Collaborative Research: Research, Synthesis, and Knowledge Transfer in a Changing Arctic: Science Support for the Study of Environmental Arctic Change (SEARCH)

Original Proposal Submitted to NSF January 2013

University of Alaska Fairbanks & Arctic Research Consortium of the U.S (ARCUS)

Note: After final negotiations, the following positions/activities that are discussed in the proposal were removed: the Arctic Observing Network Coordinator, the UAF Data Analyst, the Knowledge Exchange Fellowships, and Action Team #4 (Analyze Societal and Policy Implications of Arctic Environmental Change) was removed and the objectives were integrated into the other three Action Teams.

1. INTRODUCTION AND MOTIVATION

The Arctic is in peril. Its natural systems are undergoing large, and in many areas accelerating changes that stress local communities and challenge government agencies (Francis et al. 2009; Callaghan et al. 2011; Serreze & Barry 2011; Lovecraft & Eicken 2011). Many of the environmental changes have global consequences, as do many of the economic impacts of Arctic-focused industries (Huntington et al. 2012; Francis & Vavrus 2012; Huebert et al. 2012). Accelerating change is well documented, as is the degree of interconnection between transformations underway in different Arctic subsystems. This requires a faster and more comprehensive approach to anticipating ramifications of the changes coupled with a focused response on ever-shorter timescales.

Progress along these lines remains slow, however. Despite increasing data collections, understanding of recent changes and the flow of effective information has not kept pace with increasing demands. A significant part of this problem lies with poor coordination among scientists, agencies, and stakeholders. To remedy this situation, we propose a new framework that will lead to improvements and a transformation of the way in which scientists, decision-makers, and stakeholders work on issues of Arctic change. The new structure integrates recommendations of the Study of Environmental Arctic Change (SEARCH) and the Arctic System Science Program (ARCSS 2007) scientific communities.

The new framework addresses a major conundrum facing the Arctic research community: In a rapidly changing Arctic, how can researchers muster an effective response to the emergence of new, pressing scientific questions, while at the same time meeting the urgent information needs of stakeholders and government agencies? Building on scientific community input, partnerships with agencies and stakeholders, and collaborative networks that strengthen links to other national and international programs, we propose implementation of a support structure and a series of activities that will enable the U.S. Arctic research community to meet these complex challenges. The proposed framework leverages the resources of a network of researchers, agency personnel, and stakeholders interested in the problem of Arctic change (Fig. 1; see also Murray et al. 2012).

By fostering collaboration that allows for co-production of knowledge and exchange across a range of Arctic research disciplines and societal concerns, the proposed framework addresses the biggest challenge identified at the conclusion of the Fourth International Polar Year 2007-08 (IPY), paraphrased as “From Knowledge to Action” (K2A). Specifically, K2A highlights two challenges: 1) How can we ***synthesize*** a plethora of individual research findings and scientific products into a system-wide understanding of Arctic change? 2) How can such understanding ***empower*** the broad range of stakeholders to devise sustainable and effective responses to the problems and opportunities posed by Arctic change? As pointed out in assessments of the IPY (Krupnik et al. 2011; National Research Council 2012), these key questions remain unresolved. The new SEARCH framework was established by the Science Steering Committee (SSC) in working with a range of partners and other programs, and designed to focus on synthetic activities and connect these with needs from across the Arctic. The new SEARCH activities will help to collect, synthesize and understand the necessary information to explore scenarios of what futures are in store for the Arctic, how they may unfold, and how they might affect the rest of the global system.

The core of this proposal consists of a range of interlinked research and synthesis activities and involves the scientific community, agencies and stakeholders. Sections 2 and 3 provide background information about the evolution of SEARCH and its new orientation. Section 4 describes a proposed new SEARCH organizational structure and management structure. Proposed activities and SEARCH goals are detailed in Section 5. Products, outcomes and broader impacts are listed in Sections 6 and 7.

2. BACKGROUND: DEVELOPMENT OF SEARCH AND RESULTS OF PRIOR SUPPORT

SEARCH was conceived from the recognition of major changes in the Arctic ocean-ice-atmosphere system in the 1990’s and grew to a broadly interdisciplinary program focusing on observing, understanding, and responding to change (Morison et al. 2001; SEARCH 2003; a full timeline is available at: http://www.arcus.org/search/sciencecoordination/development). The Arctic Research Consortium of the U.S. (ARCUS) has facilitated SEARCH activities through a Cooperative Agreement with NSF, “Providing Organizational Support to the U.S. Arctic Science Program,” (ARC-0618885; $2,188,440

3/2008–2/2013). Additional support was obtained to further develop the SEARCH observing component (NSF ARC-0960363; 9/2009–8/2012; $23,017; "Task Force Activities to Aid with Design and Implementation Planning of the Arctic Observing Network - Phase 1"; PIs H. Eicken and J.E. Walsh).

One of the early foci for SEARCH was development of priorities for the IPY through a large community workshop (SEARCH 2005); the resulting report was heavily utilized in the creation of the Arctic Observing Network (AON). Work on AON continued with the Arctic Observation Integration Workshop in 2008 (SEARCH 2008) and an AON meeting in 2009 (SEARCH 2009), which focused on sharing AON results and providing recommendations for observing technologies and activities.

In spring 2008, SEARCH launched the Sea Ice Outlook (SIO; Overland et al. 2009; Calder et al. 2011). The SIO produces reports throughout summer on the expected sea ice minimum in an open process that synthesizes modeling and data analysis perspectives. Each year, over 20 U.S. and international groups contribute to the Outlook; the website receives over 40,000 hits a year and significant press attention. In 2011, an Outlook user survey showed it is valued by a diverse array of users, including scientists (e.g., by assessing modeling techniques), operational centers, resource managers (e.g., to help manage ice-dependent wildlife), educators (e.g., as a learning tool in classrooms), and the public. The National Research Council (NRC) cited the SIO as "one of IPY's key legacies" (NRC 2012). Building on the SIO, the Sea Ice for Walrus Outlook (SIWO) project was initiated to provide weekly reports and forecasts (April-June) on ice conditions relevant to walrus in the Northern Bering and southern Chukchi Sea. SIWO synthesizes weather and ice forecasts, satellite data, and local observations. It is used by subsistence hunters and coastal communities (V. Metcalf, Eskimo Walrus Commission, pers. comm).

In 2010, SEARCH and ARCUS organized the State of the Arctic Conference, which reviewed understanding of the Arctic system during rapid environmental change. The conference included over 200 talks, a day of international collaboration talks led by the International Study of Arctic Change (ISAC), and 220 posters, with 448 on-site participants and over 200 joining via webcast. Several media outlets covered the conference. Products included a resolution outlining recommendations for future Arctic science; a science highlights paper (Eicken et al. 2011a), a brochure for policymakers; and other digital media. This conference represented an important turning point in SEARCH, as it underscored the importance of information for policy and decision-makers in addition to efforts focused on scientific understanding.

Despite much progress made on AON, challenges remained. An AON Design and Implementation (ADI) Task Force led development of a report with detailed recommendations for the rigorous design and optimization of observing systems (ADI 2012). To link academic and agency efforts, SEARCH held a U.S. Arctic Observing Coordination Workshop in 2012 that brokered productive discussions and follow-up work between academic scientists, agency scientists, and resource managers (SEARCH, in press). At the same time, SEARCH turned its attention to the "Understanding Arctic Change" (UAC) component of the program through the UAC Task Force in collaboration with the ARCSS Committee. The resulting report detailed scientific questions and activities to advance system-level understanding; the SEARCH SSC adopted these recommendations into its planning efforts and this proposal (Walsh et al. 2012).

Intellectual Merit of Accomplishments: All SEARCH activities have been designed to advance knowledge of environmental arctic change. SEARCH has fostered new research efforts, such as AON and sea ice prediction projects, as well as individual research projects emerging from discussions at workshops and conferences. SEARCH white papers and reports summarize emerging research issues and key gaps by working with the broader community through committee and task force activities. In addition, SEARCH has strengthened arctic science by facilitating communication between academic scientists, agencies, and stakeholders to begin weaving together existing efforts.

Broader Impacts of Accomplishments: SEARCH has increasingly engaged stakeholders and agency personnel in activities to ensure that science recommendations (described in reports and white papers) address societal and decision-maker needs. In addition, activities such as the SIO and the SIWO specifically provide products to those outside the research community.

This proposal aims to translate past and future input from the broader research community, stakeholders and agencies into networked and cross-cutting activities that bring together observing, understanding and responding expertise within a more coherent and agile structure.

