WCRP REPORT
World Climate Research Programme
WMO UNESCO IOC ICSU International Council for Science

Revision 1 to
World Climate Research Programme
and Scientific Committee on Antarctic Research
Climate and Cryosphere (CliC) Project
Implementation Strategy Document

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The WCRP is sponsored by the World Meteorological Organization, International Council for Science, and the Intergovernmental Oceanographic Commission of UNESCO.

CliC is a core project of the WCRP, cosponsored by the Scientific Committee for Antarctic Research of ICSU (SCAR).

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Foreword

Cryosphere is involved in strong environmental feedbacks that shape the future of the climate system. Our expectation is that through activities of CliC and its partners, it will be possible to address the challenge of having the cryosphere adequately observed, understood, and represented in the climate and Earth System models, so that in the predictions and projections of the future climate, it is no longer the “weakest link”. Programmes, projects, and other alliances mentioned in this document are our partners, but the list is not inclusive. We are open to cooperation and coordination. Every opinion, proposal, initiative, expression of the desire to collaborate is very important for CliC.

The Implementation Strategy for CliC is a “living document” that succinctly presents goals and objectives of the project, and its major domains called CliC Themes, and outlines main principles of the project implementation and management. The Implementation Strategy continues focussing on our activities, building on the earlier CliC Science and Co-ordination Plan, which is a companion document to this. CliC will not have a project implementation plan *per se* because it is impossible to exactly prescribe all necessary steps that may be needed for achieving its goals and objectives until the project sunsets in a decade. Instead, we will use the strategy and guidance that can be found in this document and the earlier Science and Co-ordination Plan to move forward and adjust priorities and activities as required. We will proceed ahead with eyes open and ready to adjust the course if required.

Barry Goodison
Chair, CliC Scientific Steering Group

Preface

The World Climate Research Programme (WCRP) was established in 1980, under the joint sponsorship of the World Meteorological Organization (WMO) and the International Council for Science (ICSU). The Intergovernmental Oceanographic Commission (IOC) of UNESCO became a WCRP sponsor in 1993. The objectives of the programme are to develop the fundamental scientific understanding of the physical climate system and climate processes needed to determine to what extent climate can be predicted and the extent of human influence on climate. WCRP studies are specifically directed to provide scientifically founded quantitative answers to questions about climate and the range of natural climate variability, as well as to establish the basis for predictions of global and regional climatic variations and of changes in the frequency and severity of extreme events.

The Climate and Cryosphere (CliC) project was founded in March 2000 at the 21st session of the Joint Scientific Committee for the World Climate Research Programme (JSC). CliC is the successor of another WCRP core project, the Arctic Climate System Study (ACSYS, 1994-2003). Unlike ACSYS, which was a 10-year regional study, CliC is a much broader, global study that will run until the end of 2015. For interested parties, the CliC website <http://clic.npolar.no> provides more detailed information about the project.

This publication outlines the two aims of the *Implementation Strategy* for CliC:

1. To provide a general platform for project implementation and to start the coordinated implementation for individual CliC themes; and
2. to present the planning, coordination, and management of the project.

The CliC Science and Coordination Plan provides the necessary scientific background (WCRP 114/WMO/TD No. 1053; January 2001. Eds. I. Allison, R. Barry, and B. Goodison). The URL to a digital copy is <http://ipo.npolar.no/reports/archive/wcrp_114.pdf>.

Acknowledgements

This document was prepared by the CliC Scientific Steering Group (SSG), CliC International Project Office (CIPO), and the Joint Planning Staff for WCRP. Valuable comments and contributions by participants of the *1st CliC International Science Conference* and others in the CliC community are greatly appreciated.

Acronyms used in this document

ACIA	Arctic Climate Impact Assessment
ACSYS	Arctic Climate System Study (WCRP)
AICI	Air-Ice Chemical Interactions
AOGCM	Atmosphere-Ocean General Circulation Model
ASOF	Arctic – Subarctic Ocean Fluxes
ASPeCT	Antarctic Sea-Ice Processes, Ecosystems, and Climate
ARGO	Array for Real-time Geostrophic Oceanography
CACGP	Commission for Atmospheric Chemistry and Global Pollution
CEOP	Coordinated Enhanced Observing Period (WCRP)
CEOS	Committee on Earth Observing Satellites
CLIVAR	Climate Variability and Prediction Research Programme
COPES	Coordinated Observation and Prediction of the Earth System
CRYSYS	CRYosphere SYStem in Canada
DISC	Data and Information Service for CliC
ESSP	Earth System Science Path Finder
GCOS	Global Climate Observing System
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water Cycle Experiment
GLIMS	Global Land Ice Monitoring from Space
GOOS	Global Ocean Observing System
GPC	Global Prediction of the Cryosphere (formerly CPA4)
GTOS	Global Terrestrial Observing System
GPCC	Global Precipitation Climatology Centre
GRDC	Global Run-off Data Centre
ICSU	International Council for Science
IGBP	International Geosphere – Biosphere Programme (ICSU)
IGOS	Integrated Global Observing Strategy
IGOS-P	Integrated Global Observing Strategy Partnership
IHDP	International Human Dimensions Programme on Global Environmental Change
HYCOS	Hydrological Cycle Observing System
IMSL	Ice Masses and Sea Level (formerly CPA 2)
IOC	Intergovernmental Oceanographic Commission of UNESCO
IPCC	Intergovernmental Panel on Climate Change (WMO, UNEP)
IPY	International Polar Year
ISMASS	Ice Sheet Mass Balance and Sea Level
JCADM	Joint Committee on Antarctic Data Management
JPS	Joint Planning Staff (WCRP)
JSC	Joint Scientific Committee for the WCRP
MarC	Marine Cryosphere and Climate (formerly CPA 3)
MOC	Meridional Overturning Circulation
NEESPI	Northern Eurasian Earth Science Partnership Initiative
NPI	Norwegian Polar Institute
OASIS	Ocean-Atmosphere-Sea Ice-Snowpack
PAGES	Past Global Environmental Changes
SCAR	Scientific Committee on Antarctic Research (ICSU)

SCOR	Scientific Committee on Oceanic Research (ICSU)
SPARC	Stratospheric Processes and their Role in Climate
SEARCH	Study of Environmental Arctic Change
SOLAS	Surface Ocean - Lower Atmosphere Study
SSG	Scientific Steering Group
TCHM	Terrestrial Cryosphere and Hydrometeorology of cold regions (formerly CPA1)
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
URL	Uniform Resource Locator (world wide web global address)
WCRP	World Climate Research Programme (WMO-ICSU-IOC)
WGCM	Working Group on Coupled Models
WGNE	Working Group on Numerical Experimentation
WMO	World Meteorological Organization

1.0 Introduction

The WCRP established the CliC Project to stimulate, support, and coordinate research into the complex processes by which the cryosphere interacts with the rest of the climate system. The cryosphere considered in CliC incorporates snow, solid precipitation, permafrost and seasonally frozen ground, ice sheets, ice caps and glaciers, sea-, river-, and lake ice. As a sensitive component of the climate system, the cryosphere may provide key indicators of climate change, and CliC will focus on identifying patterns and rates of change in cryospheric parameters, over a range of temporal and spatial scales.

The principal goal of CliC is:

To assess and quantify the impacts that climatic variability and change have on components of the cryosphere and its overall stability, and the consequences of these impacts for the climate system.

To achieve this goal, CliC has the supporting objectives to enhance observation and monitoring of the cryosphere, improve understanding of the physical processes through which the cryosphere interacts within the climate system, improve the representation of cryospheric processes in models, and use observed changes in the cryosphere as indicators of climate change.

Noting the diversity of cryospheric components, the wide geographic coverage and the fast pace of scientific and technical development, CliC will encompass four main “Themes”, covering the following areas of climate and cryosphere science:

1. The Terrestrial Cryosphere and Hydrometeorology (TCHM)
2. Ice Masses and Sea Level (IMSL)
3. The Marine Cryosphere Climate (MarC)
4. Global Prediction of the Cryosphere (GPC)

CliC also has a major task to promote improvements in the management of data and information relating to the cryosphere and climate, seeking to make data more readily available for use by the broad scientific community. To this end, CliC has established a web-based Data and Information Service for CliC (DISC) and continues to work with researchers and data- and metadata centres to ensure best-practice data and information management.

A major focus for the development of CliC over the next years is the *International Polar Year (IPY) 2007-2008*. IPY is an opportunity not only to enhance studies of the cryosphere/climate system in both polar regions during that period, but also to leave a legacy of improved observational and modelling capabilities for the future. The opportunity must also be taken to improve our ability to observe, model and understand the cryosphere in all cold regions.

CliC is neither a funding body nor a funded project and must therefore achieve its aims through the initiation, coordination, and strategic development of relevant programs and activities. CliC aims to provide expert guidance for national programs and resources that are dedicated to cryospheric science, and to establish and maintain links between scientific organizations, funding agencies and the research community. Through directions by its Scientific Steering Group, CliC will develop expert panels responsible for the implementation of CliC Themes, data management and information, development of observational products and models, and as well scientific activities addressing gaps in our knowledge and understanding of cryospheric processes.

CliC actively encourages the research community to provide input to the project through the conduct of relevant research, initiation of and participation in workshops and conferences, support for scientific proposals, and the promotion of cryospheric and related science to funding and policy-making agencies. It is only through community participation that CliC can achieve its goals and the overarching goals of the WCRP: to improve our understanding and prediction of the global climate system.

