Biophysical Feedbacks and Transitions in the Arctic Regional System Online Forum February 6–8, 2002

Introduction

Post Title: Introduction: Life Webs
Posted by: *Terry Chapin* at 11:41 AM 2/6/2002

Biophysical Feedbacks and Transitions in the Arctic Regional System: Life Webs

During the past decade the arctic terrestrial system has been the focus of research under the ARCSS-LAII program, primarily through a series of coordinated field and modeling experiments called ATLAS, FLUX , and ITEX. One key focus of LAII has been to assess arctic terrestrial contributions to the global CO2 budget and surface energy balance. A second focus has been understanding the processes and controls on these mass and energy fluxes. These are, by nature, biophysical processes and feedbacks, so that much of LAII research has gone toward untangling the complex web among vegetation, climate and surface physical processes.

These research efforts have made steady progress over the decade, increasing the scale over which we can extrapolate biophysical processes (working up from plots to sub-regions) and the confidence we have in these extrapolations. The decade also has seen the development of a workable interdisciplinary approach, bringing together physical and biological scientists while developing trust and a common vocabulary and working mode that has allowed these groups to interact successfully.

This progress positions us to begin an exciting new phase of research in which we can address the arctic system as a whole, while we continue to investigate more fully the interaction of the biotic and physical parts of the arctic terrestrial and marine environments. Because of the unique geography and relatively simple biotic systems in the Arctic, this may be the most promising place on Earth to address biocomplexity and biophysical interactions at such a large scale.

The new phase of research also provides an opportunity to tackle areas where we have not done as well during the past decade as we would have liked—specifically, in the area of assessing and predicting the impacts of changing terrestrial and marine environments, primarily through affected biota, on humans living in the Arctic and elsewhere. Because many arctic residents rely on biotic systems for their livelihood, a sophisticated understanding of arctic biophysical feedbacks and transitions will be an essential underpinning to the Human Dimensions of the Arctic System (HARC) research effort.

Research is needed in three major areas to achieve an understanding of the arctic regional system at a level that will allow prediction of future states, reliable interpretation of paleo-records (PARCS) , and the ability to place in context the documented changes in the arctic environment that concern arctic and non-arctic peoples alike (SEARCH) . These areas are:

1. The biophysical feedbacks and interactions among the components of the arctic system and how they affect its connections to the global system.

2. The non-linearities, thresholds, and “surprises” in system functioning and state that result from combined complex physical and biological systems.
3. The vulnerability and resilience of the biotic systems to change, and the relationship of these aspects of the system to human activity and livelihood in the Arctic.

Improving our understanding in these areas is essential if we are to get to the heart of one of the most pressing issues of the day—are observed changes in the Arctic significant in terms of the impact they will have on people, and are they indicative of future states? Other ARCSS programs (some already in progress, others planned) address these questions, but a program with a specific focus on the biota of the Arctic and their interactions with the physical system, is indispensable if we are to assess the impact of system change on people.

With these ideas as background, we would invite discussion of several critical questions related to life webs: biophysical feedbacks and transitions in the arctic regional system.

Terry Chapin
Matthew Sturm

Are we in a position to delineate the current arctic marine and terrestrial trace gas balance?

ARCSS Planning Discussion > **Are we in a position to delineate the current arctic marine and terrestrial trace gas balance?** > **What are our largest uncertainties?**

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Post Title: What are our largest uncertainties?
Posted by: *JoshSchimel* at 3:46 PM 2/5/2002

Are we in position to delineate the current arctic marine and terrestrial trace gas balance, and can we predict with any certainty how the balance might change under future states and how has it changed in the past?

The core question of the day is, **"Are our largest uncertainties in our ability to extrapolate or in understanding and modeling of underlying processes?"**

This is a fundamental question of scale of both space and time. For extrapolating in each, we need solid process understanding to build the models and we need the appropriate driving variables. The question may therefore be more clearly stated as, "Is our ability to build models as extrapolation tools limited by process understanding or by input data?"

I suspect that for different aspects of extrapolation, the answer will switch between data and understanding. Can we identify the processes and data sets that limit our ability to develop models that we have confidence in? What are they?

From my own experience, I will put one down on each list:

Process: Soil organic matter breakdown. The more I have learned about tundra soil organic matter processing, the more confused I have become. I believe that the assumptions of decay kinetics and limiting factors may be flawed.