3. SEARCH VISION, MISSION, GOALS, AND FUNCTIONS

As a multi-agency interdisciplinary program that addresses Arctic change, SEARCH must meet inherent challenges of a complex program as it moves to full implementation. Therefore, SEARCH and ARCUS have led a collaborative strategic planning process to produce a clear vision and a supporting action plan, including: a new vision and mission; a set of prioritized cross-disciplinary five-year goals and objectives; a set of planned activities to achieve the goals that build on the energy and ongoing efforts of the research community and funding agencies, and that are responsive to decision-maker needs; and an organizational structure that allows SEARCH to be more thematically-focused and adaptive. Such a structure should also offer hooks for funding agencies to identify specific interests that can be supported.

The new SEARCH Vision is *achieving scientific understanding of Arctic environmental change to help society understand and respond to a rapidly changing Arctic*. The SEARCH mission is to provide a foundation of Arctic change science through collaboration with the research community, funding agencies, and other stakeholders.

The SEARCH five-year science goals will address the vision in areas of scientific and societal urgency, with significant input from the broader scientific community. They complement existing agency priorities and national research plans and support the overarching SEARCH science questions developed in the Understanding Arctic Change report (Walsh et al. 2012). The five-year science goals are:

1. *Improve Understanding, Advance Prediction, and Explore Consequences of Changing Arctic Sea Ice*
2. *Document and Understand How Degradation of Near-Surface Permafrost Will Affect Arctic and Global Systems*
3. *Improve Predictions of Future Land-ice Loss and Impacts on Sea Level*
4. *Analyze Societal and Policy Implications of Arctic Environmental Change*

Full descriptions of each goal and related objectives are available at www.arcus.org/search/goals. The goals integrate observing, understanding, and responding activities in a thematic approach and encourage multi-disciplinary activities. Each goal provides a central focus around which to explore issues within the physical (e.g., sea ice and land ice dynamics), natural (e.g., wildlife, tundra) and social (e.g., adaptation, public perception) sciences. They are not considered to be fully representative of the important science topics for SEARCH, but as those that are most ready for implementation, can be achieved in five years, and complement existing national Arctic science priorities (e.g., Interagency Arctic Research Policy Committee (IARPC) Research Plan, National Oceanic and Atmospheric Administration (NOAA) Arctic Vision & Strategy, U.S. Arctic Research Commission (USARC) Goals and Objectives, US Carbon Cycle Science Plan). New activities may be launched on an annual or biennial basis and can be driven from the scientific community. The specific activities proposed for each goal are described in Section 5.

The development of a new framework stems in part from detailed review of other science support structures relevant to SEARCH in combination with an analysis of strengths and weaknesses of SEARCH structure and activities, current best practices in organizational design principles, recommendations from community reports (e.g., Walsh 2012; ADI Task Force 2012), a Responding to Arctic Change workshop organized by ISAC (Murray et al. 2012), and solicited feedback. The new framework is organized around a small set of topic-oriented goals where interdisciplinary research and better integration with stakeholders is the only way to achieve advanced understanding and predictability (Fig. 1). SEARCH will maintain a focus in each of these research arenas to identify needs and challenges to help establish new research and development opportunities with funding agencies. SEARCH will also pursue critical synthesis activities that cut across these arenas, such as a well-coordinated science supporting the AON and an effort to develop Arctic Futures 2050 scenarios to align and prepare research in physical, ecological and societal domains for a possible new state.

The SEARCH activities and structure described in this proposal are designed to:

- Facilitate research activities across disciplines, among agencies, and across local-to-global scales;
- Advance scientific synthesis of data, model output, projections, and findings;
- Create networks of people that reduce overlap, promote efficiencies, and foster development of cross-disciplinary research programs;

- Develop information and tools useful to stakeholders and decision-makers;
- Enhance coordination between new and existing research efforts;
- Identify emerging issues in Arctic environmental change and contribute to prioritizing national Arctic research goals (such as past contributions to the NOAA Arctic Strategy or the IARPC Research Plan);
- Promote Arctic science and scientific discovery;
- Communicate Arctic research to the White House and Congress (through IARPC and the USARC), the private sector, and the public; and
- Collaborate with national and international science programs to achieve common goals.

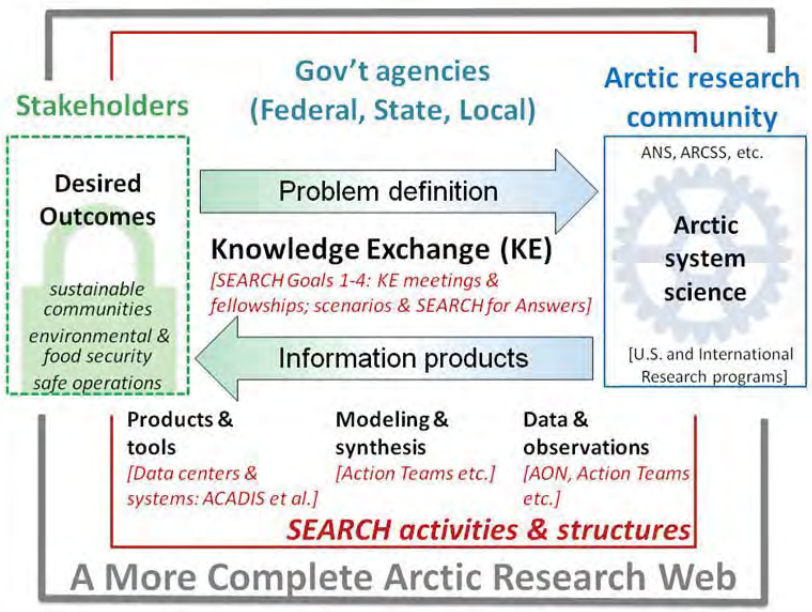

Fig. 1: Schematic illustrating how the SEARCH framework links research activities within Arctic natural science (ANS) and Arctic system science (ARCSS) while at the same time establishing a context for collaboration, coordination and exchange between the academic research community, agencies and stakeholders to address problems stemming from rapid Arctic change (see also Murray et al. 2012). ACADIS is the NSF-funded Advanced Cooperative Arctic Data and Information System.

4. NEW SEARCH STRUCTURE AND MANAGEMENT

SEARCH Structure: A more directly science-oriented organizational and support structure is necessary to address the issues of coordination, synthesis and stakeholder involvement as described above. This proposal, submitted on behalf of the SSC, seeks funding to implement the new framework (Fig. 2) and to support activities over a five-year time span. The SSC understands that agencies other than NSF and the private sector will contribute to the implementation. A core principle of the support structure is to channel scientific vision and guidance from the community, with focused, bottom-up activities contributing to the five-year goals. These activities will create opportunities for researchers, students, agency personnel and experts from the stakeholder and decision-maker communities to participate and benefit. These aims will be achieved by a hierarchy of Action Teams and ad-hoc Working Groups formed around the SEARCH five-year goals, supported by a Science Office with links to other relevant programs and entities, such as ACADIS and the University Corporation for Atmospheric Research (UCAR) National Climate Predictions and Projections support system (NCPP). The Action Teams will drive much of the science on the five-year goal timescale. They will be the nexus that links the research community to stakeholders and partners, and will be charged to refine and advance the mission of the focal question that is their subject.

The role of the ***SEARCH SSC*** will evolve into a committee tasked with ensuring that the SEARCH vision reflects the interests of the broader community SEARCH represents and that it is embodied in Action Team activities. The SSC will oversee other components within the SEARCH structure, monitor progress as outlined in Fig. 3 and Section 5 and adjust the program's trajectory. The SSC will work with the scientific community, drawing on the Action Teams, to develop the next set of five-year goals and to update SEARCH science plans. The SSC will help maintain linkages and serve functions relevant to partner agencies and other entities. This latter goal will be achieved in close collaboration with the

Science Office, which the SSC will oversee. The SSC composition would be diversified and may include more agency scientists and stakeholders, with a new SSC charter to be drafted.

The concept of ***Action Teams*** addresses several challenges confronting the scientific community. Integrating the former tri-partite approach of observing, understanding, and responding to change into each Action Team helps remove barriers that have hindered progress in the past. The Action Teams would serve as standing groups, each organized around one of the five-year goals, and responsible for implementing the specific goal activities detailed in Section 5. The Action Teams will supplant the current panel structure (with the Observing Change Panel transitioning into a different body, see below) and will be composed of 6–10 people, drawing from the broader community. They will include agency personnel and stakeholders with a range of disciplinary backgrounds and perspectives (including physical, natural, and social scientists on each Action Team). Each team will have funds for a postdoctoral researcher to help advance its goals, one month salary support for the Team chair, and project management support (see Postdoc Mentoring Plan and Budget Explanation in Supplementary Documentation).

