WCRP REPORT
World Climate Research Programme

WORLD CLIMATE RESEARCH PROGRAMME (WCRP)
SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH (SCAR)
INTERNATIONAL ARCTIC SCIENCE COMMITTEE (IASC)

Climate and Cryosphere (CliC) Project

Report of the Sixth Session of the CliC Scientific Steering Group (SSG-VI, Valdivia, Chile, 6-9 February 2010)

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of the CliC Scientific Steering Group
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Introduction

The sixth meeting of the CliC Scientific Steering Group (SSG-VI) was held at the *Centro de Estudios Científicos*[1] in Valdivia, Chile, from 4 through 9 February 2010. The meeting objectives were to: 1) review the progress of CliC initiatives and themes; 2) realign CliC activities towards tangible contributions to the WCRP objectives[2]; and, 3) to identify people and determine collaborations required to achieve the CliC/WCRP targets. Eight of the twelve SSG members participated in person, while one contributed by giving a telephone presentation. Three invited experts also contributed via the telephone. This solution worked well for the meeting attendees, while the discussions following the talks were of little use for the presenters on the remote end.

Summary

The meeting evaluated CliC progress during the past year and discussed its future activities, and its intermediate- and long-term objectives.

The SSG-VI agreed to four major long-term objectives seen as key milestones in studying the predictability of the climate system and in understanding the human effects on climate. CliC will work with partners within and outside WCRP towards achieving these goals.

Long-term objectives:

1. Enabling prediction of the Arctic climate system;
2. Enabling prediction of the Antarctic climate system;
3. Enabling prediction of terrestrial cryosphere; and
4. Enabling improved assessment of the past, current and future sea-level variability and change.

To reach its long-term objectives, a range of contributing *short-term activities* were reviewed and endorsed. These include the five integrating and cross-cutting initiatives (WCRP core projects) that CliC SSG-V formulated in Geneva in December 2008.

Short-term objectives:

1. Cryospheric input to the Arctic and Southern Ocean freshwater budgets
2. The role of carbon and permafrost in the climate system
3. Hemispheric differences in sea-ice extent and seasonal predictability
4. Regional climate modelling and improved parameterisation of cryospheric processes
5. Ice sheet dynamics and the role of the major ice sheets in sea-level rise

New initiatives – Six new initiatives were formulated and endorsed:

i. Review of passive microwave sea-ice products and community-generated sea ice concentrations and ice extent products
ii. Extension of permafrost studies in continental shelf areas
iii. Improvement of sea-ice parameterization for the Arctic- and Southern- Oceans
iv. Support for a new Arctic System Reanalysis
v. Focus on the explanation of causes and prediction of the Arctic sea-ice loss involving a CMIP5 diagnostic subproject, including the ARctic Climate HIndcasting, Modelling and PrEDiction ExperimentS (ARCHIMEDES)
vi. Continuing the Southern Ocean Observing System development and reinvigorate the Southern Ocean Physical Oceanography and Cryosphere Linkages (SOPHOCLES) initiative.

[1] A non-profit institution doing research in molecular biology and physiology, theoretical physics, glaciology and climate change.
[2] As outlined in the WCRP 2010-2015 Implementation Plan

Regional climate predictions on a decadal scale and assessment and prediction of cryospheric sources of fresh water are fast becoming key requirements for climate science. CliC will initiate activities to develop climate modelling- and downscaling-techniques on spatial scales to allow climate predictions in alpine, glaciated regions leading to an assessment of freshwater resources. In consultation with WGSIP[3] - through participation in the WCRP Polar Predictability Workshop - CliC will explore cryospheric factors of climate predictability for a range of time scales. CliC recommends continuation of the *IPY Space Task Group* after the completion of the International Polar Year, and also recommends WCRP take part in the preparation of the potential *International Polar Decade* to ensure prediction of the polar climate on decadal time scales be adequately addressed. Development of cryospheric observations will continue through the coordination of the *IGOS Theme on Cryosphere*.

CliC organises the WCRP research on sea-level rise through the WCRP/IOC *Task Group on Sea-Level Variability and Change*. Research aimed at estimating the change in the mass balance of the terrestrial cryosphere continues (especially ice sheets and their dynamics), as does the study of the role of ice shelves in these changes. This research includes both observations and modelling.

CliC will approach the *Arctic Ocean Sciences Board* with a proposal to join forces to study the role of Northern Seas in the climate system with a view towards an Arctic / Sub-Arctic Ocean data synthesis (see paragraph 6.4 in this report).

CliC will continue its regional activities, such as the Asia-CliC project. Following the successful Conference “Ice and Climate Change: A View from the South” (Valdivia, Chile, 1-3 February 2010), which was cosponsored by CliC and the International Glaciological Society, CliC will undertake a range of activities in South America.

In order to ensure continuous attention to the multitude of new and ongoing activities, the CliC Executive Committee will expand to include the Project Chair, its Vice-Chair, representatives of CliC IPO, JPS and three representatives of the CliC SSG. In the weeks following the JSC-31, this committee will prepare a CliC project working structure and will extend invitations to active and knowledgeable scientists to lead the project activities as members of the CliC SSG or CliC expert panels.

[3] Working Group on Seasonal to Inter-annual Prediction

Brief summary of main discussions and decisions

1. WCRP Polar Workshop and Initiative

Reducing the uncertainty in polar climate prediction is a major challenge. To this end, the WCRP will start a Polar Prediction Initiative, and CliC will contribute and participate in the WCRP Polar Predictability Workshop. CliC will consult and work with the WGSIP to determine the predictability of various cryospheric elements for a range of time scales.

SPARC is leading the planning of the WCRP Polar Prediction Workshop and CliC will contribute to it. An organizing committee has been formed and telecons have been arranged.

2. Arctic Ocean (AO) freshwater budget (FWB)

Over the last few years, an Arctic Ocean freshwater budget initiative has been proposed by Terry Prowse. CliC has all the relevant expertise for analyzing the FWB: snow, permafrost, sea ice, ice sheet, and river flow to the Arctic Ocean. This is a proposal for the integration and synthesis of new (land and ocean) data and knowledge obtained during the IPY years – to examine and establish a closer link between the land and ocean components of the arctic climate system. There has been interest within CliC, for instance, to quantify the Greenland ice sheet change and melt water contribution to the AO water cycle.

The AMAP SWIPA assessment provides a unique opportunity and synergy to work with other groups and to move this idea forward. CliC needs to identify a champion to lead and promote this initiative. Terry Prowse has developed a short FWB integration document for the SWIPA report that discusses the relevance of all the arctic cryospheric components. The SSG meeting nominated Terry Prowse to lead the AO freshwater budget initiative

This initiative will engage and work closely with cryo and ocean groups (such as the AOSB and others) within and outside of CliC. The original proposal of the freshwater budget analysis also includes the Southern Ocean (SO). The WCRP\JSC meeting in Turkey suggests a phased approach for some of our planned activities. CliC may need to consider and discuss the approach for the SO, maybe to put that part as the 2nd phase of the freshwater budget research.

This project, also relating to global observation systems, particularly the SAON and SOOS, has been decided as a key CliC initiative for the next few years.

3. River and lake ice in the northern regions/ESA north hydrology

River and lake ice is an important part of cold region hydrology and has changed significantly in the last decades. The study of freshwater ice fills a major gap in the arctic climate system research. Terry Prowse recently worked with the Russian groups to develop and update the river ice datasets over the arctic regions, including Canada, the USA, and Siberia. He hosted a workshop in the spring 2009 and his collaboration and work in Canada continue, and directly contribute to the SWIAP report. River ice also relates to hydrologic extremes, i.e. snowmelt flooding in the northern regions. This links to the WCRP extremes cross cut research. There is a need to model basin hydrology and hydraulics, i.e. snowmelt flow and channel ice together, in the northern rivers and regions.

ESA-CliC collaborations have progressed well in the last years. ESA and CliC co-hosted a consultation workshop in summer 2009. Based on the recommendations of the workshop, ESA has decided to create the North Hydrology Project that focuses on river and lake ice in the northern regions. ESA will fund one research project, with EUR 500K for 3 years, to study the freshwater ice and its changes in the Polar Regions. This project will also benefit the future mission, including CoReH2O, and the ECV project.

River and lake ice research can also contribute to the AO freshwater budget initiative. The links are strong, but adding this component to the FWB initiative may require longer time and more effort to complete. There is a great potential to continue and expand the CliC-ESA collaboration into other areas of cryospheric research, such as snow cover, snowfall, and ice sheets. Discussions of future cooperation with ESA need attention.

4. Snow in climate research

Snow cover is the largest component (in size) of the cryosphere system. The importance of snow cover in climate research is well understood by CliC. There are many ongoing snow research projects, such as snow CDR in NOAA, ESA GlobSnow, snow modeling, GCW, and the SWIPA assessment report.

Snow research is not a cross cut for CliC or WCRP, although it could be. CliC needs to focus on snow research with others in WCRP project and operational agencies, particularly in the areas of calibration and validation of current and future remote sensing snow data and products.

Snow on sea ice is also an important challenge for research. There is little data available of snow cover on the sea ice. We need remote sensing snow data and compile snow observations on the sea ice. IceSat data show different snow processes between the North and South poles; this should be examined in the snow cover models.

5. Solid precipitation

Solid precipitation closely relates with snow cover, and both elements are very important for water balance analysis over regions and watersheds, and for the future satellite missions, such as the CoReH2O. A presentation reviewed the activities last year and proposed various options for future, including a CliC working group on solid precipitation.

The SSG recognized that this as a large issue that requires more time for discussions. For instance, the idea of developing a cross cut project with GEWEX, was raised or to work with the national met services and the WMO, including GCW.

7. CAPER (CArbon and PERmafrost) and permafrost in climate model

This is a joint project with the IGBP-AIMES and IPA, focusing on the change in permafrost and feedback with CO_2 and CH_4 release in northern regions. CAPER advanced well in the last year. A CAPER meeting was held in Stockholm 5-6 June 2009. It has been decided at the meeting that CAPER will build on the results of the IPY's Carbon Pools in Permafrost Regions (CAPP). CAPER will review how ecosystem, land surface, and Earth system models represent carbon – permafrost feedbacks, and formulate recommendations for their further development. Based on the review, CAPER will propose a modeling framework, including parameterization schemes and sub-models for soil carbon and energy dynamics. A CAPER white paper is ready for release, and US NSF funds have been obtained for some research projects.

The CAPER project and collaboration with the IGBP\AIMES continue. New directions for this research may include an expansion to the continental shelf areas, as well as CO_2 and CH_4 release from Greenland and the Antarctic. CAPER plans for 2010 includes organizing community workshops and developing science and implementation plans.

CAPER has a team of 6 colleagues led by Vladimir Romanovsky. This project remains as one of the key initiatives for CliC.

8. Mountain glacier and water resources changes

Prediction of mountain glacier changes and their impacts on regional water sources is a key requirement for climate and hydrology science and application. Both long- and short- term regional climatic and hydrological predictions are required for adaptation and mitigation practices. CliC will initiate activities to develop glacier hydrology models and regional climate models, including downscaling techniques. CliC will work with GEWEX-HE and other international organizations, such as IGS and IAHS, to improve the predictions of mountain glacier and water resource changes, and the assessment of freshwater resources under a changing climate.

CliC will continue to support regional activities, such as Asia-CliC. CliC will also encourage and facilitate cryospheric research projects and collaborations in other regions, including South America, Alaska, and the Nordic countries.

The SSG has decided to include Mountain Glacier and Water Resource Changes as a new CliC initiative, to be co-led by Helmut Rott and Gino Casassa. This project will engage and work closely with other regional activities, including Asia CLIC and the Cold Region Hydroclimatology Project (GEWEX), to assess freshwater resources related to glacier changes in various mountain regions.

9. Sea level rise (SLR), including ice sheet modeling

CliC has assumed the coordinating role of the WCRP research on sea-level rise. This will be organized by the WCRP/IOC Task Group on Sea-Level Variability and Change. CliC will continue its research, through observation and modeling, to quantify the terrestrial cryosphere changes, including the dynamics and mass balances of ice sheets, and the role of ice shelves in sea level change. CliC will also work with the GEWEX and IHP of UNESCO on the determination of land water storage change over time.

Specifically, it has been decided by the SSG that Walled Abdalati will serve as the theme lead for research on cryospheric input to SLR. A working group for this initiative will be assembled to work on the dynamics of ice sheets, addressing aspects of both modeling and observation. Dave Holland will lead the ocean ice modeling research, including ice shelves modeling and impact to the SLR.

10. Arctic and Antarctic sea ice

Sea ice is changes in the Polar Regions. There exist remarked hemispheric differences in sea-ice regime and change. It is a huge challenge to understand the causes for the rapid loss of sea ice in the Arctic Ocean, and the reasons for the difference in sea ice change between Arctic and the Antarctic. CliC is ready to face this challenge.

The SSG has decided:

- To continue the support to the existing arctic sea ice working group. This group has been led by Sebastian Gerland since early 2009. CliC SSG encourages this group to continue its effort and to focus on AO sea ice observation, model, and predictions. It has been suggested to enhance the research on sea ice modeling and remote sensing application. This group should engage and include modeling and remote sensing experts, and work with other groups, such as the AOSB, on IPY data analyses.
- CliC collaboration with the AOSB. This will link CliC sea ice research with the AOSB work on the role of Northern Seas in the climate system, specifically a project and collaboration on Arctic and sub-Arctic Ocean data synthesis. A proposal from CliC is necessary for this activity.
- A new initiative on the analysis and assessment of remote sensing sea-ice products. This will be led by Walt Meier and Walled Abdalati. They will set up a working group for this task and collaborate with space agencies and user communities.

- Arctic sea ice change and prediction are also the hot issue for WCRP. JSC tasked CliC to lead a white paper on sea ice research and the way forward. The white paper has been done and discussed at the SSG and JSC meetings.
- Establish the SO ice working group, led by M Rafael. This group will continue the development of Southern Ocean Observing System. In addition, reinvigorating the Southern Ocean Physical Oceanography and Cryosphere Linkages (SOPHOCLES) initiative, also the SO TIP, SOOS, led by Tony Worby.
- Support the ASR. CliC will invite Mark Serreze, David Bromwich, and John Walsh to lead this group. Proposed research approaches and tasks are the CMIP5 diagnostic subproject, including the ARctic Climate HIndcasting, Modelling, and PrEDiction ExperimentS (ARCHIMEDES).

List of action items

Ref	Action item	Due date	Action
1	Contact international groups - such as IGS and IAHS, for research collaborations on mountain glacier changes and their impact on hydrology and water resources		
2	Produce a poster to show the coverage and gap of international earth science programs		VRy
3	A proposal from CliC to AOSB for future collaboration, i.e. the role of Northern Seas in the climate system and Arctic and sub-Arctic Ocean data synthesis		
4	CliC input to the iAOOS draft plan and its membership before the IPY Conference in Oslo in June 2010-?		
5	Input and comment to the IGBP program JS meeting via WCRP	Completed	DY, VRy
6	Continue the dialogue with IARC\UAF on the planning of a arctic sea ice workshop in 2010.		CliC sea ice WG and DY?
7	Inform the SSG about the changes in the CliC executive committee		KS/DY
8	Email the new working group leads for the one page doc (work plan) with budget estimate for meetings, workshops, and publications		DY
9	Discussions of CliC structure, panels and working groups for the new initiatives and activities via telecons (after item 7 is done)		CIPO
10	Produce a SSG meting report with an extended summary of major decisions and action items		CIPO
11	Form WGSIP-CliC-GEWEX Experimental Protocol Team		VRy, DY

Opening

Konrad Steffen, CliC SSG Chair, welcomed the participants and thanked the CEC host and CliC SSG member, Gino Casassa, for hosting the meeting. Following a round of self-introduction, the agenda was approved and adopted.

WCRP Update and Message to CliC, CIPO Update

WCRP/World Climate Conference-3/GFSC update and what WCRP expects from CliC

Ghassem Arsar, Director of WCRP, spoke to the group on the 2nd day of the meeting. He emphasized the need for the CliC Project to involve and engage the scientific community at large and to generate value added products. Cryosphere is changing fast. Relative to other climate aspects, the visibility of climate change is high in cryosphere. Big challenges come with the high visibility. CliC is in a good position to conduct and lead advanced research of climate and cryosphere. There have been unique opportunities for cryospheric research in general, such as the IPY and other regional and national programs. CliC should identify the future needs and move the research forward. It is important for CliC to connect more closely with other WCRP Projects, as they are interested in CliC and they need to work and collaborate with CliC. CliC should consider: what are the issues, how to organize ourselves, and how to get things done through co-ordinations. CliC has to focus on the key issues. It is up to the SSG and its leadership to decide where to go and what to do.

In the past WCRP focused on the global climate research. The current and future priority should be on the regional scales. WCRP will wok with the WMO operational departments to provide climate services at regional levels for the decision makers. WMO and WCRP will generate climate info to regions with different societal conditions and obtain feedbacks from the end users. WCRP needs regional research projects and develop regional products. WCRP Projects have regional activities, better co-ordinations and collaborations with the national centers are necessary. WCRP Projects should continue focusing on the science and provide the interface and network with other professional organizations. The detail of climate services is still under development, this relates to the function of future WCRP. WCRP has developed white papers on the future themes and structure; these documents are currently under review and will be discussed at the JSC meeting. CliC is expected to help with the discussions of WCRP in the areas of cryosphere.

Future support from WCRP on meetings and workshops were also discussed. D\WCRP confirmed that WCRP has been active in seeking funds over the past few years. Things are getting better, WCRP got good supports from its sponsors and donors - some doubled their contributions, such as the space agency and WMO member nations. WCRP will support CliC activities.

Vladimir Ryabinin, World Climate Research Programme (WCRP), outlined the WCRP intermediate- and long-term plans to be implemented by 2013 and beyond. A need for, and use of, climate information, products, and services, prompted many questions, such as how to identify these services and what the products should consists of. What are the roles-, nature-, and duration of cross-cutting activities between WCRP core projects? How to ensure society's needs are effectively met? Although WCRP project cross-cuts, are essential to address the science issues related to the needs of the end-user, they may have a limited lifetime as old needs are met and new ones arise.

The Third World Climate Conference (2009) made a decision to establish a *Global Framework for Climate Services*. More flexibility in responding to increased user needs for climate information is necessary; *i.e.*, for predictions on a regional scale, needs related to key sectors of the global economy, and for adaptation, mitigation and risk management. The message from WCRP to CliC is for its core projects to work together on cross-cutting activities *fewer, but important issues* to focus on in the future.

Discussions recommended the formation of CliC panels or groups to work on addressing these and other related issues. Predictability, as well as projection, was emphasized (D. Holland), while T. Prowse commented on the difference between predictability of the cryosphere and of things *affected by* the cryosphere. He also suggested the SSG be given more power to implement its decisions.

Expectations for International Arctic Science Committee and the Scientific Committee on Antarctic Research

Volker Rachold, IASC Executive secretary, participated via telephone from Germany. In light of the growing integration and variation of arctic programs and a strategic need to address issues affecting the physical and social sciences, an AOSB / IASC merger took place in 2009. The AOSB converted into the IASC *Standing Committee for Marine Sciences.* The core elements of the proposed new IASC structure are the *Scientific Standing Committee (SSC)* and the *Action Groups.* The science areas include, among others, terrestrial- and cryosphere systems. The importance of an IPY legacy was stressed, where CliC should play an active role. He informed the SSG that Sustaining Arctic Observing Networks Initiating Group (SAON IG) report on "Observing the Arctic" had been published and its recommendations presented to the Arctic Council. The Ministers decided the SAON process should continue, and – within the next two years – initiate work on issues such as sustained funding and data management. Users should have free access to open and high-quality data, and this could be accomplished by facilitating partnerships and promoting sharing and synthesis of data and information.

Tony Worby, provided an update on SCAR activities which included a report on the Antarctic Climate Change and Environment (ACCE), the Southern Ocean Observing System (SOOS), the Science Plan for Ice Sheet Mass Balance and Sea Level (ISMASS) and Antarctica and the Global Climate System (AGS). Parts of the Antarctic are losing ice at a rapid rate, and sea-ice extent has increased around Antarctic in the last 30 years as a result of the ozone hole. West Antarctic could make a major contribution to sea-level rise over the next century. To address these issues, improved representation of polar processes is needed in models to produce better predictions. Higher resolution global models as well as regional climate-, ecosystem-, and ice-sheet-models are required.

SCAR expects CliC to deliver products; *i.e.*, an annual update to the ACCE document reporting the latest science results; data products; review papers in refereed literature; and white papers.

CliC Project Office Report

Daqing Yang, CIPO Director, presented a summary of 2009activities. This included CIPO funding and staff, workshops and meetings (e.g. new Arctic Sea Ice WG held their first workshop at the Norwegian Polar Institute in January), workshop reports (Arctic Sea-Ice Report: WCRP Inf. No 11/2009), and CIPO contributions to major documents\articles. Travel for CliC related meetings, and CliC's website and newsletter were also discussed. While CIPO functioned well in 2009, there is a need for more operational funds to support a 3rd staff member. CIPO hopes to obtain additional funds through joint proposals, such as the Nordic Centre of Excellence in climate change in interactions with the cryosphere, and CIPO will also seek one time contributions from various potential sources. With additional funds, CliC hopes to create a visiting fellow program. For more detailed information, please see the CIPO annual report in Appendix 5.

Expected outcome of the Session

Koni Steffen summarized the CliC goals and Themes and the new CliC implementation plan (IP). CliC must address a few but *important issues of the modern climate science that are linked to the cryosphere and do them well*. New developments at WCRP require a change in CliC as well.

One of the new requirements for climate science is to provide a foundation for the development of *climate services*. WCRP is moving ahead on several key directions, focusing research on the anthropogenic climate change, climate extremes, sea-level variability and change, decadal and seasonal predictions, monsoons, etc. Expected outcomes of this meeting include:

- Prioritize cryospheric issues for CliC Themes
- Define goals for all four Themes with deliverables by the SSG-7 in 2011.
- Theme leader take active role, including one workshop on proposed focus topic.
- CliC to engage with the modelling community in all four Themes.
- Engage in two WCRP cross-cut issues.
- Redefine scope of CliC in view of WCRP requirements.
- Review SSG membership expertise **-** possible changes and additions.

Discussions included questions about how to make best use of the two existing CIPO positions, about funding in general, and whether WCRP's CliC budget could be used to finance Theme activities. The latter was confirmed by Ghassem Asrar, WCRP Director. Again, the question about CliC's working more closely with other WCRP projects through the cross-cuts where CliC can work most effectively was emphasized. The question about a definition of "climate service" was deferred as being an issue the new panels/groups would work on to identify. The four overarching CliC Themes are too broad to guide our activities, and we will define specific focus areas within and across the themes for future activities. Identify TWO cross-cuts where CliC can work effectively. An increase in CliC SSG membership was also seriously discussed.

WCRP Prediction and Assessment Activities

SWIPA

Koni Steffen, Terry Prowse, Sebastian Gerland and Jeff Key each updated the SSG on the Arctic Council's project on Snow, Water, Ice, and Permafrost in the Arctic (SWIPA). The project's purpose is to provide the Arctic Council with knowledge about the present status, processes, trends and future consequences of change in the Arctic cryosphere. Reports from recent or ongoing projects (AMAP), national implementation plans, and activities such as the IPY will highlight gaps in knowledge, and SWIPA will recommend actions for future research and monitoring to fill these gaps. Jeff Key showed the structure of the SWIPA science report with lead authors listed, with Terry Prowse being the convening lead author of the component on River and Lake Ice. Terry is also the lead for an integration section dealing with the effects of a changing cryosphere on the Freshwater Budget of the Arctic Ocean. The Sea-Ice component leads are Sebastian Gerland, Mats Granskog, Kim Holmén, (Norway), plus Walt Meier and Jeff Key (USA), with Walt being the main contact point for this component. Other components include Snow, Ice Caps and Glaciers, Permafrost, and the Greenland Ice Sheet. Koni Steffen is a contributing author for the Greenland Ice Sheet chapter as well as for the chapter on Sea-Level Rise. Products produced so far include: a *Preliminary Report on the Greenland Ice Sheet* (to COP15), a *SWIPA film*, and a *Report on Melting Ice.* CliC is involved in the reviewing process.

Discussions: CliC has been invited to review the SWIPA Science Report during the national review and has nominated several colleagues for this task. Discussions centered on what should be included in its various components, and suggestion was made to meet at the Arctic Observations Systems session at the Oslo IPY conference in June 2010 and present questions there. No actions were decided.

WCRP Seasonal, Decadal, Long-term Prediction Experiments - Update on WGCM, CMIP5 and Relevant CLIVAR activities

Via telecon, Jim Hurrel presented CLIVAR updates on issues relevant to CliC. This included the WCRP Climate-system Historical Forecast Project (CHFP) – an international multi-model experiment incorporating all elements of the climate system. Eleven groups from multiple countries participate in the project (see http://www.clivar.org/organisation/wgsip/chfp/chfp_data.php), and five of these have already completed data transfers to servers at CIMA[4] in Argentina, APCC[5] in Korea, and ENSEMBLES. The APCC server is slightly behind CIMA in becoming operational. The next Working Group on Seasonal to Interannual Prediction (WGSIP) meets in July 2010, and hopefully we will get an update on the status of when the APCC server will go live

To explore seasonal predictability associated with snow and sea ice, three areas of potential collaboration with CliC were suggested:

1. CHFP protocol encourages experiments with additional diagnostics for cryosphere
2. Sea ice prediction and initialization
3. Spring snow melt into soil moisture and influence on spring temperature anomalies

Proposal: *Form a WGSIP-CliC-GEWEX Experimental Protocol Team.*

CMIP5 is a 5-year experimental design, but a significant fraction of the experiments will be done in time to be included in AR5. CMIP5 is a huge effort that depends on tangible connections to succeed, with CliC contributing to ice sheets, sea ice and permafrost issues of the experiment. Simulations are underway, and model simulations should be available in December this year, with analysis beginning in 2011. (Initialized decadal prediction and climate change through 2300; paleoclimate, carbon cycle, and different mitigation scenarios.) First results will hopefully be ready by the WCRP science conference on climate (Boulder, October 2011).

