Concept of an IGOS-Cryosphere Theme (IGOS-Cryo)

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BACKGROUND

The IGOS-P-10bis Partners' meeting in Colorado Springs on November 21, 2003, decided that the world's realm of ice, the Cryosphere, was a key missing element in the coverage of the planet's environments by IGOS Themes. Colin Summerhayes was charged with working together with appropriate partners to develop an outline for a Cryosphere Theme for consideration by the Partners at their 11th meeting on May 27, 2004. A concept paper containing a proposal to develop an IGOS Cryosphere was submitted and presented to the Partners. The Partners endorsed the proposal for a Cryosphere Theme and approved the Theme for presentation in draft to the 12th session of the IGOS Partners, in the spring of 2005, and for completion in the autumn of 2005.

SUMMARY AND PURPOSE

This concept paper was initiated by experts of the World Climate Research Programme (WCRP) Climate and Cryosphere (CliC) Project in collaboration with Colin Summerhayes (Executive Director of the Scientific Committee on Antarctic Research (SCAR)), and in consultation with several partners, contains a proposal to IGOS Partnership to initiate an IGOS-Cryosphere Theme. It defines the term and describes the importance of observing the Cryosphere, then outlines the objectives of the Theme, anticipated roles and responsibilities of contributors, milestones and resources.

Concept Paper on the IGOS-Cryosphere Theme (IGOS-Cryo)

Background

What is the Cryosphere?: The term "cryosphere", as defined in the WCRP Climate and Cryosphere (CliC) Project Science and Co-ordination Plan, collectively describes all forms of frozen water at the Earth's surface - sea ice, ice sheets, ice caps, glaciers, snow cover and solid precipitation, river and lake ice, permafrost and seasonally frozen ground. The cryosphere spans the globe, though most of the mass of frozen water is found in the polar regions.

Why is it important?: In recent years, the cryosphere has received increasing attention from the climate science community, national and international policy makers, the media, and the general public. There are a variety of reasons for this, including:

- The cryosphere is an inherent component of the Earth Climate System and is probably the most under-sampled element within it.
- The cryosphere, particularly glaciers, the Greenland ice sheet, permafrost, and Arctic sea-ice, is expected to undergo dramatic changes associated with the climate change. The stability of the cryosphere is therefore a high priority issue for Earth Science. It has many practical implications.
- Through several feedbacks it has a large effect on the predictability of weather and climate, and knowledge of the cryosphere is therefore vital at many levels of decision-making.
- It plays an important role in generating and mediating the conditions for a possible abrupt climate change.
- It is one of the factors of largest uncertainty among contributors to mean sea level rise.
- It is an important source for fresh water resources for many countries.
- In polar regions sea-ice critically affects the pathways and hence patterns of world sea-borne trade, and strongly influences fishing activity.
- The cryosphere provides many of the most useful indicators of long-term climate change.

The importance of observing the cryosphere was noted at the Earth Observation Summit (July 2003) and is reflected in the working documents of the Group on Earth Observations. Requirements for cryospheric observations, in different forms, are included in WMO Statements of Guidance regarding how well satellite capabilities meet WMO user requirements in several applications areas. Most elements of the cryosphere, except river and lake ice, are included as essential climate variables into the Second Report on the Adequacy of the Global Observing Systems for Climate in support of the UN Framework Convention on Climate Change and in the Draft Implementation Plan of the Global Climate Observing System. The development of a coordinated observing system for the cryosphere is one of the primary goals of the WCRP Climate and Cryosphere (CliC) project. There is a consensus that cryospheric observations need more financial and institutional support and co-ordination. It is also known that several international bodies, e.g. the Expert Team on Sea Ice of the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), have reported a need to further specify and detail user requirements for cryospheric data.