To maintain flexibility, involve broader segments of the scientific community and increase capacity without creating more standing committees, Action Teams or the Science Office will have the ability to convene short-term ***Ad-hoc Working Groups*** on an as-needed basis. These groups are modeled after the SEARCH working groups driving the sea ice outlook efforts (SIO, SIWO) and structures successfully employed by the CLIVAR (Climate Variability and Predictability) and PAGES (Past Global Changes) programs. They will help address specific issues, such as development of modeling tools, review of data and information products, or address activities that integrate across the five-year goals (see also Fig. 3).

Management of SEARCH: With oversight and guidance from the SSC, a SEARCH ***Science Office*** will perform all the program management functions and will forge cooperative relationships between academia, agencies, and stakeholders. The Science Office will consist of three connected components.

(1) The ***Executive Director*** (ED) will be responsible for all tasks related to implementing SEARCH, will oversee day-to-day activities, and will report to the SSC. A program of this size cannot be effectively run through volunteer efforts alone. The ED will oversee and track progress of the Action Teams, serve as the primary contact for SEARCH and as a liaison to agencies, and ensure transparent communication between all constituencies. The ED will also work with the SSC to develop annual program plans articulating clear and measureable annual milestones. At least initially, the ED would be located at the International Arctic Research Center (IARC) at UAF. Further details are available in the UAF Budget Explanation section.

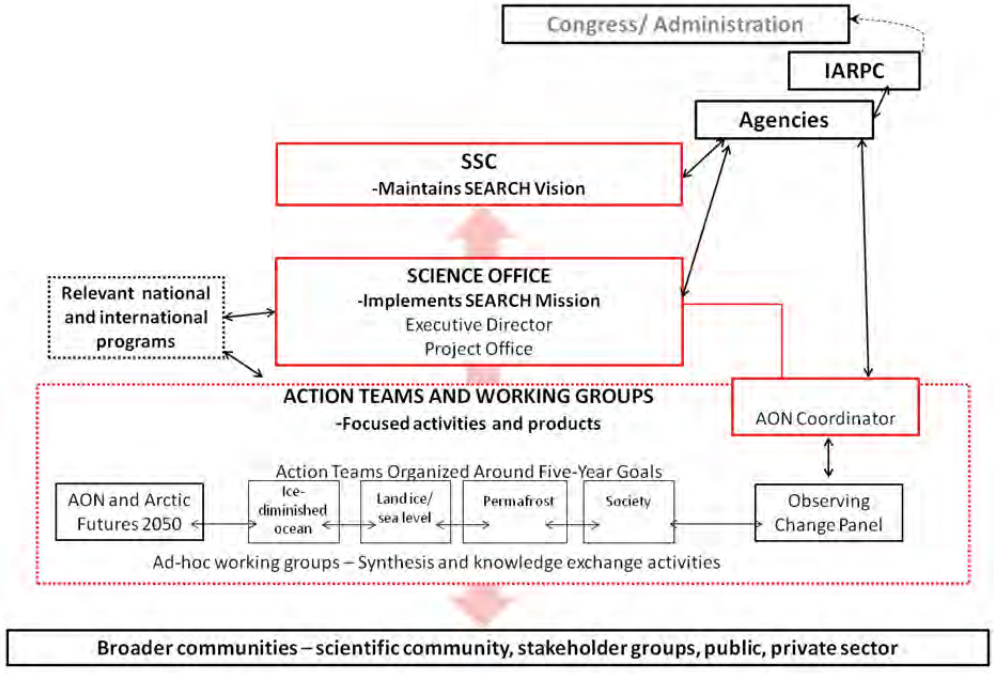

Figure 2: Schematic outline of a community and framework built around SEARCH science.

(2) The ***Project Office*** (PO) functions will be provided by ARCUS, which has a proven track record of support for SEARCH. PO responsibilities include: strategic planning, project management, meeting planning, web development, organizational support for Action Teams and the SSC, and communications and outreach. ARCUS will be responsible for ensuring timely and open exchange of information, milestones, and products between all SEARCH components and to the science and stakeholder communities. ARCUS will also ensure ongoing connection and communication between the Action Teams and collaboration that leads to synthesis products (see Fig. 4). After the kick-off meeting in Year 1 (Fig. 3), the PO will work with the ED, AC, SSC, and Action Teams to develop a program plan that provides an annual timeline and milestones for SEARCH activities. Through this program plan the SSC will track SEARCH accomplishments and adjust plans, if needed. Details on PO duties are available in the ARCUS Budget Explanation.

(3) The ***AON Coordinator*** (AC) will focus on activities that ensure the interagency AON is meeting the needs of the scientific and stakeholder communities. Success and coordination for AON can only be achieved through a dedicated point person to integrate needs, responsibilities and deliverables. The AC will translate needs and findings between the Action Teams into agency recommendations for AON; facilitate advances in AON data management; and lead a review of observations with respect to SEARCH goals and objectives. These objectives are achieved by having the AC work closely with ACADIS, the NSF AON Program Director and the IARPC implementation groups that focus on AON. The position would be co-located with ACADIS and UCAR in Boulder (see Data Management Plan and UAF Budget Explanation). To aid in the transition to a new SEARCH structure, the SEARCH ***Observing Change Panel*** (OCP) will remain in place and work closely with IARPC for the next two years (Fig. 3).

In addition, after the first year of implementation, SEARCH will convene an external advisory board for a review of SEARCH activities on an annual or biennial basis (Fig. 3). SEARCH will interact with agency representatives at several levels. The ED will hold the primary responsibility of high-level interaction with agency representatives, including IARPC. Agency scientists have already been an integral part of the SEARCH SSC and panels but will be included at a greater level in future SSC member rotations and will also be included on each Action Team. The broader scientific community will be represented on the Action Teams and related Working Groups, and will have opportunities to participate directly in many of the SEARCH activities (e.g., Knowledge Exchange Workshops, synthesis activities). In addition, SEARCH will hold townhall meetings at large conferences and offer webinars for community input.

Details on support structure implementation and administration are provided in the Budget Explanation. As SSC Chair, H. Eicken serves as PI on this proposal and will lead the initial implementation of the support structure as faculty member at UAF with a joint appointment at UAF's IARC. Once the ED and AC have been hired through a search committee based out of UAF but with representation by the SSC and key SEARCH partners (such as ACADIS), some of the functions initially served by the PI would devolve to these two positions. While ED and AC report to the SEARCH SSC, the IARC Director serves as the employment-based supervisor.

5. PROPOSED ACTIVITIES

Each of the four 5-year goals will have a specific set of activities, discussed in sections 5.2. In addition to these focused activities, SEARCH will implement cross-cutting activities that integrate across the goals to provide a more holistic system-level approach, resulting in products and outcomes detailed in Fig. 4.

5.1. Cross-cutting activities and integration framework

The four SEARCH goals originate in different disciplinary areas, involve different members of the research community, and tend to interact with different sets of stakeholders and partners. Yet, accomplishing the SEARCH mission requires integration across these themes, to be achieved through a series of connected activities, culminating in a range of products and an overarching assessment of the state of Arctic research and a vision for "Arctic Futures 2050" (Fig. 3).

A major outcome of activities is the **Arctic Futures 2050** scenarios process and open science meeting. The development of scenarios is a potentially transformative activity that has recently gained traction in

the Arctic science community (Brigham 2011; Meisen & Macklin 2012; Richter-Menge et al. 2012). Scenarios describe plausible future states of the Arctic system or its components based on recent trajectories and projected changes. They combine a range of data including climate model output, paleo-data, results from data synthesis and systems modeling as well as expert scientific and traditional ecological knowledge (Eicken & Lovecraft 2011). A recent international workshop on Responding to Arctic Change (Murray et al. 2012), organized by ISAC with participation by SEARCH, underscored the potential for scenarios development and modeling as a tool to achieve synthesis and integration while at the same time meeting stakeholder information needs and characterizing uncertainty.

Arctic Futures 2050 will focus on plausible states of the Arctic by 2050, potential trajectories leading up to these states, and identification of key uncertainties and variables that can be tracked to anticipate and respond to such change. The data, information products and modeling tools that inform the scenarios will be developed jointly with, e.g., the USGS Alaska Climate Science Center and UCAR's NCPP support system. A UAF summer school in partnership with the North Slope Science Initiative (NSSI) and the Association of Polar Early Career Scientists in Year 3 will set the stage for scenario development and synthesis. Findings from each of the five-year goal activities will feed into the scenarios development, and collaborative tools will be created that allow for advanced scenarios development and analysis through on-line participation (Gauger & Mueller-Stoffels 2007; Mueller-Stoffels & Eicken 2011).

