust parameterization used in the model. Overall, the magnitude of mass mixing ratio is underestimated, mostly due to assumptions on erosion that are inadequate for Iceland. The dashed red line corresponds to another simulation where the assumptions were changed to more realistic ones for Iceland. There is an overestimation of mass mixing ratio inside the wake area (i.e. for longitudes smaller than -20.4o East). Nonetheless, the peak around -19.5o East that is present in the meas-



Figur 1: WRF-Chem wind speed [m/s] for 22nd February 2007 at 12 UTC (coloured shadings). The black arrow indicates the track of the FAAM aircraft and the red cross marks the location of the Myrdalsjökull glacier. A photo showing the dust in the wake taken from inside of the aircraft is shown at the top left of this Figure.

urements is now quite well represented. To find the most reasonable dust parameterization in the future, more model simulations are needed.



Figur 2: Comparison of WRF-Chem simulations (red triangles/red lines) with aircraft measurements (black lines) for 22nd February 12 UTC at 400 m height. Wind speed [m/s] is shown in panel (a), while mass mixing ratio [×g/kg] is shown in panel (b). The solid and dashed red lines refer to a model run with the original and modified dust parameterization, respectively.

REFERENCES

Arnalds et al. (2001): Sandy deserts of Iceland: An overview. J. Arid. Environ., 47, 359-371.

Ingolfsson (2008): The dynamic climate of Iceland, http://www3.hi.is/~oi/climate_in_iceland.html, accessed 13.01.2010.

Ovadnevaite et al. (2009): Volcanic sulphate and arctic dust plumes over the North Atlantic Ocean, Atmos. Environ., 43, 4968-4974.

Prospero et al. (2008): Icelandic dust storms linked to glacial outwash deposits and to sub-glacial flood (Jökulhlaup) events, Eos Trans., AGU Fall Meeting 2008 (abstract A13E-08).

Renfrew et al. (2008): The Greenland Flow Distortion Experiment, Bull. Am. Meteorol. Soc., 88, 1307-1324.

Shaw et al. (2008): An evaluation of the dust erosion module in DUSTRAN, Atmos. Environ., 42, 1907-1921.

The effect of Anthropogenic Aerosols in the Arctic

Does Anthropogenic Aerosols Enhance or Suppress the Surface Cloud Forcing in the Arctic?

By K. Alterskjær1, J. E. Kristjánsson1, and C. Hoose1,2
1. Department of Geosciences, University of Oslo, Oslo, Norway; 2. Institute for Meteorology and Climate Research, Karlsruhe Institute of Technology, Karlsruhe, Germany

Jón Egill Kristjánsson

Recent studies suggest that aerosol-cloud interactions may have contributed to the increase in surface air temperature observed in the Arctic over the last decades. Unlike earlier studies that focus on long-wave effects of strong pollution events observed around Barrow, Alaska, we have used a global climate model (CAM-Oslo) to study the annual and seasonal net radiative effect of aerosol-cloud interactions over the entire Arctic region.

Well-suited climate model

The simulated cloud cover, cloud water path and surface cloud forcing were validated against observations, and model adjustments were subsequently made to better suit the model to the focus of our study. Observational data from the SHEBA (Surface Heat Budget of the Arctic Ocean) campaign were important in this process. The simulated particulate SO4 concentrations were compared both to observations made at Arctic measuring stations and to the median of ten models participating in the AeroCom project (Aerosol Comparisons between Observations and Models). We found that our results in general provide a better agreement with the observations than the AeroCom model median does (see Figure 1). Overall we find that the adjusted CAM-Oslo global climate model is well suited for this study.

Increase in Arctic surface air temperature

Our results do not support the suggestion that aerosol-cloud interactions act to increase the surface air temperature of the Arctic region. Averaged north of 71ÐN, they show that the annual change in surface net cloud forcing is - 0.30 W/m2, meaning that introducing more aerosols into liquid clouds in the Arctic leads to an overall decrease in the radiative flux at the surface. Due to long-wave dominance in the winter, the average change in net cloud forcing at the surface from October to May is positive (0.14 W/m^2), while the change in forcing averaged over the summer months is negative (- 1.18 W/m^2; see Figure 2). We do find an increase in the long-wave (LW) component of the surface cloud forcing of 0.55 W/m2 annually (0.99 W/m2 in summer and 0.33 W/m2 in winter) but this is one order of magnitude lower than what was suggested by *Garrett and Zhao* (2006) and *Lubin and Vogelmann* (2006).

Several sensitivity experiments were conducted and from these we conclude that our findings are robust against model assumptions, changes in cloud properties and aerosol concentrations.

Further studies on aerosols

In recent years (after the fall of the Soviet Union) the emissions of the SO4 precursor SO2 have decreased dramatically in Europe and Russia (Karnieli et al.,

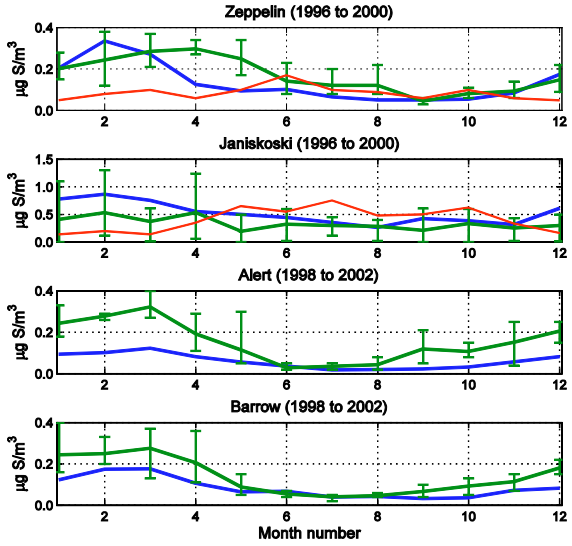


Figure 1: Observed (green) and simulated (blue) SO4 concentrations at selected Arctic stations [×g S/m3]. Observational data from *AMAP* (2006) have been averaged over five years, and error bars show the maximum and minimum observed monthly means. The median of 10 AeroCom A models (*Textor et al.*, 2006) for Spitsbergen (including Zeppelin) and Janiskoski for the year 2000 is shown in red. Simulated SO4 concentrations from both CAM-Oslo and the AeroCom A models are non-sea-salt only. Note that axes differ.

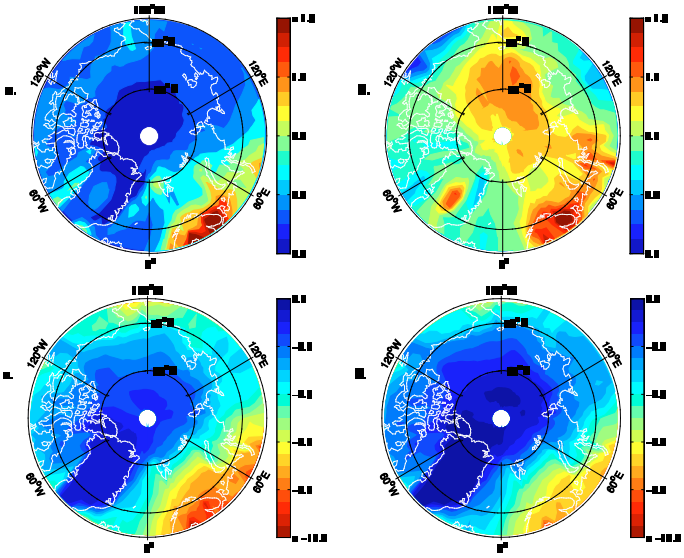


Figure 2: Simulated anthropogenic change in cloud forcing at the surface [W/m2] from pre-industrial times to present day. a) Change in LW surface cloud forcing, winter season (October – May). b) Change in LW surface cloud forcing, summer season (June – September). c) Change in SW surface cloud forcing, summer season. d) Change in surface net cloud forcing, summer season. Note that color scales are reversed in c) and d).

