

AMAP Workshop on Follow-up of ACIA
June 15–17, 2005, Oslo, Norway

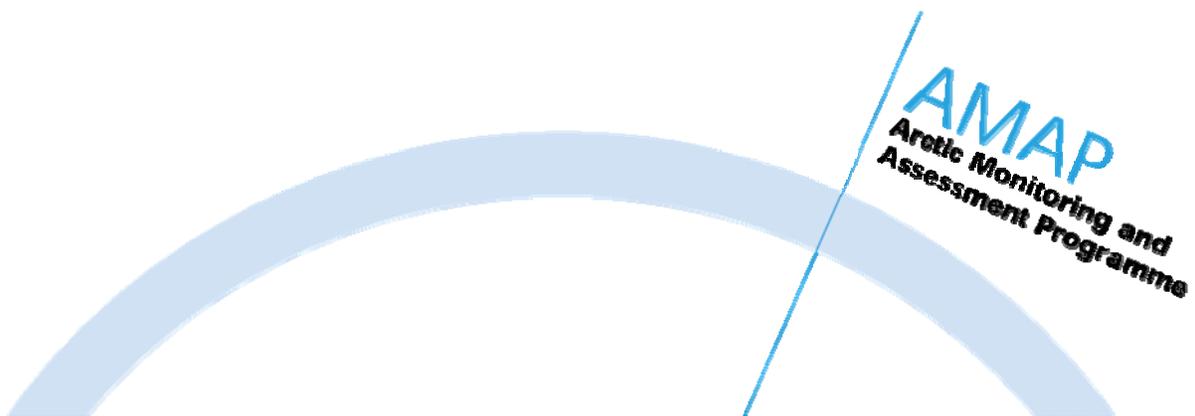


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AMAP Workshop on Follow-up of ACIA

Executive Summary

The AMAP Workshop on Follow-up of ACIA was held to review the scientific recommendations from the Arctic Climate Impact Assessment report and the recommendations from the ACIA Policy Document, issued by the Fourth Arctic Council Ministerial Meeting (Reykjavík, November 2004), and to develop more specific, implementable tasks consistent with these recommendations. Most of the work was conducted in four sub-groups, with an overview conducted during plenary sessions. The main recommendations resulting from this review are presented below.

1 Scientific Recommendations from the ACIA

1.1 Physical climate—past, present, future (Chapters 2, 4, 5) (Sub-group 1)

Arctic Climate – Past and Present (Chapter 2 recommendations)

It is important to track a range of Arctic climate and ecosystem indicators to assess ongoing changes and understand the relative roles of natural variability, anthropogenic forcing, and feedback processes. Such indicators include, but are not limited to, surface and stratospheric temperatures, ice concentration and thickness, tundra and permafrost areas, duration of snow cover, biological parameters, such as species composition and diversity, etc., and human health indicators.

In situ measurements form the backbone of monitoring, while remote sensing provides broad spatial coverage. AMAP should recommend the protection of ongoing monitoring programmes, such as:

- Upper-air sonding and meteorological stations;
- Aerosols in connection with aerosol-cloud interactions and greenhouse gas balance in Arctic regions;
- Satellite observations of radiation for determination of temperature and radiative vertical profiles of temperature and humidity, clouds, sea-ice and tundra properties;
- International Arctic Buoy Program;
- Ecosystem monitoring (e.g., Zackenberg programme, fisheries surveys, ITEX);
- Ocean measurements such as ASOF, NPEO (this should be elaborated by other groups);
- Monitoring health effects in humans.

AMAP recommends the promotion of long-term monitoring of sea-ice thickness and glacier mass balance, and the coordination of archival of past measurements by CLiC.

AMAP recommends increased analysis of paleo-measurements for the previous three centuries in the Arctic, noting regional, seasonal, and annual differences.

Future Climate Change: Modeling and Scenarios for the Arctic (Chapter 4 recommendations)

AMAP should promote understanding of how global atmosphere-ocean processes influence climate in the Arctic region. AMAP recommends that further efforts be placed on the use of global circulation models and retrospective data analysis in relation to the Arctic.

AMAP should review the now available IPCC4 model outputs with reference to the conclusions of the ACIA report. Work is under way in several countries and AMAP could coordinate evaluations in relation to the Arctic.

AMAP should encourage the development of Arctic-oriented re-analysis of observational ocean-ice-atmosphere data as Arctic models improve and observations increase during the IPY period.

AMAP should promote observations and regional (as well as small-scale and large-scale) modeling with regard to Arctic-specific processes shaping the Arctic response and feedback to global climate change. Examples of important processes include:

- energy balance of sea ice, tundra, and glaciers, including albedo feedback;
- radiative feedbacks influenced by ozone, greenhouse gas balance, aerosols, and clouds;
- hydrologic cycle;
- ocean processes.

Ozone and Ultraviolet Radiation (Chapter 5 recommendations)

There is a need for establishing a stronger link between the atmospheric science community and the community studying the effects of UV radiation on health and Arctic biology. This should include the following:

- 1) Undertaking cross-disciplinary studies to determine the biological effects of UV irradiance, which requires cooperation between the UV radiation monitoring community and the biological and impacts communities. Many questions remain concerning the impacts of UV radiation on individual species, ecosystems, and human health; understanding the magnitude of potential impacts will be critical for future policy decisions;
- 2) UV monitoring is needed at some sites together with models to provide a broader picture. Such monitoring should be tied to ecosystem studies to provide information on the impacts of the UV levels observed. Thus, monitoring stations should have broad capability to monitor other relevant parameters. In many of these sites, it may be better to use a multi-filter instrument, with less precision but better temporal resolution, rather than a highly accurate spectroradiometer.

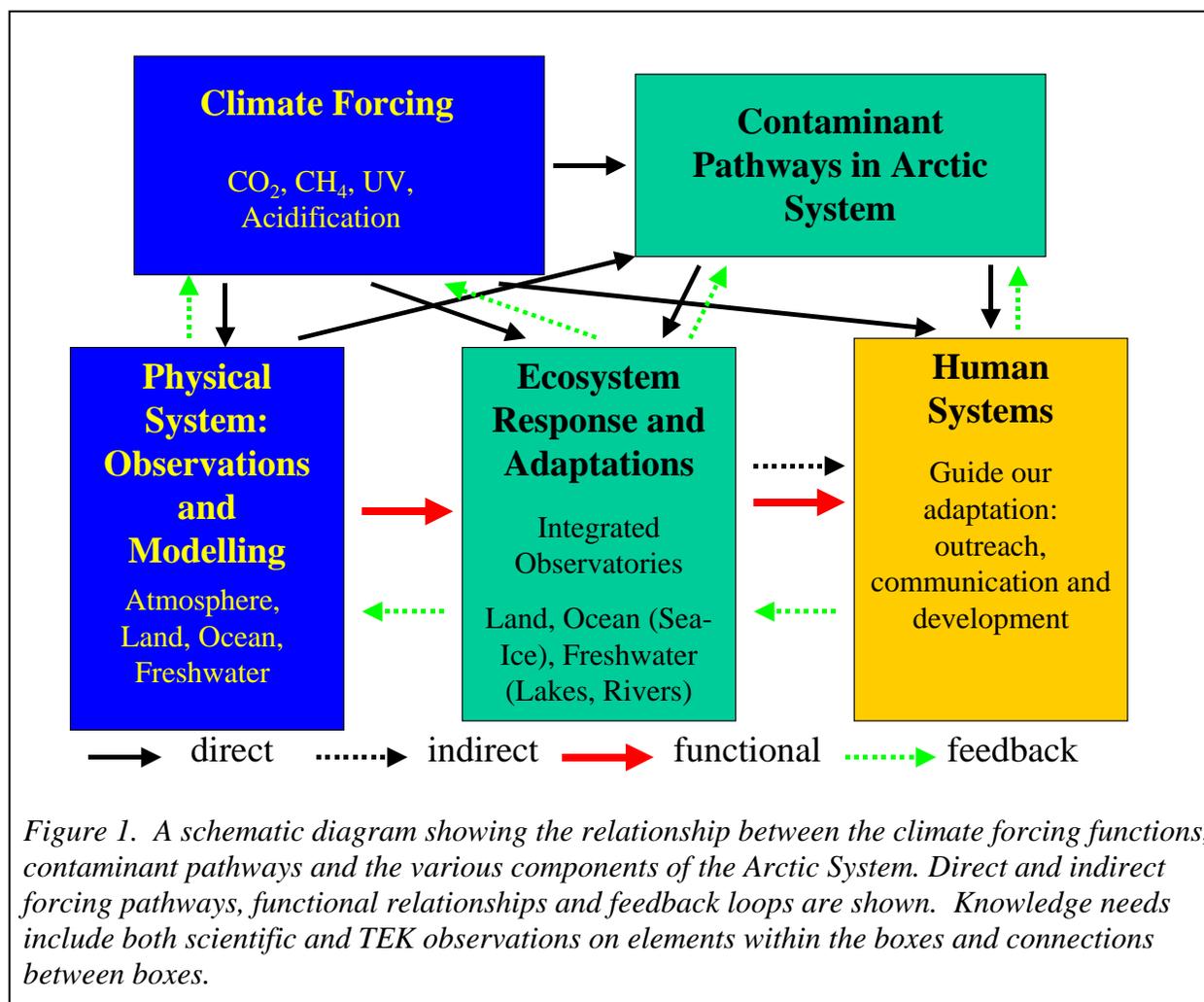
What is needed is a full understanding of the interaction of climate change and ozone levels in the Arctic. An understanding is needed of the interaction of the low-temperature stratospheric vortex in relation to the chemical processes regulating ozone production and depletion. Ozone monitoring, including ozone vertical profiles, should be maintained or increased in the Arctic. At the present time, there are large regions of the Arctic where no ozone sonde vertical profiles are available.

In addition to the available scenarios for future ozone, there is a need for an update of scenarios for future UV levels in the Arctic and an assessment of the implications. This will require scenarios for snow, aerosol, and clouds.

Satellite instruments can contribute monitoring of both ozone and UV, particularly over areas without ground-based measurements. However, distinguishing between snow and cloud cover is still a challenge for satellite UV algorithms.

1.2 Cryosphere, Hydrology, Freshwater, Marine, Fisheries (Chapters 6, 8, 9, 13) (Sub-group 2)

The ultimate objective is to increase our understanding through observations, modelling, and examination of the paleo records, to enable and refine quantitative predictions of the future state of the Arctic physical and biotic environment for the betterment of human society.



Traditional knowledge and modern science are both considered integral components of the following recommendations. Plans for observational programmes should include from the outset consideration for building and using local capacity, establishing standardization of scientific and indigenous terminology and among indigenous observers, recording observations, storing and

disseminating information, and establishing data ownership while maintaining the open access principle. Dialogue among and within the communities is essential for both planning and ongoing implementation (e.g., Russia has conducted two training sessions for the collection of environmental observations for indigenous communities that should be consulted as examples).

It is recognized that the role of Arctic Council Working Groups (e.g., AMAP, CAFF, etc.) in the implementation of these recommendations is primarily to help catalyse, advise on structure, coordinate, and assess results.

In addition to the ongoing research and monitoring activities, the following should receive special attention due to their known importance, lack of data or insufficient understanding.

Physical/Chemical System:

AMAP should lead the efforts to expand the observational networks (both indigenous and scientific) and modeling as a means to provide baseline information, monitor changes in the physical system, develop budgets (e.g., freshwater, heat, etc.), and validate models.

Local capacity will be an important element of conducting these observations.

Development of regional and local models downscaled from the global models is required for improved impact assessments.

As a starting point, AMAP should review reports and plans from, *inter alia*, the U.S. National Academy of Sciences report on Arctic Observing Network, and the implementation strategy to be developed by the International Study of Arctic Change.

From this review, a research and monitoring strategy should be developed to include, for example, the following:

Atmosphere: Winds, P-E, Clouds, Aerosols, Arctic Boundary Layer;
Momentum, heat and moisture fluxes, Radiation balance;
Carbon (CO₂ and CH₄) fluxes between air/land, air/ocean.

Ocean: Thermohaline Circulation;
Fluxes of water and ice into and out of the Arctic;
Sea Level, Wave dynamics;
Acidification.

Cryosphere: Sea-ice (Dynamics, mass balance, icebergs);
Glaciers, Ice Caps and Ice Sheets (Inventory, mass balance, dynamics);
Permafrost (Active layer parameters, thermal state—also to include discontinuous zones).

Hydrology: River flows (including carbon fluxes);
Soil moisture and evapotranspiration.

In performance of these observations, a continuing dialogue with indigenous experts regarding the integrated state of the environment will aid in the interpretation of scientific observations.

Ecosystem Response and Adaptation:

AMAP with CAFF and other relevant partners should establish a network of integrated observatories¹ (i.e., at least within the four ACIA sub-regions and preferably across latitudinal gradients, where appropriate) for each of lake, river, terrestrial, and marine (including ice-based) ecosystems to:

- provide a baseline (including acquisition of relevant paleo data) and to understand ecosystem structure (i.e., biodiversity);
- conduct long-term physical and biological monitoring to detect variability and change;
- understand functional relationships and processes;
- assess the ecosystem response to climate/UV/acidification change in the context of other large-scale changes (i.e., human habitation, etc.);
- use the above to model and predict future system states;
- establish a collaborative indigenous observation program² to ensure integration and comparability of TEK and scientific knowledge and permit extrapolation of scientific information to areas where presently only TEK information exists.

Human Systems:

All WGs of the AC should work together to establish an outreach and communication process (recognizing differences in languages and cultures) to guide adaptation, including new management and research strategies, to:

- shifts in renewable resource patterns (commercial, subsistence, recreation);
- shifts in transportation (e.g., marine, ice road);
- non-renewable resource extraction;
- shifts in traditional lifestyles;
- changes in hydropower production;
- changes in coastal dynamics (e.g., sea level rise, coastal erosion);
- changes in infrastructure needs (e.g., permafrost degradation);
- changes in economic development (e.g., tourism, recreation, industrial development, population changes, etc.);
- outreach to science and policy communities in lower latitudes;
- report to UNFCCC and IPCC.

(The Arctic Human Development Report should be reviewed for guidance to outreach and communication needs.)

¹ See main report of the Workshop for a description of “integrated observatories”.

² See main report of the Workshop for a description of “collaborative indigenous observation program”.

Data Issues:

AMAP and CAFF should take appropriate steps to ensure development, recovery, management, and dissemination of both scientific and traditional data/knowledge. This should include:

- data rescue, with necessary quality control (e.g., time stamps, frequency, etc.);
- dataset development for analyses (including model results);
- data archiving (including migration to new technologies);
- integrating TEK and scientific knowledge.

Assessments:

The AC in association with other interested organizations should produce periodic assessments of climate change and impacts in the Arctic as follows:

- a comprehensive assessment every ten years;
- targeted assessments as appropriate.

Policy Recommendation:

AMAP should (1) document the current rate of carbon storage in the Arctic marine, freshwater, and terrestrial environments to determine its importance in the global balance, (2) assess possible future changes in carbon storage under global warming, and (3) identify possible mitigation efforts to maintain and enhance carbon storage in the Arctic.

In order to meet the above objectives under each of the systems and fulfill obligations to Arctic peoples, governments should develop internal and international policies, and commit long-term funds to the establishment and maintenance of these programs. Such funds should be in addition to existing competitive scientific funding.

1.3 Wildlife, Hunting and Herding, Human Health, Indigenous Peoples Issues (Chapters 3, 12, 15, 17) (Sub-group 3)

Details of the review of the scientific recommendations from these chapters are contained in Annex 3. No further specific recommendations were made.

1.4 Forestry and Agriculture, Terrestrial Ecosystems, Conservation and Management (Chapters 7, 10, 11, 14) (Sub-group 4)

Details of the review of the scientific recommendations from these chapters are contained in Annex 3. In addition, priority actions for AMAP were identified and more specific recommendations were developed for the high priority actions, as shown in Annex 4.

2 Recommendations Regarding the ACIA Policy Document

2.1 Physical climate—past, present, future (Chapters 2, 4, 5) (Sub-group 1)

Sub-group 1 comments on the ACIA Policy Document are as follows:

- 1) The recommendations developed by the Sub-group support the policy document.
- 2) The Policy Document recommendations support the need for enhanced scientific and monitoring data to improve our knowledge of the Arctic and reduce the uncertainty in climate projections.

With regard to outreach, it was noted that there were some statements in the executive summary of the overview document “Impacts of a Warming Arctic” that do not correspond to the scientific background document. For example, the executive summary could be interpreted as indicating that CO₂ is the main source of the climate change in the Arctic, however, the main scientific document indicates that natural variability and feedbacks are also important. The recommendations made at the AMAP ACIA Workshop regarding modeling and monitoring will provide increased reliability of future estimates of Arctic change. In addition, the statement in that document that human lifetime UV doses will increase by 30% in the future is an exaggeration and cannot be found in the scientific background document.

This Workshop recommends that the Arctic Council working groups develop an outreach strategy to be prepared to answer questions regarding the overview document.

2.1 Forestry and Agriculture, Terrestrial Ecosystems, Conservation and Management (Chapters 7, 10, 11, 14) (Sub-group 4)

Mitigation Recommendations

Given that Arctic Nations collectively represent 40% of global warming pollution emission, we urge aggressive collective and individual actions at all levels to advance mitigation actions within and beyond the region. We recommend the following:

1. Member states report back to the Arctic Council on how they have considered the ACIA findings in implementing their commitments under the UNFCCC and other agreements; and the Council compile and produce a report with this information.

2. Engagement of relevant sectors in outreach and communication in developing and adopting mitigation strategies; build indigenous capacity to be effective partners in these mitigation strategies
3. The initiation of the development and adoption of alternative energy sources and technologies to promote renewable energy production and more efficient energy use at the federal, state, and local levels; initiate a circumpolar prototype project through the Sustainable Development Working Group.
4. Efforts be made by member states to develop forestry and energy policies that conserve and enhance carbon sinks and reservoirs.

Adaptation Recommendations

“Work closely with Arctic residents, including indigenous and local communities, to help them to adapt to and manage the environmental, economic and social impacts of climate change and ultraviolet radiation change. Adaptation needs will vary. Arctic residents may need inter alia enhanced access to information, decision makers, and institutional capacity building to safeguard their health, culture and well-being.”

Based on these policy guidelines, we recommend that:

1. Best management practices be applied in the use of traditional knowledge in adaptation planning and management.
2. The Arctic Council should facilitate and fund communication capacity building of Arctic residents to provide enhanced access to information and decision makers.
3. Keep ownership of traditional and local knowledge at the local level.
4. Gaps in indigenous knowledge data should be identified and collated and efforts made to fill in the data set.
5. Research efforts should apply local resources and capacity when possible to achieve greater local ownership, understanding, cooperation, and efficiency.
6. Researchers should coordinate with local and regional key contacts to evaluate opportunities for collaboration with other researchers and local and regional organizations.
7. Devolution of authority and building of leadership and management capacity should be made a priority for local and indigenous residents.
8. Efforts should be made to develop communication in local languages and in culturally appropriate ways.
9. Funding criteria should encourage constructive partnerships between researchers and local and indigenous residents.

“Recognize that opportunities related to climate change, such as increased navigability of sea routes and access to resources, should be developed and managed in a sustainable manner, including through the consideration of environmental and social impacts and taking appropriate measures to protect the environment, local residents and communities.”

1. Development must recognize indigenous rights to resources, and be done in such a way as to include the full involvement and participation of indigenous peoples.
2. Arctic nations should immediately begin to plan and budget adequate resources to provide the capacity to adapt to major changes; local and indigenous people should have full involvement in the decision-making process.

“Implement, as appropriate, adaptive management strategies for Arctic ecosystems, making use of local and indigenous knowledge and participation, review nature conservation and land and resource use policies and programmes, and to the extent possible reduce risks related to infrastructure damage, permafrost degradation, floods and coastal erosion, taking into account costs and benefits.”

1. Perform local and regional climate assessments and develop adaptive management strategies.
2. Develop models and assessment tools that can provide guidance to decision makers and leaders at the local and regional level.
3. Develop models at a scale that will contribute to adaptive management.
4. Develop funding mechanisms which can be applied for adaptation measures rapidly and as new problems emerge.
5. We recommend that member states report back to the Arctic Council on their “review of nature conservation and land and resource use policies and programmes” incorporating locally available indigenous knowledge and participation as required, in the ministerial-endorsed ACIA policy document.
6. We recommend that indigenous peoples organizations report back on the work being done by their member states to develop mitigation recommendations.

“Stress the importance of intensifying natural and social science research on impacts and adaptation, including studies to enhance understanding of fundamental processes and sustainability, procedures for integrating indigenous and local knowledge into scientific studies, and partnerships between indigenous peoples, local communities, and scientists in defining and conducting research and monitoring associated with Arctic climate and ultraviolet radiation changes.”

1. Develop monitoring and research projects which reflect a multi-stressed environment and can be used to develop practical applications to address stresses at the local and regional level.
2. Analyse the AMAP monitoring strategy to reflect the concerns raised by a multi-stressed environment.
3. Develop a cooperative approach to using knowledge and local capacity in social and natural sciences research.

AMAP Workshop on Follow-up of ACIA

June 15–17, 2005, Oslo, Norway

Introduction

The Chair, Dr John Calder (USA), opened the AMAP Workshop on Follow-up of ACIA at 9.00 hrs on 15 June 2005 and welcomed the participants. The workshop agenda is attached as Annex 1 and the list of participants is attached as Annex 2.

Dr Calder stated that the purpose of the workshop was to review the scientific recommendations from the ACIA and the recommendations from the ACIA Policy Document issued by the Fourth Arctic Council Ministerial Meeting (Reykjavík, November 2004) and develop more specific, implementable tasks consistent with these recommendations.