*Discussion*s: Need to include ice sheet model with the earth system model, but NCAR does not have any expertise on land-ice model. On the question about the status of the NCAR model in terms of cryosphere components, the meeting was informed that at coupling of land-ice models with LSM is being done at NCAR, and that the next step is to develop a fully coupled model. The establishment of a task force to deal with this issue was suggested.

WCRP Polar Workshop and Initiative

Ted Shepherd, co-Chair of the WCRP SPARC project (Stratospheric Processes and their Role in Climate), presented plans for a WCRP Workshop on Polar Predictability on Seasonal to Multi-Decadal Timescales, which will be held October 25-29, 2010 in Bergen, Norway. The workshop is motivated by the need to determine the fundamental physical basis for (and extent of) predictability in the two polar regions, based on the couplings between all components of the climate system (land, ocean, ice and atmosphere). For example, stratospheric ozone depletion is now believed to have had an impact on Antarctic Ocean circulation and ice cover. The workshop is being carried forward by SPARC and CliC.

During the *discussions* following this presentation, Bob Dickson commented that sea-ice and ocean should not be separated too rigidly as session topics since they are closely interdependent. The AOSB Report that he tabled gives examples in which features of the changing Arctic Ocean water-column appear to be of actual or potential importance to the state of the sea-ice, but where key mechanisms of change are still unknown and require testing by observations.

Cryospheric Issues in IPCC AR5

The IPCC AR5 publication to be published in 2013 will feature chapters on Cryosphere and on Sea-level. The proposed structure of the cryosphere chapter may include findings on:

- Changes in ice sheet mass balance (observations, causes/processes and uncertainties, sea level contributions)

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[4]Centro de Investigaciones del Mar y la Atmosfera
[5] Asia Pacific Economic Cooperation (APEC) Climate Centre

- Changes in ice shelves (ocean interactions, sub-ice shelf cavities, processes and trends)
- Ice sheet – ice shelf dynamics (instabilities, subsurface hydrology, ice-ocean interaction)
- Changes in mountain glaciers and small ice caps (globally and regionally, causes/processes and uncertainties, sea level contributions)
- Sea ice variability and trends (historical data sets, remote sensing, and underlying dynamics)
- Snow cover variability and trends (globally and regionally, relation to pressure indices)
- Changes frozen ground (permafrost and seasonally frozen ground, regional changes and trends)

The proposed Seal-level chapter may contain:

- Synthesis of observational results
- Methodologies, discussion, and testing of models
- Assessment of statistical modelling approaches
- Model projections
- Regional distribution of sea level
- Extreme events
- Longer-term implication and tipping point
- Implications of different emission pathways

Discussions – the IPCC cryosphere chapter calls for contributors and reviewers. A good chapter review is as important as the initial contribution (note the widely-discussed errors in an earlier publication). Should we actively approach CliC Specialists and nominate them as reviewers? Climate model limitations were discussed. We have 100-year modelling predictions, but we need 30-, 40-, and 50-year predictions in the future. Are models behaving right from a process point-of-view? The process- and modelling groups would benefit from working closer together. The WCRP cross-cuts (*i.e.*, with CLIVAR) were mentioned as a way to improve communication between the groups. A 2012 AR5 cut-off date for a 2013 release, gives us little time, considering the way crysopheric research changes. In future assessments, the AR5 should have more process results. How can the latest breaking news be ingested and included in time?

Terrestrial Cryosphere and Meteorology of Cold Regions

TCHM Introduction and Update

Based on inputs from Regional Climate Models, the first attempts at modelling lake-ice cover were outlined. The focus has been on predicting changes in ice-cover duration, thickness and composition as well as the timing of freeze-up and break-up. Changes in snowfall have been noted to be especially important in altering ice-cover composition, which has a number of implications for ice strength and radiation regimes. Validation of the modelling results is being conducted across a profile of northern lakes spanning a range in ice thickness and winter snowfall. A satellite-controlled ice/water-column buoy system has also been developed to assist in the monitoring of changes in remote regions. Plans are to gradually deploy these at key northern circumpolar sites. The ice-modelling program has a broader goal of evaluating the biogeochemical changes likely to occur in northern lake systems as a result of changes in ice cover. Such a modelling/monitoring program might make a useful contribution to the developing Global Cryosphere Watch.

T. Prowse also described the importance of river ice in producing hydrologic extremes on northern rivers, including both floods and low flows. Such extremes are often much greater than those due to, for example, spring snowmelt or open-water floods, even though such events may occur at significantly higher discharge. The greater importance of ice in creating extreme river stages is the role of ice-induced backwater. Also described were the first broad regional scale analyses of ice-induced extremes; the first having been conducted on the Mackenzie River basin with a major program now underway to extend such work to the remainder of North America, Scandinavia and Russia. Such a river-ice extreme event analyses could provide a useful link between CliC and the extreme event program of GEWEX.

The Role of Carbon and Permafrost in the Climate System, CAPER, CliC Initiative

The IPCC Working Group 1 Fourth Assessment Report (IPCC, 2007) highlighted the cryosphere as a major source of uncertainty in global climate projections. One of the most significant knowledge gaps related to cryosphere is the impact of thawing permafrost on the global carbon cycle. The magnitude of the positive feedback between the warming climate and additional emission of greenhouse gases into the atmosphere from natural sources, and particularly from thawing permafrost, is unknown. Some scientists believe the effect may be catastrophic, while others are skeptical about its significance. The picture is complicated by limited information on the quantity and form of carbon sequestered in permafrost, by inadequate knowledge of arctic biogeochemistry, and by insufficient understanding of the interactions between the terrestrial cryosphere, hydrology and vegetation in northern high latitudes (NHL) in a warming climate.

CAPER (Carbon and PERmafrost) is a joint CliC-AIMES initiative that will promote complementary approaches for understanding and quantifying carbon cycle and permafrost dynamics across scales of observations, measurements and models for regional-to-global analyses. Focus on the "Role of carbon in the climate system" is one of five short-term objectives formulated by SSG-V (2008). Much has already been done; *i.e.*, the first CAPER meeting took place in Stockholm (June 2009), and the resulting White Paper on *Terrestrial Permafrost Carbon in the Changing Climate (V. Kattsov, et al., 2009)* was circulated among a group of experts for comments. Material from this paper also appeared in the CliC and AIMES newsletters. (See Appendix 6 for the full version.)

The suggested next steps in this effort included a workshop to start the development of a science plan/implementation plan.

Discussions: Questions from the SSG included the placement of CAPER related to the importance of its impact. How many Gtons of carbon (potentially 1500), and weather CO2 and CH4 release can be monitored. It is now possible to estimate carbon storage in permafrost (Tarnocai et al., 2009 and Schuur et al., 2009). Where does the increase in methane come from? Observations methods are local, permafrost domain cannot be generalized based on ground observations. There is a strong need to develop reliable methods to monitor CO2 and methane using remote sensing data. Another need is to develop a coupled climate-permafrost-carbon model that can be used to assess the importance of the greenhouse gases release from permafrost for the global climate and to test the hypotheses about possible positive feedback between warming climate and thawing permafrost. New datasets will be needed to run and to validate this model.

So far, planned CAPER initiative includes research on permafrost on the land only. Do we need include subsea permafrost as well? Monitoring and modeling permafrost on the arctic shelves is the next step

Cold Region Hydrology and Climate Research/Modelling, including Lake- and River-ice Issues

The effects of a warming climate on the terrestrial regions of the Arctic are already quite apparent; some subsequent impacts to the hydrologic system are also becoming evident. The broadest impacts to the terrestrial arctic regions will result through consequent effects of changing permafrost structure and extent. As the climate differentially warms in summer and winter, the permafrost will become warmer, the active layer (the layer of soil above the permafrost that annually experiences freeze and thaw) will become thicker, the lower boundary of permafrost will become shallower and permafrost extent will decrease in area. These simple structural changes will affect every aspect of the surface water and energy balances. As the active layer thickens, there is greater storage capacity for soil moisture and greater lags and decays are introduced into the hydrologic response times to precipitation. When the frozen ground is very close to the surface, the stream and river discharge peaks are higher and the base flow is lower. As the active layer becomes thicker, the moisture storage capacity become greater and the lag time of runoff increases. As permafrost becomes thinner, there can be more connections between surface and subsurface water. As permafrost extent decreases, there is more infiltration to groundwater. This has significant impacts on large and small scales. The timing of stream runoff will change, reducing the percentage of continental runoff released during the summer and increasing the proportion of winter runoff. This is already becoming evident in Siberian Rivers. As permafrost becomes thinner and is reduced in spatial extent, the proportions of groundwater in stream runoff will increase as the proportion of surface runoff decreases, increasing river alkalinity and electrical conductivity. This could impact mixing of fresh and saline waters, formation of the halocline and seawater chemistry. As the air temperatures become higher and the active layer becomes thicker, we have reason to believe the surface soils will become drier. As the surface soils dry, the feedbacks to local and regional climate will change dramatically, with particular emphasis upon sensible and latent heat flux. This may impact recycling of precipitation, capabilities to predict weather and may indeed increase variability of many processes and variables, including convective storms.

Key research needs related to hydrology include:

Changes in water availability: Although climate models predict increases in precipitation, these models do not include consideration of drying soils with degrading permafrost. Consequently, the reliability of model predictions is, at best, questionable.

Quantifying the important feedback relationships: As permafrost degrades, soils will become wetter initially, and later drier as drainage improves, drier. It is necessary to quantify the spatial changes to the surface energy and water balances and incorporate these dynamic relationships into models to improve climate predictability.

Although, from a broad perspective, many of the primary research themes have not changed in the past 20 years, our advances in observational data sets and modeling capabilities have greatly advanced our understanding. At this time we should attempt to better incorporate observational networks and remote sensing tools to validate and improve modeling studies and understanding of arctic change.

Downscaling: Impacts of climate change to communities occur on local scales, therefore we need to provide climate and impact predictions at the local scale. Changes in climate will have serious impacts to the water resources of communities throughout the circumpolar arctic.

CliC Project Goal: The CliC project's principal goal is to assess and quantify the impacts that climate variability and change have on components of the cryosphere and its overall stability, and the consequences of these impacts for the climate system. Hinzman feels the CliC goal is excellent and encourages CliC to “stay the course”.

Cryospheric inputs to the Arctic and Southern Ocean Freshwater Budgets – a CliC Initiative

Over the last few years, an Arctic Ocean freshwater budget initiative has been proposed by Terry Prowse. CliC has all the relevant expertise for analyzing the FWB: snow, permafrost, sea ice, ice sheet, and river flow to the Arctic Ocean. This is a proposal for the integration and synthesis of new (land and ocean) data and knowledge obtained during the IPY years – to examine and establish a closer link between the land and ocean components of the arctic climate system. There has been interest within CliC, for instance, to quantify the Greenland ice sheet change and melt water contribution to the AO water cycle. Many new observations were taken during IPY in the oceans, these will help us to understand the freshwater in the AO, including what are the drivers and when the ice is going away.

The AMAP SWIPA assessment provides a unique opportunity and synergy to work with other groups and to move this idea forward. CliC needs to identify a champion to lead and promote this initiative. Terry Prowse has developed a short FWB integration document for the SWIPA report that discusses the relevance of all the arctic cryospheric components. CliC needs to find someone to lead and promote and move this idea forward.

This initiative will engage and work closely with cryospheric and ocean groups (such as the AOSB and others) within and outside of CliC. The proposal of the freshwater budget analysis also includes the Southern Ocean (SO).

Snow and Climate Research

Vladimir Ryabinin listed main activities supporting WCRP key deliverables and highlighted their dependence on snow data, products and models. He also indicated that most of ongoing CliC initiatives have links to snow and snowfall. Two actions (T13 and T14) of the 2010 update of the GCOS Implementation Plan in support of the UNFCCC relate directly to snow. Action T13 will help to strengthen and maintain existing snow-cover-, snowfall-observing sites; ensure an international exchange of snow data, establish global monitoring of that data on the GTS; as well as to recover historical data. Action T14 involves obtaining analyses of snow cover over both hemispheres and will be addressed by space agencies and research agencies in cooperation with CliC and Terrestrial Observations Panel for Climate (TOPC), Atmospheric Observations Panel for Climate (AOPC) and IACS.

Vladimir then discussed the non-uniform picture of snow trends, and results from recent papers that addressed snow- and river-runoff and potential future changes. In the Arctic, there is likely to be changes towards more uniform runoff throughout the year, with a multitude of accompanying changes, and up to 50% increase in runoff to the Arctic Ocean.

In the Alps, the snow line may be higher by 900m by 2071-2100. In addition, spring melt in the Alps may have a tendency for aggravating spring floods at the same time ultimately leading toward water shortages due to less annual volume (Bavay *et al...*, 2009). Vladimir then discussed promising venues in snow and climate research that addresses past and current modelling deficiencies, and problems facing atmospheric modelling for snow. Recommendations on future snow research include:

- Need to address long-standing issue of snow data input to the many WCRP prediction experiments, especially for CHFP
- Need global long-term Fundamental Climate Data Records (FCDR)s for snow cover and SWE
- Snow cover, SWE and soil moisture products should be compatible
- Need to support adequate complexity of snow schemes in the entire climate range

Discussions: Snow modelling has many different aspects, and the SSG was encouraged to suggest activities. Ted Shepherd suggested this was a weather forecast issue and recommended to start a dialogue with forecasting groups as a beginning. SCOR would be happy if WCRP came up with a project to assimilate temperature, ice, ice concentration – including melt ponds – as a joint system. Sebastian Gerland mentioned that snow is an important component when studying sea ice, but that there is a limited amount of data available for the modelling community. He suggested perhaps a larger effort towards compiling information on snow for sea-ice studies. Researchers are studying snow on sea ice and on land, and the two are fundamentally different. Snow on sea ice and on land is worked on by different people, and is fundamentally different. How do you get a diverse community together for positive action? Tony Worby then mentioned that these concerns are complicated further by the difference in snow and sea ice research between the Arctic and Antarctic.

Solid precipitation activities and proposals

Daqing Yang reviewed solid precipitation activities over the last year. This included a proposal to GEWEX CEOP for a joint project, email discussions with meteorological services of Canada, Denmark and Norway with the UAF about auto gauge snowfall observations, as well as, discussions with NASA GPCP. He also proposed various options for future development:

- Establishment of a CliC working group on solid precipitation
- Follow up discussions on the GEWEX/CEOP project
- Engaging data centres (GPCC, GPCP) and national meteorological services for collaborations and resource sharing
- CliC-GEWEX solid precipitation workshop in spring 2011
- Work towards an arctic precipitation assessment report

Solid precipitation is closely related to snow cover. Both elements are very important for water balance analysis over cold regions and watersheds, and future satellite missions (e.g. CoReH2O). The SSG recognized that this as an old problem; a large piece of an even bigger picture. Solid precipitation could be part of the arctic freshwater budget initiative, as it affects both snow cover and river flow throughout cold regions. An arctic precipitation assessment report would be too big a task for CliC to tackle alone. WMO departments, WGC and meteorological services need to be engaged. We have to agree on the best practices to build up datasets, and this includes error corrections. A regional precipitation data project is possible; CliC will need to work with data centres and model groups (*i.e.* link to re-analysis). The scope and collaboration for this research needs to be defined. This would require more time for discussions on a cross cut approach or even a project in the future. *No decision was made at the meeting about solid precipitation research. Further discussion within the CliC SSG and with the GEWEX project is necessary.*

Permafrost (schemes) in Climate Models

Vladimir began by mentioning the CAPER White Paper (Appendix 6), the database of boreholes for the Global Terrestrial Network-Permafrost (GTN-P), and the methodology of permafrost temperature reanalysis. He described the GIPL-2.0 model which is a numerical model of heat transfer that combines and uses variables such as surface geology, ground temperatures, soil properties, snow cover, vegetation, air temperature, and precipitation. This model can be used to study factors such as permafrost extent, ground temperature with daily frequency, active layer thickness, unfrozen water content, and time of freeze up. Multiple figures were presented showing how global permafrost temperatures could be affected by increasing air temperature. Next, Vladimir demonstrated how the GIPL model works, and then presented mean annual Alaskan soil temperatures at 1 meter depth from 1980 and projected to 2099.

It is important to include the permafrost in GCMs because there is no other way to include vital terrestrial feedbacks related to changes in permafrost, such as energy/mass exchange, at the ground surface and changes in carbon cycle. Vladimir discussed the difficulties related to modelling permafrost properly in GCMs, bias sensitivity, and spatial and temporal resolution. He compared and provided details on three different land vegetation models, and provided four Arctic RCMs that work on improved treatment of frozen soil and permafrost.

Several recommendations were made for possible steps forward:

- Examine recent solutions of permafrost representation in several leading GCMs and RCMs
- Test the performance of permafrost-related components of GCMs/RCMs in comparison with more sophisticated off-line permafrost models
- Formulate what critical improvements in GCM/RCM's permafrost modules are necessary and prioritize them

- Conduct sensitivity analysis using sophisticated off-line permafrost models to choose the most important input parameters and start working towards development of corresponding standard databases

Alpine Cryosphere – Review of Activities

Michael Zemp talked about challenges encountered in international monitoring of glaciers and ice caps, with an aim to identify areas of potential collaboration with CliC. He began with a short introduction to the World Glacier Monitoring Service (WGMS) and the Global Terrestrial Network for Glaciers (GTN-G)[6], its history and organisation. The GTN-G Network follows a multi-level monitoring strategy, (see box - illustration from Zemp's presentation)**.**

integrated /tiered observing strategy

Tier 1: multi-component obs. system across environmental gradients
Tier 2: process understanding and model calibration
=> extensive energy/mass balance, flow
Tier 3: regional indicators
=> mass change (index stakes, photogrammetry, LIDAR)
Tier 4: regional representativeness
=> cumulative length change of selected glaciers, DEM differencing
Tier 5: global coverage
=> inventories (remote sensing/geoinformatics)

Available data includes inventory data of about 100'000 glaciers, front variations of 1'800 glaciers and mass balance measurements from 230 glaciers, as well as an extensive glacier photograph collection (historic and current pictures) as well as information about special events.[7] An overview of available data is given in WGMS (2008; www.grid.unep.ch/glaciers/).

He talked about data-quality concerns and the lack of glacier data, especially from the Southern hemisphere.

Estimated glacier contribution to sea-level rise during 1961-90: 0.33 mm per year; 1991-2004: 0.66 mm per year. He listed areas where data is lacking: no complete detailed inventory; uncertainties in estimation of ice volume; spatial distribution and time length of mass balance observations vs. global distribution of ice cover; representativeness of observed glaciers for ice masses relevant for sea-level contribution; cold glaciers and tidewater glaciers. GLIMS, WGMS, and NSIDC are the only operational services involved in glacier monitoring. No Alpine glacier mass balance series resulted from the IPY effort. It is harder to keep ongoing measurements going.

The GTN-G has an operational monitoring network in place, and all data is available digitally (www.gtn-g.org). Analyses show a strong global glacier retreat since Little Ice Age maximum extents,

[6] GTN-G is run in cooperation with National Snow and Ice Data Centre (NSIDC) and Global Land Ice Measurements from Space (GLIMS) and is as part of the Global Terrestrial Observing System /Global Climate Observing System (GTOS/GCOS) for the United Nations Framework Convention on Climate Change (UNFCCC).

[7] For example, before and after satellite images of the 6 October 2002 ice-rock avalanche in the Kazbek region of the Russian Republic of North Ossetia, that sheared off almost the entire Kola Glacier and devastated the Genaldon valley.

with intermittent re-advances at regional and decadal scales. The “way forward“ includes challenges such as:

- Awareness of the rich variety of glacier types and characteristics
- Extend *in-situ* network to the South
- Calibrate and homogenise data series
- Make systematic use of remote sensing and geo-informatics to assess the representativeness of the few *in-situ* measurements available
- Boost downscaling and ensemble approaches
- Better tie international bodies to operational services
- Coordinate international projects with operational services

Finally, he asked CliC to help with integrating *in-situ* measurements, remote sensing and numerical modeling.

Discussions: The term “Small Glaciers” is irrelevant – the term does not give consideration to the large variability of existing glacier types (small vs. large, debris-covered vs. clean-ice, temperate/poly-thermal/cold, calving, surging, etc.) and related consequences for monitoring and research. Measurements of glacier fluctuations (e.g. glaciological mass balance) need to be calibrated with independent methods (e.g. geodetic volume change) . Not enough inventories to calculate glacier melt contribution to sea-level rise. Koni asked if he was running the models and what the models were looking at. V. Romanovsky replied that the Permafrost community also is focusing in integrating data. Jeff Key suggested identifying small task groups for now. What is the first essential step to take? Helmut Rott reminded everyone that water supply is high on the public agenda, and that the general public cannot relate mass balance to water resources. Koni Steffen said to ***form a CliC group for high altitude glaciers***, that this was decided at the High Mountain Glaciers conference in Tromsø 2009. Helmut Rott and Gino Casassa will lead this group.

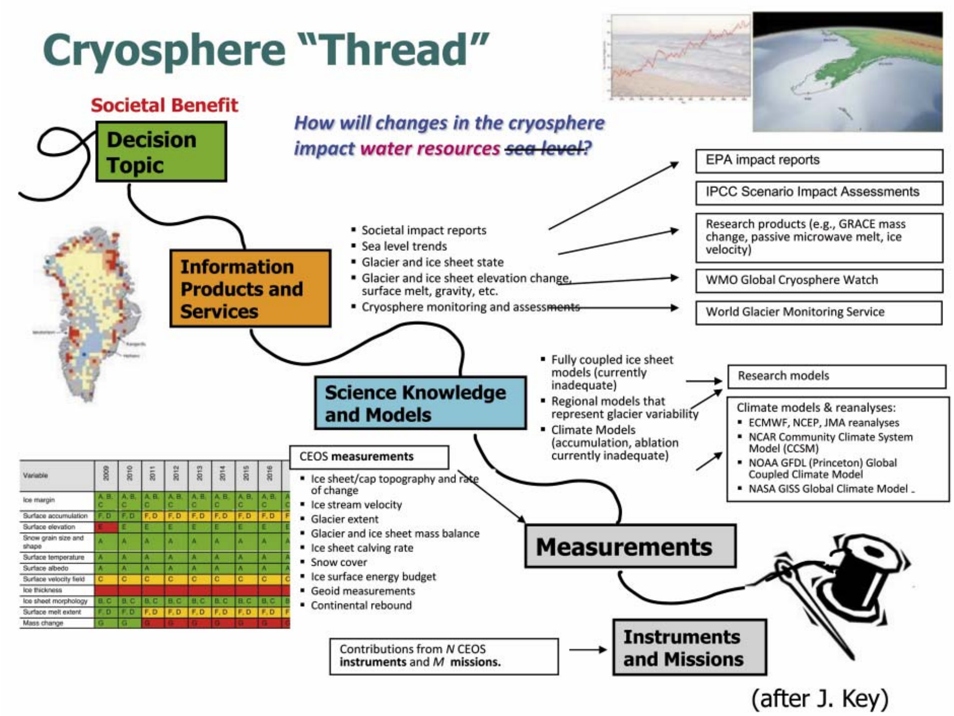
Towards Prediction of the Terrestrial Cryosphere and Water Reserves of Cryospheric Origin

The presentation began with a summary of the Global Framework for Climate Services. The main WCRP Climate Prediction initiatives currently on the go are: 1) the Coupled Model Intercomparison Experiment 5 (CMIP5) which addresses century and decadal predictions; 2) the Climate System Historical Forecast Project (CHFP) which works on seasonal predictions; and, 3) the Coordination Regional Downscaling Experiment (CORDEX).

The notion of a “Cryosphere Thread” was discussed. This “thread” connects the scientific realm to society through several steps. Instruments and missions provide measurements that will advance scientific knowledge and models. Knowledge and models impact information products and services which ultimately benefit societal decisions. It is important to ask researchers now, what are the required models and information that will benefit public decision making in the future. The example for this presentation being; how does ice sheet, ice cap and glacial melt - and their relative uncertainty - impact sea level rise forecasts and subsequently water resources?

For the purpose of describing the “thread”, several examples of scientific models and knowledge (eg. fully coupled ice sheet models and climate models), and information products and services were provided (e.g. societal impact reports, IPCC Scenario Impact Assessments, Global Cryosphere Watch, etc.).

When addressing terrestrial prediction and fresh water reserves for the 21st century, it is important to have a water prediction framework and to prioritize activities - or else end up with a program that is “an inch high and a mile wide”. This endeavor, if taken seriously, will be long term and difficult, but provide outstanding work of critical use for society. It will require commitment from several partners, and both regional and national efforts. Improvements in terrestrial cryospheric prediction will ultimately contribute to sea-level rise research and the GPC theme, and has the potential to be a lasting CliC legacy.



Discussions: CliC has done good work recently to synthesize cryo change impacts to hydrology and eater resources. The special issue of Hydrological processes, led by Terry Prowse has collections of very useful review papers about glacier hydrology change and future. CliC has many roles to play, one of them is to transfer expertise from one region to the other, such as from the Nordic groups to other regions for cold region hydrology.

Glacier contribution to river flow is a key question. Glacier contributions in centre Asia are very important in the dry regions, up to 40%. But snow in the mountains contributes to river flow as well. Lack of data on glaciers and in the mountain regions, such as in the Himalaya region, bring large uncertainty to our research results. We have to learn from the data and we need have more data and model as well. Model is the key to use in regions with weak networks to find where we need observations. Model assessment is very useful. CliC need to do more model research.