These efforts will expand through Years 4 and 5 to generate cross-cutting, synthetic scenarios and assessments (Fig. 3), culminating in the **Arctic Futures 2050 Open Science Meeting** in Year 5. This capstone conference will be patterned after the 2010 State of the Arctic Meeting and the 2003 SEARCH Open Science Meeting, also to help identify future research directions. These activities will bring together a diverse cross-section of scientific disciplines and stakeholders, driven by decision-maker information needs. Scientists and stakeholders will define framing questions and jointly establish tangible products (Fig. 4). While the scenarios speak to the state of the Arctic by mid-century, such a long view is key to identifying major uncertainties and associated indicator variables. The latter can then be tracked by observing networks to help anticipate major state changes in the Arctic system much earlier than mid-century target dates (Eicken & Lovecraft 2011). Findings from scenario development will inform AON design and other synthesis activities throughout and beyond the project period.

To set the stage of Arctic Futures 2050 and all other activities, a **Kick-off Meeting** will gather the SSC, Action Teams, and stakeholder and agency representatives. This meeting aims to articulate the SEARCH vision in the context of planned action team activities, create a shared purpose, identify the top priorities and information needs flowing from stakeholder interests and concerns, and then review and adapt the collaboration and synthesis framework to the tasks and associated deliverables at hand. The meeting will result in a clear set of agreed upon products and plans for each activity, and, equally important, establish collective trust and momentum for the program objectives.

The initial Kick-Off meeting would be followed by collaboration and establishment of activities at the Action Team level. Here online communication and – where appropriate – **Goal Workshops** (focused on the five-year goals) will drive the development of products and initial synthesis.

AON Coordination and Support is a distinct activity because of its unique needs that cut across themes. The ADI Task Force (2012) and an interagency Arctic Observing Network coordination meeting in March 2012 have provided recommendations for optimizing and coordinating an interagency AON. SEARCH will work with agencies to implement community recommendations; guiding AON to meet scientific, agency, and stakeholder needs including local observational and citizen science networks; and developing AON data products. The AON coordinator (AC, see Section 4) would facilitate and oversee these activities. A Responding to Change Stakeholder Workshop planned by ISAC (Murray et al. 2012) will contribute to SEARCH goals as well. A pilot project activity in collaboration with ACADIS and Action Team postdocs would be initiated in Year 2 to create a data/information product from existing AON data and Action Team activities that will address stakeholder information needs (Fig. 3). These products would also align with identified metrics to aid in the prioritization and siting of observations, thereby addressing a key recommendation from the ADI Task Force.

The AON Coordination Workshop led to the formation of ad-hoc working groups that can address AON issues within the SEARCH goals structure. As an example, the Barrow flagship site, comprising major AON projects, federal and state long-term observing programs and infrastructure and community support, lends itself to a cross-cutting design and optimization study because it links key science questions and processes in the coastal region. Similarly, emerging IARPC working groups with SEARCH membership can provide guidance on how to best implement an effective AON management structure as outlined in the ADI Task Force report. Through close collaboration with IARPC Implementation Groups, these SEARCH activities would help support the transition of the AON into a true interagency effort under the auspices of IARPC. Here, the SEARCH ED and AC can also rely on collaborative efforts such as the international Arctic Observing Summit (AOS, Fig. 3), planned as a biennial event under the auspices of ISAC and the Arctic Council's Sustaining Arctic Observing Networks (SAON) initiative. The SEARCH OCP and the SSC Chair are helping lead planning for this first summit and will use this forum as a way to engage the broader international community in the goals outlined below (see also Fig. 3).

For each of the four science goals and for AON, an online "dashboard" webpage, modeled on the "Arctic Report Card" project, will be developed. This "dashboard" webpage will provide an easy-to-read, real-time graphical presentation of the status of each theme—a status of science objectives, activities, progress or challenges, new findings and products. The dashboard will result in not just greater transparency in assessing progress but will also allow for closer management and tracking of tasks over time. Anyone would be able to go to the dashboard webpage to get a quick at-a-glance overview for each goal.

Building on earlier recommendations by the broader SEARCH community (Walsh et al. 2012), an important element of advancing the SEARCH vision is the establishment of **Knowledge Exchange (KE) Fellowships**. These address the challenge of cooperation across the different perspectives among and within academia, stakeholder organizations, and agencies. Fellowships will allow agency personnel and stakeholders to immerse themselves in an academic environment. Junior researchers (Ph.D students or post-docs) will participate in a reciprocal arrangement with an agency or stakeholder organization (e.g., for a week up to several months). Knowledge gained through these fellowships will be shared within the SEARCH structure and inform activities (e.g. KE workshops). Such bridge-building between the scientific and stakeholder communities is at the core of this proposal and these fellowships are an investment in improving communication between these communities, and pave the way for a new generation of scientists who are more aware of stakeholders' needs. Based on preliminary communications, private sector support for this program is anticipated. Agency-based leadership programs (Developmental Assignment) will be another source of support. The SEARCH SSC received positive feedback from a similar assignment by National Marine Fisheries Service personnel to the SEARCH SIWO in 2012.

Knowledge Exchange (KE) Workshops in Year 2 will build on the activities of Year 1 and bring together stakeholders, academic and agency researchers, and agency program managers to network, identify emerging issues, synthesize and improve access to existing datasets and model output (with ACADIS' Arctic Data Explorer tool as an important resource), and link to other activities and programs that are currently not active at this interdisciplinary breadth. The goals of each workshop will differ, but none will be typical of traditional scientific or planning meetings. Rather, these meetings will serve as a forum for knowledge co-production, identified as a key prerequisite for the development of actionable science and sustainable solutions addressing rapid environmental and socio-economic change (Kerkhoff & Lebel 2006; National Research Council 2012). A major tenet of SEARCH's new approach is to facilitate more personal interactions between different communities so that the exchanges of information, planning ideas and community needs are more fully appreciated and common goals are formed at the onset with a deeper more effective awareness of the challenges and consequences faced by each involved participant.

In subsequent years, these collaborations and networking activities will increasingly seek to develop ties between the different themes as guided by the Action Teams (Fig. 3). For example, joint workshops and cross-cutting KE fellowships will provide overarching perspectives on scientific problems and stakeholder concerns related to, e.g., a changing Arctic Ocean and coastal processes impacted by thawing permafrost.

Communications, Networking and Outreach, inherent in all of these activities, will be coordinated and organized by the Project Office. A re-structured SEARCH website will serve as the central public information resource on all SEARCH science and activities. A thematic portal will be developed for each of the five-year goals, with information on scientific results, activities, people, and products. A section of the website will be devoted to information products for decision-makers and the public, with scenarios as an ideal tool to engage these constituencies (e.g., Smith 2010). The website will be built on a dynamic database structure to allow for advanced search, filter, and user-centered tools. An open webinar series will provide opportunities for presentation and discussion of science findings or challenges. SEARCH will also organize annual informational Congressional briefings on policy-relevant Arctic change topics. Through these different activities, SEARCH will be in a position to serve as an Arctic science 'think tank', or **"SEARCH for Answers"**. Thus, scientists, agency personnel, public, the media and decision-makers will be able to contact SEARCH for Answers with scientific questions related to the five-year goals. A clear process for queries will be developed and managed through the SEARCH Project Office.

The products outlined in Fig. 4 will serve as milestones for a review of progress by the SSC on an annual basis. These SSC meetings will also serve as a venue to review and as necessary recalibrate the direction of SEARCH vis-à-vis the perspectives of the scientific community (through input at townhall meetings, etc.) and agencies (through guidance by IPMC and IARPC). Arctic Observing Summits and other meetings led by ISAC will provide a similar venue for review of activities at the international level.

5.2. Activities to Implement the Five-Year Goals

5.2.1. Goal #1: Improve Understanding, Advance Prediction, and Explore Consequences of Changing Arctic Sea Ice (Co-lead J. Francis, Rutgers University, Co-Lead TBD)

Core activities for this goal (Fig. 3) are (i) assessing the predictability of summer Arctic sea ice extent, thickness and properties on seasonal to decadal timescales and improving ice forecasts, and (ii) exploring consequences of the changing ice cover on Arctic ecosystems, the global climate system, and people.