How is it treated at present by the IGOS Partners?: At present, elements of the cryosphere are covered in several IGOS Themes. Sea ice is part of the Oceans Theme. Some elements are included in the Water Cycle Theme. For the Global Carbon Theme, the cryosphere plays an important role in modulating fluxes over land and ocean surfaces, and in storing potentially massive quantities of carbon in methane clathrates and in permafrost regions. Sea-ice, sub-sea permafrost, and coastal frozen ground are relevant for the Coastal

Theme. Glacier-related floods and mud-slides, avalanches, and loss of construction stability are all possible issues for the Geohazards Theme, although other cryosphere-related natural hazards are not, like spring floods associated with river-ice break up and snow melt, snow or ice storms, and icebergs. Good coordination will thus be needed across the IGOS Themes to avoid duplication and to capitalise on what has already been achieved.

Likewise, the observations of the cryosphere are divided between the Global Climate, Ocean, and Terrestrial Observing Systems: GCOS, GOOS and GTOS. The cryosphere elements of all three will need to be better coordinated, and this has already begun. IGOS-Cryo developments will exploit the existing GCOS Global Terrestrial Networks (GTN) for glaciers (GTN-G) and permafrost (GTN-P) and will cooperate with other GTNs.

Unfortunately, the involvement of cryosphere in many IGOS Themes does not elevate its profile within them. In fact, for a variety of reasons, expertise in cryospheric observations never achieves adequate representation on any of the Theme Panels. As a rule, cryospheric elements are included in studies for the sake of completeness, but rarely are they a central concern.

For these reasons, there is a need for an individual IGOS-Cryo Theme, in which the cryospheric components of the Earth System are given their deserved, high priority.

Objectives

The IGOS-Cryosphere theme is required to create a framework for improved coordination of cryospheric observations conducted by research, long-term scientific monitoring, and operational programmes, and to generate the data and information needed for both operational services and research. In the polar regions, the cost of *in situ* observations is very high, and satellite monitoring is challenging. Therefore there is a particularly strong need for a close coordination of observations serving the various user communities and nations. There is also a need to strengthen national and international institutional structures responsible for cryospheric observations, and to increase resources for ensuring the transition of research-based cryosphere observing projects to sustained observations. The likelihood of achieving such goals will be significantly enhanced through the development of a comprehensive, coordinated, integrated and coherent approach of the kind represented by an IGOS Theme.

Three broad streams of cryospheric observation and data applications are required under IGOS-Cryo. While the three streams focus on different aspects of the cryosphere, they are entirely complementary.

The first stream is a comprehensive system of validated remote sensing and *in-situ* observations of the land-based cryosphere, capable of providing a complete picture of precipitation (including its solid part), snow reserves, river and lake ice, permafrost, and frozen soil characteristics. In addition to its high value for operational use (e.g., water supply management, flood forecasting, drought prediction, crop forecasts, construction stability assessment, etc.), this system will bridge meteorological and hydrological applications related to the cryosphere, and ensure the incorporation of appropriate variables in the next generation of climate and hydrological models. This stream will require coordination of input from both GCOS and GTOS and their components, to create a unified and logical flow of cryospheric data.

The second stream is a system ensuring comprehensive observations of sea-ice characteristics (including ice edge position, concentration, thickness, snow depth on ice, freeboard height, floe size distribution, ridging density and ridge heights, surface albedo, melt ponds, and ice age), the efficient exchange of these data, their use in operational services, and subsequent processing for research applications and climate studies. In particular, measurement of sea ice thickness over large areas with a satisfactory accuracy and spatial resolution is still a challenge. The system should incorporate modern advances in satellite systems and air reconnaissance (including airborne electromagnetic mapping), as well as surface-based and sub-surface segments such as ice profiling sonars, sea-ice buoys, ship-borne and coastal observations. This stream would significantly enhance the observations and services provided by JCOMM and GOOS. Observations from ice-tethered platforms and the use of 'Argo'-type floats under ice, may turn operational oceanography into a truly global venture. Extension of data assimilation efforts into ice-covered regions, so as to span all of the world's oceans, will be needed.

