Agenda Item 4C AMAP WG32/4C/4

Kiruna/Giron, Sweden 25-27 September 2018

# Climate Monitoring Guidelines

## Presented by AMAP Secretariat

## 10 September 2018

### Background

Reference is made to document *WG31-10-Info-01*. The document describes how the purpose of the *AMAP Trends and Effects Monitoring Programme (ATEMP)* is to deliver the data and information necessary to conduct AMAP assessments through the specification of a harmonized programme that can be implemented across the circum-Arctic region. Among other things, the document notes that AMAP monitoring programme development needs to ensure that respective (sometimes overlapping) programmes are coordinated in a way that maximizes their ability to deliver data and information required by AMAP.

The document *AMAP WG 28/9b/1* discusses the use of the DPSIR framework in relation to structuring the AMAP monitoring guidelines. It notes that essentially, the current *ATEMP* addresses (some of the) data/information needs associated with the *State* and *Impact* DPSIR components, delivering assessments that relate to some of the *Response* component.

The enclosed document presents the draft structure for AMAP's monitoring guidelines on climate change, effects and impacts. The document is a further development of the matrix presented in document *AMAP WG31/10/Info-1*.

The most important basis for the guidelines is the *Essential Climate Variables* (ECV) by WMO's Global Climate Observing System (GCOS). Initiatives are coming up to define ECVs for cold regions[1].

In addition to listing the parameters to be monitored, the document seeks to address these questions:

- Are there developments within other initiatives to monitor these variables? Are these other initiatives the natural 'home' for this monitoring?
- What QA/QC programmes should be developed in support of these variables?
- For data reporting: Are international, recognised data centres for these variables existing?

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[1] http://www.earthobservations.org/coldregions.php

It should be noted that an attempt will be made to have a discussion of the guidelines at the Arctic Meteorological and Climate Workshop to be held 6 to 8 November 2018 in Copenhagen.

**Requests to WG**

1. The AMAP WG is invited to give advice on the structure and approach taken as described in chapter 0 (*Document structure*). The AMAP WG is not asked to comment on the actual contents of the document at this point in time.
2. Each section has text on *Input asked from*. Underlined expert names are those that have provided a response. The AMAP WG is invited to provide additional names on experts that should be asked to provide input.

# AMAP Monitoring Guidelines: Climate Change, Effects and Impacts

**Table of contents**

## 0. Document structure and approach

The structure for the monitoring guidelines is derived from the *DPSIR framework*[2]. The framework describes the interactions between society and the environment: *Driving forces, Pressures, States, Impacts,* and *Responses*. The monitoring guidelines addresses (some of the) data/information needs associated with the *States* and *Impacts* DPSIR components and is meant to deliver assessments that relate to some of the *Responses* component.

In a series of sections in Chapter 2, different *State* parameters that should be monitored are listed. The same sections are found in Chapter 3, but in this chapter, the section lists the parameters that should be observed in order to monitor the impact of changes in the *State* parameters. Chapter 4 (*Ecology)* lists parameters that should be monitored in order to understand the impact of climate changes on ecology, but without linking these to specific *State* parameters.

The most important basis for the guidelines is the *Essential Climate Variables* (ECV) by WMO's Global Climate Observing System (GCOS)[3]. A parameter in italics is an ECV.

The monitoring of the Arctic climate and the effects and impacts of climate changes is on the agenda for many organisations and initiatives. For each of the parameters listed, the guidelines seek to identify these. In addition, the guidelines provide information about:

- QA/QC programmes in support of the parameters?
- International, recognised data centres for the variables

[2] https://www.eea.europa.eu/help/glossary/eea-glossary/dpsir
[3] https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables

# 1. Introduction

*[The following text is* General considerations *in the section* Monitoring Climate Variability and Change *in* Climate change effects *in the current AMAP monitoring guidelines]*

Some of the key features of the Arctic climate variability and change that are important in determining effective monitoring are:

- Large temporal variability (diurnal, seasonal, annual, decadal, millennial, and Quaternary Epoc) with long-term oscillations and trends, but with capacity to 'flip' within a decade;
- Large regional variability e.g., some regions are warming while others are cooling, plus mesoscale gradients within regions (oceanic – continental; altitude) and microscale topographic variation. Climate change is not uniform over these scales;
- Climatic events (e.g., gales, storms, drought) are expected to increase in frequency in some areas with important implications for ecology and people;
- Ocean acidification (monitoring ocean pH, shell thickness in key species affected by changes in carbonates, etc.);
- Timing of freeze-up and thaw on land and the extent and thickness of sea ice will respond to both changing air temperature and precipitation;
- Precipitation is expected to increase generally in high latitudes, particularly in winter, through increased vigour of the hydrological cycle in a warmer atmosphere. Increased cloud cover through warmer air temperatures will modify surface temperatures. Both the quality and quantity of snow are expected to change;
- Changes in land cover and sea ice will tend to have feedback effects on local and regional climate through changes in albedo, evapotranspiration and emission of greenhouse gases. Melting of sea ice, ice caps, glaciers and permafrost will increase river flow and reduce sea temperatures and salinity, to some extent compensating for changes in radiation balance.

This short summary of some of the main climate features of the Arctic shows the intimate, atmosphere-ice-land-ocean coupling which characterizes the cryosphere. Monitoring of the effects of climate change depends on understanding this intimate relationship and it is unrealistic to separate changes in the atmosphere from the immediate physical changes on land and sea. Results of integrated multidisciplinary paleostudies can further improve effective analysis and monitoring of changes in atmosphere, land, and sea, as well as effects of these changes. There are large uncertainties in the timing, distribution and intensity of climate change and hence the likely effects. The uncertainty relates to i) the complexity of the system, ii) the sparse monitoring of climate and related physical conditions, iii) the limited effort in modelling at regional and local scales, and lack of necessary interdisciplinary paleoscience information to establish long-term trend analysis or to inform models.