2.0 Climate and the Cryosphere

The Cryosphere is an integral part of the Earth System, both responding to, and influencing, climate change and variability. cryosphere is present at all latitudes, including the Equator. *Figure 1* illustrates the countries which have snow and/or ice for at least part of the year. In addition sea ice covers much of oceans. Snow and ice have relatively high albedo, reflecting more short-wave solar radiation away from the Earth's surface than underlying land or water. Snowfall and the resulting snow cover and its subsequent melt are critical in water supply, moisture recharge, reservoir filling and the pulse of freshwater runoff to oceans. Permafrost and frozen ground alter the fluxes of water, energy and gases between the land surface and the atmosphere, and strongly influence landforms, hydrology and vegetation. Freezing and thawing processes have a profound effect on water, energy and chemical cycles. Glaciers, ice caps and ice sheets store water for hundreds or thousands of years, and if all this land ice were to melt, it is estimated that sea level would rise by about 70 metres. Sea-ice formation and melting, and processes at the bottom of ice-shelves and around icebergs, redistribute freshwater and salt in the ocean. The resulting water mass transformations drive the global ocean thermohaline circulation.

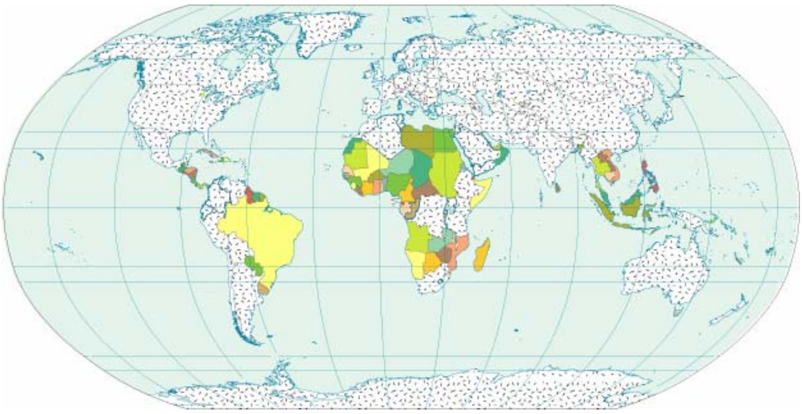

Figure 1. Countries where cryosphere exists in some form.

In a changing climate, feedbacks and amplification of climate signals through their interaction with the cryosphere will play a crucial role in the future of the Earth system. The snow-ice/albedo feedback *(Figure 2)* and the permafrost/greenhouse gas amplification would both enhance any initial warming. Indeed, many global climate models predict that the Arctic region will show the greatest anthropogenic 'greenhouse' warming largely because of the albedo feedback. Increased melting of Arctic sea ice and the Greenland ice sheet, and strengthening northern river run-off, all contribute to freshening of the surface waters in the North Atlantic. In turn, this could weaken the meridional overturning circulation (MOC) of the ocean, including a weakening of the North Atlantic Current that is responsible for the relatively mild climate of northwest Europe. This could have major implications for future European, and indeed global, climate.

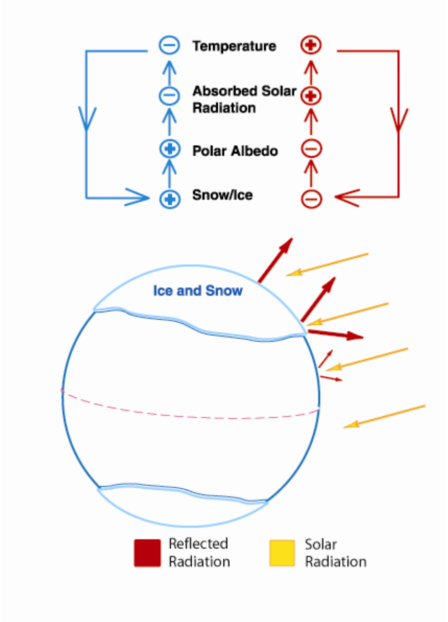

Figure 2. Snow-ice/albedo feedback

Despite its importance within the climate system, many of the processes by which the cryosphere interacts with the rest of the climate system are poorly understood. Much of the cryosphere is remote from major population centres, and its study can be difficult, expensive, and even dangerous. There is an ongoing need to stimulate and coordinate further research on cryosphere - climate interactions. Without understanding the cryosphere's role in the climate system, we cannot model and predict its variability and future change.

Understanding and predicting the future of the cryosphere/climate system is not merely an intellectual exercise, there are also major practical implications. Snow cover and sea-ice extent are important predictors in seasonal forecasting, including prediction of such critical variables as temperature, precipitation, and such phenomena as monsoons, droughts, etc. In cold regions, infrastructure (buildings, pipelines, roads and railways) may have foundations on permafrost, surface transport may rely on freezing conditions during winter or melting in summer, power generation commonly relies on snow and glacier melt, and the winter tourism industry may rely on adequate snowfall. In warmer regions, transport may be adversely affected by cryospheric conditions, and summer melt from mountain snow fields and glaciers may be critical for the supply of drinking water and crop irrigation. Low-lying regions may be vulnerable to sea-level changes *(Figure 3)* caused by melting glaciers and ice caps. Changes to the cryosphere will have many socio-economic consequences. The need for reliable observing and monitoring of all elements of the cryosphere globally is absolutely essential to address the issues of climate and cryosphere within the Earth System.

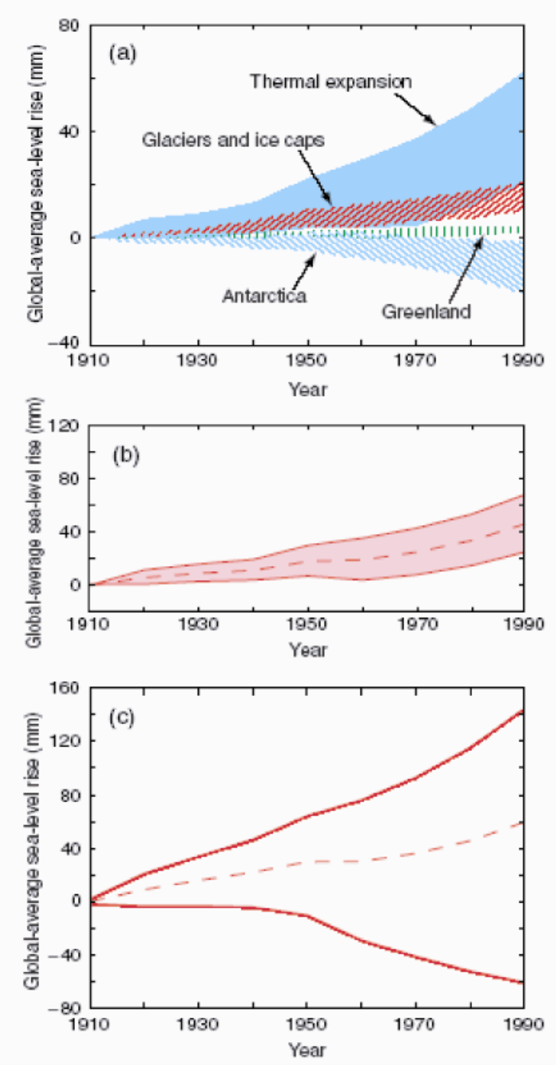

Figure 3. Estimated sea level rise from 1910 to 1990 due to Meridional Overturning Circulation (MOC) collapse.

(a) The thermal expansion, glacier and ice cap, Greenland and Antarctic contributions resulting from climate change in the 20th century calculated from a range of AOGCMs. Note that uncertainties in land ice calculations have not been included.

(b) The mid-range and upper and lower bounds for the computed response of sea level to climate change (the sum of the terms in (a) plus the contribution from permafrost). These curves represent our estimate of the impact of anthropogenic climate change on sea level during the 20th century.

(c) The mid-range and upper and lower bounds for the computed sea-level change (the sum of all terms in (a) with the addition of changes in permafrost, the effect of sediment deposition, the long-term adjustment of the ice-sheets to past climate change and the terrestrial storage terms). *Souvre, IPCC, 2001.*

3.0 The Climate and Cryosphere (CliC) Project

The WCRP established the CliC project to address the critical problem of limited observations and data coverage in many regions of the cryosphere, and the resulting inadequate representation of the cryosphere in climate models. By helping to fill these knowledge gaps, CliC is expected to contribute to the achievement of the WCRP goals of determining:

- The extent to which climate can be predicted.
- The extent of human influence on climate.

The Scientific Committee on Antarctic Research (SCAR) became a co-sponsor of the project in 2004.

3.1 Goals and Objectives

In order to achieve its principal goal (page 1), CliC has the supporting objectives to:

1. Enhance the observation and monitoring of the cryosphere and the climate of cold regions in support of process studies, model evaluation, and change detection.
2. Improve understanding of the physical processes and feedbacks through which the cryosphere interacts within the climate system.
3. Improve the representation of cryospheric processes in models to reduce uncertainties in simulations of climate and predictions of climate variability and change.
4. Facilitate assessment of changes in the cryosphere and their impact, and to use this information to aid the detection of climate change.

3.2 Key Scientific Questions

The CliC Project Science and Coordination Plan Version 1 (WCRP 114-WMO/TD no. 1053, January 2001) provides the science basis for studying the relationships between climate and the cryosphere, and these details are not repeated here. The Science and Coordination Plan identifies CliC interests in all cryosphere/climate interactions, and shows that the project is not restricted to limited science questions or themes. However, in an attempt to coordinate the scientific efforts, the Plan did identify a number of key scientific questions that broadly cover much of the research necessary to achieve the CliC goals. These key questions are:

1. What are the magnitudes, patterns and rates of change in the terrestrial cryosphere on seasonal-to-century time-scales? What are the associated changes in the water cycle?
2. What will be the contribution of glaciers, ice caps and ice sheets to changes in global sea level on decadal-to-century time-scales?
3. What will be the nature of changes in sea-ice distribution and mass balance in both polar regions in response to climate change and variability?
4. What will be the impacts of changes in the cryosphere on atmospheric and oceanic circulation? What is the likelihood of abrupt or critical climate and/or Earth system changes resulting from processes involving the cryosphere?
5. What do monitored changes in the cryosphere tell us about variability and change in the climate system? How can these monitored changes be combined with proxy or palaeo-records and the results of modelling studies to improve our understanding of climate change?

