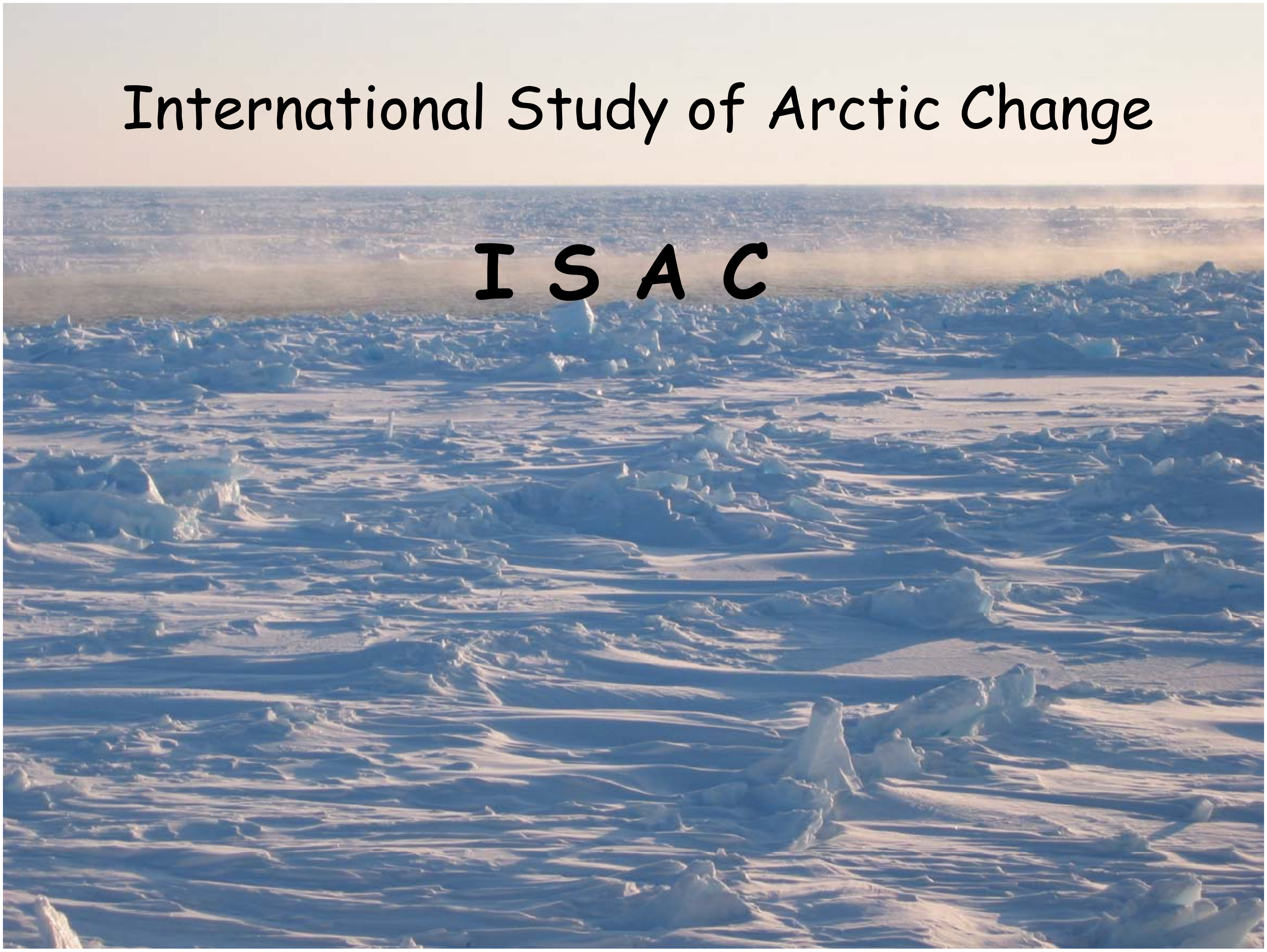
International Study of Arctic Change

I S A C



A Science Overview Document

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This document has been written by the Interim Science Planning Group that was appointed by the International Arctic Scinece Committee (IASC) and the Arctic Ocean Sciences Board (AOSB) in the spring of 2004. Valuable input from several persons outside the group is much appreciated.