The participants discussed how to tackle this review and agreed that the workshop should break up into sub-groups that should review the recommendations for clusters of chapters. The clusters of chapters were chosen, and chairs and rapporteurs for the sub-groups were appointed. Four sub-groups were agreed, as follows:

Sub-group 1: Physical climate—past, present, future (Chapters 2, 4, 5) (Chair: Hanne Petersen; Rapporteur: Janet Pawlak);

Sub-group 2: Cryosphere, Hydrology, Fresh Water, Marine, Fisheries (Chapters 6, 8, 9, 13) (Chair: John Calder; Rapporteur: Ken Drinkwater);

Sub-group 3: Wildlife, Hunting and Herding, Human Health, Indigenous Peoples' issues (Chapters 3, 12, 15, 17) (Chair: Jan-Idar Solbakken; Rapporteur: Terry Fenge);

Sub-group 4: Forestry and Agriculture, Terrestrial Ecosystems, Conservation and Management (Chapters 7, 10, 11, 14) (Chair: Gunnar Futsaeter; Rapporteur: Morten Olsen).

It was agreed that the sub-groups should focus on their assigned chapters, but they could also include discussion of any other chapters. They were to focus on the identification of activities appropriate to AMAP, but they could also consider activities appropriate for other Arctic Council working groups. It was suggested that they begin with a broad identification of tasks to respond to the ACIA recommendations, and later choose a smaller number of activities considered to be of greatest importance, most easily done, etc.

The basic documents for sub-group consideration comprised a table containing the scientific recommendations from the ACIA, prepared in advance of the meeting by the rapporteur of Sub-group 1 and distributed to participants by the AMAP Secretariat, and the ACIA Policy Document from the Fourth AC Ministerial Meeting.

The sub-groups met from 11.00 hrs on 15 June to 10.50 hrs on 17 June, with several plenary sessions to review progress and exchange proposals. At a plenary session on 16 June, Sub-group 4 proposed the addition of several columns to the table of scientific recommendations to provide information concerning whether the action required would be under the purview of AMAP, as

well as more details on the types of activities recommended and their geographical scope. Subsequently, Sub-group 3 also requested the addition of several columns regarding whether indigenous knowledge and capacity were applicable to each recommended activity.

Each sub-group used a different approach in its work, as reflected in the sub-group reports and how they filled in the additional columns on the table of scientific recommendations from the ACIA. The sub-group reports, including the record of their discussions and their scientific and policy recommendations, are given below. The compiled table of scientific recommendations from the ACIA, including the columns added by the sub-groups, is attached as Annex 3.

1 Report of Sub-Group 1: Physical climate—past, present, future (Chapters 2, 4, 5)

Participants: Vitali Fioletov (Meteorological Service of Canada, Downsview, ONT), Sebastian Gerland (Norwegian Polar Institute, Tromsø), Bruce McArthur (Meteorological Service of Canada, Downsview, ONT), James Overland (NOAA Pacific Marine Environmental Laboratory, Seattle, WA), Janet Pawlak, Rapporteur (MEC, Copenhagen), Hanne Petersen, Chair (Danish Polar Center, Copenhagen), Aapo Tanskanen (Finnish Meteorological Institute, Helsinki).

1.1 Review of scientific recommendations from ACIA

The Sub-Group reviewed the table containing the recommendations from the ACIA for Chapter 2 (Arctic Climate – Past and Present), Chapter 4 (Future Climate Change: Modeling and Scenarios for the Arctic), and Chapter 5 (Ozone and Ultraviolet Radiation). A summary of the comments is provided below along with the final recommendations from the Sub-Group.

1.1.1 Chapter 2 issues and recommendations

Key issues identified were:

- 1) Better understanding is needed of natural variability from anthropogenic signals, e.g., covering temperature vs. surface temperature and pressure, derived windfields, etc. This should include a better understanding of decadal variability in temperature and pressure, also on a smaller geographical scale;
- 2) Better estimation is needed of the influence of albedo feedback, e.g., from reduced ice cover and other changed conditions;
- 3) Is there a need for indicators for climate change? Potential indicators could include surface temperature and pressure, stratospheric temperature, ice concentration and ice thickness, tundra area, permafrost area, duration of snow cover, precipitation rates, bottom Atlantic water inflow, biological indicators.

Priority issues: sea-ice thickness is a major issue but is not a routine part of an observing set, so an AMAP recommendation to measure this could be useful (but should be taken together with other parameters for proper interpretation, including sea surface temperature and air pressure). Sea ice thickness is a useful parameter owing to its potential feedback between the atmosphere and the ocean and also because of its role as an indicator of climate change.

The change of tundra to wetlands and shrubs can have a large influence, but the effect is very difficult to measure.

It was felt that there a need to protect monitoring programmes that are currently ongoing, given that the number of stations is being decreased and manned stations are being made automatic, with attendant decrease in the value of the data. The switch from manned to automatic stations also has implications for the continuity of time-series data, as certain procedures will inevitably change when automating the data collection. There is a strong priority need for manned upper air stations.

It could be useful for AMAP to stress the need for certain programmes that conduct long-term monitoring of aerosols, etc., in terms of climate change studies; this could serve to help maintain monitoring programmes that may have difficulty maintaining funding.

Proxy studies (e.g., using trees, lake sediments, ice cores) are needed to estimate past temperature trends and estimate the large natural variability and regional differences.

The table of recommendations had only identified one recommendation in Chapter 2 and this was quite general. Instead of this recommendation, the Sub-Group agreed on four detailed recommendations, as listed below.

Chapter 2 recommendations

It is important to track a range of Arctic climate and ecosystem indicators to assess ongoing changes and understand the relative roles of natural variability, anthropogenic forcing, and feedback processes. Such indicators include, but are not limited to, surface and stratospheric temperatures, ice concentration and thickness, tundra and permafrost areas, duration of snow cover, biological parameters, such as species composition and diversity, etc., and human health indicators.

In situ measurements form the backbone of monitoring, while remote sensing provides broad spatial coverage. AMAP should recommend the protection of ongoing monitoring programmes, such as:

- Upper-air sonding and meteorological stations;
- Aerosols in connection with aerosol-cloud interactions and greenhouse gas balance in Arctic regions;
- Satellite observations of radiation for determination of temperature and radiative vertical profiles of temperature and humidity, clouds, sea-ice and tundra properties;
- International Arctic Buoy Program;
- Ecosystem monitoring (e.g., Zackenberg programme, fisheries surveys, ITEX);
- Ocean measurements such as ASOF, NPEO (this should be elaborated by other groups);
- Monitoring health effects in humans.

AMAP recommends the promotion of long-term monitoring of sea-ice thickness and glacier mass balance, and the coordination of archival of past measurements by CLiC.

AMAP recommends increased analysis of paleo-measurements for the previous three centuries in the Arctic, noting regional, seasonal, and annual differences.

1.1.2 Chapter 4 issues and recommendations

There were a large number of recommendations that had been extracted from Chapter 4 for the table of recommendations; this large number had been reduced to six by the lead author of the chapter, and the Sub-Group reviewed the author's six comments.

The first comment related to the large natural variability in the Arctic. It was noted that model simulations will become better in the next generation of models. AMAP could review the IPCC4 models to evaluate the output from the ensemble simulations with regard to the ACIA report. Currently, each country is doing some evaluation of these outputs. It would be useful for AMAP to contact some of the countries to coordinate the evaluations in relation to the Arctic. AMAP could serve as a convener for this work and collect together the information and evaluations for the Arctic.

The question was raised as to whether the IPCC models contain all the necessary parameters. The ACIA process has identified missing parameters in relation to the Arctic. The other entries under Chapter 4 provide more details about the model requirements needed for the Arctic; these recommendations can serve as a checklist of what the next models need to include. In addition, there is a need for further research to understand processes, as covered in the last three of the author's comments. The first evaluation could be a two-year project, together with a five-year project to include more Arctic-specific model parameters.

Highly dynamic, rapidly occurring processes (ice melts, brief warm periods) also need to be covered in models to refine their application. ACIA findings should be reported to other groups so that they can feed into the work of those groups.

With regard to the author's recommendation concerning fine-scale modeling, the fine-scale resolution should be part of the above exercise. We will need to discuss the extent to which an Arctic-specific model is necessary.

The sixth comment by the author concerned the importance of remote sensing to improve observational coverage of the Arctic. There was divided opinion in the Sub-group as to the value of remote sensing for the parameters listed (clouds, winds, pressure, temperature, and humidity), especially surface values. On the other hand, remote sensing is the only way to obtain data on a broad spatial basis. Radiation budgets, cloud amount and type, and vertical temperature structures are the parameters that can best be measured using remote sensing. However, remote sensing of clouds is not always satisfactory; new techniques may provide improvements (e.g., Cloudsat—to be launched in August in a polar orbit), but these need to be validated first. A combination of surface observations and remote sensing is necessary to take a large step ahead, combined also with modeling.

The need for Arctic regional models to provide high spatial resolution was noted. Current GCMs are becoming more refined, but will not come down to the km level that is needed for the Arctic, nor will they be able to adequately cover all Arctic processes.

Based on this discussion, the Sub-Group agreed on the first two specific recommendations below. On Friday, the lead author of Chapter 4 joined the meeting, and two additional recommendations were formulated.

Chapter 4 recommendations

AMAP should promote understanding of how global atmosphere-ocean processes influence climate in the Arctic region. AMAP recommends that further efforts be placed on the use of global circulation models and retrospective data analysis in relation to the Arctic.

AMAP should review the now available IPCC4 model outputs with reference to the conclusions of the ACIA report. Work is under way in several countries and AMAP could coordinate evaluations in relation to the Arctic.

AMAP should encourage the development of Arctic-oriented re-analysis of observational ocean-ice-atmosphere data as Arctic models improve and observations increase during the IPY period.

AMAP should promote observations and regional (as well as small-scale and large-scale) modeling with regard to Arctic-specific processes shaping the Arctic response and feedback to global climate change. Examples of important processes include:

- energy balance of sea ice, tundra, and glaciers, including albedo feedback;
- radiative feedbacks influenced by ozone, greenhouse gas balance, aerosols, and clouds;
- hydrologic cycle;
- ocean processes.

1.1.3 Chapter 5 issues and recommendations

A full understanding is needed of the interaction between climate change and ozone levels. An understanding is also needed of the interaction of the low-temperature stratospheric vortex in relation to the chemical processes regulating ozone production and depletion.

The role of aerosols in all relevant processes is not clear. This is a very large question and it impacts on many processes with potential positive and negative influences. Process studies are necessary, but a smaller-scale model is needed to use these results.

Maps of current UV monitoring in the Arctic show that many areas are not being monitored. However, to be really useful, spectral measurements (broad-band or multi-filter measurements) are required. A minimum number of high-caliber UV observations is needed across the Arctic and validation of satellite data will be needed to provide an adequate spatial coverage. UV measurements are the ultimate validation for remote sensing observations.

While it is useful to have some monitoring stations with high-quality instruments to validate remote sensing observations, it would also be useful to have a larger number of monitoring stations with less high-quality instruments that could provide better spatial coverage. All such stations would need to be maintained in a proper way.

Recognizing the significance that UV radiation has on humans and biota, more coordinated measurements of UV should be made across the Arctic. Possible differences between the degree of the effects on the different biological communities in Arctic ecosystems and on humans could also be studied, given that humans can take measures to protect themselves from UV while biota cannot.

UV monitoring is needed at some sites, together with models to provide a broader picture. Such monitoring should be tied to ecosystem studies to provide information on the impacts of the UV levels observed. Thus, monitoring stations should have broad capability to monitor other relevant parameters. At many of these sites, it may be better to use a multi-filter instrument, with less precision but better temporal resolution, rather than a highly accurate spectroradiometer.

The Sub-group concluded with regard to modelling that:

- 1) There is a need for better ice models: for glacial melts, sea-ice, etc. There is a need to have a better understanding of how the large ice masses will disappear (Greenland ice sheets and glaciers) and this will include integration of knowledge from other scientific fields.
- 2) There is a need to look at smaller scales, which raises many issues that are not of interest at the global scale, but are very important at the Arctic scale. This implies the need to develop more process-based models on a finer scale.
- 3) High-quality multidisciplinary process studies would be very useful to further develop the models; these should look at physical, chemical, and biological processes and their linkages to provide a better understanding of the Arctic ecosystems.

Regarding data, the Sub-group concluded that:

- 1) There are very few data concerning cryo-hydrological cycle processes.
- 2) A problem is to be able to obtain data, much of which is buried in institutes and not available broadly. IPY should help identify such data and make them available to a larger community.
- 3) Projects should ensure that the data collected are reported and handled in an agreed, standard way to permit easy access and use of the data. Although data formats are not popular, they are necessary to promote appropriate reporting and handling of the data.
- 4) Global solar radiation level data would be useful, but it was unclear to what extent this has been covered in the ACIA.

Based on this discussion, the Sub-group agreed the recommendations below.

Chapter 5 recommendations

There is a need for establishing a stronger link between the atmospheric science community and the community studying the effects of UV radiation on health and Arctic biology. This should include the following:

- 3) Undertaking cross-disciplinary studies to determine the biological effects of UV irradiance, which requires cooperation between the UV radiation monitoring community and the biological and impacts communities. Many questions remain concerning the impacts of UV radiation on individual species, ecosystems, and human health; understanding the magnitude of potential impacts will be critical for future policy decisions;
- 4) UV monitoring is needed at some sites together with models to provide a broader picture. Such monitoring should be tied to ecosystem studies to provide information on the impacts of the UV levels observed. Thus, monitoring stations should have broad

capability to monitor other relevant parameters. In many of these sites, it may be better to use a multi-filter instrument, with less precision but better temporal resolution, rather than a highly accurate spectroradiometer.

What is needed is a full understanding of the interaction of climate change and ozone levels in the Arctic. An understanding is needed of the interaction of the low-temperature stratospheric vortex in relation to the chemical processes regulating ozone production and depletion. Ozone monitoring, including ozone vertical profiles, should be maintained or increased in the Arctic. At the present time, there are large regions of the Arctic where no ozone sonde vertical profiles are available.

In addition to the available scenarios for future ozone, there is a need for an update of scenarios for future UV levels in the Arctic and an assessment of the implications. This will require scenarios for snow, aerosol, and clouds.

Satellite instruments can contribute monitoring of both ozone and UV, particularly over areas without ground-based measurements. However, distinguishing between snow and cloud cover is still a challenge for satellite UV algorithms.

1.2 Review of ACIA Policy Document

The ACIA Policy Document was reviewed and the following comments were made:

- 3) The recommendations developed by the Sub-group support the policy document.
- 4) The Policy Document recommendations support the need for enhanced scientific and monitoring data to improve our knowledge of the Arctic and reduce the uncertainty in climate projections.

With regard to outreach, it was noted that there were some statements in the executive summary of the overview document “Impacts of a Warming Arctic” that do not correspond to the scientific background document. For example, the executive summary could be interpreted as indicating that CO₂ is the main source of the climate change in the Arctic, however, the main scientific document indicates that natural variability and feedbacks are also important. The recommendations made at the AMAP ACIA Workshop regarding modeling and monitoring will provide increased reliability of future estimates of Arctic change. In addition, the statement in that document that human lifetime UV doses will increase by 30% in the future is an exaggeration and cannot be found in the scientific background document.

This Workshop recommends that the Arctic Council working groups develop an outreach strategy to be prepared to answer questions regarding the overview document.

2 Report of Sub-group 2: Cryosphere, Hydrology, Freshwater, Marine, Fisheries (Chapters 6, 8, 9, 13)

Participants: Jocelyne Bourgeois (Natural Resources Canada), John Calder, Chair (NOAA, Silver Spring, MD), Øyvind Christophersen (Norwegian Pollution Control Authority, Oslo), Gary Clow (U.S. Geological Survey, Denver, CO), Ken Drinkwater, Rapporteur (Institute of Marine Research, Bergen), Bogi Hansen (The Fisheries Laboratory Nóatún, Tórshavn), Alexander Klepikov (Arctic and Antarctic Research Institute, St. Petersburg), Atte Korhola

(University of Helsinki), Tómas Johannesson (Icelandic Meteorological Office, Reykjavik), Jim Reist (Freshwater Institute Department of Fisheries and Oceans, Winnipeg), Per Schriver (Department of Environment, Ministry of Environment and Nature, Nuuk), Yuri Sytchev (AMAP Secretariat).

2.1 Review of scientific recommendations from ACIA

The Sub-group considered recommendations from Chapter 6 (Cryosphere and Hydrology), Chapter 8 (Freshwater Ecosystems and Fisheries), Chapter 9 (Marine Systems), and Chapter 13 (Fisheries and Aquaculture). The Sub-group began with a “brainstorming” session using the recommendations for the various relevant chapters as a guide.

Cryosphere

Declassification of data (especially in Russia and the U.S.) is needed along with rescue of existing data, not only for the cryosphere but for all sectors.

There is a lack of freshwater focus in ACIA work given the important role freshwater plays as a link between the atmosphere and the marine environment.

Accurate baseline inventories of glaciers, ice caps, and ice sheets are required in order to detect changes over the years. Present-day surface mapping procedures using radar from aircraft allow for the estimation of glacier volumes and should be used in such an inventory. This could be done as part of the IPY activities. Assessment of contaminants on glaciers and in glacial meltwater should be carried out.

Other physical baseline databases need to be established, e.g., timing of sea-ice break up and formation, etc. Biological baselines are especially lacking, e.g., location of the treelines, timing of bird migrations, biological phenology, etc., and should begin to be addressed. Once established, there should be open access to these baseline data.

Given that we cannot monitor everything, careful consideration should be given to determining the most important variables and where they should be measured.

Thermohaline circulation (THC) was considered to be one of those important variables because of the large-scale impact it has on the Arctic. A weakening or shut down of the THC could lead to rapid climate change in the Arctic, resulting in cooling even under anthropogenic warming of the globe as a whole. We do not know the critical limits of the strength of the THC that could lead to the switch from warming to cooling in the Arctic. Also, because it is likely to occur rapidly if it happened, it would be expected to lead to large ecosystem responses with tremendous socio-economic impacts.

The limits of environmental change that trigger ecosystem regime shifts are unknown.

The freshwater budget within the Arctic has not been adequately determined. This will require improved gauging of freshwater runoff and monitoring of precipitation and evaporation. Also, the freshwater fluxes leaving the Arctic through sea-ice are unknown and need to be monitored. Because ice in the river makes monitoring of the runoff difficult using conventional gauges, it was suggested to estimate runoff through monitoring changes in river ice volume.

While programmes to monitor permafrost are ongoing, they are limited geographically. There is a need to broaden the spatial coverage. In order to model permafrost and possible changes under warming scenarios, data on the spatial distribution of material properties, i.e., soils, are required. This is another example of a baseline database.

Freshwater

Increased melting of snow pack and glaciers in the coming years due to warming will result in increased river discharge for a number of years with increased potential for hydropower. This may have a big impact and is presently being studied within the Nordic countries.

Although there were few recommendations that were listed for Chapter 8 on freshwater, there are many more in the chapter itself. For example, the chapter notes that contaminant transport will change due to shifts in freshwater budgets, episodic releases as pulses driven by, e.g., snow melt, a restructuring of ecosystems through regime shifts that will change contaminant pathways and rates, UV changes and their effect on biota, the possibility of accumulated and synergistic effects of contaminants, etc.

Freshwater runoff is a large gap in Arctic hydrology and necessary if we are to complete the freshwater budget for the Arctic as a whole. Comparative studies of Arctic lakes are needed, not only to understand their physical and chemical properties but also how their ecosystems function. Freshwater ecosystem studies in the Arctic continue to receive little support.

Monitoring is generally biased towards summertime measurements. There is a need to increase winter and springtime monitoring as these are the seasons that are expected to be impacted most under climate change. There is a need for automated sampling stations such as those used in the oceans. Paralleling the research should be a concentrated effort on technological developments for improved monitoring and measurement in the Arctic.

Marine Environment

Improved understanding of links between physical changes and the ecosystem response are needed in order to predict future changes. This is especially important in regions where large changes are to be expected.

Better predictions of atmospheric variables are needed in order to predict the changes to the physical oceanography under future climate change. Of these, winds and P-E are the most important. While these are predicted by GCMs, different models predict different results such that even the direction of the change is in doubt.

Different GCMs provide consistent temperature scenarios for the atmosphere and these were provided for ACIA. However, this is not adequate for determining marine impacts, where knowledge of the changes in the ocean currents, salinity, mixing, and stratification are needed along with temperature. Thus, better coupled atmosphere-ocean models are needed for scenario building that would provide the necessary ocean information required to determine impacts.

For impact studies, regional models are required with higher spatial resolution and different physics than the GCMs in order to be able to resolve some of the smaller-scale features that are of importance to the biology. This is true for the terrestrial ecosystems as well.

Long time-series in the Arctic are few and need to be continued. New time-series need to be established to provide data on those components of the ecosystem that are not presently monitored, e.g., phytoplankton, and in critical locations, e.g., at the boundaries to the Arctic. Decisions on the latter should be taken in conjunction with modeling in order to optimize the data impact.

Extreme events, such as storms, can be important in terms of mixing and primary production and need to be captured in physical and ecosystem models.

Acidification of the ocean due to CO₂ has changed substantially in recent years, e.g., around Iceland, Norway, and the UK. This could be having serious repercussions on the ecosystem, or will do so in the future. How pH changes with depth depends on mixing, which in turn depends upon the winds. Further work on acidification is required to determine its possible effects. This is an example of a “surprise” happening, as it was not predicted. We must be ready to respond to other such “surprises”.

Fisheries

It is clear that better models are needed for fisheries management—ones that include climate effects.

Little is known of the structure and function of fish populations in the Arctic Ocean or of what their response might be to climate change. In the sub-Arctic regions, where commercial fisheries are important, much more is known about the fish populations. While some clear responses to climate variability have been demonstrated, often it is unclear whether the changes to the fish populations that we have seen in the past 50 years or so are due to fishing, climate variability or both together. Determining which will be critical in providing reasonable predictions of what will happen to these fish populations in the future. Future changes to fish populations will not only depend upon climate but also on fishing intensity.

High priority issues of the day tend to be the ones that receive funding. Usually no contingency funding is available for surprises, e.g., acidification of the oceans. There needs to be built in flexibility for such surprises.

Other Issues

Coastal processes are causing high-impact problems in the present-day Arctic, e.g., severe coastal erosion has resulted in some towns having to be moved. Extreme events such as storms and wave surges have caused most of this damage.

