Cryosphere-Atmosphere Interactions in a Changing Arctic Climate (CRAICC)

Research program

Description of targets and aims

The on-going Arctic climate change and cryosphere are interlinked via the following five components (Fig. 1): A) Radiative forcing, B) Arctic warming, C) Changes in the cryosphere, D) Society and human activities, E) Feedbacks in the climate system. Traditionally, the enhanced warming of Arctic areas, as compared with the Earth as a whole, has been explained by the so-called ice-albedo feedback (IPCC, AR4 2007), which involves the loop A -> B -> C -> A (loop 1).

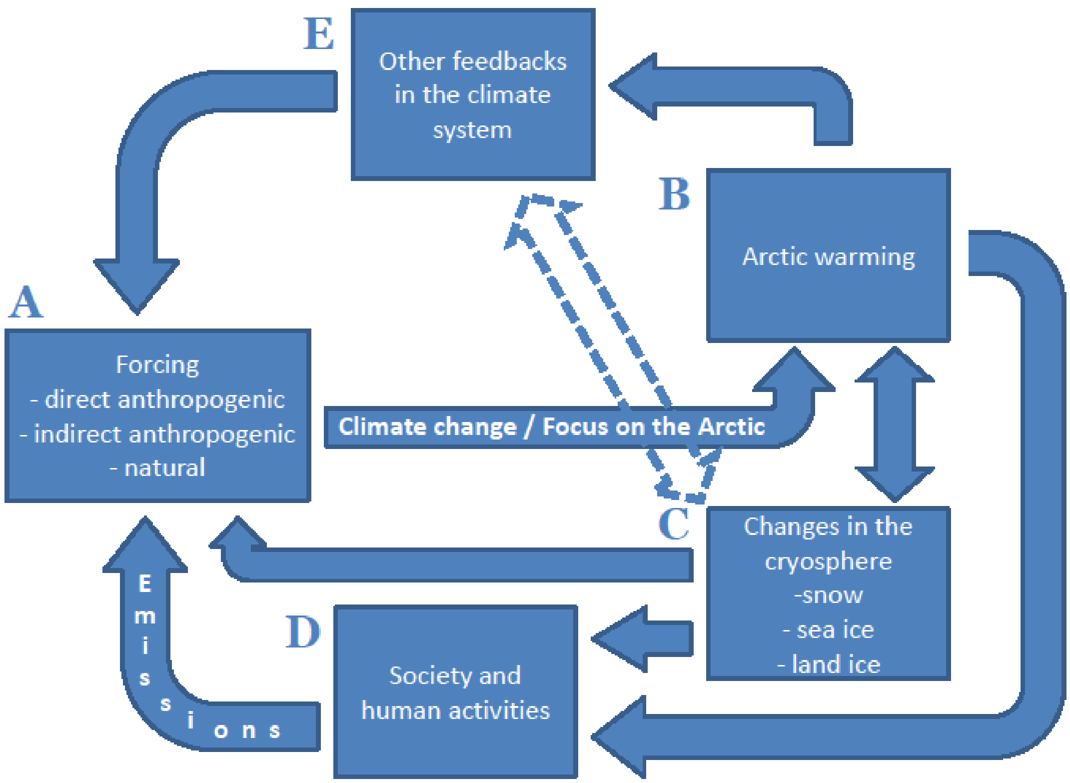

Figure 1. Interlinks between different components in climate change and cryosphere.

Here, we will expand the above thinking to include the roles of society and associated human activities (component D), as well as feedbacks other than the traditional ice-albedo feedback (component E). Related to the component D, two potential feedback loops with different starting points can be identified. First, future reductions in ice and snow cover affect human activities and concomitant emissions in the North through changes in cargo ship traffic, travel and tourism industry, oil exploration and production, fishing and agriculture. This can be described with the loop C -> D -> A -> B -> C (loop 2). Second, the society has a potential to influence Arctic warming via either targeted emission control actions or geoengineering, both corresponding to the loop D -> A -> B -> (C) -> D (loop 3). The Arctic climate system itself involves a number of yet poorly-understood feedback processes initiated by changes in i) the heat balance over surface, ii) moisture budget, or iii) natural emissions of aerosols and their precursors, and formation of secondary aerosols including also ozone which is a potent greenhouse gas (IPCC, 2007, Quinn et al. 2008). Collectively, these feedbacks can be described with the loop A -> B -> (C) -> E -> A (loop 4).

Our main aim is to quantify the feedback loops 1-4, and especially to address how the loops 2-4 compare with the loop 1 in their potential magnitude. We will focus our attention on the role played by short-lived pollutants (recently also called short-lived climate forcers, **SLCF**) and clouds and their linkages with cryospheric changes because i) their role in Arctic warming is potentially very large, yet poorly quantified, ii) their emissions are expected to be changed considerably as a result of future warming and associated changes in human activities, and iii) they might provide an additional mitigation pathway for future Arctic warming

Current status of research and research training

Climate change is proceeding fastest at the high latitudes of the Arctic, with its near-surface warming being about twice the global average during the recent decades. Simultaneously with warming, the Arctic cryosphere has experienced notable changes: the Arctic sea-ice area has been decreasing in all seasons, and precipitation and river discharges into the Arctic Ocean have been increasing. These changes have dramatic impacts on the ecology and societies of the Arctic, underlining the urgent need for a better understanding of the processes leading to climate change.

There is still no consensus on the reasons why climate changes so fast in the Arctic, and whether the amplified Arctic warming will continue in the future. It is clear, however, that the Arctic surface radiation balance regulates the melting and freezing of the pack ice, which in turn is a key climate regulator. Model simulations of Arctic clouds are particularly deficient, impeding correctly simulated radiative fluxes, vital for the snow/ice-albedo feedback. Important, yet poorly-quantified players in this context are short-lived climate forcers (SLCF), including natural and anthropogenic aerosols, ozone and methane.

The climate impacts of SLCFs are tightly connected with cryospheric changes and associated human activities. For example, transport of black carbon aerosols into high latitudes and their deposition on snow are known to decrease the surface albedo which, together with decreased sulfate aerosol emissions, has probably contributed to the observed Arctic warming. Melting of the pack ice and sea ice are likely to result in increased numbers of aerosol particles and CCN from sources in the high Arctic, thereby increasing the reflectivity of clouds. Properties of high-latitude clouds may also be affected by the changing biogenic aerosol formation associated with warming and snow-cover changes over boreal forest regions. Emissions of methane from thawing permafrost and coupling of atmospheric methane oxidation with ozone formation affect Arctic greenhouse gas forcing. Finally, cryospheric changes alter human activites in Arctic and Nordic regions, which in turn changes anthropogenic emissions of SLCFs over these areas.

The research and researcher training in the field of atmosphere-cryosphere-biosphere interactions has not been coordinated. Therefore, there is an urgent need for an interdisciplinary program which would educate researchers to understand the complex interactions and processes governing the cryosphere formation and its influences on climate. Building a Nordic research network for studying associations between Arctic climate change, cryosphere, SLCFs and human activities requires expertise from a large number of research fields. In CRAICC, we will address this issue by combining our previous BACCI (Biosphere-Aerosol-Cloud-Climate Interactions) network with additional top-level Nordic experts on: i) monitoring and modeling of emissions, transport and transformation of SLCFs over Arctic and Nordic areas, ii) remote sensing of ice and snow cover changes, iii) monitoring radiative transport and surface exchange of heat and moistrure, iv) past climate changes based on ice core studies, and v) Earth System modeling.

Despite the recognized need for multidisciplinary research on this topic, undergraduate students are typically educated within their specific disciplines without much multidisciplinary aspects, which however provide a strong scientific basis. At PhD and post-doctoral level, the shift from discipline-tied fundamental education towards multidisciplinarity is imperative for a successful career in climate and global change science. Therefore, the chief educational and knowledge transfer goal is to educate a next generation of scientists in a truly multidisciplinary way of thinking. The direct involvement in industrial research and development are also addressed at this point. It will be done through interdisciplinary intensive field courses and summer and winter schools gathering students from all Nordic and Baltic countries as well as the whole Arctic area to work together in a multidisciplinary scientific context. E-learning courses will be developed and given to students. Teachers and lecturers will be trained on teaching, communication and supervising skills, including web-based teaching, as well as training in general skills: writing of articles and proposals, presentation skills, and commercialization of scientific ideas. This work will be based on all experience from CBACCI (The Nordic Graduate School on Biosphere-Carbon-Aerosol-Cloud-Climate Interactions) and the Master’s Degree Programme ABS (Atmosphere-Biosphere Studies).

Objectives to be achieved

Our general objectives are i) to identify and quantify the major processes controlling Arctic warming and related feedback mechanisms, ii) to outline strategies to mitigate Arctic warming, and iii) to develop Nordic Earth System modeling. More specifically, we aim to clarify:

General scientific understanding of the Arctic climate system:

- What are the main reasons for the amplification of Arctic warming
- Why is warming more pronounced in winter
- What are the relevant feedbacks
- What can we learn from past and recent changes in Arctic climate

Specific questions related to cryosphere:

- How is albedo changing over sea and land surfaces
- How is radiative forcing changing at the surface and top-of-the troposphere, and which forcing agents and feedback factors are responsible for it
- How do cryospheric changes affect natural emissions and surface heat exchange
- How do emissions of halogen compounds and other key species from snow and sea ice respond to changing loads of pollutants
- How do Arctic clouds respond to emissions and changing climate
- How are the magnitude, phase and spatial pattern of precipitation changing
- What is the relative role of anthropogenic and natural aerosols
- How important is BC on snow/ice in the Arctic radiative balance
- How do all the above issues vary seasonally and regionally
- How is the variability in seasonal snow and ice extent determined

Mitigation issues:

- How effective would different emission control strategies be using short-lived pollutants to mitigate Arctic warming and melting sea ice
- What is the best way to control emissions if both climate change and air pollution issues are considered
- Do we need to consider the feedback loop 2 when designing mitigation strategies
- How does increasing human activity in the Arctic affect the Arctic climate
- Does geoengineering provide an option for mitigating Arctic warming

Nordic climate and Earth System modeling(ESM):

- How has the atmospheric composition and the associated radiative forcing changed during the past 10000 years and how will they change during the next 150 years
- How can we obtain reasonable and relevant information on what could occur if the Arctic was 5 K warmer than today
- What is the best way to implement the current process level understanding to improve ESMs and their parameterizations
- Which Earth System model components are the most important to develop further
- Integration of cryosphere component models into ESMs

Scientific content and detailed plan

In order to be able to meet our objectives, and to answer our research questions, we need to perform multi-scale and inter-, multi and cross-disciplinary research with a high level of technological and scientific innovation. Our approach relies on existing Nordic research infrastructures and various measurement and modeling tools.