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The International Study of Arctic Change, or ISAC, is a long-term, multidisciplinary program to study the effects of environmental changes (including physical/chemical, biological/ecological, and socioeconomic /cultural changes) on the circumpolar Arctic system and the globe. The main objective of ISAC is to observe and understand the characteristics of the entire Arctic System including the social domain and its responses to change in order to develop the best adaptation and mitigation strategies to counteract negative effects due to greenhouse warming and other anthropogenic activities, as well as to changes caused by natural variability affecting the region.

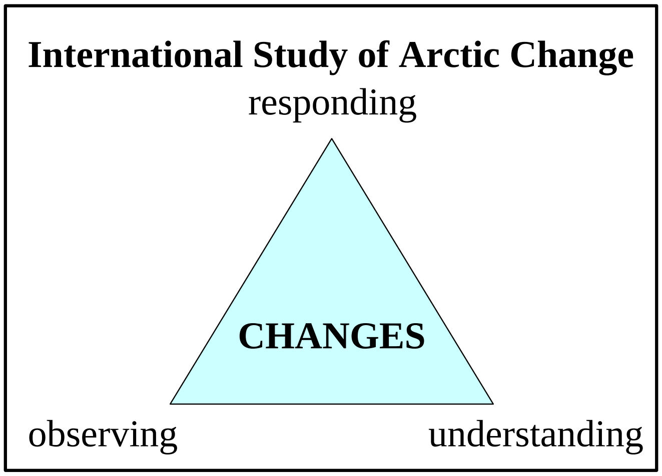

Figure 1. The three cornerstones of ISAC are observing past, present and future Arctic changes, understanding their causes and effects, and examining responses on regional to global scales.

The recently observed changes in the Arctic are caused by interaction of multiple factors and already have significant impact on people and ecosystems. For example, changes in biodiversity, land use, increased natural resource exploitation, and marine transportation are closely interlinked with social, cultural and economic activities. Significant pressure on the environment caused by human activities on all spatial scales will lead to further, probably larger, changes in the future. Understanding the interaction of the human and environmental domains in the Arctic and its effects on the globe are the major focal points of the ISAC study.

In order to reach this goal ISAC aims to facilitate a better understanding of how the Arctic evolves over time on a system scale and how it relates to the Earth System. More specifically, ISAC will i.a.:

i) collect, analyze and disseminate data from an integrated Arctic system observing network based on existing and new long-term observing sites as well as observing methods;

ii) clarify interconnections between various system components in the Arctic, including atmosphere, oceans, cryosphere, biosphere, land, and anthrosphere;

iii) study the nature and magnitude of positive or negative feedback processes which are characteristic of the Arctic system;

iv) study natural variability in the Arctic region;

v) quantify current environmental changes and predict future changes in the Arctic system;

vi) suggest ways for the adaptation of human living conditions to changes in the Arctic environment; and

vii) suggest ways for sustainable use of Arctic natural resources, in harmony with future scenarios for socio-economic development.

The overall objectives of ISAC should be reached through a closely coordinated, multi-national, Pan-Arctic effort. ISAC is based on the SEARCH (Study of Environmental Arctic Change) initiative, will build upon the outcome of ACIA (Arctic Climate Impact Assessment) and AHDR (Arctic Human Development Report) and requires close collaboration with other Arctic research programmes and organisations.

A number of international and national projects are addressing topics relevant to the ISAC objectives and the intention is not to duplicate any of these initiatives, but rather to cooperate and foster communication between ongoing activities.

1. Some recently observed Arctic changes and their socioeconomic impact

ISAC is motivated by the documented changes that already are large enough to affect the lives of native populations and other Arctic residents in the Arctic realm. Furthermore, substantial future changes are suggested by climate models and these will have a profound impact on mankind, not only in high latitudes but also in lower latitudes through climatic teleconnections. It is obvious that the distribution of marine sustainable resources will change, but to what degree and in which pattern is not possible to answer with certainty before reliable climate forecasting can be performed. It is likely that the decrease of the sea ice cover over the Siberian shelf seas will promote shipping with its positive effect on local infrastructure, but possible negative effect on the environment. However, it cannot be disregarded that some feedback mechanism might alter the dominating ocean circulation regime resulting in abrupt changes in climate.