Data: Soil organic matter distribution in mineral soils. Organic matter lenses in mineral soils are common in soils that undergo cryoturbation, yet few of us have ever studied the biogeochemistry of these materials.

What do we need to add to these lists?

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Post Title: Re: What are our largest uncertainties? (JoshSchimel)
Posted by: *Jeff Welker* at 9:06 AM 2/6/2002

I think that Josh has a good point here regarding extrapolation and processes.
Our ability to extrapolate appears to be improving at a very high rate, but our understanding of processes is still rudimentary. For instance, we now have several years of data from the High Arctic and the rates of net CO2 flux are pretty consistent between very dry to constantly wet tundra in Alex Fiord. There are some temporal differences in the sign of CO2 flux and some differences in their respones to warming. But, from the big picture they are pretty similar. However, we find very large differnces in the leaf d15N of dry, mesic and wet tundra vegetation indicating that the N cycling in these systems are distinctly different, though it is unclear if this is due to rooting depth, N mineralization/immobilization patterns or the differential use of inorganic as opposed to organic N sources. Thus, I support the dual-approach and the dual priority of extrapolation and process efforts.

Post Title: Re: An important contribution to this discussion section
Posted by: *JoshSchimel* at 3:32 PM 2/6/2002

John Hobbie entered a piece in which a group of modelers came up with things that they identified as key uncertainties. That entry:

Post Title: Key uncertainties in modeling response to change in terrestrial systems
Posted by: *jhobbie* at 8:32 PM 2/5/2002

At a recent meeting of LAII modelers we asked them to identify the key uncertainties in their modeling efforts. These were caused by a lack of understanding of key processes, by missing data, or by missing formulation of a model. We hoped to identify commonalities that cut across the wide variety of process-based models. One of the values of such a list is that it comes from the scientists actually doing the modeling and is a big step above a laundry list of interesting topics. A follow up at the Allhands meeting could be a discussion of priorities on the list and a possible white paper with more information about the models involved and the uncertainty introduced.

The list follows along with the names of the attendees or responders.

Uncertainties in modeling soils, roots, and the transformation of carbon and nutrients:

* The nature of organic carbon transformations in the soils over time (McGuire)
* Belowground productivity and root distribution (Epstein, Nadelhoffer, Sommerkorn)
* Seasonal dynamics of net nitrogen mineralization and their microclimatic and biological controls (Epstein, Shaver)
* Dynamics of belowgound pools of carbon and nitrogen including roots, microbes, soil organic matter (i.e., controls on the fate of carbon allocated belowground and its implications for nutrient dynamics – Nadelhoffer, Sommerkorn)

Uncertainties in modeling climate

* Modeling the distribution phase, and quantity of precipitation (Lynch)
* The extrapolation/interpolation of climate for regions; both temperature and precipitation are needed (Rastetter)
* The error between the observed temperatures in the Arctic, derived mostly from lowland stations, and the true temperatures that apply over the lowlands and uplands of an entire catchment (Peterson)
* The errors in the measurement of precipitation and interpolation throughout the Arctic (Peterson)

Uncertainties in land/water and material transport

* The unknown quantities of nutrients and organic matter from land entering the riparian zone and streams (Peterson) and the controls on their production (Kling/Sommerkorn)
* The retention and losses of nutrients, greenhouse gases, and organic matter in stream, lake, floodplain, and delta components of large catchments (Peterson)

The uncertainties in modeling terrestrial ecology

* The unknown role of mosses in the carbon cycling in the shoulder season (McGuire)
* The effects on mosses of competition for light (Epstein)
* The importance of the omission of mosses from the land surface model (LSM) (Beringer)
* The unknown controls of plant community composition that govern the difference between acidi and non-acidic (neutral) tundra sites (Epstein)
* The factors governing the establishment of new individual plants on disturbed sites (Epstein)
* The parameterizations of plant functional types needed in the land surface model (Epstein)
* The information on the controls of trace gas fluxes that are needed to explain the large-scale flux measurements (Sommerkorn)

The uncertainties in modeling the hydrology

* Snow heterogeneity as it affects: a) timing and amount of snowmelt; b) surface water and energy balance during snowmelt transition period; c) the impact of different representations of snow heterogeneity on the evolution of summer soil moisture (Stieglitz)
* Soil moisture heterogeneity as it affects: a) land-atmosphere water and energy fluxes, b) land-atmosphere carbon and methane fluxes (Stieglitz)
* The identification of the near surface flow pathways that affect the flushing of constituents of hills slope soils to the streams (DOC, DIN, etc.)
* There is a lack of understanding of the meteorological forcing as it pertains to precipitation which is the measurement that, compared with air temperature, humdity,

and so forth, is most in error, especially in the winter. As the observing network decreases, the only data left are from re-analysis and here too the greatest error is in the precipitation (Stieglitz).