Note that while most of these questions are phrased to look to the future of the cryosphere/climate system, the ability to make projections implies that both past and present states and processes be understood. The period of interest for CliC-related projections covers the coming decades and goes through the next few millennia. Interest in the past is limited pragmatically to that period that helps us understand the present and project the future of the cryosphere - climate system. The length of this period varies depending on the processes and elements being examined.

3.3 Approach to Planning and Implementation

Since CliC is neither a funding body nor a funded project, it must find ways to initiate and support the development of necessary activities and try to ensure coordination of existing resources provided by participating countries, institutes and scientists. CliC must work to promote the project and coordinate activities to stimulate the investment of new resources in the study of the cryosphere and its role in the climate system. In doing so, it must seek and take advantage of opportunities for major international collaborative studies of the cryosphere and cold region climate, such as the forthcoming International Polar Year 2007- 2008, and use these programs to give momentum to the 15-year project.

4.0 CliC Themes

The CliC implementation strategy is targeted at finding solutions to the main science questions and to building capacity in the areas of cryospheric monitoring, process studies, data management and access, and modelling. In addition, it seeks effective ways to communicate results to policy and decision-makers and other non-scientific users.

Noting the diversity of cryospheric components and the fast pace of scientific and technical development, it is considered effective to address the main science questions and major cryospheric domains through development of "CliC Themes". The Themes address the first four key scientific questions (section 3.2) and cover areas of climate and cryosphere science described more fully below.

The themes reflect major domains of the project activities. The borders between them are not rigidly defined. Individual scientists, projects, measurements or models may well contribute in more than one area. The Themes provide a basis for assessing scientific progress in each field and for recommending and initiating research needed to improve understanding of the cryosphere/climate system. Much of the work within Themes will be conducted in cooperation with relevant partners.

In addition, the cryosphere provides many of the best indicators of climate change. Thus, a CliC task will be to assess and report regularly on the state of these indicators, and the state of knowledge regarding their past changes. Each Theme will contribute to this cross-cutting topic.

4.1 The Terrestrial Cryosphere and Hydrometeorology (TCHM)

The terrestrial cryosphere is considered to comprise land areas with snow cover, lake- and river-ice, glaciers and ice caps, permafrost and seasonally frozen ground and solid precipitation.

Studies of the balance and exchange of water, energy and matter between the terrestrial cryosphere and the atmosphere involve the sciences of meteorology, climatology, hydrology, geocryology, glaciology, biogeochemistry and geomorphology. Each of these disciplines is relatively well developed, but multi-disciplinary research in their interaction remains a challenge. Also, many of the processes involving the terrestrial cryosphere are poorly represented in current climate models. Assessing the role of the cryosphere in climate variability and change of mountainous regions (glaciers, permafrost, snow, etc.) presents a significant challenge.

The central questions for the TCHM theme are:

- What are the magnitudes, patterns and rates of change in terrestrial cryosphere regimes on seasonal-to-century time-scales? What are the associated changes in the water cycle?
- What is the role of terrestrial cryospheric processes in the spatial and temporal variability of the water, energy and carbon cycles of cold climate regions, and how can they be parameterized in models?
- What are the interactions and feedbacks between the terrestrial cryosphere and atmosphere/ocean systems and current climate? How variable are these interactions and how will they change in the future?

A fundamental task of this theme is to improve estimates and quantify the uncertainty of water balance and related energy flux components in cold regions. This includes precipitation (both solid and liquid), distribution properties of snow, snow melt, evapotranspiration and sublimation, water movement through frozen and unfrozen ground, water storage in watersheds, river- and lake-ice properties and processes, river runoff, etc. Estimates are required of the amount and form of carbon and ice stored in the ground and their release rates to the atmosphere or surface and ground water in a warming climate.

Observations and Data

In both high latitude and high altitude regions, observations of cryospheric elements are often sparse and are concentrated in coastal and valley locations. Station networks have declined and continue to decline in most of these regions. Enhanced observations and rescue of historical data are essential for determining the past and present patterns of variation and change in the terrestrial cryosphere in all regions of the globe. Mapping of mountain glaciers using historical sources combined with recent remotely sensed imagery is a pressing need for over half of the world's glaciers that are not yet contained in the World Glacier Inventory. Rapidly shrinking tropical glaciers and ice caps merit special attention. The integration of validated in situ and satellite data to provide temporally and spatially consistent global data on the terrestrial cryosphere will be vital to replace the loss of data from traditional stations. However, efforts must also be made to prevent further decline and indeed to reverse the trend in *in situ* observational networks. The establishment of transects, like the PAGES programme of pole/equator/pole and zonal transects, and of "Super Study Sites" (long-term and intensive multidisciplinary observatories), spanning a range of terrain settings, will be needed to provide data for improved understanding of relevant terrestrial processes and their temporal variations, testing parameterizations suitable for larger-scale models and development and validation of remotely sensed cryospheric information. Meridional transects will also enable key 'transition' zones (e.g., tundra-forest and forest-steppe boundary zones) that are susceptible to rapid changes to be monitored closely. CliC will strive to establish river run-off observations in cold climate regions and facilitate exchange of corresponding observations, particularly for catchments contributing to the world oceans. Problems of measuring solid precipitation, inherent biases, correction of systematic errors, and related data interpretation issues will also be a focus.

CliC seeks to promote standardization and consistency of observations for terrestrial cryospheric variables.

Modelling

It is essential to assess, and ultimately ensure, that the terrestrial cryospheric components and the associated processes affecting the energy, water and carbon cycles are properly incorporated and validated in forecast, climate and hydrological models, and in future re-analysis activities. There is a need to develop and validate physically based land-atmosphere-cryosphere process models (including permafrost-hydrology and carbon cycle interactions) with appropriate complexity for use in coupled models at a range of scales. The proper scaling (scaling down climate parameters; scaling up cryospheric processes and properties) and verification of the scaling procedure is essential in the development of land surface process models and their link to hydrological models, and for incorporation into climate models. Improved regional climate models are needed with interactive climate-cryosphere-hydrosphere schemes that allow assessments of (i) impacts on the terrestrial cryosphere of future climate change, and (ii) the effects of changes in the cryosphere on regional and local climates on the scale of mountain systems. Modelling and monitoring studies should proceed concurrently.

Output

1. Spatial-temporal variability

- Time series of standardized cryospheric indicators of climate variability and trends.
- Evaluation of the magnitude and patterns of variability and rates of change in the terrestrial cryosphere (snow cover, glaciers, fresh water ice, permafrost, seasonally frozen ground and the coastal zone in cold regions).

2. Changes in the cryosphere and water cycle

- Improved understanding of the meteorological and hydrological processes in different cold region environments.
- Assessment of the impact of changes in the cryosphere due to global warming and other environmental factors, creating potential hazards to life and property. Assessment of other impacts of significant socio-economic importance, related to glacier recession, outburst floods, ice-jams, permafrost degradation and coastal retreat of ice-rich terrain, seasonal duration of snow and ice-cover, etc.
- Enhanced information for water resource management, especially for mountain regions, including improved knowledge of fresh water resources from melting snow, glaciers and ground ice, fresh water ice and rain on snow.
- Projections of changes in the terrestrial cryosphere, and associated changes in regional water balance and contributions to sea-level rise, for use in decision making.

3. Observations and data

- Improved and sustained in-situ and remote sensing observing systems for terrestrial elements of the cryosphere. In addition to the “essential climate variables” of the Global Climate Observing System (GCOS), spatio-temporal characteristics of properties such as snow density, liquid water content, snow and ice albedo and surface dust content, glacier debris cover etc., need to be investigated.
- Improved estimates and measurement of river runoff and its variability in cold regions, including ungauged Arctic rivers.
- Contributions to improved estimates of carbon stocks and fluxes from regions with permafrost and seasonally frozen ground, including sub-sea environments.
- Establishment and promotion of standardization in terrestrial cryospheric observations, and better systems for exchange of data.
- Establishment of transects and “Super Study Sites” in different environments for intensive measurements, scaling, process parameterization, modelling and remote sensing validation.
- New global and regional datasets based on advanced and validated remote sensing algorithms combined with in-situ data.
- Identification, recovery and archiving of high priority historical datasets of terrestrial cryosphere components.
- Maintenance, extension, and further development of ACSYS datasets and cooperating centres such as GRDC and GPCC.

4. Modelling

- Improved models of terrestrial cryospheric processes and their interactions and feedbacks with the rest of the climate system (especially for processes such as blowing snow, sublimation, ground freezing, river and lake dynamics, and ice-albedo and other feedbacks).
- Improved treatment of cryospheric processes in land surface schemes and assimilation of cryospheric data for use in numerical weather prediction and coupled climate – ocean - hydrological models. Model representation of conditions in complex terrain and high mountains via downscaling and regional high-resolution models will receive special attention.
- Projections of changes in the terrestrial cryosphere, and associated changes in regional water balance and contributions to sea-level rise, for use in policy development (for example, in Intergovernmental Panel on Climate Change).
- Attribution of the observed and projected changes in the terrestrial cryosphere.

4.2 Ice Masses and Sea Level (IMSL)

Sea-level rise is an important consequence of climate change, both for societies and the environment. Global mean sea level has risen 10–25 cm over the twentieth century, with thermal expansion of ocean water contributing from 2 to 7 cm. The most important contributor to the remainder is likely to be loss of land ice. Of all the cryospheric contributions to sea-level change, the largest uncertainty pertains to the Antarctic and Greenland ice sheets. However, glaciers in most mountain regions and ice caps in many polar areas are known to be retreating, and they too make a significant contribution to sea-level rise. Therefore, to understand past and present sea-level variations and predict future change, it is essential to measure and explain the current and past state of mass balance of glaciers, ice caps and ice sheets, how this balance is changing, and the long-term reaction of ice sheets to past, present and future climate changes. The rate of change is known to have accelerated in many areas of the world since the 1970s. Ice shelves may also play an indirect role through their influence on the flow of land based ice sheets and glaciers.