Cunde Xiao - Snow cover (e.g., over Eurasia) is a critical factor for intra-seasonal to inter-annual climate prediction for surrounding regions (e.g., mid-latitudinal areas). It is valuable for CliC community to produce reliable snow cover products (such as area, depth, water content, surface impurities including BC, etc) so that more skillful climate forecast can be achieved. It is also important to think about predicting snow cover itself, although very difficult because it determined by solid precipitation, topography, ground features, temperature seasonality etc. But can we think about predict/projection "snow cover at risk"? Where will be the regions that snow cover no longer exist under certain scenarios of winter/spring warming? What will be the consequences of regional climatic and hydrologic regime when these areas' snow cover disappeared?

Glacial meltwater is important water resources for some (not all, can be sorted out) arid/ semi-arid downstreams (basins), where population is not small. Prediction of glacier changes over these regions is important. Most glacial models are for single glacier and are not sufficient to satisfy our task to assess overall impacts of regional glacial changes. Develop basin-scale to regional-scale glacial-hydrological models (distributed?) are critical/urgency.

Frozen ground decay is key for ecological deteriorate for certain regions (such as Tibet, not sure for Siberia). Coupled atmospheric-frozen ground-vegetation model should be developed so that we could understand this better and doing prediction and adaptation.

Sea-Level Rise and Cryosphere

WCRP/IOC Task Group on Sea-Level Variability and Change and CliC "Ice Masses and Sea Level Theme"

Waleed Abdalati presented key issues for understanding land ice contributions to sea level rise. The overarching questions for this topic are:

- What are the mass balance values of the Earth's glacier, ice caps, and ice sheets?
- How are they changing?
- Why are they changing?
- How will they change in the future?

Waleed summarized the extent of research on Greenland ice sheet mass balance results from 1990 to date, and then Antarctic ice sheet mass balance results from a similar time frame, the latter having less. Ice sheet transformational discoveries from observations in the last decade were listed, followed by a list of the areas that need to be captured much more accurately in process models. These areas included coupling between ocean, floating ice, outlet glaciers and ice sheets, subglacial and englacial hydrology, and processes that could reconcile discrepancies in observational mass balance estimates. There are several challenges that face future ice-sheet observations. Many major discoveries from remote sensing data sets will have limited availability in the coming years, and while each technique is powerful in its own right they each still have limitations. Other challenges are the absence of comprehensive thickness estimates of outlet glaciers and basins, and that any future success requires integration of aircraft, altimetry, gravity, and velocity measurements which of yet is not forthcoming. Integration of data sets and coordinated observation strategies is critical. Challenges facing glacier- and ice-cap research include sampling mass change, integration of *in situ* observations, remote sensing, and modelling.

Critical issues listed were ensuring existing and planned observation systems deliver the maximum value (*i.e.* international coordination, understanding differences and integration with models), assessing ice sheet stability (*i.e.* requires significant progress on the modelling front and data not yet acquired), and developing strategies for quantifying current and predicting future SLR contributions from glaciers, ice caps and ice sheets (*i.e.* observational, modelling, and integration strategy). Lastly, developing a quantitative understanding of critical concepts, most notably ice sheet dynamics and ice/ocean interaction is an issue.

Koni Steffen presented an overview of SLR research activities. SLR is a WCRP cross cut theme sponsored by the IOC, and has direct societal implications. WCRP and IPO have established an expert group and a task group. The task group has refined the terms of reference, developed a work plan, and determined SLR deliverables. Recent outcomes include a 300 pp book (published in 2009) and the 100pp AMAP report on SLR (Nov 2009). This task group has been asked to provide periodic SLR updates and debriefs to policy makers. This was recently touched on by WCRP in a 4 pp update in December 2009. SLR research is linked to the IPCC AR5, and future meetings will determine SLR's input into the IPCC report.

Modelling - Ice Sheets

What do ice sheet modelers want? Framing questions in SCAR ISMASS report from St Petersburg can be used to help prioritize model development goals: Will climate change lead to irreversible (non-linear, rapid) ice sheet response; Are recently observed rapid changes natural variability or secular response to warming; and/or does rapid change in observed flow lead to a large mass change?

Ice-sheet modelers want data relevant to three broad development goals (*i.e.* definition of model domain, parameterization of sub-grid scale processes, and evaluation of model performance), the best resolution bed money can buy (2-5 km: maximum in fast-flowing places, finer than this is better; 5 to 10 km in slower flowing areas; maybe scale resolution according to flow speed or another ice sheet attribute), marginal classification, and repeat data records for parameterization.

Discussions: Model analysis is useful and it helps with field observations. The communication between the model- and observation groups has started. Modelers need to reach out to the observations from the community. Funding agency including space agencies like to see integration of model and observations. There is a need to promote the integration further.

Ice Shelve-Ocean Interaction

In his presentation David Holland discussed topics of the NAO and SAM, ocean circulations in the past, heat content to Greenland ice and its melt. There are similar processed in the Antarctic and Greenland, i.e. warm water reach ice sheets, resulting strong melt of ice sheets. Observations are necessary to understand the processes of melt, such as ships, hot water drilling, ice front moorings, topo sounding, and ice shelf front hydrography. It is difficult to do field data collections in the Polar Regions, thing we have to think of include where to put the stations and what types of instruments to use. As for models, the current ocean models cannot help with SLR prediction, there is a need to rewrite ocean model. CliC can get all the models together to work on this issue. Because of the uncertainly in the model, it is a question if we can predict the sea level changes in the future.

Discussion points: where were the RS data can help to get the geometry of the ice shelves, Where you can observe in the open ocean and where you cannot do much, the melt of sea ice from the top or bottom. There is a disconnection between the SOOS and the SLR research - observation groups. CliC may help to bridge the programs.

Discussion: Towards ice sheet and ice shelf models in future ES Models and the way forward for WCRP SLR research

High resolution topography is useful. Models also need internal layers, bed feature information, and observations in place with fast changes and slow changes. In addition, time series of data is important for model development. While there have been community ice sheet models in CCMs, there is room for improvement. Key questions for future modeling activities:

- What is CliC's role?
- How to link modeling activities with network and operational centres and space agencies?
- Who are the interested parties in observations and products and their application in advanced research of WCRP?
- Identify what the research requires and how to work with the modelling community on ice sheets and ice shelves, including SLR

CliC needs modelers in the SSG (*i.e.* enlarge SSG to include modellers). CliC should bring observations and modeling together, or at least connect the groups. For instance, oceanographers and glaciologists at various centers do not collaborate. These centers are all part of the WCRP family, and we can facilitate building bridges between them. CliC has not used this network as it should have in the past.

While the modelling community is moving forward, is the observation community lagging behind? This is an issue for CliC (*i.e.* how to move modeling research forward). Options for considerations include active participation in the polar prediction workshop in Oct 2010, engage and contribute to WCRP modelling working groups and activities (every WCRP project should have someone from WGCM), and organise workshops and meetings on model inter-comparison.

It is also useful to collaborate with international groups and activities, and to obtain funding from national levels. The SOOS is an international network of ocean observations with a lot of synergy. Ice shelves are part of the SOOS, and many activities are ongoing; CliC needs to identify the key site and region to engage and contribute. Ocean observations and circulation under ice shelves has been recognized as a gap, and it is difficult to have sustained observing. A number of drill holes have been done already, but it is necessary to define an ideal array of temperature sensors under ice shelves as a first step to fill this knowledge gap.

The Marine Cryosphere and Climate

MarC Theme Update for the Arctic

Sebastian Gerland summarized the Arctic MarC activities for 2009. Main highlights were the CliC Arctic Sea Ice Workshop in January and its report, and article in Eos, and the iceplan.org website. The CliC Arctic Sea Ice Working Group is initially focused on improving the coordination of surface-based sea ice and snow observations, establishing protocols for standardizing and archiving data across the different national and international programs, and linking with efforts such as SAON to ensure that functional, sustained observing networks are established for long-term observation and monitoring programs. Current objectives and future activities fro this WG were listed in the presentation, some of which include a web page within the CliC's new site, extend the steering group to cover other regions and nations with sea ice interest, mentioning agenda items for the next working shop, and the planning the IGS International Symposium on Sea Ice in the Physical and Biogeochemical System.

Discussions were mainly on the issues of future activities and directions for this working group and arctic sea ice research. It was suggested for this group to expand into other aspects of sea ice research, such as remote sensing and modeling. The group has interests in modeling and remote sensing of sea ice, for instance, at the Tromsø sea ice workshop, there were model and remote sensing presentations and discussions. This group, however, will invite others to work with them to identify the next steps and long term goals and objectives. More discussions among the group members will be arranged at the IGS sea ice conference in the summer of 2010 in Tromso. CliC understands the major issues and challenges in sea ice research – such as difference in remote sensing sea ice products and inter-comparison of sea ice modeling. These are 2 big ticket items. CliC needs to lead or someone will lead this in the WCRP.

MarC Theme Update for the Antarctic

Tony Worby, provided an update on SCAR activities which included a report on the Antarctic Climate Change and Environment (ACCE), the Southern Ocean Observing System (SOOS), the Science Plan for Ice Sheet Mass Balance and Sea Level (ISMASS) and Antarctica and the Global Climate System (AGS). Parts of the Antarctic are losing ice at a rapid rate, and sea-ice extent has increased around Antarctic in the last 30 years as a result of the ozone hole. West Antarctic could make a major contribution to sea-level rise over the next century. To address these issues, improved representation of polar processes is needed in models to produce better predictions. Higher resolution global models as well as regional climate-, ecosystem-, and ice-sheet-models are required. SCAR sponsors CliC Project and it expects CliC to deliver products; i.e., an annual update to the ACCE document reporting the latest science results; data products; review papers in refereed literature; and white papers.

A white paper was prepared by Tony Worby (appendix X). It was emphasized that integration of observation and model is the key to advance sea ice research. A Working Group was proposed to foster improved dialogue and cooperation between modelers and observers. It is recommended that the committee adopt a regional focus on the Southern Ocean, but be broadly discipline based to include physical, biogeochemical, ecological systems. This will provide a specialist focus for the Southern Ocean modeling and observational communities that would interface with other WCRP groups including the Working Group on Climate Modeling (WGCM) and the Working Group on Model Development (WGOMD). It would also interface with, and contribute to, specialist groups such as the Southern Ocean Observing System (SOOS). SOOS is useful for global fresh water budget analysis, determination of co2 from the ocean, prediction of future sea ice pattern, and impact assessment of climate change on the ecosystem. Gaps exist in the SOOS program due to lack of routine observations, particularly observations in ice-cover regions, over the deep ocean and ice shelves. CliC may have a role to play in the integration of IPY remote sensing and in situ observations and data. CliC needs to work with WCRP and CLIVAR on season prediction of sea ice, and link to other groups and programs, including the SOPHOCLES.

Future Directions in Sea Ice Modelling and Data Assimilation for Global Climate Research, Modelling, and Prediction – Including the Arctic Ice

Participating via the telephone, *Cecilia Bitz* evaluated and compared CMIP3 models and showed results from one CMIP5 model, addressing topics such as the continuum hypothesis, viscous/plastic rheology with elliptical yield curve, subgrid-scale parameterization for ice-thickness distribution, or how these account for internal melt around brine pockets, among others. (Brine pocket modeling is neglected in all but two climate models.) She listed six other factors that modelers are developing that could be included in sea-ice models used for climate studies: 1)/ /anisotropic sea ice dynamics, 2) high frequency dynamics, 3) snow redistribution, 4) prognostic salinity, 5) sea ice biology and gas transfer; and, 6) data assimilation. Names of known people and organizations currently working on these factors were listed.

The questions of weather scientist are confident that better physics give better results was raised. She concluded it appears so, but that some coupled models with good sea-ice model physics have large biases owing to errors in the atmosphere and ocean. Slide illustrated that two models (HADGEM1 and CCSM3) agree very well with the observed 30-yr trend in September sea-ice area and with the mean of the last 30 years. Cecilia showed one in seven ensemble member from CCSM3 had an decade-long upward trend. She cautioned that this suggests it is possible for prolonged periods of recovery, despite the overall high likelihood of very rapid decline and on average sea-ice free conditions by mid-century in the CCSM3 model.

Recommendations: Cecilia recommended that climate modelers should tune their sea ice models better to match the past sea ice climatology, and they should improve sea ice physics -- especially as they move towards Earth System Models -- with a need for sea ice biogeochemistry. She also recommended a new sea ice diagnostic be added to sea-ice models to trace first-year and multi-year ice types. This offers a new means of comparing with satellite data, to compensate for the lack of sea-ice thickness data.

Cecilia pointed out that data assimilation needs to mature rapidly in order to allow for sea ice to be initialized in Arctic climate forecast efforts.

iAOOS, AOSB and Arctic Ocean Issues

Attending as representative of the Arctic Ocean Sciences Board (AOSB), Dr. Dickson first thanked WCRP and CliC project for providing the opportunity to explain some of the main science issues being discussed within AOSB. In particular, their plan to establish a sustained ocean measurement program for Arctic and subarctic seas in the medium-to-long term (years to decades) during the so-called 'legacy phase' of the IPY. This work was an outgrowth of the integrated Arctic Ocean Observing System (iAOOS), originally conceived and sponsored by the AOSB as one of around 110 "coordinated proposals" approved by the Joint Committee for the International Polar Year to optimize the cohesion and coverage of Arctic Ocean science during the IPY. As such, iAOOS is not a funded programme, but is rather a pan-Arctic framework designed to achieve optimal coordination of funded projects during the IPY. Based on the >1150 Expressions of Interest received by the IPY, iAOOS draws its primary focus on Arctic change and on the role of the Northern Seas in Climate.
During the development of iAOOS, it became clear that its scope could not be restricted to the Arctic Ocean. Major studies such as the Arctic-Subarctic Ocean Flux Study (ASOF) have shown that the two-way oceanic exchanges that connect the Arctic and Atlantic oceans through subarctic seas are of fundamental importance to climate; that change may certainly be imposed on the Arctic Ocean from subarctic seas, including a changing poleward ocean heat flux that is central to determining the present state and future fate of the perennial sea-ice; and that the signal of Arctic change is expected to have a its major climatic impact by reaching south through subarctic seas, either side of Greenland, to modulate the Atlantic thermohaline conveyor.

Dr Dickson presented a new Report written jointly for the AOSB and for the Joint Committee of the IPY and edited with the assistance of WCRP which aims to provide a concise description of the development and present state of iAOOS (see http://www.aosb.org/pdf/AOSB-JC.pdf). As such, the Report had three main purposes. Firstly to describe some of the main advances that were made in the difficult business of observing the Arctic and subarctic seas during the special focus period of the IPY. Secondly, to describe some of the main results and new ideas that are still emerging from these observations. And thirdly, to use these results and ideas to make the case for which mix of observations to sustain into the future. The reason for attempting such a forward look is clear. If we are to develop the predictive skills and utility of climate models, we will need to observe, understand and 'build in' a list of processes that are not yet represented realistically (or at all) in climate models. In fact, the list is quite long [p 6 In: *Dickson, Meincke and Rhines (Eds)., Arctic Subarctic Ocean Fluxes: Defining the Role of the Northern Seas in Climate, Springer, 2008, 736 pp*]. It is also clear that it will be the 'legacy phase' of the IPY, sustained over years to decades, rather than the two-year project itself that will develop our understanding of these processes, their changes, their feedbacks and their likely climatic impacts to the point where they can be of practical use to climate models. We can't continue everything; even if we could, it would surely be ineffectual simply to continue to observe the Arctic according to what we *thought* we knew before the IPY. What have we *learned* in the IPY that might help us design its observational 'legacy phase'? At the Arctic Science Summit Week (ASSW) in Bergen in March 2009, the AOSB set itself the task of developing a costed proposal for an integrated, sustained and pan-Arctic observing effort, focused on the role of northern seas in climate, by the time of the post-IPY Conference in Oslo in June 2010. To achieve maximum focus, this plan is being structured around the following three questions:
1) Following the IPY, how would we now define the role of the Northern Seas in Climate?
2) What questions should we be testing to help us understand that role?
3) How should we design an ocean observing system to test these questions?
Dr Dickson's presentation described the present state of this draft iAOOS Plan and finished with two points of general and specific relevance to the CliC SSG. The general point was that since AOSB has now merged with the International Arctic Science Committee (IASC) to become its standing science committee on oceans, and since SCAR, IASC and WCRP now have a Memorandum Of Understanding to promote collaboration and cooperation, all the necessary mechanisms are now in place to promote collaboration on iAOOS or other aspects within the expertise of AOSB. The specific

point was that input to the iAOOS draft plan by CliC and its membership would be warmly welcomed; the draft would not be finalised until the IPY Conference in Oslo in June 2010.
The friendly and favourable response to these issues by the CliC SSG will be reported back by Dr Dickson to the AOSB Board at its SSG meeting in Nuuk Greenland in April during ASSW 2010.

Challenges of Predicting Rapidly Changing Arctic Sea Ice White Paper

CliC led an effort to produce a sea ice white paper fro WCRP. Vladimir Ryabinin, one of the authors of the white paper, presented the main points. His presentation discussed the issues of rapid sea ice change and very different results in model prediction of future sea ice change. Sea ice change is a complex issue. There are many things to observations, such as sea ice area, thickness, and snow on the ice. Models cannot take care of all the important processes and factors. Sea ice variability is large among years, and heat transfer, atmospheric mode affect sea ice conditions. It was suggested to integrate observations and model, including research on sea ice trend attribution, arctic system reanalysis, field project similar to the SHEBA somewhere in the AO. It is also necessary to plan for the longer term, including the promotion of the IPD.
Discussions include the role of CliC in this white paper and the need for the arctic system analysis, as a global reanalysis would also cover the arctic, including AO and sea ice.

Way Forward for Calibrating Ice Climate Products

Walt Meier showed several slides on the subject *Passive microwave sea-ice concentration climate records*. Sea-ice data from space-borne passive microwave sensors provide one of the longest satellite climate records. The 30+ record shows significant declining trends in Arctic sea ice extent, particularly during the summer, and a small increasing trend with strong regional and inter-annual variability in the Antarctic. Sea ice concentrations are derived from the measured brightness temperature – a function of the physical temperature and the microwave emissivity of the surface – using empirically derived algorithms – several of which have been developed over the years. The problem with comparing algorithms is that it is not possible to do basin-scale validation because there is no "truth" data available.

Arriving at a consensus on a general "authoritative" product that can be referenced by the wider community is essential. The need is for a climate data record that includes a standard sea ice concentration field, a data quality field, and associated metadata and documentation to allow for proper use. Input from the scientific community is needed to develop a consensus view, but because there is already a dedicated user community for several products, it is not likely that current products will be discontinued. However, these could be kept as secondary products at a lower level of support and little future development, while the official CDR would be the primary and most visible resource. The "way forward" includes:

- Assure continuity of data – need to convince operational resources that climate needs are important
- Improved inter-calibration at sensor data and product level (e.g., use current sensors as baseline, not oldest sensor)
- Metadata and data quality information
- Develop climate data records
    - Consistent record since 1978 (single algorithm product)
    - "Best possible", taking advantage of improvements in sensors and algorithms through the years

Discussions: There are 2-300 registered data users – only registered users receive updates. We need to think differently – find out who use the product and for what purpose. As we think about future direction of the program, the feed-back mechanism is a role we have to play. ESA has bought into this, setting aside budget to bring in major centers to provide feed-back. Otherwise money invested will be wasted. NSIDC that has good connection with US users, and CliC could be a contact point on the international level.

Discussion on the MarC Initiatives/Plans

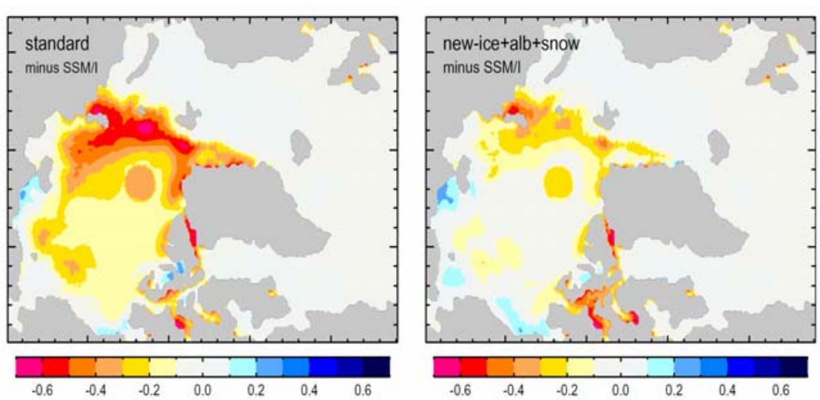
Arctic and Antarctic are very different. Given this, it is necessary for CliC to have 2 leads and 2 groups to cover both poles – Sebastian Gerland leading the arctic group and Tony Worby in charge of the Antarctic group. There is a need for CliC to engage and participate to WCRP working groups.

The Arctic sea ice working group had a successful workshop and produced a surface sea ice observation book. CliC needs to decide and envision the future of this working group, including the focus for future research and the main products from the working group. It is suggested that this group has done well in surface observations of sea ice been for process studies. The surface observations should be useful for cal/cal of RS sea ice data and products. The WG can expand into the RS and modeling of sea ice. The ISG sea ice conference in June 2010 will help to establish this WG, it is important to plan ahead to get right folks together for this working group. To link the activities between the 2 poles, Tony Worby plans to attend the arctic sea ice workshop in June 2010 in Tromos.

There are also ongoing efforts in the Antarctic, although no WG or team yet. SCAR can help in this regard. It is hoped that CliC WCRP funds for the working group.

Forcing of Cryospheric Models by Regional Climate Models

Annette Rinke gave, by telephone, an overview of the status of Regional Climate Models in Polar Regions, including the Arctic and Antarctic. She showed examples of forcing of cryosphere models with Regional Climate Models. These include active layer model for the eastern Siberia, and Greenland melt pattern from three models, the results for Greenland being very different although they are different time periods. There is a need to strengthen the development of coupled models, such as coupled atmosphere-ice-ocean RCMs, the representations of cloud, radiation, precipitation, and boundary layer; the coupling of land surface processes and other component models, such as ice sheet, dynamic vegetation, and hydrology model with river routing schemes.



Coupled atmosphere-ice-ocean RCM (Dorn et al., 2009). Difference “model minus obs.” sea ice concentration, September 1988-2000, HIRHAM (50 km)-NAOSIM (25 km)

Discussions include permafrost modeling in both Regional- and Global Climate Models and their relationship with each other (*i.e*. how much one depends on the other.) Need proposal for intercomparison models and follow-up. This is difficult due to lack of manpower. What is ECRP/CliC’s role in discussion of prediction of Arctic Climate System?

Best practices in organising research, engaging the communities and achieving agreed goals

SPARC Modus Operandi

Ted Shepherd, co-Chair of the WCRP SPARC project (Stratospheric Processes and their Role in Climate), gave a presentation on the 'modus operandi' of the SPARC project, to give some ideas on mechanisms that CliC might use to move forward on key initiatives. He emphasized the critical role of the SPARC General Assemblies in building the SPARC community, and peer-reviewed SPARC reports as extremely valued contributions for assessments and for funding agencies to determine key gaps. Unlike White Papers, such reports can carry significant weight as they are peer-reviewed.

Towards WCRP of the Future

GA briefly spoke about the future of WCRP. He emphasized the need for WCRP and its core Projects to think of 5-10 years in the future, to provide the leadership, and to keep in the forefront of the global climate change research.

Regional Activities

Asia - CliC

Tetsuo Ohata reported Japanese activities and those related with Asia CliC. He discussed the cryosphere data workshop in Lanzhou, China, in March 2009. A group was established and it is working on the data catalog for snow, frozen ground and glacier data over the Asian regions. A telecon was held for this group in November 2009 to discuss progress and future plans.

Other relevant activities include a special session on “Asian Snow-Glaciers and Climate Change” at the AOGS meeting in India summer of 2010. The co-chairs of this session include Ramesh Singh, Tetsuo Ohata, Shichang Kang, and Daqing Yang. More than 30 abstracts have been received for this session, and this will provide a good opportunity to explore collaboration in cryosheric research over the Asian nations.

Japan plans to have the 2nd international Symposium on Arctic research (ISAR) in Tokyo during December 2010. Tetsuo Ohata will play a key role in the organizing committee. CliC may consider co-sponsoring this event. Japan has more interest in arctic research. It will attend in the 2011 Arctic Council (AC) as an observer; it has participated in AC activities, including the SWIPA report. JAMSTEC continues to its collaboration with UAF and IARC.

Chunde Xiao gave a brief update on the cryospheric research activities in China. He mentioned 4 major ongoing projects. These are research projects on cryo change and impact led by Prof. Qin, the glacier inventory project (PI Liu), permafrost change and mapping over the Tibet plateau (PI Zhao), prediction of climate and cryosphere change (PI Xiao). The other activities also include data sharing and dataset development, and research on the third pole environment. Future research in China will cover snow and ice, melt water, and climate change over the China, particularly in the mountain regions.

China will host an international conference, “Cryospheric Change and its Influences - Cryospheric Issues in Regional Sustainable Development”, 12-14 August, 2010, Lijiang. CliC and WCRP are co-sponsors with the IACS, IUGG, and IGBP. CIPO will provide necessary support to this conference, including information distribution, recommendations on invited speakers, and conference report.

South American Perspectives

Gino Casassa provided a breifing of South American activities. VICC 2010 was the biggest conference in South America. He showed research projects on white glacier, rock glaciers, snow hydrology, permafrost, and snow avalanches over the regions. He also talked about South American glacier changes, including the volume and area ice. He proposed to CliC:

- Co-sponsor the Working group on snow and ice - GTNH-IHP
- Sponsor South American permafrost group
- Sponsor the South American cryosphere map (snow, glacier, permafrost, lake and river ice) initiative to update old maps made by USGS

The SSG welcomed the proposals and decided to follow up with necessary actions. IPA can help with into South America research, including tech support to the permafrost map project. WCRP has relationships with many international research programmes and space agencies. WCRP can help with networking and data exchanges. ESA is working on the GlobIce project; it can provide glacier change data. Local glacier info will be helpful for validation of remote sensing products. A workshop to exchange data and information will be useful to generate special issued journals or reports on glacier inventory in South America.