2009), and Sharma et al. (2006) find a clear downward trend in the concentrations of equivalent black carbon (BC) in the high Arctic. From the findings of this study it is likely that a reduction in CCN amount in the Arctic would decrease the magnitude of the negative indirect effect and therefore in sum work to increase the net positive cloud forcing found in this region. The less pollution that enters the Arctic, the larger the increase in surface radiative flux compared to present day.

Further study

Although the simulated changes in surface cloud forcing are smaller than what is found in earlier studies, they are of the same order of magnitude as the BC surface forcing via snow and ice albedos in areas of sea ice. For instance, Flanner et al. (2007) estimated the annual mean of the instantaneous surface forcing of BC on snow in these areas to be around 0.20 W/m2 during a year of average BC emissions. The changes in Arctic surface cloud forcing due to anthropogenic aerosols may therefore be of importance and should be studied further.

REFERENCES

Alterskjær, K., J. E. Kristjánsson, and C. Hoose, 2010: Do anthropogenic aerosols enhance or suppress the surface cloud forcing in the Arctic? *J. Geophys. Res.*, submitted.

AMAP (2006), Arctic Monitoring and Assessment Programme (AMAP) assessment 2006: Acidifying pollutants, Arctic haze and acidification in the Arctic, http://www.amap.no.

Flanner, M. G., C. S. Zender, J. T. Randerson, and P. J. Rasch (2007), Present-day climate forcing and response from black carbon in snow, J. Geophys. Res., 112, D11202, doi:10.1029/2006JD008003.

Garrett, T. J., and C. Zhao (2006), Increased Arctic cloud longwave emissivity associated with pollution from mid-latitudes, Nature, 440, 787–789, doi:10.1038/nature04636.

Intrieri, J. M., M. D. Shupe, T. Uttal, and B. J. McCarty (2002), An annual cycle of Arctic cloud characteristics observed by radar and lidar at SHEBA, J. Geophys. Res., 107 (C10), 8030, doi:10.1029/2000JC000423.

Karnieli, A., Y. Derimian, R. Indoitu, N. Panov, R. C. Levy, L. A. Remer, W. Maenhaut, and B. N. Holben (2009), Temporal trend in anthropogenic sulfur aerosol transport from central and eastern Europe to Israel, J. Geophys. Res., 114, D00D19, doi: 10.1029/2009JD011870.

Lubin, D., and A. M. Vogelmann (2006), A climatologically significant aerosol longwave indirect effect in the Arctic, Nature, 439, 453–456, doi:10.1038/nature04449.

Maslanik, J. A., J. Key, C. W. Fowler, T. Nguyen, and X. Wang (2001), Spatial and temporal variability of satellite-derived cloud and surface characteristics during FIRE ACE, J. Geophys. Res., 106 (D14), 15,223–15,249.

Sharma, S., E. Andrews, L. A. Barrie, J. A. Ogren, and D. Lavoué (2006), Variations and sources of the equivalent black carbon in the high arctic revealed by long-term observations at Alert and Barrow: 1989 - 2003, J. Geophys. Res., 111, D14208, doi: 10.1029/2005JD006581.

Textor, C., et al. (2006), Analysis and quantification of the diversities of aerosol life cycles within AeroCom, Atmos. Chem. Phys., 6, 1777–1813.

"For the first time, we have a three-dimensional picture of the chemical composition and the aerosol content of the Arctic atmosphere, from Europe to Siberia, over North America and Greenland, and up to the North Pole."

ANDREAS STOHL

Soot in the Arctic

The most important source regions of Black Carbon emissions, which are transported to the Arctic troposphere, have now been identified.

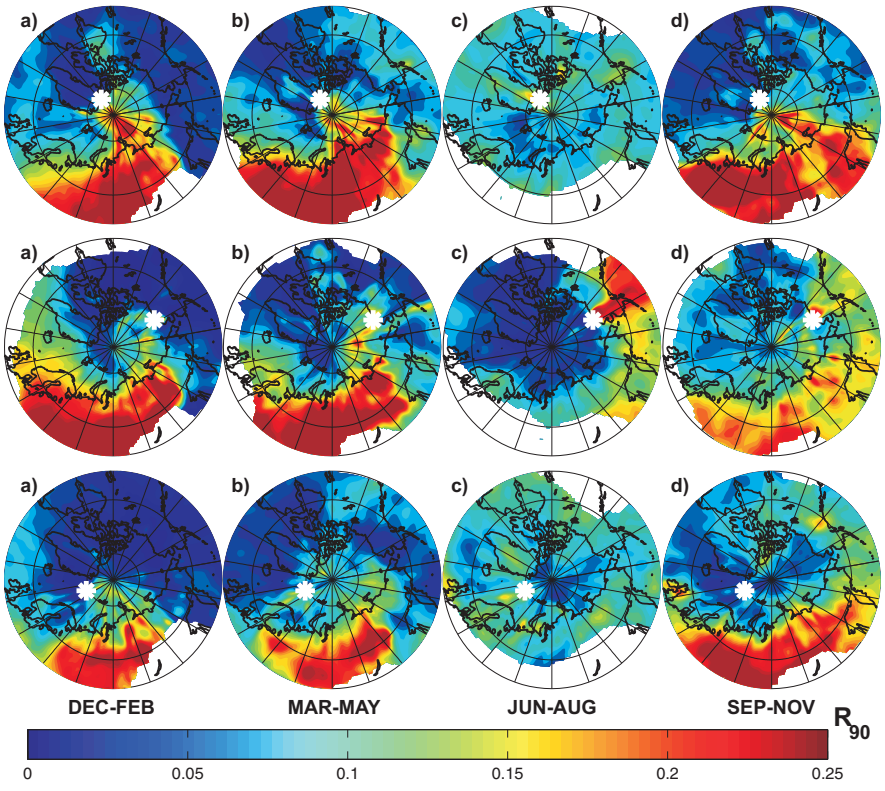
By: David Hirdman, Ph.D. candidate, NILU – Norwegian Institute for Air Research

Pollutants with a short atmospheric lifetime, particularly black carbon (BC), have recently received a lot attention as climate forcers, especially in the Arctic. In an analysis which combines measurement data of equivalent black carbon (EBC) from several Arctic stations with calculations from the Lagrangian particle dispersion model FLEXPART, we have identified the most important source regions of BC emissions, which are transported to the Arctic troposphere.