IMSL Central Questions:

- What is the contribution of glaciers, ice caps and ice sheets to sea-level rise on decadal to century time-scales?
- How can we reduce the uncertainty of these estimates?

A major objective of the *Ice Masses and Sea-Level theme* is to improve direct estimates of the mass balance of the Antarctic and Greenland ice sheets and their contribution to sea-level changes. It will also be necessary to develop an enhanced capability to estimate past and predict future ice sheet changes. There is a need to implement a system for monitoring, assessing and predicting the evolution of glacier and ice cap mass balance globally, and to determine the contribution from these sources to sea-level change.

Observations and Data

New technologies, particularly satellite remote-sensing instrumentation, will be essential to provide an observational network to monitor elevation and gravitational changes of the major ice bodies. This will be a major contribution to enable us to assess the mass balance of the bodies and thereby their contribution to sea-level changes. To improve estimates of mass loss from ice sheets, observations are required to provide better knowledge of ice stream behaviour, basal melt, ablation processes, and the role of ice shelves in restraining ice streams and glaciers. Both long-term observations and intensive process studies will be needed. In addition, improved observations of solid precipitation are needed, if not to provide comprehensive data on accumulation on glaciers and ice sheets, then at least to assist with development of models and with evaluation and calibration of satellite measurements. Methods for measuring the influence of sublimation on mass balance need to be developed.

Modelling

Relevant mass balance measurements in remote areas are usually expensive and often very difficult, so global coverage of the land ice contribution to sea level will rely heavily on having adequate models. Significant model development is required in coupling of atmospheric and ice dynamics. Improved atmospheric model estimates of precipitation, and precipitation minus evaporation are required to determine the spatial and temporal variability of snow input to the large ice sheets. Models of sublimation processes, particularly over ice sheets, must be developed. New methods for modelling the sensitivity of glacier mass balance to climate change are needed. Glaciological models of the dynamics of ice sheets, ice streams, and ice shelves, and the assessment of the effects of ice shelves on ice sheet stability are novel and need to be significantly enhanced. The most important processes must be identified and these have to be incorporated into adequate climate or Earth System models for use in extended climate simulations such as Ice Age cycles.

Output

1. Mass Balance

- Improved long-term ice-sheet, ice-cap, and glacier- monitoring system (including more measurements in data-sparse thick-ice areas, and also relevant atmospheric parameters), inventory and related database to assess the mass balance and its uncertainties.
- Mass balance records for a selection of large glaciers and ice caps representative of different climatic regions.
- Realistic representation (model and observational) of spatial and temporal variability of surface mass budget in areas, which are sensitive to sea-level change.

2. Ice Deformation and Stability of Ice Sheets

- Realistic treatment of ice deformation, basal sliding and/or deforming basal till, and appropriate stress configurations in ice stream models, and of ice sheet/ice stream/ice shelf/ocean interaction and coupling.
- Records of continuous ice velocities for a selection of sensitive regions to determine the dynamic response of ice sheets to climate perturbation on seasonal and longer time-scales.
- Assessment of the Greenland and West Antarctic ice sheet stability and vulnerability to climate change including sudden and potentially irreversible changes.

3. Proxy Data and Sensitivity Studies

- Present and future mass balance sensitivities for glaciers based on models, historical and proxy data, including biogeological knowledge of past margins of ice bodies.
- Data from firn and ice cores for sea level and climatic reconstruction and for reconstruction of past climates, including past records of mass-balance-variability and change.
- Assessment of snowfall sensitivity and snow-accumulation and melt/runoff on the large ice sheets, to climate change.

4.3 The Marine Cryosphere andClimate (MarC)

The marine cryosphere includes all forms of sea ice and the snow cover on it, icebergs, and floating ice shelves.

The sea-ice cover in both polar regions is a key indicator of climate change. Recent dramatic changes have been observed in the Arctic, including a decrease in total sea-ice extent and thickness that coincide with major shifts in the large-scale patterns of ocean circulation, ice advection and regional changes in atmospheric circulation and air temperature. Improved technology and observational networks are required to monitor sea-ice variables and processes in order to assess how these observed changes relate to natural variability and to what extent they might be indicative of a major climate shift. In the Southern Hemisphere, although total sea-ice extent appears not to have changed much since the early 1970s, there is evidence that regional shifts in sea-ice distribution and extent are linked to modes of large-scale atmospheric variability. Significant new research is needed to explain the contrasting responses of the two polar regions, and CliC must support ongoing development of satellite, buoy- and ship-based observing systems in the sea-ice zone and the polar oceans beneath the sea ice.

The rapid break up of the Larsen B ice shelf in 2002 and subsequent accelerated flow rate of the outlet glaciers that fed the ice shelf have focused attention on the sensitivity of ice shelves to change and the consequent effects on the mass balance of grounded ice. Ice shelves - while mainly products of the terrestrial cryosphere - are important to ocean processes because they provide a source of fresh melt water both at their base and front as well as along the trajectory of calved icebergs. Melting at the ice shelf/ocean interface results in the production of cold, fresh and oxygen-rich Ice Shelf Water that modifies the water mass properties of local shelf waters, which in turn are critical to the formation of Deep, and Bottom Water, and which influence sea-ice formation in front of the ice shelves.

MarC Central Questions:

- What are the present mean states, natural variability, and recent trends in sea-ice characteristics in both hemispheres, and what are the physical processes that determine these?
- How will sea ice respond in future to a changing climate; e.g., will the Arctic Ocean be ice free in summer in the 21st century?
- How will a changing sea-ice cover affect climate through its interactions with the atmosphere and ocean?
- How do processes of ice-ocean interaction, including basal melt and marine ice accretion, affect the mass balance and stability of ice shelves?
- What is the role of the seasonal production of sea ice in the neighbourhood of ice shelves in driving currents beneath the shelves and thereby influencing basal melting and re-freezing?
- What is the distribution and variability of fresh water input to the oceans from ice shelves, icebergs and ice sheet runoff, and what role does this have on ocean circulation (e.g., maintenance of global thermohaline circulation)?

The primary objective of the theme *The Marine Cryosphere and Climate* is to improve understanding of the ocean-ice-atmosphere system in the polar regions, through enhanced observations, process studies and models. This includes the dynamics and thermodynamics of sea ice and its snow cover, changes in the thickness distribution and characteristics of these media, polynya processes, the impact of sea ice on water mass modification (addition of brine during sea-ice formation, freshening during melt), and interactions of sea ice and snow with the atmosphere. In addition, ice shelf-ocean interactions, the role of ice shelves and icebergs in the ocean freshwater budget, and the impact of changes in sea ice and ice shelf properties that may affect thermohaline circulation lay within this objective.

Observations and Data

Both *in situ* and remote sensing measurements are being used to establish the current state of the sea-ice environment.

Parameters of particular interest to climate studies include the sea-ice concentration, -extent, -motion, -stage of deformation, and thickness distribution; also snow fall and snow thickness distribution on sea ice, temperature, timing of melt, melt-pond distribution, surface albedo, polynya and lead distribution, as well as ice-edge position. Validation and improvement of remote sensing algorithms are required to expand our understanding of these key variables to regions beyond the locations in which in situ field programmes have been conducted. Enhanced observation networks are of key importance for monitoring high frequency processes such as tidal effects on ocean circulation and sea ice.

Observations in polar oceans are very sparse. Therefore, in both the Arctic and Southern Ocean, CliC needs to facilitate the development of the regional components of the Global Ocean Observing System (GOOS), Arctic GOOS and Southern Ocean GOOS, which would cover not only the domain of physical oceanographic observations but also marine component of the global carbon cycle and other crucial variables.

In addition to sea-ice observations, CliC has to promote means of making observations of oceanographic parameters under the sea-ice cover. For example, coverage of sub-surface ARGO floats does not extend into the sea-ice zone, leaving a significant data gap. CliC will support novel research into *in situ* observations of polar oceans and the development, testing, calibration of new observing technologies, and their conversion into operations. Given the remoteness of most cryospheric marine regions, properly evaluated and calibrated satellite remote sensing will be vital to provide broad coverage of marine cryospheric observations. CliC will promote continuation and enhancement of satellite cryospheric missions such as ICESat and CryoSat.

Remote sensing techniques can be used to measure ice shelf velocities, height, thickness and accumulation. However, to measure the ocean circulation under the ice shelves, enhanced observations in front of, and through, ice shelves are required. Similarly, remote sensing of iceberg population provides information on drift tracks, but additional research is required for improved understanding of iceberg calving processes, dissolution rates, effects of grounded icebergs on ocean circulation and sea-ice dynamics, and impacts on ecosystems. In addition, the presence of refrozen seawater ("jade ice") in icebergs may serve as a useful indicator of areas of the parent ice shelf where refreezing processes occur.

CliC will address, jointly with other relevant programmes, the development of observations of precipitation over the polar oceans. It must also support the ongoing development of data networks and the retrieval of historical data relevant to cryospheric science.

Modelling

Improved representation of sea-ice processes in climate models is necessary for better simulation of both the mean state and interannual-to-decadal variability of sea ice, and enhanced prediction of future climate variability and change. Of major concern is the widely disputed possibility of the loss of summer sea ice from the Arctic Ocean over the next 50-100 years, if current trends continue and are amplified by the ice-albedo feedback or by other possible positive feedback mechanisms. Further work is needed to identify all possible positive and negative feedbacks related to the marine cryosphere and its interactions with the oceans and atmosphere. There is also a need for improved models of the atmosphere and oceans in regions affected by sea ice. Methods to assimilate the variety of sea-ice observations into coupled atmosphere-ocean general circulation models need to be developed. This should contribute to the weather and climate forecasting on a variety of time scales and create a basis for global ocean and climate system re-analysis.