The scientific work will be divided into 8 Work Packages in different thematic areas

WP1: Coordination, knowledge transfer and dissemination
WP2: Cryospheric changes
WP3: Natural emissions associated with warming and cryospheric changes
WP4: SLCF and cryosphere
WP5: Cryosphere-aerosol-cloud-climate interactions
WP6: Atmosphere-cryosphere-societal interactions
WP7: Past long-term changes in the Arctic
WP8: Synthesis, Integration and Earth System modeling

The detailed contents of WP's are described in the Research Environment –section. The main research tools to be exploited are the following:

In-situ field observations

Field observations will be made on ground-based stations, air craft and ships, in addition to using existing data sets and archives. Data on short-lived pollutant concentrations in air, on snow and ice surfaces, seasonal evolution of terrestrial and oceanic snow and ice cover, surface radiation and heat exchange, fluxes of key species, cloud properties and relevant meteorological data are obtained. The observation network consists of existing intensive stations and their measurement programs (snow, inland waters, permafrost, basic aerosol microphysics, optics, and chemistry), including quality analysis (QA) and data dissemination procedures developed in other projects. These are outfitted with additional instruments addressing the research questions. To ensure long-term sustainability and comparability, these measurements are connected to international networks wherever possible.

Remote sensing by satellites

Satellites will be used to retrieve information on e.g. aerosol and cloud properties, snow cover, ice extent, surface albedo, top of atmosphere radiation and BrO data. Many of the relevant quantities are measurable only from satellites. Satellites complement in-situ and modeling data related to chemistry (e.g. BrO and other trace gases), aerosols, clouds and their interactions, especially for the spatial and temporal distribution pattern of relevant quantities. Derived data are used to evaluate large-scale models simulating important Earth System components.

Laboratory experiments and field campaigns

The long-term monitoring network will be complemented with target-oriented field campaigns and lab experiments. Specific campaigns include annual UAV (unmanned aerial vehicle) campaigns, cruise expeditions on research ships, dedicated mountain top (in-cloud) field campaigns, winter-season evolution of snow and ice in selected drainage basins, snow and ice -related ecological studies and airborne studies.

Lab experiments focus on ice nucleating properties of various natural and anthropogenic aerosols and their mixtures, and snow and ice processes. The understanding of how cold and mixed-phase clouds interact with changing Arctic pollutant concentrations and climatic conditions is essential.

Ice core data

Past variations in climate and SLCF are revealed by analysis of firn and ice cores in glaciers and ice sheets. In a first step it is necessary to distinguish between different sources to be able to make predictions about which sources have dominated emissions during different climates and environmental conditions. The sulphur isotope ratio in snow and ice samples can be used as a tracer for different aerosol sources during different climatic conditions. Many firn and ice cores from Greenland ice sheet, in ice caps in the Canadian Arctic and in glaciers on Svalbard have been analyzed for their content of impurities beside climate information and physical properties. The resolution of the records depends on the snow accumulation rate at the drill site and the sample preparation and analytical technique. Our data from Greenland (GRIP, NGRIP and NEEM) reveal that the northern hemisphere polar atmospheric circulation can totally change mode from one year to the next at very abrupt climate change from cold stadials to warm interstadials/interglacials. Current climate models lack the ability to generate changes this rapidly.

Modeling

Process models are used to identify the importance of different processes on short-to-moderate temporal and spatial scales, to extrapolate measurement results and to predict future scenarios. The models, like observations, cover various spatial and temporal scales and are implemented in a hierarchical structure. The models applied by the consortium range from detailed process models (e.g. UHMA, SALSA, CALM, ADCHEM) up to regional and global chemical transport and climate models (e.g. EMEP, MATCH, DEHM, ECHAM, OsloCTM2, UCLA LES, WRF-CHEM, CAM-Oslo), radiative transfer models (DISORT), and to Earth System models (e.g. COSMOS, NorESM, EC-Earth).

Milestones and deliverables

Milestones:
1: Project starts, project office in action, webpages (M1)
2: Annual meetings (M11, M23, M35, M47)
3: Data base for cryosphere-atmosphere interactions (M16)
4: Final conference (M60)

Deliverables:
1: Annual reports (M13,M25,M37,M49)
2: Final Report (M60)

3: Snow sample analyses results (M40)
4: Identification and quantification of sources of SLCFs in the Arctic (M12)
5: Report on model analysis on past variation in emissions on SLCFs and their influence on the Arctic climate and cryosphere (M18)
6: Quantification of the current direct radiative and indirect forcing of SLCFs in the Arctic (M24)
7: Report on quantified records of variations of SLCFs over short (seasonal) and long (millennial) time-scales (M30)
8: Surface albedo changes induced by the deposition of soot to snow in the Arctic, and by the presence algae and bacteria in snow and their effect on the conversion of species (M36)
9: Report on the Arctic terrestrial albedo change during the Holocene and its feedback influence on the warming (and cooling) (M50)
10: Data and parameterizations on the cloud droplet and ice nucleating properties of different aerosol types from laboratory studies, and aerosol-cloud interactions based on the process-oriented Arctic field campaigns and process-based modeling. M(30)
11: Report on more reliable and spatially more precise reconstruction of the Arctic treeline change during the Holocene (M36)
12: Analysis of cryosphere-atmosphere interactions that need to be included in Earth System Model simulations (M12)
13: Analysis and quantification of cryosphere-atmosphere-climate feedback loops in the ESM results (M50)
14: Final results from ESM simulations on atmosphere-cryosphere-climate interactions.
15: Synthesis and integration report for CRAICC for policymakers on different climate and development scenarios in the Arctic M(56)

Originality of planned research

In an international perspective, what will be the expected scientific significance, originality and innovative elements of the research carried out by the NCoE

Understanding the complex, non-linear system, such as cryosphere-atmosphere interface, requires a diverse range of scientific and technological expertise in the different scientific areas like chemistry, physics, biology, meteorology, geophysics and geography, and involves laboratory studies, ground, ship, and airborne field studies, satellite remote-sensing and numerical modelling studies ranging from the molecular *ab initio* level to the global scale Earth system models. Our research approach covers all those observational, experimental and theoretical aspects.

Based on our experience and several scientific breakthroughs we have a unique opportunity to solve tasks related to cryosphere-atmosphere interactions and answer our research questions. One example is the task of interpreting **ice core data** correctly. In CRAICC, the atmospheric and cryospheric scientists will join forces to understand ice cores which provide the most important constraint for Earth System Models on longer time scales. Taking e.g. black carbon (BC), we need to understand where the BC recorded in a given ice core is coming from (representativity issue), how it is deposited on the ice (wet, dry, re-mobilization), how it is archived in the ice and to what extent it can be mobile in the snow, firn and ice (including issues of firn and ice core dating), and how concentrations in the ice can be converted into atmospheric concentrations.

Understanding the spatial distribution of atmospheric pollutants and trace gases, and quantifying their effects on cryosphere, climate and air quality require both observational and modelling efforts. On the other hand understanding cryosphere-climate relationships requires understanding of the dynamic interactions at the snow and ice surface. Comparisons of large-scale model simulations with existing field measurements enhance the possibility to extrapolate results from in-situ measurements to regional and global scales.

CRAICC partners have very high competence in describing the processes that determine the radiative forcing at the surface including the role of atmospheric aerosols, cloud formation, surface albedo over a time scale ranging from the episodic (a few days) to a few decades. We can include important instrumental records dating back to the early 1970s to state of the art models, e.g. large climate models. Furthermore CRAICC is able to combine above mentioned high competences with another scientifically highly competent community of paleoscientists, and the research groups focusing on long-term changes in lake and river ice cover. Therefore CRAICC is able to establish truly new, unique, multidisciplinary center to produce new science findings in the bordering disciplines, since knowledge on past and present enables us to predict future.

CRAICC is unique also in the high competence in synoptic scale/global scale heat advection in the atmospheric boundary layer and upper ocean, affecting the sea surface temperature and sea ice formation (for timescales ranging from a few days to decadal up to a century backwards and forwards), and in synoptic and climate scale wind and precipitation analysis/reanalysis and projections.

The CRAICC participants form a coherent and high-output NCoE which will amplify the importance of Nordic research in international Arctic research context. Especially the large and sophisticated measurement network and the long-lasting experience of participants in performing research at Arctic field stations will enable a novel assessment of the climate change phenomena in whole Arctic region. The NCoE CRAICC will improve our understanding of processes involved in cryosphere-atmosphere feedbacks and make better use of resources both regards in use of existing data sources and available model structures.

CRAICC will supplement and strengthen the scientific understanding in the monitoring activities within the Arctic Monitoring and Assessment Program (AMAP) by providing new insight into processes that are responsible for the surprisingly fast temperature increase in the Arctic and of the melting of glaciers, ice sheets and sea ice. In particular it will provide information of the processes that control concentrations of soot, other inorganic and organic particles and ozone in the atmosphere and how these species interact with climate and cryosphere.

The CRAICC consortium has close connections to several Nordic groups working e.g. on biogeochemical cycles, methane and glaciers. The consortium emphasizes future collaboration with these units, in order to address the research questions related to cryosphere changes as a whole. CRAICC will organize joint workshops and aim at joint use of resources wherever possible. A common Scientific Advisory Board would aid in putting together and evaluating the results gained in all funded NCoEs.

Strategic relevance of the NCoE in relation to societal and industrial interests

The climate in the Arctic is of tremendous importance to its human population, and the possibilities to explore natural resources as e.g. fishing, forestry and mining. Ice and snow conditions in both Arctic and boreal areas set the limits for shipping, transport, agriculture, industry and urban and rural life in general. It is a large societal task to adapt to climate change and to take the responsibility of reducing consequences of climate change while sustaining / improving quality of life. Nordic countries have set ambitious goals both in terms of climate change mitigation and adaptation. Therefore climate change is becoming a critical parameter in decision making processes on all levels (e.g. in policy, planning and management processes).

Due to its strong international position in science (well exceeding the critical mass), the CRAICC NCoE will strongly boost the Earth System research cooperation in the Nordic region and in northern areas in general. CRAICC aims to establish a vital contribution of science to help societies to better assess the effects of mitigation decisions and the effectiveness of the adaptation strategies. This will be done by generating new knowledge on cryosphere-atmosphere interactions and by reducing the climate model uncertainty related to short-lived climate forcers (SLCF) in cryosphere-atmosphere processes and feedbacks. This new knowledge will have great relevance for societies e.g. in complex decisions on air pollution because air pollution control may accelerate or mitigate climate warming. This has particularly important consequences in high-latitude regions.

The Arctic climate has shown large variations in the past implying that natural variations are large, but it also might be more sensitive to perturbations of e.g. climate forcing atmospheric components, ice/snow surface albedo. It also means that there are strong positive feedback processes like sea ice cover and atmospheric transport of heat and atmospheric climate response to SLCFs that will accelerate climatic changes.

Present climate models have only very limited and insufficient descriptions, if at all, of SLCF including clouds and their effect on the radiation balance. The total global effect of SLCF on the present climate is in last IPCC report considered to be considerable, however the uncertainties are still large. These uncertainties progress into the projections of the future climate, where they actually dominate the uncertainty of projected future global climate for different emission scenarios.

