

EOAS Strategic Planning Polar Change Committee Report

Contents

Committee members	2
Polar research at Rutgers	2
Rutgers research and international research priorities	4
Research Priorities for the Arctic	4
Research priorities for the Antarctic:	5
Research activities and expertise of individual Rutgers faculty	5
Recommendations by the committee to strengthen polar research at Rutgers	6
Hiring priorities	6
Fall 2017 EOAS Polar Change Meetings	7
Education	9
Undergraduate education	9
Graduate education	10
Proposed new teaching activities	11
Outreach activities	11
Proposed new outreach activities	12
Activities initiated by the committee, Fall of 2017	13
Key questions for each EOAS strategic planning thematic committee (the charge to the committee)	13
Appendix A. Rutgers faculty members' polar research interests	16
Appendix B. Participants and talk titles at Polar “meet and greet” on September 19 th , 2017	21
Appendix C. Agenda for the Polar Town Hall on October 3 rd , 2017	24
Appendix D. Summary of brainstorming activity at the Polar Town Hall on October 3 rd , 2017	25

Committee members

Co-chairs

Robert Sherrell (sherrell@marine.rutgers.edu) and Asa Rennermalm (asa.rennermalm@rutgers.edu)

Committee members

David Robinson (david.robinson@rutgers.edu), Enrique Curchitser (enrique@marine.rutgers.edu), Grace Saba (saba@marine.rutgers.edu), Jennifer Francis (francis@marine.rutgers.edu), Max Haggblom (haggblom@rutgers.edu), Oscar Schofield (oscar@marine.rutgers.edu), Lee Kerkhof (kerkhof@marine.rutgers.edu), Jim Miller (miller@marine.rutgers.edu), Hal Salzman (hsalzman@rutgers.edu)

Polar research at Rutgers

The polar regions, Arctic and Antarctic, are among the most vulnerable areas with respect to climate change and are already exhibiting dramatic changes in ecosystems, oceans, land and sea ice. Many of these changes will, in turn, have widespread implications, including for earth's carbon budget, climate at lower latitudes and global sea level rise. Rutgers currently has strong research expertise and activity in several areas of study at both poles, with principal investigators (PIs) representing several departments and schools.

Over the last 50 years, Arctic temperatures have increased at double the rate of the global average. Both in response to and amplifying the warming, Arctic land and sea ice have declined rapidly, snow cover is melting earlier, permafrost is thawing, Arctic river flow is increasing, and the overall Arctic Ocean freshwater storage has increased. All of these changes affect marine and terrestrial ecosystems, as well as biodiversity. This rapid disruption of the Arctic system is raising challenges for local communities, and they reach far beyond this region by influencing atmospheric greenhouse gas concentrations, ocean circulation, primary production, sea level and weather patterns. At Rutgers, we have expertise in climate observations, modeling, satellite remote sensing, Arctic river discharge, Greenland ice sheet melting, and the influence of fundamental changes (like the loss of Arctic sea ice) on large-scale atmospheric circulation patterns. Shorebird habitat changes and the role of microbes in carbon and nitrogen turnover and in the distribution and chemical transformations of the global pollutant mercury (Hg) are other strengths. The socio-economic dynamics and sustainability of Arctic villages currently facing numerous challenges is another area of excellence at Rutgers. Studies of the chemical composition of atmospheric aerosols are ongoing in both the Arctic and Antarctic.

Major research strengths at Rutgers: Arctic

- Studies of Northern Hemisphere snow cover, Arctic river discharge, Greenland ice sheet melting
- Connections between amplified Arctic warming and mid-latitude weather.
- Shorebird habitat changes
- Microbial ecology of Arctic soils
- Role of microbes in the distribution and chemical transformations of the global pollutant mercury (Hg)
- Trace elements and isotopes as tracers of physical oceanography and biogeochemistry in the Arctic Ocean
- The chemical composition of atmospheric aerosols
- The socio-economic dynamics of Arctic villages
- Communication and education of Arctic-related climate change issues

The Antarctic is a rapidly changing environment as well. Changes in winds, ocean circulation, and ocean heat content are driving substantial increases in glacial melt rate, especially in West Antarctica, but with some regions in East Antarctica showing signs of accelerating melting, as well. The Amundsen Sea embayment, for example, is the outlet point for several major glaciers draining the western portion of the continental ice sheet. In addition, the distribution and timing of sea ice around Antarctica are changing drastically, with the West Antarctic Peninsula experiencing much less annual sea ice cover than just a few decades ago. Resulting changes on the peninsula shelf are altering water chemistry, phytoplankton and zooplankton assemblages, impacting food web dynamics, shifting penguin species distributions, and possibly influencing whale behavior. Glacial retreat is exposing more of the underlying surface. The regional warming and sea-ice loss is causing increased snowfall owing to a more humid local atmosphere, changing the freshwater input distribution and disturbing bird nesting habitats.

Rutgers is very active in studying the oceanography of Antarctic shelf regions, which are the direct recipients of increasing glacial meltwater over the past few decades. Our faculty are renowned experts in ocean physics, biogeochemistry, and biology as they relate to ecosystem function and climate change. Rutgers is a leader in the use of autonomous underwater vehicles (AUVs) for high-resolution observational studies in these remote regions, and our teams have a decade-long history of AUV deployment in polar systems. We have a strong focus on the design and implementation of high-resolution models that integrate ocean physics with chemistry and biology, with investigations that span microbes to phytoplankton and zooplankton to fish. Our findings are illuminating fundamental controls on ocean productivity and the structure, variability and vulnerability of Antarctic food webs.

Major research strengths at Rutgers: Antarctica

- Oceanography of Antarctic shelf regions
- Ecosystem function and vulnerability
- Climate change impacts
- Ocean physics, biogeochemistry, and biology
- Microbes, phytoplankton, zooplankton, micronekton

- Autonomous underwater vehicles (AUVs)
- Design and implementation of high-resolution models that integrate ocean physics with chemistry and biology
- Education and science communication

Rutgers research and international research priorities

Polar research at Rutgers is addressing urgent science questions, including several research priorities identified in recent reports by international community working groups.