The question was raised whether there is a need for real-time data collections and monitoring. In most cases, it was felt that it was not a scientific requirement but it has the advantage of ensuring some data recovery and knowing when instruments are not working or are lost, thus allowing for the possibility of rapid repair or replacement rather than waiting for a year or so to determine whether any data have been collected. There is a cost associated with real-time data collection, however. Decisions have to be user driven.

Another question was whether the Sub-group has to prioritize its list of action items. It was felt that we must develop priorities.

There should be an effort to apply new statistical methods on older data, e.g., non-linear regression, Generalized Additive Models (GAM), and Artificial Neural Networks (ANN).

After lunch, the Chair informed the Sub-group of the various AC working groups: AMAP (contaminants, human health, climate/UV); CAFF (biodiversity and key species) and a joint monitoring activity that is to be developed between AMAP and CAFF covering all of the areas for which they are responsible. There is also SDWG (Sustainable Development WG), which is new, developing, and hence not much has been done yet; EPPR (Emergency Prevention, Preparedness and Response), which among other things is looking at radioactivity issues; and PAME (Protection of the Arctic Marine Environment). AMAP includes climate change as well as contaminated-related issues. AMAP will develop a Workplan on climate change as a result of this workshop and, if adopted by AC, then AMAP WG members would raise funds to carry it forward. In some countries, the AMAP recommendations help to raise funds, while in others they may not help.

In reviewing the “brainstorming” issues from the morning, they could be broadly structured under the following major topics: observations, data issues, modeling, analyses, and management.

It was noted that under climate change there might be a mobilization of contaminants such that the Arctic may become a source rather than a sink. Also, it is expected that species distributions will shift northwards and that there will be colonization of new species in some regions.

The rest of the day was spent in developing major recommendations (see below).

Day 2

The Sub-group returned to its major recommendations to refine the wording and add other issues that were not previously included. New issues discussed are indicated below.

The Russian data that will be rescued will also have to be quality controlled.

Paleo studies should be mentioned. There have been some very relevant studies in both lakes and the marine environment. The possibility of using and encouraging paleo studies should be explored.

Efforts need to be made to compare TEK with scientific observations. This will allow the use of indigenous data to extrapolate scientific data over a wider area. Comparison between scientific data and TEK has been tried locally in some small regions, e.g., the Tuk Peninsula in the Beaufort Sea by Eddy Carmack and colleagues. AMAP could ask for specific activities from the indigenous communities, such as dates of ice break up. Observers need to describe things similarly, at least in a manner that could be compared.

The integrated observatories need to go beyond AMAP and CAFF to other relevant groups and organizations, e.g., CLIVAR, GLOBEC, etc.

There was a discussion on what AMAP should or could do. It can foster the work, for example, through creating working groups, laying out plans for the work, and analysing the results. The actual collection of the data will be carried out by the individual nations.

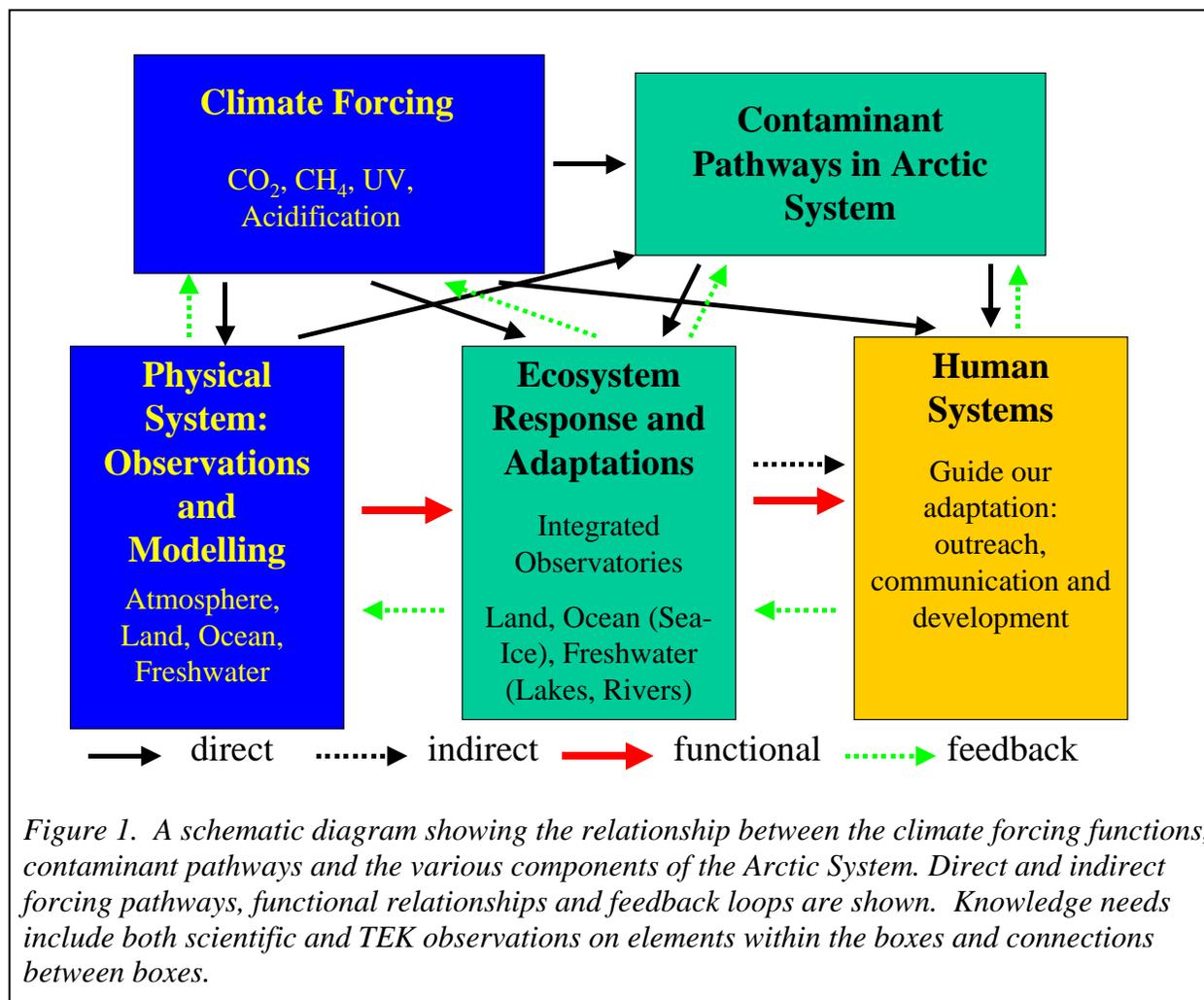
Plans are needed to give credit and permission for the use of data, i.e., the ownership of the data. The indigenous community wishes to have some control of their data, in particular, immediate access and to know who is doing what with the data. There needs to be open access to the data, but not individual credit. Coordinated activities for TEK are not practical. Some research institutions have been formed and they can archive and obtain such data. There are problems of data ownership. Indigenous people want to be able to have the data. The Sub-group agreed to highlight the issues, but not resolve them. In Russia, there have been two training sessions for indigenous people for scientific data collection. Reports on these sessions have been prepared.

Caution was expressed on not overcomplicating the issue. TEK adds value and helps science see different aspects.

2.2 Major recommendations

The Sub-group agreed on the major recommendations provided below.

The ultimate objective is to increase our understanding through observations, modeling, and examination of the paleo records, to enable and refine quantitative predictions of the future state of the Arctic physical and biotic environment for the betterment of human society.



Traditional knowledge and modern science are both considered integral components of the following recommendations. Plans for observational programmes should include from the outset consideration for building and using local capacity, establishing standardization of scientific and indigenous terminology and among indigenous observers, recording observations, storing and disseminating information, and establishing data ownership while maintaining the open access principle. Dialogue among and within the communities is essential for both planning and ongoing implementation (e.g., Russia has conducted two training sessions for the collection of environmental observations for indigenous communities that should be consulted as examples).

It is recognized that the role of Arctic Council Working Groups (e.g., AMAP, CAFF, etc.) in the implementation of these recommendations is primarily to help catalyse, advise on structure, coordinate, and assess results.

In addition to the ongoing research and monitoring activities, the following should receive special attention due to their known importance, lack of data or insufficient understanding.

Physical/Chemical System:

AMAP should lead the efforts to expand the observational networks (both indigenous and scientific) and modeling as a means to provide baseline information, monitor changes in the physical system, develop budgets (e.g., freshwater, heat, etc.), and validate models.

Local capacity will be an important element of conducting these observations.

Development of regional and local models downscaled from the global models is required for improved impact assessments.

As a starting point, AMAP should review reports and plans from, *inter alia*, the U.S. National Academy of Sciences report on Arctic Observing Network, and the implementation strategy to be developed by the International Study of Arctic Change.

From this review, a research and monitoring strategy should be developed to include, for example, the following:

Atmosphere: Winds, P-E, Clouds, Aerosols, Arctic Boundary Layer;
Momentum, heat and moisture fluxes, Radiation balance;
Carbon (CO₂ and CH₄) fluxes between air/land, air/ocean.

Ocean: Thermohaline Circulation;
Fluxes of water and ice into and out of the Arctic;
Sea Level, Wave dynamics;
Acidification.

Cryosphere: Sea-ice (Dynamics, mass balance, icebergs);
Glaciers, Ice Caps and Ice Sheets (Inventory, mass balance, dynamics);
Permafrost (Active layer parameters, thermal state—also to include discontinuous zones).

Hydrology: River flows (including carbon fluxes);
Soil moisture and evapotranspiration.

In performance of these observations, a continuing dialogue with indigenous experts regarding the integrated state of the environment will aid in the interpretation of scientific observations.

Ecosystem Response and Adaptation:

AMAP with CAFF and other relevant partners should establish a network of integrated observatories³ (i.e., at least within the four ACIA sub-regions and preferably across latitudinal gradients, where appropriate) for each of lake, river, terrestrial, and marine (including ice-based) ecosystems to:

- provide a baseline (including acquisition of relevant paleo data) and to understand ecosystem structure (i.e., biodiversity);
- conduct long-term physical and biological monitoring to detect variability and change;
- understand functional relationships and processes;
- assess the ecosystem response to climate/UV/acidification change in the context of other large-scale changes (i.e., human habitation, etc.);
- use the above to model and predict future system states;
- establish a collaborative indigenous observation program⁴ to ensure integration and comparability of TEK and scientific knowledge and permit extrapolation of scientific information to areas where presently only TEK information exists.

Human Systems:

All WGs of the AC should work together to establish an outreach and communication process (recognizing differences in languages and cultures) to guide adaptation, including new management and research strategies, to:

- shifts in renewable resource patterns (commercial, subsistence, recreation);
- shifts in transportation (e.g., marine, ice road);
- non-renewable resource extraction;
- shifts in traditional lifestyles;
- changes in hydropower production;
- changes in coastal dynamics (e.g., sea level rise, coastal erosion);
- changes in infrastructure needs (e.g., permafrost degradation);
- changes in economic development (e.g., tourism, recreation, industrial development, population changes, etc.);
- outreach to science and policy communities in lower latitudes;
- report to UNFCCC and IPCC.

³ See Box 1 for a description of “integrated observatories”.

⁴ See Box 2 for a description of “collaborative indigenous observation program”.

(The Arctic Human Development Report should be reviewed for guidance to outreach and communication needs.)

Data Issues:

AMAP and CAFF should take appropriate steps to ensure development, recovery, management, and dissemination of both scientific and traditional data/knowledge. This should include:

- data rescue, with necessary quality control (e.g., time stamps, frequency, etc.);
- dataset development for analyses (including model results);
- data archiving (including migration to new technologies);
- integrating TEK and scientific knowledge.

Assessments:

The AC in association with other interested organizations should produce periodic assessments of climate change and impacts in the Arctic as follows:

- a comprehensive assessment every 10 years;
- targeted assessments as appropriate.

Policy Recommendation:

AMAP should (1) document the current rate of carbon storage in the Arctic marine, freshwater, and terrestrial environments to determine its importance in the global balance, (2) assess possible future changes in carbon storage under global warming, and (3) identify possible mitigation efforts to maintain and enhance carbon storage in the Arctic.

In order to meet the above objectives under each of the systems and fulfill obligations to Arctic peoples, governments should develop internal and international policies, and commit long-term funds to the establishment and maintenance of these programs. Such funds should be in addition to existing competitive scientific funding.

Box 1 – Integrated Observatories

The various components of, and the freshwater, marine, and terrestrial ecosystems themselves, are typically studied from a reductionist scientific perspective. Recognizing that interconnections exist among ecosystem components and between ecosystems themselves, climate change effects can be both direct upon the component/ecosystem as well as result in indirect effects transmitted between systems.

Accordingly, the ideal approach to integrated observations includes, firstly, the collection of data for as large a suite as possible of variables within particular ecosystems including, for example, all relevant climate forcing factors, physical/chemical/biotic elements, and human dimensions for studied ecosystems. At a minimum, such studies should be conducted upon representative marine, freshwater, and terrestrial ecosystems in each of the ACIA sub-regions.

Secondly, to understand connections among ecosystems types and the consequences of climate change to these, integrated observations are required for connected freshwater, marine, and terrestrial ecosystems, each of which measures the suite of parameters noted above.

When linked to a specific geographic area (e.g., ACIA sub-regions) each of the approaches—comprehensive, integrated assessment within major ecosystems, and also between ecosystem types—constitutes an “Integrated Observatory” (IO) at different scales.

Individual IOs must be situated within each ACIA sub-region and repeated where/if diversity exists in ecosystem types (e.g., over latitudinal ranges). They must exist at a scale sufficient to encompass all relevant components and processes. For example, within the terrestrial system, at least three, and perhaps more, different ecosystems could be studied: polar desert, tundra, and northern boreal forest. Similarly, freshwater systems could include both flowing and standing water types (e.g., rivers and lakes) and various subtypes within each of these (e.g., ponds, lakes), and marine systems could include estuarine, nearshore, and offshore ecosystems. Furthermore, terrestrial-freshwater-delta-estuarine-marine connected systems must also be studied in an integrated fashion at an appropriate scale.

Box 2 - Collaborative indigenous observation programs

“Indigenous observations” are here taken to mean indications about the *status* of the environment and *changes* in the environment that may be detected by the daily interaction of indigenous peoples with their environment. It may also include similar information from fishermen, loggers, hunters, farmers, and others with experiential knowledge of the Arctic. It must be kept in mind that considerable effort is needed to identify, interpret, and communicate such indications so that they become suitable for use in a scientific context. Many subjective indications of changes are affected by the shortness of people’s memory about the past due to time-scale inconsistencies. Some informants may give misleading indications of changes or be unwilling to share what they consider data of a privileged or personal nature. Therefore, careful preparations are needed to ensure that useful data are collected and a collaborative effort between scientists and the local people is made. One way to facilitate this is to incorporate local scientific institutes in the respective Arctic areas as an integral part of such collaborative research programs. It is also preferable that databases created by programs of this kind be managed by such institutes. These programs should include scientific capacity building in the respective local societies whenever possible, and develop a method for sharing the data and the products.

3 Report of Sub-group 3: Wildlife, Hunting and Herding, Human Health, Indigenous Peoples Issues (Chapters 3, 12, 15, 17)

Participants: Jan-Idar Solbakken, Chair (Saami Council, Guovdageaidnu); Terry Fenge, Rapporteur (ICC, Ottawa) **NO LIST OF PARTICIPANTS WAS PROVIDED**

Sub-group 3 covered Chapter 3 (The Changing Arctic: Indigenous Perspectives), Chapter 12 (Hunting, Herding, Fishing and Gathering: Indigenous Peoples and Renewable Resource Use in the Arctic), Chapter 15 (Human Health), and Chapter 17 (Climate Change in the Context of Multiple Stressors and Resilience). The Sub-group concentrated its work on the ACIA Policy Document and the recommendations all relate to that document. Italicized paragraphs in the section below are direct quotations from this Policy Document.

3.1 Major recommendations

Major Themes

The major themes considered by Sub-group 3 are as follows:

- Use and management of indigenous knowledge;
- Communication;
- Education and outreach;
- Partnership development;
- Indigenous Rights;
- Application of local capacity and resources;
- Practical applications of research finding;
- Funding challenges and mechanisms.

Mitigation Recommendations

Given that Arctic Nations collectively represent 40% of global warming pollution emission, we urge aggressive collective and individual actions at all levels to advance mitigation actions within and beyond the region. We recommend the following:

5. Member states report back to the Arctic Council on how they have considered the ACIA findings in implementing their commitments under the UNFCCC and other agreements; and the Council compile and produce a report with this information.
6. Engagement of relevant sectors in outreach and communication in developing and adopting mitigation strategies; build indigenous capacity to be effective partners in these mitigation strategies
7. The initiation of the development and adoption of alternative energy sources and technologies to promote renewable energy production and more efficient energy use at the federal, state, and local levels; initiate a circumpolar prototype project through the Sustainable Development Working Group.

8. Efforts be made by member states to develop forestry and energy policies that conserve and enhance carbon sinks and reservoirs.

Adaptation Recommendations

“Work closely with Arctic residents, including indigenous and local communities, to help them to adapt to and manage the environmental, economic and social impacts of climate change and ultraviolet radiation change. Adaptation needs will vary. Arctic residents may need inter alia enhanced access to information, decision makers, and institutional capacity building to safeguard their health, culture and well-being.”

Based on these policy guidelines, we recommend that:

10. Best management practices be applied in the use of traditional knowledge in adaptation planning and management.
11. The Arctic Council should facilitate and fund communication capacity building of Arctic residents to provide enhanced access to information and decision makers.
12. Keep ownership of traditional and local knowledge at the local level.
13. Gaps in indigenous knowledge data should be identified and collated and efforts made to fill in the data set.
14. Research efforts should apply local resources and capacity when possible to achieve greater local ownership, understanding, cooperation, and efficiency.
15. Researchers should coordinate with local and regional key contacts to evaluate opportunities for collaboration with other researchers and local and regional organizations.
16. Devolution of authority and building of leadership and management capacity should be made a priority for local and indigenous residents.
17. Efforts should be made to develop communication in local languages and in culturally appropriate ways.
18. Funding criteria should encourage constructive partnerships between researchers and local and indigenous residents.

“Recognize that opportunities related to climate change, such as increased navigability of sea routes and access to resources, should be developed and managed in a sustainable manner, including through the consideration of environmental and social impacts and taking appropriate measures to protect the environment, local residents and communities.”

3. Development must recognize indigenous rights to resources, and be done in such a way as to include the full involvement and participation of indigenous peoples.
4. Arctic nations should immediately begin to plan and budget adequate resources to provide the capacity to adapt to major changes; local and indigenous people should have full involvement in the decision-making process.

“Implement, as appropriate, adaptive management strategies for Arctic ecosystems, making use of local and indigenous knowledge and participation, review nature conservation and land and resource use policies and programmes, and to the extent possible reduce risks related to infrastructure damage, permafrost degradation, floods and coastal erosion, taking into account costs and benefits.”

7. Perform local and regional climate assessments and develop adaptive management strategies.
8. Develop models and assessment tools that can provide guidance to decision makers and leaders at the local and regional level.
9. Develop models at a scale that will contribute to adaptive management.
10. Develop funding mechanisms which can be applied for adaptation measures rapidly and as new problems emerge.
11. We recommend that member states report back to the Arctic Council on their “review of nature conservation and land and resource use policies and programmes” incorporating locally available indigenous knowledge and participation as required, in the ministerial-endorsed ACIA policy document.
12. We recommend that indigenous peoples organizations report back on the work being done by their member states to develop mitigation recommendations.

“Stress the importance of intensifying natural and social science research on impacts and adaptation, including studies to enhance understanding of fundamental processes and sustainability, procedures for integrating indigenous and local knowledge into scientific studies, and partnerships between indigenous peoples, local communities, and scientists in defining and conducting research and monitoring associated with Arctic climate and ultraviolet radiation changes.”

4. Develop monitoring and research projects which reflect a multi-stressed environment and can be used to develop practical applications to address stresses at the local and regional level.
5. Analyse the AMAP monitoring strategy to reflect the concerns raised by a multi-stressed environment.
6. Develop a cooperative approach to using knowledge and local capacity in social and natural sciences research.

4 Report of Sub-group 4: Forestry and Agriculture, Terrestrial Ecosystems, Conservation and Management (Chapters 7, 10, 11, 14)

Participants: Gunnar Futsæter, Chair (Norwegian Pollution Control Authority, Oslo), Jesper Madsen (Danish Environmental Research Institute, Roskilde), Stephan Norris (WWF, Oslo), Morten Olsen (Danish EPA, Copenhagen), Pål Prestrud (CICERO, Oslo).

Sub-group 4 considered the scientific recommendations from Chapter 7 (Arctic Tundra and Polar Desert Ecosystems), Chapter 10 (Principles of Conserving the Arctic's Biodiversity), Chapter 11 (Management and Conservation of Wildlife in a Changing Arctic Environment), and Chapter 14 (Forests, Land Management, and Agriculture).

The Sub-group considered the recommendations for scientific work from these chapters as contained in the table and decided to add several columns to the table to provide further details concerning the types of actions recommended and other comments. Thus, most of the work of this Sub-group is reflected in the table, which is attached as Annex 3. In addition, the Sub-group reviewed priorities for most of the recommended actions, as reflected in Annex 4; time did not permit a completion of this priority review.

In the discussion, the Sub-group made the following general observations and recommendations:

- The issue of forestry and agriculture does not fit well in the existing structure of the Arctic Council. However, land use, vegetation zones, etc., are important for the understanding of regional and global carbon fluxes and feedback mechanisms, and global climate change understanding and modeling.
- Some recommendations fall between WG mandates or are so broad that they cover several WG mandates, and this gives us a challenge with regard to the responsibility for implementation.
- There is a need to merge recommendations across chapters.
- Since funding is limited, we should discuss which of the key findings are the most important to be strengthened (or to reduce their uncertainty). The highest priority should then be given to the activities that strengthen these key findings.
- To facilitate the prioritizing of activities, it could be useful to categorize/group the activities according to topics. This would better emphasize the topics of higher importance (e.g., carbon cycle, thermohaline circulation)
- There are no recommendations in the science report on mitigation and adaptation. Recommendations on activities/action on these issues need to be developed (cf. the Policy Document's recommendations).
- When all working groups have reviewed the scientific recommendations against their mandates, we suggest that the WGs also discuss how to best coordinate and implement follow-up activities, including the Arctic Council organization of the follow-up work.