The third stream is a significantly enhanced ice-sheet, ice-cap, and glacier monitoring system, including measurements of: spatial extent, surface elevation, ice thickness, surface flow rate, calving rate (for tidewater glaciers), equilibrium line elevation, mass balance, albedo, and aerodynamic roughness. The basic challenge here is to transform research-based systems like glacier monitoring into a sustained, truly global system, producing data with the accuracy required for projection of sea level rise, water management, and disaster mitigation. Again, a combination of data sources will be required, and existing, planned and future satellite missions must be complemented by a global land-based support system.

Many topics, such as freshwater flux to the oceans, and prediction of future carbon fluxes, require information from all three of the streams. Precipitation is a critical component affecting all three streams. Methods of observation may be similar in all three streams. They may use the same sensors and satellites or *in situ* platforms. All will need a unified system for data management, archival and distribution. Preparing one IGOS Theme for the whole cryosphere would provide economy of scale, and ensure that the cryosphere is adequately addressed by the observing systems that support climate, weather and environmental research and operations.

The main objective of IGOS-Cryo will be increased co-ordination of existing activities and the development of future observing activities for the cryosphere that will facilitate the collection of the continuous validated datasets that are needed for applications and climate projections. A list of data users and providers is being compiled. However, it is already clear that the work on the Theme should start with an update of user requirements, and a study of how they are met by current, planned and prospective *in situ* and remotely sensed observations. This work needs to be initiated and, if successful, will result in establishment of institutional collaboration between user organisations and data providers.

Roles and Responsibilities

IGOS-Cryo is expected to involve representatives of ICSU, IOC, WMO, several space agencies, GOOS, GCOS and GTOS, IGBP, WCRP, and other appropriate organisations. The initiators of the theme are the Executive Director of ICSU's Scientific Committee on Antarctic Research (SCAR) and the leadership of the WMO/ICSU/IOC WCRP's Climate and Cryosphere (CliC) Project. It is hoped that many interested organisations will join the team in the near future, and the leadership of the project may change accordingly.

The present IGOS-Cryo team is comprised of representatives from GOOS, SCAR, WCRP, the Meteorological Service of Canada, and CliC, with additional written contributions from ESA, the Geological Survey of Canada, the International Permafrost Association, the Finnish Institute of Marine Research, the British Antarctic Survey, the Australian Department of the Environment and Heritage, the Nansen Environmental and Remote Sensing Center of Norway, Universitaet Innsbruck, the University of Bremen, the University of Colorado, and the Ohio State University. There have also been expressions of interest from NOAA, JAXA, NERSC, and GMES-ICEMON. The final leadership and make up of the writing team for the full Theme document is yet to be decided, and expressions of interest, especially from space agencies, are welcome. A leading role is envisioned for the WCRP CliC Observation Products Panel.

Milestones

Significant milestones for the full Theme will be the achievement of key objectives such as

(i) the Theme report (the timetable of its preparation is addressed in detail below);
(ii) an outline of a system for cryospheric observations management, archival and distribution;
(iii) a significantly enhanced ice-sheet, ice-cap, glacier and permafrost monitoring system;
(iv) measurement of sea ice thickness over large areas, with a satisfactory accuracy and spatial resolution;
(v) systematic measurements of water temperature and salinity under sea-ice;
(vi) a comprehensive system of validated remote sensing and *in situ* observations over land areas, capable of providing a complete picture of precipitation (including its solid part), snow reserves, river- and lake- ice, and seasonally frozen soil characteristics.

Milestones en route to these larger ends will be defined within the full Theme document.