* The lack of hydrology and permafrost in the LSM (Beringer)
* The effect of changes in surface morphology and subsurface structure such as changes in channel networks changes in active layer thickness and permafrost distribution and changes in soil profiles (e.g., in the thickness and properties of organic layers (Hinzman).
* The lack of high resolution digital terrain data is the primary data deficiency for hydrologic modeling
* There is a lack of gridded files on soil properties and geologic substrates (Hinzman)
* There is a lack of year-round, high-resolution (~100 m) atmospheric forcing (e.g., wind speed and direction, temperature, humidity) distributions (Liston)
* There is a lack of information on winter (snow) precipitation quantities and timing (Liston)
* During the winter, there is an unknown amount of sublimation from wind-blown snow (Liston).

The uncertainties for modeling permafrost

* For modeling the active layer thickness and the permafrost temperatures, the biggest uncertainties are the future climates (air temperature and precipitation, especially the snow depth distribution) and the future surface conditions (drainage, vegetation, moss dynamics) (Romanovsky)
* Need to know the geometry (3D, 2D) of development of a talik (Romanovsky).

Post Title: Re: What are our largest uncertainties? (Jeff Welker)
Posted by: *jhobbie* at 9:15 PM 2/9/2002

Jeff mentions the 15N signature of arctic plants and suggests that the differences observed reflect different sources of nitrogen. One additional difference that he did not mention is that many (most? all?) arctic plants obtain nitrogen (some? all?) through mycorrhizal connections to their roots. Organic and inorganic N is taken up by the fungi. Biochemical transfers result in isotope fractionation so the mycorrhizal material becomes heavy in 15N. The light 15 is transferred (probably as two amino acids) to the plant roots making the plants negative compared to the source of N. In the symbiosis, the fungi receive fresh photosynthate from the plant and this may account for 20-30% of the carbon produced in photosynthesis.

What are the consequences of changes in the biotic systems on the livelihood of human residents?

ARCSS Planning Discussion > **What are the consequences of changes in the biotic systems on the livelihood of human residents?** > **Biotic system changes and people**

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Post Title: Biotic system changes and people
Posted by: *Matthew Sturm* at 4:19 PM 2/5/2002

Undertaking a new phase of research into biocomplexity and biophysical interactions provides an opportunity to tackle areas where we have not done as well during the past decade as we would have liked, specifically in the area of assessing and predicting the impacts of changing terrestrial and marine environments, primarily through affected biota, on humans living in the Arctic and elsewhere. Because many arctic residents rely on biotic systems for their livelihood, a sophisticated understanding of arctic biophysical feedbacks and transitions will be an essential underpinning to the Human Dimensions of the Arctic System (HARC) research effort.

Here are two questions to stimulate a disucssion along these lines:

What are the consequences of changes in the biotic systems, both terrestrial and marine, on the livelihood of their human residents?

Can we predict future states with enough certainty to recognize thresholds, estimate their effects, and mitigate their consequences?

Post Title: Re: Biotic system changes and people (Matthew Sturm)
Posted by: *Tom Dunning Newbury* at 8:36 PM 2/5/2002

Matthew, you asked about connections between arctic changes and humans.
I think that the Navy predicts that the Northwest Passage will be ice-free during summer in about 4 decades. That loss of ice all around the Arctic will have a big impact on the marine mammals which depend on it, especially walrus and polar bear populations. Both are subsistence species.

A similar research topic with primarily theoretical implications is that the loss of ice in the Northwest Passage will allow the bowhead stocks in the Beaufort and Hudson's Bay to re-mix.

Post Title: Re: Biotic system changes and people (Matthew Sturm)
Posted by: *Henry Huntington* at 3:52 PM 2/6/2002

Good questions, and not simple ones, either. With regard to the human consequences of biotic system change, the answer will probably vary widely. In North America, government support for infrastructure, welfare, etc., gives people some options. In Chukotka, by contrast, there is no support available today, and people are living in a way that is probably closer to 200 years ago than today in many respects. Thus, a net loss of hunting opportunities in Chukotka will be far more devastating than the same loss in North America.