5 Plenary discussions and presentations

In plenary discussions, it was agreed that there is a need to synthesize the most important recommendations across the chapters. They should be synthesized according to topics, as there are many overlapping recommendations. Some objectives in the recommendations are so broad that it is not clear which working group or organization is relevant to handle the topic. Furthermore, for each recommendation, an indication should be given of its feasibility and priority, as well as the timing of when it can or should be done.

The workshop noted that the recommendations are very ambitious and will require a large amount of resources to fulfill them. The recommendations will be presented to the Arctic Council and can also be an input to the Second International Conference on Arctic Research Planning (ICARP II), which will be held in Copenhagen in November 2005.

A number of participants gave presentations on various projects in which they are involved. Presentations were given as follows:

- Morten Olsen on DANCEA, a project to document climate change and its impact on the environment in the Arctic, with a special focus on Greenland; as part of this project, the results of the ACIA are being distributed in Greenland via various media;
- Jim Overland on NOAA and the International Polar Year, outlining programmes proposed by the U.S. to contribute to IPY;
- Joan Eamer on ARCIS, a project to link issues facing the Arctic and Small Island Developing States in relation to their vulnerability and response to climate change impacts, providing also outreach and awareness of these issues on a broad basis and assistance in capacity building;
- Svein Mathiesen on RENNETH, an IPY project on coping mechanisms for reindeer herding in a changing climate, that will be carried out by Saami University College, Kautokeino, Norway;
- Ralf Döscher on DAMOCLES, an EU FP6 project with 46 collaborating institutions which aims to better understand climate change and its impact in the Arctic, with special focus on the potential for a significantly reduced sea-ice cover and subsequent impacts this might have on the environment and human activities;
- Ken Drinkwater on the GLOBEC programme Ecosystem Studies of Sub-Arctic Seas (ESSAS), which will compare, quantify, and predict the impact of climate variability and change on the productivity and sustainability of Sub-Arctic Marine Ecosystems;
- Øyvind Christophersen on a Norwegian national ACIA project, an important aspect of which is to assess climate change and its impacts on the area between East Greenland and the Barents Sea;
- Jon Eyvind Uhlman on a new AMAP project on human health in the Arctic.

6 Closing of the meeting

The Chair stated that the draft report of the workshop will be circulated to participants for final comments. The results of the workshop will be used for the AMAP working group meeting in St Petersburg in September. It will also serve as input to the Senior Arctic Officials meeting in October, and will also be given to other Arctic Council working groups for their use. It will also be sent to the IASC. Several participants will also provide the results to the ICARP meeting taking place on the weekend after the workshop.

The Chair then thanked the participants for their contributions and closed the workshop.

Annex 1 : Final Agenda

Final Agenda for the Workshop on Follow-up of ACIA; June 15-17, 2005, Oslo, Norway.

Tuesday	14	Arrivals	
Wednesday	15	0830 – 0900	Registration.
		0900 – 1030	Opening of the workshop. Presentation of participants. Practical information. Approval of the Agenda. Introduction and presentation of the task and objectives for the work. Questions for clarification. Presentation of the draft list of proposals for follow up of projects under AC WGs. Questions for clarification.
		1030 – 1050	Health break.
		1050 – 1200	Organizing sub-groups, based on scientific background, nationality, WG, etc.
		1200 – 1300	Lunch.
		1300 – 1430	Sub-groups updating the draft list of proposals or follow up of projects.
		1430 – 1450	Health break.
		1450 – 1630	Sub-groups continue.
		1630 – 1730	Plenary, summing up the work done by the sub-groups. Questions to be solved? Special wishes for re-organizing the work/sub-groups? Questions and proposals to the Focal Point meeting.
		1730	End of day.
		1900	Dinner
Thursday	16	0900 – 1030	Sub-groups cont. working
		1030 – 1050	Health break
		1050 – 1200	Plenary, summing up the work done by the sub-groups.
		1200 – 1300	Lunch
		1300 - 1430	Updating of the AMAP monitoring programme for Trends and Effects of Climate and UV. What is needed to be adjusted in the programme priorities, recommended methodologies, QA/QC, etc.? Who can take the lead for different issues of concern?

1430 – 1450 Health break.
1450 – 1730 Sub-groups to continue the work.

1900 Dinner.

Friday 17 0900 – 1030 Plenary, summing up the work done by the sub-groups.
1030 – 1050 Health break.
1050 – 1200 Presentation of National and International projects that may contribute to the follow up of ACIA.
Update of the AMAP Project Directory.
1200 – 1300 Lunch.
1300 – 1430 The link and coordination between IPY and the ACIA follow up.
Criteria that might be applied to priorities projects.
Financial possibilities for international projects.
1430 Summing up.
Recommendations.
Closing remarks.
Next meeting.
1500 End of workshop.

The meeting of the Focal Point will be run in parallel with the workshop on Friday.

Annex 2: Final List of Participants

Version: Friday 17 June, 2005

Final Participation List: AMAP Workshop on the Follow-up of ACIA, Oslo, Norway, 14 – 17 June, 2005

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Annex 3: Table of Recommendations:

ANNEX 3

ANNOTATED TABLE OF RECOMMENDED ACTIONS BASED ON ACIA CHAPTERS

The table in this Annex lists the recommendations for action derived from the scientific chapters of the Arctic Climate Impact Assessment report covering research, monitoring, modelling, and other proposed actions. For each entry under the column “Action required”, the section of the chapter from which the recommendation was drawn is indicated in parentheses. Additional recommendations in this column from authors of the respective chapters are shown in italics. Recommendations for “Action required” developed during the Workshop have been underlined. The categories for the columns to the right of “Action required” were decided during the Workshop. Entries for Chapters 15 to 18 were not filled in owing to a lack of time at the Workshop.

Explanation of some of the columns:

AMAP y/n:	y= yes it is relevant to AMAP, n=no
Global, regional, local:	Activities would give input to global, regional or local processes
Essential knowledge:	Y= yes, N= not assessed as essential, but could still be important.
Type of activity:	Modeling = modeling, simulations, scenarios, Effects= Research on specific effects on species, ecosystem components System dynamics= Understanding system dynamics Planning= Management, planning implications Monitoring trends Improving, adjusting methodology Funding
KF:	Key Finding (Numbers refer to relevant Key Findings from the ACIA overview document).

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Model development	1.1 Develop impact models that can be used to address the diversity of topics in this assessment. (p. 8)									
	1.2 Develop models and scenarios that are able to show more detailed regional and sub-regional variations and that can be used for local impact assessments. (p. 8)									
Environmental observations	2.1 The complex processes of the atmosphere, sea-ice, ocean, and terrestrial systems should be further explored in order to improve projections of future climate and to assist in interpreting past climate. As the Arctic is a region of large natural variability and regional differences, more uniform coverage must be obtained to clarify past changes. In order for the quantitative detection of change to be more specific in the future, it is essential that steps be taken now to fill in observational gaps across the Arctic, including the oceans, land, ice, and atmosphere. (§2.8)	Good, but too general; more specific recommendations below								
	<u>2.2 It is important to track a range of Arctic climate and ecosystem indicators to assess ongoing changes and understand the relative roles of natural variability, anthropogenic forcing, and feedback processes. Such indicators include, but are not limited to, surface and stratospheric temperatures, ice concentration and thickness, tundra and permafrost areas, duration of snow cover, biological parameters, such as species composition and diversity, etc., and human health indicators.</u>	Yes	ISAC, IASC, CLIVAR, CLiC, IPA	Yes	Yes	Research, Outreach/ education	Global	Yes	System dynamics	1, 2, 3, 4, 6, 7, 9, 10

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Environmental observations	<p><u>2.3 In situ measurements form the backbone of monitoring, while remote sensing provides broad spatial coverage. AMAP should recommend the protection of ongoing monitoring programmes, such as:</u></p> <ul style="list-style-type: none"> • <u>Upper-air sonding and meteorological stations;</u> • <u>Aerosols in connection with aerosol-cloud interactions and greenhouse gas balance in Arctic regions;</u> • <u>Satellite observations of radiation for determination of temperature and radiative vertical profiles of temperature and humidity, clouds, sea-ice and tundra properties;</u> • <u>International Arctic Buoy Program;</u> • <u>Ecosystem monitoring (e.g., Zackenberg programme, fisheries surveys, ITEX);</u> • <u>Ocean measurements such as ASOF, NPEO (this should be elaborated by other groups);</u> • <u>Monitoring health effects in humans.</u> 	Yes	ISAC, CEON, WMO (GCOS, GAW), WCRP, IABP, UNEP	Yes	Yes	Monitoring, Outreach & education, Capacity building	Global, regional, local	Yes	Monitoring	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
	<p><u>2.4 AMAP recommends the promotion of long-term monitoring of sea-ice thickness and glacier mass balance, and the coordination of archival of past measurements by CLiC.</u></p>	Yes	CLiC, IABP	Yes	Yes	Monitoring, Research, Outreach & education	Global, regional, local	Yes	Monitoring, modeling, process studies	1, 2, 5, 6, 8

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
	<u>2.5 AMAP recommends increased analysis of paleo-measurements for the previous three centuries in the Arctic, noting regional, seasonal, and annual differences.</u>	Yes	PAGES, PARCS, ANSC, GRIP, GISP2, NGRIP, CliC	Yes	Yes	Research, Capacity building	Global, regional	Yes	Analysis, modeling	1, 2, 3, 4, 5
Collection and compilation of indigenous observations	3.1 For some areas, such as the central and eastern Russian Arctic, few or no current records of indigenous observations are available. To detect and interpret climate change, and to determine appropriate response strategies, more research is clearly needed. (§3.6)	Responsibility is across all AC WGs, especially AMAP and CAFF	Several IPY projects, Indig Orgs and communities and others. Other AC WGs and UArctic, national gov't orgs, comanagement orgs	Yes	Yes	Monitoring, Outreach & education, Capacity building	Global, regional, local	Yes	Effects, system dynamics, planning, monitoring trends, method adjustments, funding	8
	3.2 Although much research on knowledge documentation has taken place in Canada, particularly among Inuit, regarding indigenous knowledge of climate change, even there a great deal more can be done. (§3.6)			Yes	Yes					
	3.3 In Eurasia and Greenland, little systematic work on indigenous knowledge has been done, and research in these regions is clearly needed. Indigenous observation networks have been set up in Chukotka, Russia, and some projects have taken place in Alaska, but little systematic work has been done to set up, maintain, and make use of the results from such efforts. (§3.6)			Yes	Yes					

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Research on linking indigenous observations with scientific knowledge	3.4 In terms of indigenous perspectives and interpretations of climate change, most research has taken place in Canada. To date, however, little has been done to connect these perspectives to potential response strategies. Some research on responses has been undertaken recently or is under way in Alaska, but more is needed to determine the needs of those designing response strategies, the ways in which information is used in the process of designing them, and the ways in which researchers and indigenous peoples can contribute to the linking of indigenous and scientific observations of climate change and the interpretation of these observations. More must be done to bridge this gap. (§3.6)	Responsibility is across all AC WGs, especially AMAP and CAFF	Several IPY projects, Indig Orgs and communities and others. Other AC WGs and UArctic, national gov't orgs, comanagement orgs	Yes	Yes	Research, Outreach & education, Capacity building	Global, regional, local	Yes	Modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	8
Research on linking indigenous observations with scientific knowledge	3.5 Problems to be tackled: <ul style="list-style-type: none"> • Determining how indigenous knowledge can best be incorporated into scientific systems of knowledge acquisition and interpretation; • Finding ways to involve indigenous communities in scientific research and to communicate scientific findings to indigenous communities; • Establishing the trust necessary to find appropriate solutions to both goals. Collaborative research is the most promising model for addressing these challenges, Further development of the collaborative model, from small projects to large research programs and extending from identifying research needs to designing response strategies, is an urgent need. (§3.6)	Responsibility is across all AC WGs, especially AMAP and CAFF	Several IPY projects, Indig Orgs and communities and others. Other AC WGs and UArctic, national gov't orgs, comanagement orgs	Yes	Yes	Research, Outreach & education, Capacity building	Global, regional, local	Yes	Modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	8

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
	3.6 Given the widespread indigenous observations of and concern over increased weather variability, this is an important area for further research, particularly in collaboration with meteorologists and climatologists. Some initial work has been done to link indigenous and scientific observations of weather variability for one community on Baffin Island. Further investigation covering a larger region would be useful and desirable. (§3.7)		ment orgs							
Environmental observations	3.7 More information about the potential types of changes that may be seen will help identify particular areas of vulnerability. Increased variability in weather, changes in wind patterns, changes in sea ice and snow, more freeze-thaw cycles, more and stronger storms are topics that are not well addressed in typical climate models. Greater attention to the climate parameters that affect local people and ecosystems directly will help to identify critical areas for local and regional action. (§3.7)	Responsibility across all AC WGs, esp. AMAP & CAFF		Yes	Yes					
Devolution of authority and increase of response options	3.8 Increasing flexibility and the response options available to people will allow a broader array of potential responses. We need to better understand how the devolution of authority and capacity to more local levels enhances or constrains the ability of local people and communities to choose for themselves the responses that make the most sense in their particular situation, given the costs and benefits of those responses. Such responses range from changing regulations concerning resource use to moving settlements to more favorable locations. (§3.7)			Yes	Yes					

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Improvement of climate change predictions for the Arctic	4.1 To provide more reliable climate change scenarios for the Arctic, numerical climate models need further development. This includes physical parameterization schemes, as there is an insufficient knowledge of many of the physical processes active in the Arctic domain. The large-scale flow is dominated by variability patterns such as the AO and the NAO. In climate change simulations, both the frequency and nature of these flow patterns may be altered. To assess changes in the flow patterns, there must be a greater focus on the climate predictability problem to probe the inevitable natural uncertainty. To do this, ensemble projections are required where both initial states and uncertain model parameters are varied within a realistic range associated with a probability distribution. Research and model development priorities should aim at an improvement of AOGCM performance in the Arctic and, particularly, at an increase in the credibility of AOGCM-based projections of future climate. (§4.7)	More specific recommendations below								
Improvement of arctic AO-GCMs: research and model development	4.2 Improvements are needed to sea-ice components of current AOGCMs, including more sophisticated treatments of sea-ice dynamics and thermodynamics and adding (to the extent possible) heat distribution between concurrent lateral and vertical melt or growth of the ice and convective processes inherent in sea ice (melt-pond and brine convection). (§4.7.1)	More specific recommendations below								
	4.3 Further research is needed to understand the physics of the atmospheric boundary layer in the Arctic to develop appropriate parameterizations for use in AOGCMs. (§4.7.1)	More specific recommendations below								
	4.4 Further research is needed to develop better parameterizations of radiative transfer, to account for specific features of the arctic atmosphere and the underlying surface, including both the vertical and horizontal heterogeneity of this complex system. (§4.7.1)									
	4.5 Models need to be improved to better represent the multilayer arctic clouds with their specific complexities associated with mixed phases and low temperatures, as well as the radiative properties of ice crystals and their different types. (§4.7.1)									

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Improvement of arctic AO-GCMs: research and model development	4.6 Future modelling efforts should try to more fully address climate-change effects in the ocean, to provide better projections of changes in such variables as Arctic Ocean temperatures and salinities, stratification, and circulation (including thermohaline circulation); this will require better resolution in the ocean models and improved coupling between the dynamic atmosphere and dynamic ocean components, particularly in the presence of sea ice. (§4.7.1)	More specific recommendations below								
	4.7 For satisfactory simulations of the freshwater budget of the Arctic Ocean, river discharge into the Arctic Ocean needs to be properly represented in order to maintain the observed stratification and sea-ice distribution and transport. Accounting for the freshwater influx into the ocean from glaciers and the Greenland Ice Sheet will require more advanced parameterizations than those employed today and, ideally, require introducing dynamics into the ice-sheet components. (§4.7.1)	More specific recommendations below								
	4.8 The development of comprehensive interactive dynamic vegetation components of AOGCMs should eventually increase confidence in AOGCM-based projections of future climate; these components should include the effects of vegetation on terrestrial snow cover and surface albedo, evapotranspiration processes, and the possible expansion of boreal forests into regions currently occupied by tundra. (§4.7.1)	More specific recommendations below								
Improved resolution of arctic processes	4.9 Models with a high spatial resolution are required to model climatically important processes in the Arctic; regional models are required to complement the global simulations, because their results are closer to actual local climatic conditions and can more easily be translated into impacts than global model results. (§4.7.2)	More specific recommendations below								

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
	4.10 To simulate the coupled atmosphere–ice–ocean system in the Arctic, a high-resolution ocean component is required; as the coupling processes occur on small horizontal and vertical scales, a high-resolution regional coupled atmosphere-ocean model is needed. Some early versions of coupled models exist, but much additional development work is required. (§4.7.2)	More specific recommendations below								
Improved resolution of arctic processes	4.11 A further increase in atmospheric resolution (to <10 km horizontally) will require the use of non-hydrostatic model equations. New parameterizations of physical processes such as cloud formation and turbulence are also necessary at these scales. With a very high resolution (<1 km), non-hydrostatic models start to resolve individual clouds, thus necessitating further changes in cloud parameterizations. (§4.7.2)	More specific recommendations below								
	4.12 Special emphasis is needed on cloud microphysics, including the ice crystals and aerosols that provide nuclei for the condensation process. The arctic climate depends on the unique high-latitude characteristics of processes such as ice dynamics and persistent low-level clouds. Simulation deficiencies are due to coarse model resolution and inadequate model process descriptions. Most model formulations are based on low-latitude observations that do not cover the extreme conditions occurring in the Arctic. To validate coupled high-resolution models in the Arctic, improved and extended observational datasets are required. Some <i>in situ</i> observations exist, but more datasets are needed. To obtain better coverage in space and time, remote sensing instruments are necessary. (§4.7.2)	More specific recommendations below								
Better representation of the stratosphere in AGCMs	4.13 To model current arctic climate and stratospheric and tropospheric ozone concentrations, as well as to project their future changes, AGCMs must describe the troposphere and the stratosphere in comparable detail. In order to resolve vertically propagating waves realistically, more resolution is needed in the middle and upper stratosphere. (§4.7.3)	More specific recommendations below								

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	4.14 A better resolution of the stratosphere in models is required to determine whether the gradual increase in the AO positive phase persistence observed in recent years may be a result of increased atmospheric GHG concentrations, and if it is, whether further increases in GHG concentrations are likely to exert a greater influence on the AO. (§4.7.3)	More specific recommendations below								
Coupling chemical components to GCMs	4.15 GCMs must incorporate detailed photochemical components for better simulation of ozone formation and destruction in the atmosphere. Due to the complicated character of ozone photochemistry in the arctic stratosphere, which has significant input from heterogeneous reactions on polar stratospheric cloud (PSC) particle surfaces, the inclusion of the microphysics of particle formation and destruction must be considered, especially in the simulation of arctic ozone “mini-holes” and their rapid evolution in space and time. (§4.7.4)	More specific recommendations below								
	4.16 The denitrification of cold polar air in winter is another process in the microphysics of PSC formation and the chemistry that activates ozone-depleting chlorine radicals and repartitioning of bromine species resulting in significant denitrified stratospheric layers. This phenomenon as well as the PSC microphysics and chemistry have spatial and temporal scales finer than current GCM and CTM grids can resolve. A suitable parameterization of these effects is needed in addition to an elaboration of the whole photochemical computation scheme. Together with the necessary refinement of the simulation of dynamic processes, these requirements make the problem of arctic ozone modeling computationally demanding and scientifically challenging. (§4.7.4)	More specific recommendations below								

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	4.17 Another atmospheric chemistry aspect of the Arctic is the production of cloud condensation nuclei near the surface and the possible involvement of naturally occurring dimethyl sulfide (DMS) in this process. Dimethyl sulfide particles originate from arctic seawater, and the flux to the atmosphere is strongly coupled to the existence of sea ice. The local arctic production of DMS may be a determining factor for droplet size distributions in low clouds and thus may have a significant effect on low-cloud radiative properties. If this is the case, cloud properties would be sensitive to the occurrence of sea ice and a dramatic change in sea-ice distribution would affect the arctic radiative balance. This type of effect as well as arctic haze effects need to be included in AGCMs. (§4.7.4)	More specific recommendations below								
Ensemble simulations	4.18 Further research is needed to find a reasonable balance between ensemble size, model resolution, and the complexity of physical process descriptions. For climate simulation ensembles, it is also necessary to perturb model parameters and external forcings. The uncertainty aspects to be addressed include natural variability, uncertainties in model sensitivity to prescribed forcings, and uncertainties in the forcings. Estimates of extreme events and their frequency of occurrence also require ensemble simulations. For precipitation in particular, extreme events are often more interesting than changes in the mean. To obtain reliable estimates of changes in the frequency of extreme events, ensemble simulations are necessary. (§4.7.4)	More specific recommendations below								
Model development	4.19 <i>Natural variability is large in the Arctic. Global models still suffer from giving very different climate change projections using the same emission scenarios. We still need to understand why and how this is so. What is an attainable signal/noise ratio? (Author's comment)</i>	More specific recommendations below								
	4.20 <i>Fine-scale modelling for the Arctic is needed, but the quality of results is limited by the global input data. (Author's comment)</i>									