As SLCF or sea/ice/land albedo descriptions are strongly varying,both temporally and spatially, they may currently have a stronger regional effect than shown by available regional climate models. Recently observations show a faster warming in the Arctic than suggested by the IPCC projections, indicating that important elements are missing in the present models, even though the observation period is too short to draw any firm conclusions. However, it is most likely that SLCF have a considerable regional climatic influence, and that abatement of regional emissions of these components thus will affect the regional climate.

A better understanding of the influence of SLCF on the past and present Arctic climate will open possibilities for a proactive regional mitigation policy on SLCF, in order to balance or smooth the major climate change induced by the long lived climate gases such as CO_2.

There is growing recognition that well planned investments and new technological innovations in climate mitigation and adaptation may also be manifested as new economic opportunities, particularly if compared to potential costs of doing nothing. CRAICC activities will generate opportunities to companies and stakeholders, interested in short term mitigation techniques and in developing new environment monitoring techniques and tools. Over the last years, several spin-off companies have been established related to former BACCI NCoE activities, and it is foreseen that CRAICC activities will have similar effects.

One aspect in directing the research, as well as making the results available for the policymaking in national and international level, is a close interaction with relevant governmental and international bodies during the project. CRAICC has several members with long experience of making scientific knowledge available in the policy making process through close interaction with the national governmental bodies as EPA of respective Nordic country and participation in international bodies as the Convention of Long Range Transboundary Air Pollution (CLTRAP), its support organization EMEP and similar EU working groups as CAFÉ and EAA. If possible with the aid of a common advisory board, CRAICC will contribute to a joint general report for policymakers from all founded NCoEs, in regards to the interaction between climate and cryosphere and its implications for future climate and development in the Arctic.

What main activities and results can be achieved by the NCoE program funding, which cannot be achieved with funding from other sources?

The unique feature in CRAICC is the extensive research network, covering multidisciplinary studies on cryosphere-climate interactions in Arctic and subarctic ecosystems and environments. The network will be structured and operated so that the experimental and observational datasets and modeling results will support the general project aims. The existence of wide Nordic network would not be feasible without a NCoE.

The CRAICC consortium brings the ice core community together with aerosol scientists and atmospheric chemists for the first time. Actually, interpreting **ice cores** correctly is probably the area where atmosphere and cryosphere scientists have the greatest potential of working together, since both fields are needed if we are to understand the ice cores which provide the most important constraint for Earth System Models on longer time scales. CRAICC activities will be the nucleus for further development.

CRAICC provides a forum for discussion, new ideas and knowledge exchange across scientific disciplines on every level from students to professors. E.g. students immediately become members in a stimulating, high profile international scientific community and network.

Research environment

How will the individual research partners contribute to the NCoE as a whole? Denote each partner by team leader

WP1 Coordination, knowledge transfer and dissemination/Bäck, Lauri

The CRAICC has 2 organizational bodies: **Scientific Steering Committee (SSC),** responsible for scientific management and **Coordinating Office (CO),** in charge of daily administration management.

WP2 Cryosphere changes/de Leeuw, Ström, Leppäranta

Objectives:

- short and long term variability of the surface albedo, in particular deposition of aerosols and snow and ice cover changes
- the long and short term variability of reflected radiation and near-surface heat transport in relation to changes in surface albedo and snow/ice cover, aerosol concentrations, and cloud cover and properties
- changes in precipitation and its effects on the radiation balance in the cryosphere and on lakes and rivers
- the evolution of snow and ice climatological zones
- the influence of changing ice conditions on boreal and arctic lakes and wintertime utilization of lakes
- the impact of changing climate to the coastal zone and river basins, and implications to power plants, flooding and water quality in Baltic region

To achieve these objectives, we use satellite and ground based remote sensing techniques. Surface albedo, areal extent of snow, radiation at the top of the atmosphere, and trace gas (e.g., BrO) column concentrations will be determined using Optical/IR instruments. Microwave radar and radiometers are used to measure snow water equivalent, sea ice, the presence of open leads and precipitation characteristics. Ground based remote sensing measurements include tower based surface albedo, microwave emission and backscattering observations at FMI-ARC, radiation measurements from the existing networks. Snow and ice investigations are based on test areas across Nordic region. Lab experiments will be performed for small-scale process studies. Existing cryosphere models and new models to be developed will be worked on for a common interface toward other components in ESMs (WP8).

WP3 Natural emissions, their fate in the atmosphere and their relation to warming and cryospheric changes/Nilsson, Skov, Nikinmaa

Objectives:

1. Quantify natural sources of primary aerosols and precursor gases for secondary aerosol, e.g. sea salt, organic sea spray, dust, DMS, VOC, halogens, and sea/soil/snow bacteria. Emphasis is given to interactions with climate and cryosphere

changes, directly or through associated changes in physical/chemical/biological properties/processes or in the biosphere
2. Describe reaction pathways and effects on aerosol and ozone formation of the emitted gases
3. Characterize the aerosols formed from cryosphere related sources: Chemical/physical properties, biological fraction, internally/externally mixed, potential to act as CCN or IN

Experimental results are used in climate models as improved process parameterizations for present Arctic conditions. WP3 will develop new (or validate existing) source parameterizations to be used in atmospheric transport and climate models. Focus is on Arctic conditions and processes that can't be extrapolated from lower latitudes, and changes in emissions due to climate and cryosphere changes.

We use direct micrometeorological flux methods as well as flux chambers, in situ sea spray tank experiments, laboratory experiments and chemical analysis of snow samples. These are designed to cover present Arctic conditions and proxy conditions for changed climate and cryosphere and associate changes in biosphere composition. Field experiments are carried out at Arctic stations, on board ships and aircrafts. The source parameterizations are evaluated in process models, and tested in climate models. WP3 will depend on WP2 for information on cryosphere changes and deliver experimental data and parameterizations to WP5, 7 and 8. Field work is coordinated with WP4 and 5.

WP4 SLCF and cryosphere/Stohl, Massling, Krejci

Objectives:

- To characterize the spatial and temporal variability of Arctic short-lived pollutants (BC, OC, inorganic aerosol species, and ozone) and to investigate their trends
- To quantify the importance of source regions and source types for the Arctic concentrations of anthropogenic aerosols and to determine their transport pathways
- To calculate the direct radiative forcing of these SLCFs in the Arctic
- To estimate the albedo effect of BC on snow and ice
- To identify the role of bacteria and algae, carried by and deposited with aerosols, in snow

WP4 will measure aerosol chemical composition, physical parameters and optical properties as well as ozone and other gase concentrations at the Arctic and sub-Arctic stations. Long-term measurements of CO, levoglucosan and other molecular tracers, combined with C-14 analysis clarify the origin of species (including BC) and the sources (agricultural fires, natural biomass burning, fossil fuel combustion, etc.) contributing to Arctic air pollution (comparison with WP7). To determine the aerosol vertical distribution and the associated radiative forcing, we measure ground-based and airborne measurements of aerosol optical depth.

The data are used to validate chemical transport models and ESMs described in WP8, and also analyzed in combination with transport models and source-receptor models to determine the sources of SLCFs measured near the ground and aloft.

Radiative transfer models are used to determine the impact of aerosols and ozone on the radiative forcing both at the surface and at the top of the atmosphere. With long-term measurements, changes in radiative forcing are determined.

We measure the concentrations of BC in snow and the spectral albedo and grain size of snow in Scandinavia, Svalbard and Greenland, using a combination of ground-based measurements and remote sensing techniques with unmanned aerial vehicles. This allows studying the albedo impact of BC both directly and via enhanced ageing of the snow pack, and evaluating how well the ESMs can describe the snow albedo effect of BC.

The number of microorganisms in filter-collected airborne particles and aerosols are determined. The filters are examined by electron microscopy to determine the number of microbial cells. Collected material is subjected to metagenomic analysis for the determination of the composition of the microbial community. and compared with snowpack to determine the contribution of airborne microbes to the colonization of snow cover. The data provides the foundation for studies on the microbial transformations of chemical substances and their effect on albedo.

WP5 Cryosphere-aerosol-cloud-climate interactions/Bilde, Svenningsson, Swietlicki

The aim is to gain detailed understanding of the relation between the cryosphere, aerosols and clouds, as well as their climate feedbacks in the Arctic, with a combination of field and lab studies and modeling. The objectives are to analyze:

- the contributions of natural and anthropogenic aerosol types in the North (primary, secondary, BC and their combinations) to different cloud types
- how cloud properties (radiative influence, microstructure and precipitation) depend on aerosol characteristics
- how these properties change moving into and out of the Arctic, and how they have changed and will change over the coming decades

This is done by a combination of 1) field studies including existing long-term data sets as well as new Arctic field data. Key components are Cloud Condensation Nuclei counters, the Droplet Aerosol Analyzer, and radiation measurements, together with aerosol data from WP 3 and 4. In addition Ice Nuclei counters are developed and deployed as part of this project; 2) satellite retrievals of cloud properties and extent; 3) laboratory studies on ice nucleating properties of aerosols and cloud droplet formation ability of e.g. organics from the Arctic sea surface water; 4) detailed modeling of the quantum chemistry and microphysics of ice nucleation; 5) process-based modeling evaluated against field observations generate parameterizations to be supplied to ESMs in WP8.

WP6 Atmosphere-cryosphere-societal interactions/Hov, H-C Hansson, Iversen

We use NorESM to address the topic of geo-engineering (i.e. feedback loop 3) by analysing a historic “geo-engineering experiment” that inadvertently has taken place, and how it may have affected Arctic climate, including its sea ice prevalence. This historic “geo-engineering experiment” is the change in European SO_2 emissions from ca. 20MtS in 1900 to a maximum of ca. 80MtS in 1980 with most of the rise after 1950 and down to a level of ca. 25MtS today.

We propose a priority list of 4 experiments, that assume that basic NorESM simulations exist for the pre-industrial, multi-century control climate, and for the time-evolving climate from 1850 through 2010.

The first experiments employ on-line aerosols with prescribed sea-surface temperatures (SST). Only the atmosphere and upper land-surface thus give rise to feedback. A pair of runs can be made with **(1a)** time-varying and **(1b)** constant emissions of aerosols and precursors (as of 1980).

The next experiments are for further quantifying climate response to the emissions in (1a) and (1b), including the feedbacks between the relevant atmospheric composition and climate. The experiments are time-dependent climate response runs with deep-ocean calculations and on-line aerosols, and with: **(2a)** time-varying and **(2b)** constant emissions of aerosols and precursors (as of 1980). The relevance for the climate change – atmospheric composition coupling problem of a full climate response calculation with an interactive deep-ocean arises from the hypotheses that the slow climate fluctuations governed by the deep ocean variability control the systematic changes in the synoptic weather pattern over important aerosol source regions. Eventually, these factors can cause significant spatial and temporal variability in the abundance of air pollutants even if pollutant emissions stay constant.