Research Priorities for the Arctic

The 2017 Snow, Water, Ice, and Permafrost in the Arctic (SWIPA) report by the Arctic Monitoring and Assessment Programme (an Arctic Council working group) identifies several data and knowledge gaps. Addressing these gaps is critical for improving projections of the timing of future Arctic changes, and enhancing confidence in predictions of interactions between the Arctic and global systems. Specifically, SWIPA singles out nine research needs to address specific knowledge gaps: 1) Improve quantification of the timing, magnitude and risk of future Arctic change; 2) Determine the amount of global warming that would trigger abrupt shifts in the Arctic system, e.g. changes to sea ice, Greenland ice sheet, snowpack, permafrost or boreal forest. 3) Document and project changes in storms, moisture fluxes, vegetation, freshwater-marine interactions and North Atlantic teleconnections, 4) Improve knowledge of current and future sea ice loss, including impacts on mid-latitude weather, climate variability and predictability, and ecosystems, 5) Understand how changes in permafrost affect coastal erosion, ecosystems, and infrastructure, including impacts of carbon emissions, 6) Better quantify processes that accelerate melting of ice sheets and glaciers, and improve estimates of contributions to future sea level rise, 7) Improve understanding of snow-land hydrological changes and how they couple with ecological feedbacks and transform the Arctic landscape, 8) Improve monitoring, satellite interpretation, coordination of monitoring efforts, process studies, and modeling, 9) Improve climate models for use in future climate and risk assessments, including multi-model comparisons, determining variable confidence levels, developing strategies for downscaling and to assess uncertainties, and 10) Better quantify the economic and societal costs of Arctic change.

Current Rutgers research contributes to knowledge gaps identified by SWIPA 2017 in a multitude of ways. Data gaps (priority 1 and 8) are being addressed by collecting various ecosystem observations (shore-bird habitat, soil microbes, pollutants), field observations of land ice (Greenland ice sheet meltwater drainage, storage and transport to the ocean), and satellite remote sensing of land snow cover extent. These data collection efforts inform studies of how the Arctic system is changing and the potential for abrupt changes (priority 2). Rutgers researchers are examining the impacts of Arctic sea ice loss on midlatitude weather (priority 4), how Greenland ice sheet surface hydrology is speeding up overall melting and providing better quantification of the ice sheet meltwater budget (priority 6), and terrestrial ecosystems including soil microbes,

pollutants and shorebird habitat (priority 7). Furthermore, research at Rutgers quantifies global sea level rise (priority 9), and economic and societal cost of climate change through detailed studies of communities on the Alaskan North Slope (priority 10). Some of the research gaps at Rutgers include specific work on sea ice trends (priority 4), thawing permafrost (priority 5), future climate and risk assessment modeling related to Arctic changes (priority 9).

Research priorities for the Antarctic:

The 2015 National Academies report “A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research” identifies large-scale research priorities based on community input. The three main themes are (1) studying mass loss from Antarctic Ice sheets and resulting sea level rise (“how much, how fast”), (2) understanding how Antarctic biota evolve and adapt to the changing Antarctic environment, using genomic and transcriptomic approaches, and (3) pursuing the next generation of Cosmic Microwave Background studies to better understand how our Universe began and what laws govern its dynamics.

Current Antarctic research strengths at Rutgers align reasonably well with the first two priorities, and also pursue other essential questions. For example, we have a strong research presence exploring the controls on modern and past sea level, the mechanisms causing warming in West Antarctica, forcing ice sheet melting, and the role of Antarctic biota in driving and responding to a changing ecosystem. However, while our use of “omics” approaches to this problem is thus far limited, we have important research thrusts on other critical Antarctic issues, for example the fundamental controls on Antarctic shelf primary productivity, informing its future role in ocean-atmosphere CO₂ exchange. The third priority of the NAS report is technology-based, taking advantage of the physical properties of the atmosphere over the south pole to study the inflation of the Universe, not research into the Antarctic environment itself. Rutgers does not, to our knowledge, have a substantial contribution to this astrophysics research priority at present.

Research activities and expertise of individual Rutgers faculty

Rutgers faculty research covers many aspects of the polar earth systems. Table 1 provides a matrix of current Research Areas and Research Approaches, with faculty involved in each intersection listed. A more comprehensive list of faculty involved in polar studies and a short description of each faculty member’s polar research interests can be found in Appendix A.

Table 1. Polar research activity matrix for Rutgers faculty

Research Areas ->	Biogeochemistry	Physical Systems	Ice Sheets	Glaciology Snow Hydrology	Atmosphere	Evolution/ Paleo climatology	Ecology	Social Systems
Approaches								
Observations Physics	Kohut	Kohut, Francis	Rennermalm	Rennermalm , Miller Robinson	Robinson, Francis, Miller	Wright	Kohut, Saba	
Observations Chemistry	Saba, Sherrell, Falkowski	Sherrell			Gao	Wright, Rosenthal	Saba, Sherrell	
Observations Biology	Saba, Schofield, Kustka, Kerkhof Haggbloom,	Schofield, Saba					Lathrop, Saba, Schofield Haggbloom	
Observations Geophysics/P aleo climatology	Wright, Rosenthal			Rennermalm Robinson		Wright, Rosenthal		
Model Physics	Sherrell	Francis, Sherrell, Miller		Rennermalm	Francis, Robinson			
Model Biogeochemi stry	Sherrell, Schofield, Falkowski				Gao			
Large GCM Model	Curchitser, Miller	Curchitser, Miller						
Sociological Surveys	Salzman							Salzman

Recommendations by the committee to strengthen polar research at Rutgers

Hiring priorities

In order to fill some of the current gaps in polar research expertise, the Committee identified the following potential faculty hiring priorities (not in priority order):

- Terrestrial processes in polar environments
- Polar marine biology at high trophic levels
- Sea ice dynamics
- Ice sheet modelling
- Physics of melting at the ocean-ice interface.
- Arctic ocean circulation (observation or modelling)

We recommend the formation of a new EOAS Polar Research Cluster at Rutgers that new hires in these areas could join and invigorate.

Fall 2017 EOAS Polar Change Meetings

The Polar Change Committee organized a polar “meet and greet” on September 19th, 2017 in order to bring together Rutgers researchers working on polar themes so that connections across numerous departments and spanning the Raritan River could get acquainted and share ideas. Over 20 Rutgers researchers shared their work in a series of short “lightning talks” and engaged in discussions about urgent research questions that can be addressed using current expertise. These questions fell into a number of broad themes (Figure 1). Presenters included six PhD students and two postdocs. A Powerpoint combining all of the presentations is available from the Committee Co-Chairs. (For a list of presenters and topics see Appendix B)