David Hirdman

Seasonal variations

We have also seen how this changes with the seasons. For all seasons except summer, long-range transport from northern Eurasia is the dominating source of EBC at the Arctic stations Alert (Canada), Barrow (Alaska, USA), and Zeppelin (Svalbard, Norway). During summer, the situation is more complex, with the major contribution coming from regional sources such as boreal forest fires. These records of measured EBC are now also long enough for meaningful trend analysis. In our analysis we see a general downward trend in the EBC at all three stations. Decreasing emissions in Northern Eurasia drives this trend, and a long-term change in the atmospheric circulation may only explain a minor fraction. In wintertime, however, there are indications that the EBC emissions in the eastern parts of northern Eurasia have increased over the last decade.



Fields of R90 for measurements of EBC at Alert (top row), Barrow (middle row), and Zeppelin (bottom row), for December-February (far left column), March-May (middle left column), June-August (middle right column) and September-November (far right column). The locations of the stations are marked by white asterisks.

REFERENCES

Hirdman, D., Sodemann, H., Eckhardt S., Burkhart J.F., Jefferson A., Mefford, T., Sharma, S., Ström, J., and Stohl, A.: Source identification of short-lived air pollutants in the Arctic using statistical analysis of measurement data and particle dispersion model output, Atmos. Chem. Phys., 10, 669-693, 2010.

Hirdman, D., Burkhart J.F., Sodemann, H., Eckhardt S., Jefferson A., Quinn, P.K., Sharma, S., Ström, J., and Stohl, A.: Long-term trends of black carbon and sulphate aerosol in the Arctic: Changes in atmospheric transport and source region emissions, Submitted to ACP, 2010.

Tropospheric Ozone and the Siberian Forests

Siberia is an important subarctic region that impacts the Arctic atmosphere. The objective of the Norwegian-Russian project RAPSIFACT has been to investigate the importance of Russian forests for the concentrations of ozone measured in Siberia.

By Ann-Christine Engvall Stjernberg, Post Doc, NILU – Norwegian Institute for Air Research

The Arctic is a remote area where air chemistry is largely affected by pollutants released at lower latitudes via long-range transport. One of these regions is Siberia, a vast region which is very important for the Arctic climate. Still there is little knowledge of how much the region of Siberia acts as a source and sink for gaseous pollutants such as ozone and methane.

Source and sink for atmospheric compounds

Almost 75 percent of the world's boreal forest is located in Russian territory, which also has significant areas of tundra and wetlands. These areas are an important source of biogenic volatile organic compounds (BVOCs) and they also act as an important sink for many of the gaseous pollutants in our atmosphere.

In the Norwegian-Russian project RAPSIFACT we have studied sources of Russian air pollution and their impact on the atmospheric composition in the Arctic. We have used trace-gas data from the TROICA (Tran-Siberian Observations on the Chemistry of the Atmosphere) railway carriages and the Siberian station Zotino, located at 300 meters above sea level, 60°N, 89°E. TROICA was established 1995 (Crutzen et al. 1998) and there have been a total of 14 campaigns since then, both in the east-west direction between Moscow and Vladivostok and in north-south direction between Murmansk and Kislovodsk. We also have access to measurements from the Arctic station Zeppelin (474 meters above sea level, 79°N, 12°E) and measurements over the Siberian region from the airborne campaigns YAK-AEROSIB 2006-2008. (Paris et al. 2008).

Ann-Christine Engvall Stjernberg

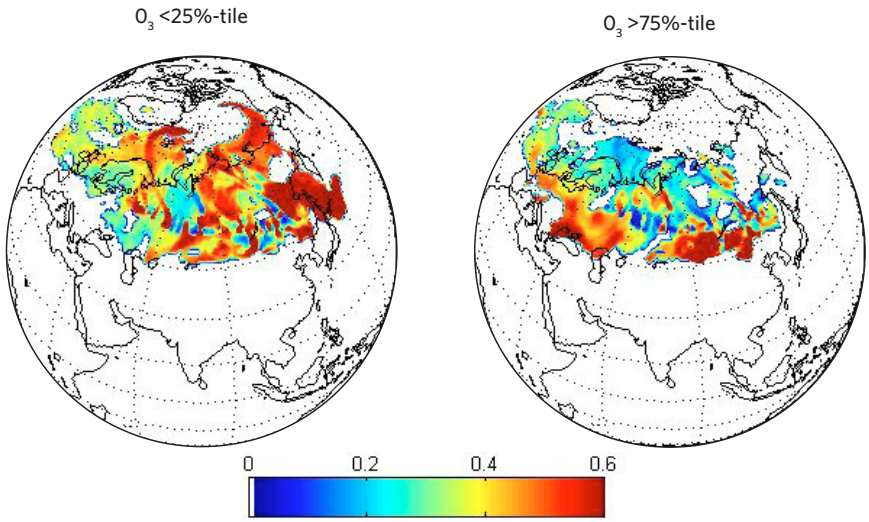


Figure1. The PES field for TROICA measurements performed during summer (SUM). The upper panel shows PES when low (<25%-tile) concentrations of ozone are measured and the lower panel represent when high (>75%-tile) concentrations are observed.

Measuring ozone concentrations

The gas investigated in this project was ozone (O3), which is an important greenhouse gas. Ozone background concentrations have been doubled since the pre-industrial era and are believed to have a radiative forcing of about 0.35415 W m-2. This is approximately 20-25 percent of the combined effect of all greenhouse gases on the climate (Monks et al., 2009).

We used the Langrangian particle dispersion model FLEXPART to analyze the air-mass transport. (e.g. Stohl et al. 1999). In order to determine the amount of air mass that has been in contact with the surface, and where, we ran the model 20 days back in time from when the data was measured. The output (the so called 'potential emission sensitivity fields' or PES field) was analyzed statistically in order to see if the regions acted as a source or sink for the measured ozone. We found that the sink and source regions changed with the seasons, due to change in the general global circulation. During summer, for example, source regions are located at lower latitudes (the region around the Mediterranean Sea, Middle East, Kazakhstan, and Mongolia), while sink regions are associated with transport from the Pacific Ocean and the Arctic region. During autumn, sources are found in the northern parts of Europe and also in the North-Atlantic, while the sink regions are mainly associated with the areas of north Siberia as well as central Europe.

ACKNOWLEDGEMENTS

N. Elansky and A. Skorokhod from the Obukhov Institute for Atmospheric Physics in Moscow, Russia, provided data from TROICA and the Zotino station. The RAPSIFACT project is funded by the Research Council of Norway.

Aircraft campaigns above Central and Eastern Siberia

Six YAK-AEROSIB aircraft campaigns over Siberia have documented the atmospheric distribution of trace gases and as aerosols since 2006. During POLARCAT, two campaigns particularly targeted a better understanding of the atmospheric impact of wildfires in the Siberian forest, including their long-range transport towards the Arctic.

By Jean-Daniel Paris, Laboratoire des Sciences du Climat et de l'Environnement (LSCE/IPSL), CEA Saclay

Jean-Daniel Paris.

Despite the unique characteristics of the Siberian air shed, including the lack of large local anthropogenic emissions, a vast forest expanse, and its position as a gateway for Eurasian emissions transported toward the Arctic, there are very few large scale observations of the tropospheric composition over this region.