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Research to understand processes	4.21 Arctic warming is mainly restricted to the surface and tied with temperature inversion processes. This is a research area where an enhanced, fundamental understanding of turbulent processes is needed. (Author's comment)	More specific recommendations below								
	4.22 Ice-ocean-atmosphere feedbacks are vital to Arctic warming. Better process understanding is needed. Observations of sea-ice thickness and extent as well as temperature and salinity profiles in the ocean are required. (Author's comment)									
	4.23 Cloud formation and cloud drop/ice size distribution is governed by aerosol formation and transformation. Fundamental process understanding as well as modelling of interactions with the climate system are needed. (Author's comment)									
Remote sensing	4.24 Remote sensing is the best hope for improved observational coverage in the Arctic. Clouds, winds, pressure, temperature, and humidity are basic atmospheric quantities that need to be well observed. (Author's comment)									
	<u>4.25 AMAP should promote understanding of how global atmosphere-ocean processes influence climate in the Arctic region. AMAP recommends that further efforts be placed on the use of global circulation models and retrospective data analysis in relation to the Arctic.</u>	Yes						Yes	Modeling, analysis	
	<u>4.26 AMAP should review the now available IPCC4 model outputs with reference to the conclusions of the ACIA report. Work is under way in several countries and AMAP could coordinate evaluations in relation to the Arctic.</u>	Yes	IPCC, IASC	No	No	Research	Global, regional	Yes	Analysis, modeling	1-10
	<u>4.27 AMAP should encourage the development of Arctic-oriented re-analysis of observational ocean-ice-atmosphere data as Arctic models improve and observations increase during the IPY period.</u>	Yes					Regional, local	Yes	Analysis	

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
	<p>4.28 AMAP should promote observations and regional (as well as <u>small-scale and large-scale</u>) modeling with regard to Arctic-specific processes shaping the Arctic response and feedback to global climate change. Examples of important processes include:</p> <ul style="list-style-type: none"> • <u>energy balance of sea ice, tundra, and glaciers, including albedo feedback;</u> • <u>radiative feedbacks influenced by ozone, greenhouse gas balance, aerosols, and clouds;</u> • <u>hydrologic cycle;</u> • <u>ocean processes.</u> 	Yes	IASC, CLiC, GLOBEC , IGBP	Yes	Yes	Research	Global, regional, local	Yes	Modeling	1–10
Research on ozone levels and UV irradiance	<p>5.1 Four key areas of research activity will improve the ability of the scientific community to assess the changes in and effects of ozone depletion and UV radiation in the Arctic:</p> <p>(1) Addressing unanswered scientific questions concerning variability and long-term changes in both ozone levels and UV irradiance, including improved knowledge to quantify the effects of trace gases, dynamics, and temperature on arctic ozone levels; a better understanding of the influence of climate change on both ozone and UV radiation levels; a better understanding of the controls on and interactions between various processes; and quantifying the following factors across the Arctic: ozone levels, cloud conditions, aerosol concentrations, and surface albedo, which all affect surface UV irradiance. (§5.8)</p>	More specific recommendations in 5.5 to 5.7								

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Monitoring of ozone and UV radiation levels	5.2 (2) Ensuring accurate and comprehensive monitoring of ozone and UV radiation levels. Monitoring efforts are necessary both to document the evolution of ozone and UV radiation levels over time and to validate model projections. Such monitoring should include regional observations, which have been shown to be critical for assessing the overall status of the Arctic, as well as satellite monitoring of the Arctic for most times of the year. Adding UV radiation monitoring in the Russian Arctic and coordinating the existing surface UV radiation and ozone level monitoring throughout the Arctic would allow for a more accurate assessment of the changes that are occurring. Detailed monitoring of trace gases and vertically resolved ozone concentrations is also important. (§5.8)	More specific recommendations in 5.5 to 5.7								
Data analysis and improvement of models	5.3 (3) Improving analysis of emerging data and incorporating this new understanding into modeling efforts. Analyzing the detailed measurements of trace gases, vertically resolved ozone concentrations, and other parameters and using the available information in conjunction with model results will help achieve the best possible insight into future ozone and UV radiation levels, as well as the impacts of specific changes in these levels. Recent studies support the idea that advanced three-dimensional models will be fundamental for obtaining improved projections of future ozone levels over the Arctic. (§5.8)	More specific recommendations in 5.5 to 5.7								
Cross-disciplinary research	5.4 (4) Undertaking cross-disciplinary studies to determine the effects of changes in UV irradiance, which requires coordinated cooperation between the UV radiation monitoring community and the biological and impacts communities. Many questions remain concerning the impacts of UV radiation on individual species, ecosystems, and human health; understanding the magnitude of potential impacts will be critical for future policy decisions. (§5.8)	More specific recommendations in 5.5 to 5.7								

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	<p><u>5.5 There is a need for establishing a stronger link between the atmospheric science community and the community studying the effects of UV radiation on health and Arctic biology. This should include the following:</u></p> <p>5) <u>Undertaking cross-disciplinary studies to determine the biological effects of UV irradiance, which requires cooperation between the UV radiation monitoring community and the biological and impacts communities. Many questions remain concerning the impacts of UV radiation on individual species, ecosystems, and human health; understanding the magnitude of potential impacts will be critical for future policy decisions;</u></p> <p>6) <u>UV monitoring is needed at some sites together with models to provide a broader picture. Such monitoring should be tied to ecosystem studies to provide information on the impacts of the UV levels observed. Thus, monitoring stations should have broad capability to monitor other relevant parameters. In many of these sites, it may be better to use a multi-filter instrument, with less precision but better temporal resolution, rather than a highly accurate spectroradiometer.</u></p>	Yes	e.g., FUVIRC, Abisko, Ny-Aalesund, other national UV monitoring programmes	Yes	Yes	Research, Outreach & education, Capacity building	Regional	Yes	Effects	9, 10
		Yes	National UV monitoring programmes	No	No	Monitoring	Regional	Yes	Monitoring, databases	9
	<p><u>5.6 What is needed is a full understanding of the interaction of climate change and ozone levels in the Arctic. An understanding is needed of the interaction of the low-temperature stratospheric vortex in relation to the chemical processes regulating ozone production and depletion. Ozone monitoring, including ozone vertical profiles, should be maintained or increased in the Arctic. At the present time, there are large regions of the Arctic where no ozone sonde vertical profiles are available.</u></p>	Yes	IASC, NDSC, SPARC, IOC	No	No	Research	Global	Yes	Research, data collection, modeling	1, 2, 9
	<p><u>5.7 In addition to the available scenarios for future ozone, there is a need for an update of scenarios for future UV levels in the Arctic and an assessment of the implications. This will require scenarios for snow, aerosol, and clouds.</u></p>	Yes	UNEP-WMO	No	No	Research	Global, regional	Yes	Modeling	9

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
	<u>5.8 Satellite instruments can contribute monitoring of both ozone and UV, particularly over areas without ground-based measurements. However, distinguishing between snow and cloud cover is still a challenge for satellite UV algorithms.</u>	Yes	ESA, NASA, SPARC, national meteorological institutes, EUMETSAT	No	Yes	Monitoring, Research	Global	Yes	Monitoring, modeling	1, 2, 9
Model validation and comparison	6.1 As models differ widely in their simulations of P and P-E in baseline climate simulations and in projections of future climate, there is a very large range in uncertainty for future rates of moisture supply to the arctic surface. This range in uncertainty should be narrowed by determining the reasons for the large across-model variances in P and E, and by bringing the models' baseline simulations of P and E into closer agreement with observational data. The uncertainty of observational data also indicates a need for collaboration between the observational and modeling communities, including the remote sensing community, in reconciling models and data. In particular, datasets for validating and calibrating model-simulated E (including better use of satellite data) are one of the most urgent needs for developing scenarios of arctic hydrology. (§6.2.5)	Yes	CLIVAR, GTN-H	No	No	Monitoring	Global, regional, local	Yes	Monitoring, modeling	1, 2
	6.2 Among the main challenges involved in modeling ocean mixing in ice-covered seas is a representation of the effects of small-scale inhomogeneities in sea-ice cover. Processes specific to the surface boundary layer are subgrid-scale effects. Their successful representation in a climate model requires a combination of detailed observations, mathematical and physical process modeling, stochastic analysis, and numerical modeling at a range of resolutions and physical complexity. The understanding and modeling of these processes are critical to more consistent and accurate simulations of sea-ice cover and climate. (§6.3.5) <i>(Author's comment: issue of secondary priority; could be deleted or omitted)</i>									

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Monitoring surface albedo	6.3 Data on surface albedo, particularly its seasonal, interannual, and interdecadal variations, are needed for a more rigorous assessment of the albedo–temperature feedback, including its magnitude in the present climate and the validity of its treatment in climate models. (§6.3.5)	Yes	WMO, CLiC, CLIVAR	No	Yes	Monitoring, research	Global, regional	Yes	Modeling, monitoring	1, 2, 3
Monitoring and data collection	6.4 Systematically compiled data on sea-ice thickness are needed to provide a spatial and temporal context for the recent decrease in sea ice observed in the central Arctic Ocean. Satellite techniques for measuring sea-ice thickness throughout the Arctic are particularly valuable. The role of sea-ice variations in the thermohaline circulation of the North Atlantic and the global ocean must be clarified. A better understanding of the relationship between sea ice and ocean circulation is perhaps the highest priority for assessments of arctic–global interactions, given the potential for sea ice to have a substantial effect on the thermohaline circulation, which in turn has the potential to change the climate of northern Europe and much of the Arctic Ocean. (§6.3.5)	Yes	CLiC, CLIVAR	Yes	Yes	Monitoring, Research, Outreach & education	Global, regional	Yes	Monitoring, modeling, system dynamics	1, 2
Environmental observations	6.5 A climatology of the spatial distribution of snow water equivalent in each month is a critical need for model validation and hydrological simulations; this is especially urgent for high latitudes. Information on snow albedo over northern terrestrial regions, especially for vegetated areas and for the late winter and spring seasons when the timing of snowmelt is hydrologically critical, is an additional requirement. (§6.4.5)	Yes	CLiC	Yes	Yes	Monitoring, Research	Regional, local	Yes	Monitoring	1, 2, 3

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Compilation of glacier inventory	6.6 The compilation of an up-to-date global glacier inventory is a critical research need. A global satellite-derived dataset of exposed ice areas is a minimum requirement. Ideally, a complete glacier database describing individual glacier locations, areas, and geometries should be compiled, so that mass-balance measurements on individual benchmark glaciers can be extrapolated to unmeasured glaciers with greater certainty. For future projections, it would be useful to develop additional mass-balance models so that spatial variations can be better depicted and so that the records can be extended back in time at locations for which atmospheric data are available. (§6.5.5)	Yes	MAGICS, IASC GTN-G	No	No	Monitoring, Research	Global, regional	Yes	Monitoring, modeling	1, 2
Research and modeling	6.7 In order to improve projections of future mass-balance changes, the following studies should be given high priority: <ul style="list-style-type: none"> • improving understanding of albedo changes and feedback mechanisms; • studies of outlet glacier dynamics with emphasis on their potential for triggering persistent, rapid changes in ice-sheet volume; • improving ice-dynamic models for determining the long-term response of the ice sheet to past climate change; • improving parameterization and verification of internal-accumulation models; and • improving understanding of the relationships between climate change, meltwater penetration to the bed, and changes in iceberg production. (§6.5.5) <i>(Author's comment: issue of secondary priority; could be deleted or omitted)</i> 									
Model comparison	6.8 In order to improve the credibility of model projections of future permafrost change throughout the Arctic, the soil/vegetation models must be validated in a more spatially comprehensive manner. In particular, there is a need for intercomparison of permafrost models using the same input parameters and standardized measures for quantifying changes in permafrost boundaries. (§6.6.1.5) <i>(Author's comment: issue of secondary priority; could be deleted or omitted)</i>									

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Monitoring of permafrost–climate interactions and coastal and offshore cryosphere	6.9 Long-term field data are required to increase understanding of permafrost–climate interactions and the interaction between permafrost and hydrological processes, and for model improvement and validation. (§6.6.1.5) <i>(Author’s comment: issue of secondary priority; could be deleted or omitted)</i>									
	6.10 A circumpolar program to monitor changes in the coastal and offshore cryosphere is required, as is a better understanding of the processes that drive those changes. There is no monitoring of coastal and subsea permafrost, and this lack represents a critical gap in the understanding of coastal stability in the Arctic. A comprehensive understanding of coastal permafrost processes, including the interaction between storms and permafrost, is needed. The role of brine exclusion and convection in enhancing coastal and subsea permafrost degradation also requires further investigation. (§6.6.2.5)	Yes	CLiC, GTN-P, ACD, IASC	Yes	Yes	Monitoring, Research	Regional, local	Yes	Monitoring, system dynamics	1, 2, 7
Environmental observations	6.11 The gas hydrates in coastal and subsea permafrost require further study in order to evaluate their stability over the range of future climate change scenarios produced by climate models. (§6.6.2.5)	Yes	CLiC, GTN-P, ACD, IASC, oil and gas industry	No	No	Research	Regional, local	Yes	System dynamics, planning	1, 2
Research and modeling on freshwaters	6.12 Critical research needs with regard to river and lake ice include improved understanding of the interacting hydrological and meteorological controls on freeze-up and breakup, reliable projections of changes in these controls over the 21st century, and further refinement of models of lake-ice growth and ablation and river-ice dynamics for use in forecasting future conditions. There is a particular need for more credible model projections of precipitation and surface solar radiative fluxes. (§6.7.5) <i>(Author’s comment: issue of secondary priority; could be deleted or omitted)</i>									

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Enhancement of monitoring network of gauge stations	6.13 Perhaps the most critical need pertaining to surface flows in the Arctic concerns the network of gauge stations for monitoring discharge rates. This network has degraded seriously in the past decade, such that present measurements of surface flows in the Arctic are much less complete than in the recent past. Many of the monitoring station closures have occurred in Russia and Canada, and to a lesser extent in Alaska. It is important to reopen some of these stations or otherwise enhance the current monitoring network. Better estimation of subsurface flows is also required. A related need is an improved understanding of the relationship between net atmospheric moisture input (P-E), river discharge, and changes in permafrost. (§6.7.5)	Yes	WMO, IAHS	Yes	Yes	Monitoring, Research	Global, regional, local	Yes	Monitoring, system dynamics	1, 2
Monitoring coastal surface winds and coastal stability	6.14 Assessments of coastal vulnerability in the Arctic suffer from the limitations of the observational network for monitoring coastal surface winds and coastal stability. Data from the existing station network are of limited utility for driving numerical wave and surge models, which require offshore wind fields. There is even less availability of surface wind data from the Arctic Ocean. Evaluations of current trends in storm events and the associated coastal vulnerabilities will require additional sources of reliable surface wind data from coastal and offshore areas in the Arctic. Observations of coastal responses to wind and sea-level forcing are also essential in order to quantify the relationships between environmental processes and coastal impacts. (§6.7.5)	Yes	WMO, GTN-P	Yes	Yes	Monitoring	Regional, local	Yes	Monitoring	1, 5, 8

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Development of scenarios and long-term experiments Extreme events and thresholds	7.1 Changes in microbe, animal, and plant populations are triggered by trends in climate and UV radiation levels exceeding thresholds, and by extreme events, particularly during winter. However, information is uneven and dominated by trends in summer climate. Appropriate scenarios of extreme events are required, as is deployment of long-term experiments simulating extreme events and future winter processes in particular. A better understanding of thresholds relevant to biological processes is also required. (§7.7.2.1)	Yes	CAFF, WMO, IPCC			Research	Regional	Yes	Models, system dynamics	3, 4, 9
Simulation experiments; monitoring of certain species Biodiversity	7.2 Some groups of species are very likely to be at risk from climate change impacts, and the biodiversity of particular geographic areas is at risk. It is not known whether currently threatened species might proliferate under future warming, nor which currently widespread species might decrease in abundance. The nature of threats to species, including microbes, must be reassessed using long-term climate and UV-B radiation change simulation experiments. There is also a need to identify and monitor currently widespread species that are likely to decline under climate change, and to redefine conservation and protection in the context of climate and UV radiation change. (§7.7.2.1)	(Yes)	CAFF			Research, Monitoring	Regional	No	Effects, management	3, 4, 9
Compilation and analysis of observations Distribution patterns	7.3 The dominant response of current arctic species to climate change is very likely to be relocation rather than adaptation. Relocation possibilities are very likely to vary according to region and geographic barriers. Some changes are already occurring. However, knowledge of rates of relocation, impact of geographic barriers, and current changes is poor. There is a need to measure and project 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. (§7.7.2.1)	(Yes)	CAFF			Monitoring, Research	Regional, local	Yes	System dynamics	3, 4

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Model development and linkage Improved climate model for vegetation distribution	7.4 Forest is very likely to replace a significant proportion of the tundra and is very likely to have a great effect on species composition. However, several processes (including land use and permafrost dynamics) are expected to modify the modeled response of vegetation redistribution related to warming. Models of climate, hydrology (permafrost), ecosystems, and land use need to be developed and linked. These models need to be based on improved information about the current boundaries of major vegetation zones, defined and recorded using standardized protocols. (§7.7.2.1)	(Yes)	CAFF			Research, Monitoring	Regional	No	Modeling	3
Long-term monitoring with better geographical balance; model development Arctic carbon balance	7.5 Current models suggest that arctic vegetation and active-layer soils will be a sink for carbon in the long term because of the northward movement of vegetation zones that are more productive than those they displace. Model output needs to be reconciled with observations that tundra areas that are carbon sources currently exceed those that are carbon sinks, although the measurements of circumpolar carbon balance are very incomplete. To what extent disturbance will reduce the carbon sink strength of the Arctic is also unknown. There is a need to establish long-term, annual carbon monitoring throughout the Arctic; to develop models capable of scaling ecosystem processes from plot experiments to landscapes; to develop observatories, experiments, and models to relate disturbance such as desertification to carbon dynamics; and to improve the geographic balance of observations by increasing high-arctic measurements. There is also a need to combine estimates of ecosystem carbon flux with estimates of carbon flux from thawing permafrost and methane hydrates. (§7.7.2.1)	Yes	Many, coordination needed			Monitoring, Research	Global, regional	Yes	Modeling, system dynamics	1, 2

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Long-term measurements and analysis; model development Improved climate model for vegetation distribution	7.6 Displacement of tundra by forest is very likely to lead to a decrease in albedo with a potential for local warming, whereas carbon sequestration is likely to increase with potential impacts on global concentrations of greenhouse gases. However, the timing of the processes and the balance between the processes are very uncertain. How local factors such as land use, disturbance, tree type, and possible desertification will affect the balance is also uncertain. There is a need for long-term and annual empirical measurements, analysis of past remotely sensed images, and collection of new images together with the development and application of new models that include land use, disturbance, and permafrost dynamics. (§7.7.2.1)	(Yes)	CAFF, SDWG			Research, Monitoring	Regional	No	Modeling	3

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Long-term monitoring and data handling Monitoring	7.7 Long-term environmental and biological monitoring are becoming increasingly necessary to detect change, to validate model projections and results from experiments, and to substantiate measurements made from remote sensing. Present monitoring programs and initiatives are too scarce and are scattered randomly. Data from the Arctic are often not based on organized monitoring schemes, are geographically biased, and are not long-term enough to detect changes in species ranges, natural habitats, animal population cycles, vegetation distribution, and carbon balance. More networks of standardized, long-term monitoring sites are required to better represent environmental and ecosystem variability in the Arctic and particularly sensitive habitats. Because there are interactions among many co-varying environmental variables, monitoring programs should be integrated. Observatories should have the ability to facilitate campaigns to validate output from models or ground-truth observations from remote sensing. There should be collaboration with indigenous and other local peoples' monitoring networks where relevant. It would be advantageous to create a decentralized and distributed, ideally web-based, meta-database from the monitoring and campaign results, including relevant indigenous knowledge. (§7.7.2.2)	Yes	Other monitoring programs and initiatives within and outside AC			Monitoring	Regional	Yes	Monitoring trends	1-5, 8
Processing of remotely sensed data	7.8 Monitoring requires institutions, not necessarily sited in the Arctic, to process remotely sensed data. Much information from satellite and aerial photographs exists already on vegetation change, such as treeline displacement, and on disturbances such as reindeer/caribou overgrazing and insect outbreaks. However, relatively little of this information has been extracted and analyzed. (§7.7.2.2)	(Yes)	GEOSS, GRID			Monitoring	Regional	No	Adjustment of methodology	

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Measurement of carbon fluxes; research to support modeling Arctic carbon balance Overlapping 7.5	7.9 Past temporal and spatial scales of measurement used to directly measure carbon flux have been a poor match for the larger scale of arctic ecosystem modeling and extrapolation. It is a challenge to determine whether flux measurements and model output are complementary. There are significant technological difficulties in extrapolating many non-linear, complex, interacting factors that comprise fluxes at hundreds to thousands of square kilometers over time, space, and levels of biological and environmental organization in the Arctic. Research is needed to better understand how the complex system behaves at the meter scale related to larger spatial scales that can be efficiently modeled and evaluated at the regional and circumpolar scale. To do this, extensive long-term and year-round eddy covariance sites and other long-term flux sites, including repeated aircraft flux measurements and remote sensing, provide the basis for estimating circumpolar net ecosystem CO ₂ exchanges. Currently, the circumpolar Arctic is disproportionately covered by current and recent measurements, with Canadian and high-arctic regions particularly poorly represented. (§7.7.2.2)	Yes	Many, coordination needed			Monitoring, Research	Global, regional	Yes	Models and system dynamics	1, 2
Long-term observations Overlapping 7.7	7.10 Long-term (>10 years) observations and experiments are required in order to enable transient responses to be separated from possible equilibrium responses; increase the chances that disturbances, extreme events, and significant interannual variation in weather are included in the observations; and allow possible thresholds for responses to be experienced. (§7.7.2.2)	Yes	CAFF			Monitoring	Regional, local	Yes	Monitoring trends	1
Year-round observations Overlapping 7.1	7.11 Year-round observations are necessary to understand the importance of winter processes in determining the survival of arctic species and the function of arctic ecosystems. Such observations are necessary to recognize the projected amplification of climate warming in winter and to redress the current experimental bias toward summer-only warming. For microbes, it is particularly important to understand changes in winter respiration and nutrient mobilization during freeze-thaw events in spring and late autumn. (§7.7.2.2)	Yes	CAFF			Monitoring, Research	Regional, local	Yes	Monitoring trends	1