Nordic Council of Ministers top-level research initiative and its subprogramme – Interaction between Climate Change and the Cryosphere

Daqing Yang presented a short update for this agenda item. The Nordic Council of Ministers has a new top-level research initiative – a Nordic flagship. This initiative consists of six sub-programmes:

1) Interaction between climate change and the cryosphere
2) CO2 – capture and storage
3) Integration of large-scale wind power
4) Effect studies and adaptation to climate change
5) Sustainable bio-fuel
6) Energy efficiency with nanotechnology

CliC was invited to collaborate on a joint proposal for the sub-programme on “Interaction between Climate Change and the Cryosphere”. The CliC director participated in a proposal preparation meeting held at the Finnish Meteorological Institute in late January 2010. Here, CliC became a key member of the team on a proposal entitled: Nordic Centre for Sea Ice, Snow and Climate (NORSEC), led by PI Timo Vihma of the Finnish Met Institute.

The proposal team consists of 13 Nordic research institutions, covering a broad range of climate and cryosphere issues. The team members represent institutions with national responsibilities and mandates for climate research (all four met offices FMI, DMI, SMHI, MetNo, and NPI), educational institutions in four countries (UH, UNIS, BBCR, DTU), and existing research centres and institutes (SYKE, NR, GINR). It also includes institutes across Greenland, Norway, Denmark, Sweden and Finland. Membership of CliC ensures a direct link to internationally coordinated climate and cryosphere activities.

The research goals are:

- Better understanding the role of sea ice and snow in the changing northern climate
- Educate 19 young scientists for research in climate and cryosphere
- Combine major Nordic research forces to an internationally strong *Centre of Excellenc*e
- Enhance assessment of climatic impact
- Benefit socioeconomic sphere and improve human living conditions

The first year milestone has been set:

- NORSEC Kick-off Meeting in 2010
- CHINARE expedition in 2010
- Start of the Coordinated Nordic program on sea ice observations in the Arctic
- Joint Nordic Summer School in UNIS 2011
- Coordinated Nordic participation in CryoSat experiment 2011
- RV Lance Expedition in 2011
- RV Polarstern Expedition in 2011
- Field studies north of Greenland / Canada 2011

CliC's role in this collaboration include:

- Enhance Earth system research co-operations in the Nordic region and beyond, and establish an important communication and feedback mechanism between the Nordic nations and the Earth science research community at large
- Evaluate the interests and needs of society and industrial partners in climate and cryosphere changes at regional and national scales
- Collect necessary data and information through professional agencies and survey of representative societal and industrial groups in the Nordic countries. Apply statistical and model approaches to analyze the data and information
- Make recommendations for mitigation and adaptation of cryosphere changes in the Nordic regions

CliC has submitted a budget request of 838,928 NOK to support one PostDoc level researcher or visiting scientist for 3 years at the CIPO, with 50% funding from this proposal.

WMO EC Panel of Experts on Polar Observations, etc

Jeff Key - The WMO Executive Council created a Panel of Experts on Polar Observations, Research, and Services (PORS). The first PORS meeting was held in October 2009. The creation of PORS was motivated, in part, by the International Polar Year. PORS subsumed the existing Working Group on Antarctic Meteorology. J. Key is one of the U.S. representatives to PORS. The WMO Global Cryosphere Watch (GCW) has become a mandate of PORS. A PORS task group has been created in order to define GCW tasks that can be achieved before the next WMO Congress meeting in 2011. It has been proposed that the WMO IPY Space Task Group (STG) be formally re-established within EC-PORS with an updated mandate.

Update on CliC – ESA Cooperation

Daqing Yang and Helmut Rott updated the SSG on ESA-CliC collaborations which has progressed well in the last years. ESA and CliC co-hosted a consultation workshop at the University of Innsbruck in summer 2009. Based on recommendations from the workshop, ESA has decided to create the North Hydrology Project that focuses on river and lake ice in the northern regions. ESA will fund one research project, with EUR 500K for 3 years, to study the freshwater ice and its changes in the Polar Regions. This project will also benefit future goals, including CoReH2O, and the ECV project.

River and lake ice research can also contribute to the AO freshwater budget initiative. The links between the two are strong, but adding this component to the FWB initiative may require more time and effort to complete. There is a great potential to continue and expand the CliC-ESA collaboration into other areas of cryospheric research, such as snow cover, snowfall, and ice sheets. CliC may need to identify research gaps for future research, including snow cover and hydrology models.

WCRP has an agreement with ESA on collaboration, including free data exchange for research. Discussions of future co-operations with ESA continue via WCRP.

Partnerships

Cooperation with IACS

Gino Casassa, representative of IACS, spoke about the common interests between CliC and IACS in research on mountain glaciers. Recent deliverables from IACS include a book on Snow and Climate (2008, Cambridge University Press), and the IHP UNESCO handbook *The International Classification for Seasonal Snow on the Ground* (Charles Fierz, draft, 2009). The former is a result of an earlier working group within IACS predecessors ICSI/UCCS[8]. In addition, the third draft of a Glacier mass balance glossary (Graham Cogley) is accepting comments and will hopefully be published in 2010.

CliC formerly hosted regular Cryo manager teleconferences in the past, and was encouraged to take this up again. The need for a cryospheric dictionary has been discussed by CECS and IACS.

Cooperation with IPA

Vladimir Romanovsky, the VP of IPA, represented the association at the SSG meeting. In his briefing, he emphasized CliC-IPA relations as a high priority. IPA has decided to invite CliC representatives to their meetings. With Vladimir Romanovsky being a CliC SSG member, he can represent CliC. CliC modeling activities need help from IPA. CliC will work with IPA to insert permafrost models into the climate models and also use field observations for model validations over the cold regions.

IGBP Cryosphere Initiative

IGBP is planning a second major international synthesis of key policy-relevant areas within global environmental change research, with a view to providing a snapshot of the state of the Earth. The synthesis topics have been selected by IGBP Scientific Committee with input from key stakeholders, including other international research programmes and the IPCC. The topics cover research under IGBP's core projects, joint projects and beyond. One of topics is the Earth System Impacts from Changes in the Cryosphere (ESICC). Dr. Ray Bradley is the lead of the ESICC. According to his PPT file to the SSG meeting, the ESICC is considering to arranging 4-5 workshops in 2010-2011 to address cryosphere changes and related issues at regional to global scales. It also plans to produce review articles and special issues of journals. CliC recently communicated (in person and via email) with Dr. Bradley about potential collaborations, such as joint workshops and publications. Both sides are interested in working together in the future. The dialogue continues, and CliC hopes to establish close collaborations with the ESICC on cryosphere research. CliC Project is ready to expand and enhance the collaborations with the IGBP and other earth system science research programs, particularly in the areas of societal impacts and mitigation strategies of cryospheric changes.

IARC and CliC – Mutual Interests

Larry Hinzman, Director of the International Arctic Research Centre (IARC) at the University of Alaska Fairbanks (UAF), gave a talk on and CliC and IACR mutual interests. He pointed out that IARC and CliC have many common interests and objectives, and IARC hopes to offer its assistance to help CliC achieve their stated goals.

IARC's mission is to foster arctic research in an international setting to help the nation and the international community to understand, prepare for, and adapt to the pan-Arctic impacts of climate

[8] International Commission on Snow and Ice/Union Commission on Cryospheric Sciences

change. In order to fulfill that mission, IARC will build an integrated science and service program for the benefit of the arctic community. Key elements of that program will be analysis, synthesis and provision of Arctic climate information, including Arctic Ocean hydrographic information for scientists, students, decision-makers, and the public. IRAC provides support and coordination of Arctic System Modelling, by providing a nexus for model validation and assessment and by exploratory development of new component modules. For many research groups, IARC serves as a gateway to Alaskan and other research sites for the arctic research community through international project offices, secretariat functions, and the coordination of targeted synthesis workshops, with special attention to collaboration with international scientists and institutions.

IARC hopes to provide specific services to the arctic community to advance understanding of the Arctic as a system. One service includes a daily update of the Arctic sea ice extent. http://www.ijis.iarc.uaf.edu/cgi-bin/seaice-monitor.cgi?lang=e

IARC is the host of the Science Management Office of the International Study of Arctic Change (ISAC, http://www.arcticchange.org/). ISAC is an open-ended international research program designed to understand the future state of the Arctic System under anthropogenic stress. The driving force behind ISAC is the need to build understanding, improve capacity for predicting Arctic System changes, and develop necessary mitigation and adaptation strategies to minimize the adverse effects of such changes. ISAC facilitates international co-operative efforts to understand the Arctic System and all its components on a pan-Arctic scale. See

Under the leadership of the CliC Program's Arctic Sea Ice Working Group, a workshop was convened in Tromsø, Norway in January 2009, to discuss different approaches of better coordinating Arctic sea-ice field research. This website (http://www.iceplan.org/?year=2009) is based on recommendations and input provided by the more than 30 participants from 13 nations on how to help improve coordinated planning for field-based sea-ice research. Over the next few months, the web site, hosted by IARC) at UAF will be improved based on feedback received to better serve the international Arctic research community.

IARC hosts ten to fifteen workshops each year (http://www.iarc.uaf.edu/workshops/). IARC believes that is a valuable service it can provide to the community and would be happy to consider suggestions for timely and important workshops. IARC is hopeful that CliC will consider co-sponsoring a workshop on trends and projections of sea-ice dynamics. IARC is also willing to provide assistance in establishing an office extension in the U.S.

CliC Plans for 2010 and Beyond

Preliminary Exchange of Views

Koni Steffen opened the discussions and pointed out future key CliC research directions:

- Freshwater budget over the arctic and southern ocean
- Sea ice change in the polar regions
- Role of permafrost and CO2 release
- Regional climate modeling
- Ice sheets in sea level rise

Koni also emphasized that CliC needs to set goals that will be achieved by the next SSG meeting in 2011. CliC should carry out cross-cut research within WCRP and establish panels or working groups to focus on specific research areas and tasks. CliC will arrange and contribute to workshops across WCRP to advance predictions of cryosphere and climate at regional and global scales.

Dr Dickson, representing the AOSB, suggested that three of the themes or developments running through the Valdivia meeting were closely allied to AOSB, when thinking of 'future objectives and initiatives'. First we would endorse the growing need (expressed by Dr. Asrar and others throughout the meeting) to downscale our science and our services. The difficulty is, that although we can't understand global change in the ocean-atmosphere-cryosphere system, except at the largest space and time scales (pan-Arctic; years to decades), we are limited unless we find some way of downscaling the science to the local and regional scales that make sense to people. That difficulty is being overcome (e.g. Shukla, Hagedorn, Hoskins, Kinter, Marotzke, Miller, Palmer and Slingo. *'Revolution in Climate Prediction is both necessary and possible* BAMS 2009 (DOI:10.1175/2008BAMS2759.1).

Second, there needs to be a closer working relation between AOSB and CliC in understanding the drivers and processes of change in the ocean-cryosphere system. Both boards appear to recognize this need, and the current MOU between SCAR, IASC and WCRP provides the formal mechanism by which AOSB and CliC might extend their collaboration and cooperation. Involvement in the current iAOOS plan is just one possible element of that collaboration. Bob Dickson suggested it might be proper, in cases where CliC needs advice in areas of AOSB's expertise, for CliC to direct these issues/questions to AOSB for its consideration. This suggestion was well received by the CliC SSG, and the issue will therefore be tabled formally by Bob Dickson for consideration/endorsement by the AOSB SSG at its next meeting in April 2010.

Third, AOSB interest in designing an effective medium-term ocean observing plan for high latitudes seems similar to the nascent plans for an International Polar Decade that was proposed by the 60th meeting of the WMO Executive Council in 2008. Whether or not this initiative goes ahead, there will be a continuing need for AOSB-CliC to develop a forum to debate long-term research questions as they arise, are tested and alter. Prompted by the CliC Chair to give examples, Bob Dickson suggested that an IPD or an extended iAOOS will be a success if, by their close, we have jointly learned to understand and maybe anticipate the subtle changes in circulation, stratification and mixing across the Arctic Deep basins as the seasonal ice dwindles away.

CliC structure and SSG was also discussed. It was suggested that panel chairs should be the SSG members. Some think that the role of CliC is not very clear in the community, and that it is young and might be too big. It should find its identity and focus on fewer initiatives. CliC has to identify key areas and work on the issues with big impacts, including regional impacts. CliC should set up goals for the next few years and work on the deliverables that greatly increase knowledge. CliC has to connect with other WCRP projects, aiming at prediction of cryosphere. Climate prediction is a major challenge for CliC, and prediction might be too long-term if a goal. Cryospheric processes are already in the earth system research, and there is a need to produce and update state of the cryosphere report.

Summary of discussions

Vladimir Ryabinin provided a summary of the discussion. Main points of the summary and discussion include:

CliC major long-term objectives

- Enabling prediction of the Arctic climate system;
- Enabling prediction of the Antarctic climate system;
- Enabling prediction of terrestrial cryosphere; and
- Enabling improved assessment of the past, current and future sea-level variability and change.

A range of short-term activities will contribute to the achievement of the long-term objectives. They include all the five initiatives that CliC SSG formulated at its Fifth SSG session in Geneva in December 2008:

- Freshwater budget of the Arctic Ocean and Southern Ocean
- Carbon and permafrost;
- Cryospheric input to sea level;
- Hemispheric differences in sea-ice; and
- Regional climate modelling as forcing cryospheric models.

In addition to the planned and ongoing activities, new initiatives have been formulated and leadership commitment has been confirmed from SSG members and other colleagues:

a. Arctic Ocean (AO) freshwater budget (FWB)

Arctic Ocean freshwater budget initiative was proposed by Terry Prowse. CliC has all the relevant expertise for analyzing the FWB: snow, permafrost, sea ice, ice sheet, and river flow to the Arctic Ocean. This is a proposal for the integration and synthesis of new (land and ocean) data and knowledge obtained during the IPY years – to examine and establish a closer link between the land and ocean components of the arctic climate system. There has been interest within CliC, for instance, to quantify the Greenland ice sheet change and melt water contribution to the AO water cycle.

The AMAP SWIPA assessment provides a unique opportunity and synergy to work with other groups and to move this idea forward. CliC needs to identify a champion to lead and promote this initiative. Terry Prowse has developed a short FWB integration document for the SWIPA report that discusses the relevance of all the arctic cryospheric components. The SSG meeting nominated Terry Prowse to lead the AO freshwater budget initiative

This initiative will engage and work closely with cryospheric and ocean groups (such as the AOSB and others) within and outside of CliC. The original proposal of the freshwater budget analysis also includes the Southern Ocean (SO). The WCRP\JSC meeting in Turkey suggests a phased approach for some of our planned activities. CliC may need to consider and discuss the approach for the SO, maybe to put that part as the 2nd phase of the freshwater budget research.

This project, also relating to global observation systems, particularly the SAON and SOOS, has been decided as a key CliC initiative for the next few years.

b. Permafrost ad CO2

The CAPER project and collaboration with the IGBP\AIMES continue. New directions for this research may include an expansion to the continental shelf areas, as well as CO2 and CH4 release from Greenland and the Antarctic. CAPER plans for 2010 includes organizing community workshops and developing science and implementation plans. A CAPER white paper is ready for release, and US NSF funds have been obtained for some research projects. CAPER has a team of 6 colleagues co led by Vladimir Romanovsky Kathy Harber. This project remains as one of the key initiatives for CliC.

c. Regional modeling - support to the ASR

CliC will invite M Serreze, D Bromwich, and J Walsh to lead this group. Proposed research approaches and tasks are the CMIP5 diagnostic subproject, including the ARctic Climate HIndcasting, Modelling, and PrEDiction ExperimentS (ARCHIMEDES).

d. Artic and Antarctic sea ice

Continue to support the existing arctic sea ice working group led by Sebastian Gerland since early 2009. SSG encourages this group to continue its effort and to focus on AO sea ice observation, model, and predictions. SSG suggests enhancing the research on sea ice modeling and remote sensing (*i.e*.

group should engage and include modeling and remote sensing experts, and work with other groups, such as the AOSB, on IPY data analyses).

CliC collaboration with the AOSB. This will link CliC sea ice research with the AOSB work on the role of Northern Seas in the climate system, specifically a project and collaboration on Arctic and sub-Arctic Ocean data synthesis. A proposal from CliC is necessary for this activity. It has not been discussed who will lead this proposal.

A new initiative on the analysis and assessment of remote sensing sea-ice products. This will be led by Walt Meier and Walled Abdalati. They will establish a team for this task and collaborate with space agencies and the user communities.

Arctic sea ice change and prediction are also the hot issue for WCRP. In 2009 JSC tasked CliC to lead a white paper on sea ice research and the way forward. The white paper has been done and discussed at the SSG and JSC meetings.

Establish the SO ice working group, led by M Rafael. This group will continue the development of Southern Ocean Observing System. In addition, reinvigorating the Southern Ocean Physical Oceanography and Cryosphere Linkages (SOPHOCLES) initiative, also the SO TIP, SOOS, led by Tony Worby.

e. Mountain glacier and water resources changes

The SSG decided to have Mountain Glacier and Water Resource Changes as a new CliC initiative, to be co-led by Helmut Rott and Gino Casassa. This project will engage and work closely with other regional activities, including Asia CliC and the Cold Region Hydroclimatology Project (GEWEX), to assess freshwater resources related to glacier changes in various mountain regions.

CliC will continue to support regional activities, such as Asia-CliC, and will also encourage and facilitate cryospheric research projects and collaborations in other regions, including South America, Alaska, and the Nordic countries.

f. Sea level rise (SLR), including ice sheet modeling

CliC has assumed the coordinating role of the WCRP research on sea-level rise. This will be organized by the WCRP/IOC Task Group on Sea-Level Variability and Change. CliC will continue its research through observation and modeling, to quantify the terrestrial cryosphere changes, including the dynamics and mass balances of ice sheets, and the role of ice shelves in sea level change. CliC will also work with the GEWEX and IHP of UNESCO on the determination of land water storage change over time. Walled Abdalati will serve as the theme lead for research on cryospheric input to SLR. A working group for this initiative will be assembled to work on the dynamics of ice sheets, addressing aspects of both modeling and observation. Dave Holland will lead the ocean ice modeling research, including ice shelves modeling and impact to the SLR.

Project Coordination and support

Project Coordination of the new initiatives is necessary to achieve the goal of climate and cryosphere prediction. A very direct and clear message from the WCRP Director is that project coordination is the function of the CIPO, not WCRP via JPS. WCRP will provide necessary funding support to the new initiatives, and CliC will decide how to best use the funds.

Concluding Part of the Session

CliC SSG-VII, Venue and Dates

Next SSG meeting location and date have been discussed. Several potential hosts have been identified.

SSG Membership

Executive committee met in a closed session to discuss SSG membership and necessary changes. An update will be provided to the SSG members in the future.

Session closure

CliC SSG-6 was closed by its Chair Koni Steffen on 9 February 2010 at 1430.

Appendices

Appendix 1
Agenda

Appendix 1: Agenda of CliC SSG-VI, Valdivia, Chile, 6-9 Feb 2010

Day 1, 6 February 2010, Saturday

Item	**begin**	**Duration/end**	**Topic**	**Speaker / resp.**
1.	0900	15'/0915	Opening, welcome remarks	
			Opening remarks	K. Steffen (KS)
			Round of self-introductions	All
			Welcome by CECS	Representative of SECS
			Adoption of agenda	KS
			Logistical information	G. Casassa (GC)
2.	WCRP Update and Message to CliC, CIPO Update			
2.1	0915	30'	WCRP / WCC3 / GFCS update and what WCRP expects from CliC	G. Asrar (GA), V. Ryabinin (VRy)
2.2	This item postponed to 1620 (IASC/SCAR) - Telecon			
2.3	0945	10'	CIPO Report	D. Yang (DY)
2.3	0955	10'	Expected outcomes of this SSG meeting	KS
2.4	1005	15'	Discussion	All
	1020	**25'/1045**	**Coffee**	
3.	WCRP prediction and assessment activities			
3.1	1045	25'	SWIPA – update, actions required	KS+TP+S. Gerland (SG)
3.2	1110	30'	WCRP seasonal, decadal, long-term prediction experiments, update on WGCM, CMIP5 and relevant CLIVAR activities	J. Hurrell (JH) – **TELECON**
3.3	1140	25'	WCRP Polar Workshop and Initiative	T. Shepherd (TSh), VRy
3.4	1205	20'	Cryospheric issues in IPCC AR5	KS
	1225	**60'/1325**	**Lunch**	
4.	The Terrestrial Cryosphere and Hydroclimatology of Cold Regions (TCHM)			
4.1	1325	10'	THCM Introduction and Update	T. Prowse (TP)
4.2	1335	25'	The role of carbon and permafrost in the climate system, CAPER, CliC Initiative	V. Romanovsky (VRo)
4.3	1400	25'	Cold region hydrology & climate research/modelling including lake- & river- ice issues	L. Hinzman (LH), TP
4.3	1425	25'	Cryospheric inputs to the Arctic and Southern Ocean freshwater budgets – CliC Initiative	TP
4.4	1450	15'	Snow and climate research	VRy
	1505	**25'/1530**	**Coffee**	
4.5	1530	20'	Solid precipitation activities and proposals	D. Yang (DY)
4.6	1550	30'	Permafrost (schemes) in climate models	VRo
2.2	1620	20'	Expectations from IASC and SCAR	V. Rachold, T. Worby (TW) - **TELECON**
4.7	1640	30'	Alpine Cryosphere – review of activities	M. Zemp + GC
4.8	1710	30'	Towards prediction of the terrestrial cryosphere and water reserves of cryospheric origin	Discussion by All, led by TP, to be initiated by VRy
		1740	**Good night**	

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Day 2, 7 February 2010, Sunday

Item	Begin	Duration/end	Topic	Speaker / resp.
5.	Sea-Level Rise (SLR) and Cryosphere			
5.1	0900	30’	WCRP/IOC Task Group on Sea-Level Variability and Change and CliC “Ice Masses and Sea Level Theme” – issues	KS Waleed Abdalati
5.2		30’	Modelling - ice *sheet*s	C. Hulbe (CH)
5.3		30	Modelling - ice *shelves*	D. Holland (DH)
	1030	**30’/1100**	**Coffee**	
5.4	1100	20’	Discussion: Towards ice sheet and ice shelf models in future ES Models	All, led by CH and DH
5.5		20’	Discussion: way forward for WCRP SLR research	All, led by KS
6.	The Marine Cryosphere and Climate (MarC)			
6.1	1140	30’	MarC Theme Update for the Arctic	S. Gerland (SB)
6.2	1210	30’	MarC Theme Update for the Antarctic	TW
	1240	**80’/1400**	**Lunch**	
6.3	1400	35’	Future directions in sea ice modelling and data assimilation for global climate research, modelling and prediction - including the Arctic Ice issue	C. Bitz - **TELECON**
6.4	1435	40’	iAOOS + AOSB, Arctic Ocean issues	R. Dickson (RRD)
6.5	1515	30’	Challenges of predicting rapidly changing Arctic sea ice (Group) – White Paper	VRy, TW, RRD, SG
	1545	**30’/1615**	**Coffee**	
6.6	1615	30’	Way forward for calibrating ice climate products	W. Meier and VRy
6.7	1645	30’	Discussion on the MarC initiatives / plans	All, led by SG and TW
6.8	1715	15’	CliC WG on Arctic Ice	SG
6.9	1730	20’	Update on Arctic System Reanalysis and CCSM Polar Climate WG	TBD
6.10	1750	20’	Forcing of cryospheric models by regional climate models	A. Rinke - **TELECON**
6.11	1810	20’	Discussion on the prediction of the Arctic climate system and role of WCRP and CliC in it	All, led by KS, DY, VRy TP, SG
		1830		

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Day 3, 8 February 2010, Monday

Item	**Begin**	**Duration/end**	**Topic**	**Speaker / resp.**
7.	CLIVAR and SPARC functions and governance: best practices in organising research, engaging the community and achieving agreed goals			
7.1	0900	20’	SPARC modus operandi	TSh
7.2	0920	20’	CLIVAR modus operandi	TSh for JH
7.3	0940	20’	Towards WCRP of the future	GA
8	Regional Activities			
8.1	1000	15’	Asia – CliC	T. Ohata (TO) & C. Xiao
8.2		15’	South American Perspectives	GC
8.3		15’	Nordic Top-level Research Initiative and its subprogramme “Climate Change Interaction with the Cryosphere”	DY based on input from TRI staff
8.4		15’	WMO EC Panel of Experts on Polar Observations, Research and Services - 1st Session	JK
	1100	**30’/1130**	**Coffee**	
9.	Cryospheric Observations, Data and Information Issues			
9.3		15’	GCOS Implementation Plan – new edition	VRy
9.1		10’	WOAP Update	J. Key (JK)
9.2		25’	CryOS, plans for future	JK
9.4		20’	International Polar Year Legacy, International Polar Decade, GEO Work Plan Subtask on IPY Legacy	VRy
9.5		15’	IPY Space Task Group and GIIPSY - to adopt by CliC?	JK
	1255	**65’/1400**	**Lunch**	
9.6	1400	25’	Global Cryosphere Watch	JK
9.7		15’	Update on CliC – ESA cooperation	DY, Helmut Rott (HR)
9.8		20’	Future of CliC data management and fate of the ACSYS datasets	DY
9.9		30’	Discussion on observations, products & data management	All
10	Partnerships			
10.1	1530	10’	Cooperation with IACS	TBD
10.2		10’	Cooperation with IPA	VRo
10.3		10’	IGBP Cryosphere Initiative	VRy based on input from R. Bradley
	1600	**30’/1630**	**Coffee**	
10.5	1630	20’	IARC and CliC – mutual interests	LH
10.6		10’	NPI “Ice, Climate and Ecology” Centre and CliC – mutual interests	SG, DY
10.7		10’	Voluntary updates on other relevant issues and discussion on cooperation	All
11.	1710	20’	CliC website and Newsletter	T. Villinger/DY
		1730		
12.	CliC plans for 2010 and beyond			
12.1	1730	30’	Preliminary exchange of views	All led by KS
		1800		

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Agenda

Day 4, 9 February 2010, Tuesday

Item	Begin	Duration/end	Topic	Speaker / resp.
12.	CliC plans for 2010 and beyond – cont.			
12.2	0900	30’	Proposed CliC objectives & initiatives for 2010-2011	DY
12.2		45’	Required CliC structure, working groups, rapporteurs, representation on other bodies	KS+DY+VRy
12.3		30’	Commitments, expressions of interest by SSG members	All led by KS
	1045	**30’/1115**	**Coffee**	
12.4	1115	30’	Proposed meetings in 2010 and 2011	DY
12.5		30’	CliC beyond 2011 – discussion	All led by KS
		1215		
13.			Closure of the open session	
13.1	1215	15’	CliC SSG-VII, venue and dates	
13.2		10	Concluding remarks	KS
		1240		
	1240	**80’/1400**	**Lunch**	
14.	Closed Session			
14.1	1400	45’	SSG Membership	
14.2		?	AOB	
		1445?		
			Meeting of CliC Executive	

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Appendix 3: Our Way Forward: Letter to CliC SSG Meeting - VI

The main goal of this letter is to help you maximise the positive output of the forthcoming meeting. Please read it even if you are not able to come to Valdivia - your input is important for the success of the SSG. Please do send your comments on this letter, slides or write-ups that will be posted on the SSG website and shared with others. It is particularly important that we hear from those who are unable to come to Valdivia.