Whereas dealing with changes is difficult enough, the lack of predictability compounds the problem because it does not allow development of strategies to deal with the changed environment. AMAP (Arctic Monitoring and Assessment Program) has summarized extensive data sets on pollutants in the Arctic. The transport and bioaccumulation of heavy metals and particulate organic pollutants is variable, but results in that certain regions are a considerable threat to the indigenous people. Changes in climate, prey abundance/distribution and bioaccumulation of persistent organic pollution/heavy metals/radionuclides pose a real threat to indigenous people in the Arctic that decrease their options for sustainable development and endanger their existence. The following paragraphs highlight the nature, magnitude and socioeconomic impact of selected changes recently observed in the Arctic.

1.1. Arctic fisheries in a climate change perspective: serious present problems and escalating trouble ahead

Some of the recent changes in the Arctic have effects in regions of high economic importance. In fisheries these changes are measured in billions of dollars. Fishing grounds of the Arctic-influenced Northeast Atlantic (10.5 million tons in 1995) and the Northwest Pacific (24 million tons) have been among the worlds most productive. For many northern peoples, fishing constitutes the chief local resource and the foundation for economic development and future prosperity.

Fishing contributes substantially to the economies of northern countries such as Iceland, Norway, the Faeroe Island, Greenland, as well as in regions like Alaska, northwest and maritime Canada, and Russia’s Kola Peninsula. The Bering Sea ecosystem alone supplies fishing fleets from the U.S., Russia, Japan, Norway, China, Poland and the Koreas with an annual catch worth some US$1 billion.

Variations in environmental conditions including climate and ocean circulation directly affect commercial fish populations through variables such as water temperature, salinity, vertical mixing, sea-ice cover, and currents. Fisheries-dependent communities throughout the northern Atlantic have experienced population changes that are co-occurring with climate variability during the past decade caused by shifts in, for instance, the west Greenland cod and shrimp fisheries, the collapse of Newfoundland's northern cod fishery in 1991–92 or Norway's cod fishery that was partially recovering, assisted by a Northeast Atlantic warming phase.

The imbalance between the population of seals and target key food organisms such as fish is partly involved in declining fish stocks in certain parts of the Arctic. In Canada this imbalance has resulted in programs that aim at reducing the seal population. As logical as these measures appear for most of the arctic nations, there is serious resistance to be found in other countries with complicating ramifications that can reduce income from tourism and fisheries.

1.2. Increased maritime transport around the pan-Arctic shelves

The changes in fisheries illustrated above appear to be closely linked to changes in the physical, chemical, and biological conditions in the Arctic, such as penetration of warmer waters into the central deep basins, shrinking sea ice cover and thickness, and shifts in the dominating atmospheric pressure field. The combined set of changes leads to socioeconomic conditions that, in turn, can influence the Arctic environment through factors such as land use and changes in navigation. For instance, the Northern Sea Route is the shortest sea route from Europe to the Pacific Ocean and the Far East. However, difficult sea ice conditions present a natural obstacle to traffic and the period for navigation in ice-free waters only lasts from August to October. During this period, however, the Northern Sea Route is of great importance to service transports of northern Russia, with some 7 million tons of goods shipped along this sea route in the late 1980s. In recent years the volume has fallen to some 1.5 million tons, a third of which is fuel transports to Russia's northern regions, and another third essential copper and palladium exports from the Norilsk Combinate on the River Yenisey.

In 1991 Russia officially opened the route to international traffic and with a decrease in sea ice cover there is a substantial potential to increase this traffic within an international framework. The increase in traffic can result in increased prosperity for northern people, but opens also the door for increased pollution and more frequent accidents threatening the environment. Already today the Kola Peninsula and the Norwegian coast experience significant increases in oil transport from Russian terminals and on ships of "Prestige" quality. The traffic will soon increase to about two single hull tankers a day. It is highly likely that in the future part of this oil transport will use the Northern Sea Route to Japan. Significant oil spills along the northern Norwegian coast, the Barents Sea and along the Siberian shelf have to be expected. Russia has also opened up for nuclear waste disposal in its northwestern territories. In this case, highly toxic substances are transported *into* the Arctic region, giving rise to significant threats to the terrestrial and marine environments, in particular due to possible accidents in physical plants and during transport. Obviously, there exists considerable concern in the Arctic realm about environmental pollution in decades to come with less ice and increased maritime traffic.