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Improve timing of observations	7.12 It is important to improve the appropriateness of the timing of observations and experiments. For example, current information about the impacts of increased UV-B radiation levels is mainly derived from general summer enhancements or filtration of UV-B radiation, although future increases in UV-B radiation levels are likely to be highest in spring and during specific stratospheric ozone depletion events. The frequency of observations should be fitted to the rate of change of the species or processes of interest, e.g., decadal measurements may suffice for some variables such as treeline movement. (§7.7.2.2)	Yes				Monitoring			Adjustment of methodology	9
Multi-factorial environmental and ecosystem experiments	7.13 Single-factor manipulation experiments have limited applicability because it is clear that there are many interactive effects among co-occurring environmental change variables. There is need for well-designed, large, multifactorial environmental (e.g., climate, UV-B radiation levels, and CO ₂ concentrations) <i>and</i> ecosystem (e.g., species removal and addition) manipulation experiments that are long-term and seek to understand annual, seasonal, and event-based impacts of changing environments. The complexity of appropriate treatments and timescales is vast and the spatial scale is also a significant challenge, as it is important to have manipulations that can be related to larger plants (e.g., trees, shrubs) and animals (e.g., reindeer/caribou). (§7.7.2.2)	Yes	CAFF, ITEX			Research	Local	Yes	Adjustment of methodology, effects	3, 4
Assessing probabilities of cooling THC-monitoring, modeling	7.14 Scenarios of increased temperature dominate the approaches to projecting responses of ecosystems to future climate. However, cooling in some areas remain a possibility. As the impacts of cooling on terrestrial ecosystems and their services to people are likely to be far more dramatic than the impacts of warming, it is timely to reassess the probabilities of cooling projected by GCMs and the appropriateness of assessing cooling impacts on ecosystems. (§7.7.2.2)	Yes	IPCC, EU			Monitoring, Research	Global, regional	Yes	Monitoring trends, modelling	2

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Development of high-resolution models at landscape scale Overlap with 7.9	7.15 High-resolution models are needed at the landscape scale for a range of landscape types that are projected to experience different future envelopes of climate and UV-B radiation levels. Modeling at the landscape scale will simulate local changes that relate to plot-scale experiments and can be validated by results of experiments and field observations. A particular challenge is to provide scenarios for changes in climate and UV-B radiation levels at the scale of tens of meters. (§7.7.2.2)	Yes	CAFF			Monitoring, Research	Regional, local		Adjustment of methodology, effects	9
Long-term funding	7.16 Current short-term funding is inappropriate to support research into long-term processes such as ecosystem responses to climate change and UV-B radiation impacts. A stable commitment to long-term funding is necessary. (§7.7.2.3)		Arctic Council, EU, National research programs, Bill Gates or Ted Turner						Funding	
Circumpolar funding	7.17 Funding possibilities that are restricted to single nations, or only a few nations, make it extremely difficult to implement coordinated research that covers the variability in ecosystems and projected climate change throughout the circumpolar north, even though the instruments for coordination exist. Limitation of international funding possibilities leads to geographic biases and gaps in important information. Circumpolar funding is required so that coordinated projects can operate at geographically appropriate sites over the same time periods. (§7.7.2.3)		Arctic Council, EU, National research programs, Bill Gates or Ted Turner						Funding	

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Integrated circumpolar monitoring of freshwaters	<p>8.1 Filling the gaps listed below, the most outstanding of which include inter-regional differences in the availability of and access to circumpolar research, would greatly improve understanding of the effects of climate and UV radiation change on arctic freshwater ecosystems. Furthermore, comprehensive monitoring programs to quantify the nature, regionality, and progress of climate change and related impacts require development and rapid implementation at representative sites across a broad range of the type and size of aquatic ecosystems found within the various regions of the Arctic. Coupling such programs with ongoing and new research will greatly facilitate meeting the challenges that will result from climate change and increased UV radiation levels in the Arctic. Key scientific gaps are:</p> <ul style="list-style-type: none"> • the limited records of long-term changes in physical, chemical, and biological attributes throughout the Arctic; • differences in the circumpolar availability of biophysical and ecological data (e.g., extremely limited information about habitat requirements of arctic species); • a lack of circumpolar integration of existing data from various countries and disparate programs; • a general lack of integrated, comprehensive monitoring and research programs, at regional, national, and especially circumpolar scales; • a lack of standardized and networked international approaches for monitoring and research; • the paucity of representative sites for comparative analyses, either by freshwater ecosystem type (e.g., small rivers, wetlands, lakes) or by regional geography (ecozone, latitude, elevation); • the unknown synergistic impacts of contaminants and climate change on aquatic organisms; • a limited understanding of the cumulative impacts of multiple environmental stressors on freshwater ecosystems (e.g., land use, fisheries, forestry, flow regulation and impoundment, urbanization, mining, agriculture, and poleward transport of contaminants by invasive/ replacement species); • the unknown effects of extra-arctic large-river transport on freshwater systems induced by southern climate change; • a limited knowledge of the effects of UV radiation–temperature interactions on aquatic biota; • a deficient knowledge of the linkages between structure (i.e., biodiversity) and function of arctic aquatic biota; • a poor knowledge of coupling among physical/chemical and biotic processes; and • a lack of coupled cold-regions hydrological and ecological theories and related projective models. (§8.8.2) 	Yes	CAFF, CLIVAR, GTN-H	Yes	Yes	Monitoring, Research	Regional, local	Yes	All	1, 3, 4, 8, 10

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Administrative, management, and educational actions	<p>8.2 A number of gaps in the scientific understanding of arctic freshwaters could be addressed by the following policy and/or program-related adjustments:</p> <ul style="list-style-type: none"> Establish funding and mechanisms for the creation of a coordinated network of key long-term, representative freshwater sites for comparative monitoring and assessment studies among arctic regions (e.g., creation of a Circumpolar Arctic Aquatic Research and Monitoring Program). Based on the results of this assessment, establish a science advisory board (preferably at the international level) for targeted funding of arctic freshwater research. Secure long-term funding sources, preferably for an international cooperative program, for integrated arctic freshwater research. Adjust current northern fisheries management policies and coordinate with First Nations resource use and consumption. Establish post-secondary education programs focused on freshwater arctic climate change issues at both intra- and extra-arctic educational institutions, preferably involving a circumpolar educational consortium. (§8.8.3) 	No	AC, Ministers and SAO	No	Yes	Outreach & education	Regional	NA—Policy Related	Planning	
Application of observational technologies	9.1 The application of recently developed technologies for marine studies should be increased. Recent developments range from current meters, to satellite sensors, to monitors for marine mammals. (§9.7.2)	Yes	CLIVAR, GLOBEC, CLiC, etc.	No	Yes	Monitoring, Research	Regional, local		Monitoring	1, 2
	9.2 Remote Underwater Vehicles (RUVs) capable of working reliably under the sea ice for extended periods should be developed. This will reduce sampling costs and enable data collection in regions difficult to access using conventional sampling methods. Instrumentation on the RUVs should include means to sample the biota. (§9.7.2)	Yes	CLIVAR, GLOBEC, CLiC, etc.	No	No	Monitoring, Research	Regional, local		Monitoring	1, 2

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Surveying and monitoring	9.3 Surveys should be undertaken in those areas of the marine Arctic that are poorly mapped and whose resident biota have not been surveyed (high priority). These include surveys under the permanent ice cap in winter (perhaps using RUVs), and surveys to quantify the CH ₄ and carbon reserves in the arctic marine sediments. (§9.7.2)	Yes	GLOBEC	No	Yes	Monitoring	Regional, local	Yes	Monitoring	1, 2, 4
Surveying and monitoring	9.4 The existing monitoring programs should be continued and expanded (high priority), both spatially and in breadth of measurement. New monitoring activities should be established in areas where they are presently lacking and these should be designed to address the effects of climate change. Issues to be addressed include the timing and amount of primary and secondary production, larval fish community composition, and reproductive success in marine mammals and seabirds. Key ecosystem components, including non-commercial species, must be included. (§9.7.2)	Yes	GLOBEC, CLIVAR, ASOF, Fisheries groups	Yes	Yes	Monitoring	Regional, local	Yes	Monitoring	1, 2, 4
	9.5 Monitoring data should be evaluated through data analysis and modeling to determine their representativeness in space and time. (§9.7.2)	Yes	GLOBEC, CLIVAR, ASOF, Fisheries groups	No	No	Research	Regional	Yes	Modeling, planning, monitoring	1, 2, 4
Data analysis and reconstruction	9.6 The twentieth-century forcing fields over the arctic regions should be reconstructed. Present reconstructions only extend back to around 1950. These reconstructions would help to model past climates. (§9.7.2)	Yes	GLOBEC, CLIVAR, ASOF, Fisheries groups, WMO	No	No	Monitoring, Research	Global, regional	Yes	Modeling	1
	9.7 An arctic database should be established that contains all available physical and biological data. There should be open access to the database. (§9.7.2)	Yes	WDCs, linked to centers of IK	Yes	Yes	Monitoring	Global, regional, local	Yes	Monitoring	1, 2, 4

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	9.8 Past physical and biological data from the Arctic should be recovered. There are many data that are not presently available but could be recovered. (§9.7.2)	Yes	WDCs, linked to centers of IK	Yes	Yes	Monitoring	Global, regional, local	Yes	Monitoring	1, 2, 4
	9.9 An analysis of past climate events should be undertaken to better understand the physical and biological responses to climate forcing. An example is the dramatic air temperature warming that took place from the 1920s to 1960 in the Arctic. (§9.7.2)	Yes	GLOBEC, CLIVAR	No	No	Monitoring, Research	Regional	Yes	System dynamics	1, 2
Field programs	9.10 Field studies should be undertaken to quantify climate-related processes (high priority). Examples of particular processes that require attention are: open ocean and shelf convection; forces driving the thermohaline circulation (THC); physical and biological processes related to oceanic fronts; sequestrating of carbon in the ocean, including a quantification of air–ice–ocean exchange; long-term effects of UV-B radiation on biota; and interactions between benthic, ice, and pelagic fauna. (§9.7.2)	Yes	GLOBEC, CLIVAR, CAFF	No	Yes	Research	Regional, local	Yes	System dynamics	1, 2, 4
Modeling	9.11 Modeling of the ocean and sea ice in global circulation models should be improved (high priority) to cover such issues as how the THC will change, and the consequences of change in the THC for the position and strength of ocean fronts, ocean current patterns, and vertical stratification. (§9.7.2)	Yes	GLOBEC, CLIVAR	No	No	Research	Global, regional	Yes	System dynamics	1, 2, 4
	9.12 Reliable regional models for the Arctic should be developed (high priority). These are essential for determining impacts on the physics and biology of the marine Arctic. (§9.7.2)	Yes	GLOBEC, CLIVAR	No	No	Research	Global, regional	Yes	System dynamics	1, 2, 4
	9.13 The bio-physical modeling of the Arctic should be strengthened. Increased emphasis is required on coupling biological models with physical models in order to improve predictive capabilities. (§9.7.2)	Yes	GLOBEC, CLIVAR	No	No	Research	Global, regional	Yes	System dynamics	1, 2, 4

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Research	9.14 Ecosystem-based research should be prioritized (high priority). Previous biological research programs were often targeted on single species. While these data are essential for input to larger-scale programs, the approach must be complemented by a more holistic ecosystem-based approach. Alternative concepts, methods, and modeling approaches should be explored. More effort should be placed on integrating multiple ecosystem components into modeling efforts concerning climate effects. Research on microbial communities, which may play a future role in a warmer Arctic, must be included. (§9.7.2)	Yes	GLOBEC, CLIVAR, CAFF	No	Yes	Research	Regional, local	Yes	System dynamics	1, 2, 4
Taxonomy research	10.1 There are many areas of arctic taxonomy that require exploration and research; it is vital to the conservation of the Arctic's biodiversity that these taxonomic subjects are addressed. (§10.4.8)	No	CAFF							
Monitoring biodiversity	10.2 Monitoring is important for understanding how the Arctic's biodiversity is changing and whether actions to conserve biodiversity are being successful; monitoring needs to occur at both the system level and the species level. (§10.4.8)	No	CAFF							
Habitat classification	10.3 There needs to be a supply of trained ecologists who can devise appropriate circum-Arctic classifications of habitats and then survey them so as to measure their extent and quality and to establish their dynamics. (§10.5.1)	No	CAFF							
Inventory of species	10.4 There needs to be a supply of trained taxonomists who can draw up inventories of the Arctic's species. There are already good data on which species of vertebrate animals and vascular plants are to be found in the Arctic, so particular attention needs to be given to the training of taxonomists who can work with non-vascular plants, invertebrate animals, fungi, and micro-organisms (protozoa, bacteria, etc.). (§10.5.1)	No	CAFF							

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Inventory of biodiversity	10.5 Inventories need to be generated for the Arctic's biodiversity (both species and habitats), indicating for each entry in the inventory where it occurs and either the size of the overall species population or the extent of the habitat. Such inventories need to be on a circum-Arctic basis rather than on a national basis as nations with arctic territory also have territory south of the Arctic. (§10.5.1)	No	CAFF							
Research on genetics	10.6 The genetic diversity of many of the Arctic's species is presently poorly known or unknown. Much research is needed to explore this aspect of the Arctic's biodiversity and conservation management will need to ensure that genetic diversity is not lost. (§10.5.1)	No	CAFF							
Management philosophy	10.7 Management of the Arctic's biodiversity must work with ecological succession and not against it. This thinking needs to be incorporated into all aspects of the management of biodiversity in the sea, in freshwater, and on the land. (§10.5.2)	No	CAFF							
Model development	10.8 Models need to be further developed to explore changes in biodiversity under the various scenarios of climate change. These models will need to explore biodiversity change in the sea, in freshwater, and on land. (§10.5.2)	No	CAFF							
Circum-Arctic monitoring networks	10.9 Circum-Arctic monitoring networks need to be fully implemented throughout the Arctic. Data on the state of the Arctic's biodiversity, on the drivers of change in that biodiversity, and on the effectiveness of responses to those changes, need to be collected, analyzed, and used in the development of future arctic biodiversity policy. (§10.5.3)	No	CAFF							
Monitoring strategy	10.10 Attention needs to be given to establishing the kinds of subsidiary aspects of monitoring, such as integrated monitoring and monitoring of phenology, genetic diversity, and invertebrate fauna. These are vital if a holistic view is to be taken of the Arctic's biodiversity, its conservation in the face of a changing climate, and the management of the biodiversity resource for future generations of people to use and enjoy. (§10.5.3)	Yes	CAFF			Monitoring	Regional, local	Yes	Monitoring trends, adjustment of methodology	

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Development of indicators	10.11 A suite of indicators needs to be devised and agreed, monitoring for them undertaken, and the results made publicly available in a format (or formats) so as to inform public opinion, educators, decision-makers, and policy-makers. (§10.5.3)	Yes, in a broad context	All AC WGs			Monitoring	Global, regional, local	Yes	Monitoring trends, adjustment of methodology	
Development of guidelines	10.12 Best practice guidelines need to be prepared for managing all aspects of the Arctic's biodiversity. These need to be prepared on a circumpolar basis and with the involvement of all interested parties. (§10.5.4)	No	CAFF							
Completion of CPAN	10.13 The Circumpolar Protected Area Network needs to be completed and then reviewed so as to ensure that it actually covers the full range of the Arctic's present biodiversity. (§10.5.4)	No	CAFF							
Assessment of protected areas	10.14 An assessment needs to be made for each protected area of the likely effects of climate change, and in the light of this assessment the management methods and any revisions of the area's boundary need to be reviewed. (§10.5.4)	No	CAFF							
Integrated management	10.15 Integrated forms of management, incorporating the requirement for biodiversity conservation, need to be explored for all uses of the land, freshwater, and sea in the Arctic. (§10.5.4)	No	CAFF							
Biodiversity conservation	10.16 Biodiversity conservation needs to be incorporated into all policy development, whether regional, national, or circumpolar. (§10.5.4)	No	CAFF							
Testing of Ecosystem Approach	10.17 The Ecosystem Approach (or Ecosystem-based Approach) should be trialed for a number of situations in the Arctic, so as to assess its ability to harmonize the management of land and water both for the benefit of the local people and for the benefit of wildlife. (§10.5.4)	No	CAFF and other AC WGs							

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Implementation of CBD	10.18 All nations with Arctic territory should be working toward full implementation of the Convention on Biological Diversity, coordinating their work on a circumpolar basis, and reporting both individually and jointly to the regular Conferences of the Parties. (§10.5.4)	No	CAFF							
Management of migratory species	11.1 Management and conservation of migratory or wide-ranging species requires broad participation by all those with interests and responsibilities for arctic wildlife. This requires that management be expanded from local jurisdiction to include regional, national, and international collaboration and shared responsibility in the management of migratory and wide-ranging wildlife. (§11.5.3)	No	CAFF							
Research and monitoring of pollutants and their consequences	11.2 International oversight, coordination, reporting, collating of information, and associated stimulation of national efforts are needed to better understand the importance of pollutants and contaminants entering the Arctic. Inventories and monitoring of the pollutants and contaminants entering arctic ecosystems, and research on their consequences for the health of arctic wildlife, as well as the health of the arctic residents who consume the wildlife, are critical to the management of arctic wildlife. An understanding of the role of pollutants and contaminants in wildlife food chains, wildlife health, and associated human health, and the influence of climate change on these relationships underlies interpretation of the consequences of other environmental variables on wildlife, which is basic to management and conservation of wildlife in the Arctic. The reduction of levels of pollutants and contaminants entering the Arctic, and management of their impacts on arctic wildlife will require action at the national level through joint international efforts. (§11.5.3)	Yes	CAFF			Monitoring, Research	Research	Yes	Effects monitoring, system dynamics, management	10

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Team-building among governments for management and conservation	11.3 Achieving effective conservation and management of wildlife in a changing Arctic will require a team-building approach among governments at all levels that relate to the environment and human well-being, and with all other groups with an interest in the Arctic. This effort should include the indigenous peoples and other residents of the Arctic, and scientists undertaking research in the Arctic, representatives of industry and business seeking development of arctic resources or other economic opportunities in the Arctic, those who travel to the Arctic for recreation or tourism, and the non-governmental organizations seeking to protect or sustain environmental, aesthetic, and other less tangible values of the Arctic in the broader interest of society. The successful management and conservation of arctic wildlife requires that these groups be represented in the management process and that adequate information is available for equitable consideration of the diverse interests that relate to arctic wildlife. The role of international, non-governmental environmental organizations is particularly important in maintaining focus of the public on the broad spectrum of environmental values existing in the Arctic when proposals for large-scale industry- or government-sponsored projects become politicized at the regional or national levels. (§11.5.3)	No	CAFF							
Development of land and water use plans	11.4 <i>Land and water use plans need to be developed on a regional basis throughout the Arctic. These plans will require a detailed inventory of distribution, population numbers, and habitat relations of wildlife and fish species and patterns of human use of fish and wildlife. Well-developed land and water use plans, based on detailed mapping of resource distribution and patterns of human use and dependency, are needed prior to layout of proposed human activities on the land and waters, such as roads, pipelines, shipping routes, communities, other structures, and their cumulative effects to avoid conflicts with critical habitats of wildlife, their movement corridors, and patterns of human use of the wildlife. (Author's comment)</i>	No	SDWG, CAFF, PAME							

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International efforts for marine areas	11.5 <i>The international or bi-national nature of many species of marine wildlife requires international efforts in the development of marine area use and agreements to assure identification and protection of critical habitats for marine wildlife. (Author's comment)</i>	No	PAME, CAFF							
Marine research	11.6 <i>Marine ecosystems are more difficult to study and less well known than terrestrial ecosystems and will require more complex and costly research efforts if arctic wildlife in the marine environment is to be effectively conserved and managed. (Author's comment)</i>	No								
Research on socioeconomic impacts of climate change	12.1 The case studies in Chapter 12 illustrate the importance of research on the localized, regional, and circumpolar studies of socioeconomic impacts of recent climate change. The emphasis of scientific research on climate change is to assess the impacts on the environment, ecosystem processes, and wildlife. One gap in knowledge is how climate change affects social relations in indigenous communities. This is a critical aspect of climate change research, as a change in the ability of indigenous peoples to access traditional/country food resources can have a corresponding impact on the social fabric of their communities. (§12.4)	No	PPs, Indigenous institutes and organizations, AC WGs (SDWG, CAFF), national, regional and local authorities, UArctic	Yes	Yes	Research, Capacity building	Global, regional, local	Yes	Effects, system dynamics, planning, monitoring trends, method adjustments	8, 10

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	12.2 Research should place emphasis on understanding climate change impacts within the broader context of rapid social and economic change and seek to determine ways of distinguishing between changes that occur as a result of societal, cultural, and economic events, and changes that result from physical processes. Future research on climate change should result in a deeper understanding of what exactly forms the basis for the social, cultural, political, and economic viability of arctic communities, and attempt to explore the research priorities highlighted by communities themselves. (§12.4)		As above, and note relation to AHDR	Yes	Yes	Research, Capacity building	Global, regional, local	Yes	Effects, system dynamics, planning, monitoring trends, method adjustments	8, 10
Research on adaptive capacity of indigenous societies	12.3 Research is needed on understanding how much change can be accommodated by the existing ways of life of indigenous peoples. Case studies have pointed to the <i>resilience</i> , or the amount of perturbation that the resource use systems of indigenous peoples can absorb, and how they can adapt by learning and self-organization. The question of resilience and limits to adaptability is important and further research is needed since little is known about building adaptive capacity in the face of climate change. Above all, there is need to match or coordinate physical climate data on extreme weather events and the impact of these events on actual hunting, fishing, and herding practices. (§12.4)	No	As above	Yes	Yes	Research	Global	Yes	All	
Research on governance institutions	12.4 Further research is needed on co-management and governance institutions and whether they can create additional opportunities to increase resilience, flexibility, and the ability to deal with change. (§12.4)	No		Yes	Yes					