At the moment you will find there the meeting agenda, this letter, WCRP Implementation Plan (IP) and Achievement Report. Very soon we will post on the website other documents for the meeting including a list of participants and some white papers. They will not be available at the session in hard copy, so please print them if you wish to read them on paper and have with you during the long flight and at the meeting.

The main message of WCRP and the CliC Executive to the CliC SSG and community at large is that the new developments at the WCRP require a change in CliC. One of the major requirements for climate science is now to provide a foundation for the development of climate services. WCRP is moving ahead on several key directions, focussing research on the anthropogenic climate change, climate extremes, sea-level variability and change, decadal and seasonal predictions, monsoons, and some other areas. CliC has not been delivering strongly on all these directions.

This is not to say that CliC has been unsuccessful. We have managed a lot: the IGOS-Theme on Cryosphere, many great IPY projects, huge promotion of the cryosphere, which is now high on the research agenda in the world, solid plans for polar and cryospheric research for climate – to name just few achievements. We wish to thank the previous CliC leadership for that, especially Barry Goodison. However, it is widely accepted now that the project has to refocus more towards producing more input into WCRP modelling and prediction research.

In 2009 we prepared the CliC IP for the years 2010-2015, which was used as a contribution to the WCRP IP 2010-2015. To a great extent, the CliC IP was based on the previously existing implementation considerations and on the five initiatives that the CliC SSG agreed in Geneva in December 2008. The reviews of the CliC IP by JSC were positive (except one) but none of the reviewers expressed a major excitement about our intentions. WCRP is the leading research program in the world that has the pedigree of addressing key issues in climate science. CliC has to address few but *important issues* of the modern climate science that are linked to the cryosphere and do them well, with full commitment of the SSG Members and the community to the identified activities.

In Appendix to this letter, we summarised what we think is expected in terms of science from CliC by the WCRP and the broader climate community. The list is not complete nor do we claim that this is the truth in its last incarnation. This paper and Appendix to it serve only as the initial basis for a discussion at the forthcoming CliC SSG meeting in Valdivia, in streamlining and focusing our way forward. The agenda of the SSG is oriented towards delivering on the issues indicate in Appendix. Please comment on the Agenda and feel free to propose amendments to it.

How do we see the meeting going? We will review the CliC Themes focussing on our agreed Initiatives and the key areas of science delivery specified in the Appendix. Please consider these areas, and take part in the discussions. If we agree on the goals, we will then do our best to discuss how to achieve them. Personal interests and commitments of members will be sought. We would need to define who to invite to CliC SSG and groups and how to organise the Project its working bodies. May be we will need to restructure the SSG. Even if we cannot agree on all details, we will at least have to agree on the way forward and continue to plan activities after coming back from Chile.

Appendix 3
CliC: Future Directions

The SSG is ending on 9 February 2010, and already on 15-19 February 2010 a meeting of the WCRP Joint Scientific Committee (JSC) will be held in Antalya, Turkey. CliC will have to report to JSC and seek its advice and guidance on the way forward.

On the CliC SSG agenda, against various items, you will see names or initials of various participants. Some talks will be given in remote mode. If you see your initials against an agenda item, then you are expected to report on it, alone or in a group, or lead the discussion periods. Please prepare your talks and suggestions on way forward. We do not really want a lot of reporting at the SSG. Please try to be forward-looking and focus on gaps in knowledge and science, on how to cover them, scientifically and methodologically, how to find resources and interested talented people to address the identified challenges, who (projects, groups, experts) can be a partner in achieving the goals. Please contact all people involved in the item as a group and agree on your roles.

Please send us your comments and suggestions, reactions on this letter, populate the Session website with your materials, and be very active at the Session.

We wish you a safe and comfortable travel to Valdivia.

Yours sincerely,

The CliC Executive Committee
Konrad Steffen, Vladimir Ryabinin, Daqing Yang

Future Directions Appendix

Important cryospheric issues on the climate agenda**:**

1. ***Prediction of sea-level rise (SLR)***
    a. Taking into account all contributing factors in SLR assessments so that the society would be able to see the SLR growth curves corresponding to the various emission scenarios.
    b. A key is requirement to include verified representations of ice sheet dynamics in the models. There are several activities underway by several research groups, panels, and funding agencies, but an overall coordination is lacking. Apart from the summer school in Portland in August 2009, there is no significant progress in modelling that would be associated with CliC efforts.
    c. The SLR from glaciers is ~65 cm total by 2100 according to new studies. A glaciers and ice caps prediction and assessment is required to adequately take this factor into account for SLR prediction.
    d. We need to find ways of assessing water storage on land through cross-cuts with other WCRP projects.
    e. We assume that CLIVAR will be successful in predicting the contribution of the ocean water thermal expansion to SLR, probably also on decadal scale, which will be essential also for representing the geographical variation of SLR.
    f. The WCRP sea level rise "cross-cut" is expected to be supported by CliC. John Church and Konrad Steffen are Co-Chairs of the WCRP/IOC Task Group on sea level. The Group will arrange several activities and meetings this year and participate in the IPCC "Sea level and ice sheet instabilities" workshop in Malaysia, June 2010.

2. ***Availability of water - a key issues for the world in this century***
    a. Prediction of cryospheric sources of water is becoming a key requirement. The major problem is that regional climate predictions, especially decadal, are not in place, and existing predictions are largely global. But we need predictions at the scale of large glaciers (*i.e.*, not more than several km or better).
    b. There are two communities who need to work together on this issue. WCRP with its modelling community should move ahead on regional and decadal/centennial climate prediction. The CliC/WGMS/IPA community and national partners should work on preparing for massive prediction of cryosphere, *i.e.* permafrost, snow cover, and glaciers. Downscaling climate projections to the resolution required for forcing models for cryospheric elements is an essential issue.
    c. Calibrated part of this study output could be used to estimate the mass balance change of glaciers and to estimate SLR contributions from glaciers and ice caps. CliC could start this initiative, and/or provide the glue between modelling groups and cryospheric communities.
    d. Partnership (eg WGMS, GLIMS) are essential for this activity.

3. ***Future of the multi-year ice in the Arctic Ocean***
    a. The predictions in IPCC AR4 were too conservative and underestimated the loss of ice. At present, the SEARCH Sea-Ice Outlook works on predictions on monthly- and seasonal scales.
    b. Significant decadal and multi-year variability in the Arctic and heat transport from Atlantic and Pacific to the Arctic Ocean are not well understood despite they are crucial for the prediction of the future sea ice cover. Furthermore, ice-atmosphere interaction and feedbacks are poorly quantified.
    c. Prediction of sea ice in the Arctic requires modelling and prediction of the whole Arctic climate system. There is some preliminary commitment from a few individuals to contribute to it. But it has to be initiated, all key players should be asked to agree to participate, and a White Paper must be written on the way forward.

d. The absolute record of minimal ice cover in the Arctic (during the satellite observations) era took place during the IPY. Due to Arctic IPY activities there is a better coverage of the Ocean with observations and there were some good SAR data. We have an unprecedented dataset to work with and tune the models.

e. It may well be that we have to reconsider the initiative on “Changes and feedbacks in Arctic and Antarctic Sea Ice”. Links with modelling community are key for achieving a success in this area of research.

4. A joint project with GCOS/GOOS WG on SST and Sea-Ice

a. An effort is required to validate and calibrate satellite estimates of the Arctic and Southern Ocean sea-ice area/cover. It can be a contribution to Global Cryospheric Watch (GCW). The International Ice Charting WG has agreed to participate at a level of individual scientists and some leading world experts agreed to move ahead on this subject. They are in position to propose a way forward for calibrating PMW sea-ice concentration based data products.

5. Carbon and Permafrost (CAPER)

a. The work is progressing.

6. Freshwater Initiative

a. This initiative should be considered as an early building block towards a set of activities aimed at the multi-disciplinary prediction of polar regions such as those required to address the problem of predicting the Arctic sea ice for decades ahead.

b. An analysis of all components of the water balance in the Arctic is needed for better understanding of the multitude of governing processes, defining key processes in the region and validating and constraining models.

7. Solid precipitation

a. This proposal could be a part of the freshwater initiative. Estimating biases and errors associated with several measurement techniques is needed to improve P-E estimates. What seems necessary is to target the work on contributing to the bigger picture. Probably, it should result in a CliC Assessment of Solid Precipitation in the Arctic, a peer-reviewed report to be used in a variety of applications. Preparation of this report should not take more than 2 years.

8. Polar Initiative

a. WCRP is organising a pan-WCRP workshop on polar climate. It will focus on interactions of the various components of the polar climate system, from the ocean through the troposphere to the stratosphere. Attention will also be paid to the teleconnections with low- and mid-latitudes.

b. A key objective of the workshop will be to examine climate predictability in the Polar Regions on a range of time scales. Some scientists are pessimistic about the possibility of developing meaningful meteorological predictions for the high- and even mid- latitudes for time scales exceeding several months.

c. The pan-WCRP Workshop will also review asynchronous relations between climate variables that have a polar-, mid-latitude or extratropical manifestation an account of which might contribute to improved climate prediction skills from monthly- and seasonal- through yearly- to decadal-time scales.

9. ***Cryospheric modelling and cryospheric modules in leading climate models***

a. The representation of the cryosphere in climate models is moving ahead slowly and with great difficulty. The cryosphere is almost “the second priority”. We were not able to ensure significant progress in models used for AR5. There is a divide between CliC and WGCM communities. We should start a systematic dialogue with the modelling community, bridge the gap and find a way to help cryospheric science to find its way to climate models.

b. We could start by preparing a review of cryospheric modules in modern climate models and associated problems. Possible contributors could be: Diana Verseghy for land, Cecilia Bitz for sea-ice, Annette Rinke for coupling and Jens Christensen atmosphere, John Pomeroy for snow, Vladimir Romanovsky for permafrost, Ayako Abe-Ouchi for ice sheets, David Holland for ice shelves, and , Terry Prowse for cold region hydrology. A modeller for solid precipitation should be identified.
c. We need to show that without a significant progress in representation of these processes the biases and errors in climate models will be high.

Appendix 4: Southern Ocean Sea-Ice Working Group discussions

Tony Worby, Australian Antarctic Division and Antarctic CRC

Rationale

Over the Southern Ocean, sea ice extends from the Antarctic continent to as far north as 55N in winter and retreats to the continental edge in summer. This ice has an important influence on global climate as it moderates the flux of energy between the ocean and the atmosphere, reflects a significant percentage of the solar radiation that falls on it and redirects surface ocean currents. Additionally, the ice and ocean support unique bio-geochemical and ecological systems that are of global importance. Currently, the Antarctic and its surrounding ocean are undergoing substantial changes generally associated with global climate change. These changes, and our understanding of them, are not as clear as appears in the case of the Arctic Ocean. Future changes are expected to have substantial impacts on the physical, ecological and bio-geochemical systems. Clearly there is a need to understand both the current state of the system and to predict potential change.

More and more, prediction relies on climate models, large and small scale, statistical and fully-coupled climate system models. These models have shown steady improvement over time due to increasingly better computer processing capabilities, better understanding of the physical processes and better datasets for model evaluation and validation, among other factors. Despite these improvements, significant limitations remain, particularly at the high southern latitudes. Significant differences exist between what is simulated and what is observed. Current sea ice models generally treat ice as isotropic when in fact the main observational features are anisotropic leads and ridges. Also equations are typically solved using Eulerian methods that generate numerical errors as the transport equations for sea ice parameters related to sea ice thickness are being solved (*Reference*). IPCC models have large systematic biases between the simulated mean and observed SST of the Southern Ocean (*Reichler and Kim, 2008 BAMS*). IPCC models are able to replicate the annual cycle of sea ice but their representations of sea ice extent, thickness and variability are significantly different from that which is observed (*Holland and Raphael, 2006*).

Understanding how polar sea ice responds to global change is critical if we are to make accurate predictions about the Earth's future climate. Robust predictions require a sound physical understanding of decadal-scale climate processes and phenomena. Thus, climate models should produce correctly not just the means of variables of interest but also the extremes and other measures of natural variability. Additionally, our models should be capable of simulating changes in statistics caused by relatively small changes in the Earths energy budget that result from natural and human actions.   *One reason why these discrepancies exist is that there remains a lack of understanding of some key physical processes and they remain poorly quantified.*

All of this begs the question how do we improve our climate predictions? Rind (2008) answers this quite succinctly - "*Real progress will be the result of continued and newer observations along with modelling improvements based upon these observations*." The pressing need for model improvement is recognized by major climate organisations. The US Climate Change Science Program was quite clear about this need in its recent (2008) assessment of the strengths and limitations of climate models. More recently, WCRP has distributed a questionnaire to the science community, designed to address model improvements. Several of the questions address directly and indirectly the relationship between the modelling and observation community. There is the suggestion that improved connections between these communities would have a positive impact on model improvement.

Implicit in the foregoing paragraphs is the recognition/acknowledgement that those who model and those who observe need to develop a closer working relationship. There is a clear and increasing need to develop a coordinated approach that advances our understanding of climate variability in the Southern Ocean with the overall aim of improving the representation of the Southern Ocean (and all that that means) in climate models. This necessitates cooperation among modelling and observational groups with the aim of developing databases and metrics to inform climate models. We note here that such cooperation has the potential of benefiting not only the models. For example, Timmermann *et al.* (2004) show that model analysis of seasonal variability allowed the identification and reduction of bias in the climatological ice thickness in ASPeCt data.

Based on the preceding arguments, we propose that a Working Group be formed to foster improved dialogue and cooperation between modellers and observers. It is recommended that the committee adopt a regional focus on the Southern Ocean, but be broadly discipline based to include physical, biogeochemical, ecological systems. This will provide a specialist focus for the Southern Ocean modelling and observational communities that would interface with other WCRP groups including the Working Group on Climate Modelling (WGCM) and the Working Group on Model Development (WGOMD). It would also interface with, and contribute to, specialist groups such as the Southern Ocean Observing System (SOOS), by informing discussion about observing requirements and optimal network design, and with the Cryosphere Working Group within the International Society for Photogrammetry and Remote Sensing.

Potential Objectives and means of Achievement:

Establish closer working relationships between the modelling and observing communities. Identify and categorize the connecting issues between observers and modellers. This requires a workshop.

Identify the needs of the modelling community with respect to Southern Ocean data. This could be done via questionnaire developed at the Workshop and would include discussion of the following:

- That in large scale climate models the inherent problems arise from the fact that grid size is too large to capture smaller scale processes e.g. ocean-atmosphere flux, ice-atmosphere flux, convergence and divergence of ice leading to ridging or polynyas, sea ice thickness etc. Measurements – point and areal – would provide information to improve the necessary parameterization for modelling at this scale. At the smaller scale, knowledge and availability of observations – surface mass balance, ice dynamics – is key.

- Sea ice properties to be considered - ice extent, ice concentration, ice thickness, snow depth, ice motion, and ice albedo. Also structural, chemical and thermal properties of the snow and ice. These data are required to derive forcing and validation fields for climate models

Identify/Inventory current observed data – what they are (variable, resolution, accuracy) where they are located, contact details; these would be the data that models need for parameterisation and validation. Include caveats concerning these data. This requires personnel.

Determine whether current and planned observing systems are adequate to initialize models for decadal predictions. This can be determined at the workshop.

Convey information to modellers on detailed aspects of sea ice to help formulate the physical equations etc. used in the models – advances in understanding of sea ice unique to people who closely study the ice. This can be done using a variety of means including wikis, web pages and at meetings.

Determine in turn how the interaction between modellers and observers will also bring insight to the observing community. Addressed in discussions at the workshop.

Potential Deliverables – these should be the outcome of the above Objectives:

1. If objectives are met we will have established a means of communication between the climate modelling and observation communities that will pave the way for improvement of climate models and improvement of observations.
2. Online databases of observed data with clear (and distributed) directions for access. These online databases would be in compliance with CF-metadata standards and the data would be structured similarly to CMIP data model output. This would emerge from an examination of the list of requested CMIP5 model output – the fields, sampling intervals, resolution – with the aim of providing observed “validation” data that are similar (*i.e.* model ready).
3. Clear guidance on the limitations of the observed data and the relative merits of different alternative datasets.
4. Publishable papers arising out of collaboration among observers and modellers.

Potential People

We have identified a number of people who possess the skills that are needed for the proposed committee and who are interested in doing such work.

The people serving on this Working Group must have skills/interests in measuring and modelling the ice, ocean, and atmosphere. We need strong representation of people who model because they would, arguably, have a clear idea of what the models need to do a creditable job of representing the Southern Ocean. Equally important would be those who measure, directly at the surface and remotely (satellite). They would be better equipped to understand the local scale surface processes. Committee members need to have time to commit to generating gridded data products, documenting them and making them publicly available. Initially, a core group of 12 people would be ideal, with 4 each representing the modelling, observational and remote sensing communities. Additional invited experts would be invited to attend on an ad hoc basis to ensure a solid array of expertise is present at meetings.

Sea-Ice Panel

Modelling

- Marilyn Raphael – Large scale modelling, USA – ***Interim Chair – Chair to be chosen at first meeting of the committee.***
- Martin Vancoppenolle – smaller scale modelling, measurements, http://www.astr.ucl.ac.be/index.php?page=vancop%23HomePage France

Remote Sensing

- Stefan Kern - Remote Sensing - http://www.ifm.zmaw.de/mitarbeiter/dr-stefan-kern/ University of Hamburg
- Thorsten Markus – Remote Sensing http://www.acecrc.sipex.aq/access/page/?page=48 NASA-Goddard
- Katherine Giles – Remote Sensing http://www.acecrc.sipex.aq/access/page/?page=113 United Kingdom
- Walt Meier, NSIDC- Remote sensing, with observation interest

Observations

- Ted Maksym – sea ice BAS emak@bas.ac.uk;
- Sharon Stammerjohn - measurements/modelling interest: sstammer@ucsc.edu http://oceansci.ucsc.edu/faculty/stammerjohn.html
- Sebastian Gerland, NPI and CliC/MarC liaison
- Tony Worby, AAD and CliC/MarC liaison

Appendix 5: CliC International Project Office (CIPO): Annual Report

December 2008 – January 2010
Daqing Yang, Director
Tordis Villinger, Coordinator

1. Overview

The CliC International Project Office (CIPO) mission is to support the CliC Scientific Steering Group (SSG) and the World Climate Research Programme (WCRP) in implementing the Climate and Cryosphere project. Specifically, CIPO coordinates and facilitates CliC research activities across the CliC themes, working groups, panels, regional and national cryo programs and projects. CIPO oversees the implementation of recommendations from WCRP and CliC SSG, and plays a central role in the outreach of CliC and WCRP through website and newsletter publications, and organisations of relevant science workshops and conferences. CIPO also provides an interface between CliC and other WCRP Projects, and international earth science research programs, including the space sciences.

2. CIPO Objectives and responsibilities

- Provide direct support to the WCRP on all aspects of CliC and its implementation
- Support the CliC SSG, its co-chairs, and theme leads
- Coordinate and support activities among CliC working groups, panels, and regional\national programs
- Report and assist others to report CliC activities to international bodies and government agencies
- Implement an active outreach program for CliC, *i.e.* website and update, newsletter, and other publications as appropriate
- Represent CliC at scientific conferences and other international forums through scientific presentations and exhibitions
- Facilitate the development of cross-cutting activities and the linkages of CliC with its host institution and other programs, including the IPCC, ESSP, and Arctic Council AMAP SWIPA assessment
- Prepare and publish meeting reports and other documents of relevance to CliC and WCRP
- (Co)sponsor and (co)organise workshops, meetings, and EGU\AGU sessions relevant to CliC and cryo research community
- Host and co-host visitors at NPI and ClPO
- Seek funding support for the CIPO through joint proposals and other collaborations

3. Funding and staff

The NPI Norwegian Polar Institute (NPI) supports the CIPO. The funds from NPI include salaries, travel, and office expenses. In-kind support includes office space, office supplies, photocopying, and communications (phone/fax, postage, and internet connections). Total budget for 2009 was about 240K USD, including a one-time additional support of 14K USD. The standard support is highly likely to continue for several more years. The Norwegian Polar Institute's support of the CliC project office is gratefully acknowledged.

CIPO staff includes: Daqing Yang, CIPO Director (80%), Tordis Villinger, Office Coordinator (100%), and Calista Morrison, Intern (Oct 2009 through Mar 2010). The intern placement at CliC has been funded by IPY and facilitated by the Circumpolar Young Leaders Program of the International Institute for Sustainable development based in Winnipeg, Canada.

There is a continuing need for additional long-term, full-time staff for the office in Tromsø, Norway.

4. Workshops and meetings

a. CliC workshops

- CliC Arctic sea ice workshop, NPI, Jan 2009
- Asia cryo data workshop, Lanzhou, Mar 2009
- ESA consultation workshop, Innsbruck, Jun 2009

b. CliC (co)sponsored workshops and conferences

- Mountain glacier conference, NPI, June 2009 (K Steffen\CIPO)
- NRB, Aug 2009 (T Prowse)
- NEESPI and CEOP HE WS, Aug 2009 (D Yang)
- Tarim river basin climate and hydrology workshop, Sept, 2009 (C Xiao)
- IPY International Early Career Researcher Symposium, APECS, Dec 2009 (C Morrison)
- AGU cryo reception (K Steffen\G Asrar\V Ryabinin\D Yang)

c. Future meetings

- 31st session of the Joint Scientific Committee for WCRP, Feb. 2010, Antalya, Turkey (K Steffen\V Ryabinin\D Yang)
- ESA cold regions hydrology, Innsbruck, Apr 2010 (H Rott)
- EGU, Cold region hydrology, Vienna, May 2010 (D Yang\Co-convener)
- IGS sea ice conference, Tromsø, Jun 2010 (S Gerland)
- IPY science conference, Oslo, June 2010 (T Villinger\ D Yang)

5. Workshop reports

- CliC 08 SSG meeting report (on the new CliC website)
- Asia cryo data workshop report (final draft)
- CliC arctic sea ice workshop report (final draft)

6. Contributions to major documents\articles

- CliC Implementation plan (on the CliC new website)
- Contribution to WCRP IP document (WCRP pub)
- Contribution to WCRP achievements report (WCRP pub)
- Contribution to ACSYS book chapter (in press?), Evolution of CliC (Steffen, Yang, Ryabinin, Asrar)
- Contribution the NPI Melting Snow and Ice – a call for action (COP 15 released)
- Contribution and review of the SWIPA report (in prep)

7. Hosting visitors\visiting fellows

- Tony Worby, SSG co-chair
- Richard Armstrong, NSIDC
- Baisheng Ye, CAREERI, CAS
- Koni Steffen, SSG co-chair
- A group of students from Germany
- Timo Vigma, FMI
- Lanbo Liu, U. Connecticut\CRREL

8. Travel for CliC related meetings

During the reporting period, the Director attended the following meetings and conferences:

Dec 2008 AGU, San Francisco

Feb 2009	China CliC Committee meeting, Beijing, China
	CliC Asian Snow Project, Lanzhou, China
	ESARIN meeting, Rome, Italy
Apr 2009	WCRP JSC, Baltimore, MD
	EGU, Vienna, Austria
Jun 2009	ESA-CliC Scientific Consultation WS, Innsbruck, Austria
Aug 2009	Climate Days 2009, Nuuk, Greenland
Sep 2009	NEESPI and CEOP HE WS, Bishkek, Kyrgyzstan
Dec 2009	AMAP meeting, Copenhagen, Denmark
	AGU, San Francisco
Jan 2010	Helsinki, Finland, Nordic Centre of Excellence

The Office Coordinator attended the SSG-V in Geneva (Dec 2008), and the intern participated in the CliC-sponsored IPY *International Early Career Researcher Symposium* in Victoria, Canada, December 2009.

CIPO supported travel in the form of per diem for one scientist from China who participated in the World Glacier conference in (Tromsø, June 09). He spent four days at CIPO working on matters related to the cryosphere and Asia-CliC.