1.3. The challenges of Arctic change on husbandry and forestry

Physical and biogeochemical processes in the Arctic affect atmospheric circulation and the climate of regions beyond the Arctic. Resources from terrestrial ecosystems have been central to the mixed economies of Arctic regions during the last 1000 years, and many inland Indigenous communities still derive most of their protein from subsistence activities such as caribou hunting. Changes in Arctic terrestrial ecosystems and their biota are important to the peoples of the Arctic in terms of food, fuel and culture and potentially could have global impacts because of the many linkages between the Arctic region and those regions further south. For example, several hundreds of millions of birds migrate to the Arctic each year and their success in the Arctic determines their roles at lower latitudes. Changes in the productivity and the biogeographical zonation in the Arctic will result in significant changes for indigenous people in the region.

Recent climatic changes in the Arctic are already affecting ecosystems on land and these impacts will affect people. New species are being recorded by indigenous and scientific observations while characteristic population cycles of some animals are disappearing and some animals and plants are becoming rare and threatened. The tree line is increasing in latitude and altitude in some areas and the tundra of Alaska is becoming more shrubby. The carbon balance also appears to be changing in response to thawing permafrost and results in drier tundra ecosystems in Alaska, and wetter ecosystems in the sub-Arctic Sweden.

Increased forest disturbances due to insect infestations are very likely to result from climate warming, where two important examples are increased problems with spruce bark beetles and spruce budworms in the North American Arctic. Forest fires will also cause an increasing problem. The area of boreal forest in Eurasia subjected to fire has greatly increased during the past two decades to an estimated 10 million hectares annually, with estimates that fire extent will increase three fold in Eurasia in the coming 100 years. It is projected that about one billion tons of this organic matter will burn annually, increasing carbon emissions to atmosphere in addition to changes in climate, dramatic human impacts on Arctic terrestrial ecosystems occurred after World War II through exploitation of minerals and oil and fragmentation of the Arctic landscape by infrastructure. Industrial activities and forestry have displaced the Russian forest tundra southwards by deforesting 470 000 to 500 000 km^2 of lands that now superficially resemble the tundra.

Changes are also taking place in the forestry-based socio-economic systems in the Arctic. Comparisons between taiga forest-sector employment within the Arkhangelsk Oblast and the county of Norrbotten in Sweden illustrate striking differences in technology and production emphasis, as well as characteristic core-periphery relationships between coastal centres and inland. During 1989-1996 the number of people actively employed within the forest sector in the Arkhangelsk Oblast decreased by 25%. This was related to the slump in production due to ongoing economic and political crises, but it is probably the prelude to a phase of reorganisation, mechanisation and rationalisation, and the fall will undoubtedly continue. In both regions, global warming will aggravate socio-economic problems within the taiga forest sector, as it has negative effects on timber quality, fire and insect damage, and winter transport conditions.

1.4. Impacts of atmospheric changes on the human domain

Atmospheric changes have both direct and indirect consequences for people living in the Arctic. Recent observations reveal a rapid warming of the Arctic of up to 1.25 ^{o}C per decade in mean annual temperature over North America and central Siberia. Increasing temperatures is now melting off an increasingly larger portion of the sea ice cover in the Arctic Ocean. The changes are connected with alterations in the atmospheric circulation and synoptic storm tracks and weather systems. The exposed open water provides a large source of heat and moisture, compared to the ice surface, which feeds back to the atmospheric circulation in generating more frequent and intense storms and a more variable weather. The Arctic has been a region with a strong annual cycle in weather patterns and indigenous peoples have learned to live with these cycles, where each season has been dominated by activities suitable for the climate. With the changing climate, the weather system in the Arctic is becoming more variable and the traditional ways of life relying on the regularity are becoming increasingly disrupted.