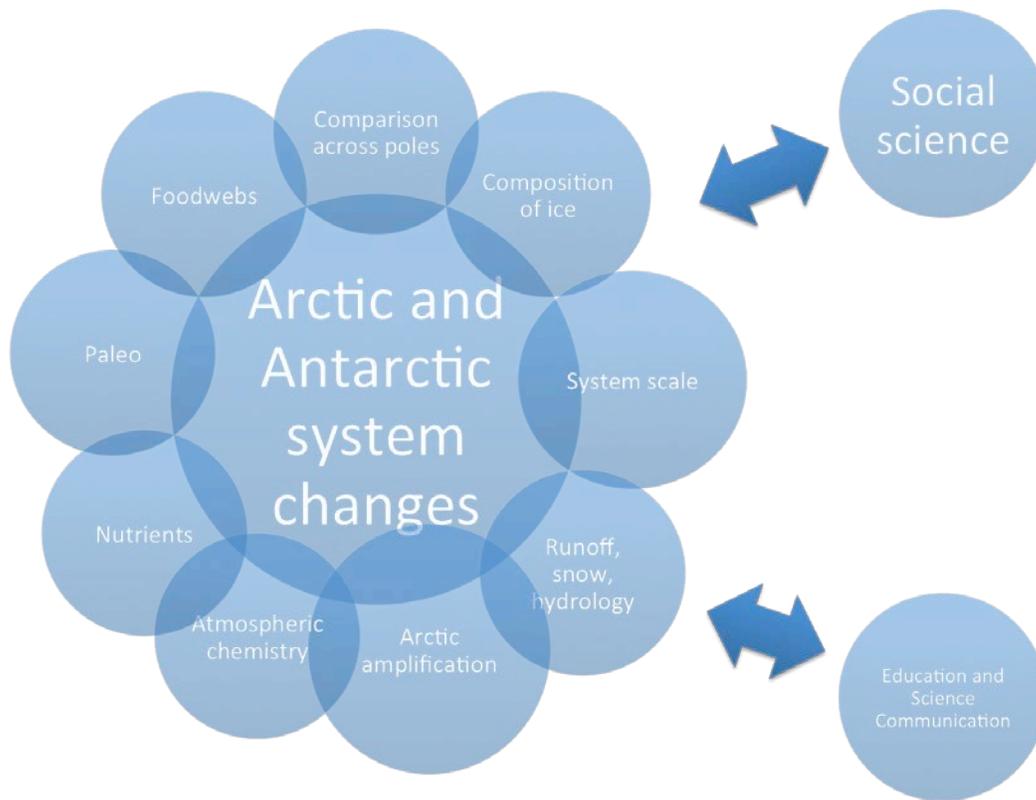


Figure 1. Research themes that can be addressed with current expertise

At the subsequent “town hall” meeting on October 3rd, 2017, more than 40 participants brainstormed around the question “What polar research do you want Rutgers to be doing within the next 10 years?” A different set of priorities were identified (Figure 2). Themes that emerged from a “Post-It” group-think exercise can be categorized into eight groups, five groups directly focused on research questions about Arctic and Antarctic system science (Ice Sheets, Oceans, Coastal Processes, Ecosystems, Feedbacks and connections) while the three remaining were more

about building Rutgers infrastructure to support polar research (Tools, Facilities/Organizations) and strengthen outreach (Society) (Figure 2). For the meeting agenda and a complete list of ideas from the brainstorming activity see Appendix C and D.

While several participants at the October 3rd town hall meeting would like to see more research that bridges social and physical sciences, the majority of the research ideas focused on the physical sciences. Research ideas about the ice sheets were concerned with understanding aspects of the ice sheet mass balance and its impact on global sea levels, marine environments, and ocean circulation. Ideas about oceans and fjords included the role of the Southern Ocean in the global climate system, interdisciplinary studies of fjord processes, and linking Arctic terrestrial freshwater fluxes and local shelf process. Ideas about ecosystems ranged from understanding life at subzero temperatures, studies of physiological changes in polar organisms, Southern Ocean biogeochemistry, connections between sea ice loss and microbial growth, to comparative studies of food webs in the Arctic and Antarctic. Participants expressed a wish to build on Rutgers' current strengths in observing systems, including ocean observing systems and data products derived from satellite remote sensing. To better support polar research at Rutgers several participants had ideas about how to strengthen connections and collaborations between Rutgers polar faculty and enhance graduate and undergraduate education in polar regions. Those ideas ranged from considerable efforts such as creating graduate certificate programs and undergraduate minor programs to more rapidly implemented ones such as developing individual courses and facilitating networking among graduate students. Finally, a common theme of improving our communication of polar research through education and to groups outside of academia emerged and included thoughts about how to do outreach to US Congress, student, the general public and Arctic communities.