9. Summary of CliC activities with ESA

- Development of CliC Science requirement document, Sept 08 – April 09
- CIPO visit to ESRIN, Feb-Mar 2009
- ESA-CliC consultation workshop, Univ. of Innsbruck, Jun 2009
- Review of draft Invitation to Tender (ITT) for the North Hydrology Project, ESA meeting at ESRIN, Sep 2009
- Evaluation of proposals for the ITT, Jan 2010

10. Website and newsletter

Web site: Work on a new CliC website continues to evolve. A draft site has been done in Jan 2010, with the link released to the SSG for review and comment. The final publication is scheduled during the first quarter of 2010. We appreciate suggestions and comments from the SSG and need inputs from the Theme leads on theme pages and cross cut research activities.

Newsletters: The *June 2009* issue lead article presented a fresh focus on WCRP and CliC cross-cutting activities, and six new SSG members were introduced. Among other cryosphere articles, research updates from Brazil, Russia, and China were featured.

The contents of the *November 2009* issue concentrated mainly on IPY activity, while the lead article summarized the WCRP Implementation Plan 2010-2013. A new feature – the Early Career Scientists' Corner – was introduced in this issue with an article on Soot in Svalbard Snow. The two-page spread is dedicated to contributions by young researchers and to issues concerning their career development and opportunities.

11. Main issues

CIPO needs more operational funds to hire and support the 3rd staff at the office. We hope to obtain additional funds through joint proposals, such as the Nordic Centre of Excellence in climate change in interactions with the cryosphere. CIPO will also seek one-time contributions from various potential sources. With additional funds, we also hope to create a CliC visiting fellow program.

Appendix 6: Terrestrial Permafrost Carbon in the Changing Climate

Authors: *Vladimir Kattsov[9], Kathy Hibbard[10], Annette Rinke[11], Vladimir Romanovsky[12], Diana Verseghy[13]*
Reviewers: *Torben R. Christensen[14], Peter Kuhry[15], David Lawrence[16], David McGuire[17]*

Introduction

The IPCC Working Group 1 Fourth Assessment Report (IPCC, 2007) highlighted the cryosphere as a major source of uncertainty in global climate projections. One of the most significant knowledge gaps related to cryosphere is the impact of thawing permafrost on the global carbon cycle. The magnitude of the positive feedback between the warming climate and additional emission of greenhouse gases into the atmosphere from natural sources and particularly from thawing permafrost is unknown. Some scientists believe the effect may be catastrophic, while others are skeptical about its significance. The picture is complicated by limited information on the quantity and form of carbon sequestered in permafrost, by inadequate knowledge of arctic biogeochemistry, and by insufficient understanding of the interactions between the terrestrial cryosphere, hydrology and vegetation in northern high latitudes (NHL) in a warming climate.
The purpose of this paper is to initiate an inter-community discussion of possible joint efforts to address the potential role of terrestrial permafrost carbon in enhancing global warming.

1 Physical characteristics of permafrost

1.1 *Definitions and background*

Permafrost is present within rock, sediment or any other earth material (except for glacier and sea ice) when the temperature of this material remains below 0°C for two or more years. Terrestrial permafrost zones occupy up to 24 % of the exposed land area of the Northern Hemisphere (Zhang *et al.*., 2000). Permafrost temperature, thickness, and geographic continuity are controlled to a large extent by the surface energy balance and thus vary strongly with latitude. Permafrost ranges from very cold (temperatures of -10°C and lower) and very thick (more than 500 meters and as much as 1400 meters) in the Arctic and boreal forest/taiga areas under continental climate, to warm (within one or two degrees of the melting point) and thin (several meters or less in thickness) in subarctic and some other areas. Permafrost can be classified into two types: continuous and discontinuous. In the continuous permafrost zone, permafrost occupies the entire area (except beneath large rivers and deep lakes) and is characteristic for all types of landscapes. In the discontinuous permafrost zone, including the sporadic zone, anywhere from less than 1 to 90% of the surface is underlain by permafrost.

Recent observations indicate a warming of permafrost in many northern and mountain regions with resulting degradation of ice-rich and carbon-rich permafrost (Brown and Romanovsky, 2008). Permafrost temperature has increased by 1 to 2°C in northern Russia during the last 30 to 35 years. This observed increase is very similar to what has been observed in Alaska where the detailed characteristic of the warming varies between locations, but is typically from 0.5 to 2°C. In the Arctic, projected warming during the 21st century may ultimately result in the disappearance of the warmer and thinner permafrost in the southernmost zones (Romanovsky *et al.*., 2007). Recent studies revealed

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[11] Alfred Wegener Institute for Polar and Marine Research, Potsdam, Germany
[12] University of Alaska, Fairbanks, Alaska, USA
[13] Environment Canada, Downsview Ontario, Canada
[14] Lund University, Lund, Sweden
[15] Stockholm University, Stockholm, Sweden
[16] National Centre for Atmospheric Research, Boulder, Colorado, USA
[17] University of Alaska, Fairbanks, Alaska, USA

active permafrost degradation in Alaska, Canada, Russia, Mongolia, China and Scandinavia (Anisimov *et al.*. 2007; Jorgenson *et al.*. 2001; Oberman, 2008; Romanovsky *et al.*., 2008; Sharkhuu *et al.*., 2008; Åkerman and Johansson, 2008). If recent trends continue, it would take less than a century for permafrost in some of the areas of the present discontinuous zone where it is actively warming and thawing to disappear completely (Fronzek *et al.*. 2006). For other areas the complete disappearance of permafrost would take much longer (centuries and even millennia). However, the negative consequences of this degradation may be pronounced from the very beginning because the highest ice and carbon content in permafrost usually is found in the upper few tens of meters.

1.2 Quantities

The total pool of organic carbon stored in permafrost is composed of carbon frozen at depth in peatlands (concentrations from 20% to 60%C) and carbon intermixed with mineral soils (<1% to >30% C). The estimated size of the permafrost carbon pool can vary depending on the regions under consideration and on the depth of the permafrost included (Chien-Lu Ping *et al.*., 2008; McGuire *et al.*. 2009). Total soil carbon in the northern circumpolar permafrost zone is currently estimated at 1400 to 1850 billion metric tons (Schuur *et al.*., 2008). Under a warming climate, release of carbon from permafrost to the atmosphere will occur primarily through accelerated microbial decomposition of organic matter. However, the rate and form of this carbon release will depend on landscape-level processes (including the rate and forms of permafrost degradation) that are not very well understood quantitatively (Schuur *et al.*., 2008).

1.3 Processes

The patterns of permafrost distribution, especially in the discontinuous zone, are determined to a large extent by local factors. In upland areas, permafrost is more common on north-facing slopes and less typical for south-facing slopes (e.g. Dornes *et al.*., 2008). Snow cover, with its insulating effect, is an important factor; increased snow cover and depth is thought to have played a significant role in the warming of permafrost during the twentieth century (Stieglitz *et al.*., 2003), though the relative influence of snow compared to climate warming may diminish through the 21st century (Lawrence and Slater, 2009). At the southernmost range of permafrost extent, local pockets of permafrost are typically relict features from the Little Ice Age, and are therefore extremely sensitive to ongoing and future climate change (Turetsky *et al.*., 2007).

In continuous permafrost zones, the aggradation of permafrost can lead to the formation of ice-rich features such as layers of segregated ice in soil, pingos or ice wedges. In wetland areas in discontinuous permafrost zones, permafrost aggradation produces palsas or raised peat plateaus which (under continental climates) develop a tree cover, while the intervening fen areas remain permafrost-free. The relative importance of variable permafrost features and the processes that lead to changes are not well understood with regard to their influence on the biogeochemistry and climate systems. For example, small areas of change in wetlands and methane emissions are clearly important, however the consequences or feedbacks of landscape permafrost dynamics to climate are not understood.

Carbon stocks in permafrost-dominated areas basically exist mainly in two reservoirs: living vegetation and dead soil organic matter. In areas of continuous permafrost, in North America the vegetation cover is generally dominated by shrub or sedge tundra which has a low biomass, while in Siberia about half of the area of continuous permafrost is covered by boreal forest. In areas of discontinuous permafrost, a boreal forest cover tends to dominate, interspersed with fens or bogs. Cold temperatures and the short growing season tend to retard vegetation growth rates, but low soil temperatures slow down the subsurface decomposition rates. As a result, boreal forest and tundra biomes represent an important carbon reservoir in the present-day C cycle. The amount of carbon sequestered in living biomass in these biomes is typically small compared to that which has been stored in the soil over hundreds to thousands of years.

Increases in temperature lead to increased photosynthesis, but if permafrost thaws, it also leads to increased soil respiration rates. In areas underlain by mineral soils, it is generally assumed that increased soil respiration will dominate. On the other hand, if a surface soil organic layer is present, it has the effect of insulating the underlying permafrost from temperature increases (Yi *et al.*., 2007). Surface disturbances to permafrost areas, as a result of coastal or river erosion, forest fires, landslides or human activity, may result in catastrophic melt events and the development of thermokarst and thermal erosion[18], with the potential for substantial releases of carbon. A unique situation exists in northern and central East Siberia, where large areas of the Lena, Yana, Indigirka, and Kolyma River basins are covered with deep, ice-rich deposits of frozen, wind-blown soil or *yedoma*, deposited during the glacial periods, which are high in organic matter (Zimov *et al.*., 2006). Similar deposits but with much smaller geographical extent exist in Alaska. The thawing of *yedoma* results in the collapse of the soil and in the development of thermokarst lakes and wetlands. The anaerobic decomposition of the organic matter in the soil underlying the lakes leads to an efflux of methane bubbling up through the water, with occasional large outbursts (Walter *et al.*., 2006).

In wetland areas, it is less clear as to whether warmer temperatures lead to increased sequestration or release of carbon (Moore *et al.*., 1998). It is generally found that net organic matter accumulation is greater in unfrozen bogs and fens than in neighbouring peat plateaus, suggesting that near-surface permafrost inhibits peat accumulation (Turetsky *et al.*., 2007). Thawing of the permafrost under these peat plateaus leads to the formation of collapse bogs in the centre or collapse fens at the margins, and thus a warming climate may lead to increased carbon accumulation rates in these collapse features (unless thermokarst develops with open water conditions). Yet warmer peat temperatures, greater soil aeration and greater rates of peat decomposition may provide limits to this increase (Robinson and Moore, 2000). Ground water storage is an important factor; under anaerobic conditions decomposition produces methane, while under aerobic conditions it produces carbon dioxide. Downward movement of the water table is fundamentally linked to decreased methane fluxes from organic soils (Moore *et al.*., 1998). In a palsamire with degrading permafrost in subarctic Sweden it was found that between 1970 and 2000 this ecosystem had increased methane emissions (Christensen *et al.*., 2004) while at the same time increased its carbon sink strength due to the thawing permafrost and resulting wetter soil conditions (Johansson *et al.*., 2006). The result in terms of greenhouse warming was a net increase in radiative forcing due to a stronger impact of increased methane emissions compared with the uptake of carbon dioxide (Johansson *et al.*., 2006). Changes in surface hydrology can thus also have a large effect; degradation and collapse of peat palsas is strongly related to changes in the water level in neighbouring river floodplains and fens (Vallee and Payette, 2004). Thawing of permafrost in peatlands has been found to lead to increased export of dissolved organic carbon through streamflow in Western Siberian watersheds that drain to the Arctic Ocean (Frey and Smith, 2005).

Finally, changes in the land cover can lead to changes in carbon cycle dynamics. The expansion of shrub tundra in the 20th century to replace grass and moss has altered the carbon balance in these areas (e.g., Tape *et al.*., 2005). Model-based analyses from Euskirchen *et al.*. (2009) for the 21st century indicate that shrub tundra will become shrubbier, but that increases in shrubs in sedge tundra will be modest. In addition, drier conditions can lead to increased risk of fire, which can produce massive losses of carbon in very short periods of time (Turetsky *et al.*., 2002).

2 State of the Art Process Modelling

2.1 Ecosystem Models

Ecosystem, or biogeochemistry models simulate the elemental flux of carbon, nitrogen, water and energy for the plant-soil system. They have been used to simulate biogeochemical response to climate for local to global grassland and temperate forest ecosystems, but studies over permafrost

[18] It should be noted that thermokarst and thermal erosion are part of the normal dynamics in these landscapes and are not necessarily the result of climate changes or large-scale disturbances. So, the issue really is if there will be an accelerated rate in these processes in the warming climate.

areas have been limited. Grant *et al.*. (2003) evaluated a comprehensive ecosystem model *ecosys* at an arctic tundra location in Alaska using CO_2 fluxes measured in a growth chamber, and investigated the effects of driving a 100-year simulation using air temperature and precipitation obtained from the IS92a emissions scenario. Zhuang *et al.*, (2002, 2006) used a land surface model incorporating soil thermal, hydrologic, and ecosystem processes to investigate how the carbon budgets of boreal forests will respond to changes in atmospheric CO_2, climate, and fire disturbance. They also investigated the sensitivity of the model to nitrogen fixation, moss growth, changes in the depth of the organic layer, soil drainage, and fire severity. The circumpolar carbon balance of arctic tundra was evaluated by Sitch *et al.*. (2007) using remote sensing and ecosystem models. Studies involving only the energy and moisture cycles of the land surface models provide additional information on model performance (Yi *et al.*. 2009).

Some more basic studies have addressed the modelling of the soil climate alone. A simplified heat transfer model, driven by atmospheric data, was used by Oelke and Zhang (2004) to carry out a study of soil temperatures, comparing them to observations over Alaska and Siberia and analyzing temperature trends over a 20-year period. A similar study using a simple heat transfer model was carried out by Sushama *et al.*. (2006) to evaluate future changes in soil temperature over north-eastern Canada using the IS92a emissions scenario. They calculated for north-eastern Canada an increase of active layer thickness by more than 50% for most of the continuous permafrost, and projected the disappearance of most of the discontinuous permafrost by the end of the century. A more comprehensive permafrost model was used to project permafrost dynamics in Alaska (Marchenko *et al.*, 2008). According to this model, permafrost in Alaska will be actively thawing by the end of 21st century practically everywhere south from the Brooks Range. Sazonova *et al.*. (2004) and Stendel *et al.*. (2007) simulated within an East Siberian transect an increase of active layer thickness by up to 2 meters and permafrost degradation by the end of the century (under SRES A2 and B2 scenarios). The importance of conceptually locating the bottom soil boundary at a sufficient depth to resolve the annual temperature harmonics was discussed by Stevens *et al.*. (2007), and the effect of discretization of the modelled soil layers as well as the placement of the bottom of the modelled soil depth were examined by Alexeev *et al.*. (2007). It was shown that to accurately simulate the annual cycle of temperature dynamics for cold permafrost, the modeled soil depth should be at least 30 meters.

2.2 Land Surface Models: Regional to Global

Land surface models (LSMs) are utilized in both global and regional climate models. Primary characteristics of an LSM are to simulate highly resolved (e.g., 15second time step) water, energy, and momentum exchange between the atmosphere and land, of the terrestrial hydrological cycle, and of soil temperature dynamics. The processes simulated include both biophysical (radiation, turbulent heat and momentum fluxes, heat transfer in a multi-layer soil) and hydrological processes (soil hydrology, snow, interception of snow/rain by canopy, runoff). Most land surface models simulate only few soil layers and a soil column depth of less than 10 m. Generally, mineral soils are assumed and organic layers are neglected. Vertical transfers of water between soil layers are calculated, and soil moisture can freeze and thaw. Lateral flows of energy and water (e.g. river flow, lake/wetland dynamics) are not generally modelled. Snow and soil albedo, and snow cover parameterizations of different complexities are used, but snow aging effects are often not addressed. Soil and vegetation types (comprised of multiple plant types) are specified from global datasets, but arctic wetlands are often incorrectly identified in these datasets. The treatment of vegetation parameters influences the evapotranspiration, surface roughness and albedo, thereby controlling the moisture flux into the atmosphere, and heat and momentum exchanges between the surface and the atmosphere. Verseghy *et al.*. (2000) evaluated a land surface model using field data from alpine tundra, and Lafleur *et al.*. (2000) did an analogous study over subarctic open woodland.

2.3 Regional climate models

Regional climate models (RCMs) simulate high horizontal resolution (e.g., 5-50 km grid) atmospheric dynamics accounting for topographic complexity, and, when available, detailed paramaterization of soil properties, vegetation, snow cover and ice contents. Currently, for the pan-Arctic domain, RCM simulations with a horizontal resolution of 25 km are available, while for smaller regions (Greenland, Alaska, northern Russia) a horizontal resolution down to 4 km is available. RCMs are coupled atmosphere-land models, *i.e.* represent the land-atmosphere interactions as coupled processes, with boundary conditions from atmosphere-ocean general circulation models (AOGCM) or reanalysis (e.g., ECMWF or NCEP/NCAR reanalyses).

Regional climate models do not generally simulate biogeography, or vegetation dynamics, (*i.e.* vegetation composition and fractional areas are time-invariant). Few regional land surface models simulate biogeochemical processes (photosynthesis, plant and microbial respiration, net primary production) and thus consider carbon exchanges between atmosphere and land. Only CO_2 (and not CH_4) fluxes are typically considered. Soil processes like decomposition and mineralization are generally not included; biomass and soil carbon are prescribed for each plant type. However, recent RCM developments with regard to soils, vegetation, wetlands, permafrost and the carbon cycle and their role in the Arctic climate are providing insight into the importance of the biogeochemical contributions to energy and climate dynamics.

The importance of freezing/thawing and snow depth for ground temperature was discussed in Saha *et al.*., (2006) for a pan-Arctic RCM using two land surface schemes. Rinke *et al.*. (2008) included a surface organic layer in a land surface scheme of a pan-Arctic RCM, demonstrating that not only the ground thermal and hydrological regimes are modified (in summer resulting in a significant cooling of the ground and increased evaporation), but also feedbacks to the atmosphere are significant over the annual seasonal cycle via changed turbulent heat fluxes. Göttel *et al.*. (2008) investigated the vegetation feedback to climate change using an offline-coupled simulation. An RCM simulation over the Barents Sea region was conducted using the results of a dynamic vegetation model to provide the RCM with information about changing vegetation. It was shown that the vegetation feedback effects (via surface albedo, roughness, evapotranspiration) are one order of magnitude lower than the effects of greenhouse gas forcing. Gutowski *et al.*. (2007) examined the capacity of Arctic wetlands to influence atmospheric dynamics and thus water cycling in a pan-Arctic RCM for a selected summer. It was shown that adding Arctic wetlands changed the large-scale atmospheric circulation (appearing as a propagating, equivalent barotropic wave), and that the largest influence (via surface energy flux changes) occurred in central Siberia. The period of most significant influence extended from the spring thaw of wetlands until the diminishing occurrence of synoptic storms in midsummer. There have been some efforts to simulate permafrost dynamics by RCMs. Christensen and Kuhry (2000) simulated in a high-resolution RCM over the East European and Russian Arctic a quasi-realistic present-day permafrost distribution, derived from mean annual temperature using a semi-empirical approach (frost index). Sushama *et al.*. (2007) modelled with an RCM the soil thermal and moisture regimes for the North American permafrost region. They showed a maximum warming for the continuous permafrost zone (near-surface annual soil temperature increase by 4-6°C) and a decrease (increase) in the frozen (liquid) water content (under the A2 scenario). Wu and Lynch (2000) investigated the effects of perturbed temperature and moisture on terrestrial carbon exchange in an RCM over Alaska. The perturbations were shown to affect the amplitude and phase of the seasonal cycle of the simulated net carbon flux. The response of ecosystems to climate change was biome-dependent: in boreal forest a larger response (due to drier soil) and in tundra a smaller response (primarily forced by temperature) were simulated. From this, it was hypothesized that in consequence of a northward tree line migration, the sensitivity of regional carbon exchange to climate perturbations could increase (due to replacement of less sensitive tundra by more sensitive boreal forest).

2.4 From AOGCMs to ESMs

The IPCC AR4 (Randall *et al.*., 2008) concludes that most AOGCMs represent the continental-scale land surface adequately *unless warming strongly affects the terrestrial carbon balance*.

The current generation Earth system models (ESM) do not include processes that specifically account for high-latitude carbon-cycle dynamics, but rather, include carbon cycle models that primarily represent upland soils that do not account for functional attributes of organic or peatland soils. Because there has been limited progress in regional modelling efforts about how the NHL carbon cycle will respond to climate change, it is not surprising that the global coupled carbon-climate models do not represent processes that are thought to be important in the arctic carbon cycle. A few modelling groups have implemented physical and/or hydrologic dynamics of NHL into global climate models (e.g., Lawrence *et al.*., 2008), but these models do not account for the biogeochemistry of the coupled hydrology and carbon cycle-permafrost dynamics at this time.

Carbon stocks in permafrost soil are estimated to range from 1450-1850 PgC (McGuire *et al.*., 2009). As permafrost warms and thaws, wetland expansion, changes to microbial and coupled carbon/nitrogen dynamics all lead to altered efflux of CO_2 and CH_4 from soils as well as biogeographic shifts from deeply rooted sedges to shallow rooted shrubs alter potential for carbon sequestration (McGuire *et al.*, 2006, Chapin *et al.*., 2005, 2006; Euskirchen *et al.*., in press). None of these dynamics are currently captured in global ESMs nor are changes to landscape structure (e.g., thermokarst) or potential feedbacks from changes in surface and sub-surface runoff (from land or ice) to the freshwater budge of the Arctic ocean. These omissions do not reflect a lack of commitment, rather, there is an inherent lag in translation from observations and measurement through to ecosystem and regional modelling that relates to scale and inherent bio- and eco-physiological process understanding.

Future work planned for several modelling groups relevant to terrestrial carbon and permafrost dynamics in global ESMs include arctic soil carbon dynamics, wetland CH_4 emissions modelling, dynamic vegetation (including shrubs), dynamic wetlands including biophysical processes such as soil subsidence and thermokarst dynamics. Many global ESMs are able to perform simulations ‘off-line’, and uncoupled from the climate model (e.g., they are driven by off-line temperature, precipitation, etc.) and as such, are much more computationally efficient than fully coupled ESMs (e.g., coupled carbon-climate models).

There have been a number of studies that provide a mechanism for including wetland methane dynamics in the global ESMs that investigate the relationship between precipitation and evaporation, and temperature changes (e.g., Gedney *et al.*., 2004, Shindell *et al.*., 2004). However, the role of thermokarsting is not addressed and could have significant implications to permafrost thaw-methane emission feedbacks. Further, there is a hypothesis that is relatively unexplored that suggests that deep decomposition heating could lead to self-sustaining permafrost thaw and further organic matter decomposition (e.g., Khvorostyanov *et al.*., 2008*a,b*).

With regard to the Coupled Model Intercomparison Project (CMIP5) simulations that will form the basis of the Fifth IPCC Assessment Report (AR5), methane emissions and wetlands components will not be available for most models. However, some ESMs are likely to have an initial representation of thermal and hydrological permafrost processes.

3 Understanding and projecting needs

3.1 Observational needs

To further the understanding of carbon cycle and permafrost dynamics and to support modelling efforts, a variety of observations and databases are required:

- Current spatial extent (horizontally and vertically), temperature, and ice content of northern hemisphere permafrost;
- Soil texture and hydraulic properties, and also soil permeable depth in permafrost areas, to enable realistic modelling of soil freezing and thawing and water storage;
- Spatial distribution of wetlands and organic soils (horizontally and vertically);
- Quantitative and qualitative information on the vertical distribution of carbon stocks;

- Vegetation type and coverage;
- Physiological and biological characteristics of vegetation present in permafrost areas.
- Long term (multi-year) flux measurements of energy, water, and carbon fluxes in conjunction with atmospheric and soil climate monitoring and detailed metadata on soil and vegetation characteristics across a range of permafrost-affected ecozones.
- Landscape dynamics.

McGuire *et al.*. (2009) recommended the integration of information from different temporal and spatial scales to support testing of scaling approaches.

3.2 Local scale through regional climate modelling

The shallow soil profile currently used in RCMs is a limitation for ground temperature simulations (see Riseborough *et al.*. (2008) for detailed discussion). For Arctic landscapes, an upper organic soil layer is a key feature. Those improvements are being implemented in the next generation of RCM simulations. Besides improved description of physical permafrost dynamics, its coupling with hydrology needs to be taken into account. Generally, this development in RCMs will have to be guided by off-line permafrost-soil model development.

Up to now, within RCMs, vegetation distributions have been prescribed, which is appropriate for short-term studies. For long-term transient simulations (e.g. of the northward tree line migration or shrub encroachment into tundra zones), fully coupled atmosphere-land-vegetation RCMs are needed. The role of wetlands in the climate system (for carbon cycle and energy, moisture, and momentum exchange with the atmosphere) and their changes governed by permafrost degradation need to be studied.

It is valuable to continue the two complementary approaches for permafrost simulations using RCMs: RCM-driven simulations with sophisticated off-line permafrost-soil models, and direct RCM simulation of ground thermal and moisture regimes.

The ground thermal and moisture regimes are controlled by spatially highly variable surface parameters (snow, vegetation) and soil characteristics. This emphasizes the need for as high as possible horizontal resolution RCM runs.

Of great value are off-line and coupled sensitivity studies (addressing land surface-soil parameters) to identify the key processes and feedbacks important for climate-permafrost simulations.

3.3 Understanding and projecting needs for ESMs

As McGuire *et al.*. (2009) note, “scaling is the key challenge to designing integrated studies that link observations and processes of carbon dynamics, which are often conducted at fine spatial and temporal scales, in a way that the understanding can be transferred to models that operate at coarse spatial and/or temporal scales. Scaling requires both the representation of fine-scale processes at a coarser scale and the representation of interactions of processes that operate across a spectrum of scales.”