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Research and monitoring of physical and chemical marine environment	13.1 Present monitoring of the physical and biological marine environment must be continued and in many cases increased. Basic research is a prerequisite for understanding biological processes. Modern technology enables the automation of many of the time-consuming tasks previously conducted from expensive research vessels, e.g., buoys can now be deployed in strategic locations on land and at sea for continuous measurement of many variables required in marine biological studies. The monitoring of commercial stocks must also continue, applying new technologies as these become available. There is a general shortage of ship time for sea-based work. Administrators or governments are often unaware of this, also that despite computers enabling more extensive and deeper analyses of existing datasets, people are still required to operate and program the computers. (§13.7)	Yes	Fisheries Groups, GLOBEC, IASC	No	Yes	Monitoring, Research, Capacity building	Regional	Y	Monitoring trends, planning	1, 4, 8, 9, 10
Modeling of marine processes at regional or ecosystem level	13.2 Although the modeling of marine processes, particularly the modeling of climate variability, is still in its infancy, such work is the key to increasing understanding of the effects of the projected climate change scenarios. The development of regional applications is particularly important. Regional effects might differ substantially from those considered average global effects. In order to relate physical changes in the atmosphere and oceans to changes within specific ecosystems, the modeling of regional effects is essential. Current fisheries management models are based on general assumptions of constant environmental factors. The use of ecosystem-based approaches for fisheries management will require that physical and biological factors that do not directly affect the target species are also taken into account. (§13.7)	Yes	Fisheries Groups	No	No	Research	Regional, local	Y	Modeling	1, 4, 8, 10

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Development of methods for socio-economic consequences	13.3 As it is extremely difficult to estimate the economic consequences of climate change on the world fisheries or the fisheries for any given region, it is important to invest in the development of better methods for examining the economic and social consequences of climate change, at both the global and regional level, and at the national and local level. (§13.7)	Yes	SDWG, IASSA	Yes	Yes	Research	Regional, local	Yes	Effects	8, 10
Development of models and assessments	14.1 (a) Future assessments of the likely effects of climate change on northern agricultural potential should include in-depth analyses of perennial crops and livestock, including scenarios of non-climate factors such as markets and public-sector policies. Better climate/crop models specific to agriculture in high-latitude regions (i.e., special crop varieties, long day-length effects) are also needed for future assessments. The effects of temperature increases and moisture changes on soil processes should be an integral part of the modeling systems. Future assessments should include many more climate stations in the boreal and arctic regions. <u>(b) Future assessments should include many more climate stations in the boreal and Arctic regions.</u> <u>(c) The insect, disease, and weed issues that might accompany climate change and expanded agriculture should be addressed, particularly those with a unique high-latitude dimension. (§14.13.1)</u>	(Yes)	SDWG, CAFF WMO/ WWW			Monitoring	Regional	Yes	Monitoring trends	1
Policy-making	14.2 Given the critical role of public policy in agriculture in the region, an important issue is to identify national and international policies that might accommodate expansion of specific crops in the Arctic and subarctic. The infrastructure change needed to accommodate climate change should be identified along with the economic impacts of constructing new infrastructure and the economic impacts once such projects are constructed. (§14.13.1)	No	SDWG, CAFF							

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
<p>Observations of current and past tree growth</p> <p>Carbon flux model input</p> <p>Relates to 7.9</p>	<p>14.3 Given the large contribution of the boreal forest to the terrestrial carbon sink, and the large stocks of carbon stored in it, the health and vigor of the forests of this region are a particularly significant input to climate change policy, science, and management. Climatic models, recorded data, and proxies all indicate that there are significant spatial differences in temperature anomalies and associated tree growth changes around the globe. Not all species and relatively few forest site types have been examined to determine the strength and components of climate controls on tree growth. In order to determine the current and probable future carbon uptake of the boreal forest, these spatial differences in climate change and tree growth need to be systematically identified, both in the contemporary environment and in the recent historical past. Particular attention should be given to ways of effectively combining ground-level studies, which clarify mechanisms of control and provide a historical perspective, with remote-sensing approaches, which provide comprehensive spatial coverage that can be easily repeated and updated. (§14.13.2)</p>	Yes	CAFF			Research, Monitoring	Regional, local	Yes	Monitoring, modeling	2, 3, 10
<p>Review of tree growth–climate relationships</p>	<p>14.4 Trees and forest types that change their level of sensitivity to climate or even switch their growth responses to temperature are of particular interest. If climate controlled growth more at some times and less at other times in the past, tree-ring data used to reconstruct past climates will contain biases from the recorded climate data they are calibrated to, especially if the calibrating climate data cover a short time period. It is important to establish whether this change or reduction in tree growth–climate relationships is unique to the 20th century, whether the climate change of recent decades is largely responsible for growth declines, and finally, whether the mechanism of climate control is direct or indirect. (§14.13.2)</p>	Yes	CAFF			Research	Regional		Method adjustments	2, 3, 10

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Collection of information on forest issues Carbon flux model	14.5 In order to better understand, measure, and project the rapid transformations that are possible in the boreal forest, better information is needed on the role of climate and forest condition in triggering major fire and insect disturbances. The specific characteristics of fires that result in maximum production of charcoal, which represents an important form of long-term carbon sequestration, are not well documented. Further insight is needed into the interaction of climate, forest disturbance, forest succession (and its influences in carbon dynamics), water and nitrogen dynamics, and changes in carbon stocks. (§14.13.2)	Yes	CAFF			Research	Global, regional	Yes	Modeling	2, 3, 10
Circumpolar treeline monitoring Carbon flux Model Overlaps 7.4, 7.6	14.6 Forest advance into tundra has the potential to generate a large positive temperature feedback. Unfortunately, the understanding of change at this crucial ecological boundary comes from a small number of widely separated studies undertaken to achieve many different objectives. A coordinated, circumpolar treeline study and monitoring initiative will be necessary to address definitively the question of how and why this boundary is changing at the scale required to address its potential global importance. (§14.13.2)	Yes	CAFF			Research	Global, regional	Yes	Modeling	2, 3, 10
Studies of effects on evergreens and forests Overlaps 7.13	14.7 The UV-radiation survival strategies of evergreens appear to include simultaneous inhibition and avoidance. Late-winter and early-spring conditions are critical, and their importance should be studied further and effects quantified. More studies, longer-term studies, and well-designed ecosystem studies that incorporate the previously established effects from individual plot studies and consider the multiple influences of UV-B radiation on plant chemistry in settings of ecological communities will be needed to understand the cumulative effect of increased UV-B radiation levels on forests at high latitudes. (§14.13.3)	Yes	CAFF			Research, Monitoring	Regional, local		Modeling, effects monitoring	2, 3, 9, 10

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Health status data collection	15.1 There is a lack of comparability in health status data between countries. A core group of health status indicators, gathered and defined identically, should be a high priority for Arctic Council member nations. (§15.7.1)									
Monitoring, data analysis, evaluation	15.2 There is a need for a carefully planned strategy, at the community and regional level, to monitor and document environmental change. Arctic Council members and program workgroups should provide technical assistance regarding monitoring strategies, climate impact mitigation and pilot studies, data analysis, and evaluation. (§15.7.1)									
Collection of indigenous knowledge	15.3 There is a lack of an organized effort to collect and utilize indigenous knowledge regarding climate and climate changes. Indigenous knowledge, and its preservation, should be encouraged among Arctic Council member nations. (§15.7.1)									
Research and monitoring strategies for UV-B radiation	15.4 There are few data on the impact of changing UV-B exposure in the Arctic, on the biota and human residents. There is little systematic monitoring of ground-level UV-B radiation. Academic and United Nations organizations have created UV-B research strategies. With regional and community collaboration, research and monitoring strategies relevant to circumpolar populations should be created. (§15.7.1)									
Monitoring programs for wildlife disease, diet changes	15.5 There are few data on climate change impact on regional biota. A critical need exists for the monitoring of wildlife diseases, and human-wildlife disease interaction. There are few data on climate-induced changes in the diet of subsistence species, which affects their nutritional value in traditional diets. Arctic Council programs have the expertise to design effective regional and international monitoring programs in cooperation with communities. This critical activity should be given a high priority. (§15.7.1)									

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Monitoring/communication of safe conditions	15.6 There is no systematic monitoring in all regions for safety of snow and ice conditions for local/regional travel and subsistence activities. Regional governments should collaborate with communities to establish appropriate monitoring and communication networks; dissemination of appropriate traditional and modern survival skills should be systematically taught to children and young people. (§15.7.1)									
Community-based monitoring	15.7 Monitoring is critical in regions of the Arctic where physical infrastructure depends on permafrost or where a village site depends on sea ice protection from storm erosion. Regional governments should assist in developing community-based monitoring. (§15.7.1)									
International coordinated research and monitoring of contaminant transport pathways	15.8 Data on contaminant transport into and out of the Arctic is critical for projecting impact and risk for arctic wildlife and residents. Changing climate makes monitoring essential. International coordinated research and monitoring of changing contaminant transport pathways should continue and expand where needed. In all areas, there is a need for local and regional integrated analyses of the associations between arctic health status and climate variables. This can be accomplished by the establishment of monitoring and data collection mechanisms where they do not already exist. Also, public health education programs should incorporate, where possible, information on risks associated with the environmental changes most relevant to their region. (§15.7.1)									
Monitoring for thermal stress and arctic human health	15.9 Regarding thermal stress and arctic human health, organized monitoring and data collection programs (inclusive of local perspectives and indigenous knowledge) should be established involving, but not limited to, the indicators identified in Chapter 15 to support community understanding of changes in arctic health owing to thermal stress. (§15.7.2)									

Type of action	Action required	AMAP y/n	Other stake- holders	Indigen- ous know- ledge applies y/n	Use of local capa- city ap- plies y/n	Monitor- ing/ Research/ Outreach & education/ Capacity building	Global/ local/ regional	Essen- tial know- ledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Monitoring of UV-B radiation exposure and collection of epidemiological data on UV-B health issues	15.10 Regarding UV-B radiation and arctic human health, incident UV-B radiation should be measured at ground and individual levels using personal dosimeters and ground-based integrating and spectral radiometers. Cross-sectional population-based surveys and follow-up studies should be conducted in the Arctic and other areas to investigate the causal relationship between UV-B irradiance and cataract and other UV-B induced health effects to the eye such as climatic droplet keratopathy. Local residents' knowledge and perceptions of UV-B radiation and its effects on health should be compiled in order to supplement scientific data and obtain new knowledge about existing UV-B related habits, particularly with regard to skin, and immune system and eye impacts. An international network of UV radiation research centers and monitoring programs should be established. The collection of epidemiological data on key UV-B and health issues (e.g., arctic cataract data are difficult to obtain as is sunburn and cold sore data) should be expanded. (§15.7.2)									
Monitoring programs for indicators in Chapter 15	15.11 Regarding wildlife, diet, and health, community-based and regional-scale monitoring programs should be established for the indicators identified in Chapter 15. Where problems are identified (e.g., increasing incidences of exposure to zoonotic diseases), surveillance programs should be established to protect the health, social, economic, and cultural benefits of harvesting subsistence species while maintaining confidence in and the benefits of consuming these foods. (§15.7.2)									

Type of action	Action required	AMAP y/n	Other stake- holders	Indigen- ous know- ledge applies y/n	Use of local capa- city ap- plies y/n	Monitor- ing/ Research/ Outreach & education/ Capacity building	Global/ local/ regional	Essen- tial know- ledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Surveil- lance and com- munica- tion networks for safety issues; educa- tion programs	15.12 Regarding snow, ice, and arctic community health, surveillance and communication networks should be established at the community level to support early warning of dangerous conditions for travel and land-based activities (weather, ice conditions etc.). Support should be provided for community freezers and other food supplement and food safety programs to ensure access to safe and healthy traditional foods in arctic communities. Education programs should be developed for young people, based on traditional survival skills, to enhance individual capacity to continue aspects of a traditional lifestyle. (§15.7.2)									
Local moni- toring programs for infra- structure	15.13 Regarding infrastructure and arctic human health, local level monitoring programs should be established for data collection on permafrost and infrastructure stability. Ground temperatures, basal depth of permafrost, and coastal and river bank erosion should all be monitored and compared to the respective historic measurements. The incidence of flooding caused by storm surges or heavy precipitation, as well as emergency projects for the repair of failing infrastructure should be monitored. (§15.7.2)									
Research on the role of environ- ment in com- munity change	15.14 Regarding society, culture, climate, and arctic health, research should be conducted on the role of the environment, specifically climate-related variables, in community change for small remote locations. Research should be conducted to support the understanding of the cultural context and variables influencing individual and community vulnerability, capacity, and resilience in relation to the impacts these changes represent. (§15.7.2)									

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Development of site-specific scenarios	16.1 In relation to the impacts of climate change on infrastructure, the main gaps in knowledge are the lack of site-specific scenarios providing the probability of occurrence of various meteorological conditions (temperature, precipitation, wind, snow and sea-ice thickness and extent, waves, and erosion rates). Monitoring of infrastructure and the coastal environment is essential, as are climate sensitivity analyses. (§16.5)									
Integrated evaluation	16.2 There is a need to combine engineering knowledge with socioeconomic development scenarios and environmental impact assessments (see Chapters 3, 12, and 15) to evaluate how projected climate change may affect human lives in the Arctic. (§16.5)									
Development of methods for vulnerability assessment	17.1 Vulnerability assessment requires varied forms of knowledge and the development of new analytical tools and methodologies. Understanding the stresses facing place-based examples of the coupled human–environment system and the adaptive measures the system might take in response to these stresses necessitates novel modes of inquiry. It is extremely important to involve indigenous peoples and other arctic residents in the research process in developing such understandings. Methods to integrate indigenous knowledge and scientific knowledge such as biology, climate science, political science, and anthropology are similarly important. Climate downscaling, pollutant modeling, scenario development for societal trends, environmental monitoring, interviews, focus groups, workshops, and ethnography comprise additional approaches that could be integral to vulnerability analysis. (§17.5)									

Type of action	Action required	AMAP y/n	Other stake- holders	Indigen- ous know- ledge applies y/n	Use of local capa- city ap- plies y/n	Monitor- ing/ Research/ Outreach & Education/ Capacity building	Global/ local/ regional	Essen- tial know- ledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Research for vulnerability analysis	17.2 Future place-based pollutant research for vulnerability analysis would ideally consist of exposure and trend monitoring, human health and epidemiological analyses, and collection of other relevant data such as information about dietary intake, smoking, and other influences on pollutant burden. All these types of study are feasible and have been done at various sites; however, a vulnerability study necessitates that this information be available for a specific location. There is also a need to better understand local means of adaptation to problems with pollution, both in terms of what has been done and what could be done. (§17.5.2)									
Conduct of vulnerability analyses	17.3 A more comprehensive and complete analysis of human and societal trends within the context of a fully-fledged vulnerability analysis would require the broad and systematic engagement of people living in the case study locations, and the use of tools such as surveys, participant observation, workshops, interviews, focus groups, and ethnography to ascertain what human and societal conditions are most relevant to the local coupled human–environment system, how these conditions have changed over recent decades, and how they are expected to change in the future. The development of several alternative future societal scenarios would be useful in carrying out the difficult task of projecting future human and societal conditions and assessing their implications for coupled human–environment system vulnerabilities. The production and comparison of multiple scenarios could facilitate sensitivity analysis. (§17.5.3)									
Assess- ment of regional impacts	18.1 Regional impacts: The ACIA mostly addressed impacts at the large-scale circumpolar level. The attempt to differentiate between impacts within the four ACIA regions was exploratory and did not cover these regions in depth. There is a need to focus future assessments on smaller regions (perhaps at the landscape level) where an assessment of impacts of climate change has the greatest relevance and use for residents in the region and their activities. (§18.5)									

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & education/ Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Better assessment of economic impacts	18.2 Economic impacts: There are many important economic sectors in the Arctic, including oil and gas production, mining, transportation, fisheries, forestry and agriculture, and tourism. Some will gain from a warmer climate, others will not. In most cases, only qualitative information about the economic impacts (in monetary terms) of climate change is presently available. It is essential to involve a wide range of experts and stakeholders in future climate impact assessments to fill this gap and provide relevant information to users and decision makers. (§18.5)									
Research to improve vulnerability assessments	18.3 Assessing vulnerabilities: Climate change occurs amidst a number of other interacting social and environmental changes across scales from local to regional and even global, and includes industrial development, contaminant transport and effects, and changes in social, political, and economic conditions. In this context, it has become important to assess the vulnerabilities of arctic coupled human–environment systems. To undertake improved assessments on these three research topics, a suite of improved observations and process studies, long-term monitoring, climate modeling, and impact analyses on society are necessary. These require new research efforts and studies funded by the various arctic countries. (§18.5)									
Additional observations and process studies	18.4 Observations and process studies: To improve future climate impact assessments, many Arctic processes require further study, both through scientific investigations and more detailed systematic documentation of indigenous knowledge. Priorities include collection of data ranging from satellite, surface, and paleo data on the climate and physical environment, to rates and ranges of change in arctic biota, and to the health status of arctic people. (§18.5)									

Type of action	Action required	AMAP y/n	Other stakeholders	Indigenous knowledge applies y/n	Use of local capacity applies y/n	Monitoring/ Research/ Outreach & Capacity building	Global/ local/ regional	Essential knowledge	Type: modeling, effects, system dynamics, planning, monitoring trends, method adjustments, funding	KF
Long-term monitoring	18.5 Long-term monitoring: Long-term time series of climate and climate-related parameters are available from only a few locations in the Arctic. The need for continuing long-term acquisition of data is crucial, including upgrading of the climate observing system throughout the Arctic and monitoring snow and ice features, the discharge of major arctic rivers, ocean parameters, and changes in vegetation, biodiversity, and ecosystem processes. (§18.5)									
Improvement in modeling	18.6 Climate modeling: Improvements in numerical modeling of potential changes in climate are needed, including the representation in climate models of key arctic processes such as ocean processes, permafrost–soil–vegetation interactions, important feedback processes, and extreme events. The development and use of very high-resolution coupled regional models that provide useful information to local experts and decision makers is also required. (§18.5)									
Better analysis of impacts on society	18.7 Analysis of impacts on society: Critical needs for improving projections of possible consequences for the environment and society include development and use of impact models; evaluating approaches for expressing relative levels of certainty and uncertainty; developing linkages between traditional and scientific knowledge; preparing scenarios of arctic population and economic development; and identifying and evaluating potential mitigation and adaptation measures to meet expected impacts. (§18.5)									
Future impact assessment	18.8 Future impact assessments should conduct comprehensive vulnerability studies of arctic communities, in which impacts modulated by adaptive capacity are examined in the context of both environmental and societal changes. The latter include changes in resource exploitation, human population, global trade and economies, introduction of new species, contamination, and new technologies. (§18.6)									

Annex 4: Priority Setting for Recommendations from Chapters 7, 10, 11, and 14

ANNEX 4

PRIORITY SETTING FOR RECOMMENDED ACTIONS REQUIRED FROM CHAPTERS 7, 10, 11, AND 14

Priority designations for recommended actions required from Chapters 7, 10, 11, and 14 (time did not permit completion of priority setting for Chapter 14) of the Arctic Climate Impact Assessment report, indicating the relation to the Policy Document and more specific recommendations for implementation by AMAP. The shading indicates that the action required were considered to be the least relevant for AMAP, and thus should have the lowest priority for AMAP.