These changes also leave increasingly larger areas of coastline, previously protected by the ice cover, exposed to storms, ocean waves and storm surges. Thawing of permafrost additionally weakens already exposed land, while increased precipitation increases the risk of flooding of many coastal areas thus making them even more vulnerable to erosion. These changes now lead to a rapid increase in coastal erosion and inhabitants of the northern coasts are facing the very real prospect of having to relocate whole societies, since the land they used to live on is swept out to sea. The present infrastructure, such as roads and buildings, is adapted to the presence of the permafrost. With a warming of the permafrost, transport on the tundra becomes significantly more limited, and buildings and roads are becoming increasingly damaged; this includes both residential buildings and industrial facilities. The risk of flooding and of slides also increases with the thawing of the permafrost. This all enhances the risk of environmental disasters.

Just as increased transport of heat from southerly latitudes changes the physical climate there are also real concerns that transport of other properties from the south will also increase. The levels of long-lived pollutants such as semi-volatile organic pollutants (e.g., DDT, PCBs, etc.) and mercury are higher in the Arctic than what is motivated by local emissions. It is believed that many of these pollutants enter the atmosphere in lower latitude warm regions and condense in the Arctic. With a more vigorous atmospheric transport this process would even more effectively carry pollutants from southern industrial regions into the Arctic environment where they would accumulate. A more intense cyclonic circulation may also lead to a spinning up of the polar vortex, which facilitates lower wintertime stratospheric temperatures. This may have the effect of enhancing the depletion of stratospheric ozone and an increased UV-radiation with health effects on humans as a consequence.

2. Hypotheses guiding ISAC

During the past two decades a set of interrelated changes have been detected and documented in the Arctic system. The changes occurred in the physical/chemical, biological/ecological domains and already have impacted life in the Arctic. ISAC will be designed to follow these changes, understand their causes, nature and connectivity, and to study possible socioeconomic, cultural and political responses to these changes in order to minimize negative effects. To guide the work of ISAC we developed a set of hypotheses:

(1) The complex of interconnected changes is driven by global change but also influenced by regional Arctic feedbacks.

(2) Amplification of climate signals in high latitudes, especially in the Arctic, lead to amplitudes of observed changes that are larger than those observed in lower latitudes.

(3) The observed changes are expected to continue and possibly accelerate in the future.

(4) The observed changes in the Arctic have a large impact on ecosystems and societies.

3. Design of ISAC: testing the hypotheses

As highlighted above, a number of impacts on the social and economic structure of the Arctic have recently been experienced as a result of environmental change. Some of these impacts have been assessed by ACIA, based on the present knowledge of the Arctic climate system and anthrosphere. Future assessments will rely on an increased knowledge of the Arctic system including the social domain. ISAC will provide the underpinning for this expanded knowledge base, which will lead to improved assessments of the impact of environmental changes (including climate change) on the Arctic.

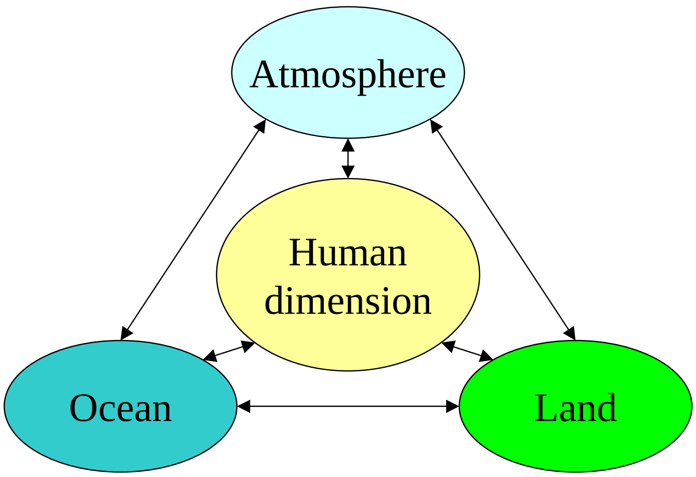

Figure 2. Processes and their relations within the Earth System compartments as well as their interaction with the human dimension is the platform of ISAC.

The objective of ISAC is to take an Earth System approach to facilitate expansion and deepening of our knowledge base of the Arctic system. The gaps of the Earth System compartments, atmosphere, land and ocean, as well as the interaction between them and the human dimension, are outlined below.