ESMs should continue to evolve to include as full as possible a range of processes that may influence carbon cycling, which are not limited to permafrost components (e.g. dynamic vegetation and comprehensive terrestrial hydrology components). Implementation and testing of scaling approaches will be needed to incorporate the understanding gained from observational and process studies across a spectrum of spatial and temporal scales into ESMs. It will be important to maintain a dialogue between the ecosystem and regional modelling and process study communities with the global modelling communities to ensure that those processes that can have significant impacts on feedbacks to the climate system are considered.

CAPER (CArbon and PERmafrost) – a joint CliC-AIMES initiative

The EU project CARBO-North "Quantifying the carbon budget in Northern Russia: past, present and future" (http://www.carbonorth.net; 2006-2010) integrates flux measurements, carbon stock inventories, ecological understanding and earth system and permafrost modelling (using RCMs, GCMs, ecosystem models) to quantify the long-term fluxes of greenhouse gases from the Northern Russian land mass. Results are used for integrated ecosystem modelling, calculation of net radiative effects and assessment of the sensitivity of climate model predictions to transient environmental changes.

The IPY/IPA project CAPP "Carbon pools in permafrost regions" (http://www.geowiss.uni-hamburg.de/i-boden/capp/index.htm) aims at quantifying below-ground organic matter quantity and quality in high latitude and high altitude regions characterized by the presence of isolated to continuous permafrost.

We propose CAPER ("CArbon and PERmafrost") – a joint WCRP's CliC (http://clic.npolar.no/) and IGBP's AIMES (http://www.aimes.ucar.edu/) activity that will promote complementary approaches for understanding and quantifying carbon cycle and permafrost dynamics across scales of observations, measurements and models for regional to global analyses and projections. A goal is to develop a coordinated modelling framework that provides paramaterization sets and submodels for soil carbon and energy dynamics that are applicable for cold region processes that can be inserted or incorporated into current and future generation land surface or ecosystem models. A goal of CAPER is to contribute to the land/ecology efforts of ongoing NHL projects, e.g., the Arctic System Model (Hinzmann *et al..*, 2008) to develop a regional fully coupled (ice, ocean, land, atmosphere, ice sheet, ecology) and the development of arctic processes in global climate models.

An implementation strategy includes collaboration with existing international coordinated bodies, for instance, from the observation and measurement perspective, the Global Carbon Project (http://www.globalcarbonproject.org/index.htm), NEESPI (http://neespi.org/), SAON (http://www.arcticobserving.org/) and from the global climate perspective the C^4MIP (http://www.atmos.berkeley.edu/c4mip/home.html) communities. The CliC-AIMES NHL-focused activity will aim to improve the representation of key processes in RCMs and ESMs, drawing on studies from local and regional observational, experimental and modelling communities through an iterative process to facilitate analyses of feedbacks between biogeochemistry and climate across scales with an emphasis on the coupled permafrost-carbon and hydrologic system.

Coordinated strategies are needed for translating process understanding to model parameterization and initialization and to providing feedback from model experiments from regional to global contexts for carbon-permafrost interactions with the climate system. In addition, it will be critical to initiate the necessary dialogue and communication not just with the few groups that are working on select components of global ESM development, but those that are in a position to implement new components based on, and building from previous and ongoing model development activities.

References

Alexeev, V.A., D..J. Nicolsky, V.E. Romanovsky and D.M. Lawrence, 2007: An evaluation of deep soil configurations in the CLM3 for improved representation of permafrost, *Geophys. Res. Lett*. 34, L09502.

Anisimov, O.A., D.G. Vaughan, T.V. Callaghan, C. Furgal, H. Marchant, T.D. Prowse, H. Vilhjálmsson and J.E. Walsh, 2007: Polar regions (Arctic and Antarctic). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, 653-685.

Åkerman, J., and M. Johansson, 2008: Thawing permafrost and thicker active layers in Sub-arctic Sweden. *Permafrost and Periglacial Processes*, 19, 1-14.

Brown, J. and V. E. Romanovsky, 2008: Report from the International Permafrost Association: State of Permafrost in the First Decade of the 21st Century, *Permafrost and Periglacial Processes*, 19: 255–260.

Chapin, F.S., III, M.D. Robards, H.P. Huntington, J.F. Johnstone, S.F. Trainor, G.P Kofinas R.W. Ruess, N. Fresco, D.C. Natcher, and R.L. Naylor, 2006: Directional changes in ecological communities and social-ecological systems: A framework for prediction based on Alaskan examples. *American Naturalist* 168:S36-S49.

Chapin, F.S., M. Sturm, M.C. Serreze, J. P. McFadden, J.R. Key, A.H. Lloyd, A.D. McGuire, T.S. Rupp, A.H. Lynch, J.P. Schimel, J. Beringer, W.L. Chapman, H.E. Epstein, E.S. Euskirchen, L. D. Hinzman, G. Jia, C.-L. Ping, K.D. Tape, C.D.C. Thompson, D.A. Walker, and J.M. Welker, 2005: Role of land-surface changes in arctic summer warming. *Science* 310:657-660

Chien-Lu Ping, G. J. Michaelson, M. T. Jorgenson, J. M. Kimble, H. Epstein, V. E. Romanovsky, and D. A. Walker, 2008: High stocks of soil organic carbon in the North American Arctic region, *Nature Geoscience*, doi10.1038/ngeo284.

Christensen, J.H., and P. Kuhry, 2000: High-resolution regional climate model validation and permafrost simulation for the East European Russian Arctic, *J. Geophys. Res.* 105, 29647-29658

Christensen, T.R., T. Johansson, N. Malmer, J. Åkerman, T. Friborg, P. Crill, M. Mastepanov, and B. Svensson, 2004: Thawing sub-arctic permafrost: Effects on vegetation and methane emissions, *Geophys. Res. Lett.*, 31, L04501, doi:10.1029/2003GL018680.

Dornes, P.F., B.A. Tolson, B. Davison, A. Pietroniro, J.W. Pomeroy and P. Marsh, 2008: Regionalization of land surface hydrological model parameters in subarctic and arctic environments, *Physics and Chemistry of the Earth*, 33, pp. 1081-1089.

Euskirchen, E.S., A.D. McGuire, F.S. Chapin III, S. Yi, and C.C. Thompson, 2009: Changes in vegetation in northern Alaska under scenarios of climate change 2003-2100: Implications for climate feedbacks. In press to: *Ecological Applications*.

Frey, K.E. and L.C. Smith, 2005: Amplified carbon release from vast West Siberian peatlands by 2100, *Geophys. Res. Lett*. 32, p. 9401.

Fronzek S, Luoto M, Carter TR, 2006; Potential effect of climate change on the distribution of palsa mires in subarctic Fennoscandia. *Climate Research* 32:1-12.

Göttel, H., J. Alexander, E. Keup-Thiel, D. Rechid, S. Hagemann, T. Blome, A. Wolf, and D. Jacob, 2008: Influence of changed vegetations fields on regional climate simulations in the Barents Sea Region, *Climate Change* 87, 35-50, doi:10.1007/s10584-007-9341-5

Grant, R.F., W. Oechel, C.-L. Ping, 2003: Modelling carbon balances of coastal arctic tundra under changing climate, *Global Change Biology* 9, pp. 16-36.

Gutowski, W.J., H. Wei, C.J. Vörösmarty, and B.M. Fekete, 2007: Influence of Arctic Wetlands on Arctic Atmospheric Circulation, *J. Climate* 20, 4243-4254, doi: 10.1175/JCLI4243.1

Hinzman, L.; Cassano, J.; Doescher, R.; Holland, M.; Mitsudera, H.; Roberts, A.; Sumi, A.; Walsh, J., 2008: A Science Plan for Development of an Arctic System Model. *American Geophysical Union, Fall Meeting 2008*, abstract #C41A-0477, 2008AGUFM.C41A0477H.

IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Quin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Jorgenson, M.T., C.H. Racine, J.C. Walters, and T.E. Osterkamp, 2001: Permafrost degradation and ecological changes associated with a warming climate in central Alaska, *Climatic Change*, 48(4), 551-571.

Johansson T, Malmer N, Crill PM, Friborg T, Akerman JH, Mastepanov M, Christensen T.R., 2006: Decadal vegetation changes in a northern peatland, greenhouse gas fluxes and net radiative forcing. *Global Change Biology* 12 2352-2369.

Khvorostyanov, D. V., Krinner, G., Ciais, P., Heimann, M. and Zimov, S.A., 2008a: Vulnerability of permafrost carbon to global warming. Part 1. Model description and role of heat generated by organic matter. Tellus 60B, 250-264.decomposition. *Tellus*, 60B, doi:11.1111/j.1600-0889.2007.00333.x.

Khvorostyanov D. V., P. Ciais, G. Krinners, S. Zimov, Ch. Corradi, and G. Guggenberger, 2008b: Vulnerability 14 of permafrost carbon to global warming. Part II: sensitivity of permafrost carbon stock to global warming. 15 *Tellus*, *60B*, 265–275

Lafleur, P.M., M.R. Skarupa and D.L. Verseghy, 2000: Validation of the Canadian Land Surface Scheme (CLASS) for a subarctic open woodland, *Atmosphere-Ocean* 38, pp. 205-225.

Lawrence, D.M., A.G. Slater, V.E. Romanovsky, and D.J. Nicolsky, 2008: The sensitivity of a model projection of near-surface permafrost degradation to soil column depth and inclusion of soil organic matter. *J. Geophys. Res.*, **113**, F02011, doi:10.1029/2007JF000883.

Lawrence, D.M., and A.G. Slater, 2009: The contribution of snow condition trends to future ground climate. *Clim. Dyn.*, 10.1007/s00382-009-0537-4.

Marchenko, S., V. Romanovsky, and G. Tipenko, 2008: Numerical Modelling of Spatial Permafrost Dynamics in Alaska, In *Proceedings of the Ninth International Conference on Permafrost*, June 29-July 3, Fairbanks, Alaska, 2008, Vol. 2, pp. 1125-1130.

McGuire, A.D., L. Anderson, T.R. Christensen, S. Dallimore, L. Guo, D. Hayes, M. Heimann, T. Lorenson, R. Macdonald, and N. Roulet. 2009. Sensitivity of the carbon cycle in the Arctic climate change. *Ecological Monographs*. In press.

McGuire, A.D., F.S. Chapin III, J.E. Walsh, and C. Wirth, 2006. Integrated regional changes in arctic climate feedbacks: Implications for the global climate system. *Annual Review of Environment and Resources* 31:61-91.

Moore, T.R., N.T. Roulet and J.M. Waddington, 1998: Uncertainty in predicting the effect of climatic change on the carbon cycling of Canadian peatlands, *Clim. Change* 40, pp. 229-245.

Oberman, N., Contemporary Permafrost Degradation of Northern European Russia, In *Proceedings of the Ninth International Conference on Permafrost*, June 29-July 3, Fairbanks, Alaska, 2008, Vol. 2, pp. 1305-1310, 2008.

Randall, D.A., R.A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R.J. Stouffer, A. Sumi and K.E. Taylor, 2007: Climate Models and Their Evaluation. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Rinke, A., P. Kuhry, and K. Dethloff, 2008: Importance of a soil organic layer for Arctic climate: a sensitivity study with an Arctic RCM. *Geophys. Res. Lett.* 35, L13709, doi:10.1029/2008GL034052

Riseborough, D., N. Shiklomanov, B. Etzelmueller, S. Gruber, and S. Marchenko, 2008: Recent Advances in Permafrost Modelling. *Permafrost Periglac. Process.* 19, 137-156, doi: 10.1002/ppp.615

Robinson, S.D., and T.R. Moore, 2000: The Influence of Permafrost and Fire upon Carbon Accumulation in High Boreal Peatlands, Northwest Territories, Canada, *Arct. Antarct. Alp. Res*. 32, no. 2, pp. 155-166.

Romanovsky, V.E., Gruber, S., Instanes, A., Jin, H., Marchenko, S.S., Smith, S.L., Trombotto, D., and K.M. Walter, 2007: Frozen Ground, Chapter 7, In: *Global Outlook for Ice and Snow*, Earthprint, United Nations Environment Programme/GRID, Arendal, Norway, pp. 181-200.

Romanovsky, V.E., A.L. Kholodov, S.S. Marchenko, N.G. Oberman, D.S. Drozdov, G.V. Malkova, N.G. Moskalenko, A.A. Vasiliev, D.O. Sergeev, and M.N. Zheleznyak, 2008: Thermal State and Fate of Permafrost in Russia: First Results of IPY *(Plenary Paper)*, In *Proceedings of the Ninth International Conference on Permafrost*, June 29-July 3, 2008, Fairbanks, Alaska, Vol. 2, pp. 1511-1518.

Saha S.K., A. Rinke, K. Dethloff, and P. Kuhry, 2006: Influence of a complex land surface scheme on Arctic climate simulations, *J. Geophys. Res.* 111, D22104, doi:10.1029/2006JD007188.

Sazonova, T. S., Romanovsky, V. E., Walsh, J. E., and D. O. Sergueev, 2004: Permafrost dynamics in 20th and 21st centuries along the East-Siberian Transect, *Journal of Geophysical Research,* VOL. 109, D01108, doi:10.1029/2003JD003680.

Schuur, E.A.G, J. Bockheim, J. Canadell, E. Euskirchen, C.B. Field, S.V Goryachkin, S. Hagemann, P. Kuhry, P. Lafleur, H. Lee, G. Mazhitova, F. E. Nelson, A. Rinke, V. E. Romanovsky, N. Shiklomanov, C. Tarnocai, S. Venevsky, J. G. Vogel, S.A. Zimov, 2008: Vulnerability of permafrost carbon to climate change: implications for the global carbon cycle, *BioScience*, Vol. 58, No. 8: 701-714.

Sharkhuu, N., A. Sharkhuu, V.E. Romanovsky, K. Yoshikawa, F.E. Nelson, and N.I. Shiklomanov, 2008: Thermal State of Permafrost in Mongolia, In *Proceedings of the Ninth International Conference on Permafrost*, June 29-July 3, Fairbanks, Alaska, 2008, 2, pp. 1633-1638.

Sitch, S., A.D. McGuire, J. Kimball, N. Gedney, J. Gamon, R. Engstrom, A. Wolf, Q. Zhuang, J.S. Clein, and K.C. McDonald, 2007: Assessing the carbon balance of circumpolar arctic tundra using remote sensing and process modelling. *Ecological Applications* 17:213-234.

Stendel, M., V.E. Romanovsky, J.H. Christensen, and T. Sazonova, 2007: Using dynamical downscaling to close the gap between global change scenarios and local permafrost dynamics. *Glob. Planet. Change* 56, 203–214, doi:10.1016/j.gloplacha.2006.07.014

Stieglitz, M., S.J. Dery, V.E. Romanovsky and T.E. Osterkamp, 2003: The role of snow cover in the warming of arctic permafrost, *Geophys. Res. Lett*. 30, p. 1721.

Sushama, L., R. Laprise, and M. Allard, 2006: Modeled current and future soil thermal regime for North East Canada. *J. Geophys. Res.* 111, D18111, doi:10.1029/2005JD007027

Sushama, L., R. Laprise, D. Caya, D. Verseghy, and M. Allard, 2007: An RCM projection of soil thermal and moisture regimes for North American permafrost zones, *Geophys. Res. Lett.* 34, L20711, doi:10.1029/2007GL031385

Tape, K., M. Sturm and C. Racine, 2005: The evidence for shrub expansion in Northern Alaska and the Pan-Arctic, *Global Change Biology* 12, pp. 686-702.

Turetsky, M., R. K. Wieder, D. H. Vitt, R. J. Evans and K. D. Scott, 2007: The disappearance of relict permafrost in boreal north America: Effects on peatland carbon storage and fluxes, *Global Change Biology* 13, pp. 1922-1934.

Turetsky, M., K. Wieder, L. Halsey and D. Vitt, 2002: Current disturbance and the diminishing peatland carbon sink, *Geophys. Res. Lett.* 29, p. 1526.

Vallee, S., and S. Payette, 2004: Collapse of permafrost mounds along a subarctic river over the last 100 years (northern Quebec), *Geomorphology* 90, pp. 162-170.

Walter, K.M., S.A. Zimov, J.P. Chanton, D. Verblya and F.S. Chapin III, 2006: Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming. *Nature* 443, p. 71-75.

Wu, W., and A.H. Lynch, 2000: Response of the seasonal carbon cycle in high latitudes to climate anomalies, *J. Geophys. Res*. 105, 22,897-22,908

Yi, S., M. Woo, and M. A. Arain, 2007: Impacts of peat and vegetation on permafrost degradation under climate warming, *Geophys. Res. Lett.*, 34, L16504.

Yi, S., A.D. McGuire, J. Harden, E. Kasaschke, K. Manies, L. Hinzman, A. Liljedahl, J. Randerson, H. Liu, V. Romanovsky, S. Marchenko, and Y Kim. 2009. Interactions between soil thermal and hydrological dynamics in the response of Alaska ecosystems to fire disturbance. *Journal of Geophysical Research – Biogeosciences*. In press.

Zhang, T., *et al.*., 2000: Further statistics on the distribution of permafrost and ground ice in the Northern Hemisphere. *Polar Geography*, 24:126-131.

Zhuang, Q., A.D. McGuire, J. Harden, K.P. O'Neill, V.E. Romanovsky, and J. Yarie, 2002: Modelling soil thermal and carbon dynamics of a fire chronosequence in interior Alaska. *Journal of Geophysical Research – Atmospheres* 107, 8147, doi:10.1029/2001JD001244 [printed 108(D1), 2003].

Zhuang, Q., J.M. Melillo, M.C. Sarofim, D.W. Kicklighter, A.D. McGuire, B.S. Felzer, A. Sokolov, R.G. Prinn, P.A. Steudler, and S. Hu, 2006: CO_2 and CH_4 exchanges between land ecosystems and the atmosphere in northern high latitudes over the 21st Century. *Geophys. Res. Lett.* 33, L17403, doi:10.1029/2006GL026972.

Zhuang, Q., J. M. Melillo, A. D. McGuire, D. W. Kicklighter, R. G. Prinn, P. A. Steudler, B. S. Felzer, and S. Hu, 2007: Net emissions of CH_4 and CO_2 in Alaska: Implications for the region's greenhouse gas budget. *Ecological Applications* **17**:203-212.

Zimov, S.A., S.P. Davydov, G.M. Zimova, A.I. Davydova, E.A.G. Schuur, K. Dutta and F.S. Chapin, 2006: Permafrost carbon: stock and decomposability of a globally significant carbon pool, *Geophys. Res. Lett*. 33, p. 20502.

Appendix 7: RAPID LOSS of sea ice in the Arctic: (WCRP white paper)

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[Introduction]

Over the period of modern satellite observations (1979-present), Arctic sea-ice extent at the end of the melt season (September) has declined at a rate of more than 11% per decade, and there is evidence that the rate of decline has accelerated during the last decade. Every September since 1996 the sea-ice extent has been below the 1979-1999 mean. The winter ice extent has been also declining, but slower. The sea ice cover has been also thinning (e.g., Rothrock and Maykut, 1999). According to Kwok *et al.*. (2009), the Arctic Ocean has lost 40% of its multiyear ice in the last 5 years.

The WCRP CMIP3 coupled global atmosphere-ocean general circulation models (AOGCMs) are the main source of climate projections assessed by IPCC in its 4th Assessment Report (AR4: IPCC, 2007). While there is a significant inter-model scatter in simulations of the Arctic sea ice (Arzel *et al.*., 2006; Zhang and Walsh, 2006; Kattsov *et al.*., 2007), they all project decreasing ice mass and extent through the 21st century. For the most aggressive GHG emission scenarios (e.g. A2), some CMIP3 AOGCMs project total disappearance of the Arctic ice in late summer by the end of the century. However, *as an ensemble*, the CMIP3 AOGCMs are conservative in simulating the observed September ice extent trend. The ability of most of the models to realistically project the 21st century sea-ice response to GHG forcing is thus an ongoing concern. A number of studies suggest that the Arctic Ocean may lose its multi-year ice cover in the early to mid-21st (Holland *et al.*., 2006; Stroeve *et al.*., 2007; Wang and Overland, 2009; Alekseev *et al.*., 2009).

The future of Arctic sea ice cover is of enormous economic significance (e.g., ACIA, 2005). Due to several climatic feedbacks, in which sea-ice is a factor, the ability of climate models to realistically project the future of the Arctic sea-ice is an important condition for adequately projecting the global climate (e.g. Bony *et al.*., 2006).

The main goal of this paper is to consider possible reasons behind the apparent discrepancy between observation and model simulations, and to suggest steps towards minimizing uncertainties in predicting/projecting the future of the Arctic sea ice.

[Observation uncertainties]

Addressing the problem of rapid ice loss requires accurate information on ice thickness, velocity, age, salinity, density, snow cover and other factors. Data on some of these variables are absolutely necessary, while records for others are helpful. Satellite passive microwave (PMW) sensors are the main data source for estimates of ice extent The accuracy of algorithms for sea-ice PMW concentration estimates has been examined in many studies (Meier, 2005; Meier and Stroeve, 2008; etc.), and there is continuing disagreement regarding which of many sea-ice extent products is most accurate. As an example of this problem, in 2009 NSIDC reported a September minimum of 5.1 M km^2 on 12 September (NSIDC website, 2009), whereas the Arctic Regional Ocean Observing System

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(Arctic ROOS based at the Nansen Environmental and Remote Sensing Centre in Bergen, Norway) estimate shows a 6.0 M km^2 minimum on that day (Arctic ROOS website). The significant difference of the order of 20% is characteristic for both daily and monthly means and seems to relate to the algorithm used. Differences of the same order of magnitude can be found between products from other centres. There is hence a clear need for further product intercomparison and verification.

It is even more difficult to assess uncertainties in sea-ice thickness estimates. Both the analysis of satellite-derived sea-ice age data and a new proxy record of ice thickness for past decades (Maslanik *et al.*., 2007; Kwok *et al.*., 2009; Kwok and Rothrock, 2009) suggest that in addition to an overall reduction of multi-year ice in the Arctic, the mean age and thickness of the remaining multi-year pack have decreased. This reflects loss of the oldest ice types. The remaining relatively old and thick ice is now confined to a much smaller portion of the Arctic Ocean than in the earlier years. Given this, the sea-ice cover is increasingly susceptible to pronounced summer ice loss or an anomalous ice drift.

Climate model evaluation requires data on the oceanic and atmospheric conditions. Global reanalyses, such as ERA-40, ERA-Interim and JRA-25, are presently the best sources of gridded atmospheric data. Significant attention has been given to improving their accuracy in the Arctic/ Shortcomings in representation of the Arctic precipitation are particularly problematic (Serreze and Hurst, 2000). Almost all fields from reanalysis products in the Arctic have large errors (Walsh *et al.*., 2009). The ongoing Arctic System Reanalysis (Bromwich *et al.*., 2010) may help to address some of these shortcomings. New data sets, to be produced by IPY projects, several ESA projects (e.g., GlobIce, GlobSnow, GlobGlacier, GlobPermafrost), composites of cryospheric parameters generated by the IPY GIIPSY project, and output of several other related activities, will provide a useful data base for verification studies. Observations directed at identifying and quantifying the physical processes, especially feedbacks, are the highest priority.

Many ocean regions have seen systematic data synthesis efforts spearheaded by the WCRP CLIVAR Project and its Global Synthesis and Observations Panel (GSOP). At present there is no attempt to produce a long-term data synthesis for either the Arctic Ocean or the southern Ocean

[Model uncertainties]

The sensitivity of AOGCM sea-ice components to GHG forcing has been a research focus for more than a decade. The 0- through 1-D simple thermodynamic parameterizations of sea ice were the state-of-the-art in mid-1990s and reflected in AOGCMs that took part in CMIP and CMIP2. Such parameterizations were found to be overly sensitive to external forcing/ Emerging dynamic-thermodynamic models were giving reasons to expect a major improvement in the sensitivity over the thermodynamic models (Hilmer and Lemke, 2000).

One of the major developments in modelling over the past decade has been the implementation of sea-ice dynamics in almost all AOGCMs (Randall *et al.*., 2007). Sea-ice components of CMIP3 AOGCMs usually predict ice thickness (or volume), fractional cover, snow depth, surface and internal temperatures (or energy) and horizontal velocity. Sea-ice albedo is typically prescribed, with only crude dependence on ice thickness, snow cover and puddling effects. The complexity of sea-ice dynamics varies from the relatively simple 'cavitating fluid' approach to more comprehensive viscous-plastic and elastic-viscous-plastic models. Sea-ice thermodynamics modules in climate models typically use constant conductivity and heat capacities for ice and snow (if represented) and account for a heat reservoir simulating the effect of brine pockets in the ice. Some models include snow ice formation, which occurs when a part of the ice floe is submerged under the weight of the overlying snow and the flooded snow layer refreezes. As a significant advance over the previous decade, a few modern sea-ice models (even with relatively high resolution) incorporate sub-grid scale ice thickness distributions with several thickness 'categories', rather than considering the ice as a uniform slab with inclusions of open water. Although parameterizations of ridging mechanics and their relationship with the ice thickness distribution have improved, inclusion of advanced ridging parameterizations has lagged development of other aspects of sea-ice dynamics (rheology, in particular) owing to a lack of observational constraints.

The most reliably measured characteristic of sea ice for model evaluation is still its seasonally varying extent. Despite the significant differences between models, the CMIP3 multi-model mean of sea-ice extent agrees reasonably well with observations. The mean extent of simulated sea ice extent (concentrations above 15%) exceeds the observed values by up to roughly 1 M km2 throughout the year (Arzel et al.., 2006). This difference is with respect to the Hadley Centre Sea Ice and SST dataset (HadlSST, Rayner et al.., 2003), and is of the same order as differences between various sea-ice extent products (see discussion above). In many models the regional distribution of sea ice is poorly simulated, even if the hemispheric extent is approximately correct (Arzel et al.., 2006; Zhang and Walsh, 2006). The biases may influence the model climate sensitivity. There is a tendency for models with relatively large sea-ice extent in the present climate to have higher sensitivity. This is apparently especially true for models with low to moderate polar amplification (Holland and Bitz, 2003).