In a third experiment, the time-dependent climate response to 2-3 scenarios for future emissions with the fully coupled model is calculated.

The last experiment is related to feedbacks caused by society responses to new opportunities when Arctic climate change (feedback loop 2). Using scenarios for emissions from increased ship-traffic and off-shore oil- and gas-exploitation when Arctic sea-ice is drastically reduced, a pair of experiments **(4a)** without and **(4b)** with the possible new Arctic emissions for the next few decades can be made. Important question is the relative importance of the intrinsic Arctic emissions for Arctic climate change, and if the emissions serve to enhance or damp the climate change signal.

WP7 Past long term changes in the Arctic/M. Hansson, Isaksson, Seppä, Korhola

The objective is to incorporate the view of the long-term Arctic change, especially linking the Greenland and Svalbard ice-core records and lake sediments. We’ll combine physical (predictor) and biological (response) proxy methods for reconstructing and exploring Arctic changes in the past and future. More specifically, we aim:

-to quantify past variations in short-lived agents, e.g. insoluble (BC, soot) and soluble (sulfates, nitrates and chlorides) particles on several timescales (from seasonal to millennial) in the Holocene and relate these to present day concentrations and modern climate
-to use the available millennial-scale climate data, especially the temperature record, from the Greenland ice cores, as the long-term predictor of Arctic environmental change,

and explore the key long-term environmental and ecosystem dynamics, such as the Arctic tree-line response, in relation to changing climate and cryosphere
-to explore the feedback processes associated with the large-scale environmental changes in the circumpolar Arctic region. This is done by using the recent Greenland ice-core –based temperature reconstruction as the independent climatic predictor, and by combining existing palaeoecological records from the circumpolar region, to create Holocene time-series maps depicting the location of the Arctic treeline as a function of time, calculating the areal change of the Arctic and Boreal regions, and as an ultimate aim, modeling to simulate the resulting change of albedo and biogenic aerosol precursors. This approach can predict the corresponding ecosystem/albedo change in the future under predicted warm conditions.

WP8: Synthesis, Integration and Earth System modelling/Kristjansson, Laaksonen, Kerminen

WP8 will address cross-cutting issues between the different components of the Earth system. These issues include interactions between the atmosphere and the cryosphere, including various feedback mechanisms. WP8 receives and exploits input from all other WPs. For instance, in collaboration with WP3, WP4 and WP5 new findings from detailed observational, laboratory or high-resolution modeling studies are used to develop new parameterizations. The objectives are to:

- Analyze cryosphere-atmosphere interactions to be included in ESM simulations
- Develop parameterizations of relevant processes for the ESM simulations
- Carry out multi-decadal ESM simulations, investigating the influence of changes in the atmospheric composition on the cryosphere
- Analyze and evaluate cryosphere-atmosphere feedback loops

ESM simulations are the only tool which can provide quantitative information on the global implications of the interactions in question. In ESMs, the sea ice extent and thickness, as well as snow cover and snow depth are interactive, responding to changes in energy fluxes and temperature due to e.g., aerosol-cryosphere interactions, but only very few models consider changes in the extent and thickness of ice caps.

In the development of the relevant parameterizations, high-resolution models are needed, enabling a direct validation against data for specific times and regions. After implementation in the ESMs, the parameterizations will be validated also by focusing on monthly and annual means. Relevant high-resolution models in this context are non-hydrostatic weather prediction models (e.g., WRF) or large-eddy simulation (LES) models.

The research groups participating in CRAICC:

Kulmala

Dept of Physics and Dept of Forest Sciences

We are responsible for **WP1** (Coordination, co-chairs Bäck and Lauri), and participate actively in most WPs. The specific tasks include: **WP2** (co-chair Leppäranta): Connecting the quality and length of ice season in lakes and rivers to climatological conditions, studying the role of snow cover in freezing water bodies and the linkages between ecosystems and ice conditions in lakes and rivers. **WP3** (co-chair Nikinmaa): Identifying the key processes related to new particle formation in the atmosphere in Arctic and subarctic areas, and analyzing the changes in emissions and properties of biogenic aerosol precursors from oceans and forests in the changing Arctic climate. Determination and analyzing the role of algae photosynthesis as driving force of CO2 and VOC flux between ocean and atmosphere. **WP4:** Evaluating the role of biogenic and anthropogenic freshly-formed aerosol particles changed from pre-industrial time to the present, and changes in future. **WP5:** Measuring and modeling freshly-formed particles and their ablility to grow to cloud condensation nuclei size and form cloud droplets in the Arctic. Analyzing how the changing sources and sinks affect these cloud droplet populations, and how does atmospheric new particle formation affect the aerosol load and radiative forcing. **WP6:** Evaluating the impact of changing ice seasons to human living conditions in the Arctic. Analyzing the 'historic geoengineering' experiments with changing sulfate deposition. **WP8**: Synthesis and evaluation of feedbacks and their impacts on ESM modeling.

Dept of Geosciences and Geography and Dept of Environmental Sciences (ECRU)

WP7 is co-chaired by Seppä and Korhola.

The specific aims of H. Seppä's group in WP7 are

- to map and analyse the structure of the tree-line and to parameterize the key plant taxa in order to model the future and past tree-line dynamics
- to use the recent Greenland ice-core temperature reconstruction data as the climatic predictor to understand the relationship between past changes of temperature and arctic treeline

The specific tasks of ECRU

- the lake sediment biological communities to provide annual-to-millennial time series of changes in lake ice-cover duration for Arctic Europe to address how the lake ice will change in the future (**WP7**)
- the deposition history of BC for the last 200 years in the Arctic and to assess its role in changes in ice and snow (**WP3)**

de Leeuw

FMI co-chairs WP2 (de Leeuw) and WP8 (Kerminen), and participates in WP3, WP4, WP5 and WP6. The main tasks are 1) remote sensing of snow cover and albedo changes over Arctic and sub-Arctic areas (WP2), 2) measurement of natural aerosol precursor emissions and anthropogenic organic constituents (WP3, WP4), 3) continuous aerosol measurements and air pollution monitoring (WP4), 4) field measurements of aerosol-cloud interactions (WP5), and 5) climate and Earth System modeling, especially development of aerosol modules and parameterizations (WP6, WP8).

<u>Laaksonen</u>

WP3:
- boreal forests
- Direct radiative effects by natural aerosols

WP4:
- mainly sulfate and organic carbon
- main source areas and source types in the Arctic and outside
- direct radiative forcing of short-lived anthropogenic pollutants in air

WP5:
- cloud properties (cloud cover, cloud microphysics)
- ice nuclei and clouds
- Indirect radiative effects by natural and anthropogenic aerosols

WP8 (co-chair Laaksonen):
- evaluation of cryosphere-atmosphere feedback loops
- analysis of cryosphere-atmosphere interactions to be included in ESM
- parameterization of most relevant processes

<u>Skov</u>

AU will contribute with sampling and advanced chemical analysis of organic aerosols to provide information on aerosol composition, sources and atmospheric processing. A set of molecular organic tracers of primary and secondary organic aerosols are investigated to study the couplings between the cryosphere, atmosphere and biosphere. Relevant molecular tracers include tracers of bacteria, marine and terrestrial sources. We also contribute with advanced chemical analysis of organic aerosols in WP3-5 as well as advanced model description of the transport of e.g. BC to the Arctic (WP4-7). We will co-chair WP3 (Henrik Skov) and WP4 (Andreas Massling).

<u>Bilde</u>

Role in the project:
WP5: lab experiments on cloud droplet formation, development of instrument for studying ice nucleation, WP co-chair Bilde.
WP3: lab studies of primary marine particle production and the properties and aging of the particles as a function of e.g. salinity and organic content

<u>Gryning</u>

Role in the project: micrometeorological measurements (WP2); (WP4); (WP5).

Measurements of profiles of aerosols and cloud cover by use of a ceilometer. This instrument has successfully been used on a marine expedition, the so-called Galathea III project, in 2007/2008, and is planned to be installed on Station Nord (Greenland). The instrument is based on a lidar that shots vertically up to several km with a resolution of 20 meters. The measurements can provide the cloud cover, cloud height and profiles of aerosols from which the height of the boundary layer can be determined.

Isaksson

The NPI will be concentrating on Arctic radiation energy fluxes and the interaction between cryosphere, atmosphere and clouds. Contributions to WP2, WP4, WP5 and WP7 (co-chair Elisabeth Isaksson):

- Continuous radiation measurements: Longterm broadband observations with data set from 1974. From Jan 2010 continuous spectral observations of snow albedo. Two ramses instruments are placed with the other radiation measurements in Ny-Ålesund
- BC effects on albedo: Snow samples close to the albedo measurements sites are analyzed for the content of OC and EC
- Meltpond effects on albedo: Expeditions on the cruises by Lance. Measurements of relevant fluxes (radiation and heat) in the air above the pond, in the pond water, in the ice underneath and in the immediate water masses below the pond, water salinity is also monitored
- The impact of pollutants on the long-wave emissivity of Arctic clouds: Microphysical properties of clouds at the Zeppelin station, aerosol microphysics and chemistry, CCN, and the radiation measurements performed at the Sverdrup station. The Zeppelin station is frequently embedded in cloud and this provides the possibility to study aerosol-cloud-radiation effects on a seasonal basis
- BC in a Svalbard ice core record: The development of BC in the Arctic with an ice core from Svalbard. A 149 m deep ice core was drilled at Lomonosovfonna (1202 m asl, 78°49'24.4" N; 17°25'59.2"E) in March of 2009 in collaboration with Margit Schwikowski, Paul Scherrer Institut. The ice core is being analyzed for BC concentration and a variety of other components related to climate variability and pollution

Stohl

A. Stohl will act as co-chair in WP4. We contribute to WP4 with particle dispersion model calculations, data from the Zeppelin and Troll stations, data analysis and interpretation. We shall focus on characterizing the optical and chemical properties as well as the sources of Arctic aerosols. NILU researchers collaborate with others to quantify the BC deposition on snow and ice and its impact on the snow/ice albedo. In addition to WP4, we contribute also to WP2, WP6, WP7 and WP8.

Kristjánsson

J.E. Kristjánsson will act as co-chair in **WP8**. In addition, UiO will contribute to the development of parameterization schemes for aerosol-cloud-cryosphere-climate interactions (WP4, WP5). We use and provide fine-scale models such as WRF-CHEM and UCLA LES, in addition to advanced satellite data retrievals, e.g., MODIS, CALIPSO, CloudSat and CERES. In WP6 and WP8, we test and validate the parameterization schemes, and participate in the studies on cryosphere-atmosphere feedback loops. We use the NorESM to simulate the direct and indirect effects of aerosols, as well as interactions between climate and the cryosphere.

Alfredsen

NTNU is analysing the climate impacts on river ice, effects of shorter duration of river ice on the albedo and on the climate system (WP2), and impacts of changes in river ice conditions on physical, ecological and socio-economic systems (WP6). The objective is to extend current modeling efforts on ice regimes to a larger scale and to describe trends in future ice conditions and what impacts this will have on the physical system and on ecology/socio-economic systems that today depends on ice conditions.