That said, determining if in fact we are headed for a net loss is complex, and the answer is probably different depending on the time scale of interest. Changes in weather that lead to more ice on the tundra will be devastating for herbivores such as caribou in the short term. If those conditions persist, the tundra may not be able to support large herds in the future. If, however, the icing conditions are transient and are replaced by something more conducive to wintering herbivores, increases in plant quality and mass may allow the tundra to support more animals in the long-term. Other dynamics may affect summer residents of the tundra, such as geese.

And this is just the start. Would more caribou compensate for fewer seals? Would salmon runs offset losses of whitefish? What does all this mean for villages located to take advantage of specific resources?

Predicting future states I will leave to the ecologists. But, predicting human responses can be aided by looking at responses to past changes, as well as by comparing the situations faced in different villages and areas of the Arctic today. Some villages are located for ecological reasons, whereas others were created for political or economic reasons. How do the latter compensate for their less-than-ideal location? How have other factors influenced the dynamics of villages in the past, e.g., changes in job opportunities, housing, etc.? What does the archeological record tell us about sudden shifts in resource use?

In other words, there are many approaches that can be used to better understand how people interact with their surroundings, both in stable times and in times of sudden change. Such research should help shed light on what we can anticipate for the future.

Post Title: Re: Biotic system changes and people (Henry Huntington)
Posted by: *Matt Berman* at 6:23 PM 2/6/2002

Henry: I agree with your view that variation around the Arctic and across the archeological and historical record can tell us a lot about how communities may adapt to hypothesized changes. In addition, I would like to add that some types of adaptations are much easier for people to make today than in the past, and others much more difficult. It is much easier for individuals and households to move long distances to take advantage of new opportunities than it was even 50 or 100 years ago, even in Chukotka. In contrast, it is much more difficult for communities to move, because they are weighted down -- so to speak -- with fixed infrastructure. There is much more public assistance available for people (except in Russian Arctic) to get through hardships. Will this availability of government assistance weaken solidarity at the community level that got people through historical disasters? People neither could nor thought it appropriate to manage resource stocks in the past other than through ethical harvest practices. Now scientists and politicials increasingly manage populations of fish and wildlife in the Arctic. Research on the human consequences of biotic change that looks at past adaptations must take these institutional changes into account.

Post Title: Re: Biotic system changes and people (Matt Berman)
Posted by: *kofinas* at 7:08 PM 2/6/2002

Yep, institutions matter a lot when talking about human adaptation. Let's also remember that we are talking about more than climate-related effects on biota. Changes in biota have to be considered in the context of the rapidly growing extent of infrastructure (roads), greater industrial development (mines, airports, and oil fields), local and regional economic booms-bust cycles, changing community demographics, greater interactions with / travel to / supplies from urban regional centers, and…and.. . Given the dynamism and complexity of the system, can we

predict future states, thresholds, adaptive responses, resilience? It seems that as the complexity of the system increases, the time horizon about which we can assess a possible future decreases. Gary Kofinas

Post Title: Re: Biotic system changes and people (kofinas)
Posted by: *Matthew Sturm* at 2:57 PM 2/8/2002

Sorry for the late post, but I just returned from the field. The discussion about infrastructure and institutional response vs. climate change is right on the mark. I think one of the reasons that ARCSS has had difficulty in getting fully plugged into HARC-like initiatives is that climate-related changes propogate slower and have a lower immediate impact than societal or infrastructure-driven changes. A new road to Barrow would have a far more profound impact than a few years of warmer weather, for example. For the longer-term outlook, however, the climate drivers become increasingly important. Perhaps we have not explored in suffient detail the issues of time scale of response and change in human vs. natural systems, and learning how to balance these two very different scales. In some ways, that discussion might lead to the bridge between the predominately physical scientists in ARCSS, and making the link to people of the Arctic. I think there even in the face of large societal changes had a fast time scale, the ARCSS community has much to offer about the more distant prospects for the future.