Milestones in the development of the full Theme document are envisaged as follows, within a plan to present a draft of the full document to the meeting of IGOS-P-12 in the spring of 2005, and the full document to IGOS-P-12bis in the autumn of 2005. This may turn out to be ambitious, given recent experience with Theme development (the Ocean Theme took less time, the Carbon Theme took much more). However, much background information already exists in the form of documents like the JCOMM Polar Strategy and the WCRP's CliC Science and Coordination Plan. Furthermore, a considerable database of in-situ and remote sensing requirements already exists within WMO, although it will need to be refined with respect to cryospheric elements. The timeline for Theme document development is:

- Theme team forms: summer 2004
- Outline of the Theme document and concise description of chapter contents completed (working by e-mail): September – October 2004
- IGOS-P-11 meeting, in association with CEOS Plenary, reviews the draft and offers advice on direction: November 2004
- CEOS SIT offers initial implementation advice: November 2004
- Draft of the report and initial implementation plan completed: March 2005
- CEOS SIT reviews the draft and the initial implementation plan: end March 2005
- CliC science conference in April 2005 provides additional inputs to the Theme draft; and helps to identify peer reviewers
- Second draft of the Theme: May-August 2005 (available draft submitted to IGOS-P-12, end May 2005, for advice)

- Peer review: September 2005
- Adjustments to the document: October 2005
- Submission of full Theme document to IGOS-P-12 in association with CEOS Plenary: end October 2005
- Fall-back position: final draft submitted to IGOS-P-13: end May 2006.

This process envisages regular e-mail consultation with the wider community on the form and content of the document.

Ideally IGOS-Cryo will be up and running and producing results well before the commencement of the International Polar Year 2007-08, which will run from March 2007 to March 2009, thus enabling IGOS-P to make a significant contribution to the achievement of the goals of the IPY.

Evaluation Criteria

The writing team will be charged with evaluating progress. At present it is envisaged that a small, targeted, international workshop will be needed in December 2004 or January 2005, involving representatives of practitioners, modellers, and users. However, it may turn out that up to another two such workshops may be needed (e.g. in Canada, the UK, or Geneva) in which case the strategy and timing will be adapted. The Canadian Space Agency has offered to host a workshop early in 2005. Performance criteria for each milestone within the full Theme document will be defined at the first and second workshops.

At present the process is a top-down approach containing several phases associated with a review of (1) data requirements, (2) how the requirements are met by current and planned observing systems, (3) what developments are needed to ensure that the requirements are continuously met, and (4) what the basis for facilitating and coordinating the required observations should be. A rolling review process of requirements should be initiated. The wider community should be consulted.

Resources

Personnel: The IGOS-Cryo will become a significant focus of the WCRP CliC project, especially of the CliC Observations Products Panel (OPP). In addition, it will become a significant focus of the SCAR programmes on Ice Sheet Mass Balances and Sea Level (ISMASS) and Antarctic Sea-Ice processes and Climate (ASPeCt), and for the JCOMM Expert Team on Sea-Ice. The Chair of the CliC OPP, J. Key (NOAA National Environmental Satellite, Data, and Information Service, NESDIS), will chair the IGOS-Cryo writing team. Core team members include M. Drinkwater (European Space Agency, ESA) as vice-chair, C. Summerhayes (SCAR), V. Ryabinin (WCRP), B. Goodison (Meteorological Service of Canada, MSC), and C. Dick (CliC Project Office). D. Hinsman (WMO) will serve as the liaison to IGOS.

Other team members will provide a balance of expertise in all aspects of the cryosphere, from sea ice and ice sheets to snow cover, permafrost, and precipitation, a balance between northern and southern hemisphere interests, and a balance of *in situ* and satellite observational systems. Scientists from Australia Austria, Canada, Germany, Italy, Japan, the Netherlands, Norway, Switzerland, UK, and USA have already agreed to participate in the IGOS-Cryo effort. Representatives from other countries have been invited to participate.

Funding: It is likely that new resources will be needed for the preparation of the full Theme document. Currently it is planned to hold workshops in conjunction with meetings that people are already supported to attend whenever possible. Four team meetings and/or workshops are envisioned for the development of the Theme report. The Canadian Space Agency (CSA), MSC, and SCAR are providing some funding to support participant travel. Additional funding is being solicited from U.S. agencies (NOAA, NASA, and NSF) and European agencies. Successful completion of the Theme Report should help to generate resources for cryospheric observations.