Vegetation fires, either man made or natural, constitute a major source of pollutants to the atmosphere and have an impact on air quality at the hemispheric scale. In particular Siberian forest fires are known to be a major extratropical source of carbon monoxide (CO), as well as a significant source of black carbon and other climate-relevant species to the atmosphere, dominating other biomass burning sources at high latitudes.

High-precision measurements

The YAK-AEROSIB program started in 2006 as a French-Russian collaboration. Aircraft campaigns were designed to take into account various constraints on the flight route. During each campaign the Antonov-30 aircraft collected high-precision measurements of the vertical distribution of CO2, CO, O3, black carbon and ultrafine particles distribution in the Siberian troposphere, on a 4000-km aircraft transect. In July 2008, in the frame of the POLARCAT project, a special campaign was designed to additionnally sample the troposphere along the Russian Arctic coast and investigate the atmospheric emissions and transport of biomass burning plumes.

The campaigns have documented the poorly-known background tropospheric composition and the tracers' concentration variability, useful for a better knowledge of atmospheric chemistry. The campaigns also provide a wealth of data on the impact of large-scale transport of anthropogenic emissions from Europe and Asia, as well as the transport of biomass burning plumes from regional sources in Siberia and Kazakhstan. Long range transport of anthropogenic emissions is shown to have a discernible impact on O3 distribution, although its lower-tropopsheric variability is largely driven by surface deposition.

Using FLEXPART

In July 2008 (POLARCAT's summer intensive period), the rather low pollutants' background concentrations over the Arctic coast were sometimes interspersed with polluted layers. During a specific day, as we were able to demonstrate eventually using the FLEXPART model, the aircraft on its way from the Arctic coast to eastern Siberia, crossed several times highly polluted plumes originating from the same forest fire but at different times in the last few days. This proved to be an interesting way to measure how the plume disperses and how black carbon and other aerosol components get removed during transport. For example, the lifetime of black carbon was found to be very similar to earlier estimates used in modelling studies. It was then realized that the burning forest area was in the vicinity of the landing airport. From data collected during the approach manoeuvre of the aircraft we were therefore able to estimate various parameters related to the wildfire (combustion efficiency emission factor) whose outflow was sampled earlier.

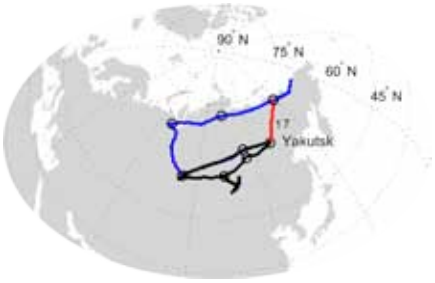


Fig. 1 Aircraft itinerary in July 2008. Successive flights are shown in red and black. Each "loop" takes between 1 and 2 weeks for completion. (fig1.png)

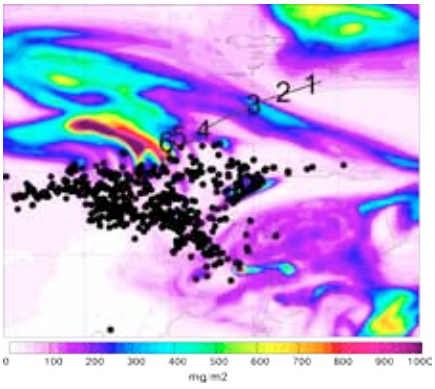


Fig. 2. Observed plumes and Flexpart forward simulation of forest fire carbon monoxide during the flight from the Arctic coast to Yakutsk. Observed plumes are indicated by their sequential order (1-6). (fig2.png)

REFERENCE:

Paris JD et al., Wildfire smoke in the Siberian Arctic in summer: Source characterization and plume evolution from airborne measurements, *Atmos Chem Phys*, 9, 9315–9327, 2009.

Aerosol pollution in the Arctic and source apportionment with the EMEP model

Targeting aerosol pollution may be a potentially more efficient and immediate measure to deal with climate change in the Arctic. Thus identifying the sources of Arctic aerosol pollution becomes increasingly important.

By Svetlana Tsyro, Michael Gauss and Hilde Fagerli, Research and Development Department, Norwegian Meteorological Institute, Oslo

The arctic climate is affected not only by long-lived greenhouse gases, but also by air pollution, in particularly aerosols. Black carbon is estimated to have a particularly large warming effect. The direct effect of sulphate, nitrate and ammonium is radiative cooling; however they may cause significant long-wave warming through interaction with thin Arctic clouds in winter.

Given these facts, targeting aerosol pollution has been suggested as a potentially more efficient and immediate measure to deal with climate change in the Arctic. Therefore it is important to identify the sources of Arctic aerosol pollution.

Characterising aerosol pollution

The EMEP chemical transport model has been applied to characterise aerosol pollution in the Arctic in 2006. Figure 1 (left) shows the model calculated annual mean PM10 concentrations (particles smaller than 10 _m) due to European anthropogenic emissions and natural sources (e.g. sea spray, dust). The monthly variation of PM10 and its chemical composition is presented on Figure 1 (right).

The aerosol levels are enhanced in the late winter and spring. Among the anthropogenic pollutants, sulphate aerosols (mostly from stationary combustion sources) dominate in the Arctic air, followed by nitrate (predominantly due to traffic) and ammonium (due to agriculture) particles. Primary, i.e. directly emitted aerosols (PPM), which include black

Svetlana Tsyro

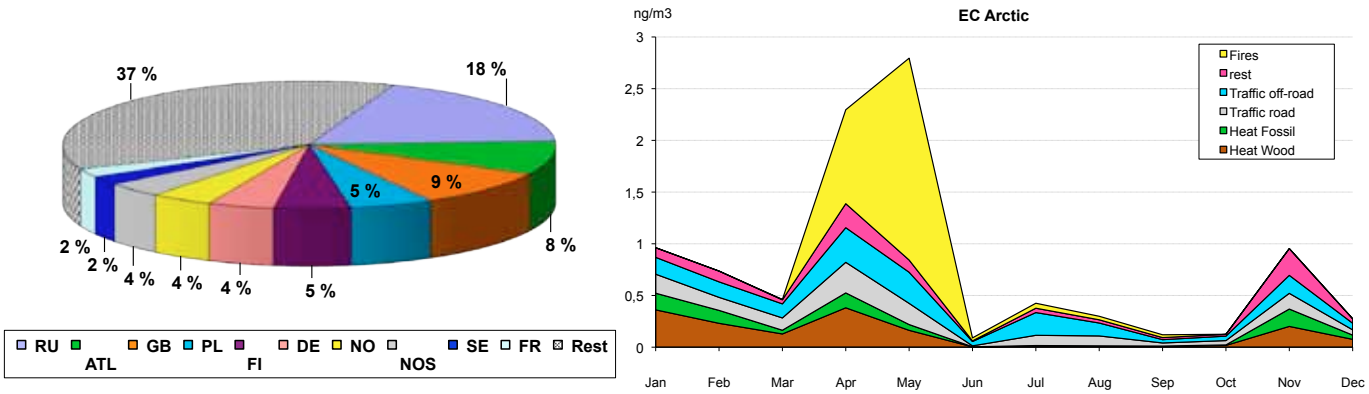


Figure 1. EMEP model calculated annual mean concentrations in _g/m3 (left) and the monthly variation of chemical composition (right) of PM10 in the European Arctic in 2006.