Iversen

The topics of NMET fit in most WPs.

Basic methodology to be contributed: Earth System Model NorESM

NorESM is a global coupled climate and earth system model developed mainly at the Norwegian Meteorlogical Institute, the Bjerknes Centre for Climate Research in Bergen, Inst. of Geosciences at the Univ. of Oslo and the Nansen Centre (NERSC) in Bergen. The atmospheric model includes a module for aerosol life-cycling, aerosol optics, and aerosol - cloud droplet interactions. The module includes dust, sea-salt, primary organic carbon and black carbon, and sulfate. NorESM is capable to estimate both the direct climate effects as well as the indirect effects. CCSM4 from NCAR provides the basis for the atmospheric part of NorESM. CCSM4 is expected to include a glacier/ice-sheet model in the 2010-2015 time frame .

Potential NorESM contributions to CRAICC: WP6

The extent and thickness of the sea-ice cover in the Arctic are climate indicators that are sensitive to almost any process in the climate system. The climate models used in IPCC AR4 depict huge uncertainties when modeling present-day Arctic sea-ice extent, and none of these models have been able to indicate the apparent rapid decrease of Arctic sea-ice extent during the last decade. NorESM is at present under preparation for producing production runs for the next phase of IPCC (AR5). The scenario data will be analyzed with emphasis on the Arctic, and prepared for further use in the project. New emissions in the Arctic region due to new economic activities are particularly potent, and NorESM is ready to be applied for such studies. In particular we will focus on absorbing aerosols in the air and deposited on snow and sea-ice. Time-slice experiments with higher spatial resolution are part of the interpretation associated with the modeling of meridional transport (constituents, heat, and water vapor) in the atmosphere and the ocean.

EMEP model calculations: Source-receptor calculations are carried out for Arctic regions of all relevant gases and aerosols that are direct or indirect forcers of sea and land ice.

Myhre

CICERO will contribute in **WP4** with CTM and radiative forcing calculations. With global atmospheric transport models and radiative transfer calculation the radiative forcing of short-lived compounds in the Arctic will be simulated. The transport model simulate includes a module for deposition of BC in the snow and ice. The radiative forcing will be calculated both for atmospheric compounds as well as the BC impact on snow and ice albedo.

Swietlicki

LU will co-chair **WP5** (Swietlicki, Svenningsson) and contribute to it by conducting dedicated process-oriented Arctic field studies. Also data from previous ice-breaker expeditions will be used. We'll use satellite retrievals to determine cloud microphysical properties related to aerosol properties, and process-based modeling evaluated against field observations to generate parameterizations to be supplied to **WP8** and ESMs. LU will conduct lab studies on hygroscopic and cloud-nucleating properties of various natural model aerosols of Arctic relevance as a part of **WP5**. LU will contribute to **WP3** and **4** field work by quantifying the secondary mass derived from biogenic gaseous and anthropogenic precursors relevant to the Arctic. We perform lab studies on changes in the potential for aerosol mass formation from biogenic precursors as function of changing climate and CO_2 concentration. LU will also contribute to **WP4** by using the network stations to quantify ship traffic influence on BC, CCN/IN and new particle formation.

Hansson

Role in the project: M. Hansson (team leader) is co-chair in WP7 and member of SSC, D. Nilsson is co-chair in WP3, R. Krejci in WP4 and HC Hansson in WP6.

SU participates actively in most Work Packages. The specific tasks include:
WP3: Sea spray source measurements in the field and laboratory, and parameterization of these sources. Process modeling and evaluation of parameterizations in process to large scale (climate) models. Coordinated field campaign between WP3+5; Long term full annual cycle study of the aerosol-cloud interactions at Zeppelin, Ny Ålesund, and long term study on Arctic aerosol fluxes at coastal site outside Ny Ålesund.
WP4: Evaluating the role of biogenic and anthropogenic freshly-formed aerosol particles changed from pre-industrial time to the present, and how will it change in future.
WP5: Laboratory experiments including ageing of sea spray, and sea spray aerosol characteristics, aerosol/cloud satellite retrieval, aerosol process modeling, atmospheric

aerosol measurements on ship, airplane and long term station at Ny Ålesund. Coordinated field campaign between WP3+5, see above.
WP6: Evaluating the impact of changing ice seasons to human living conditions in the Arctic. Analyzing the 'historic geoengineering' experiments with changing sulfate deposition.
WP7: High-resolution ice core measurement on NEEM deep ice core, Greenland, focusing on present interglacial period Holocene. Combining existing Arctic ice core records of climate and short-lived agents to reveal past environmental changes in source areas, transport and deposition processes.
WP8: Past, present, future climate model simulations with emphasis on the response in marine aerosol sources on withdrawing Arctic sea ice, initially using the CAM-Oslo model, eventually the EC-Earth model.

Weyhenmeyer

The group at UU has access to all inland ice data, soil nutrient data and biogeochemical monitoring data of thousands of lakes and rivers in Sweden. With this unique data material we aim to answer the question on how cryospheric changes will affect physical and biogeochemical processes in lakes and rivers and how these changes will affect feedback mechanisms (**WP2**).

Pettersson

An Electrodynamic Balance (EDB) system is used to study heterogeneous freezing of supercooled droplets (WP5). Experiments where the properties of aerosol particles are varied to evaluate the importance of e.g. particle composition, adsorption of water and other components on the surface of aerosol particles, particle size and particle morphology. These observations are used in development of parameterizations for the conversion of supercooled water to ice (cloud, climate, and weather prediction models, **WP8**).

We also contribute with unique aerosol mass spectrometer techniques for in situ characterization of aerosol produced by agricultural fires, natural and anthropogenic biomass burning (**WP4**) and marine aerosol (**WP3**).

Jónsdóttir

UI contributions to CRAICC are within the scope of WP2, 3 and 7:

WP2 Remote sensing and measurements of aerosol, dust and smoke, studying source areas, and possibly accompanying change in albedo of glaciers and snow.

WP3: Identifying source areas of particulate matter in Iceland, Effect of climate change for the potential source areas, Coupling of aerosol data with climate forcing for models of glacier responses, Modeling of PM source strength based on field observations

WP7 Historical variation of sea ice in the Greenland Sea (AD 1850 onwards) and connection with climate, Remote sensing and monitoring of sea ice in the Greenland Sea. Ice drift and consequences, Study of how historical data and remote sensing data can compliment each othe, how sea ice has affected nature and society in past and present.

Description of the existing intensive station network

The core permanent research infrastructures are the well established field stations (Figure 2), covering ecosystems from arctic to boreal locations, where continuous measurements and intensive campaigns are performed. The stations are equipped with up-to-date instruments and run according to internationally established measurement protocols. The stations have been developing a comprehensive education program, which is efficiently utilized in organizing summer and winter schools. The large number of stations makes also comparisons between different environments possible.

The field stations involved are:

1. Troll station, Antarctica
2. Vavihill, S-Sweden
3. Birkenes, S-Norway
4. Lille Valby, Denmark
5. Vindeby, Denmark
6. Sorø, Denmark
7. Aspvreten, central Sweden
8. SMEAR III, S-Finland
9. SMEAR II, central Finland
10. SMEAR IV, Kuopio, central Finland
11. Sodankylä, N-Finland
12. SMEAR I, Värriö, N-Finland
13. Abisko, N-Sweden
14. Pallas GAW station, N-Finland
15. Tiksi, Siberia
16. Daneborg and Zackenberg, Greenland
17. Ny-Ålesund, Spitzbergen
18. Station Nord, Greenland

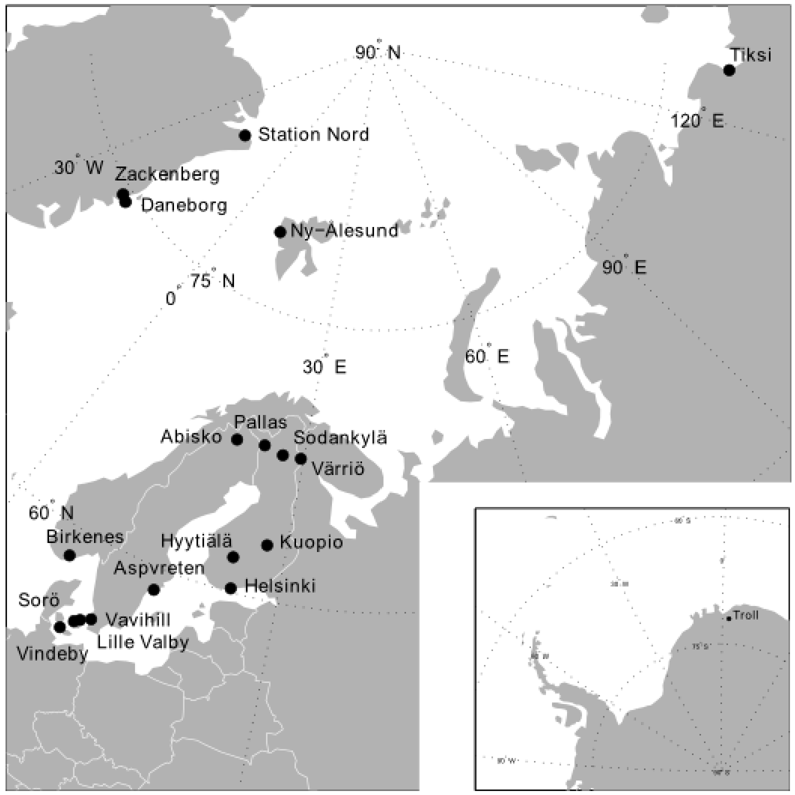

Figure 2. The station network .

<u>Outline the present and future plans for cooperation and organisation of activities (incl. staff/ researcher mobility, if any) between the research teams of the proposed NCoE</u>

In order to be able to answer questions related to the challenging tasks outlined above, interdisciplinary approaches are needed. Our objectives will be achieved by jointly working multidisciplinary teams. The knowledge on different areas under the common framework creates the added value and synergy benefits of co-operating groups.

The partners in the CRAICC have vigorously promoted researcher exchange and staff mobility over the last decades e.g. in the former NCoE BACCI. The partners have created a network where visiting scientists from student level up to professor level can spend research periods between weeks to months in a partner institution. As an example, in year 2007 the BACCI partners organized 11 international workshops, made 23 visits to foreign institutions, and hosted 70 visitors from other institutions. In addition to the specific research topics included in the WPs, knowledge transfer in CRAICC includes joint analysis of results, transfer of good practices, and benchmarking. Joint field measurements and campaigns targeted to specific questions will be performed within the consortium.