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation			
7.1. Development of scenarios and long-term experiments Extreme events and thresholds	Changes in microbe, animal, and plant populations are triggered by trends in climate and UV radiation levels exceeding thresholds, and by extreme events, particularly during winter. However, information is uneven and dominated by trends in summer climate. Appropriate scenarios of extreme events are required, as is deployment of long-term experiments simulating extreme events and future winter processes in particular. A better understanding of thresholds relevant to biological processes is also required. (§7.7.2.1)	Yes	CAFF, WMO, IPCC	Research, observations, monitoring, and modeling, Bullet 3.	See 7.7			
7.2 Simulation experiments; monitoring of certain species Biodiversity	Some groups of species are very likely to be at risk from climate change impacts, and the biodiversity of particular geographic areas is at risk. It is not known whether currently threatened species might proliferate under future warming, nor which currently widespread species might decrease in abundance. The nature of threats to species, including microbes, must be reassessed using long-term climate and UV-B radiation change simulation experiments. There is also a need to identify and monitor currently widespread species that are likely to decline under climate change, and to redefine conservation and protection in the context of climate and UV radiation change. (§7.7.2.1)	(Yes)	CAFF	Research, Monitoring	R	N	Effects and management	3, 4, 9

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation
<p>7.3. Compilation and analysis of observations</p> <p>Distribution patterns</p>	<p>The dominant response of current arctic species to climate change is very likely to be relocation rather than adaptation. Relocation possibilities are very likely to vary according to region and geographic barriers. Some changes are already occurring. However, knowledge of rates of relocation, impact of geographic barriers, and current changes is poor. There is a need to measure and project 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. (§7.7.2.1)</p>	(Yes)	CAFF	Research, observations, monitoring, and modeling, Bullet 3.	<p>Partly covered by 7.7</p> <p>Systematic monitoring of species distribution is difficult to achieve in the Arctic.</p> <p><i>Therefore, feasibility of approach should be considered carefully before implementation.</i></p>
<p>7.4. Model development and linkage</p> <p>Improved climate model for vegetation distribution</p>	<p>Forest is very likely to replace a significant proportion of the tundra and is very likely to have a great effect on species composition. However, several processes (including land use and permafrost dynamics) are expected to modify the modeled response of vegetation redistribution related to warming. Models of climate, hydrology (permafrost), ecosystems, and land use need to be developed and linked. These models need to be based on improved information about the current boundaries of major vegetation zones, defined and recorded using standardized protocols. (§7.7.2.1)</p>	(Yes)	CAFF	Research, observations, monitoring, and modeling, Bullet 3.	<p>Ecosystem models need to be improved in order to project future vegetation changes.</p>
<p>7.5. Long-term monitoring with better geographical balance; model development</p> <p>Arctic Carbon Balance</p>	<p>Current models suggest that arctic vegetation and active-layer soils will be a sink for carbon in the long term because of the northward movement of vegetation zones that are more productive than those they displace. Model output needs to be reconciled with observations that tundra areas that are carbon sources currently exceed those that are carbon sinks, although the measurements of circumpolar carbon balance are very incomplete. To what extent disturbance will reduce the carbon sink strength of the Arctic is also unknown. There is a need to establish long-term, annual carbon monitoring throughout the Arctic; to develop models capable of scaling ecosystem processes from plot experiments to landscapes; to develop observatories, experiments, and models to relate disturbance such as desertification to carbon dynamics; and to improve the geographic balance of observations by increasing high-arctic measurements. There is also a need to combine estimates of ecosystem carbon flux with estimates of carbon flux from thawing permafrost and methane hydrates. (§7.7.2.1)</p>	Yes	Many, coordination needed	Mitigation, Bullet 4 (not specifically mentioned in the policy document under Research, ...!)	<p>There is a need to establish long-term, annual carbon monitoring throughout the Arctic; to develop models capable of scaling ecosystem processes from plot experiments to landscapes; to develop observatories, experiments, and models to relate disturbance such as desertification to carbon dynamics; and to improve the geographic balance of observations by increasing high-arctic measurements.</p> <p>There is also a need to combine estimates of ecosystem carbon flux with estimates of carbon flux from thawing permafrost and methane hydrates.</p> <p>Previous and projected changes in vegetation (landcover?), land use, forestry, permafrost, and disturbance should be included in new models.</p> <p><i>Relation to 7.7</i></p>

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation
7.6. Long-term measurements and analysis; model development Improved climate model for vegetation distribution	Displacement of tundra by forest is very likely to lead to a decrease in albedo with a potential for local warming, whereas carbon sequestration is likely to increase with potential impacts on global concentrations of greenhouse gases. However, the timing of the processes and the balance between the processes are very uncertain. How local factors such as land use, disturbance, tree type, and possible desertification will affect the balance is also uncertain. There is a need for long-term and annual empirical measurements, analysis of past remotely sensed images, and collection of new images together with the development and application of new models that include land use, disturbance, and permafrost dynamics. (§7.7.2.1)	(Yes)	CAFF, SDWG		See 7.5
7.7. Long-term monitoring and data handling Monitoring	Long-term environmental and biological monitoring are becoming increasingly necessary to detect change, to validate model projections and results from experiments, and to substantiate measurements made from remote sensing. Present monitoring programs and initiatives are too scarce and are scattered randomly. Data from the Arctic are often not based on organized monitoring schemes, are geographically biased, and are not long-term enough to detect changes in species ranges, natural habitats, animal population cycles, vegetation distribution, and carbon balance. More networks of standardized, long-term monitoring sites are required to better represent environmental and ecosystem variability in the Arctic and particularly sensitive habitats. Because there are interactions among many co-varying environmental variables, monitoring programs should be integrated. Observatories should have the ability to facilitate campaigns to validate output from models or ground-truth observations from remote sensing. There should be collaboration with indigenous and other local peoples' monitoring networks where relevant. It would be advantageous to create a decentralized and distributed, ideally web-based, meta-database from the monitoring and campaign results, including relevant indigenous knowledge. (§7.7.2.2)	Yes	Other monitoring programs and initiatives within and outside AC	Research, observations, monitoring, and modeling, Bullet 3.	Networks on standardized long-term integrated monitoring and research necessary to detect change, to validate model projections and results from experiments, and to substantiate measurements made from remote sensing shall be established. The monitoring and research shall be year-round to capture, e.g., extreme events, and biological and geophysical processes in the winter, which is currently poorly covered. A suite of indicators needs to be devised and agreed, monitoring for them undertaken, and the results made publicly available in a format (or formats) so as to inform public opinion, educators, decision-makers, and policy-makers. Monitoring schemes, should be long-term enough to detect changes in species ranges, natural habitats, animal population cycles, vegetation distribution, and carbon balance Research on thresholds is needed. <i>AMAP/CAFF to describe recommendations on coverage, and extend monitoring strategy and guidelines.</i>

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation			
					R	N		
7.8. Processing of remotely sensed data	Monitoring requires institutions, not necessarily sited in the Arctic, to process remotely sensed data. Much information from satellite and aerial photographs exists already on vegetation change, such as treeline displacement, and on disturbances such as reindeer/caribou overgrazing and insect outbreaks. However, relatively little of this information has been extracted and analyzed. (§7.7.2.2)	(Yes)	GEOSS, GRID		R	N	Adjustment of methodology	
7.9. Measurement of carbon fluxes; research to support modeling Arctic Carbon Balance Overlapping 7.5	Past temporal and spatial scales of measurement used to directly measure carbon flux have been a poor match for the larger scale of arctic ecosystem modeling and extrapolation. It is a challenge to determine whether flux measurements and model output are complementary. There are significant technological difficulties in extrapolating many non-linear, complex, interacting factors that comprise fluxes at hundreds to thousands of square kilometers over time, space, and levels of biological and environmental organization in the Arctic. Research is needed to better understand how the complex system behaves at the meter scale related to larger spatial scales that can be efficiently modeled and evaluated at the regional and circumpolar scale. To do this, extensive long-term and year-round eddy covariance sites and other long-term flux sites, including repeated aircraft flux measurements and remote sensing, provide the basis for estimating circumpolar net ecosystem CO ₂ exchanges. Currently, the circumpolar Arctic is disproportionately covered by current and recent measurements, with Canadian and high-arctic regions particularly poorly represented. (§7.7.2.2)	Yes	Many, coordination needed		See 7.5 and 7.7			
7.10 Long-term observations Overlapping 7.7	Long-term (>10 years) observations and experiments are required in order to enable transient responses to be separated from possible equilibrium responses; increase the chances that disturbances, extreme events, and significant interannual variation in weather are included in the observations; and allow possible thresholds for responses to be experienced. (§7.7.2.2)	Yes	CAFF		See 7.7			

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation			
7.11. Year-round observations Overlapping 7.1	Year-round observations are necessary to understand the importance of winter processes in determining the survival of arctic species and the function of arctic ecosystems. Such observations are necessary to recognize the projected amplification of climate warming in winter and to redress the current experimental bias toward summer-only warming. For microbes, it is particularly important to understand changes in winter respiration and nutrient mobilization during freeze-thaw events in spring and late autumn. (§7.7.2.2)	Yes	CAFF		See 7.7			
7.12. Improve timing of observations	It is important to improve the appropriateness of the timing of observations and experiments. For example, current information about the impacts of increased UV-B radiation levels is mainly derived from general summer enhancements or filtration of UV-B radiation, although future increases in UV-B radiation levels are likely to be highest in spring and during specific stratospheric ozone depletion events. The frequency of observations should be fitted to the rate of change of the species or processes of interest, e.g., decadal measurements may suffice for some variables such as treeline movement. (§7.7.2.2)	Yes					Adjustment of methodology	9
7.13. Multifactorial environmental and ecosystem experiments	Single-factor manipulation experiments have limited applicability because it is clear that there are many interactive effects among co-occurring environmental change variables. There is need for well-designed, large, multifactorial environmental (e.g., climate, UV-B radiation levels, and CO ₂ concentrations) <i>and</i> ecosystem (e.g., species removal and addition) manipulation experiments that are long-term and seek to understand annual, seasonal, and event-based impacts of changing environments. The complexity of appropriate treatments and timescales is vast and the spatial scale is also a significant challenge, as it is important to have manipulations that can be related to larger plants (e.g., trees, shrubs) and animals (e.g., reindeer/caribou). (§7.7.2.2)	Yes	CAFF, ITEX	Research, observations, monitoring, and modeling, Bullet 3.	There is need for well-designed, large, multifactorial environmental (e.g., climate, UV-B radiation levels, and CO ₂ concentrations) <i>and</i> ecosystem (e.g., species removal and addition) manipulation experiments that are long-term and seek to understand annual, seasonal, and event-based impacts of changing environments			
7.14 Assessing probabilities of cooling THC-monitoring, modelling	Scenarios of increased temperature dominate the approaches to projecting responses of ecosystems to future climate. However, cooling in some areas remain a possibility. As the impacts of cooling on terrestrial ecosystems and their services to people are likely to be far more dramatic than the impacts of warming, it is timely to reassess the probabilities of cooling projected by GCMs and the appropriateness of assessing cooling impacts on ecosystems. (§7.7.2.2)	Yes	IPCC, EU	Research, observations, monitoring, and modeling, Bullets 2 and 3.	Probabilities of cooling projected by GCMs should be reassessed and the appropriateness of assessing cooling impacts on ecosystems should be addressed .			

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation			
					R, L			
7.15 Development of high-resolution models at landscape scale Overlap with 7.9	High-resolution models are needed at the landscape scale for a range of landscape types that are projected to experience different future envelopes of climate and UV-B radiation levels. Modeling at the landscape scale will simulate local changes that relate to plot-scale experiments and can be validated by results of experiments and field observations. A particular challenge is to provide scenarios for changes in climate and UV-B radiation levels at the scale of tens of meters. (§7.7.2.2)	Yes	CAFF	M&R	R, L		Adjustment of methodology, effects	9
7.16 Long-term funding	Current short-term funding is inappropriate to support research into long-term processes such as ecosystem responses to climate change and UV-B radiation impacts. A stable commitment to long-term funding is necessary. (§7.7.2.3)		Arctic Council, EU, National research programme, Bill Gates or Ted Turner				Funding	
7.17 Circumpolar funding	Funding possibilities that are restricted to single nations, or only a few nations, make it extremely difficult to implement coordinated research that covers the variability in ecosystems and projected climate change throughout the circumpolar north, even though the instruments for coordination exist. Limitation of international funding possibilities leads to geographic biases and gaps in important information. Circumpolar funding is required so that coordinated projects can operate at geographically appropriate sites over the same time periods. (§7.7.2.3)		Arctic Council, EU, National research programme, Bill Gates or Ted Turner				Funding	
Taxonomy research	10.1 There are many areas of arctic taxonomy that require exploration and research; it is vital to the conservation of the Arctic's biodiversity that these taxonomic subjects are addressed. (§10.4.8)	No	CAFF					
Monitoring biodiversity	10.2 Monitoring is important for understanding how the Arctic's biodiversity is changing and whether actions to conserve biodiversity are being successful; monitoring needs to occur at both the system level and the species level. (§10.4.8)	No	CAFF					
Habitat classification	10.3 There needs to be a supply of trained ecologists who can devise appropriate circum-Arctic classifications of habitats and then survey them so as to measure their extent and quality and to establish their dynamics. (§10.5.1)	No	CAFF					

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation			
Inventory of species	10.4 There needs to be a supply of trained taxonomists who can draw up inventories of the Arctic's species. There are already good data on which species of vertebrate animals and vascular plants are to be found in the Arctic, so particular attention needs to be given to the training of taxonomists who can work with non-vascular plants, invertebrate animals, fungi, and micro-organisms (protozoa, bacteria, etc.). (§10.5.1)	No	CAFF					
Inventory of biodiversity	10.5 Inventories need to be generated for the Arctic's biodiversity (both species and habitats), indicating for each entry in the inventory where it occurs and either the size of the overall species population or the extent of the habitat. Such inventories need to be on a circum-Arctic basis rather than on a national basis as nations with arctic territory also have territory south of the Arctic. (§10.5.1)	No	CAFF					
Research on genetics	10.6 The genetic diversity of many of the Arctic's species is presently poorly known or unknown. Much research is needed to explore this aspect of the Arctic's biodiversity and conservation management will need to ensure that genetic diversity is not lost. (§10.5.1)	No	CAFF					
Management philosophy	10.7 Management of the Arctic's biodiversity must work with ecological succession and not against it. This thinking needs to be incorporated into all aspects of the management of biodiversity in the sea, in freshwater, and on the land. (§10.5.2)	No	CAFF					
Model development	10.8 Models need to be further developed to explore changes in biodiversity under the various scenarios of climate change. These models will need to explore biodiversity change in the sea, in freshwater, and on land. (§10.5.2)	No	CAFF					
Circum-Arctic monitoring networks	10.9 Circum-Arctic monitoring networks need to be fully implemented throughout the Arctic. Data on the state of the Arctic's biodiversity, on the drivers of change in that biodiversity, and on the effectiveness of responses to those changes, need to be collected, analyzed, and used in the development of future arctic biodiversity policy. (§10.5.3)	No	CAFF					

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation			
Monitoring strategy	10.10 Attention needs to be given to establishing the kinds of subsidiary aspects of monitoring, such as integrated monitoring and monitoring of phenology, genetic diversity, and invertebrate fauna. These are vital if a holistic view is to be taken of the Arctic's biodiversity, its conservation in the face of a changing climate, and the management of the biodiversity resource for future generations of people to use and enjoy. (§10.5.3)	Yes	CAFF		See 7.7			
Development of indicators	10.11 A suite of indicators needs to be devised and agreed, monitoring for them undertaken, and the results made publicly available in a format (or formats) so as to inform public opinion, educators, decision-makers, and policy-makers. (§10.5.3)	Yes	All AC WGs		See 7.7			
Development of guidelines	10.12 Best practice guidelines need to be prepared for managing all aspects of the Arctic's biodiversity. These need to be prepared on a circumpolar basis and with the involvement of all interested parties. (§10.5.4)	No	CAFF					
Completion of CPAN	10.13 The Circumpolar Protected Area Network needs to be completed and then reviewed so as to ensure that it actually covers the full range of the Arctic's present biodiversity. (§10.5.4)	No	CAFF					
Assessment of protected areas	10.14 An assessment needs to be made for each protected area of the likely effects of climate change, and in the light of this assessment the management methods and any revisions of the area's boundary need to be reviewed. (§10.5.4)	No	CAFF					
Integrated management	10.15 Integrated forms of management, incorporating the requirement for biodiversity conservation, need to be explored for all uses of the land, freshwater, and sea in the Arctic. (§10.5.4)	No	CAFF					
Biodiversity conservation	10.16 Biodiversity conservation needs to be incorporated into all policy development, whether regional, national, or circumpolar. (§10.5.4)	No	CAFF					
Testing of Ecosystem Approach	10.17 The Ecosystem Approach (or Ecosystem-based Approach) should be trialed for a number of situations in the Arctic, so as to assess its ability to harmonize the management of land and water both for the benefit of the local people and for the benefit of wildlife. (§10.5.4)	No	CAFF and other AC WGs					

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation			
Implementation of CBD	10.18 All nations with Arctic territory should be working toward full implementation of the Convention on Biological Diversity, coordinating their work on a circumpolar basis, and reporting both individually and jointly to the regular Conferences of the Parties. (§10.5.4)	No	CAFF					
Management of migratory species	11.1 Management and conservation of migratory or wide-ranging species requires broad participation by all those with interests and responsibilities for arctic wildlife. This requires that management be expanded from local jurisdiction to include regional, national, and international collaboration and shared responsibility in the management of migratory and wide-ranging wildlife. (§11.5.3)	No	CAFF					
Research and monitoring of pollutants and their consequences	11.2 International oversight, coordination, reporting, collating of information, and associated stimulation of national efforts are needed to better understand the importance of pollutants and contaminants entering the Arctic. Inventories and monitoring of the pollutants and contaminants entering arctic ecosystems, and research on their consequences for the health of arctic wildlife, as well as the health of the arctic residents who consume the wildlife, are critical to the management of arctic wildlife. An understanding of the role of pollutants and contaminants in wildlife food chains, wildlife health, and associated human health, and the influence of climate change on these relationships underlies interpretation of the consequences of other environmental variables on wildlife, which is basic to management and conservation of wildlife in the Arctic. The reduction of levels of pollutants and contaminants entering the Arctic, and management of their impacts on arctic wildlife will require action at the national level through joint international efforts. (§11.5.3)	Yes	CAFF	Research, observations, monitoring, and modeling, Bullets 3 and 4.	Contaminant transport and effect studies shall incorporate anticipated changes due to climate change. <i>Joint effort needed from AMAP and CAFF</i>			

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation			
Team-building among governments for management and conservation	11.3 Achieving effective conservation and management of wildlife in a changing Arctic will require a team-building approach among governments at all levels that relate to the environment and human well-being, and with all other groups with an interest in the Arctic. This effort should include the indigenous peoples and other residents of the Arctic, and scientists undertaking research in the Arctic, representatives of industry and business seeking development of arctic resources or other economic opportunities in the Arctic, those who travel to the Arctic for recreation or tourism, and the non-governmental organizations seeking to protect or sustain environmental, aesthetic, and other less tangible values of the Arctic in the broader interest of society. The successful management and conservation of arctic wildlife requires that these groups be represented in the management process and that adequate information is available for equitable consideration of the diverse interests that relate to arctic wildlife. The role of international, non-governmental environmental organizations is particularly important in maintaining focus of the public on the broad spectrum of environmental values existing in the Arctic when proposals for large-scale industry- or government-sponsored projects become politicized at the regional or national levels. (§11.5.3)	No	CAFF					
Development of land and water use plans	11.4 <i>Land and water use plans need to be developed on a regional basis throughout the Arctic. These plans will require a detailed inventory of distribution, population numbers, and habitat relations of wildlife and fish species and patterns of human use of fish and wildlife. Well-developed land and water use plans, based on detailed mapping of resource distribution and patterns of human use and dependency, are needed prior to layout of proposed human activities on the land and waters, such as roads, pipelines, shipping routes, communities, other structures, and their cumulative effects to avoid conflicts with critical habitats of wildlife, their movement corridors, and patterns of human use of the wildlife. (Author's comment)</i>	No	SDWG, CAFF, PAME,					
International efforts for marine areas	11.5 <i>The international or bi-national nature of many species of marine wildlife requires international efforts in the development of marine area use and agreements to assure identification and protection of critical habitats for marine wildlife. (Author's comment)</i>	No	PAME, CAFF					

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation
Marine research	11.6 <i>Marine ecosystems are more difficult to study and less well known than terrestrial ecosystems and will require more complex and costly research efforts if arctic wildlife in the marine environment is to be effectively conserved and managed. (Author's comment)</i>	No		Statement	
Development of models and assessments	<p>14.1 (a) Future assessments of the likely effects of climate change on northern agricultural potential should include in-depth analyses of perennial crops and livestock, including scenarios of non-climate factors such as markets and public-sector policies. Better climate/crop models specific to agriculture in high-latitude regions (i.e., special crop varieties, long day-length effects) are also needed for future assessments. The effects of temperature increases and moisture changes on soil processes should be an integral part of the modeling systems.</p> <p>(b) Future assessments should include many more climate stations in the boreal and arctic regions.</p> <p>(c) The insect, disease, and weed issues that might accompany climate change and expanded agriculture should be addressed, particularly those with a unique high-latitude dimension. (§14.13.1)</p>	(Yes)	<p>SDWG CAFF</p> <p>WMO/ WWW</p>	M	To be dealt with in chapter 2 recommendation

The rest of the recommendations in chapter 14 were not assessed since time ran out! However it is important to assess them to develop recommendations for actions.

The issue of forestry and agriculture does not fit well in the existing structure of the Arctic Council. However, land use, vegetation zones etc. are important for the understanding of regional and global carbon fluxes and feedback mechanisms and global climate change understanding and modeling.

Type of action	Action required	AMAP y/n	Other stakeholders	Relation to policy document	Recommendation			
Policymaking	14.2 Given the critical role of public policy in agriculture in the region, an important issue is to identify national and international policies that might accommodate expansion of specific crops in the Arctic and subarctic. The infrastructure change needed to accommodate climate change should be identified along with the economic impacts of constructing new infrastructure and the economic impacts once such projects are constructed. (§14.13.1)	No	SDWG, CAFF					
<p>Observations of current and past tree growth</p> <p>Carbon flux model input</p> <p>Relates to 7.9</p>	14.3 Given the large contribution of the boreal forest to the terrestrial carbon sink, and the large stocks of carbon stored in it, the health and vigor of the forests of this region are a particularly significant input to climate change policy, science, and management. Climatic models, recorded data, and proxies all indicate that there are significant spatial differences in temperature anomalies and associated tree growth changes around the globe. Not all species and relatively few forest site types have been examined to determine the strength and components of climate controls on tree growth. In order to determine the current and probable future carbon uptake of the boreal forest, these spatial differences in climate change and tree growth need to be systematically identified, both in the contemporary environment and in the recent historical past. Particular attention should be given to ways of effectively combining ground-level studies, which clarify mechanisms of control and provide a historical perspective, with remote-sensing approaches, which provide comprehensive spatial coverage that can be easily repeated and updated. (§14.13.2)	Yes	CAFF					

ACRONYMS

AC	Arctic Council
ACD	Arctic Coastal Dynamics
AHDR	Arctic Human Development Report
AMAP	Arctic Monitoring and Assessment Programme
ANSC	Alaskan Native Science Commission
ASOF	Arctic-Subarctic Ocean Flux Study
CAFF	Conservation of Arctic Flora and Fauna
CEON	Circum-Arctic Environmental Observatories Network
CLiC	Climate and Cryosphere
CLIVAR	Climate Variability and Prediction Program
ESA	European Space Agency
EU	European Union
EUMETSAT	European Union Meteorological Satellite
FUVIRC	Finnish UV International Research Center
GAW	Global Atmospheric Watch
GCOS	Global Climate Observing System
GEOS	Global Earth Observing System
GISP	Greenland Ice Sheet Project
GRID	Global Resource Information Database (UNEP)
GRIP	Greenland Ice Core Project
GTN-G	Global Terrestrial Network - Glaciers
GTN-H	Global Terrestrial Network- Hydrology
GTN-P	Global Terrestrial Network - Permafrost
IABP	International Arctic Buoy Program
IAHS	International Association of Hydrological Science
IASC	International Arctic Science Committee
IASSA	International Arctic Social Science Association
ICARP	International Conference on Arctic Research Planning
IGBP	International Geosphere-Biosphere Programme
IK	Indigenous Knowledge
IOC	International Ozone Committee
IPA	International Permafrost Association
IPCC	International Panel on Climate Change
ISAC	International Study of Arctic Change
ITEX	International Tundra Experiment
MAGICS	Mass Balance of Arctic Glaciers and Ice Sheets
NDSC	Network for Detection of Stratospheric Change
NGRIP	Northern Greenland Ice Core Project
NPEO	North Pole Environmental Observatory
PAGES	Past Global Changes (IGBP project)
PARCS	Paleo-Environmental Arctic Sciences
SAO	Senior Arctic Officials
SDWG	Sustainable Development Working Group
SPARC	Stratospheric Processes and their Role in Climate
WDC	World Data Centers
WMO	World Meteorological Organization