Use of interdisciplinary paleoscience data in assessments is needed to assess past conditions in biodiversity, climate, metals, human health, inputs and concentrations of compounds and chemicals etc., for estimating past trends with more fidelity, to add perspective in projecting future trends, and to help frame possible mitigation measures based on past responses.

*Marine climate*

For the marine climate, the tables below reflect the general importance of observations on temperature and salinity related to standard sections and fixed stations. In contrast, sea ice extent and concentrations are regularly measured by remote sensing. More intensive observations of the fronts between warm and cold water masses and the volume flux at main 'gateways' are important targets.

Sea level is an important physical variable which, while not specifically a climatic factor, is closely related to it, and, like other marine physical variables, is an important driver of biotic and ecosystem change. It should be included as a generally measured variable, possibly by remote sensing.

# 2. State

Monitoring to define spatial patterns and temporal changes across the Arctic region

## 2.1 Climate/meteorology

*[Input asked from Arni Snorrason, Barry Goodison, Etienne Charpentier, Jeff Key, John Walsh, Rodica Nitu, Øystein Hov]*

### 2.1.1 Parameters

| Theme | Parameter |
|---|---|
| Atmosphere (surface) | *Precipitation (Estimates of liquid and solid precipitation)* |
| | *Pressure (surface)* |
| | *Surface Radiation Budget (Surface ERB longwave; Surface ERB shortwave)* |
| | *Surface Wind Speed and direction* |
| | *Temperature (near surface)* |
| | *Water Vapour (surface)* |
| Upper atmosphere | *Earth Radiation Budget (Top-of-atmosphere ERB longwave; Top-of-atmosphere ERB shortwave (reflected); Total solar irradiance; Solar spectral irradiance)* |
| | *Lightning (Number of lightnings)* |
| | *Temperature (upper-air) (Tropospheric Temperature profile; Stratospheric Temperature profile; Temperature of deep atmospheric layers)* |
| | *Water Vapour (upper air) (Total column-water vapour; Tropospheric and lower-stratospheric profiles of water vapour; Upper tropospheric humidity)* |
| | *Cloud Properties (Cloud amount; Cloud Top Pressure; Cloud Top Temperature; Cloud Optical Depth; Cloud Water Path (liquid and ice); C, effective particle radius (liquid and ice))* |
| | *Wind speed and direction (Upper-air wind retrievals)* |
| Atmospheric composition | *Aerosols properties (Optical depth; single-scattering albedo; layer height; extinction profiles for the troposphere and the lower to middle stratosphere)* |
| | *Carbon Dioxide, Methane and other Greenhouse gases (Tropospheric CO2 column; Tropospheric CO2; Tropospheric CH4 column; Tropospheric CH4; Stratospheric CH4)* |
| | *Precursors (supporting the Aerosol and Ozone ECVs) (NO2 tropospheric column; SO2,HCHO tropospheric columns; CO tropospheric column; CO tropospheric profile)* |
| | Radiatively Important Trace Species (RITS) – concentrations |
| Storm frequency | |
| Ocean/Coastal (physical) | *Ocean Surface Heat Flux (Latent Heat Flux; Sensible Heat Flux)* |
| | *Sea Level (Global Mean Sea Level; Regional Sea Level)* |
| | *Sea State (Wave Height)* |
| | *Sea Surface Salinity* |
| | *Sea Surface Temperature* |
| | *Subsurface Currents (Interior Currents)* |
| | *Subsurface Salinity (Interior Salinity)* |
| | *Subsurface Temperature (Interior Temperature)* |
| | *Surface Currents (Surface Geostrophic Current)* |
| | *Surface Stress* |
| | Position of fronts (Current patterns and flux measurements) |

| | |
|---|---|
| | Establishing paleo-sea level baselines |
| Ocean/Coastal (biogeochemical) | *Inorganic Carbon (Surface Ocean Partial Pressure of CO2 (p CO2); Subsurface ocean storage of CO2)* |
| | *Nitrous Oxide (Interior ocean N2O; N2O air-sea flux)* |
| | *Nutrients (Interior ocean concentrations of silicate, phosphate, nitrate)* |
| | *Ocean Colour (Water Leaving Radiance; Chlorophyll-a Concentration)* |
| | *Oxygen (Interior ocean oxygen concentration)* |
| | *Transient Tracers (Interior ocean CFC-12, CFC-11, SF6, tritium, 3He, 14C, 39Ar)* |
| | pH |
| Terrestrial | Vertical temperature profiles into soil and water |

### 2.1.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

WMO:

- Global Atmosphere Watch (GAW)
- Global Observing System (GOS) surface synoptic network
- WMO Executive Council Panel of Experts on Polar and High Mountain Observations, Research and Services (EC-PHORS)
- World Weather Watch (WWW)

National meteorological services

### 2.1.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 2.1.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

## 2.2 Stratospheric ozone, UV-B

*[Input asked from <u>Signe Bech Andersen</u>, Niels Larsen, Nis Jepsen (nje@dmi.dk), Markus Rex (Markus.Rex@awi.de)]*