3.1. Atmosphere

Two fundamental areas of research need to be addressed:

- The nature and magnitude of regional feedback processes particular to the Arctic
- The links between Arctic climate change and the global atmospheric circulation

Both these issues concerns a number of climate related processes that relates to development and improvement of regional and global climate models. Through model simulations of past and present climate we will learn about the natural variability of the climate system and validate models that can be used for climate scenarios. An improved understanding of regional feedback processes will improve model quality; improved models will allow better quantification of the effects of internal feedbacks in the system. Both issues generate a set of science questions that needs an answer:

- How will the Arctic climate respond to changes in the global atmospheric circulation and what are the effects of changes in the Arctic atmosphere on the global climate system?
- What are the feedbacks due to changes in cloudiness and interactions with atmospheric radiation?
- What are the effects on the atmospheric transport of airborne pollutants by atmospheric circulation changes and will it feedback on the radiation balance through changes in for example Arctic haze?
- In interactions with other parts of the climate system, what are the feedbacks by the energy exchanges with the ocean and terrestrial surfaces? How does the exchange of various gases and particles across the ocean/atmosphere and with the terrestrial surface change and what are the feedbacks from these on the atmospheric radiation balance? Are there feedbacks from the biology of the ocean and land that will impact the atmosphere, for example through changing vegetation cover or in biogenic aerosols?

To answer these questions require an integral approach, including climate related process studies and monitoring observations, together with modeling work using coupled global and regional climate models.

3.2. Terrestrial ecosystems and cryosphere

The very complex interaction of different climate related processes on land, including changes in greenhouse gas emissions from the terrestrial biosphere, changes in permafrost, as well as changes in ice and snow cover, necessitate extensive interdisciplinary studies to answer some knowledge gaps, like:

- Which factors are responsible for changes in the physical environment of the terrestrial Arctic in the recent decades and which are the main mechanisms controlling the effects of changing climate on cryosphere and the feedback of cryospheric changes to climate system?
- What are the nature of threats to species from environmental change on all scales from microbes to long-term climate and UV-B change, and how does species react to extreme events and what are thresholds relevant to biological processes?
- We need to measure and predict rates of species migration by combining paleo-ecological information with observations from indigenous knowledge,

environmental and biodiversity monitoring, and experimental manipulations of environment and species.

- What are the links of climate, hydrology (permafrost), ecosystems and land use and can these be modeled based on improved information of relevant processes?
- How will the tundra and its ecosystem effect the emission of the greenhouse gases under warmer climatic conditions?

3.3. Ocean

Scientific issues related to sea ice cover, ocean circulation (including deep water formation), impact by river runoff and the marine ecosystem (sustainable resources as well as biodiversity) generate a set of science questions that needs an answer, of which some are summarized as:

- What is the cause and significance of observed changes in sea ice extent and thickness: Are the recent changes a manifestation of a long-term trend or decadal variability?
- What are the consequences of the changing sea-ice and river run-off with regard to phytoplankton assemblages, dense shelf water production and ventilation and biogenic matter fluxes? How could such changes affect the uptake of CO_2 from the atmosphere?
- Is there an effect of changing Atlantic inflow to Arctic ice cover and atmosphere? What other feedbacks by the Arctic Ocean to the atmosphere could occur?
- Will a reduction in ice cover change the standing stocks of major Arctic species towards temperate species? Will earlier warming of the surface layer influence the hatching of fish such as Arctic cod?
- Can we separate internal variability in population dynamics from externally forced trends?

To answer these questions requires a flexible system-scale observations that will allow us to describe the Arctic Ocean circulation, ice cover and ecosystem, as well as its variability and change over many decades together with further efforts to retrieve historical data, particularly on ice thickness. It will include the integration of classical observation methods with multi-sensor observations of the ocean and ice cover using, for example, satellites, ice-tethered platforms, floats/profilers/gliders, long term moorings, tracers, etc. Finally there is a need to develop models that can properly reproduce and assimilate modern observations. The models should be coupled and link the Arctic (Ocean?) to the global ocean (at least the north Atlantic).