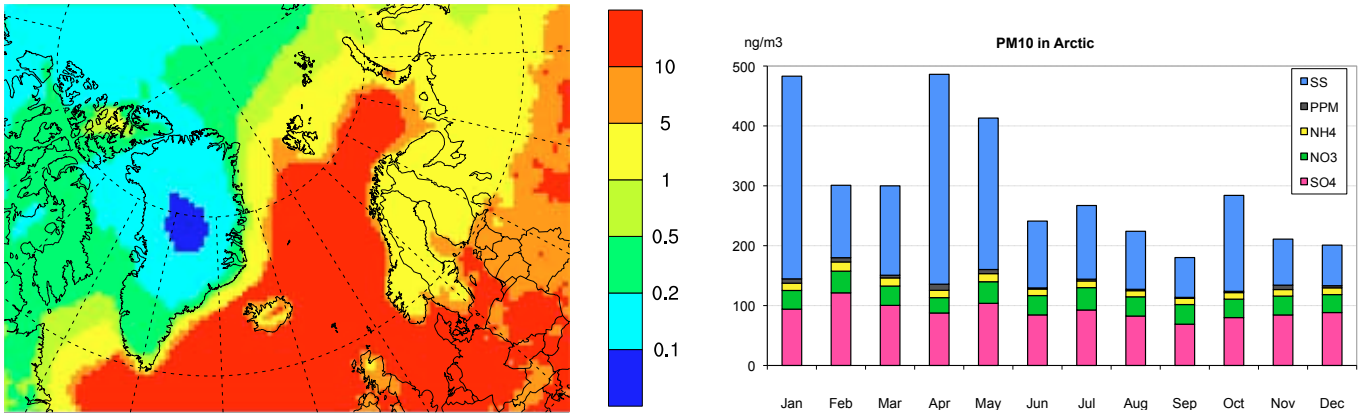


Figure 2. EMEP model calculated relative contribution from major European countries/source areas to PM2.5 (left) and monthly variation of source contributions to black carbon concentrations (right) in the European Arctic in 2006.

carbon (BC), contribute less in the total PM10 mass. The contribution of sea salt aerosol (SS) is significant, especially from January to May.

Shipping a dominant source

Focusing on Europe, the model calculations suggest that Russia was the largest source of primary PM2.5 in the Arctic, followed by Norway, Finland and shipping traffic in the North-Eastern Atlantic in 2006 (Figure 2, left). Sweden, the UK, Poland, France and Germany are also among the top ten contributors. As pointed out, climate relevant black carbon is a part of primary PM.

Given the special climate impact of black carbon, we look at the relative importance of its main sources, i.e. burning of wood and fossil fuel, road traffic and other (off-road) mobile sources (shipping), in different seasons in 2006 (Figure 2, right).

One of the main findings is that a considerable contribution to BC in the Arctic comes from shipping, which becomes a dominating source in summer. Residential combustion is the main source of BC in the cold period, while road traffic contributes through the whole year. Finally, the effect from vegetation fires on BC levels in the Arctic was very pronounced when large agricultural fires occurred in Eastern Europe in April-May in 2006.

ACKNOWLEDGEMENTS

Quinn, P. K. et al., (2007). *Tellus*, 59B, 99-114

Quinn, P. K. et al., (2008). *Atmos. Chem. and Phys.*, 8, 1723-1735.

Simpson, D. et al. (2003). Status report 1/2003 Part I. http://www.emep.int.

Tsyro, S. (2008). *Russian Meteorology and Hydrology*, Vol. 33, 2, 82-90.

Carbon Monoxide in the Arctic Atmosphere

Data from two POLARCAT aircraft campaigns proves that fossil fuel from Asia is the dominant source of Arctic carbon monoxide pollution in the free troposphere, while Asian and European sources play equal roles closer to the surface.

By Jenny Fisher, Ph.D. Candidate, Harvard University

For more than 50 years, pollution from industrial regions has been observed in the Arctic every winter and early spring. While the sources are undoubtedly distant, their distribution is widely debated.

Now data from two POLARCAT aircraft campaigns, along with observations from the AIRS satellite instrument and simulations from the GEOS-Chem chemical transport model have shown that fossil fuel from Asia is the dominant source of Arctic carbon monoxide pollution in the free troposphere, while Asian and European sources play equal roles closer to the surface.

Jenny Fisher

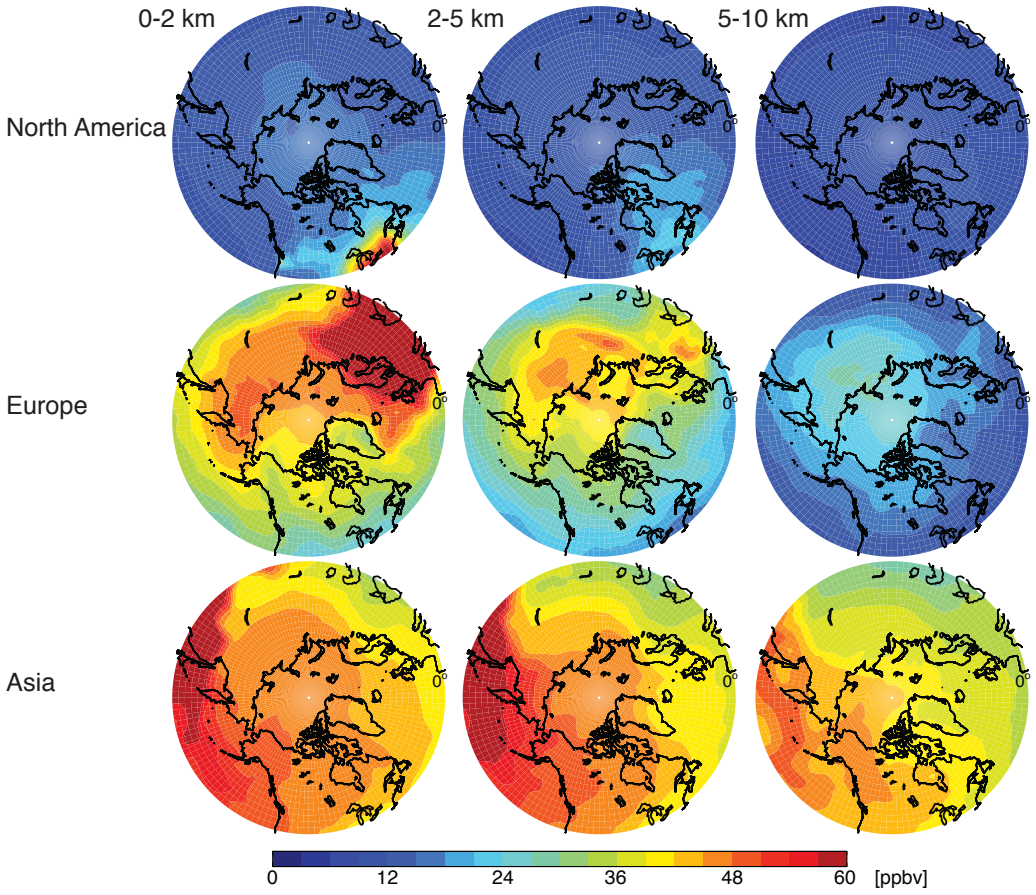
A receptor for pollution

The Arctic has long been known to be a receptor for pollution from distant anthropogenic activities, but the sources influencing the Arctic remain uncertain. Early studies in the 1970s and 1980s attributed the pollution to industrial activity in Europe and the former U.S.S.R. Over the past 20 years, however, the collapse of the Soviet Union, strict emission controls in Europe, and the rapid industrialization of Asia have led to dramatic changes in the global distribution of pollutants, and recent studies disagree as to the sources responsible for Arctic pollution.