### *2.2.1 Parameters*

| Theme | Parameter | Coordinating organizations/initiatives |
|---|---|---|
| *Atmospheric Composition* | *Ozone (Total column ozone; troposphere Ozone; Ozone profile in upper and lower stratosphere; Ozone profile in upper strato-and mesosphere)* | **Monitoring:**<br>• Global Atmosphere Watch (GAW)<br>• Network for the Detection of Atmospheric Composition Change (NDACC)<br>• Ozone profiles/LIDAR stations: Summit, Ny-Alesund, Pallas<br><br>**Satellite data and products**: CSA/ESA/EUMETSAT/NASA/NOAA/USGS<br><br>Global Ozone Monitoring Experiment (GOME): Total ozone |
| Atmosphere | Polar stratospheric clouds | CALIPSO (Polar Stratospheric Clouds) |
| UV-B Radiation | Short wave radiation | |
| | Photosynthetically active radiation | |

### *2.2.2 Coordination activities*

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### *2.2.3 Quality Assurance/Quality Control*

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### *2.2.4 Data reporting*

*[Are international, recognized data centres for these variables existing?]*

## 2.3 Carbon cycle

*[Input asked from Torben Christensen, Greg Flato, Søren Rysgaard]*

### *2.3.1 Parameters*

| Parameter | Coordinating organizations/initiatives |
|---|---|
| *Anthropogenic Greenhouse Gas Fluxes* | |
| *Soil Carbon (%Carbon in soil; Mineral soil bulk density to 30 cms and 1m ; Peatlands total depth of profile, area and location)* | IPA**:** Carbon Pools in Permafrost Regions (CAPP) |

### *2.3.2 Coordination activities*

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### *2.3.3 Quality Assurance/Quality Control*

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### *2.3.4 Data reporting*

*[Are international, recognized data centres for these variables existing?]*

## 2.4 Hydrology/river/lake ice

*[Input asked from Terry Prowse, Arvid Bring]*

### 2.4.1 Parameters

| Parameter | Coordinating organizations/initiatives |
|---|---|
| *Lakes (Lake water level; Water Extent; Lake surface water temperature; Lake ice thickness; Lake Ice Cover; Lake Colour (Lake Water Leaving Reflectance))* | |
| *River discharge (River discharge; Water Level; Flow Velocity; Cross-section)* | |
| Sediment loads | |
| Run-off | |
| Timing of river/lake ice freeze- and break-up | |

### 2.4.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### 2.4.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 2.4.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

## 2.5 Land ice

*[Input asked from Michele Citerio (GCW), Martin Sharp, Jason Box, Jeff Key, Tedesco (USA), Valerie Delamotte]*

*Comments to the cryosphere sections (snow, permafrost, sea ice, and land ice) from Jeff Key (email, 11th September 2017): This idea strongly overlaps with the Arctic Polar Regional Climate Centres (PRCC) concept, doesn't it? If you agree, WMO PRCC should be mentioned in the Coordination activities column. In fact, it may be that PRCC should be the "home" for this monitoring, rather than AMAP. PRCC link: http://www.wmo.int/pages/prog/wcp/wcasp/meetings/PRCC_Scoping_Workshop2015.html]*

### 2.5.1 Parameters

| Theme | Parameter | Coordinating organizations/initiatives |
|---|---|---|
| *Glaciers* | *Glacier area* | |
| | *Glacier elevation change* | |
| | *Glacier mass change* | |
| | Volume change | |
| | Glacier flow rate | |
| | Front position | |
| | *Albedo* | |
| Greenland Ice Sheet (GRIS) | Volume change | Programme for Monitoring of the Greenland Ice Sheet (PROMICE) |
| | Mass change | |
| | Glacier flow rate | |
| | Front position | |
| | *Albedo* | |
| *Ice Sheets and ice shelves* | *Surface Elevation Change* | |
| | *Ice velocity* | |
| | *Ice mass change* | |
| | *Grounding line location and thickness* | |
| Atmosphere | Air temperature | |
| Snow | Accumulation rate | |
| Fresh water | Run-off/discharge | |
| Marine/coastal | Iceberg prevalence | |

### 2.5.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

Satellite data and products: CSA/ESA/EUMETSAT/NASA/NOAA/USGS

Global Cryosphere Watch (GCW)

### 2.5.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### *2.5.4 Data reporting*

*[Are international, recognized data centres for these variables existing?]*

## 2.6 Permafrost

*[Input asked from Bo Elberling, Dimitry Drozdov, Jeff Key, Vladimir Romanovsky]*

### *2.6.1 Parameters*

| Parameter | Coordinating organizations/initiatives |
|---|---|
| Extent | |
| Classification | |
| *Active layer thickness* | |
| *Thermal State of Permafrost* | |

### *2.6.2 Coordination activities*

IPA:

- Global Terrestrial Network for Permafrost (GTN-P)
- Circumpolar Active Layer Monitoring (CALM)
- Carbon Pools in Permafrost Regions (CAPP)

Satellite data and products: CSA/ESA/EUMETSAT/NASA/NOAA/USGS
Global Cryosphere Watch (GCW)

### *2.6.3 Quality Assurance/Quality Control*

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### *2.6.4 Data reporting*

*[Are international, recognized data centres for these variables existing?]*

- NSIDC Frozen Ground data Centre
- Global Terrestrial Network for Permafrost – Database (http://gtnpdatabase.org/)

## 2.7 Snow

*[Input asked from Jeff Key, Ross Brown, Terry Callaghan]*

### 2.2.1 Parameters

| Parameter | Coordinating organizations/initiatives |
|---|---|
| *Precipitation (Estimates of liquid and solid precipitation)* | |
| *Snow (Area covered by snow; snow depth; snow water equivalent)* | |
| Snow cover duration | |
| Snow quality | |