Ongoing Activities: Through ongoing work led by SEARCH in partnership with US and international programs (World Climate Research Program, Climate and Cryosphere, CliC; World Meteorological Association Polar Prediction Project; and others), the sea ice prediction component has already made significant progress, resulting in the establishment of two communities of practice centered around seasonal pan-Arctic prediction (SIO; Calder et al. 2011) and regional information products related to ice use and marine mammal habitat (SIWO; Eicken et al. 2011b). These communities support their activities by leveraging a broad range of international resources, and developing partnerships with agencies (e.g. NSF; NOAA, National Weather Service; NASA IceBridge flights) and others (Eskimo Walrus Commission). The activities generate data products and sea ice forecasts; surveys and interaction with users indicate that these products are used by residents from coastal communities, resource managers and to a lesser extent industry. We anticipate that community activities can be sustained using existing funding opportunities. The team will leverage past and current research projects focused on how rapid Arctic change is affecting local ecosystems and the climate system beyond the borders of the Arctic. Gaps in our knowledge of these connections will be identified, prioritized, and explored for possible agency-funded investigations.

Collaborative Scenario Development "Arctic Futures 2050": The framework and activities are part of an iterative process where, (1) stakeholders identify questions of concern related to consequences of an ice-diminished Arctic by 2030-50; (2) the research community develops independent scenarios of ice-diminished Arctic Ocean futures for 2030-50 using collaborative on-line tools (e.g., model simulations); (3) stakeholders review the scenarios and potentially refine questions or ask new ones; (4) researchers explore ways in which data and information products can address stakeholder questions and further refine the scenarios; and (5) further iterations occur as necessary. Products from this activity will include scenarios presented in the form of narratives, visuals, data and information products, model output, and summary documents that are written up specifically for different audiences (e.g., policymakers, general public, transportation industry etc.). These theme-based products will then tie into the overarching KE meeting and Arctic Futures 2050 Open Science Meeting (Section 5.1, Fig. 3). Due to the pan-Arctic, international relevance of this goal, we will partner with ISAC (details in Murray et al. 2012).

Kick-off and Knowledge Exchange Meetings: These meetings will foster collaborative work that cannot occur without networking and building new interdisciplinary research programs. A new study from the National Academies of Science (Richter-Menge et al. 2012) provides a wealth of information about the current state and future directions of sea-ice prediction and stakeholder needs for sea-ice products on seasonal and decadal time scales. This report and stakeholder participation will guide Action Team activities and will drive the kick-off meeting, Year 2 workshop and Year 3 KE meeting (Fig. 3). Support lined up by CliC, ONR Global and others for the nascent sea ice prediction network will foster working group activities under the guidance of the Action Team and lead into KE meetings and other activities connecting sea ice change with ecological and global impacts. Outcomes will be determined by further work at the team and Working Group level to include, e.g., a synthesis of plausible consequences of an ice-diminished Arctic Ocean on ecosystems on 5-10 year time scales, analysis of the value of geographic or paleo-analogs for sea ice in a warming Arctic, summarized findings from other research (e.g., NOAA's Synthesis of Arctic Research), and lessons for ecosystem managers, regulators, Arctic coastal communities and policymakers.

Knowledge Exchange Fellowship: We propose two KE fellowships that would allow (i) an agency representative to join an academic research group focusing on, e.g., links between a changing ice cover, marine mammals, ecosystems and people, and (ii) a junior researcher to work with an agency to gain insight into translation of management mandates into science questions.

5.2.2. Goal #2: Document and Understand How Degradation of Near-Surface Permafrost Will Affect Arctic and Global Systems (E.A.G. Schuur, University Florida, Lead)

The tentative sequence of planned activities follows the plan outlined in Fig. 3. Briefly, this goal is composed of science, coordination, and communication objectives. The science objective has three main themes: (i) improve observation and prediction of the nature, timing, and location of permafrost thaw; (ii) improve prediction of how degradation of near-surface permafrost will influence the dynamics of the Arctic landscape; (iii) improve prediction of how permafrost degradation will influence fish, wildlife, and human communities. Each theme will be managed by independent Working Groups put in place by the Action Team with guidance from the SSC.

Related National and International Activities: Opportunities for progress toward this goal will benefit from linking with ongoing US activities such as the Permafrost & Carbon Research Coordination Network (RCN), NASA's Carbon in Arctic Reservoirs Vulnerability Experiment and Arctic-Boreal Vulnerability Experiment, Department of Energy's Atmospheric Radiation Measurement program and Next Generation Ecosystem Experiment - Arctic (see letter of support in Supplementary Documentation), and Department of Interior's Landscape Conservation Cooperative initiative. There are a number of international activities and networks, some currently with U.S. participants, that could also be linked, such as the Global Terrestrial Network for Permafrost, the Circumpolar Active Layer Monitoring program, the Changing Permafrost in the Arctic and its Global Effects in the 21st Century project, and the Arctic Monitoring and Assessment Program of the Arctic Council. Currently these initiatives are only loosely coordinated. SEARCH can facilitate their coordination, seek additional national and international partners (especially in industry), and develop outreach and education materials based on a synthesis of results from these projects that can be used to inform critical stakeholders and decision-makers.

Working Groups and Community Meetings: After the kick-off meeting each working group will hold an initial community meeting to assess the state of the art in research for their theme, identify the areas or specific topics most important to advance the science, and lay out a first coordination and activities plan (Fig. 3). As is the case with Action Teams, each Working Group will interact primarily via email and conference calls, along with an annual face-to-face meeting. The community-wide, open meetings in Years 2 and 4 will help define and review the focus and progress, and to summarize the results.

Scenario and Data Product Development: Each Working Group will engage with key Arctic stakeholders, agencies, and the research community to identify a set of scenarios for likely impacts of permafrost degradation on ecological and human communities. Additional expertise and guidance will be provided by the Action Team for Goal #4. The scenarios will be used to identify where data already exist

to address the community-generated scenarios and where tangible, urgent research questions could be addressed in the short-term. Outcomes from these activities will allow working groups to facilitate the development of potential partner-funded research projects to develop the data products needed to address the scenarios defined by the community. In Year 5, the Action Team will create a summary report that provides a community view on the trajectory of future permafrost change and the likely impacts on Arctic and global systems. The report will summarize the accomplishments of the Goal #2 theme, evaluate the scenario analyses, describe available data products, and outline additional research needed to address the next priorities as SEARCH continues to evolve (the latter in coordination with IARPC and USARC).

Knowledge Exchange Fellowships: We propose to coordinate at least two extended stays by an agency representative (e.g., USGS, USFWS) with an academic research group and the placement of at least two junior permafrost researchers with a partnering agency.

Research Coordination Activities: We will build on the successful Permafrost & Carbon RCN. This network has taken the first steps to coordinate the community of researchers who focus on carbon dynamics in the permafrost zone, and to synthesize scientific information into datasets useable by regional and global models. The Action Team will expand that coordination (facilitated through the community meetings and scenario development activities) to include the broader context of permafrost research, including changes in permafrost temperatures, permafrost extent, and landscape evolution and also facilitate connections with potential stakeholders to include community leaders, industries, non-governmental organizations, and policy-makers. As an outcome of increased research coordination and synthesis, the Working Groups will be able to evaluate how scientific information and knowledge is assimilated by potential end users and will seek partner funding to begin to address questions that also meet end users' interests. An ongoing activity within ACADIS to benefit the activities is the development of a data "showcase" focused on borehole temperature data, designed to standardize data formats from automatic loggers to facilitate broader data reuse.

Communication: In addition to communication and outreach activities (see 5.1), we also propose to produce and circulate an annual "State of Permafrost Research" report that summarizes Working Group progress, and observations for existing networks. This product will assist in the location, analysis and digestion of important and useful existing permafrost data and will be designed for use by influential, non-technical audiences.

5.2.3. Goal #3: Improve Predictions of Future Land-ice Loss and Impacts on Sea Level (F. Straneo, Woods Hole Oceanographic Institution, and T. Scambos, National Snow and Ice Data Center, Co-Leads with assistance from SSC member R. Bindschadler)

Progress in this goal requires a multi-faceted approach as the environmental science involves not only ice and ocean processes, but also atmospheric dynamics and geodesy, and while the topic intersects the interests of many funding organizations, it falls fully within none. Thus it is imperative that the funding agency representatives be engaged in the discussion leading to an integrated, multidisciplinary research strategy so that a coherent, feasible and meaningful research program is formulated. Specific Working Groups have yet to be defined but likely will be led by scientists with expertise in the areas of atmospheric dynamics (or coupled-climate modeling) and geodesy as well as stakeholder representatives of groups directly impacted by sea level rise (e.g., coastal communities, fisheries or coastal industries and perhaps the US Navy), so that the Action Team covers not only the environmental processes at play, but also represents those impacted by rising sea level.