Post Title: Re: Biotic system changes and people (Matthew Sturm)
Posted by: *Henry Huntington* at 4:25 PM 2/8/2002

I like Matt's and Matthew's comments about fixity and time scale. Perhaps one way to think about the link between humans and climate is to consider human activities that have a similar time scale to climate change effects. For example, moving a village is a major undertaking these days (as opposed to the past, as Matt points out), and perhaps village location is one of the human factors that needs to take into account the potential effects of climate. What kind of boat you purchase this year, or other more transient decisions, may reflect more immediate inputs. On the other hand, moving a village can't be done or undone lightly, and would probably require very strong evidence and motivation. Predicting climate far enough in advance and with enough certainty, and then convincing politicians, may be a high barrier to moving villages in advance of a major crisis such as faced by Kivalina or Shishmaref, for example.

Development throws another wrinkle into things, as Gary says. I wonder if one conclusion would be that most of the human dimensions of the Arctic are human activities--in other words, the relationship with the unimpacted natural environment is fairly stable, and the source of most environmentally mediated changes to society is in fact human actions such as development, overharvest, etc. Any thoughts?

Post Title: Re: Biotic system changes and people (Henry Huntington)
Posted by: *Matthew Sturm* at 5:21 PM 2/8/2002

I am reminded by this discussion of the dynamics of families. As long as most of the internal workings of the family are doing well, the family thrives and is happy. External stresses (loss of job; having to move, illness) have an impact, but cannot upset the basic equilibrium.....unless too much external stress is applied. Then even the most stable arrangement begins to come apart. The analogy is that the health and well being of arctic communities arises in large measure from human and societal interactions...but always the climate, the natural environment, is applying external pressure. Enough pressures, and the internal arrangement can begin to

unravel. Our job as natural and social scientists in ARCSS seems to me to be figuring out just how much stress is "enough". The answer is different for every community and human system.

Propagation of spatial and temporal changes

ARCSS Planning Discussion > **How do changes in the arctic region biophysical systems propagate spatially and temporally?** > **Propagation of spatial and temporal changes**

Post Title: Propagation of spatial and temporal changes
Posted by: *Joe McFadden* at 4:34 PM 2/5/2002

How do changes in the arctic region, particularly in its biophysical systems, propagate spatially and temporally?

* Are we able to recognize, let alone predict, emergent properties as a function of spatial and temporal scale?

* In what ways must heterogeneity be considered in order to be represented correctly in our system models, and how is the degree of heterogeneity related to system state? How do local rates of biotic change combine at sub-regional and regional levels?

* Are we able to estimate pan-Arctic response times from our knowledge of local response rates?

Post Title: Re: Propagation of spatial and temporal changes (Joe McFadden)
Posted by: *Larry Hinzman* at 4:26 PM 2/8/2002

This question is quite complex due to the inherent interdepencies of the biotic and abiotic systems. Work that we are conducting near Council, Alaska with Chris Fastie and Andrea Lloyd indicates that the process of spruce invasion is strongly related to thermokarsting. As very ice-rich permafrost degrades, substantial surface subsidence occurs, creating very wet zones, bordered by banks that are quite dry. It appears that these banks are more suitable spruce habitat and they initially become established there. However, as the karst spreads, the spruce may perish due to subsidence of the surface and inundation. If the spruce become well established, they may also shade the surface and preserve the permafrost. So, the interaction of warming climate, degradation of permafrost and northern expansion of spruce (and consequent impacts to the surface energy balance) will introduce additional heterogeneity in an already complex problem.

Marine Pathways

ARCSS Planning Discussion > **What are the probable pathways of change of the arctic land surface? Arctic marine environment?** > **Marine pathways**

Post Title: Marine pathways
Posted by: *vbarber* at 4:38 PM 2/5/2002

What are the probable pathways of change and the future states of the arctic marine environment?

* Do thresholds exist or will changes be continuous?
* How will these changes influence thermohaline circulation, surface energy budget, and trace gas fluxes?
* Can we constrain our predictions of future states with current knowledge of biophysical processes and paleo-records, or are the two sets of knowledge too disparate?

While we expect to see changes occurring in the arctic marine environment on different temporal and spatial scales than the terrestrial environment, we know that changes have occurred in modern history. Some folks argue that the changes are due to natural variability from forcing by the Arctic oscillation, the North Atlantic oscillation and El Nino cycles. While distinct boundaries don't exist in the marine environment as they do in the terrestrial world, documented changes in modern history are still difficult to attribute solely to natural variability. Coccolithophore blooms off the coast of Alaska and sightings of marine fish not usually found in Arctic waters along with changing sea ice extent and thickness are just some of the evidence of change seen recently. What other changes might we expect to see? An increase in storm surges along with retreating ice cover is causing increased erosion along the Seward Peninsula. Is this natural variability or an increasing trend in climate change? What is the fate of sub-sea permafrost and methane hydrates and what feedback cycles might be induced? With changes in the terrestrial environment, how might run-off be affected and what will this do to oceanic circulation patterns. Can we predict changes to the oceanic environment given what we know about biophysical processes and interpretations of paleo-records from oceanic sediment cores and other proxy data? If not, what other research is needed?