Better numerical modelling of the three-dimensional ocean circulation and thermohaline circulation in sub-ice shelf cavities is essential to improving our knowledge of the exchange of ice and heat at the base of ice shelves, which are expected to respond sensitively to changes in ocean temperature. Such models must ultimately be coupled to sea-ice models in order to adequately simulate the seasonal variations of temperature and salinity in the adjoining ocean. Experiments involving the comparison of the various available ice-shelf-cavity models are also a priority.

Modelling of the ice-shelf dynamics should proceed in parallel with the modelling of ice shelf cavities. Ultimately, coupled ice-shelf/cavity models should be used to simulate the changes of shelf geometry and ice flux resulting from changes in basal melting and freezing induced, in turn, by changes in ocean and atmospheric properties.

Output

1. Observations / assimilation / indicators

- Contribution to the design and implementation of Arctic Ocean and Southern Ocean observing systems.
- New methods and systems for observations of marine cryosphere and oceanographic observations in areas with sea ice.
- Sea-ice data assimilation methods and contribution to ocean and climate system re-analysis.
- Indicators of climate change related to the marine cryosphere.

2. Sea-ice processes

- Improved understanding of the present sea ice and snow thickness distributions (and associated mass and energy fluxes) in both hemispheres, and reduced uncertainties in data on past variability and trends in sea-ice cover.
- Assessment of sea-ice formation processes and associated water mass modification, especially in areas of high ice production such as coastal polynyas.
- Enhanced understanding of the interactions and feedbacks between the atmosphere and rapidly changing sea-ice properties, such as lead, polynya and melt pond distribution, ice edge position and stage of deformation.
- Substantiated scenarios of atmospheric CO_2 concentration growth rates that take account of processes and (expected) changes in sea ice and high latitude oceans.
- Better knowledge of the role of ice-ocean interaction in the maintenance of the global thermohaline circulation (linked with the theme, *Global Prediction of the Cryosphere*).
- Explanation of the asymmetric response of the Arctic and Antarctic sea-ice zones to climate change, and improved global predictive capability for future change.
- Considerably improved models of the ocean circulation with inclusion of all types of sea-ice.

3. Ice shelf processes and icebergs

- Enhanced understanding and improved models of ocean circulation beneath ice shelves and of ice shelf-ocean interaction, including basal melt, marine ice accretion and water mass modification beneath ice shelves.
- Enhanced understanding and improved models of ice-shelf dynamics.
- Coupling of models of ice shelves and of the surrounding ocean (including beneath-shelf cavities). Such models will simulate the response of the whole system (e.g. changes of basal melting and freezing; changes in ice-shelf geometry and ice flux; seasonal changes in sea ice and ocean properties) to changes in the properties of the adjacent ocean.
- Improved understanding of iceberg calving processes and the influence of grounded icebergs on ocean circulation, sea-ice distribution and ecosystem processes.
- Improved estimation of the distribution and variability of freshwater input to the oceans from ice shelves, icebergs and ice sheet runoff.

4.4 Global Prediction of the Cryosphere (GPC)

The cryosphere exerts a major influence on the Earth’s climate through complex radiative, thermal, hydrological, and chemical interactions with the atmosphere. In addition, the cryosphere can have a profound impact on global ocean circulation via the redistribution of fresh water and salt and subsequent modifications of water masses. Understanding these interactive roles of the cryosphere within the Earth’s climate system remains a challenge.

Central GPC questions:

- What will be the impact of changes in the cryosphere on atmospheric and oceanic circulation?
- What is the likelihood of abrupt or critical climate and/or Earth system changes resulting from processes involving the cryosphere?

The scope of this Theme is to deal primarily with cryosphere - a climate interaction on spatial scales larger than the regional, i.e., GPC involves broader-scale issues than the other Themes. The timescale is from the beginning of the Pleistocene (when useful for understanding current and predicting future climate), through the instrumental period, and over the next few millennia. GPC is highly cross-disciplinary, linking the variability and change of the cryosphere to atmospheric and oceanic circulations and biogeochemical cycles.

Within this Theme, a broad range of questions linking the cryosphere and the rest of the Earth's climate system will be addressed. Activities are therefore divided into three science themes dealing with (i) mechanisms linking the cryosphere and the rest of the Earth's climate system, (ii) global teleconnections, and (iii) natural and anthropogenic changes in the cryosphere. The scale of interactions being addressed means that both broad-scale observations and coupled modelling are essential features for all of these themes. Ultimately there is a need to understand the predictability of the cryosphere and to make meaningful predictions about its state over the next few millennia.

Mechanisms Linking the Cryosphere and the Rest of the Earth's Climate System

We currently have a poor understanding of the means by which many aspects of the cryosphere are linked to the global atmospheric and oceanic circulations. For example, changes in snow or ice extent alter albedo and hence surface heating, providing a positive feedback on an initial change. However, more complex changes in cloud and radiation fields and atmospheric circulation also arise, altering the overall feedback. Similarly, permafrost changes may affect water and energy balances, but second order changes in land surface and vegetation increase the complexity of any feedbacks. Furthermore, dominant modes of atmospheric variability are important in linking the cryosphere and other components of the Earth's climate system as exemplified by studies of co-variability between annular modes and polar variables in recent years. We need to learn more about the underlying mechanisms behind those links, thus enhancing our ability to predict future variations and changes.

Key issues to be addressed are:

- The feedbacks and amplifications of climate variability and change due to the cryosphere.
- The mechanisms responsible for the decadal-to-multi-millennial variability in the cryosphere.
- The consequences of abrupt changes in the cryosphere on the Earth's climate system, e.g., the possible collapse of the West Antarctic ice sheet resulting in sea-level rise or the flooding of the North Atlantic Ocean by fresh water from the melting cryosphere resulting in an abrupt weakening of the thermohaline circulation.
- The impact on biogeochemical cycles of changes in the cryosphere, e.g., the release of various gases as a result of a decrease in sea-ice extent or permafrost degradation.

It will be necessary to maintain strong communication with groups addressing the other Themes, in order to ensure plans and activities complement, rather than duplicate, one another.

Global Teleconnections

There is now evidence that there are links between widely spaced elements of the cryosphere and the global atmospheric and oceanic circulation. For example, it is well established that changes in the atmospheric and oceanic conditions across the Tropical Pacific Ocean significantly affect the Antarctic sea-ice distribution and precipitation across much of West Antarctica. However, such links are highly non-linear and there is evidence of variability of these teleconnections on decadal-to-centennial timescales. In addition, fresh water release from a melting cryosphere has the potential to alter the global ocean circulation.

Key issues to be addressed are:

- The impact on the cryosphere on extra-polar atmospheric and oceanic variability and change.
- The impacts of changes in the cryosphere on global atmospheric and oceanic circulation.
- Arctic-Antarctic links on the glacial timescale.
- The routes by which global and regional climate signals become locked into palaeoclimatic records.

Natural and anthropogenic changes in the cryosphere

A key issue in geoscience is to understand the extent to which humankind is influencing the environment. Although we have observed major changes in the cryosphere over recent decades, attribution of these changes is still unclear.

Key issues to be investigated are:

- The natural interactions between the cryosphere, climate and greenhouse gases on glacial time-scales.
- The impact on the cryosphere of anthropogenically-induced changes in the Earth's climate system, such as the increase in greenhouse-gas and sulphate-aerosol concentrations and the reduction in the concentration of stratospheric ozone at high latitudes.
- The interactions between the cryosphere and the large-scale modes of atmospheric and oceanic variability.

Output

1. Observations and data

- An assessment of the effectiveness of the current cryospheric observing system and recommendations for the development of the future system.
- A snapshot view of the state of the global cryosphere during the forthcoming IPY. (This will be a dynamic rather than static snapshot, including both the mass balance of the cryosphere and its elements, and a comprehensive view of the atmospheric and oceanic conditions that influence that mass balance.)
- As a legacy of IPY, the capability to carry out long-term monitoring of the global cryosphere.

2. Process studies

- Improved insight into the highly non-linear links between the various components of the cryosphere and the rest of the Earth's climate system.
- Quantitative understanding of the physical mechanisms responsible for past abrupt climate changes involving the cryosphere.

3. Modelling

- Assessment of the cryospheric components of the current generation of climate and Earth system models for both glacial and interglacial conditions and recommendations regarding future improvements.
- Development and validation of the next generation of climate and Earth system models, including comprehensive representations of all relevant components of the cryosphere.

4. Prediction

- Improved predictions of the evolution of the cryosphere over the next thousand years.
- Determination of the likelihood of rapid changes in climate and sea level over the third millennium and of the role played by the cryosphere in those changes.
- An assessment of the predictability of the cryosphere at the global scale.

5.0 Data and Information Management

The principal objective of CliC data and information management is to provide timely information on CliC-related datasets and ancillary information, and to facilitate the information flow within the global climate and cryosphere research community. Building on experience with WCRP's Arctic Climate System Study (ACSYS), CliC has already made progress in the areas of data management and information provision. A data policy has been developed, a website is in place, and a newsletter is published. In addition, a Data and Information Service for CliC has been developed (section 5.1). CliC must continue this work, maintain and enhance these services.

CliC will promote the collection and archival of relevant data through retrieval of historical records, maintenance of ongoing measurements, or initiation of new programmes. It will participate actively in identifying gaps in data required to meet the goals of the project, seeking opportunities to fill these gaps, and, where necessary, initiating the relevant programmes for data collection. CliC will facilitate the identification of appropriate data centres for the long term archival and access of cryospheric datasets.

5.1 Data and Information Service for CliC (DISC)

CliC will meet the needs of the international climate and cryosphere research community through DISC, a web-based Data and Information Service for CliC <http://clic.npolar.no/disc/index.html>. The core of DISC is a single-point access, fully searchable database of information and metadata about the cryosphere and cryosphere - climate research.