CRAICC will establish a Nordic staff exchange scheme available for all levels (professors, senior researchers, postdoctoral researchers, doctoral students and technical staff). The researcher mobility will be carried out by 7 kinds of activities:

1. Long-term fellowships (3 mo - 2 yrs)
2. Short-term fellowships (1-3 mo)
3. Fellowships for visiting researchers (1-3 mo)
4. Laboratory and field site visits (1-4 wks)
5. Workshops (2 d - 1 wk)
6. Summer and winter schools and field courses (1-2 wks each; mainly for research students)
7. Joint field campaigns (at field stations or elsewhere)

Activities 1-2, 4-5 and 7 are mainly targeted towards internal exchange within CRAICC. Activity 3 (visiting researchers) is targeted towards high-profile international experts coming from outside the CRAICC network. Research training courses (activity 6) are open for the wider community, but the hosts of the training courses may collect fees from external participants.

The **summer and winter schools and field courses** combine several Work Packages each, and offer the participants hands-on teaching in specific topics, as well as excellent opportunities for exchanging knowledge and interacting with more experienced researchers in multi-disciplinary arena. The training will be a combination of theoretical lectures, field measurements, computer modelling and complementary skills. Training on complementary skills is usually given by internationally acknowledged and inspiring visiting researchers.

Joint field campaigns will enable the efficient use of field station infrastructures and the equipment and personnel available, and will be common efforts of the CRAICC community to address specific questions related to cryopshere-atmosphere interactions. These will include for example: annual UAV campaigns, expeditions on the cruises made by research ships, dedicated mountain top field campaigns, winter-season evolution of snow and ice in selected drainage basins, snow and ice -related ecological studies, and airborne studies

- coordinated WP3 and WP5 campaign (Svalbard and research ship) to quantify natural sources of primary aerosols and precursor gases for secondary aerosol, and their effects on cryosphere
- Targeted field intensive campaigns conducted at two (in-cloud) mountain top sites (e.g. Vavihill, Zeppelin), one sub-Arctic and one Arctic in order to detect changes under transport, in both summer and winter

The **CRAICC workshops** will provide an authentic experience with the complexity and problems related to the measurements and modelling. Annual three-day CRAICC general workshops include a two-day seminar where each researcher involved in the network presents their recent results, and a networking day where distinguished researchers and industry representatives are invited. Furthermore, CRAICC will organize a series of more specific scientific workshops related to the relevant research topics. At the end of the project, an open conference for a wider researcher and end-user community is organised. The annual workshops will be partly open also for participants outside CRAICC (e.g. for members of other NCoEs). The consortium has excellent networks through international research consortia and projects such as EMEP, iLEAPS/IGBP, IGAC, AEROCOM, ICOS, SIOS, EUCAARI, GRACE and GHG-EUROPE. The CRAICC final conference will be open for the wider research community. A total of 300 participants are expected in this five-day event. Hosting of the workshops and summer schools is circulated between partners which enables all students to get to know each of the participant institutes.

Within CRAICC, special attention is paid to the transfer of good practices. The internal events include discussions and evaluation of the practices of the partners. Furthermore, the staff exchange and network internal visits are utilised as a means to transfer good practices. A small number of visiting researchers of CRAICC will take part in two kinds of activities: (i) mentoring and supervising doctoral students and postdoctoral researchers, and (ii) special skills training. The visiting researcher positions will be mainly targeted at scientists having private sector experience or having other specific background like developing countries or international organisations. Visiting researchers will be giving keynote lectures and hands-on training in the specific areas of their expertise, and they will be invited to several consequent events in order to ensure continuous collaboration with the researchers within CRAICC. Experienced visiting researchers, particularly those from the private sector, are also involved in the planning and implementation of the special skills during the workshops. Among the visiting researchers will be:

Prof. Tamar Barkay (Rutgers University, USA)

Dr. Barkay is an Associate Professor in the Department of Biochemistry and Microbiology at Rutgers University. Her expertise is microbiology, especially bacteria in the snow pack.

Dr. Patricia K. Quinn (NOAA, USA)

Dr. Quinn is a Research Chemist at the Ocean Climate Research Division. She is the co-chair with A. Stohl on the AMAP expert group on SLCF. Her scientific interests are measurement of trends and variability in Arctic aerosol chemical composition, and relationship of aerosol trends to changes in Arctic atmospheric transport pathways and source emissions.

Dr. Barbara Delmonte (DISAT–University Milano-Bicocca, Milano, Italy)

Dr. Delmonte is studying dust provenance by Sr/Nd isotope analyses on deep ice cores.

Dr. Yoshinori Iizuka (Inst. of Low Temperature Science (ILTS), Hokkaido University, Japan)

Dr. Iizuka is studying chemical (aerosol) compounds in Dome Fuji ice core.

Dr. Alexander Kokhanovsky, Prof. Wolfgang von Hoyningen-Huene (Univ. Bremen, Germany)

Dr. Kokhanovsky is a senior researcher at Institute of Environmental Physics and Remote Sensing and at the B. I. Stepanov Institute of Physics, Belarus. Prof. von Hovningen-Huene is the leader of the aerosol research group at the Institute of Environmental Physics. Their main input to CRAICC will deal with remote sensing of clouds and aerosol over snow and ice and snow reflectance modeling.

Prof. Hannes Tammet (Univ.Tartu, Estonia)

Prof. Tammet is Professor Emeritus at the Institute of Physics/Air Electricity Laboratory. His studies focus on atmospheric ion dynamics.

Prof. John H. Seinfeld (California Institute of Technology, USA)

Prof. Seinfeld is the Louis E. Nohl Professor and Professor of Chemical Engineering at California Institute of Technology, USA. The role of Prof. Seinfeld is to study the role of gas-phase chemistry in Arctic aerosol formation.

Dr. Margit Schwikowski and Dr. Urs Baltensperger (Paul Scherrer Institute, Switzerland)

Dr. Schwikowski is the deputy head of the Laboratory of Radio and Environmental Chemistry at PSI. She has studied past black carbon concentrations in the Arctic atmosphere by ice core studies. Dr. Baltensperger is the head of the Laboratory of Atmospheric Chemistry. His special area of interest is formation and growth of organic aerosols.

Dr. Frank Stratmann (Institute for Tropospheric Research, Leipzig, Germany)

Dr. Stratmann is the Head of the Cloud Group at the Institute for Tropospheric Research. His research focus is aerosol dynamics, especially nucleation.

Prof. Colin O’Dowd (National University of Ireland, Galway)

Prof. O’Dowd is a professor of Physics, NUI Galway. His research focuses on marine field observations and atmospheric aerosols.

Prof. Nikolay Elansky (Obukhov Institute of Atmospheric Physics, Moscow, Russia)

Prof. Elansky is head of the Atmospheric Composition Division. He is the organizer and leader of a number of scientific field stations and of the international project TROICA. In addition, he is Chair of the Ozone Commission of the Russian Geophysical Union, a member of the IGAC Scientific Steering Committee, chairman of the Russian Ozone Seminar, and chairman of the Annual School-Conference for Young Scientists on atmospheric composition and atmospheric chemistry.

Dr. Boris Belan (Institute of Atmospheric Optics, Tomsk, Russia)

Dr. Belan has studied atmospheric chemical composition during YAK AEROSIB aircraft campaigns over Siberia.

Dr. Marjorie F. Shepherd, Dr. Sangeeta Sharma (Environment Canada)

Dr. Shepherd is Senior Science Advisor at the Atmospheric and Climate Science Directorate, Meteorological Service of Canada. She studies methodologies for ambient volatile organic compounds. She has coordinated projects within the Canadian multi-stakeholder science assessment for ground-level ozone. As science advisor for the Meteorological Service of Canada, she co-lead the development of science assessments for HF, CO, ozone and particulate matter. Dr. Sharma coordinates and manages a Canadian Aerosol Baseline Measurement program where changes in various chemicals are being monitored in relation to optical properties of the particles.

Describe briefly the use of international contacts

The backbone of CRAICC research is excellent Nordic research infrastructures, which are closely linked to ESFRI RI's (e.g. ICOS, SIOS). CRAICC partners have direct connections to >100 international laboratories and have participated in > 90 EU-projects. The international collaboration is an essential part of CRAICC implementation in the form of research visits, common field campaigns, modeling activities and training. Many partners are coordinating /participating in global research programs and assessment processes such as Fluxnet (flux tower network) and GAW (Global Atmospheric Watch), EMEP and AMAP, and international field campaigns to investigate atmosphere-surface (land, ocean, cryosphere) interactions. UHEL is a key partner in many international organizations and networks (e.g. iLEAPS/IGBP is co-chaired by Kulmala, UHEL hosts international iLEAPS project office, Korhola coordinates Arctic2k PAGES/IGBP activities, Seppä coordinated NEPAL-Nordic Network of Palaeoclimatology and is a member of LANDCLIM - Land cover-climate feedbacks 10000). SU is a member of the Bert Bolin Centre for Climate Research. EMEP operational model, administered by NILU, is the major tool used in Europe for air quality policy design and it is closely linked to CRAICC activities. CRAICC research is also linked to IPY and CRAICC will, e.g. contribute to the Ocean, Sea Ice Snowpack Project (OASIS), with focus on interactions between ice, snow and atmosphere (http://www.oasishome.net/). The long-term programmes NGRIP, EPICA, EPICA-MIS and NEEM, included extensive international co-operation with scientists from B, CH, D, DK, F, Is, I, J, NL, N, UK and USA. Extensive collaboration with Japanese scientists in connection with the Japanese-Swedish Antarctic Expedition (JASE).

An example of earlier field campaigns by CRAICC partners was IPY Arctic field experiment ASCOS (http://www.ascos.se/), carried out on the Swedish icebreaker Oden, 2008. Other examples include LAPBIAT aerosol experiments, Värriö, Lapland 2003, Antarctic aerosol expeditions by ship 2005, Galathea III cruises in 2007/8 and the TROICA-9 expedition in Trans-Siberian railroad 2005. CRAICC partners also participated in IPY POLARCAT research aircraft expeditions to follow pollution plumes of different origin as they are transported into the Arctic (NILU/Andreas Stohl).

CRAICC has close collaborations with e.g. NCAR, NOAA, NASA, Rutgers Univ., Yale Univ., Univ. of Michigan (USA), Queens Univ., Laval Univ.– Quebec, Environment Canada (CANADA), Nansen Centre for Environment and Remote Sensing (NERSC) and the Bjerknes Centre for Climate Research (NORWAY), UK Met office (UK), Univ. Karlsruhe, Max Planck Institute Hamburg and Mainz, Univ Bremen – IUP, Institute for Tropospheric Research Leipzig (GERMANY), Paul Scherrer Institute (SWITZERLAND), Obukhov Inst. Atmospheric Physics, Russian Academy of Sciences (RUSSIA), Dalian Univ. Technology (CHINA) and Hokkaido Univ. (JAPAN).

What considerations are made to increase equal participation of women and men?

Although the number of female scientists engaged in climate change and cryosphere research has steadily increased over the past decades, their number in high level positions is still low. Our objective is to increase the number of women aiming at a professional career in cryosphere research. Special attention is paid to recruitment, division of labour within the research project, provision of equal working conditions and to principles of equal pay for equal work. The SSB will take all the necessary actions to ensure that at least 40% of the participating researchers are women. 26% of the WP leaders and half of the steering committee members are female.