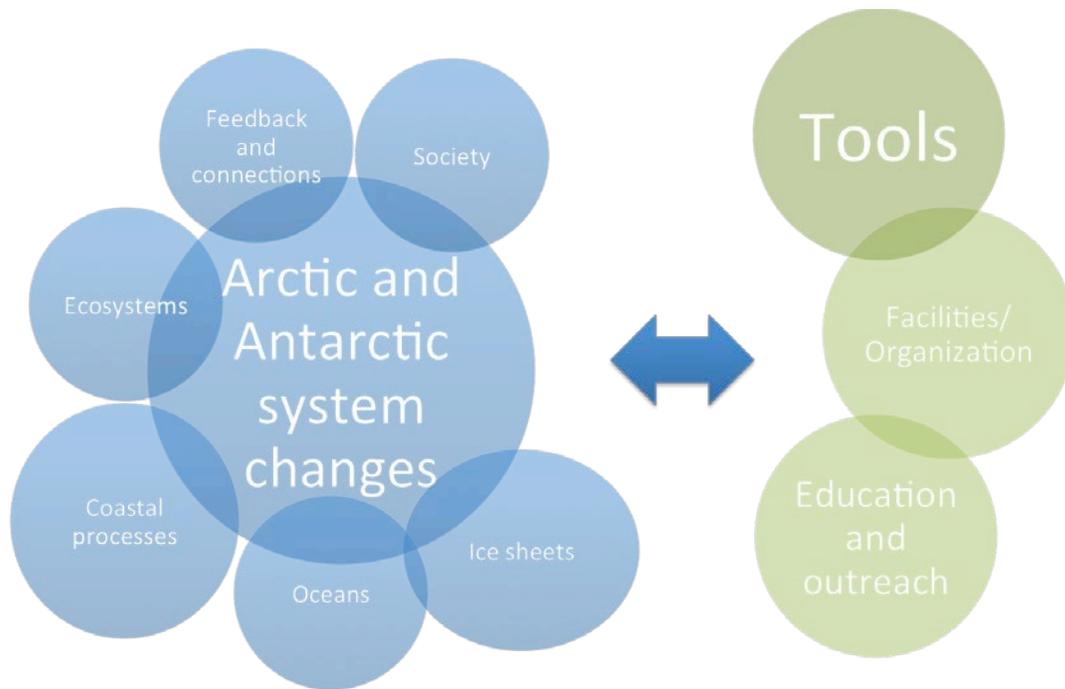


Figure 2. Research themes that Rutgers should pursue in the next 10 years

Education

Undergraduate education

There exists a strong need for Rutgers students who are pursuing environmental science, in its broadest expression within several Rutgers departments, to learn about polar processes and change. However, there are just a few dedicated courses with a polar theme that have been taught at Rutgers. In the Departments of Marine and Coastal Sciences (DMCS) and Geography two upper-level undergraduate courses were offered in the last decade, one with an Antarctic theme (The Antarctic: Ocean, Ice, Climate and Biota, taught by Sherrell/Rosenthal, Spring 2015) and one with a broad polar focus (Advanced Physical Geography: Polar Environments, taught by Rennermalm, Fall 2009). There is perhaps no urgent need for additional specialized courses on polar topics, but there is a need to facilitate the adoption of polar topics into a wide range of earth, atmosphere, and ocean science courses at both the introductory and upper levels. While several Rutgers EOAS faculty with active polar research programs can and do readily infuse their courses with polar themes (e.g. Department of Geography's Earth Systems course; Biological Oceanography course at Marine and Coastal Sciences), there is a need to develop a portal where this expertise can be made available to all faculty for teaching polar themes. The purpose of this polar education portal will be to aid faculty in sharing and developing teaching material, including annotated PowerPoint files, video clips, readings, websites, guidelines for active learning activities with polar themes,

syllabi, and a listing of all courses with polar content. The portal should be equipped with technology to keep track of downloads to evaluate its usage among Rutgers faculty.

Undergraduate student engagement in polar research has been facilitated by programs such as the Aresty undergraduate research and the George H. Cook Senior Honors programs, which pair an undergraduate student with a faculty member. For example, Rennermalm has worked with four students who have subsequently presented their research at the Rutgers Undergraduate research symposium and the American Association of Geographers (AAG) Annual Meeting. One of these four students was awarded the AAG Cryosphere R.S. Tarr best undergraduate presentation for his work. J. Miller has also worked with two Aresty undergraduates on projected future changes in Arctic river systems. Additionally, Kohut, Saba, and Schofield have mentored several Honors undergraduate students who have deployed to the Antarctic and/or used Antarctic data to conduct their research projects. Schofield, a co-PI of the Palmer Long Term Ecological Research (PAL-LTER) program, also leverages this project's annual Antarctic field season to provide research experiences for Rutgers undergraduates. On average 2-3 undergraduates have been active members on these expeditions over the last five years. Future efforts to secure funding to allow undergraduate students to work with faculty and their laboratory groups and projects would provide an exciting learning opportunity. Some of these interactions could be channeled through the NSF Research Experience for Undergraduates program, which funds active research participation of undergraduates in NSF-funded projects. The RIOS REU program, run by DMCS faculty, was recently renewed by NSF and could host polar-related projects by highly-qualified summer undergraduate researchers. Janice McDonnell has developed a range of education outreach tools, including a national set of Polar Literacy principles that are being adopted nationally by a wide range of universities and schools.

Graduate education

Several Rutgers graduate students are working on PhD theses with polar themes or components, in the following programs: Geography (4), Oceanography (4), Earth and Planetary Sciences (2), Environmental Sciences (1), and Microbial Biology (1). Courses with polar themes targeting PhD students are rare at Rutgers. Both of the above-mentioned undergraduate courses offered in DMCS and Geography were provided to and attended by both undergraduate and graduate students. Additionally, several independent studies on Cryosphere science have been offered in the Department of Geography. In the Bloustein School of Planning and Public Policy, Salzman has led an Arctic studio where graduate student specialized in planning for community and natural resource development for indigenous/rural communities in Alaska. While currently there may not be a critical mass of Rutgers students for specialized polar-themed courses, there is a need to facilitate connections and networking among those students conducting polar research. Such connections could be achieved through a broad polar field course, as well as polar-themed symposia, seminars, and meetings.

Rutgers does not provide an opportunity for terminal Masters degrees for students who want to focus on polar science. Rather than creating a terminal Masters degree with a polar theme, efforts have now been initiated to develop a competitive terminal Masters program with an earth, atmosphere, and ocean science focus. Such a program should be hands-on and provide training in critical thinking, analysis and technical skills such as satellite data manipulations, big data, and programming/coding. A new Masters of Operational Oceanography program in the Department of Marine and Coastal Sciences (including coursework with polar content) has recently been approved by the University.

Proposed new teaching activities

- Develop an EOAS polar education portal where Rutgers faculty can share teaching resources.
- Develop a three credit topics/seminar course titled “Rapidly Changing Polar Regions” where faculty with polar expertise contribute one or two classes on topics related to their expertise. Feed particularly interested students into REU opportunities.
- Secure funding to incorporate undergraduate research experiences with existing faculty grants, including bringing students to field sites in polar regions. This kind of financing could originate from gifts and donations or perhaps by applying to the NSF Research Experience for Undergraduates (REU) program, either for a polar themed REU center or individual REU awards associated with awarded grants.
- Other ideas to strengthen teaching and research experiences focusing on polar themes at Rutgers include expanding the number of Byrne Freshman Seminars with polar themes.
- Facilitating networking and community building among Rutgers graduate students specializing in polar topics in their Ph.Ds. This could be achieved by offering a polar field course, regular symposium and/or seminars, and meet-ups.

Outreach activities

There are several exciting outreach projects with polar themes at Rutgers. One of the most ambitious is Polar-Interdisciplinary Coordinated Education (Polar-ICE; <http://polar-ice.org/>, PI Schofield, co-PI McDonnell, co-PI Kohut), which is an NSF-funded project designed to connect scientists, educators and students using data from Arctic and Antarctic regions. The program has several components, including professional development of teachers, development of teachers’ lesson plans, training of young scientists, the creation of web-based educator tools and infrastructure, and helping Rutgers PIs to develop Broader Impact components of their NSF proposals. Polar-ICE is modelled upon a project co-lead by Kohut named Converge (<http://coseenow.net/converge/>). Other NSF-funded projects with outreach components are the Ross Sea Connection project (<http://coseenow.net/ross-sea/>, Kohut), the PARKA project (Planting Antarctica in Kansas; <http://coseenow.net/project-parka/>, Saba), and Assessing the Impact of Arctic Sea Ice Variability on the Greenland Ice Sheet Surface Mass and Energy Balance (GREASE, Rennermalm).

Additional current outreach efforts with polar themes include an NSF-funded award-winning documentary film produced by Rutgers School of Environmental and Biological Sciences and entitled “Antarctic Edge 70 Degrees South” (Director Dena Seidel, formerly Mason Gross School of the Arts). This film prominently features Schofield and several other scientists working out of the Palmer Research Station in Antarctica (<http://beyondtheice.rutgers.edu/>), in association with the PAL-LTER (<http://pal.lternet.edu>). A collaboration between Rennermalm and Salzman, with Zimmerli Museum curator Donna Gustafson, resulted in several innovative and transdisciplinary seminars and activities, including an art exhibit titled Glacial Perspectives at the Zimmerli Museum with landscape painter Diane Burko depicting changing glacial landscapes (<http://www.zimmerlimuseum.rutgers.edu/diane-burko-glacial-perspectives#.WZqrBJMjE6g>).