3.4. Couplings between the subsystems Atmosphere – Ocean - Land and Humans

Numerous couplings between human activities and the Earth subsystems atmosphere, ocean and land are evident and simplified in Figure 3. These couplings are not different in the Arctic compared to the rest of the globe, but rather augmented by the amplified signal of observed changes. The human impact of global change can be addressed only in a broad perspective, recognizing the earth environment as a coupled system, in which interacting physical, chemical and biological processes are influenced by mankind. The earth system consists of the atmosphere, ocean, and land, connected to each other through fluxes of energy, water, tracer and matter. These climate related interactions and the incorporation of them in coupled climate system models generate a set of science questions that should be investigated:

- What are the interconnections between various system components in the Arctic, including atmosphere, oceans, cryosphere, biosphere, land, and anthrosphere?
- What is the role of coupling mechanisms between the different subsystems, between the lower and the middle atmosphere, between tropical and polar latitudes and between the upper and deeper ocean?
- To what extent is it necessary to include biogeochemical cycles, atmospheric and oceanic chemistry, tropo- and stratospheric aerosol processes and their interactions with other parts of the climate system?
- What are the main feedback loops and how are they represented by the coupled climate models and what are the mechanisms that lead to seasonal and multi-decadal climate variability?
- What is the level of detail with respect to the physical, chemical and biological process parameterizations and resolution that has to be taken into account to successfully predict climate on seasonal to multi-decadal time scales?
- How predictable is climate variability from seasonal to multi-decadal time scales and how do the natural circulation modes interact with external influences and anthropogenic climate change?

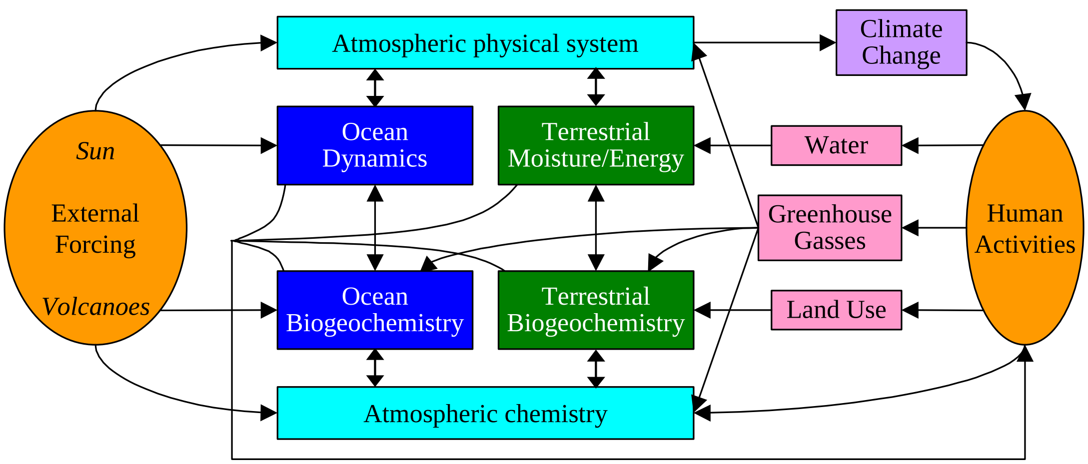

Figure 3. Schematic illustration of the couplings between the Earth subsystems atmosphere, ocean, land and human activities.

4. Projections based on observed changes

The atmosphere plays a central role in the earth system since changes directly affect the radiation budget, the circulation patterns and the water cycle. The atmosphere is the major natural transport system for energy, water, heat, momentum and trace substances being effective on different space and time scales and is linked with slower responding system components such as the hydrosphere (including the oceans), cryosphere and biosphere covering seasonal to multi-decadal time scales.

The atmosphere is characterized by large-scale teleconnection patterns. Global warming patterns occurred with winter and springtime temperatures over Northern Europe and Siberia warmer than normal and linked to the observed trend toward a high index polarity of the Arctic Oscillation (AO). The AO as a monthly mean extratropical tropospheric pattern of variability shows a strong correlation with long-term climate trends of the troposphere and important connections to the stratosphere. Recent trends in the tropospheric circulation can be interpreted as a shift to a stronger westerly flow, connected with trends in the lower stratospheric polar vortex, which are largely due to stratospheric photochemical ozone losses. The stratosphere has shown a tendency to cool over the last decades and the polar vortex over the Arctic tends to be stabilized. Several different kinds of external forcing connected with increasing concentrations of greenhouse gases, aerosols and stratospheric ozone appear to be capable of introducing a response in the AO pattern.