We'll increase equal opportunities by the following actions:

- an annual action plan specifying the measures to be implemented and resources required will be created, and the equality measures will be followed up in the SSB meetings

- Female PhD students and researchers will be encouraged to apply for grants and participate in the network activities

- Part of the program in summer and winter schools is dedicated to gender equality and ethics in science. Mentoring and career discussions will be promoted at all levels during the annual workshops and other activities

- participation in the Earth System Women Network actions (ESWN; http://eswn.aos.wisc.edu/) and the Association of Polar Early Career Scientists (APECS http://www.apecs.is/) for mentoring and assistance in career-related issues will be encouraged

- Where possible, women and men shall be equally represented among lecturers and participants at events, seminars, conferences, exploratory workshops and science reviews

- The problems related to combining family life and work will be actively discussed and dealt with at all levels (MSc students, doctoral students, post-docs and senior scientists). This discussion will involve, naturally, both male and female scientists

- results of the working group 'Gender Equality' (led by Prof. Hanna Vehkamäki, UHEL) will be utilized in the summer schools and workshops

- Parental leaves will be taken into account in strategic planning of the group actions. Maternity or other forms of parental leave for younger principal investigators becomes less challenging when being partner in a NCoE; since during times of leave collaborative scientific projects can (at least in part) be carried forward by the Nordic colleaques, and students and post docs of the PI on leave have a supportive and highly qualified network among NCoE partners

Researcher training

<u>Describe plans for researcher training within the proposed NCoE during the funding period</u>

CRAICC will establish a dedicated educational programme that includes both master and doctoral level studies. The programme covers several adjacent disciplines, including chemistry, biology, physics, geology, geophysics and meteorology. The master-level education is provided as an Arctic-oriented study module in the already existing Nordic Atmosphere-Biosphere Studies (ABS) Master's Degree Programme, which is funded by universities, ministries of education and the Nordic Council. The doctoral level studies are organized together with national graduate schools and the Nordic Graduate School CBACCI (Biosphere-Carbon-Aerosol-Cloud-Climate Interactions). The modalities will be organised within each host organisation, through short-term research visits, and especially via regular network-wide training courses and workshops.

The core of the educational programme is the science programme based on 7 scientific work packages. The multi- and cross-disciplinary training is based on understanding of processes, linkages and feedbacks in the cryosphere-atmosphere continuum. CRAICC is able to provide training covering the complete range of research methods with the finest instrumentation, comprehensive field sites, and state of the art numerical models for simulating earth system processes. The chief educational and knowledge transfer goal is to educate a next generation of scientists in a truly multidisciplinary way of thinking. The direct involvement in industrial research and development are also addressed at this point.

Altogether 20 interdisciplinary intensive courses - field courses and summer and winter schools - will be organized during the NCoE funding period. These courses will gather students from Nordic countries and the whole Arctic region, including Russia, Northern America and Japan. During the courses, the students work together in a multidisciplinary scientific context.

Furthermore, a series of e-learning courses will be given to Arctic-oriented students and researchers. A workshop for teachers and supervisors will be an annual CRAICC activity. Some special aspects have been included in the planning of these activities. These aspects are transfer of best practices and knowledge transfer both horizontally and vertically as well as complementary skills (such as project management, intellectual property rights, science philosophy, and writing grant proposals), and public outreach (language, presentation and communication skills, media relations).

Training through research

Each student who is working with the topics covered by CRAICC will make a study and research plan based on the WP topics. The plans will also identify the skills to be developed (the gap between the current situation and the desired outcome) and educational activities including courses and training on complementary skills, needed to meet the goals in the specific time window. The personalized projects include inter-sectoral visits and/or secondments to another partner institution.

Each MSc and PhD work done in the context of the NCoE includes secondments in another partner institution(s) and participation in joint courses and workshops. The study plans are designed by recognising the research career as a whole. Also the funding during the postdoc period is taken into account in the study plan.

Network-wide activities

In addition to the specific research topics included in the Work Packages, research in the proposed NCoE includes joint analysis of results, transfer of good practices, and benchmarking. The NCoE partners can already provide existing web-based tools like Moodle and Blackboard for e-learning, and Adobe Connect Pro for distributing seminars and lectures network-wide. In the context of the NCoE, new technologies to improve and support researcher education are developed and applied (e.g. Smart-SMEAR). Expert groups on transfer of best practices will be established and special sessions on this issue will be organised in the annual workshops.

The NCoE partners propose to organise a series of research training courses, altogether 4 annual workshops, 10 researcher training courses (summer and winter schools and field courses) and a final conference in the NCoE period 2010-2015. The students to be selected to the educational programme will come from quite different scientific backgrounds such as geosciences, chemistry, ecology, and physics. An international research environment with inter- and multidisciplinary approaches affects also the educational experience of the students working in the training network. Challenging problems, a combination of theoretical and modelling approaches with laboratory experiments and field measurements, and topics having both fundamental scientific relevance and socio-economic values can make students with different backgrounds uniformly enthusiastic. The training courses will cover e.g. the following topics:

- Arctic air pollution
- Role of ions in the Arctic atmosphere, ice nucleation
- Field course on atmospheric measurements
- Analysis of atmospheric measurement data with focus on the Arctic
- Air quality - climate interactions in the Arctic region
- Remote sensing technologies for cryospheric studies
- Model-data assimilation
- Global and regional modelling, focus on the Arctic
- Interaction between climate and cryosphere

The network-wide training activities within the educational programme include three annual activities: one summer school, one winter school or field course, and a research student workshop. The training will be a combination of theoretical lectures, field measurements, computer modelling and complementary skills. The workshops will provide an authentic experience with the complexity and problems related to the measurements and modelling. Hosting of the workshops and summer schools is circulated between partners which enables all students to get to know each of the participant institutes.

The summer and winter schools and field courses combine several Work Packages each, and offer the participants hands-on training in specific topics, as well as excellent opportunities for exchanging knowledge and interacting with more experienced researchers in multi-disciplinary arena. They also always include training on complementary skills given by internationally acknowledged and inspiring visiting researchers. Annual three-day workshops include a two-day seminar where each researcher involved in the network presents their recent results, and a networking day where distinguished researchers and industry representatives are invited. At the end of the project, an open conference for a wider researcher and end-user community is organised.

The annual workshops will be partly open also for participants outside the training programme. The consortium has excellent networks through international research consortia and projects.

The final conference will be open for the wider research community. A total of 300 participants are expected in this five-day event.

Special attention is paid to the transfer of good practices. The network internal events include discussions and evaluation of the practices of the partners. Furthermore, the secondments and network internal visits are utilised as a means to transfer good practices.

Outline practical plans for scientific and administrative management and organisation of the proposed NCoE

Organisation of CRAICC NCoE

The organizational hierarchy of the CRAICC will be kept relatively slim, yet effective to ensure optimal management of the Centre of Excellent. CRAICC NCoE has two organizational bodies 1) Scientific Steering Committee (SSC), which is responsible for NCoE's scientific management and 2) Coordinating Office (CO), which is in charge of daily administration management of the NCoE. Figure 3. outlines the overall management structure of the NCoE. Through these organizational bodies, CRAICC will have an appropriate management framework, linking together all the NCoE partners and maintaining fluent communications with the Program Committee (PC) and with their Scientific Advisory Board (SAB).

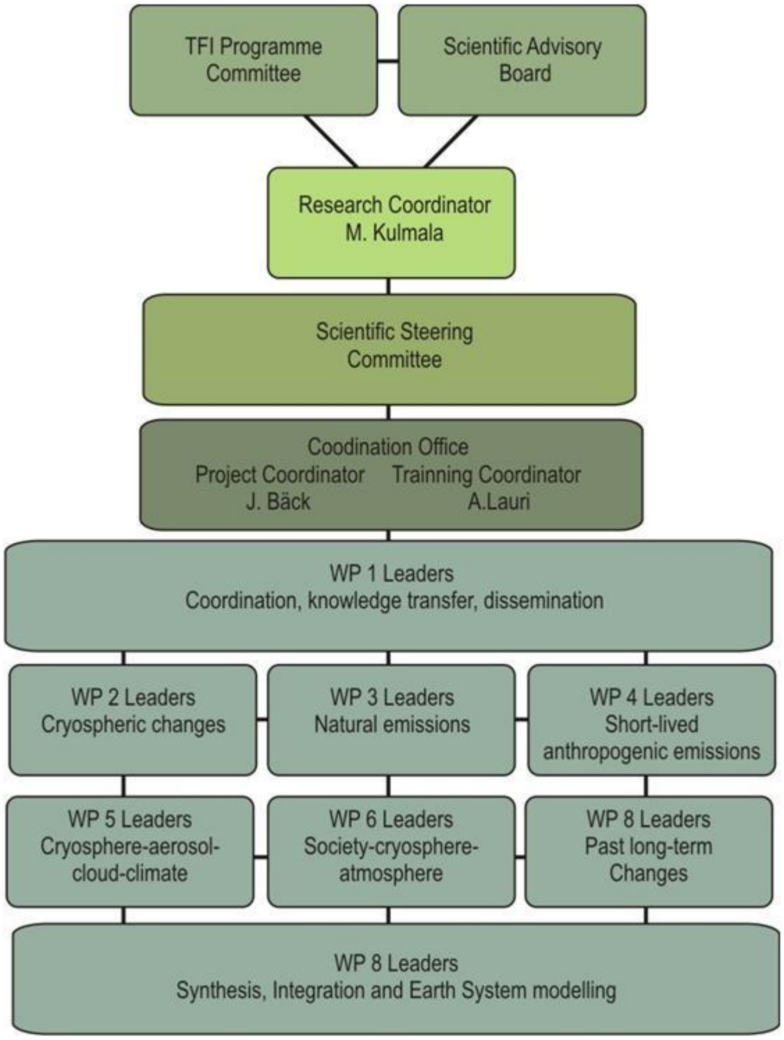

Figure 3. The management structure of CRAICC.

Scientific management

The Scientific Steering committee (SSC) of CRAICC consists of the Research Coordinator and one member per partner country. The SSC will oversee the integration and completion of the NCoE objectives, tasks, and is responsible for 1) defining, dividing and developing the tasks of work packages; 2) supervising the progress of the work; 3) coordinating the research teams; 4) coordinating the preparation of the reports (technical, financial, etc.); 6) advising and directing the partners on the developments necessary for the project; and 7) permitting exchanges of information between the partners. The work of the SSC is frequently translated into daily management and representation duties for Coordinating Office. The SSC will have face-to-face meetings annually and tele/videomeetings bi-monthly.