Better understanding of these sources was the primary goal of two POLARCAT aircraft campaigns based in Fairbanks, Alaska in April 2008: NASA's Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) and NOAA's (National Oceanic and Atmospheric Administration) Aerosol, Radiation, and Cloud Processes affecting Arctic Climate (ARCPAC).

Unique experience

I was in the field as part of the flight planning team for ARCTAS, interpreting model forecasts to help determine the flight paths and analyzing early data to ensure the mission objectives were being met. As a modeler, working alongside the experimenters in Fairbanks provided me with an enhanced understanding of the in-situ datasets, along



Contributions of different mid-latitude source regions to CO pollution in the Arctic in April 2008, as indicated by the GEOS-Chem simulation. Results are shown as mean CO mixing ratios in altitude bands of 0–2, 2–5, and 5–10 km.

with the chance to experience firsthand the Arctic environment.

Wide Range Samples

Both ARCTAS and ARCPAC measured carbon monoxide (CO), which serves as an excellent indicator of pollution. CO is emitted by incomplete combustion – fossil fuel and biomass burning – and has an atmospheric lifetime of weeks to months, long enough to track long-range transport but short enough to remain distinct from the background atmosphere.

The aircraft sampled a wide range of conditions, ranging from clean background air to fossil fuel and smoke plumes. We used the aircraft observations as constraints for GEOS-Chem, a chemical transport model that uses our best understanding of CO sources and processes to predict CO concentrations. The data showed that while GEOS-Chem reproduced the qualitative pollution features observed by the aircraft, the simulated CO concentrations were consistently too low. By fitting the modeled concentrations to the observed CO, we found that the state-of-the-science fossil fuel emissions used in GEOS-Chem are underestimated by 50 percent for Europe and by 20 percent for Asia.

Asian pollution dominant

With improved estimates of CO emissions, we used GEOS-Chem to quantify the sources affecting Arctic pollution during spring 2008. The figure shows the simulated impact of fossil fuel burning in North America, Europe, and Asia on CO pollution in the Arctic. Asian pollution was clearly dominant at all altitudes, although European pollution had an equivalent influence near the surface. In contrast, North American pollution had virtually no impact on the Arctic. Forest fires in Russia, which were anomalously intense during the campaigns, were largely unimportant for Arctic CO concentrations.

Long-term perspective

Satellite observations of CO offer a longer-term perspective, providing context for the 2008 results. Data from the Atmospheric InfraRed Sounder (AIRS) satellite instrument show that CO over Alaska was lower than average in April 2008 and that it is correlated with the strength of El Niño. Meteorological changes associated with El Niño, enhance transport of Asian pollution to Alaska. This result suggests that the impact of Asian pollution on the Arctic, already dominant, could be even greater during a strong El Niño event.

Soot deposition on snow and ice

— a counter-intuitive modeled climate response

Aerosol particles counteract globally the forcing by greenhouse gases; most particles reflect sunlight and contribute to whiter clouds. Soot, on the other hand, absorbs sunlight and gives a positive forcing over white surfaces. Model calculations show that a global warming is not an obvious response. Non-linear dynamics and regional feedbacks can produce a surprise.

By Trond Iversen Professor, Assist. Research Dir. and Alf Kirkevåg, Senior Scientist The Norwegian Meteorological Institute

Both air-borne and ground-deposited soot absorb sunlight. For a ground surface covered with ice and snow, soot increases absorption of sunlight and produces positive radiative forcing. The interaction of snow and ice with soot from snow-fall to snow-melt, and the penetration of radiation in snow and ice, render the modeling of these effects complex.

The global climate model NorESM (see box) is used to estimate the climate response to deposited black carbon (BC). The emission data are those for IPCC. In addition to BC, the cycling of several aerosols, their size, composition, and interactions with radiation and clouds, are calculated in NorESM.

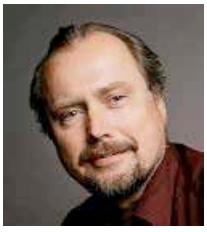
Two 51-years simulations for present-day climate are run, one with full aerosol physics included and another where the deposited BC is re-set to zero every time-step. After 20 years the simulated statistics are close to stationary and the climate difference is estimated over the latter 32 of the 51 years.

The four panels show calculated effects of deposited BC (soot) on 2-meter temperature, surface albedo, snow-cover, and sea-ice cover. The proper forcing at the top of the atmosphere (TOA) is not yet calculated. The global net radiation flux at TOA during climate response is smaller and averages at ca. 0.1 Wm-2, similar to its year-to-year variation. In parts of the Arctic and Himalaya it can reach a few (1-3) Wm-2.

Positive Forcing Produces Cooling

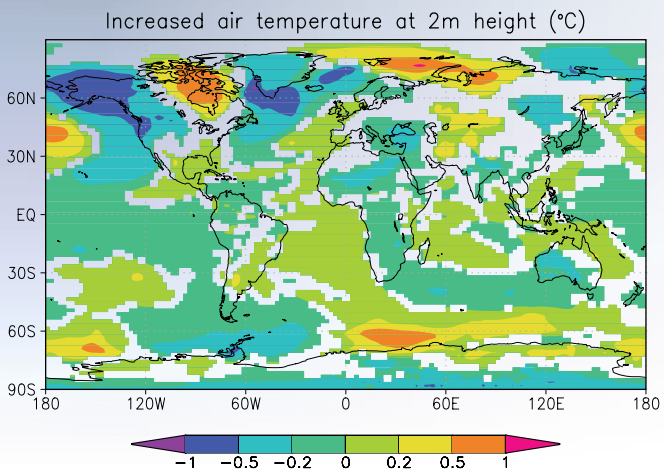
The change in air temperature (upper left) is patchy. The global mean is actually slightly negative (-0.03oC), and the climate system - in NorESM - tends to have negative climate sensitivity for this specific mechanism.

This can only be happen if negative feedback processes dominate over the direct linear response of the soot deposition. The small positive forcing thus triggers internal processes which counter-act warming. If the BC-deposition for testing purpose is uniformly set to 10000 times the calculated maximum, a considerable warming is calculated with negligible noise from internal processes.