Participation in ongoing national and international activities: SEARCH's integrated, end-to-end approach will complement existing activities related to the land ice/ sea level goal. It will leverage existing reports defining necessary science (e.g., the recent white paper from the U.S. CLIVAR Working Group on Greenland Ice Sheet/Ocean Interactions; U.S. CLIVAR 2012), informal discussions held to discuss the establishment of a new observational network, and an upcoming U.S. CLIVAR and other agencies-sponsored workshop on Greenland Ice Sheet mass change**.**

Kick-off and Knowledge Exchange Meetings: The initial meeting will help participants see the Land Ice/Sea Level topic through new eyes and better appreciate the financial and technological limitations of

what is possible. Broad participation during the meetings is encouraged, and some meeting talks may be webcast. The outcomes of this meeting include specific plans that define what measurements must be undertaken, specific recommendations about where to undertake these studies, how to maintain these measurements and what products the studies must produce for which target audiences. A timetable will be established among the participants and agencies against which acceptable progress can be judged. This plan and timetable, then, define the tasks and pace of separate Working Groups. Meeting discussions may also assist funding agencies to identify an appropriate topic, timing, and scale of research solicitations.

Working group activities: These cannot be specified at this time, but current research provides a means to anticipate some of the tasks around which Working Groups might form. In the case that the initial meeting identifies two particular fjords (say, one in Greenland and one in coastal Alaska) that present a simple geometry or offer historical data or hold some other advantage as research sites, then an interdisciplinary Working Group might coalesce around each site with investigators skilled in establishing a suite of oceanographic instruments to be deployed at the near-ice and near continental-slope-break regions as well as on-ice GPS and meteorological sensors. Local residents could also be involved in some of the instrumentation maintenance (led by a post-doctoral researcher); and geodesists may contribute various past and future scenarios of local sea level rise to compare with local history and to give a sense of what the future might hold. Another Working Group might focus on the broader pattern of net sea level change, accounting for rates of uplift and sea level change, to identify and work with stakeholders in the most vulnerable areas to develop mitigation strategies tuned to the likely magnitude and rate of shoreline intrusion.

Knowledge Exchange Fellowship: An example of a KE fellowship would be a junior scientist placed in a local community and charged with ensuring the quality of data collected by local residents. Such an opportunity would provide valuable experience not only in communicating the importance of data collection and analysis, but also give the researcher a view into what scientific data and analyses are most meaningful to the local residents.

Contributions to Arctic Futures 2050 Synthesis: It is anticipated that the Working Groups active under this topic will make a number of specific contributions to SEARCH's synthesized assessment of the state of the Arctic in 2050. Predictions of land ice loss will provide not only the obvious projections of contributions to global sea level change, but geodetic analysis will provide a regional to local distribution of relative sea level along Arctic coastlines highlighting the risk level at each location. These risks impact human health, economic well-being and community stability, thus strongly influence public policy and link to the Action Team for Goal #4. Lost land ice exposes new ground, frequently permafrost, and alters the thermal gradients of remaining ice-covered ground giving the permafrost Working Groups new areas and thermal conditions to consider. Similarly, the discharge of increasing amounts of freshwater not only affects the oceanography of the fjords fed by the discharging glaciers, but also alters the broader-scale oceanographic circulation that can have a direct impact on the presence and movement of sea ice.

5.2.4. Goal #4: Analyze Societal and Policy Implications of Arctic Environmental Change (SSC members Susan Crate and Karen Pletnikoff will serve as primary contacts until an interim Team Lead has been appointed)

Humans, who are both agents of change and vulnerable to it, are integral to the rapid change in contemporary Arctic environments. Therefore, it is equally critical to understand how people living in the Arctic perceive, understand, and respond to those changes. Due to the interdependence the Arctic has with the rest of the world, it is also imperative to understand how Arctic change is perceived outside the Arctic, including how perceptions influence policy development which in turn influences the rate and extent of change. The aim of this goal is to understand Arctic inhabitants' experiences and responses to environmental change, and develop methods to anticipate future adaptations, assess and improve perceptions on the part of the public and policymakers, and raise general knowledge about Arctic environmental issues. The implementation of this goal requires two overall strategies.

The first will be to focus on the social science of Arctic change. Although humans are an integral part of the ecosystem, understanding them requires an approach that is vastly different from the other research

areas. The Action Team will undertake two major tasks: (1) summarize findings to date and identify gaps in knowledge about how Arctic communities, both urban and rural, are perceiving, understanding, responding, and adapting to Arctic change, and (2) generate a comprehensive assessment of societal response based on that summary. A post-doc will work with the team on this focus.

The second is to work towards the integration of society-policy issues into the other five-year goals, as well as into the AON and into the cross-cutting synthesis activities. For each of these tasks, society-policy issues will be used in concert with scientific needs, to define all products and activities. The Action Team for this goal will coordinate with each of the other Action Teams and AON to ensure that the society-policy issues within each five-year goal are sufficiently addressed by involving social scientists in the activities and KE workshops. The Action Team will also coordinate the participation of social scientists for an emphasis on society/policy issues in the scenarios development activities (see Section 5.1).

In addition to the activities undertaken within the SEARCH structure itself, SEARCH will advocate for funded research to address key scientific gaps for this goal. The gaps include:

- Cross-sectional and longitudinal studies of responses, policies, and unintended consequences of changes such as sea level and weather effects to provide insights for near-future choices;
- Rigorous studies of perceptions and knowledge about Arctic environmental issues among the general public, Arctic residents, and other stakeholders as relevant to policy development;
- Evaluation of the progress to date, including gaps and success, in efforts to communicate with and educate the broad public about Arctic change.

Building on research results, SEARCH and the broader Arctic science community can develop innovative ways to strengthen communication efforts through effective outreach and education approaches. In addition, there continues to be a need to entrain more society-policy experts in the Arctic science enterprise. This need will be addressed through targeted capacity-building activities, for example, through inclusion of social science experts outside the Arctic into SEARCH activities, networking at meetings, and closer collaboration with other U.S. and international programs with a social-science component (e.g., International Social Sciences Association, ArcticNet, etc.).

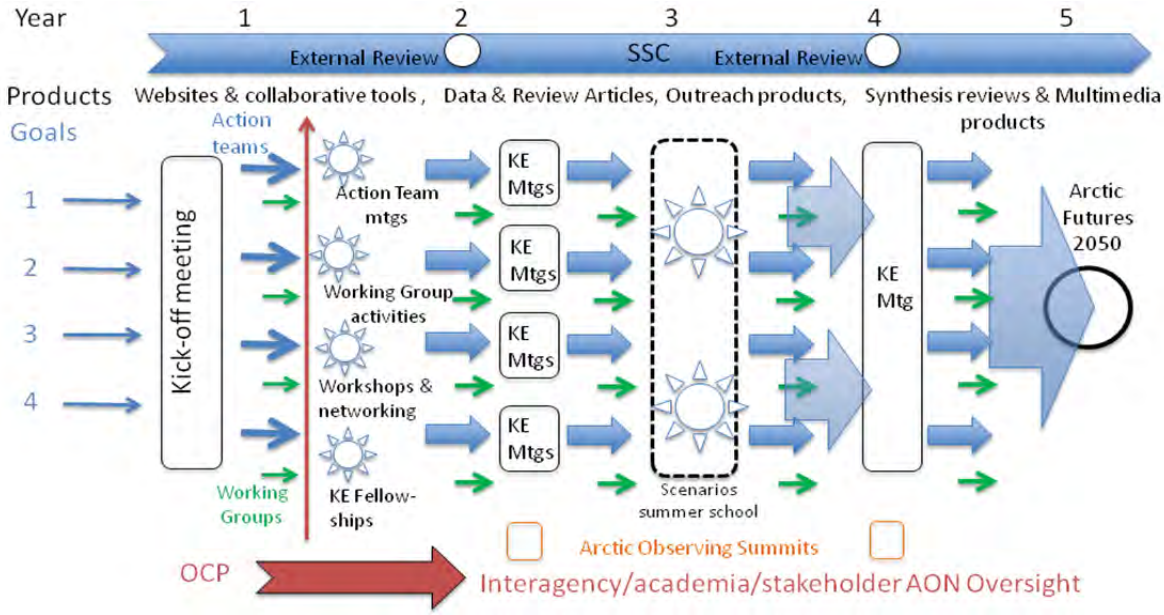

Fig. 3. Schematic of structure and timeline of Action Team and Working Group activities over five years. Project activities will alternate between targeted goal-focused activities and cross-cutting synthesis tasks.

6. OUTCOMES AND PRODUCTS

The new SEARCH structure encompasses science-topic oriented goals as well as cross-cutting synthesis efforts. While the science goals are driven by Action Teams, the broad synthesis-oriented

activities (AON, Arctic Futures 2050) are coordinated out of the PO. Each of these activities has clear objectives that fall under scientific or applied syntheses, as well as critical educational and strategic communication contributions. SEARCH offers a suite of logistic and organizational tools that ensure success in meeting the needs of the communities. Fig. 4 summarizes these synthesis efforts and describes the teams and cross-cutting elements that are coordinated through SEARCH and its new PO.