Members of the Scientific Steering Committee (SSC)

Prof. Markku Kulmala, University of Helsinki, Finland
Prof. Andreas Stohl, Norwegian Institute for Air Research, Norway

Prof. Margareta Hansson, Stockholm University, Sweden
Prof. Merete Bilde, University of Copenhagen, Denmark
Prof. Ingibjörg Jónsdóttir, University of Iceland, Reykjavik, Iceland
Dr. Jaana Bäck, Secretary General, University of Helsinki, Finland

Research Coordinator

The Research Coordinator of the NCoE is responsible for the overall coordination and performance of the Centre. CRAICC Research Coordinator is Prof. Markku Kulmala. Currently, M. Kulmala leads the Finnish Centre of Excellence in Physics, Chemistry, Biology and Meteorology of Atmospheric Composition and Climate Change. The FCoE consists of over one hundred scientists. M. Kulmala has also been the head of one Nordic centre of Excellence (Research Unit on Biosphere – Aerosol – Cloud – Climate Interactions) as well as the corresponding NordForsk Graduate School (Carbon - Biosphere – Aerosol – Cloud – Climate Interactions). He coordinates also the European Integrated project on Aerosol Cloud Climate and Air Quality Interactions (EUCAARI). He has participated in 35 other EU-projects, four of which as coordinator.

Work Package Leaders

Work Package (WP) Leaders are appointed for each work package to ensure the flow of information between the different work packages, and for day-to-day management of the groups that contribute to each WP. WP leaders will represent the different aspects in each WP to ensure that multidisciplinarity is efficiently present in all WP actions. Telemeetings, videoconferences and regular emailing are used to communicate between WP leaders and research groups; to check the progress of the works; to coordinate the preparation of the reports and whenever it is necessary to advise and direct the partners on the developments relevant for the NCoE. Special emphasis will be put on the rapid communication and progress monitoring in CRAICC. The communication will be implemented through regular meetings and by establishing of a website. Overall progress of the CRAICC WPs will be monitored against the mutually agreed milestones by the SSC.

Coordination Office

The Coordination Office will be placed at University of Helsinki in order to ensure the constant information flow between Research Coordinator and Coordination office. The Coordination Office is responsible for overall financial and administrative management of the NCoE; coordination of fellowship grants and visits, network meetings, seminars and workshops; training (organization and coordination of courses); knowledge exchange between partners; and dissemination and outreach of the CRAICC activities and results.

A full-time Project Coordinator, Dr. Jaana Bäck, at the Coordination Office is responsible for day-to-day administrative management of the NCoE. Dr. Jaana Bäck has wide experience of science and project coordination. She has been coordinating the NCoE BACCI activities, and currently she is responsible for project coordination of Finnish Centre of Excellence in Physics, Chemistry, Biology and Meteorology of Atmospheric Composition and Climate Change, consisting of over 150 scientists in two universities and the Finnish Meteorological Institute. The CRAICC coordination office will be supported by the experts of the Research Affairs Unit of the University of Helsinki. The

Research Affairs Unit provides centralized research administration and management services for the researchers at the university. During the last years, they have gathered administrative expertise from over 450 international projects.

Coordination Office will also have a Training Coordinator, Dr. Antti Lauri, who is responsible for designing and coordinating the CRAICC training program that includes both master and doctoral level studies. Dr. Antti Lauri has wide experience on educational coordination activities. He is currently coordinating Finnish Graduate School in Atmospheric Composition and Climate Change: From Molecular Processes to Global Observations and Models, Nordic Atmosphere-Biosphere Studies (ABS) Master's Degree Program and Nordic Graduate School CBACCI (Biosphere-Carbon-Aerosol-Cloud-Climate Interactions).

The administration strategy aims to keep all the CRAICC partners fully informed about the status of the research program, the planning issues and all other issues which are important to partners in order to obtain maximum transparency for all involved and to increase the synergy of the cooperation. To reach optimal communication within the CRAICC community, day-to-day progress of the CRAICC will be monitored through frequent communication via Internet (e-mails and CRAICC web pages), telephone, informal and formal meetings, and mail. In addition, CRAICC organizes regularly general information, discussion and planning meetings for the staff as well as smaller meetings (5-10 persons) in individual research themes and WPs.

Describe briefly plans on how to distribute excellence (e.g. publications, knowledge transfer) to recipients outside the NCoE incl. a brief plan for dissemination to the public(

Dissemination of research findings to the science community

The main philosophy of CRAICC is to support and promote creative thinking and research. This will be done by supporting creative ideas and aims by accepting risk of failure as well. Creative and innovative research needs strong international collaboration and communication. Distributing of novel scientific ideas and results to the international science community is an important part of the CRAICC activities.

All the scientific results will be published in international peer-reviewed journals. The focus of the scientific publications is one hand in integrated synthesis papers and perspective papers (e.g. in papers combining several methodological approaches, temporal and spatial scales) and on the other hand in publishing novel specific research findings.

In addition to international peer-reviewed journals, scientific results will be published in various report, newsletters, conference, and meeting publications in order to reach wider scientific audience. Shorter popular scientific articles will also be published, aiming at reaching the National Environmental Agencies and international programs like UNEP-Chemical Branch.

CRAICC researchers will actively participate in national and international conferences, meetings and workshops to present CRAICC data and results. A central part of the dissemination of the research findings and activities is a CRAICC webpage and databank linked to the web pages. The webpage will be establish and constantly updated enabling colleagues, end-users and the general public to follow the outcomes of the research.

In order to disseminate the knowledge obtained in CRAICC not only to the science community representatives from the various international organisations will be invited to the yearly workshops. Constant knowledge transfer between CRAICC and science community outside the Centre will be done via participating actively in 1) national, European and global research networks; 2) national and international graduate schools, international master programs, summer/winter schools and other training activities. In addition, CRAICC will design and organize courses, seminars and workshops for promoting knowledge transfer in partners' home countries as well in international arenas. CRAICC will also organize cryosphere-atmosphere related science sessions e.g. in European Geosciences Union and American Geosciences Union meetings. These meetings gather annually thousands of Earth scientists to discuss the state-of-the-art research findings and scientific questions. Among other activities, these sessions will ensure high international visibility for Nordic researchers and will effectively distribute CRAICC results.

Several CRAICC researchers are members in international research programs (e.g. IGBP: iLEAPS, PAGES, WCRP: CliC, AMAP), EC-Earth (European Centre Earth system model) and in other international efforts, such as IPY (e.g. POLARCAT, OASIS). Via these activities CRAICC results will directly be distributed and utilized in global science community across the disciplines and continents. Memberships and leading roles in above mentioned international research efforts will result great visibility for Nordic research.

Our excellent track records in NCoE BACCI show that the research teams in CRAICC are capable for effective dissemination of results. As a result of BACCI, we published over 660 research articles in highly ranked, scientific journals, educated 44 doctors (PhD or equivalent) and ca 60 MSc's in the field of atmosphere-biospheric science, and established several new, international collaborative projects, such as EUCAARI (European Integrated Project on Aerosol-Cloud-Climate-Air Quality Interactions), EUSAAR (European Supersites for Atmospheric Aerosol Research), iLEAPS (Integrated Land Ecosystem – Atmosphere Processes Study). CRAICC will participate in the Association of Polar Early Career Scientists (APECS) which aims to provide a continuum of knowledge in polar research and foster interactions between experienced polar researchers and professionals.

The CRAICC Web page will be including the developed model framework with subroutines for each and every parameterization we develop in several languages (matlab, Fortran, C++ etc) openly available + background information and link to original peer review reference.

Dissemination of CRAICC activities and results to public

The CRAICC research contributes directly to current debate on climate change by delivering valuable state-of the art data for science policy and policy making processes, especially related to climate adaptation strategies and mitigation decisions. CRAICC will contribute its science findings to international assessments, such as IPCC assessment reports, Arctic Monitoring and Assessment Program (AMAP), Arctic Climate Impact Assessment (ACIA). Many of the CRAICC researchers are authors of the listed reports. CRAICC partners have also been involved in the SPAC (Short-Lived Pollutants and the Arctic Climate) policy initiative (for more information: http://niflheim.nilu.no/spac, http://www.catf.us/projects/climate/international_climate/) from the very beginning. SPAC has started a policy dialogue within AMAP, IPCC, and others, and with the countries bordering the Arctic, in order to utilize the potential of emission reductions of SLPs for the Arctic climate. With these activities CRAICC is able to feed results directly into the climate policy process. The results of WP6 modeling activities and the implications concerning future climate and development plans for mitigation of climate change will be summarized in a report for policymakers and presented in relevant national and international bodies.

CRAICC results can be applied in European environmental policy such as in formulating national and EU-wide air pollution directives and in negotiating the climate policy for EU. CRAICC findings are relevant for example to the Kyoto protocol, the Vienna Convention on the Protection of the Ozone Layer and the Convention of Long-range transport of Air Pollutants.

In addition to assessment reports, the non-scientific end-users of the data are informed using distributed written material and press conferences, which generates interviews and articles in popular science magazines and in domestic and international newspapers as well as in the television and radio. Stakeholders and key data-user groups will also be invited to some CRAICC meetings. At the beginning and the end of the project end-user workshops f will be organised. Many partners are presently working also in close co-operation with elementary as well as high schools to familiarize pupils and students with simple analyses of environmental data and the scientific world, and by means of generating improved awareness of environmental awareness and issues.

The co-operation with several industrial enterprises already exists. This cooperation will be continued and enhanced further. Especially relevant collaboration for CRAICC has been joint developing activities of Neutral cluster and Air Ion Spectrometer, NAIS, by manufacturer AIREL (http://www.airel.ee/) to studying the role of rain, snow, and ice crystals in ion formation of aerosol particles. A spin-off company AirModus Inc. more text here

Visions for continued cooperation beyond the grant period (2500 characters = 1 page)

As reported in Nordic Climate Change Report (NordForsk Policy Briefs 2009-8), atmospheric research stands out as particularly strong research area together with paleoclimatology, climate modelling, and oceanography in Nordic countries. CRAICC will set an excellent platform to Nordic atmospheric researchers and geoscientists to deepen and enhance the research and training collaboration among excellent, individual Nordic research groups. With CRAICC activities, Nordic atmospheric research and geosciences will stand out internationally even stronger than today. Five years close collaboration and intensive research and knowledge exchange will result new scientific breakthroughs, joint training programs and common working culture with assessed best practises. However, our long-term aim is to shift from short-term project oriented activities towards long-term development and implementation of common strategic research and training agendas, which are based on joint vision and objectives at the level of the participating organizations and nations. CRAICC research groups have gained international recognition and to keep the leading position in a strongly competing science field, we need to accept the scientific leadership and establish trans-national organizational structure that fosters excellence. Top-level science is based on state-of the-art research infrastructures, talented scientists and innovative and dynamic research and learning environments. Nordic collaboration can be enhanced by developing joint facilities and increasing shared access to current research facilities, proving integrated Nordic databases, and supporting joint long-term research activities among research groups. During the next five years CRAICC will work toward joint strategic research agendas and infrastructures of the Nordic research organizations to establish a Nordic research institute in the field of atmospheric research and Earth system science.