### 2.2.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

- WMO
  - Global Cryosphere Watch (GCW)
  - Global Observing System (GOS) surface synoptic network
  - World Weather Watch (WWW)
- Climate and Cryosphere (CliC)
- National meteorological services
- Satellite data and products: CSA/ESA/EUMETSAT/NASA/NOAA/USGS

### 2.2.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 2.2.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

## 2.8 Sea ice

*[Input asked from Dave Barber, Jeff Key, Rasmus Thonboe (DMI), Sebastian Gerland, Thomas Lavergne (NO), Walt Meier]*

### 2.8.1 Parameters

| Parameter | Coordinating organizations/initiatives |
|---|---|
| *Sea Ice Concentration* | |
| *Sea Ice Extent/Edge* (Comment: Sea ice volume is derived from this) | |
| *Sea Ice Thickness* (Comment: Sea ice volume is derived from this) | |
| *Sea Ice Drift* | |
| Sea ice age | |
| Sea ice surface temperature | |

### 2.8.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

Satellite data and products: CSA/ESA/EUMETSAT/NASA/NOAA/USGS

Global Cryosphere Watch (GCW)

### 2.8.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 2.8.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

**National Snow and Ice Data Center (NSIDC)** (Products)

## 2.9 Land

*[Input asked from Tom Barry (CAFF/CBMP)]*

### 2.9.1 Parameters

<table>
<tr><td>Parameter</td><td>Coordinating organizations/initiatives</td></tr>
<tr><td>Anthropogenic Water Use</td><td></td></tr>
<tr><td>Fire (Burnt Area; Active fire maps; Fire radiative power)</td><td></td></tr>
<tr><td>Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)</td><td></td></tr>
<tr><td>Land Cover</td><td rowspan="2">CAFF is developing a land cover change index which is addressing variables such as land surface temperature etc for the Arctic (as defined by the CAFF Boundary) see here for the outcomes for the first phase of this work: https://caff.is/indices-and-indicators/land-cover-change-index.</td></tr>
<tr><td>Land Surface Temperature</td></tr>
<tr><td>Latent and Sensible Heat fluxes</td><td></td></tr>
<tr><td>Soil moisture (Surface soil moisture; Freeze/thaw; Surface inundation; Root-zone soil moisture)</td><td></td></tr>
<tr><td>Groundwater (Groundwater volume change; Groundwater level; Groundwater recharge; Groundwater discharge; Wellhead level; Water quality)</td><td></td></tr>
<tr><td>Albedo</td><td></td></tr>
<tr><td>Evaporation from land (Latent heat flux; Sensible heat flux)</td><td></td></tr>
</table>

### 2.9.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### 2.9.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 2.9.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

## 2.10 Anthroposphere

*Input asked from X*

### 2.10.1 Parameters

| Parameter | Coordinating organizations/initiatives |
|---|---|
| *Anthropogenic Greenhouse Gas Fluxes (Emissions from fossil fuel use, industry, agriculture and waste sector; Emissions/ removals by IPCC land categories; Estimated fluxes by inversions of observed atmospheric composition - continental; Estimated fluxes by inversions of observed atmospheric composition - national; Hi-res CO2 column concentrations to monitor point sources)* | |
| *Anthropogenic Water Use (Volume of water per year)* | |

### 2.10.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### 2.10.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 2.10.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

# 3. Impact: Changes in *State* parameters

## 3.1 Climate/meteorology

*Input asked from X*

### *3.1.1 Parameters*

| Theme | Parameter | Coordinating organizations/initiatives |
|---|---|---|
| Terrestrial | Vegetation/greening (NVDI, etc.) | Satellite data and products: CSA/ESA/EUMETSAT/NASA/NOAA/USGS |
| | Timing of events | |
| | Drought/flooding | |
| | Primary production | |
| Fresh water | Timing of events | |
| | Drought/flooding | |
| Marine/coastal | Timing of events | |
| | Drought/flooding | |
| Human | Disease vectors | AMAP Human Health Assessment Group (HHAG) |
| | Food and water security | |
| Socio-economic | Resource development | The Economy of the North (ECONOR) International Arctic Social Sciences Association (IASSA) |
| | Resource access | |
| | Ecosystem services | |

### *3.1.2 Coordination activities*

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

CBMP (above and below): Data generated by CAFF/CBMP is being made available on the Arctic Biodiversity Data Service (ABDS) - https://www.abds.is/. CAFF works with a range of partners to further develop cooperation, access to and management of biodiversity data. Partners include the Arctic Spatial Data Infrastructure (Arctic SDI); Global Biodiversity Information Facility (GBIF); Ocean Biogeographic Information System (OBIS); Group on Earth Observations Biodiversity Observation Network (GEOBON); the Polar Data Catalogue (PDC) and the Global Earth Observation System of System (GEOSS). ABDS serves as arctic node within GBIF and OBIS - see here for CAFF ABDS Arctic node: https://www.gbif.org/publisher/44862593-2fdd-4491-ab79-b500b8272aac

### *3.1.3 Quality Assurance/Quality Control*

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### *3.1.4 Data reporting*

*[Are international, recognized data centres for these variables existing?]*

## 3.2 Stratospheric ozone, UV-B

*[Input asked from X]*

*[The following text is from* UV-B effects *in the current AMAP monitoring guidelines]*

UV levels in the Arctic have been increasing over the past two decades owing to decreases in ozone. In six of the last nine years of the 1990s, severe stratospheric ozone depletion episodes were observed during the Arctic late-winter/spring periods. Current springtime ozone levels for the Arctic are between 25 and 50 Dobson units below normal.