Building of communities: Building new networks and relationships with stakeholders is an important outcome that will be particularly beneficial for young scientists and post-docs. SEARCH will create opportunities for the scientific community to respond to the grand challenge emerging from the IPY that calls for Knowledge to Action (NRC 2012). The successful development of the ensuring new cross-disciplinary research programs and networks can be tracked by monitoring the number of disciplines and backgrounds represented in KE workshops and Action Team activities. Here the PO and ED will provide a new service by making such networking information available to the SSC, the scientific community and SEARCH agency partners for planning and evaluation purposes. The ED will also play an important role in building networks for SEARCH, particularly with agencies and the private sector.

Action Team products*:* Cross-disciplinary collaborative research projects will generate products such as publications, conference presentations, data products and white papers that will synthesize findings across Action Teams, furthering scientific research on Arctic system change. Synchronizing activities across themes as outlined in Fig. 3, will enhance the impact and information content of these products as they examine interrelated processes and development from different disciplinary perspectives. Prior to completion of synthesis products, Action Teams may create intermediate products such as online visual dashboards (see 5.1), which will allow others to see who is working on part of the synthesis activity as it progresses, and this will help foster more collaborative work.

AON-related products and outcomes*:* An important outcome from the work of the AON Coordinator, the Observing Change Panel and the Action Teams is guidance and coordination for the AON to continue to serve the scientific community while meeting broader sets of stakeholder needs. This can take the form of implementing recommendations that the AC provides to agencies, using input from the scientific community. Another outcome is the creation of new data and information products through collaborative work between post-docs, the AC and ACADIS to leverage data from the AON and other sources. The new SEARCH structure will also foster the emergence of an interagency oversight structure for the AON. Activities at the level of the Action Teams and Working Groups will foster advances in observing system design and optimization by using team-derived criteria and metrics to guide model- and theory-based assessments.

Arctic Futures 2050 products*:* A Working Group will be established to develop different scenarios for a future Arctic state in 2050 across the goals. Final synthesis products will be made easily accessible and will take the form of narratives, visuals, online and interactive information tools, conceptual models and model output, or other multimedia synthesis products (Fig. 4). Such products will meet major needs identified by government agencies such as those in the Department of Interior (e.g., NSSI partner agencies, J. Payne, pers. comm.) while at the same time serving the private sector and engaging the broad public.

Education, Public Outreach and Strategic Communication products*:* The SEARCH Science Office will facilitate greater communication between a wide range of participants involved in SEARCH activities. Interdisciplinary workspaces, regular Video/Teleconference and webinar updates will link SEARCH communities. Outreach activities will also include town hall activities, SEARCH-sponsored panel discussions at national conferences (e.g., American Meteorological Society Polar Meteorology and Oceanography Conference) and informational Congressional briefings. The Science Office will also work on open communication products that will allow the public to interact with SEARCH scientists on questions related to Arctic change, such as online forums (as described in SEARCH for Answers).

7. BROADER IMPACTS

Our proposal will allow SEARCH to act as the nexus that brings together scientists, stakeholders and agencies to address pressing issues related to Arctic change, leverage resources and work collaboratively.

These disparate groups rarely meet but SEARCH is uniquely positioned to provide networking opportunities and a support structure that facilitates travel, meetings, communication and coordination. Agencies and scientists will also benefit from increased AON-related coordination that results in useful information products. SEARCH synthesis and scenarios activities will generate multimedia products and tools designed to help stakeholders reduce uncertainty and plan for future Arctic change. Additionally, SEARCH activities invest in capacity building for young scientists, bringing them closer to stakeholder groups through KE workshops, fellowships and research projects that may involve local communities. We anticipate that SEARCH will facilitate the formation of transdisciplinary networks with links to existing national and international efforts. Finally, SEARCH will broaden understanding of the consequences of Arctic change, highlight emerging issues with social and policy importance, and communicate these findings to the public, media and decision-makers.

<table>
<tr><th></th><th>Permafrost</th><th>Land Ice Loss</th><th>Arctic Sea Ice</th><th>Societal & Policy</th><th>AON</th><th>Arctic 2050</th><th>New goals</th></tr>
<tr><td>Scientific Syntheses
(for science)
assess, describe, budget, integrate, assimilate, predict</td><td>• observing & predicting nature & timing of thaw
• carbon budget
• community report on landscape response to thaw</td><td>• design targeted instrument network
• integrating modeling tools (energy, melt, geodesy, sea level)</td><td>• determine sea ice predictability seasonal – decadal
• guide observ. network design
• seasonal outlook
• support CliC in sea ice prediction
• find low summer ice analog</td><td>• develop databases of: (i) social science/ interdisciplinary research in Arctic communities on climate change; (ii) qualitative & quantitative approaches proven to work efficiently
• develop best-practices recommendations for integrating across disciplines & stakeholders
• integration into each goal</td><td>• ACADIS integration
• pilot project with ACADIS data
• network design
• Arctic-systems reanalyses
• serve activities
• Barrow flagship site + new ones</td><td>• Environmental & human scenarios across all SEARCH goals
• feedback systems in 2050
• Interdisciplinary workspaces</td><td>• ...</td></tr>
<tr><td colspan="8">SEARCH Coordination for New Research Needs and Opportunities:
• SEARCH works with agencies, industry & communities to identify data & research needs, then coordinates development of new funding opportunities.
• Each Action Team will rely on team websites & collaborative tools to facilitate synthesis & collaborative research</td></tr>
<tr><td>Applied Syntheses
(for stakeholders)
deliver timely information, predict, warn, link broad range of interests</td><td>• prediction of social-ecological system responses
• 2050-scenarios</td><td>• projected regional sea level estimates
• Stakeholder-driven products
• 2050-scenarios
• coastal risk tool</td><td>• Sea ice prediction network with outlooks
• Sea Ice for Walrus Outlook
• sea ice area, property & thickness products
• 2050-scenarios</td><td>• perception of Arctic change in & outside of Arctic
• ecosystem & people response to changes
• Life in 2050-Arctic</td><td>• Internat. Arctic Observing Summit
• open data archives
• real time data
• develop funding opportunities to fulfill agency needs</td><td>• 2050-scenarios
• scenario tools
• multi-media products
• novel tele/ meet frame-work to link scientists & stakeholders</td><td>• ...</td></tr>
<tr><td colspan="8">Knowledge Exchange Interns/Fellows: Junior scientists & managers bridging between science, government, business & local communities to educate about tools and scientific knowledge, ensure data quality, learn from needs & develop response options
SEARCH Coordination for New Tools: SEARCH works with agencies, industry & communities to identify monitoring, management & prediction tools for stakeholder needs & adaptation planning</td></tr>
<tr><td>Education, Public Outreach & Strategic Communication
exchange knowledge & capability, translate</td><td colspan="7">SEARCH Knowledge Exchange Workshops: Every 2 or 3 years, Open Science meeting with Knowledge Exchange activities provides cross-links between science & stakeholder groups & activities and sets research plans & products with agencies

SEARCH for Answers:
• Communication and Educational Outreach by SEARCH Program Office building on its community resources
• Organize regular open Webinars and distribute Newsletters, Multimedia products and videos, and other products for scientists and stakeholders
• Expand knowledge about Arctic change across Arctic communities and beyond the Arctic
SEARCH Publication Series:
• Arctic Now and Arctic Futures 2050 book, White papers, Special issues, Review articles, Team and Topic Monographs for State of Science or Management Challenges</td></tr>
</table>

Fig. 4: Outcomes and products of the new SEARCH framework.

References cited

AON Design and Implementation Task Force. 2012. Designing, Optimizing, and Implementing an Arctic Observing Network (AON): A Report by the AON Design and Implementation (ADI) Task Force. Study of Environmental Arctic Change (SEARCH), Fairbanks, Alaska. 64 pp.

ARCSS. 2007. Arctic System Synthesis Workshop Summary. 7 May 2007. Available from: http://www.arcus.org/arcss/message_050707.html

Brigham, L. W. 2011. Globalization and challenges for the maritime Arctic. In: Davor Vidas and Peter Johan Schei (eds), The World Ocean in Globalisation (Leiden/Boston: Martinus Nijhoff Publishers/Brill, 2011), pp. 305–320.

Calder, J., H. Eicken, J. Overland. 2011. The Sea Ice Outlook. In: Krupnik, I. and eight others (eds.) Understanding Earth's Polar Challenges: International Polar Year 2007–2008 - Summary by the IPY Joint Committee. University of the Arctic, Rovaniemi, Finland /CCI Press (Printed Version), Edmonton, Alberta, Canada and ICSU/WMO Joint Committee for International Polar Year 2007–2008, pp. 405-410.