Policy engagement has occurred mostly on national and international levels. For example, Robinson and Francis met with congressional staffers during NSF-sponsored events such as an Arctic Action event and Science Day on the Hill. Schofield is the co-chair of the Southern Ocean Observing Systems, an international organization coordinating science activities. While Rutgers research on polar regions focuses more on national and international than state and local policy, some aspects such as the impact of melting glaciers and ice sheets on driving up sea levels are directly relevant to coastal inhabitants world-wide. Efforts and initiatives for scientists to decode science language for policymakers should be encouraged. Many policy activities go unnoticed within the University because there is no clearinghouse where these activities are collated and synthesized. The EOAS could be such a clearinghouse, and could also help foster a culture where EOAS faculty promote each other for high-profile external lectures and leadership positions. Systematic methods to capture outreach activities should also be developed, perhaps modeled on 4H methods (<http://4h.ucanr.edu/files/167457.pdf>) that ensure that critical target groups are included.

Proposed new outreach activities

- Build upon the Polar-ICE project at Rutgers, particularly to help faculty learn how they can develop cost and time efficient Broader Impacts components in their grants.
- Develop a website with news about Rutgers research and activities related to polar regions and polar change
- Strengthen collaboration with the Rutgers Film Bureau and the Mason Gross School of Art, the Zimmerli Museum, the Rutgers Geological Museum, as well as the New Jersey Liberty Science Center.
- Prepare outreach material about Rutgers polar-themed activities for alumni outreach.
- Create a clearinghouse that keeps track of policy and other outreach activities by Rutgers faculty and staff.
- EOAS should foster a new type of environment where Rutgers faculty become better at promoting their Rutgers colleagues for important lectures and other opportunities.

Activities initiated by the committee, Fall of 2017

- A half-day “meet and greet” for Rutgers polar scientists took place September 19th, 2017. See description above.
- A Polar Town Hall occurred October 3rd, 2017 where all EOAS members were invited to discuss input for this strategic plan document. See description above.
- A polar symposium has been planned for academic year 2018/19. The goal is to bring Rutgers and other regional scientists together, put focus on the pressing polar issues that are being investigated at Rutgers, and encourage interdisciplinary synergy.
- Other initiatives that should be prioritized are securing gifts/funding to offset travel costs for students doing research, endowed postdoctoral or graduate fellowships for polar research, and annual seminars or symposium.

Key questions for each EOAS strategic planning thematic committee (the charge to the committee)

Research

1. What are the existing research strengths within EOAS in this theme? (It would be helpful to produce 1-2 pages that could be used in a brochure or on the EOAS web site.)
2. What are prominent gaps within EOAS in this theme?
3. What are likely to be nationally prominent research areas within this theme in the next decade?
4. What are the top ~3 faculty hiring priorities in this theme?
5. What potential new research collaborations could be formed in this theme within EOAS, elsewhere at Rutgers or elsewhere in the region?
6. What research linkages could be strengthened between this theme and the other key EOAS themes (planetary habitability, Earth system history, Earth observations & forecasting, Earth system risks, and polar change)?
7. If EOAS received an unrestricted gift of \$5 million to support research in this area, what would be the top ~3 priorities?
8. By what metrics and milestones could EOAS measure progress in promoting research in this theme over the next five years

Teaching

1. Suppose a student wanted to come to Rutgers to get an undergraduate degree within this theme. What pathways are currently available to the student? What career options would be available to the student? What potential new undergraduate teaching initiatives could be launched that would enhance revenue and/or our position of national and global leadership?
2. Suppose a student wanted to come to Rutgers to get a Ph.D. within this theme. What pathways are currently available to the student? What potential new doctoral teaching initiatives could be launched that would enhance our position of national and global leadership?
3. Suppose a student wanted to come to Rutgers to get a terminal masters' degree within this theme. What career options would be available to the student? What pathways are currently available to the student? What potential new teaching initiatives could be launched that would enhance revenue and/or our position of national and global leadership?
4. What teaching linkages could be strengthened between this theme and the other key EOAS themes (planetary habitability, Earth system history, Earth observations & forecasting, Earth system risks, and polar change)?
5. If EOAS received an unrestricted gift of \$5 million to support teaching in this area, what would be the top ~3 priorities?

Outreach and Policy Engagement

1. What sort of public outreach activities is Rutgers currently undertaking related to this theme? What potential new outreach activities could be launched that would contribute to the broader impact of Rutgers research and teaching?
2. What sort of policy engagement activities (at local, state, national, and international levels) is Rutgers currently undertaking related to this theme? What potential new policy engagement activities could be launched that would contribute to the broader impact of Rutgers research and teaching?
3. other key EOAS themes (planetary habitability, Earth system history, Earth observations & forecasting, Earth system risks, and polar change)?
4. If EOAS received an unrestricted gift of \$5 million to support outreach and policy engagement in this area, what would be the top ~3 priorities?

5. By what metrics and milestones could EOAS measure progress in promoting outreach and policy engagement in this theme over the next five years?

Appendix A. Rutgers faculty members' polar research interests

Tamar Barkay's laboratory work on Arctic microbes and mercury (Hg) is proceeding in two stages. The first addressed the role of microorganisms in the cycling of Hg in snow packs in conjunction with the observation of atmospheric deposition of Hg. This project (funded by the Danish government and a Marie-Curie fellowship) focused on redox transformations and the microbes that carry them out. The second stage is focused on methylation of mercury in Alaskan peatlands and how it is affected by global climate change. This work is funded by NSF Office of Polar Programs.

Bob Chant has carried out NSF-funded physical oceanographic research about the Chukchi Sea in the Arctic Ocean. In 2014 and 2015 he conducted a series of dye experiments in the Chukchi Sea as part as a BOEM-funded project in collaboration with the University of Alaska. The dye studies revealed how water masses from distinct regions interact and mix. We observed, for example, that warm coastal waters were subducted underneath the cool melt waters to form an intermediate layer of warm water that interleaved above the cold "winter water" and below the fresh meltwater layer. We observed that strong wind events could mix this warm water up to the surface and thus transport heat from the coastal region off-shore. These mechanisms of physical water dynamics will play an important role as the Arctic warms and loses sea ice.