The most optimistic estimates for the future are that ozone recovery will take place at a rate of less than 5 Dobson units per decade. These estimates imply that Arctic UV will be elevated through 2050. The estimates for recovery rate are considered optimistic because they do not include the effects of climate change that may exacerbate ozone depletion in the Arctic. Global warming results in cooler stratospheric temperatures and may affect atmospheric dynamics. In the Arctic, cooler stratospheric temperatures along with changes in atmospheric circulation can cause greatly increased ozone destruction, particularly in the presence of polar stratospheric clouds. The frequency of occurrence of polar stratospheric clouds has increased in the past decade and is expected to continue to increase with climate change. Therefore, the Arctic is likely to have elevated UV levels for the foreseeable future. There is also considerable uncertainty about future Arctic ozone levels due to natural variations caused by meteorological conditions. It is presently unclear what the full impacts of climate and meteorological variations will be.

Climate change also has a direct effect on UV levels in the Arctic. Predicted climate change includes not only temperature changes but also changes in clouds, precipitation and snow-cover extent. As these parameters change, UV reaching the biosphere is also expected to change. The effects of climate change can also combine non-linearly with UV in plants and animals.

UV levels have long been an important environmental stressor in the Arctic. With increased UV levels, not only must human health effects be considered, but also the effects of UV on aquatic and terrestrial ecosystems. Initial studies have shown that UV levels can have detrimental effects on individual species and thus create a distinct pressure on balances among species within ecosystems. These effects have been observed and reported on phytoplankton, zooplankton, fish larvae, and terrestrial plants and animals. UV can cause cataract formation in a number of mammals.

Human health effects include sunburn and other skin damage due to UV exposure. Changes in the elasticity of the skin of the Greenland Inuit population have been reported. These changes can be linked to UV exposure. Likewise, UV radiation is also a cause of erythema (sunburn), which is linked to malignant melanoma. Frequent incidences of actinic prurigo, an idiopathic photodermatosis, have been reported in the Canadian Inuit population and linked to UV sensitivity

***Terrestrial ecosystems***

Research on effects of UV-B on terrestrial ecosystems and plants and animals under field conditions started only one decade ago and, even worldwide, there are still relatively few studies. Studies under field conditions are essential because shading within natural canopies and interactive responses among species are difficult to simulate in laboratories. Existing studies show individualistic responses of plants and animals to UV-B and also individualistic responses of ecosystem processes such as decomposition, nutrient cycling and nitrogen fixation. In general, UV-B radiation is more difficult to measure than, for example, temperature, and responses of plants, animals and ecosystem processes to UV-B radiation are also more difficult to measure than, for example, responses to temperature change or atmospheric nitrogen deposition. Generally, there is a lack of a highly specific response of organisms to UV-B that can be separated from concurrent responses to other environmental

stressors. Because of these difficulties, there are currently few, if any, standard methodologies that can be easily and immediately applied to monitor UV-B effects.
(…)

***Aquatic ecosystems***

Chemical and biological processes and food webs in Arctic marine and freshwater systems are clearly influenced by present-day UV radiation (UV-R), and may be further so with a continued ozone thinning. While there are similarities in responses in planktonic and littoral biological compartments, there are also a number of major differences. Minima in stratospheric ozone have been recorded in spring, when the marine productivity is approaching its peak but most freshwaters are still ice covered. Large-scale environmental effects, such as reduced primary production (reduced $CO_2$ uptake) and effects on fisheries would also be most significant in marine areas. On the other hand, freshwater systems may be more vulnerable; they are generally shallower and hence lack depth refuge. A major determinant of UV-R penetration, and thus effects in aquatic systems, is the presence of dissolved organic carbon (DOC), notably humus compounds, that attenuates UV-R far more efficiently than particulate matter. Altered climate and hydrological patterns may substantially alter the flux of DOC from terrestrial to aquatic areas. For the Barents Sea, the flux of DOC from the large Russian rivers is a major determinant of UV-R penetration, and changes in this DOC flux could be more important than actual changes in UV-R as a result of stratospheric ozone depletion.

Recent studies have verified the potential effects of UV-R on shallow freshwater ecosystems. For marine systems the data are more scattered, and there is a general lack of *in situ* studies confirming effects of UV-R in the Arctic. For marine systems, it is important to note that the results from studies of the persistent ozone depletion over Antarctic areas cannot be directly applied to Arctic systems, due to the widely different species and food-web structures involved.

It is also important to remember that aquatic systems can be affected not only by direct effects of UV-R on organisms, but also indirectly, for example through UV-R generating a complex photochemistry in reaction with organic substances such as DOC. Such reactions may create toxic compounds, free radicals and oxidants, but also increase availability of nutrients, trace metals and organic compounds.

(…)

***Recommendations for Studying Effects on Human Health***

Components of the *AMAP Effects Monitoring Programme* that address UV effects on human health are covered in the next section of this document (Monitoring effects of contaminants in humans). These effects monitoring components are directly related to the following requirements and issues:

- **Effects of changing UV levels on human skin**

  Establishment of baseline data on the prevalence of acute skin damage in the Arctic population is essential to understanding whether such cases are becoming more prevalent as UV levels increase.

- **Improved understanding of the relation between UV levels and ocular dysfunction**

  Work is required to determine direct links between snow blindness, cataracts, and other ocular disorders and UV, including possible follow-up studies to earlier work such as that conducted by researchers in Alaska.

- **Additional work directed to understanding the role of UV radiation in immune suppression.**

  There is a need to investigate the ability of UV radiation to induce changes in immune suppression.