Callaghan, T. V., M. Johansson, J. Key, T. Prowse, M. Ananicheva, A. Klepikov. 2011. Feedbacks and interactions: from the Arctic cryosphere to the climate system. Ambio 40: 75-86.

Eicken, H., A. L. Lovecraft. 2011. Planning for Northern Futures: from social-ecological change in the Alaska region. In: Lovecraft, A. L., H. Eicken (eds.) 2011. North by 2020: Perspectives on Alaska's Changing Social-Ecological Systems. University of Alaska Press, Fairbanks, AK, pp. 679-700.

Eicken, H., B. Forbes, H. Wiggins. 2011a. State of the Arctic Conference 2010: International Perspectives on Progress of Research Responsive to Decision-Makers' Information Needs. Ambio 40: 824-827.

Eicken, H., G. Hufford, V. Metcalf, S. Moore, J. Overland, H. Wiggins. 2011b. Sea Ice for Walrus Outloook (SIWO); in: Krupnik, I. and eight others (eds.) Understanding Earth's Polar Challenges: International Polar Year 2007–2008 - Summary by the IPY Joint Committee. University of the Arctic, Rovaniemi, Finland /CCI Press (Printed Version), Edmonton, Alberta, Canada and ICSU/WMO Joint Committee for International Polar Year 2007–2008, pp. 550-554.

Francis, J. A., D. M. White, J. J. Cassano, W. J. Gutowski, L. D. Hinzman, M. M. Holland, M. A. Steele, and C. J. Vorosmarty. 2009. An Arctic Hydrologic System in Transition: Feedbacks and Impacts on Terrestrial, Marine, and Human Life. J. Geophys. Res., 114, G04019, doi:10.1029/2008JG000902.

Francis, J. A., S. J. Vavrus. 2012. Evidence linking Arctic amplification to extreme weather in mid-latitudes. Geophys. Res. Lett. 39: L06801. doi:10.1029/2012GL051000.

Gauger, E., M. Mueller-Stoffels. 2007. ScenLab v1.7 users manual. evolve:IT Scientific Software Systems. Electronic document.

Hamilton, L.C. 2012. Did the Arctic ice recover? Demographics of true and false climate facts. Wea. Climate Soc. 4:236–249.

Hamilton, L.C., M.J. Cutler, A. Schaefer. 2012. Public knowledge and concern about polar-region warming. Polar Geogr. 35:155–168.

Huebert, R., H. Exner-Pirot, A. Lajeunesse, J. Gulledge. 2012. Climate change & international security: The Arctic as a Bellwether. Arlington, Virginia: Center for Climate and Energy Solutions. Available at: http://www.c2es.org/publications/climate-change-international-arctic-security/

Huntington, H.P., E. Goodstein, E.S. Euskirchen. 2012. Towards a tipping point in responding to change: Rising costs, fewer options for arctic and global societies. Ambio. 41:66-74.

IARPC. 2012. Draft Interagency Arctic Research Policy Committee Arctic Research Plan: FY2013-2017. Available from: http://www.nsf.gov/od/opp/arctic/iarpc/iarpc_5yr_plan/arc_res_5yr_plan_septdraft.pdf. 100 pp.

Kerkhoff, L. van., L. Lebel. 2006. Linking knowledge and action for sustainable development. Annu. Rev. Environ. Resour. 31: 445-477.

Krupnik, I., I. Allison, R. Bell, P. Cutler, D. Hik, J. Lopez-Martinez, V. Rachold, E. Sarukhanian, C. Summerhayes (eds.). 2011. Understanding Earth's polar challenges: International Polar Yea 2007-2008. World Meteorological Organization. 724 pp. http://www.wmo.int/pages/themes/wmoprod/documents/IPYJointCommitteeSummaryFINAL2011.pdf

Lovecraft, A. L., H. Eicken (eds.) 2011. North by 2020: Perspectives on Alaska's Changing Social-Ecological Systems. University of Alaska Press, Fairbanks, AK, 736 pp.

Meisen, A., L. Macklin. 2012. Summary report Jasper Innovation Forum 2011 – The Global North 2050. Alberta Innovates Technology Futures, Edmonton, AB.

Michalak, A. M., R, B. Jackson, G. Marland, C. L. Sabine. 2011. A U.S. Carbon Cycle Science Plan. Available from: http://www.carboncyclescience.gov/USCarbonCycleSciencePlan-August2011.pdf. 81 pp.

Morison, J., V. Alexander, L. Codispoti, T. Delworth, B. Dickson, H. Eicken, J. Grebmeier, J. Kruse, J. Overland, J. Overpeck, P. Schlosser, M. Serreze, J. Walsh. 2001. SEARCH: Study of Environmental Acrctic Change, Science Plan, 2001, Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle, 89 pp.

Mueller-Stoffels, M., H. Eicken Futures of Arctic marine transport 2030: An explorative scenario approach, In A.L. Lovecraft and H. Eicken eds. 2011. North by 2020: Perspectives on Alaska's Changing Social-Ecological Systems. University of Alaska Press, Fairbanks, AK, pp. 477-501.

Murray, M.S., H. Eicken, S. Starkweather, S.C. Gerlach, B, Evengaad, S. Gearheard, P. Scholosser, M. P. Karcher, D. McLeannan, H. Epstein, N. Bock, C, Juillet, S. Graben, B. Grimwood, D. Labonte, K. Pletnikof, N. Scott, M. Sommerkorn, M. Vardy, V. Vitale, I. Wagner, Wagner. 2012. Responding to Arctic Environmental change: Translating our growing understanding into a research agenda for action. International Study of Arctic Change, Stockholm/ Fairbanks. 35 pp.

National Research Council. 2012. Legacies and lessons of the International Polar Year 2007-2008. National Academies Press, Washington, DC

NOAA. 2011. NOAA's Arctic Vision and Strategy.Available from: http://www.arctic.noaa.gov/docs/NOAAArctic_V_S_2011.pdf. 32 pp.

Overland, J., H. Eicken, W. Meier, H. Wiggins. 2009. International Arctic sea ice monitoring program continues into second summer. Eos, Trans. Am. Geophys. Un., 90:321-322.

Richter-Menge, J., J. Walsh, L. W. Brigham, J. A. Francis, M. Holland, S. C. Nghiem, R. Raye, R. Woodgate. 2012. Seasonal to decadal predictions of Arctic sea ice: Challenges and Strategies. The National Academies Press. Washington D. C., U.S.A. 80 pp.

SEARCH. 2003. SEARCH: Study of Environmental Arctic Change, Implementation Strategy, Revision 1.0. Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle, Washington, U.S.A. 370 pp.

SEARCH. 2008. Arctic Observation Integration Workshops Report. Fairbanks, Alaska: SEARCH Project Office, Arctic Research Consortium of the United States (ARCUS). 63 pp.

SEARCH. 2009. Arctic Observing Network (AON) Program Status Report – 2009. Results from the Third AON Principal Investigators (PI) Meeting, 30 November – 2 December, 2009, Boulder, Colorado, U.S.A. 175 pp.

SEARCH. 2013 U.S. Arctic Observing Coordination Workshop, 20-22 March 2012. Anchorage, Alaska. U.S.A. In prep.

Serreze, M. C., R. G. Barry. 2011. Processes and impacts of Arctic amplification: A research synthesis. Global and Planetary Change **77**: 85-96.

Smith, L. C. 2010. The world in 2050: Four forces shaping civilization's northern future. EP Dutton. New York, U.S.A. 336 pp.

Stroeve, J. C., V. Kattsov, A. Barrett, M. Serreze, T. Pavlova, M. Holland, and W. N. Meier (2012), Trends in Arctic sea ice extent from CMIP5, CMIP3 and observations. Geophys. Res. Lett. 39: L16502, doi:10.1029/ 2012GL052676.

USARC. 2012. Report of the goals and objectives for Arctic Research 2011-2012 for the US Arctic Research Program Plan. Available from: http://www.arctic.gov/publications/2011-12_usarc_goals.pdf . 28 pp.

US CLIVAR. 2012. Understanding the dynamic response of Greenland's marine terminating glaciers to oceanic and atmospheric forcing: A white paper by the U.S. CLIVAR Working Group on Greenland Ice-Sheet Ocean interactions (GRISO) Report 2012-2. US. CLIVAR Project Office, Washington DC 20006. 22 pp.

Walsh, J., S. Elliott, J. Schimel, H. Wiggins. (eds.) 2012. Recommendations for Understanding Arctic System Change: Report from a Workshop. 17 pp.