Enrique Curchitser is an oceanographer interested in understanding how large-scale climate drivers impact regional ocean circulation and ecosystems. His high-latitude work includes past and current work on climate and ecosystem variability in the Bering Sea as part of the NSF-sponsored Bering Sea Ecosystem Studies (BEST) program, a North Pacific Research Board sponsored project on tanner crab population variability in the Bering Sea and various projects sponsored by the U.S. Department of Interior in the Bering, Chukchi and Beaufort seas, focused on modeling the ocean and sea ice dynamics of these seas at high-resolution. Output from the Arctic and Bering Sea models are used to assess the impacts of potential oil spills in the particular regions.

Paul Falkowski is focused on understanding the biogeochemistry of Earth, in which the polar oceans play a disproportionately large role. His research in Arctic and Antarctic marine systems has focused on the understanding conversion of light into organic chemical compounds that fuel marine ecosystems.

Jennifer Francis' research is focused on the rapidly changing Arctic: why change is happening, how changes are affecting the Arctic system, and how disproportionate warming there is affecting temperate regions on Earth, where billions of people live. She is also involved in projects related to science communication, helping non-scientists gain a deeper understanding of why the climate is changing and how it already affects and will continue to affect each and every one of us in profound ways.

Yuan Gao has conducted NSF-funded atmospheric composition and chemistry research efforts in both the Arctic and Antarctica, including the air-sea chemical exchange of nutrients, particularly the input of atmospheric iron (Fe) to the ocean. In the Arctic, her efforts include land-based measurements in the Svalbard Archipelago and shipboard measurements in the western Arctic Ocean, as part of the 2015 US GEOTRACES expedition (geotraces.org). In Antarctica, her efforts include shipboard experiments on transects of the East Antarctic sector of the Southern Ocean and land-based measurements at Palmer Station, West Antarctica. Laboratory experiments and numerical modeling complement the field work efforts. Several minority undergraduate students have been involved in these efforts.

Juliane Gross is a planetary geologist who studies meteorites. For optimal geochemical analysis, the condition of found meteorites needs to be in as pristine as possible. Therefore, she collects meteorites in the Trans-Antarctic Mountains where meteorites are found in abundance due to sublimation of the ice surface, and there are no microbes or other factors that could contaminate the meteorites. A major field expedition was completed in February 2018.

Max Haggblom seeks to delineate the active microbial community in Arctic tundra soils and discern their roles in carbon and nitrogen turnover. By understanding microbial processes in frozen soil systems, we can better predict the extent of soluble organic matter remineralization, as contributions to climate change. His central hypothesis is that the divergent life-styles and growth strategies (e.g. broadly copiotrophic vs. oligotrophic, as well as different competitive strategies, i.e. competitor-stress tolerators-ruderals) of these different microorganisms will be reflected in their ability to function in frozen soils and in their responses to environmental perturbations, leading to seasonal dynamics of activities and soil organic matter decomposition. His recent focus has been on elucidating the subzero-active members of the soil microbial community.

Shantenu Jha is leading an NSF-funded Research Coordination Network aiming to facilitate collaboration among polar researchers and high-performance distributed computing specialists. He is also involved in research to build efficient, high-performance computing systems for digital elevation models derived from high-resolution satellite imagery and covering the polar regions.

Lee Kerkhof's research aims to elucidate the active microbes in a variety of complex environments, and to understand the mechanisms driving microbial diversity and biogeochemical processes. He uses nucleic acid based analyses to identify those microorganisms (prokaryotic, archaeal, and eukaryotic) that are making ribosomes or incorporating C and N into their genomes. His study sites include aeolian, aquatic, association with eukaryotic hosts, and sediments/soils systems including permafrosts/tundra. His research has been funded by NSF, DOE, NASA, NIH, ONR, and DOD-SERDP.

Josh Kohut conducts Antarctic research in the Ross Sea and the West Antarctic Peninsula. His research is focused on the ways ocean physics structures marine ecosystems. He uses novel high frequency radar and gliders to characterize the physical and biological dynamics. His research is

tightly coupled to extensive outreach focused on getting pre-college students to conduct original research using oceanographic data.

Adam Kustka works with lab cultures and field populations of phytoplankton from the Ross Sea and Western Antarctic Peninsula. He is most interested in how these organisms are influenced by iron availability and how large blooms continue to fix carbon dioxide, despite drawdown to levels below those in equilibrium with the atmosphere. He has integrated this work into several outreach programs that offer authentic research opportunities to Newark area high school students.

Richard Lathrop is studying resilience of Arctic-breeding shorebird habitat under climate change. He combines existing shorebird population and habitat data (derived from the literature, established sightings databases and Arctic experts) with species distribution models (SDM) to identify and map current, high-quality locations for the target species, the red knot and semipalmated sandpiper.

Jim Miller's research focus is on climate feedbacks that contribute to the enhanced rate of warming in the Arctic, with a particular emphasis on water vapor and cloud feedbacks. For the terrestrial Arctic, he uses global climate models to investigate how long-term trends in temperature and precipitation affect river flow in the major high-latitude river systems. These changes in river flow lead to altered freshwater fluxes into the Arctic Ocean, which in turn have implications for Arctic Ocean circulation as well as potential impacts on the North Atlantic, also topics of his research.

John Reinfelder is interested in the sources, transformations, and bioaccumulation of mercury in polar marine ecosystems, and the role of tidewater glaciers in the productivity of fjords. The goal of his polar mercury research is to understand the accumulation of methylmercury in coastal polar marine food webs. He and his students have been characterizing the chemical forms of mercury in seawater, sea ice, and biota, and examining the biological and environmental controls of the production and degradation of methylmercury in the continental shelf waters west of the Antarctic Peninsula. A current NSF-funded project addresses the production of methylmercury in the digestive tract of Antarctic krill. Reinfelder is just beginning to examine biological-physical coupling in fjords with Rutgers colleague Bob Chant.

Åsa Rennermalm's research centers on understanding Greenland ice sheet mass loss and runoff. Her work spans from small-scale, fieldwork-based studies of ice sheet surface hydrology to Greenland-wide studies of how ice sheet hydrology and mass-loss connects to atmospheric and oceanographic conditions. She has created educational modules for pre-college students about the changing Arctic in collaboration with a NJ high school teacher. Her work is funded by NASA and NSF.

David Robinson's research focuses on hemispheric and regional snow cover dynamics and interactions of snow cover with other climate elements. This includes maintaining an

internationally-recognized database of Northern Hemisphere snow extent throughout the satellite era (<http://snowcover.org>). This information is used in his Global Snow Lab's research endeavors, efforts of others, and in contributions to national and international climate assessments.

Alan Robock is involved in determining whether volcanic eruptions, particularly four large decadal-spaced eruptions near the end of the 13th Century CE, produced the Little Ice Age. His research group has conducted detailed models of the climate of Baffin Island in the Arctic, and are now analyzing long global climate model simulations for the past 1000 years and conducting new model simulations with volcanic eruptions, singly and combined, and with and without solar variations.