DISC concentrates on providing the following information and services:

- Metadata, that allows a researcher to find appropriate cryospheric datasets;
- Information about CliC, climate and cryosphere science, ongoing projects, and relevant meetings;
- Links to related cryospheric information, researchers and resources; and,
- Information about the state of the cryosphere (e.g., through interactive maps).

While DISC is not a data archive, it will make it easier for scientists to gain access to the climate and cryospheric data needed for their research. It also provides an important access point for the public and policy makers to learn about the cryosphere and the climate research work being done in cold regions worldwide.

Metadata Importance and Standards

In its data and information management activities, CliC highly recognizes the role of metadata as a key component of a complete dataset enabling the user to identify, locate and access relevant datasets for their research. Metadata written in recognized standards supports inter-operability among national and international archive centres. CliC will be proactive in seeking and collecting metadata for relevant datasets, through requests to individuals and institutions to provide metadata for known datasets; assisting with the preparation of metadata for projects that require such help; and downloading relevant metadata from metadata centres and websites.

All CliC metadata will conform to ISO 19115 standard for geographic metadata and to the WMO Core Metadata Profile. Adherence to the ISO 19115 standard is essential to maintain inter-operability between data centres, to make the use of search engines easier, and to obtain and update metadata from other data centres and services.

It is possible for researchers to add links for their data via the DISC. They need only to complete a metadata profile questionnaire that is linked from the DISC site. This is one way in which it is hoped to keep the system dynamic and responsive to the cryospheric community.

Activities

The tasks for the duration of the project include:

- Collaborating with data centres and research projects in the application of standards and techniques for data and information management;
- Leading data policy and service development where necessary;
- Reviewing relevant technological and other improvements in the field of data and information management;
- Identifying gaps in climate and cryospheric data required by the CliC project and seeking opportunities to address these gaps;
- Identifying relevant data, then encouraging and initiating data collection and recovery projects;
- Advising individual projects on data and information management issues;
- Maintaining informative and useful web pages for both the CliC project and for its data and information service; and,
- Promoting data and information management policies that simplify access to data and information regardless of users' location and level of resources.

5.2 CliC Data Policies

The CliC data and information policy has been developed with consideration for the data policies of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission of UNESCO (IOC), and the International Council for Science (ICSU), the WCRP, and other related programmes.

The principles of the CliC data policy are:

- Data should, in general, be available in an open and unrestricted manner for non-commercial purposes.
- Costs involved should not exceed the cost of reproduction by the data provider (i.e., a data centre, research institution, or a national agency that stores the data).
- Data should not be redistributed without authorization.
- Data shall not be used for commercial purposes unless special arrangements have been made.
- All data held in a data centre are owned by the original data provider such as a national agency or individual researcher and the user shall acknowledge the ownership of the data provider, including citation of the data source in all publications (preferably in the publication reference list or bibliography).
- The data provider holds the obligation to update and ensure the quality of data provided and has the right to replace, correct or withdraw data from a data centre.
- CliC will follow established metadata standards (ISO 19115) and will encourage and assist users in exchanging relevant data and metadata.

CliC considers that relevant data should be submitted to a recognized data centre for storage immediately after data collection, along with metadata to assist with the location and use of the data. (It is important to note that this does not lead to the data collector losing control of the data, but merely ensures that it is secure for future use.) Whenever possible these data should be made available for distribution at the same time, although restriction of access may need to be considered in special circumstances. Such restriction should be as short as possible, and should not generally exceed two years.

CliC will maintain expertise for provision of advice on data and information management to the cryosphere/climate scientific community and other projects and programmes as appropriate.

6.0 The International Polar Year - a Springboard for CliC Activities

The International Polar Year 2007 - 2008 (IPY) is jointly sponsored by the World Meteorological Organization (WMO) and the International Council for Science (ICSU). Its observing period will take place from 1 March 2007 until 1 March 2009. The IPY is seen as both an intensive period of activity in polar science and as the chance for a step-change in our ability to conduct future polar research. To be successful, not only must there be significant studies during this intensive period, but the IPY should leave a legacy of improvements (observational facilities, methods and algorithms, data and data management resources, numerical models and model results, and informed scientists, policy makers, funders and the general public, new generation of young polar researchers) that allow for greater future development of polar science and understanding of the polar regions.

Whilst the IPY is envisaged to cover all aspects of polar science, the polar regions are dominated by cold climate and the cryosphere. Studies of the cryosphere and its role in local, regional and global climate will therefore form a major part of IPY activities. The CliC project has already been heavily involved in the development of IPY and its Framework through participation in meetings, written submissions to WMO and ICSU planning bodies, and organization of WCRP contributions to IPY. CliC will coordinate the cluster of IPY activities associated with monitoring, assessing, and understanding the variability, uncertainty, and change in the global cryosphere and cooperate with those involved in developing observing systems and data and information management. CliC will also link with projects involved in socioeconomic and cultural issues and those that will provide education and outreach, including traditional knowledge. The project will play a leadership, management, and coordinating role in the development of a sustained long-term cryospheric polar observing system, which would be implemented in the future through GCOS, GOOS, GTOS, CEOS, and possibly GEOSS. The objectives of this work are to

- assess the current state of cryospheric parameters in the high latitude regions, providing a snapshot of the cryosphere and an evaluation of its current (IPY) state in the context of past states and projections of the future;
- formulate the observational requirements of cryospheric variables for weather and climate monitoring and prediction and for other environmental assessments;
- strengthen international cooperation in the development of cryospheric observing systems.

The objective of CliC in IPY is to evaluate the entire global cryosphere as an integrated component of the global climate system, to place current changes in the context of past variability and change, and to document the impact of changes in the cryosphere on biological and human systems. The planned outputs (deliverables) are:

- a near real-time integrated product on the current state of the global cryosphere during IPY,
- a global, quantitative assessment of the current state of cryospheric parameters based on a snapshot of the cryosphere during IPY, presented in report and data set forms with estimated error bars,
- a detailed compilation of the observational requirements of cryospheric variables for weather and climate monitoring, prediction and projection with an identification of gaps in the current observing system, taking into account the rates of detected changes in the cryosphere,
- an evaluation of the current (IPY) state of the cryosphere in the context of past states through comparison with existing data on past states and also provision of a benchmark for future evaluation thus creating the foundation for more accurate estimates of the cryospheric contribution to sea level rise, information on freshwater resources and related decision making,
- an assessment of future cryospheric conditions through regional and global climate modelling,
- the establishment of the initial elements of the Arctic Ocean and Southern Ocean observing systems and start of the implementation of the Arctic HYCOS project,
- the establishment of multidisciplinary “super sites” that would include cryospheric observations in their set of measurements with CEOP as main means for data integration,
- an assessment of cryospheric-climate linkages and feedbacks that can be used to understand and explain the observed cryospheric variability and change,
- an assessment of the ecological and human implications of the observed/predicted changes.

IPY provides an unprecedented opportunity to develop effective methods of collecting, quality checking, archiving and distributing data. Tracking IPY data and making it available to all will be a major and complex task. CliC will work with the IPY International Project Office to foster international cooperation and collaboration with international projects and organizations, especially regarding development of a consistent data management strategy for the IPY.

CliC has proposed some immediate steps that include development of a consistent IPY data policy and the collection of metadata at the proposal stage for IPY projects and activities, which will provide an accessible catalogue of IPY activities before any data is collected. Such a catalogue will provide the ability to track data collection efforts, and to prompt investigators to submit data and metadata after data collection. This catalogue is one step that can be taken to help assure the data legacy of IPY is useful and accessible for years into the future.

CliC considers it very important for the success of IPY multidisciplinary studies to use the positive experience of WCRP in organization of field experiments and subsequent data processing. For example, CEOPII and its cold climate component can potentially work as an IPY multidisciplinary data integrating mechanism.

The IPY will concentrate on polar regions, but many of the techniques applied to observations, many of the processes studied and many of the models developed or improved, will be applicable to other cryospheric regions as well. Throughout IPY, CliC will seek to promote the application of all IPY initiated improvements to the global cryosphere and indeed to the entire global climate system. Such application will be a necessary part of the legacy left by IPY, if this intensive period of effort is to be truly effective in increasing our understanding of the climate system.

While the IPY provides a timely opportunity for CliC to promote cryospheric and climate research, it must be remembered that CliC has a longer time frame than the IPY (until 2015), and coverage of the entire global cryosphere, not just the polar regions, is necessary for a full understanding of the cryosphere's role in climate. The IPY then is seen as a stimulus for CliC studies with a view to promoting longer-term research.

7.0 Participating in CliC

While the CliC project does have a management structure with a Scientific Steering Group and expert panel members, the project itself has no formal membership. Any scientist working in the field of the interactions of climate and the cryosphere and working towards the goals of CliC may be considered as a contributor to the project. (Particular emphasis is given to the four CliC Themes, the use of cryospheric indicators of climate change, and relevant data management activities, but all aspects of climate/cryosphere interactions are of interest.) This scientific community forms the 'membership' of CliC, and all CliC groups and panels are essentially representatives of this community.

Since it cannot directly fund research activities, amongst CliC's most important tasks must be one of project initiation and review. It must also provide a mechanism for communication, coordination, and promotion of climate and cryosphere science. The level of resources available to CliC allows the project to work on assessment of the science and identification of priorities for future research, initiation of research activities (e.g., coordination of scientific proposals to funding agencies), and the communication of results to users including scientists, policy makers or the general public. But when a task or activity is suggested to CliC, very often the lead role must be taken by the scientist who made the suggestion. CliC can provide an independent, expert assessment of the proposed activity, advice based on a pool of relevant experience and expertise, support (non-financial) for initiation of the activity, access to communication channels with other members of the scientific community (particularly international communication), publicity for the activity, and the name of a recognised project (i.e., CliC), which may be of help when seeking funding.