Appendix A
Required Variables

Ice sheets, ice caps, and glaciers: spatial extent surface elevation ice thickness surface flow rate calving rate (for tidewater glaciers) equilibrium line elevation mass balance aerodynamic roughness	**Terrestrial snow**: extent depth grain size density water content
Sea ice: ice edge position concentration thickness snow depth on ice freeboard height floe size distribution ridging density ridge heights melt pond fraction ice age brine volume snow grain size frost flower coverage	**Solid precipitation**: rate particle size water equivalent
River and lake ice: thickness extent age	**Surface albedo**
Permafrost and seasonally frozen ground: vertical thickness lateral extent ground temperature active layer thickness ground ice content depth of winter frost penetration length of freeze/thaw season	

Appendix B
IGOS-Cryo Writing Team

Name	Role	Specialization	Institute/Agency	Country
Jeff Key	Chair	Satellite remote sensing of clouds, snow/ice (vis/IR)	NOAA/NESDIS	USA
Mark Drinkwater	Vice-chair	Satellite remote sensing of snow/ice (microwave)	ESA	Netherlands
Colin Summerhayes	Core		SCAR (ICSU)	UK
Vladimir Ryabinin	Core		WMO	Switzerland
Barry Goodison	Core	Snow/ice general	MSC; CliC	Canada
Chad Dick	Core		CliC Project Office	Norway
Don Hinsman	Liaison to IGOS		WMO	
Helmut Rott		Remote sensing of snow cover, ice sheets, glaciers; snow hydrology	Universitaet Innsbruck	Austria
Ken Jezek		Ice sheets and sea ice processes, remote sensing	Ohio State University	USA
Stein Sandven		Arctic sea ice, altimeter	Nansen Environmental and Remote Sensing Center	Norway
Konrad Steffen		Ice sheets (Greenland); sea ice	University of Colorado; CliC	USA
David Vaughan		Glaciology, Antarctica	British Antarctic Survey	UK
Xiao Cunde		Glaciology	Chinese Academy of Meterological Sciences, CMA; Chinese CliC	China
Sharon Smith		Permafrost	Geological Survey of Canada	Canada
Jerry Brown		Permafrost	International Permafrost Association	USA
Tingjun Zhang		Frozen ground	National Snow and Ice Data Center	USA
Anne Walker		Remote sensing of snow cover, sea ice, lake ice (passive microwave)	Meteorological Service of Canada	Canada
Georg Heygster		Remote sensing of sea ice (passive and active microwave)	University of Bremen	Germany

Fumihiko Nishio or representative		Antarctica, sea ice	Japanese CliC; Chiba University	Japan
Pierre-Philippe Mathieu		Modeling; remote sensing of sea ice (microwave and optical)	ESA	Italy
John Falkingham		Sea ice monitoring and forecasting	Canadian Ice Service	Canada
Roger Barry		Arctic climate, sea ice	University of Colorado	USA
Ola Johannessen		Arctic climate	Nansen Environmental and Remote Sensing Center	Norway
Ian Allison		Ocean-ice-atmos interaction; ice sheet processes; southern hemisphere	Department of the Environment and Heritage	Australia
Timo Vihma		Polar and boundary-layer meteor., sea ice thermodynamics	Finnish Institute of Marine Research	Finland
Tom Carroll		Operational snow cover, precipitation	National Operational Hydrologic Remote Sensing Center, NOAA/NWS	USA
Florence Fetterer		Sea ice observations	National Snow and Ice Data Center	USA
Dorothy Hall		Snow and ice cover; satellite remote sensing	NASA Goddard Space Flight Center	USA
Dave Robinson		Snow and cover	Rutgers University	USA
Georg Kaser		Snow, ice general	University of Innsbruck	Austria