### 3.2.1 Parameters

| Theme | Parameter | Coordinating organizations/initiatives |
|---|---|---|
| Human | UV exposure | AMAP Human Health Assessment Group (HHAG) |
| Terrestrial | Primary production | CAFF is developing a land cover change index which is addressing variables such as land surface temperature etc for the Arctic (as defined by the CAFF Boundary) see here for the outcomes for the first phase of this work: https://caff.is/indices-and-indicators/land-cover-change-index. |

### 3.2.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### 3.2.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 3.2.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

## 3.3 Carbon cycle

*Input asked from X*

### 3.3.1 Parameters

| Parameter | Coordinating organizations/initiatives |
|---|---|
| Societal impact of ocean acidification | |

### 3.3.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### 3.3.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 3.3.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

## 3.4 Hydrology/river/lake ice

*Input asked from X*

### *3.4.1 Parameters*

| Theme | Parameter | Coordinating organizations/initiatives |
|---|---|---|
| Freshwater | Timing of events | |
| | Change in ecosystem structure | CBMP: Provision of complementary information on population and ecosystem level effects and habitat degradation |
| Human | Access | |
| | Transport | |
| | Ice roads | |
| Socio-economic | Flooding | |

### *3.4.2 Coordination activities*

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### *3.4.3 Quality Assurance/Quality Control*

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### *3.4.4 Data reporting*

*[Are international, recognized data centres for these variables existing?]*

## 3.5 Land ice

*Input asked from X*

### 3.5.1 Parameters

| Theme | Parameter | Coordinating organizations/initiatives |
|---|---|---|
| Freshwater/Marine/Coastal (biotic) | Timing of events | Satellite data and products: CSA/ESA/EUMETSAT/NASA/NOAA/USGS<br><br>TLK: Wildlife observations<br><br>CBMP: Provision of complementary information on population and ecosystem level effects and habitat degradation |
| | Change in ecosystem structure | |
| Human | Access/ice roads | TLK: Access/travel on ice |
| Socio-economic | Sea level rise | |
| | Hydropower | |
| | Flooding | |

### 3.5.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### 3.5.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 3.5.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

## 3.6 Permafrost

*Input asked from X*

### 3.6.1 Parameters

| Theme | Parameter | Coordinating organizations/initiatives |
|---|---|---|
| Terrestrial (biotic) | Carbon cycle | Satellite data and products: CSA/ESA/EUMETSAT/NASA/NOAA/USGS |
| | CH4 | |
| Freshwater (biotic) | Hydrology | |
| Marine/Coastal (abiotic) | CH4 release | |
| Human/Socio-economic | Access | TLK: Access, infrastructure integrity |
| | Infrastructure | |
| | Landscape impacts (hydrological regime) | |

### 3.6.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### 3.6.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 3.6.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

## 3.7 Snow

*Input asked from Jeff Key*

### *3.7.1 Parameters*

| Theme | Parameter | Coordinating organizations/initiatives |
|---|---|---|
| Terrestrial (biotic) | Ecosystem effects | Satellite data and products: CSA/ESA/EUMETSAT/NASA/NOAA/USGS<br>TLK: Wildlife observations, reindeer husbandry<br>CBMP: Provision of complementary information on population and ecosystem level effects and habitat degradation |
| Freshwater (biotic) | Timing of run-off | |
| Socio-economic | Reindeer husbandry | *[Is this covered by CBMP?]* |
| | Agriculture | |
| | Power generation | |
| | Water supply | |

### *3.7.2 Coordination activities*

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### *3.7.3 Quality Assurance/Quality Control*

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### *3.7.4 Data reporting*

*[Are international, recognized data centres for these variables existing?]*

## 3.8 Sea ice

*Input asked from X*

### 3.8.1 Parameters

| Theme | Parameter | Coordinating organizations/initiatives |
|---|---|---|
| Marine/Coastal (abiotic) | Timing of events | CBMP: Provision of complementary information on population and ecosystem level effects and habitat degradation |
| | Change in ecosystem structure | |
| | Ice-edge habitat/communities | |
| | Productivity | |
| | Marine mammals | IUCN: Marine mammals |
| Human | Coastal travel | TLK: Access/travel on ice |
| | Coastal erosion | |
| Socio-economic | Fisheries | ICES: Fisheries statistics<br><br>Socio-economic data sources: National fisheries statistics<br><br>Socio-economic data sources:<br>• The Economy of the North (ECONOR)<br>• National agencies responsible for resource development, waste treatment and disposal |
| | Shipping | |
| | Marine access | |
| | Marine tourism | |

### 3.8.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### 3.8.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 3.4.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

## 3.9 Land

*Input asked from X*

### 3.9.1 Parameters

| Parameter | Coordinating organizations/initiatives |
|---|---|
| | |
| | |
| | |

### 3.9.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

### 3.9.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 3.9.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

## 4. Ecology (Monitoring effects of climate change on biota and ecosystems)

*[The following text is* General considerations *in the section* Monitoring Effects of Climate Change on Biota and Ecosystems *in the current AMAP monitoring guidelines]*

Some basic principles emerge from the background documents and from the experience of other monitoring programmes:

- Monitoring should be designed to answer specific questions and targeted by explicit consideration of expected or desired change (hypotheses, scenarios, models or policy targets).
- Sampling strategies (experimental design) should be designed
    i. To provide adequate replication over the systems.
    ii. To include key sources of environmental variation within and between systems or sites (altitude, sea depth, or other gradients) to provide comparative information.
    iii. To distinguish between causes of change (elements of climate, pollution, natural fluctuation, exploitation).
    iv. To provide observations at appropriate times and frequencies in relation to expected change.
- Maximum use should be made of information on past changes (e.g., long-term experiments, historical records, tree rings, sediment and ice cores, etc.) and linking them with current trends and model predictions of future changes that can be validated by monitoring.
- Variables selected should be relevant to the target question, sensitive to the particular driver under consideration, and interpretable in terms of the consequences of change to the system. In relation to the latter, it is vital to select species with a strong (physiological, demographic, etc.) 'signal-to-noise ratio'. Furthermore, longer-term dynamics must be understood before attempts are made to interpret future trends in the context of climate change. Many Arctic species exhibit dramatic fluctuations in populations (e.g., lemmings) or in developmental processes, and in other cases, systems or populations show a long ecological memory, possibly following a trend initiated by events at the end of the Little Ice Age.
- Methods of measurements should be repeatable over decades with minimal operator or instrument error, robust so that there is flexibility in timing of observations, accurate enough to detect change, and inexpensive and undemanding of time and skill.

These principles may be obvious – and sometimes conflicting – but they help to distinguish competing interests, e.g., the enthusiasm of the specialist who wants his organism or site to be included and the realist who wants only the most appropriate elements to be included.

*(From Tom Barry (CAFF/CBMP): See focal ecosystem components being addressed by CBMP ecosystem groups – may be of relevance here (https://caff.is/monitoring); also indicators programme see here: https://caff.is/indices-and-indicators e.g. the Arctic Species Trend Index)*

## 4.1 Marine

*Input asked from*
*Marine:*

- *General: Eddy Carmarck, Hein-Rune Skjoldahl, Ronnie Glud, Warwick Vincent*
- *Phytoplankton: Christine Michelle, Chris Mundy*
- *Zooplankton: Jeff Bowman, Torkel Gissel]*

*[The following text is* Marine Biota and Ecosystems *in the section* Monitoring Effects of Climate Change on Biota and Ecosystems *in the current AMAP monitoring guidelines]*

Detection of long-term changes in marine ecosystems has very different implications for monitoring, relative to terrestrial systems. Fundamentally, the large-scale dynamics of physical, chemical, and biotic components of oceans require sophisticated sampling and detection systems and the use of purpose-built vessels and satellites. Such facilities, particularly in polar waters, are associated with major research programmes which are often international. Compared to terrestrial systems, marine environments also provide very limited opportunity for experimental manipulation to isolate the effects of specific factors.

Current understanding highlights a number of key physical factors which drive actual or potential biotic responses, particularly in the Barents and Bering Sea regions (e.g., Weatherhead, 1998). Some key factors identified are higher ocean temperatures and lower salinity, contraction of the extent of seasonal sea ice, shifts in the exchange of water masses between neighboring seas, increased mixing of surface waters due to changing wind regimes, and rising sea levels. These, combined with El Niño, are known to significantly affect the biota, and some indicative changes have been detected. Quantification of specific interactions is largely a matter of theory and confounded by the influence of unrelated factors (resource exploitation, pollution, increased UV-B, etc.). However, the observed and expected changes are important in targeting monitoring, as shown for monitoring of climate and related physical variables.

In considering the biological effects of climate change, a simple but important distinction can be made between direct and indirect responses through food-web interactions. This distinction has specific implications for monitoring.

- Changing physical conditions act directly on the distribution and performance of individual species. For example, many gadoids, herring, salmonids and other fish species have specific temperature limits and are known to respond directly to changing conditions. Ringed seals, walrus and polar bear are particularly dependent on the sea-ice edge habitat and are directly affected by changes in its extent.
- Implications for monitoring include: i) direct effects of changes in temperature and/or salinity are likely to be detected (in species with defined tolerance limits) by changes in distribution at the geographical edge of their range (both northern and southern); ii) responses to temperature are likely to be detected in changes in timing of specific events (phenology) such as arrival/departure at breeding sites, time of nesting, or molt.
- The intimate food-web relationships result in a complex of interactions between species. Thus, there can be an indirect 'domino' effect as a result of one species being affected by climate change. A particular distinction can be made between food webs in the open ocean and those at the sea-ice edge, but in both cases the effects are most obvious at the higher trophic levels. As a result of the interactions, it is difficult to determine the extent to which species changes are the result of response to climate change or to one of the many other natural or anthropogenic drivers of change.

- The study of past climate change events can provide important information on conditions in biodiversity and effects of climate change on species, habitats and ecosystems. Integration of this data into the planning and conduct of current and future monitoring programmes will result in better trend analysis for projecting future trends, and will help frame possible mitigation measures based on past responses.

This summary is a gross simplification and needs to be improved by relevant specialists. Although marine research is strong and there is a high level of international cooperation, there is no established monitoring programme for the effects of climate change on marine ecosystems. Elements exist in some regions and for some sectors which may be targeted because of their sensitivity to climate. For example, member countries of ICES and PICES regularly monitor commercial fish stocks.

Seabird and marine mammal monitoring is also undertaken in connection with a number of international instruments (conventions, protocols) related to their conservation. However, many factors are involved in changes in species dynamics of which climate change is only one. More precise information on the effects of climate change can be obtained by targeting particular species, climate sensitive phenological variables and the climatically sensitive edges of species ranges closely coordinated with CAFF, and interdisciplinary paleoscience studies.