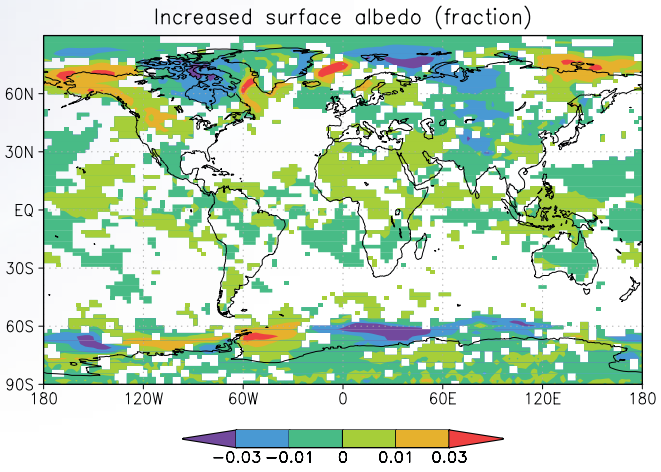


Trond Iversen

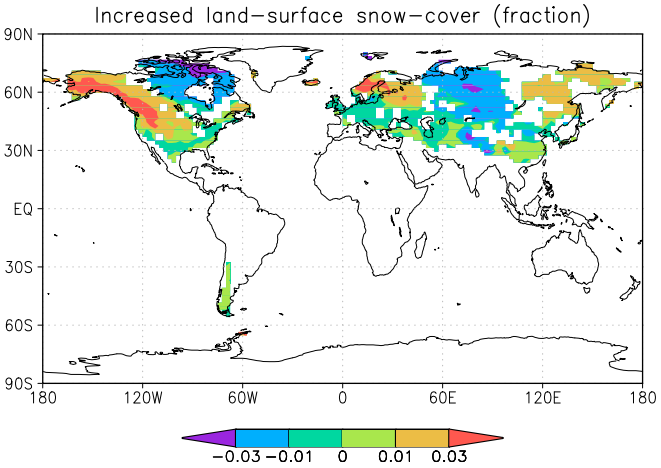
Alf Kirkevåg



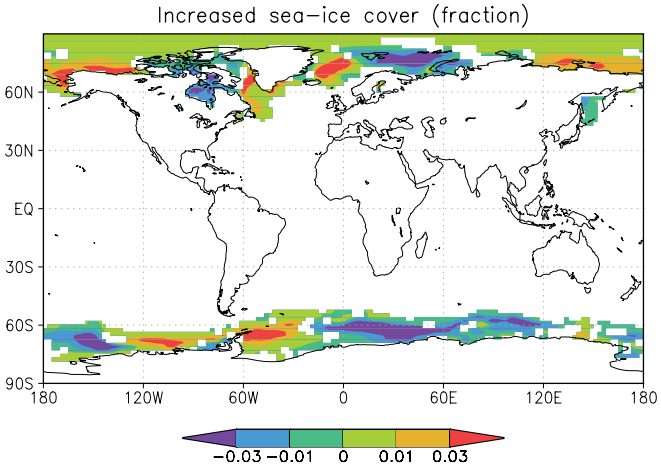
Increased annual mean 2m-temperature



Increased ground surface albedo



Increased land-surface snow cover fraction



Increased sea-ice cover fraction

Flow Regimes and Negative Feedback

Two conceptual views of the relation between forcing and response can be relevant. The non-linear dynamical view of Palmer (*J. Climate* 12, 575–591, 1999), explains the response in terms of natural flow regimes. The internal feedback view of Boer and Yu (*Clim. Dyn.* 20, 415–429, 2003) explains the response by geographically located feedbacks.

Both views are useful. The surface albedo response (upper right) correlates negatively with the temperature change, in support of a linear view. However, the patchy temperature and albedo fields indicate non-linearity. Even in parts of the Arctic, the model estimates increased albedo in response to soot-deposition.

This can be understood as follows. The positive forcing leads to a slightly stronger North-Atlantic Oscillation (NAO). This is associated with increased sea-ice fraction (lower right) in the north-western North Atlantic Ocean, reduced sea-ice in the Barents Sea, and increased winter precipitation and snow cover (lower left) over north-western Eurasia. A similar response is seen over the northern Pacific Ocean and North America, associated with a weakened Pacific-North-American pattern (PNA).

In conclusion: In NorESM the regional increase in snow and sea-ice cover associated with flow regimes, constitutes a negative feedback yielding a negative global response to the positive forcing of soot deposition.

NorESM: Norwegian Earth System Model is a coupled model developed in the Norwegian Climate Centre. Core developers are the Bjerknes Centre of Climate Research (BCCR) and the Norwegian Meteorological Institute (met.no), with contributions from Univ. of Oslo, the Nansen Centre (NERSC), and Cicero. Based on CCSM4 from National Center for Atmospheric Research (NCAR, USA), qualified changes include: on-line aerosol–cloud-radiation interactions, isopycnic ocean modeling,, and on-line carbon cycling. NorESM is mainly developed in the NorClim project (The Research Council), and partly in other projects, e.g. IPY-Polarcat. Computer resources are granted by The Research Council's NOTUR programme.

Cristina Prados working on instrumentation.

POLARCAT CAMPAIGNS

NASA – ARCTAS
Arctic Research of the Composition of the Troposphere from Aircraft and Satellites

The Arctic is undergoing significant environmental changes related to global climate change. NASA is extensively studying the role of air pollution in this climate-sensitive region as part of the ARCTAS field campaign, the largest airborne experiment ever to do so.

Organization: National Aeronautics and Space Administration (NASA)
Country: USA
Location: Fairbanks, Alaska/ Cold Lake, Alberta
Platform: DC8 & P3 aircraft
Dates: April 1-21, 2008/ June 26 – August 14, 2008
Contact: J Crawford, NASA & D Jacob, Harvard
Internet: www.espo.nasa.gov/arctas/

NOAA – ICEALOT
International Chemistry Experiment in the Arctic Lower Troposphere

ICEALOT was a springtime research cruise in an ice-free region of the Arctic. Topics included springtime sources and transport of pollutants to the Arctic, evolution of aerosols and gases into and within the Arctic, and climate impacts of haze and ozone.

Organization: The National Oceanic and Atmospheric Administration (NOAA)
Country: USA
Location: North Atlantic
Platform: R/V Knorr
Dates: March 11 – 23. April, 2008
Contact: P. Quinn, NOAA
Internet: http://saga.pmel.noaa.gov/Field/icealot/

NOAA – ARCPAC
Aerosol, Radiation, and Cloud Processes affecting Arctic Climate

ARCPAC was established as an airborne field experiment in Alaska to address the four major areas of non-greenhouse-gas atmospheric climate processes in the Arctic. A NOAA WP-3D aircraft was used for the experiment, and was based at Fairbanks, Alaska.

Organization: The National Oceanic and Atmospheric Administration (NOAA)
Country: USA
Location: Fairbanks, Alaska
Platform: P3 aircraft
Dates: April 1-25, 2008
Contact: C. Brock, NOAA
Internet: www.esrl.noaa.gov/csd/arcpac/

YAK – AEROSIB

The YAK-AEROSIB objective is to establish systematic observations of atmospheric concentrations in CO2, CO and O3 over the interior of Eurasia. The measurements will be collected over several years over a transcontinental route between Western and Eastern Siberia.