In general, CliC activities should contribute to the assessment of relevant science, the initiation of new research to fill gaps in knowledge, communication with policy makers and funding agencies, and the communication of results (data, knowledge, predictions, etc.) to users. Assessment activities include:

- Meetings of experts for assessment and reporting purposes.
- Workshops on specific cryosphere/climate topics.
- Conferences covering broad issues;

the outputs from such meetings should include concrete ideas for initiating research and other activities to fill gaps in knowledge. A primary role of the project should then be:

- Initiation and coordination of projects where international collaboration is of scientific value, including coordination of proposals and conducting specific investigations such as model intercomparison projects.

Additional activities should ensure that the importance of cryosphere/climate issues is recognised by researchers, policy makers, planners and the general public. Activities include:

- Review of relevant documents and reports to ensure adequate attention is given to cryospheric and climate issues; and,
- Preparation of reports for relevant bodies such as the Integrated Global Observing Strategy Partnership (IGOS-P), Intergovernmental Panel on Climate Change, etc.

Comprehensive information regarding all of these activities will be maintained on the CliC website at http://clic.npolar.no, where appropriate contact points for community input to the project are identified.

8.0 Partners

Many organizations exist with similar or overlapping aims to those of CliC. Some national or regional CliC programmes were initiated following the development of the international project. Through WCRP, its original sponsor, CliC is related to other core WCRP projects and has overlapping areas of interest. In addition, WCRP's modelling groups both benefit from, and contribute to, improved understanding of the interactions between the cryosphere and the rest of the climate system. WCRP is also a member of the Earth System Science Partnership, and through this link, CliC is related to projects within the International Geosphere - Biosphere Programme, the International Human Dimensions Programme on Global Environmental Change and DIVERSITAS (an international programme of biodiversity science). SCAR also has a Physical Sciences programme, which includes both climate and cryosphere and other related studies. Outside WCRP and SCAR there are other projects and organizations whose science contributes to CliC goals and that benefit from CliC activities. Some of these have Memoranda of Understanding with CliC while many others interact with CliC informally. Involvement with any of these other projects or organizations can make a contribution to CliC if the science involved is relevant to CliC goals.

National CliC Programmes

Several national or regional CliC programmes have been set up to provide a mechanism for efficiently linking scientists and funding agencies in individual countries with the international project. Different nations will have different priorities and expertise, depending on their location, the cryospheric elements that affect them, and their social and economic priorities. National or regional CliC programmes allow a focus of expertise on particular cryosphere and climate problems, and provide a mechanism for transferring that knowledge and expertise to the international research community.

The nature of national or regional CliC programmes is determined within each nation or region. In some cases, it may be an umbrella for a full scientific programme with funding attached, or a separate programme with scientific objectives that overlap those of CliC, and which contribute to CliC through the achievement of their own goals. In others it may be a national committee whose job is to coordinate and prioritize activities (several such committees have been established). It may be merely a point of contact within a country as a means for contributing to two-way information flow. All these models are encouraged as methods of assisting in the global coordination of climate and cryospheric research, and involvement of individual scientists with their national or regional CliC programmes is encouraged.

WCRP, SCAR and ESSP Projects

Freezing and melting of water has a major effect on both water and energy fluxes, which are the main focus of WCRP's Global Energy and Water Cycle Experiment (GEWEX). Hence, CliC will interact with GEWEX to conduct hydrologic and related studies for the world's cold regions. The cryosphere also influences climate variability and predictability on a range of time-scales, so there are inevitable areas of common interest with WCRP's Climate

Variability and Predictability (CLIVAR) project. In addition, the stratosphere is known to play an important role in climate, with some particularly influential processes occurring in polar regions, which points to the need to interact with WCRP's Stratospheric Processes and their Role in Climate (SPARC) project. Sea ice also has a strong effect on fluxes of energy, water, gases and particles between the ocean and the atmosphere, and these fluxes in turn affect climate and the cryosphere. CliC will work with WCRP/IGBP/SCOR/CACGP's Surface Ocean - Lower Atmosphere Study (SOLAS) to understand these interactions. Involvement with these and other projects will be actively promoted as a mechanism for contributing to CliC goals. Where appropriate, CliC will set up joint activities with these other projects, such as joint workshops or panels.

In order to improve the representation of the cryosphere in models of both weather and climate, CliC will interact with the Working Group on Coupled Models (WGCM) and a Working Group on Numerical Experimentation (WGNE). In addition, both groups can point to areas where improved observations and parameterizations of the cryosphere and its interactions with the rest of the climate system are particularly needed. This will help to focus the CliC project on some of the most critical issues for climate.

The climate research community recognizes the need for a major new effort to improve our understanding of the predictability of the global climate system, as well as our predictions of its future state. The potential exists for improved and better-coordinated observations to be made, for more rapid transfer of these new data, and for improvements to models based on this information. From studies of the global climate system, the research community is beginning to address the complexity of the full Earth System and manifestations of the climate variability and change on a regional scale. With this in mind, WCRP is developing a new strategic framework entitled Coordinated Observation and Prediction of the Earth System (COPES). CliC will be actively contributing to implementation of this framework through participation in relevant activities. Initial plans include the work aimed at studying cryospheric contributions of mean sea level rise, climate predictability on a variety of temporal scales, etc.

The principal mechanism of collaborating with SCAR is through their Standing Scientific Group on Physical Sciences and their Joint Committee on Antarctic Data Management (JCADM). The Physical Sciences group has a number of "Action" and "Expert" groups with interests in, amongst other topics, sea ice (Antarctic Sea-ice Processes and Climate (ASPeCt)) and ice sheet mass balance (Ice Sheet Mass Balance and Sea Level (ISMASS)). CliC will interact with these groups to develop projects and assess and review appropriate topics. In addition, CliC will collaborate with JCADM on data management and information issues.

Some areas of interaction with other ESSP groups are already identified. CliC works with the Global Carbon Project on such issues as carbon in permafrost. Inevitably more interactions will be established as both CliC and the ESSP develop.

Memoranda of Understanding (MoUs) and informal interactions

CliC currently has MoUs with the International Permafrost Association (IPA) and the US led Study of Environmental Arctic Change (SEARCH). It is also negotiating a similar agreement with the Northern Eurasian Earth Science Partnership Initiative (NEESPI). Due to the close links between them, contributions to these programs are also an effective way to contribute to CliC. CliC formally recognized that several programmes provide important contributions to the project goals. Such programmes are Arctic – Subarctic Ocean Fluxes (ASOF), Ocean-Atmosphere-Sea Ice-Snow pack (OASIS), and Air-Ice Chemical Interactions (AICI). Further agreements are welcome by CliC.

Many organizations have already been set up to investigate specific aspects of climate and cryosphere interactions. Examples include the Global Land Ice Monitoring from Space (GLIMS) project, the International Arctic Buoy Programme (IABP), the International Glaciological Society (IGS), and many others; such as: the IUGG Commission for Cryospheric Sciences, International Arctic Science Committee, Arctic Ocean Sciences Board, International Study of Arctic Change, etc. The WCRP/SCAR International Programme for Antarctic Buoy's contribution to ocean observations is reviewed by the WCRP JSC through CliC. Activities will build on existing climate assessments such as the Arctic Climate Impact Assessment (ACIA), etc.

Contributing to the goals of these organizations/projects often makes a direct contribution to CliC goals. CliC is happy to work informally with such organizations or projects, or to make formal ties (e.g., endorsement, Memoranda of Understanding) if these are sought. Whatever the level of cooperation, CliC seeks to promote the relevant science carried out by these organizations or projects and will also work to ensure that CliC does not duplicate their work.

Practical steps to involvement

CliC does not have a formal membership, and welcomes the participation of field scientists, modellers, remote-sensing scientists, climate analysts, and all others who have an interest in cryospheric science, administration, or policy. There are many avenues by which people can get involved, and CliC actively encourages everyone within the cryospheric community to see themselves as part of the CliC community and to participate in the activities of the program.

Research activities

Carrying out activities that contribute to the goals of CliC or help to answer the key scientific questions can be considered as involvement in CliC. Researchers are encouraged to consider these goals and key scientific questions when initiating research projects or when reporting results of cryospheric or climate studies. Where possible, CliC encourages the use of this Implementation Strategy document, the CliC Science and Coordination Plan, and other CliC documents (such as workshop and meeting reports, which often contain helpful recommendations), to support funding proposals. The benefits of this are mutual since appropriate reference to CliC and CliC documents will help CliC to promote relevant scientific activities.

Furthermore, wide participation in CliC initiated projects is encouraged, and it is hoped that community members will respond positively when given the chance to assist in the development of CliC projects.

Modelling and observation activities

CliC encourages scientists to initiate relevant model intercomparison experiments, develop more advance models and parameterization schemes for cryospheric elements and conduct experiments revealing the role of cryosphere in the variability and change of the whole climate system and as well the predictability potential associated with the cryosphere.

Similarly, CliC would welcome the conduct of relevant observational experiments, the development of new, more efficient and robust technologies for observing both the cryosphere and the environment affected by the cryosphere. Converting experimental observations into sustained monitoring is one of most important tasks for CliC. In its observing practice, CliC fully recognizes the need of adhering to standards set forth by the Global Climate Observing System climate monitoring principles including the principles for the climate monitoring using satellites. It supports and works closely with key data centres to develop data sets to support climate-cryosphere studies, including the Global Runoff Data Centre and the Global Precipitation Data Centre.

Data and metadata submission

The wide and inexpensive dissemination of data and model output is important for the improvement of our understanding of climate/cryosphere interactions. Making relevant data available, especially through recognised data centres, is therefore a contribution to CliC. Submission of data must be accompanied by submission of metadata, and this easy task can be accomplished through the Data and Information Service for CliC (DISC) (See “Add” button at http://clic.npolar.no/disc/disc_datasets.php) in collaboration with the Global Change Master Directory. The metadata will automatically become available through DISC, so that others can locate your dataset.