Among the primary causes of biases in simulated sea ice (especially its geographical distribution) are problems with high-latitude winds (Bitz et al.., 2002), ocean heat advection (Bitz, 2010) and vertical and horizontal mixing in the ocean (Arzel et al.., 2006). Also important are errors in surface energy fluxes (Sorteberg et al.., 2007), which may result from inadequate parameterizations of the atmospheric boundary layer in the Arctic and from generally poor simulation of high-latitude cloudiness which is evident from the large inter-model scatter (Vavrus et al.., 2009). Ice transport out of the Arctic Ocean through the Fram Strait (e.g., Tsukernik et. al., 2009) also needs to be adequately represented in AOGCMs.

[Outstanding issues]

One likely contributor to the observed rapid decline of the Arctic ice extent and thickness is multi-year and decadal climate variability. This includes factors such as heat storage in the upper layer of the ocean during the summer and ocean heat transport from the Atlantic and Pacific to the Arctic Ocean. Due to their coarse resolution, the AOGCMs tend to underestimate the amount of heat delivered to the sea ice by the horizontal oceanic heat transport. As shown in (Bitz, 2010), faster rates of decline in sea ice extent were produced in the climate models with larger heat transports to the Arctic Ocean from Atlantic.

There are a number of ways in which sea ice is influenced by and interacts with the atmosphere and ocean; and the nature and magnitude of associated feedbacks, both positive and negative, are still poorly quantified (e.g. NRC, 2003; Overland and Wang, 2010). Additionally, potentially important small scale processes, such as convection in brine pockets or in melt ponds, are not included in the sea-ice components of current AOGCMs. Possible impacts of black carbon aerosols that induce atmospheric warming and black carbon on snow and ice that decreases the surface albedo (e.g. AMAP, 2009) have so far only been examined in climate models in idealized model simulations (e.g. Hansen and Nazarenko, 2004).

In principle, the possibility exists that the sharp downward trend in ice extent is a statistically rare event associated with natural (unforced) climate variability. Until concentrations of GHGs reach higher values, climate signals from natural climate variability may be comparable in magnitude to those from external forcing. The CMIP3 ensemble arguably does not have enough members to capture low probability events. Additionally, the CMIP3 models appear to have limited abilities to generate unforced atmospheric variability with magnitude comparable to observations, e.g., the major Arctic warming event in the first half of the 20th century (Wang *et al.*., 2007). On the other hand, at least some of the CMIP3 models do simulate rapid changes in the Arctic sea ice due mainly to natural variability. The timing of the rapid ice decline events simulated by a model cannot be expected to match the ones observed, but at least the general character of the simulated (rapid) changes in some models resembles well the observed behaviour of the ice cover. Together with the possibility that the observational data for 1953-1978 (pre-satellite) may overestimate the earlier ice extent this means that the models may not be so bad after all at sea-ice hindcasting.

Improving predictions of sea ice conditions on seasonal through interannual timescales also bears on predicting its longer-term (century-long) fate. The eventual goal is a timescale-independent “seamless prediction” system. Motivated by the recent dramatic changes in Arctic sea ice, several groups (e.g. Drobot 2007; Lindsay *et al*.. 2008; Zhang *et al*.., 2008), have started to issue seasonal forecasts of Arctic sea ice conditions. So far these efforts have been either purely statistical or have used a sea ice-ocean model with atmospheric forcing prescribed from past years to predict the future sea-ice cover. These methods show a promise because sea ice exhibits autocorrelation, with a several months’ lag for the sea-ice extent (Drobot *et al*.. 2006, Lindsay 2008) and with a several years’ lag for the sea-ice volume (Bitz *et al*.., 1996; Flato *et al*.. 2004; L'Heveder and Houssais, 2001). Mixed layer heat storage in the ocean also offers some additional predictability (Lindsay 2008). A number of other groups are providing seasonal predictions of seasonal minimum extent for the SEARCH Sea-Ice Outlook Project. These groups also use a combination of statistical and uncoupled model estimates and expert knowledge. Only one group appears to use the statistics from a fully-coupled model, and none uses a coupled climate system model, akin to the methods employed e.g. for the ENSO prediction.

[Conclusions and recommendations]

Meaningful prediction/projection of the Arctic sea ice conditions for the coming decades and beyond requires progress in several interconnected areas of research and observations including:

- Determining priorities of observational and modelling developments (e.g. dedicated ice thickness satellite missions, sea-ice modelling allowing data assimilation, etc.) aimed at improving credibility of the sea-ice predictions and projections;
- Better understanding of the predictability of sea ice conditions on seasonal, interannual, decadal, and centennial time scales in the wider context of the polar climate predictability;
- Detection and attribution of the Arctic sea-ice change (*i.e.* quantification of the interplay of its forced and unforced aspects) and evaluation of the ability of the state-of-the art climate models to reproduce the observed sea-ice behaviour as a part of the broader climate system, with as full as possible accounting of ice-atmosphere-ocean processes, interactions and feedbacks.

CMIP5 will provide an opportunity to address some of these issues. We recommend undertaking a coordinated multi-aspect study of the Arctic sea-ice loss based on CMIP5 output (along with other diagnostic CMIP5 subprojects exploring different environmental problems). The WCRP could facilitate this effort, taking into account the timeline of AR5, by compiling a list of major study areas and approaching individual scientists and research groups with a request to organise and coordinate corresponding targeted diagnostic projects. Such a collective approach, coexisting with the previous “individualist’s” approach of CMIP3, may help the scientific community to study complex environmental problems, one of them being the Arctic ice loss, within the time limits of AR5 preparation.

Predictions and hindcasts on seasonal through decadal time scales will require model initialization, which was not done for the CMIP3 simulations. To draw conclusions about the success or failure in hindcasting the observed loss of the Arctic ice, reliable regional observations will be needed to initialize a number of fields, e.g. the sea-ice thickness distribution (because of the strong impact of the initial sea ice thickness on the change in ice extent) and enable verification. The same is true for the thermohaline structure of the ocean. In the absence of the data needed for the initialization, a possibility of generating a proxy of initial conditions through the use of regional models of the Arctic Ocean forced with the observed (reanalysed) atmospheric fields could be explored (Gerdes and Koberle, 2007). Some ongoing activities, especially the Arctic System Reanalysis, promise an important contribution towards solving this problem.

The record sea-ice extent minimum over the satellite record took place in September 2007, during the International Polar Year 2007-2008 (IPY). IPY efforts, many of which are ongoing, have generated a wealth of data. Also, there have been several projects directed at Arctic system prediction, including sea ice. Nevertheless, there has yet to be study that would unify efforts of the climate research community in analyzing available data in its entirety and using it to improve the prediction of the Arctic climate at different time scales. WCRP could propose to the climate and Arctic research communities to prepare a roadmap to an **AR**ctic **C**limate **HI**ndcasting, **M**odelling and Pr**ED**iction **E**xcersi**S**e (ARCHIMEDES). This initiative could benefit from a synthesis of work at very high resolution (e.g. a new SHEBA-like campaign – to better understand local processes, include sea-ice biogeochemical connections and validate various remote sensing algorithms), and as well regional and global observational, modelling, and data synthesis efforts. Such an initiative could become a cornerstone for the proposed International Polar Decade. An inventory of all Arctic data would help this major synthesizing activity.

References

ACIA, 2005: Arctic Climate Impact Assessment. Cambridge, Cambridge University Press. pp. 1042.

Alekseev, G.V., A.I. Danilov, V.M. Kattsov, S.I. Kuzmina, and N.E. Ivanov, 2009: Changes in the climate and sea ice of the Northern hemisphere in the 20th and 21st centuries from data of observation and modelling. *Izvestia of Russian Academy of Sciences: Physics of Atmosphere and Ocean*, 45, 6, 723–735.

AMAP, 2009: Update on Selected Climate Issues of Concern, AMAP, Oslo, 2009, v+15 pp., ISBN 978-82-7971-049-3

Arzel, O., T. Fichefet, and H. Goosse, 2006: Sea ice evolution over the 20th and 21st centuries as simulated by current AOGCMs, Ocean Modelling, 12, 401– 415.

Bitz, C.M, D. S. Battisti, R. E. Moritz, and J. A. Beesley, 1996: Low Frequency Variability in the Arctic Atmosphere, Sea Ice, and Upper Ocean Climate System. - *Journal of Climate*, *9*, 394-408.

Bitz C., G. Flato, J. Fyfe, 2002: Sea ice response to wind forcing from AMIP models. *J.Climate.* 15, 523–535.

Bitz, C., 2010, pers. comm..

Bony, S., R. Colman, V. Kattsov, R. Allan, C. Bretherton, J.-L. Dufrense, A. Hall, S. Hallegatte, M. Holland, W. Ingram, D. Randall, B. Soden, G. Tselioudis, M. Webb, 2006: How Well do we Understand and Evaluate Climate Change Feedback Processes? *J.Climate*, 19, 3445-3482.

Bromwich, D. H, Y.-H. Kuo, M. Serreze, J. Walsh, L.-H. Bai, M. Barlage, K. Hines, and A. Slater, 2010: Arctic System Reanalysis: Call for community involvement. *EOS Trans. AGU*, in press.

Drobot, S. D., J. A. Maslanik, and C. F. Fowler, 2006: A long-range forecast of Arctic summer sea-ice minimum extent, Geophys. Res. Lett., 33, L10501, doi:10.1029/2006GL026216.

Drobot, S. D. 2007: Using remote sensing data to develop seasonal outlooks for Arctic regional sea-ice minimum extent. -Remote Sens. Environ., 111, 136– 147, doi:10.1016/j.rse.2007.03.024.

Flato, G.M. and CMIP contributors, 2004: Sea-ice climate and sensitivity as simulated by global climate models, Climate Dynamics, 23: 229-241.

Gerdes R., and C. Koberle, 2007: Comparison of Arctic sea ice thickness variability in IPCC Climate of the 20th Century experiments and in ocean–sea ice hindcasts. *J.Geophys.Res*, **112**, doi:10.1029/2006JC003616

Hansen, J., and L. Nazarenko, 2004: Soot climate forcing via snow and ice albedos. - Proc. Natl. Acad. Sci., 101, 423-428, doi:10.1073/pnas.2237157100.

Hilmer, M. and P. Lemke, 2000: On the decrease of Arctic sea ice volume. *Geophys. Res. Lett.*, 27(22), 3751-3754.

Holland, M.M., C.M. Bitz, and B. Tremblay, 2006: Future Abrupt Reductions in the Summer Arctic Sea Ice, *Geophys. Res. Lett*, 33, L23503, doi: 10.1029/2006GL028024.

IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Kattsov, V.M., G.A. Alekseev, T.V. Pavlova, P.V. Sporyshev, R.V. Bekryaev, V.A. Govorkova, 2007: Modelling the evolution of the World Ocean ice cover in the 20th and 21st centuries. *Izvestia of Russian Academy of Sciences: Physics of Atmosphere and Ocean*, 43, 2, 165–181.

Kwok, R., G. F. Cunningham, M. Wensnahan, I. Rigor, H. J. Zwally, and D. Yi, 2009: Thinning and volume loss of the Arctic Ocean sea ice cover: 2003–2008, *J. Geophys. Res.*, 114, C07005, doi:10.1029/2009JC005312.

Kwok, R., and D. A. Rothrock, 2009: Decline in Arctic sea ice thickness from submarine and ICESat records: 1958–2008, Geophys. Res. Lett., 36, L15501, doi:10.1029/2009GL039035.

Lindsay, R. W., J. Zhang, A. J. Schweiger, and M. A. Steele, 2008: Seasonal predictions of ice extent in the Arctic Ocean, *J. Geophys. Res*., 113, C02023, doi:10.1029/2007JC004259.

L'Heveder, B., M.-N. Houssais, 2001: Investigating the variability of the Arctic sea ice thickness in response to a stochastic thermodynamic atmospheric forcing. - Clim. Dyn., 17, no. 2-3, pp. 107-125.

Maslanik, J.A., C. Fowler, J. Stroeve, S. Drobot, J. Zwally, D.Yi, and W. Emery, 2007: A younger, thinner Arctic ice cover: Increased potential for rapid, extensive sea-ice loss, *Geophys. Res. Lett*., 34, L24501, doi: 10.1029/2007GL032043.

Meier, W. M. 2005. Comparison of passive microwave ice concentration algorithm retrievals with AVHRR imagery in Arctic peripheral seas. *IEEE Transactions in Geoscience and Remote Sensing* 43(6): 1324-1337, doi:10.1109/TGRS.2005.846151.

Meier, W. N., and J. Stroeve, 2008. Comparison of sea ice extent and ice edge location estimates from passive microwave and enhanced-resolution scatterometer data. *Annals of Glaciology* 48(1): 65-70, doi:10.3189/172756408784700743.

NRC, 2003: National Research Council of the National Academies. Understanding climate change feedbacks. Washington D.C., National Academies Press, 2003, 152 p.

Overland, J. and M. Wang, 2010. Large-scale atmospheric circulation changes are associated with the recent loss of Arctic sea ice. *Tellus*, 62A, 1-9.

Perovich, D., R. Kwok, W. Meier, S. Nghiem, J. Richter-Menge, 2009: Arctic Report Card, Update for 2009. Sea-Ice Cover. October 19, 2009

Randall, D.A., R.A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R.J. Stouffer, A. Sumi and K.E. Taylor, 2007: Climate Models and Their Evaluation. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK and New York, USA.

Rayner, N., *et al*.. 2003: Global Analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *JGR, 108(D14), doi: 10.1029/2002JD002670*.

Rothrock, D.A., Yu, Y. and Maykut, G.A., 1999: Thinning of the Arctic sea ice cover. *Geophys. Res. Lett*. 26: 3469-3472.

Serreze, M.C. and C. M. Hurst, 2000: Representation of Mean Arctic Precipitation in NCEP–NCAR and ERA Reanalyses, J. Climate, 13, pp. 182-201.

Sorteberg, A., V. Kattsov, J.E. Walsh, T.Pavlova, 2007: The Arctic Surface Energy Budget as Simulated with the IPCC AR4 AOGCMs. *Climate Dynamics*, doi:10.1007/s00382-006-0222-9

Stroeve, J., M.M. Holland, W. Meier, T. Scambos, and M. Serreze, 2007: Arctic sea ice decline: Faster than forecast. *Geophys. Res. Lett.*, 34, L09501, doi:10.1029/2007GL029703.

Tsukernik, M., C. Deser, M. Alexander, R. Tomas, 2009: Atmospheric forcing of Fram Strait sea ice export: a closer look. – Climate Dynamics, doi: 10.1007/s00382-009-0647-z.

Vavrus, S., D. Waliser, A. Schweiger, and J. Francis. 2009: Simulations of 20th and 21st century Arctic clouds in the global climate models assessed in the IPCC AR4. *Climate Dynamics*, 33, 1099-1115.

Walsh, J.E., W. L. Chapman, D. H. Portis. 2009: Arctic Cloud Fraction and Radiative Fluxes in Atmospheric Reanalyses. – J. Climate, 22, 2316–2334.

Wang M., Overland J.E., Kattsov V., Walsh J.E., Zhang X., Pavlova T., 2007: Intrinsic versus forced variation in coupled climate model simulations over the Arctic during the 20th Century. *J. Climate*, 20, 1084-1098.

Wang, M., and J. E. Overland, 2009: A sea ice free summer Arctic within 30 years? *Geophys. Res. Lett.*, 36, L07502, doi:10.1029/2009GL037820

Zhang, J., M. Steele, R. Lindsay, A. Schweiger, J. Morison, 2008: Ensemble 1-Year predictions of Arctic sea ice for the spring and summer of 2008, *Geophys. Res. Lett.*, 35, L08502, doi:10.1029/2008GL033244

Zhang, X., and J.E. Walsh, 2006: Toward a seasonally ice-covered Arctic Ocean: scenarios from the IPCC AR4 model simulations. *J. Climate*, 19, 1730-1747.

Appendix 8: The Way Forward for Calibrating Sea Ice Products

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Background

Sea ice data from space-borne passive microwave sensors provide one of the longest satellite climate records. The 30+ record shows significant declining trends in Arctic sea ice extent, particularly during the summer, and a small increasing trend with strong regional and interannual variability in the Antarctic.
Sea ice concentrations are derived from the measured brightness temperature – a function of the physical temperature and the microwave emissivity of the surface – using empirically derived algorithms. Over the years, several algorithms have been developed. Each algorithm is able to reasonably track the season and interannual variability, but each has limitations and significant uncertainties, most notably during summer melt conditions, over thin new ice, and near the ice edge. No single algorithm has been found to be clearly superior. Thus, several different products have been developed. The most commonly-used algorithms in the scientific community are the NASA Team and Bootstrap algorithm (e.g., Comiso et al., 1997), both developed at NASA Goddard. Other algorithm products include the Norsex (Nansen Environmental and Remote Sensing Center Arctic ROOS) and ARTIST (University of Bremen) algorithms. Other algorithms that are not (to my knowledge) used for publically distributed products include the Cal/Val or AES York (Hollinger et al., 1991; Ramseier et al, 1988), the Bristol (Smith, 1996).

Other algorithms, including an enhanced NASA Team algorithm (Markus and Cavalieri, 2000; often called NASA Team 2) and the ARTIST algorithm (Spreen et al., 2007) have been developed to take advantage of high frequency channels (85.5 GHz or 89 GHz) on SSM/I and AMSR-E (see below for acronyms) sensors. The algorithms provide improved spatial resolution and improved discernment of surface properties. However, they are not consistent with other algorithms and they are not applicable to the earlier period (1978-1987) of the SMMR period, as well as some parts of the SSM/I record. Thus, they are not able to provide the longest consistent time series.

The problem with comparing algorithms is that it is not possible to do basin-scale validation – there simply isn't available "truth" data. Validation has been done primarily through case study evaluations using SAR, visible/infrared, and/or in situ data in limited regions over limited time periods (e.g., Kwok, 2002; Emery et al., 1994; Steffen, K., 1991; Cavalieri et al., 1991). Two of the more comprehensive evaluations compared the passive microwave concentrations over a variety of conditions and times of year (Andersen et al., 2007; Meier, 2005) found that the performance of the algorithms varied depending on atmospheric and surface conditions. It was not possible to determine a clearly superior algorithm.

Impacts of Multiple Sea Ice Products

For each of the algorithm products, there are dedicated user communities, particularly for the NASA Team and Bootstrap algorithm, both of which are distributed by NSIDC. (There are roughly three times as many NASA Team users [737 users according to latest user statistics] as Bootstrap [286 users]). There are also a number of users of the AMSR-E sea ice products, which in addition to the NASA Team 2 concentration also makes available a Bootstrap product. It should be noted here that the follow-on to AMSR-E, AMSR2, to be launched in late 2011, on the JAXA GCOM-W satellite, has selected the Bootstrap to be the primary algorithm, although the NASA Team 2 and ARTIST products will be available as "research products". A different standard algorithm product is possible for the NPOESS MIS sensor if and when it is launched.

So, if anything, the family of sea ice products is growing and diversifying. Within each dedicated knowledgeable user community, the issues may not be relevant. As long as they understand the algorithms and their limitations and use them properly, any algorithm is potentially suitable.

However, sea ice has been found to be an important component of the global climate system with impacts across a broad spectrum of activities – e.g., climate modeling, biological monitoring, native populations, resource access, national sovereignty, national defense, tourism. These varied communities do not have the detailed experience with the vagaries of passive microwave remote sensing. They need one sea ice product, with clear associated uncertainty estimates and metadata. In addition, sea ice has become an icon of climate change in the non-science community of politicians, educators, students, media, and the general public. They also do not understand the details of the different products and varied estimates from the products sows confusion within the public discourse.

The Way Forward

While individual products will likely continue into the future due to dedicated user bases who want continuity in their research, the way forward is to come to a consensus on a general "authoritative" reference product that can be referenced by the wider (i.e., non sea ice scientist) community. Essentially, the need is for a climate data record that includes a standard sea ice concentration field, a data quality field, and associated metadata and documentation to allow for proper use.

There are several NOAA Climate Data Record (CDR) projects being funded, including at least two directly relating to sea ice products (W. Meier is PI on one and co-PI on the other) through the NOAA Scientific Data Stewardship program. There are also NASA Earth Science Data Record (the equivalent of CDRs) projects, though none (to my knowledge) specifically focused on passive microwave sea ice products. Finally, the European Space Agency is also developing a CDR to use as a basis for their operational sea ice products (and potentially other users).

The NOAA projects are developing metadata standards and parameters for data quality information as well determining a single standard product to be archived as a CDR. However, selection of a standard product should be a community decision. Thus, input from the scientific community is needed to develop a consensus view. It may be that a combined algorithm will prove to be the best decision or it may be one of the current products that have already been developed. A dedicated workshop with a representative group of invited users to review the current products and recommend future directions would be most useful, though town hall meetings at a scientific conference (e.g., AGU) where interested parties are likely to attend and/or some sort of online survey may be sufficient. CliC's support of such an activity would be beneficial because CliC can act an impartial arbiter and has the reputation within the polar science community to build a consensus. (NSIDC, as distributor of products, is not able to officially endorse either NASA Team or Bootstrap [or other algorithm] products.)

Because there is already a dedicated user community for several products, it is not likely that current products will be discontinued. However, they could be kept as secondary products at a lower level of support and little future development, while the official CDR would be the primary and most visible resource. In addition, because sensor systems have improved over time and algorithms to exploit those improvements (e.g., NASA Team 2 and ARTIST for AMSR-E), it likely makes sense to provide parallel CDRs: (1) a climate CDR that uses a consistent algorithm and methods from the beginning of the passive microwave record in 1978, and (2) an operational CDR that uses the best available sensor, algorithm, spatial resolution, etc. for any given time period to provide the most accurate estimates at that time (but will not be consistent over time, so not suitable for tracking long-term trends and variability over the full passive microwave record).

References

Andersen, S., R. Tonboe, L. Kaleschke, G. Heygster, and L. T. Pedersen, 2007. Intercomparison of passive microwave sea ice concentration retrievals over the high-concentration Arctic sea ice, *J. Geophys. Res.*, 112, C08004, doi:10.1029/2006JC003543.

Cavalieri, D.J., J.P. Crawford, M.R. Drinkwater, D.T. Eppler, L.D. Farmer, R.R. Jentz, and C.C. Wackerman, 1991. Aircraft active and passive microwave validations of sea ice concentrations from the DMSP SSM/I, *J. Geophys. Res.*, vol. 96, pp. 21989-22008.

Comiso, J.C., , D.J. Cavalieri, C.L. Parkinson, and P. Gloersen, 1997. "Passive microwave algorithms for sea ice concentration: a comparison of two techniques, *Rem. Sens. Environment*, vol. 60, pp. 357-384.

Emery, W.J., C. Fowler, and J.A. Maslanik, 1994. Arctic sea ice concentrations from special sensor microwave imager and advanced very high resolution radiometer satellite data, J. Geophys. Res., vol. 99, no. C9, pp. 18,329-18,342.

Hollinger, J.R., R. Lo, G. Poe, R. Savage, and J. Pierce, 1991. *Special Sensor Microwave/Imager Calibration/Validation*, Washington, DC, U.S. Naval Research Laboratory, Final Report.

Kwok, R. (2002), Sea ice concentration estimates from satellite passive microwave radiometry and openings from SAR ice motion, Geophys. Res. Lett., 29(9), 1311, doi:10.1029/2002GL014787.

Markus, T. and D.J. Cavalieri, 2000. An enhanced NASA Team sea ice algorithm, *IEEE Trans. Geosci. and Rem. Sensing*, vol. 38, no. 3, pp. 1387-1398.

Ramseier, R., I.G. Rubinstein, and A.F. Davies, 1988. *Operational evaluation of Special Sensor Microwave/Imager by the Atmospheric Environment Service*, Centre for Research in Experimental Space Science, York University, North York, Ontario, Report.

Smith, D. M., 1996. Extraction of winter sea-ice concentration in the Greenland and Barents Seas from SSM/I data, Int. J. Remote Sens., 17(13), 2625–2646.

Spreen, G., L. Kaleschke, and G. Heygster, 2007. Sea ice remote sensing using AMSR-E 89 GHz channels, J. Geophys. Res., 113, C02S03, doi:10.1029/2005JC003384

Steffen, K., and A. Schweiger, 1991. NASA team algorithm for sea ice concentration retrieval from the defense meteorological satellite program special sensor microwave imager: comparison with Landsat imagery, *J. Geophys. Res.*, vol. 96, 21971-21987.

List of sea ice concentration products:

National Snow and Ice Data Center: http://nsidc.org/data/seaice/
University of Illinois, Cryosphere Today: http://arctic.atmos.uiuc.edu/cryosphere/
Nansen Environmental and Remote Sensing Center Arctic ROOS: http://www.arctic-roos.org/
University of Bremen: http://www.iup.uni-bremen.de:8084/amsr/amsre.html
NASA Goddard: http://polynya.gsfc.nasa.gov/seaice_datasets.html
JAXA: http://www.ijis.iarc.uaf.edu/cgi-bin/seaice-monitor.cgi?lang=e
PolarView: http://www.seaice.dk/

Passive microwave sensor summary

Nimbus-5 Electonically Scanning Microwave Radiometer (ESMR), 1972-1977
Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR), 1978-1987
Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I), 1987-2009
DMSP Special Sensor Microwave Imager & Sounder (SSMIS), 2002-present
NASA Earth Observing Satellite Program Advanced Microwave Scanning Radiometer (AMSR-E), 2002-present
JAXA Global Change Observation Mission for Water (GCOM-W) AMSR2, planned launch Nov. 2011