Organization: CNRS – French National Center for Scientific Research, The French Ministry of Foreign Affairs (CEA), Institute of Atmospheric Optics, SB-RAS, Tomsk, Russia, and NILU
Country: France, Russia, Norway
Location: Siberia
Platform: Antonov-30 aircraft
Dates: July 1-20, 2008
Contact: D Paris, CNRS & B. Belan, CEA
Internet: www.lsce.ipsl.fr/Pisp/17/jean-daniel.paris.html

POLARCAT – France

During the POLARCAT-France summer campaign, aircraft based measurements were performed out of Greenland, with the objective to investigate pollutant transport pathways to the Arctic, with respect to European outflow, Canadian and Siberian boreal forest fires. During the winter campaign, the aircraft was based at Kiruna, Sweden.

Organization: CNRS – French National Center for Scientific Research
Country: France
Location: Kiruna, Sweden/ Kangerlussuaq, Greenland
Platform: ATR - 42 aircraft
Dates: March 3. – April 7. 2008/ July 4 – 22. 2008
Contact: K Law, CNRS
Internet: www.latmos.ipsl.fr/index.php/en/tact/themes-de-recherche/polarcat

GRACE – Greenland Aerosol and Chemistry Experiment

The GRACE field deployment of the DLR Falcon research aircraft is a German contribution to the POLARCAT activity. The campaign was targeted at aircraft and satellite-remote sensing observations of biomass burning emission transport into the Arctic.

Organization: Institut für Physik der Atmosphäre (DLR)
Country: Germany
Location: Kangerlussuaq, Greenland
Platform: Falcon aircraft
Dates: July 4 – 22., 2008
Contact: H. Schlager, DLR
Internet: www.pa.op.dlr.de/polarcat/

TROICA

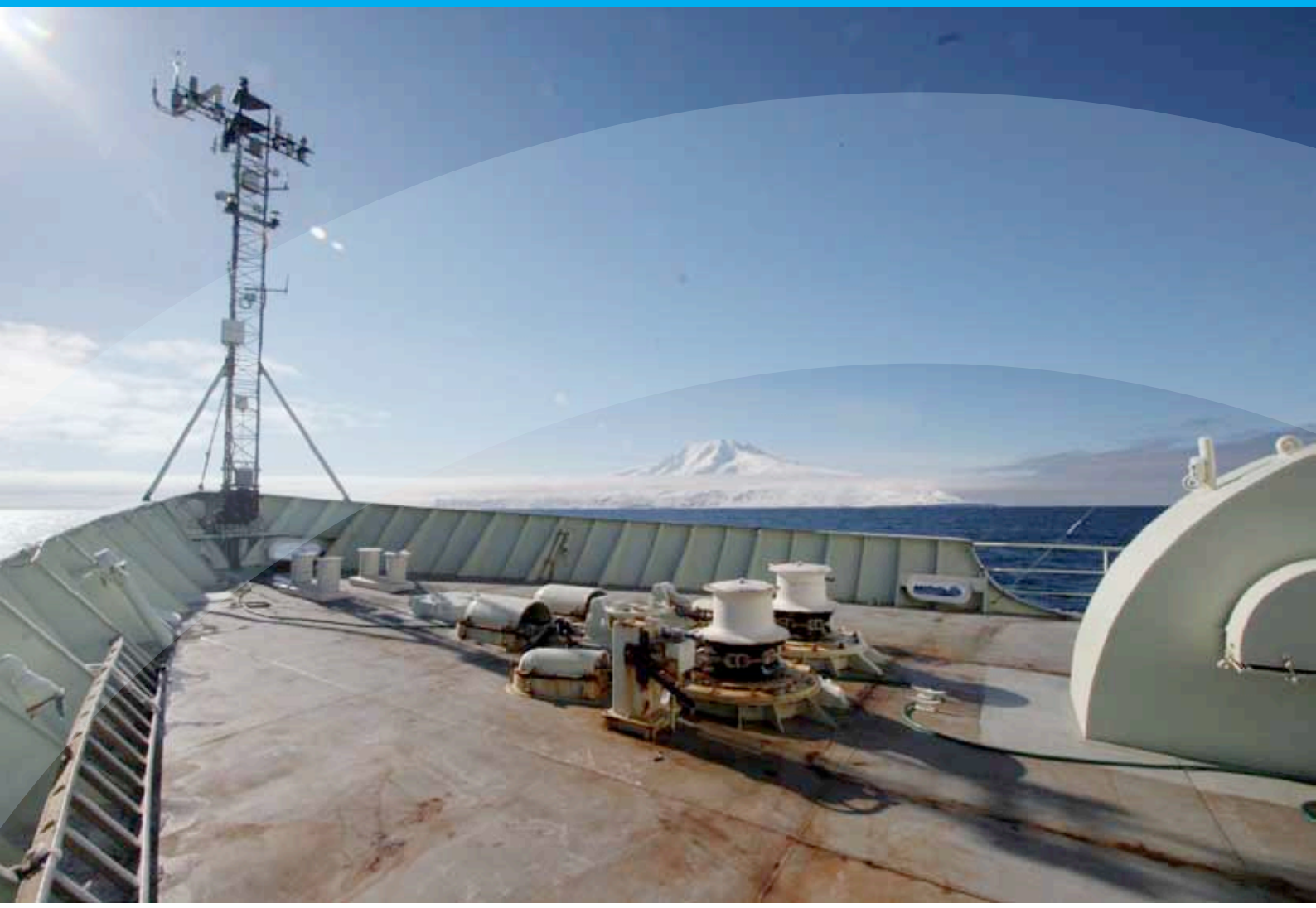
Troica missions have been conducted within POLARCAT-Norway and RAPSIFACT - a study of Russian Air Pollution Sources and their Impact on Atmospheric Composition in the Arctic. The missions included use of the instrumented TROICA railway carriage, data from several Russian air chemistry measurement stations, data from Svalbard and the FLEXPART transport model

Organization: Obukhov Institute of Atmospheric Physics (OIAP), NILU
Country: Russia, Norway
Location: Siberia
Platform: TROICA Train Carriage
Dates: various
Contact: A. Skorokhod, OIAP & A. Engvall, NILU
Internet: http://transport.nilu.no/projects/rapsifact

ASTAR - Arctic Study of Aerosol, Clouds and Radiation

The main focus is on the measurement of aerosol and cloud properties in the polar troposphere using research aircraft. The ASTAR 2007 campaign was timed to capture the end of the Arctic Haze season where pollution events were expected to occur.

Organization: AWI – Alfred Wegner Institute
Country: Germany
Location: Svalbard
Platform: DLR Falcon and AWI Do-228 aircraft
Dates: - March 26 - April 17, 2007
Contact: Andreas Herber, AWI and Andreas Minikin, DLR.
Internet: http://www.pa.op.dlr.de/aerosol/astar2007/



Publication by:
NILU - Norwegian Institute for Air Research
Po.box 1002027 Kjeller
Tel: +47-63898000
Fax: +47-63898050
E-mail: nilu@nilu.no

Editors: Communication Manager, Anne Nyeggen Stephansen & Munch Kommunikasjon
Design: Melkeveien
Printers: Andvord Grafisk as
Published: June, 2010

ISBN: 978-82-425-2232-0

Norsk institutt for luftforskning
Norwegian Institute for Air Research