Yair Rosenthal's research centers on the links between climate variability in the high latitudes of the North Atlantic and Southern Ocean and the equatorial Pacific, on centennial, orbital and geologic time scales. Of specific interest are the mechanisms and feedbacks by which climate perturbations at the high polar latitudes are transferred via ocean deep currents to the equatorial regions and back. Current projects include the study of response of ocean circulation to the melting of ice sheets during previous warm interglacials, both in the North Atlantic and the South Pacific.

Grace Saba focuses research in both the West Antarctic Peninsula and the Ross Sea. She uses autonomous glider observations and experimental approaches to better understand how organisms respond to their physical environment, how those processes reverberate through food webs, and how climate change impacts the dynamics of these interactions. She has been involved in several K-12 outreach programs focused on her polar work, and uses Antarctic data and research in undergraduate and graduate teaching.

Hal Salzman is a sociologist researching the socio-economic dynamics of community sustainability in the Arctic in the face of climate, social, and economic challenges. Supported by the NSF Arctic Social Science Program, his fieldwork in Arctic Alaska examines governance institutions, with implications for communities throughout the Arctic and the sustainability of indigenous/marginalized communities globally. Arctic Planning Studios he taught worked on plans for arctic villages that will have infrastructure development to support increased marine activity. His projects include short videos on community development based on his fieldwork in the communities, and middle and high school curricula.

Oscar Schofield is involved with several Antarctic projects spanning from the Amundsen Sea to the West Antarctic Peninsula where he is part of an interdisciplinary 25-year time series study documenting how regional warming can alter marine ecosystems. His efforts combine traditional measurements with modern satellite remote sensing and undersea robotics. He integrates real-time data into his classroom teaching and has conducted extensive outreach ranging from K-12 teacher training to full-length documentary movies.

Rob Sherrell has conducted several NSF-funded research efforts in the Amundsen Sea and the West Antarctic Peninsula, as well as the western Arctic Ocean, focusing on ocean-ice-sediment interactions and their effect on nutrient trace metal dynamics in these rapidly warming regions. Collaborators include scientists from several US institutions as well as British and Swedish researchers. This effort has involved water column sampling, novel analytical method development, shipboard phytoplankton incubation experiments, and numerical modeling approaches. He has participated in the NSF PolarTREK program and the Rutgers Polar Science Symposium for middle school students in New Jersey.

Liz Sikes has over 25 years of experience in Southern Ocean sea-going science. She has been on 7 voyages to the Southern Ocean (one as chief scientist) spanning activities that include a WOCE transect, sediment trap deployments, and coring. She will be leading a coring voyage to the Southeast Indian sector in 2018. Liz's research focuses on the interconnection of global carbon cycling, ocean circulation and climate change. Using isotopic ($\delta^{13}\text{C}$, $\delta^{18}\text{O}$, and ^{14}C) and organic (biomarker, Uk37) techniques, she investigates past sea surface temperature and circulation changes in the Southern Ocean to determine how this traps and releases CO_2 from the deep ocean on glacial to interglacial time scales. She also examines sources, pathways, and sinks of terrestrial and marine carbon in modern environments and their role in ocean acidification.

Jim Wright's research interests in polar climates lie in understanding the behavior of past ice sheets on millennial to million-year time scales. On the timescale of the past 2.5 million years, he is interested in how the large northern hemisphere large sheets influenced atmospheric circulation and melt water discharge into regions where deep water forms in the North Atlantic Ocean. These changes influenced the density and overall production of North Atlantic deep water. The Antarctic ice sheet has been a permanent feature over the past 12.5 million years. However, prior to that time, the southern hemisphere ice sheet was temperate and therefore waxed and waned on various timescales. It is fundamental to understand what changes led to the establishment of a polar Antarctic ice sheet that became a permanent feature on our planet. Understanding the geologic history of ice sheets provides important constraints on predictions of future climate change.

Appendix B. Participants and talk titles at Polar “meet and greet” on September 19th, 2017

1. Oscar Schofield

Understanding how a melting West Antarctic Peninsula is altering the marine food-webs: The Palmer Long Term Ecological Research (LTER) program

Professor

Department of Marine and Coastal Sciences

2. Michael Brown

Drivers of phytoplankton community composition, and corresponding impacts on biogeochemistry, along the Western Antarctic Peninsula

PhD Student

Department of Marine and Coastal Sciences

3. Corie Charpentier

Polar interests: Responding to the environment

Postdoc

Department of Marine and Coastal Sciences

4. Grace Saba

Physical-Biological Coupling and Trophic Dynamics in a Changing Antarctic

Professor

Department of Marine and Coastal Sciences

5. Dave Robinson

Global Snow Lab

Professor

Department of Geography

6. Michael Brady

Local views of shoreline change risk along Alaska’s northern coastline

PhD student

Department of Geography

7. Phil Sontag

Krill in Antarctica

PhD student

Environmental Sciences

8. Max Haggblom

Divergent Life-Styles of Bacteria Active in Frozen and Thawing Arctic Tundra Soils

Professor

Department of Biochemistry and Microbiology

9. John Reinfelder
Mercury in the coastal Southern Ocean
Professor
Department of Environmental Sciences

10. Kyle Clem
Influence of the Tropics on Antarctic Climate
Postdoc
EOAS

11. Jim Miller
Feedbacks in the Arctic climate system
Professor
Department of Marine and Coastal Sciences

12. Marie McCrary
Freshwater Content Variability in the Beaufort Gyre
PhD Student
Department of Marine and Coastal Sciences

13. Schuyler Nardelli
Antarctic Acoustics
PhD Student
Department of Marine and Coastal Sciences

14. Jennifer Francis
Arctic Systems Science and arctic/mid-latitude linkages
Professor
Department of Marine and Coastal Sciences

15. Asa Rennermalm
Greenland Ice Sheet hydrology and contemporary climate change
Professor
Department of Geography

16. Rohi Muthyala
Modeling Surface Hydrology in Southwest Greenland
PhD student
Department of Geography

17. Sasha Leidman
Greenlandic Glacial Hydrology
PhD Student

Department of Geography

18. Tamar Barkay

Bioavailability and toxicity of Hg in the Arctic, Effect of global warming on Methylmercury production in the Arctic

Professor

Department of Biochemistry and Microbiology

19. Yuan Gao

Marine Atmospheric Chemistry in the Polar Regions

Professor

Department of Earth and Environmental Sciences (RU Newark)

20. Songyun Fan

Chemical Composition and Oxidation State of
Iron-Containing Aerosol Particles Over West Antarctic Peninsula
PhD student

Department of Earth and Environmental Sciences (RU Newark)

21. Nicole Waite

Phytoplankton at the Palmer LTER

Research Staff

Department of Marine and Coastal Sciences

22. Rob Sherrell

Phytoplankton and ocean chemistry

Professor

Department of Marine and Coastal Sciences and Earth and Planetary Sciences

23. Hal Salzman

Sustainability & Employment in the Arctic: Indigenous Governance and
Alternative Institutional Models for Development

Professor

Bloustein School of Planning and Public Policy

24. Isatis Cintron

Source apportionment and impact of black carbon in the Cryosphere

PhD Student

Environmental Science

Appendix C. Agenda for the Polar Town Hall on October 3rd, 2017

10 am: [Rob Sherrell]: Welcome, presentation of agenda.