Most climate model scenarios for the 21st century show an enhanced warming over the high-northern latitudes as a response to the anthropogenic release of greenhouse gases and aerosols. The main reason for the polar amplification of the global warming is the sea-ice albedo feedback. The magnitude and regional structure of the polar amplified warming pattern of the troposphere and the stratospheric cooling pattern varies strongly among the different models. The large discrepancies in the high-northern latitude climate scenarios are likely due to different physical parameterizations and feedbacks in the various models. It has been suggested that natural low frequency variability and anthropogenic forcing will drive future changes in the Arctic. Natural variability arises from the nonlinear interactions between atmosphere, ocean, sea-ice and land. Anthropogenic changes are caused mainly by greenhouse gases emissions and aerosols and changes in land use.

Models and paleoclimatic analysis are the key tools to put the present changes into the context of past and expected future changes. It is necessary to extend the observational records to enable a better description of multi-decadel climate variability. This requires a close cooperation with paleoclimatology and the synthesis of paleoclimatic data with complex earth system models and the development of an effective global climate and earth observing system.

The successful prediction of Earth System variations on the seasonal to multi-decadal time scales is a key to ISAC. The climate system is a highly nonlinear system with considerable predictability, but with considerable natural fluctuations arising from, for instance, the complex interactions between the atmosphere and the ocean. Any anthropogenic or external signal will be overprinted by the presence of such climate variability. Furthermore, our understanding of several relevant processes, i.e., stratospheric chemistry and dynamics, is not sufficient to model the future development of the stratosphere. Investigations of these processes and how they respond to the greenhouse warming of the troposphere and the stratospheric cooling are needed. The rate of future changes in greenhouse gases concentrations, especially water vapor is uncertain. This is why the interaction between natural variability and anthropogenic changes are not yet understood.

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5. Requirements of ISAC

ISAC is planned as a long-term, international, cross-disciplinary, pan-Arctic program aiming at answering the scientific questions that are the basis of scientific impact assessments of Arctic change. For this purpose the most fundamental requirement is a documentation of the changes with respect to spatial and temporal patterns. Description of these spatial patterns and temporal trends require an unprecedented multi-national commitment to a dense and long-term system-scale Arctic observation platform. Sustaining and modifying this platform to changing requirements defined by new scientific insight and theoretical studies will be a major effort within ISAC. An Arctic observing platform will be synchronized with those of global observations.

A key question for ISAC is the predictability of the Arctic system including its variability and change. Without such predictions, assessments will be reduced to past and present states of the Arctic system and will not be useful in designing adaptation and mitigation schemes. In order to answer the questions of the nature of the presently observed change in the Arctic and its projection into the future, ultimately requires Arctic system models with predictive capability on seasonal to decadal time scales. A major activity within ISAC will be the development of such models in close synchronization with the observing efforts. Additionally, the models have to be tested by system-scale multi-variable data sets obtained from the Arctic observing system. Similar to the observing platforms the model development requires a multi-national long-term effort. The Arctic system models will be integrated into Earth System Models. This will ensure the seamless integration of the high-latitude studies of environmental changes into the global change studies. The incorporation of Arctic models into Global Earth System Models will improve their performance in the Arctic and its global impact to determine and understand their global influences via atmospheric and oceanic teleconnections and consequences for decadal scale climate variability.

A defining feature of ISAC is its cross-disciplinary nature requiring close collaboration with other organizations and programs addressing Arctic (and global) change issues. ISAC will study the physical, chemical, and biological elements of the Arctic system in symbiosis with elements in the socioeconomic, cultural and political domains. This approach will assure proper focus on the human dimension of Arctic environmental change. The need to understand the impact of environmental change on human life and the options for sustainable development in an anthropogenically driven increasing pressure on the environment is the ultimate driving and motivational force behind ISAC.