Using and contributing to CliC and DISC web pages

The CliC International Project Office will maintain a website for the project, and a Data and Information Service for CliC to provide information on datasets, meetings, publications, reports, etc. The DISC site also contains reference materials, such as electronic posters and presentations, available for general use (with appropriate reference to the source). Use of these sites is encouraged, as is contributing to them with information about meetings, links, new datasets, or any other relevant information. CliC may be willing to help publicize major results through its web pages. Without community input these pages cannot be kept fully up-to-date, but with help they will provide a comprehensive service for information for the cryosphere and climate research community.

Participation in meetings

CliC welcomes research community participation in meetings. Whilst some expert meetings and workshops must be by invitation only because of space and agenda limitations, CliC encourages open participation in many of its meetings. This is not limited to participation at the meeting itself, but community members are welcome to suggest workshop or conference topics, and to participate actively in developing an agenda or programme to maximize the scientific benefits.

Contributing to and receiving the CliC Newsletter

As with the websites, contributions to the CliC Newsletter are welcome following approach to the CliC International Project Office. Assistance can be given to publicize meetings and other news, as well as publishing popularized versions of interesting results. The newsletter will be distributed free of charge, and anyone can be added to the mailing list simply by contacting the project office.

With these methods of involvement in CliC it is clear that involvement is a two-way process. Without science community input, the services that CliC provides will not be as useful to that community. The CliC project can work well for the research community if, and only if, the community works well for the project.

9.0 Project Management

To carry out its functions of review and assessment, identifying gaps in scientific knowledge and making recommendations for future research, stimulate new studies, and support data management and information activities, CliC must maintain expertise in each CliC Themes and in data and information management. It must also maintain an ability to communicate with other relevant projects, programmes and institutes, with scientists who have an interest in cryosphere - climate interactions, and with funding agencies, policy-makers and the public.

The initial management structure for CliC was inherited from WCRP's Arctic Climate System Study (ACSYS), which was managed in parallel with CliC for more than three years. This structure was based on panels, which addressed the tools used to study the Arctic climate system, i.e., observations (both remote sensing and *in situ* and including long-term monitoring and intensive process studies), numerical modelling, data management, and re-analysis. In moving to a structure based around the Themes, CliC must not only retain the ability to assess the use of these tools in cryosphere/climate research, but must also have a global point of view. . In addition, CliC must coordinate its work with other WCRP projects and similar groups, so that efforts are complementary rather than competing. Finally, whatever expert panels or rapporteurs are employed by CliC, the system must remain flexible to meet changing needs, opportunities and priorities. The details given below are for CliC's current management structure *(Figure 4)*, but this can and will change over the duration of the project.

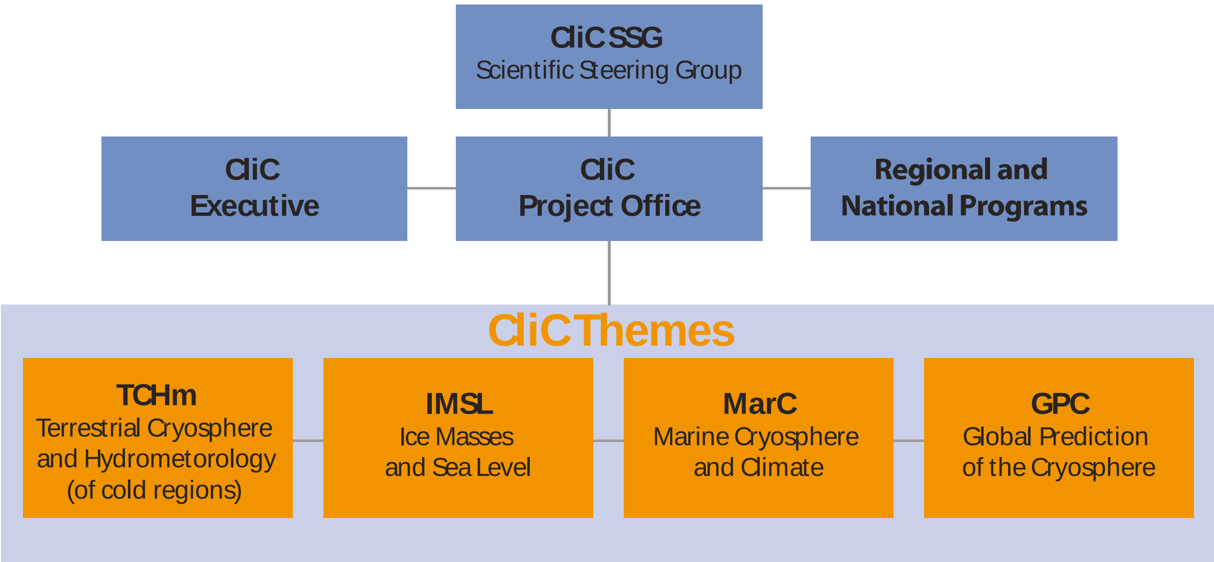

Figure 4. CliC structure - May 2007 (subject to change)

In making nominations for the CliC governing bodies, panels and groups, maximum consideration will be given to assembling the highest expertise in corresponding fields, and also to achieving the broadest geographical member representation and gender balance. Initial term of service on all CliC management bodies is three years, with the possibility of extension dependent on panel needs.

9.1 CliC Scientific Steering Group (SSG)

Like all WCRP projects, a Scientific Steering Group is responsible for the general conduct of CliC, setting the projects' overall scientific direction and ensuring that all key questions and Themes are appropriately addressed. It must also ensure adequate attention is given to the crosscutting issue of the use of cryospheric indicators of climate change. The group will retain expertise that covers the various cryospheric elements and their interaction with other parts of the climate system, as well as expertise for a wide range of observational and modelling techniques.

The CliC SSG has a Chair and two co-Vice chairs, which along with the Director of the CliC International Project Office (see below) and the officer at the WCRP Joint Planning Staff with responsibility for CliC, form the *CliC Executive Committee*. This committee organises the work of the SSG and takes administrative decisions between sessions. The Chair presides at SSG sessions, represents CliC, and reports to the Joint Scientific Committee (JSC) of the WCRP. Twelve SSG members are appointed by the JSC in consultation with SCAR. In additional to their collective work as members of the SSG, they are expected to lead or assist in the development of one or several Themes. As a rule, the CliC SSG meets once a year.

9.2 Other CliC working bodies

Theme Panels

Since progress towards the goals of the CliC project will primarily come through the CliC Themes, panels will be created, as needed, to support the Themes' advancement. The panels will be responsible for developing, coordinating and implementing specific activities, and will report to the SSG. In addition, they will help to publicise the science of their Themes, through the CliC web pages and through the initiation or support of appropriate scientific activities such as workshops and conferences.

Arctic Climate Panel (ACP)

The Panel is responsible for assessing and stimulating scientific efforts to understand climate variability and predictability of the coupled land-ocean-atmosphere-cryosphere system in the Arctic, as well as the Arctic's role in the global climate system. This includes identification of needed process studies, sustained observations, model experiments and data management; stimulation of the development of the Arctic Ocean Observing System as part of the Global Ocean Observing System and Global Climate Observing System; and facilitation of enhanced interaction between the relevant meteorological, oceanographic, cryospheric, biogeochemical and palaeoclimate communities.

Antarctic Sea-Ice Processes and Climate (ASPeCt)

Needs text

CLIVAR/CliC/SCAR Southern Ocean Implementation Panel (SOIP)

The Panel is responsible for assessing and stimulating scientific efforts to understand the role of Southern Ocean processes in influencing regional and global climate. CliC maintains representation on this panel to ensure that relevant expertise related to sea ice, ice shelf, and other cryospheric processes is present on the panel. It is considered necessary that at least one panel Co-Chair maintains cryospheric expertise, and will report to the SSG through formal meeting reports, and, when appropriate, attendance at SSG meetings.

International Programme on Antarctic Bouys (IPAB)

Needs text

IGOS-Cryosphere Team (IGOS_Cryo)

A group of experts led by CliC is preparing a comprehensive report, which is aimed at providing a widely agreed perspective for further development of cryospheric observations. All CPAs are expected to contribute to the report. The website of the IGOS-Cryosphere Theme is at http://stratus.ssec.wisc.edu/igos-cryo. Through the report and its subsequent implementation, CliC will create a basis for fulfilment of one of its major goals – the development of an **adequate cryosphere observing system meeting the coordinated requirements of IGOS Partners.**

Observation Products Panel (OPP)

Needs text

Rapporteurs

A number of activities relevant to the CliC project are supported by groups external to CliC. Current examples include the assessment and reporting procedures of the Intergovernmental Panel for Climate Change, the various re-analysis efforts being undertaken by meteorological and environmental agencies, and the assessment of mountain initiatives. CliC will appoint rapporteurs for such activities, who will be responsible for maintaining an overview of their progress in areas relevant to CliC, and for seeking opportunities for CliC to make contributions to their successful outcome. The rapporteurs will enhance interaction with these activities and help to avoid duplication, and will identify opportunities for mutual scientific benefit. They will also be the initial point of contact for scientific communication with the external activities.

CliC International Project Office and WCRP Joint Planning Staff

The CliC International Project Office (CIPO) and the officer responsible for the CliC Themes at the WCRP Joint Planning Staff have joint responsibility for supporting the activities of all the above groups, panels, and people contributing to the implementation of the CliC project. In addition, the project office is the focal point for coordination with other national and international bodies. An important function of the office is to support the activities of the CliC SSG and its chairperson. The Director of the Project Office reports to the Director of the WCRP.

The Project Office assists with the organization of CliC meetings, workshops and conferences, and the promotion of the project (for example, through production of a website and newsletter). This office, in liaison with CliC groups and panels and other scientific bodies, must also play an active role in identifying opportunities for relevant new research and for initiating efforts to take advantage of such opportunities.

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