10:10am: [Asa Rennermalm]: Brainstorming activity with the “post-it method”. Write down three answers to the following question on post-it notes, each answer should be on a separate note: "What polar research do you want Rutgers to do within the next 10 years?" Place your notes on the blackboard, stay by the board and organize yours and others notes into topics and themes.

10:40am: [Asa Rennermalm]: Summary of the brainstorming activity.

10:50am: [Asa Rennermalm] Overview of current Rutgers polar expertise and opportunities. This will include a report from the Polar research meetup (Sept 19th).

11:10 am: [Asa Rennermalm] Questions/comments from audience. Did we miss anything polar related going on at Rutgers?

11:20am: [Rob Sherrell] Summary of EOAS polar theme strategic group report draft and recommendations.

11:40am [Rob Sherrell]: Questions/comments from audience.

12:00 pm: LUNCH and more conversation. Continue with one-on-one or small group discussions to continue. Share your ideas with a polar theme committee member (see list on other side)

Appendix D. Summary of brainstorming activity at the Polar Town Hall on October 3rd, 2017

Facilities/Organizations:

- 1) A graduate certificate and/or undergraduate minor in polar studies
- 2) Begin new LTER programs in other Arctic locations
- 3) Integrate Rutgers Faculty to holistically study Arctic region from natural and social sciences
- 4) Start polar science center, possibly within EOAS
- 5) Polar Institute for the study of atmospheric, ecological, ocean and glaciology connections
- 6) Trip to Greenland (Alumni + Faculty + Students)

Society

- 1) Combine studies of Social and “Hard” science
- 2) Conduct briefings + field visits with congress delegation, relevant committees in congress that can benefit from Rutgers research in polar regions (even shipping)
- 3) Societal engagement in science policy around climate change
- 4) Outreach with communities in the Arctic and students/general public of the importance of polar research and polar regions
- 5) Advance polar literacy of public audiences
- 6) Investigating the effects of ice sheet/glacier melting on local communities, fish, krill, etc.
- 7) Become the leaders in building virtual connections between the poles and diverse audiences
- 8) Better communicate the connection between Antarctic Science & Society through polar impacts on local + global scale
- 9) Increase public appreciation for scientific research
- 10) Help the public relate polar warming to their own lives and future; why should they care?
- 11) Develop/increase collaboration with indigenous populations to help educate + research

Ice sheets

- 1) Participate in international drilling efforts in East Antarctica to reconstruct glacier flow since the Pliocene
- 2) Connections between Arctic land surface hydrology and atmospheric, terrestrial ecosystems, marine environments
- 3) RU AUVs/gliders routinely monitoring ice sheets + ocean-terminating glaciers around Greenland and Antarctica
- 4) Connect Sea level rise and ice sheet melting (both Antarctica and Greenland)
- 5) How likely are rapid/abrupt changes in the polar ice sheets?

- 6) Polar ice sheet mass balance

Oceans

- 1) Effect of Greenland melting on Atlantic ocean or in general circulation patterns
- 2) Southern ocean circulation influence/interaction with climate & climate change
- 3) Southern ocean temperature and climate change interactions
- 4) Generate a major program to understand the mechanisms driving the most productive region in Antarctica, the Amundsen sea Polynya
- 5) What do failures in global climate model projections of sea ice and other polar changes imply for projections of lower latitude human and ecological impacts?
- 6) Polar ice melt on global sea level
- 7) Understanding how ice sheet freshwater influence ocean circulation and marine environments
- 8) Southern ocean's control on atmospheric CO₂
- 9) Marine focus – multi variate

Coastal Processes

- 1) An interdisciplinary study of Fjord processes -> Buoyancy exchange (heat, fresh water) between ocean and ice; Exploit modeling and observational assets.
- 2) Linking Arctic fresh water fluxes to local shelf processes
- 3) Study connecting Arctic shelves and arctic basin processes, cross shelf exchange processes
- 4) Coastal and mesoscale process studies

Tools

- 1) Ocean/climate observations (large scale)
- 2) Send an autonomous glider that senses and samples seawater, under the Doston Ice Shelf, Antarctica
- 3) Lead efforts to discuss and deploy ocean observing technologies
- 4) Observing systems
- 5) Correction of satellite based climatological data from in-situ measurements
- 6) Develop ocean observing program in Ross sea
- 7) Model/monitor sea ice

Prediction

- 1) Polar climate prediction
- 2) Polar ice melt on polar climate through albedo feedback
- 3) Arctic amplification of climate change
- 4) Prediction of cryosphere albedo change

Feedbacks and connections

- 1) Cryosphere focus – multivariate
- 2) Study of the atmospheric chemistry of the polar and tropical glaciers
- 3) Impacts and effects of melting permafrost feedbacks
- 4) What would the consequences of rapid polar change be for regional and global circulation and ecology
- 5) Connections between arctic, Antarctic and tropical glaciers atmospheric chemistry, physical and ecological changes
- 6) Connecting tropics to polar regions (atmospheric-ocean processes)
- 7) Physical climate change – understanding feedbacks
- 8) Connections: to polar to rest of the globe via observations and modeling
- 9) Arctic Ocean connection to north Atlantic – did it produce little ice age?

Ecosystems

- 1) Influence of polar climate change on ecosystems
- 2) Effect of sea ice loss on polar microbial growth
- 3) Greater focus on physiological change in polar organisms
- 4) Develop taxonomic library through genomes
- 5) Launch an interdisciplinary study of atmospheric effects on southern ocean biogeochemistry
- 6) Document effects of polar greening
- 7) Physical and ecological impacts of warming in the WAP
- 8) What are the effects of glacial runoff on coastal marine ecosystems
- 9) Leaders in comparative food webs in Arctic Ocean and coastal Antarctica
- 10) Start a comprehensive global investigation of cryosphere microbes and their metabolism
- 11) How do biogeochemical cycles in the water, sediments and on the land as a result of ice-shelf retreat?
- 12) Understand life at subzero temperature