### 4.1.1 Parameters

<table>
<tr><td>Parameter</td><td>Coordinating organizations/initiatives</td></tr>
<tr><td>Marine Habitat Properties (Coral Reefs; Mangrove Forests, Seagrass Beds, Macroalgal Communities)</td><td></td></tr>
<tr><td>Plankton (Phytoplankton; Zooplankton)</td><td></td></tr>
<tr><td>Species diversity (changes)</td><td rowspan="6">CBMP: Provision of complementary information on population and ecosystem level effects and habitat degradation. CAFF is developing a land cover change index which is addressing variables such as land surface temperature etc for the Arctic (as defined by the CAFF Boundary) see here for the outcomes for the first phase of this work: https://caff.is/indices-and-indicators/land-cover-change-index.</td></tr>
<tr><td>Species abundance (changes)</td></tr>
<tr><td>Species productivity (changes)</td></tr>
<tr><td>Species growth rates (changes)</td></tr>
<tr><td>Invasive species</td></tr>
<tr><td>Migration</td></tr>
</table>

### 4.1.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

**CBMP**: Provision of complementary information on population and ecosystem level effects and habitat degradation

### 4.1.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### *4.1.4 Data reporting*

*[Are international, recognized data centres for these variables existing?]*

## 4.2 Terrestrial and freshwater

*[Input asked from*
*Terrestrial: Terry Callaghan, Gus Shawer, Niels-Martin Schmidt, Arvid Bring, Magnus Lund*
*Freshwater: Kirsten Christoffersen, Fred Wrona, Jim Reist]*

*[The following text is* Terrestrial and Freshwater Biota and Ecosystems *in the section* Monitoring Effects of Climate Change on Biota and Ecosystems *in the current AMAP monitoring guidelines]*

Understanding of the effects of climate variability and changere in terrestrial and freshwater systems has probably been more fragmented than that for marine systems. This may be because access to biological sites on land is easier, allowing greater opportunity for individual studies, and there have been more limited incentives for international cooperation. Therefore, given the need for more comparative circumpolar information, there is probably more opportunity for improvements in monitoring systems on land than at sea.

Synthesis of understanding of observed changes and future scenarios is now providing a reasonable basis for the design of monitoring programmes. Due to the fact that field validation of computer model output lags far behind the development of these models, which in turn leads to possible large errors (e.g., errors in the sign/direction of the change), reviews and scenarios also provide important information to focus monitoring. Such scenario models have been developed on the basis of a combination of physiological and ecological information to summarize the sequence of responses to warming in tundra ecosystems, including feedback to the atmosphere and associated information on the certainty and magnitude of change (Chapin et al., 1992). Subsequent syntheses have emphasized the diversity of response. For example:

- that species (and physiological) responses are highly individualistic;
- environmental gradients have marked effects on responses;
- the response of species dominant in their communities are likely to be particularly apparent at the northern/upper edges of their ranges, and different from within the range, but the responses of subdominant species (affected more by the responses of dominant species rather than their own direct responses to climate) can be important throughout their ranges;
- actual changes in species distribution will lag behind changes in climate;
- winter conditions, snow and ice cover, and extreme climatic events will be at least as important as changes in mean climate;
- unexpected species introductions and epidemics (including pests and diseases) will occur;
- migratory species are vulnerable to differential climate changes within their range;
- the extinction of Pleistocene megafauna may still be affecting changing ecosystems today.

There is a general need for both validation and refinement of existing models and the development of new models, reviews and scenarios.

The effects of climate change in Alpine regions are also likely to be applicable to the mountain areas in the Arctic and there are many similarities with expected and observed effects of climate change in freshwater.

The understanding of the effects of climate change, outlined above as hypotheses, has been used to identify biological variables for monitoring at particular levels of resolution). Measuring all of these variables is desirable; however, intercorrelations between parameters should be made in large databases so that a limited number of proxies for effects can be used in the longer term.

### *4.2.1 Parameters*

| Theme | Parameter | Coordinating organizations/initiatives |
|---|---|---|
| Terrestrial (plant) | *Above-ground biomass* | |
| | *Leaf Area Index (LAI)* | |
| | Chlorophyll concentrations of communities (at peak biomass) | |
| | Peak shoot and root biomass | |
| | Surface roughness | |
| | Spectral vegetation greenness | |
| | Maximum stomal conductance | |
| Freshwater (plant) | Net primary production (derived or measured) | |
| | Chlorophyll concentrations | |
| | Nutrient pool in organic and inorganic matter | |
| Terrestrial and freshwater (plant and animal) | Species diversity (changes) | CBMP: Provision of complementary information on population and ecosystem level effects and habitat degradation. CAFF is developing a land cover change index which is addressing variables such as land surface temperature etc for the Arctic (as defined by the CAFF Boundary) see here for the outcomes for the first phase of this work: https://caff.is/indices-and-indicators/land-cover-change-index. |
| | Species abundance (changes) | |
| | Species productivity (changes) | |
| | Species growth rates (changes) | |
| | Species richness (changes) | |
| | Species distribution (changes) | |
| | Invasive species | |
| | Migration | |
| | Demographic processes (selected species) | |
| | Phenology (selected species) | |
| | Displacement of ecotones (Changes at edges of range) | |
| Processes | $CO_2$, $CH_4$, and $N_2O$ flux. Especially | |

| | | |
|---|---|---|
| | wetlands; soil and above canopy. Terrestrial (Freshwater) | |
| | Decomposition. Organic matter accumulation | |
| | N mineralization | |

### 4.2.2 Coordination activities

*[Are these parameters monitored by other organizations/initiatives? Should these be considered the 'home' for these parameters?]*

**CBMP**: Provision of complementary information on population and ecosystem level effects and habitat degradation

### 4.2.3 Quality Assurance/Quality Control

*[What QA/QC programs exist or should be developed in support of these parameters?]*

### 4.2.4 Data reporting

*[Are international, recognized data centres for these variables existing?]*

## 5. Feedbacks

- Energy balances
- Hydrology circle
- Nutrient circle