Jump on in with your predictions of probable pathways of change and the future states of the arctic marine environment.

Post Title: Re: Marine pathways (vbarber)
Posted by: *Robie Macdonald* at 3:15 PM 2/8/2002

I've been working on the topic of how contaminant pathways might change in response to 'climate change' with the arctic as a context. It's been an intriguing effort and one that has led me down a bewildering number of paths. Organizing the theme around contaminants has been very helpful because it's caused me to think about contaminants as markers that illuminate environmental pathways. These pathways include the physical (water, air, ice), the geochemical (particles, sediments, degradation) and the biological (food web). None of these pathways operate in isolation, nor do they operate the same way, nor are they impacted in the same way by identical change. Biological pathways can be changed - indeed have been changed - in three ways (maybe more). The first is the alteration of trophism which can occur top down (take away

fish, bears, seals for example by resource extraction or removing ice) or bottom up (alter the nutrient cycle, change stratification) and both of these impact biomagnfiying contaminants. The second is change at a bifurcation point - for example, change the coupling of ice production from pelagic to benthic or vice versa with obvious effect on pelagic species (fish) or benthic feeders (walrus, birds) one being advantaged at the cost of the other (a biological zero sum game, I suppose). Again, biomagnifiers get caught in this bifurcation. But, there can be other bifurcations like the ones mentioned by Barber - diatoms vs coccoliths (has an impact on what the carbon drawdown does, while holding PP constant, for example) or change from diatoms to flagellates which puts in more low trophic levels. The third way is to alter biota as vectors - change the ice and you change where bowheads go; change the ocean and you change where fish go.

So, I think it really helps to focus our speculations on the meaning of change by looking at the system as a set of connected pathways - for example, following organic carbon through its complete biogeochemical cycle then makes sense as a pathway that can be pushed around in different places including the water, the food web and the sediments. I think much the same can be said of the CHAMP document. I found it illuminating probably because it organizes change around the central theme of freshwater. Once one does that, one finds that fresh water exhibits similar features to those described above - changes in amounts, changes in timing, bifurcations and vectors. These themes require of us the single most important thing we need to do in our planning: make sure we get down to the details - the devil really does lurk there.

Terrestrial pathways

ARCSS Planning Discussion > **What are the probable pathways of change of the arctic land surface? Arctic marine environment?** > **Terrestrial pathways**

Post Title: Terrestrial pathways
Posted by: *vbarber* at 4:37 PM 2/5/2002

What are the probable pathways of change and the future states of the arctic land surface?

* Do thresholds exist or will changes be continuous?

* How will these changes influence the hydrologic cycle, surface energy budget, and trace gas fluxes?

* Can we constrain our predictions of future states with current knowledge of biophysical processes and paleo-records, or are the two sets of knowledge too disparate?

This is a broad topic and encompasses many disciplines. Some of these questions have been touched upon in previous online workshops. HARC had a series of workshops in December that discussed northern treeline, sea ice and Arctic weather, all very pertinent to today's workshop. To review the reports for these workshops, go to the website: http://www.arcus.org/harc/webshops.html. There have also been online ARCSS-All hands meeting workshops prior to this and much that was written relates to today's discussion.

So what are some of the probable pathways of change and future states of the arctic land surface. Whether or not we believe anthropogenic induced global warming is occurring, we know that Arctic climate is changing from historical long-term means. We see the effects in melting permafrost, changing treeline, declining glacial mass-balance, etc. We know from paleo-

records that large-scale changes have occurred from glacial to interglacial periods. More and more the general consensus is that the changes we are seeing today are unprecedented over century time scales.

If modern climate trends continue, what might we expect?Do thresholds exist that if reached might trigger large-scale catastrophic changes or should we expect gradual change. For example, we know that in some areas of the Arctic treeline is advancing. We also know that thermal/moisture limitations might preclude the advance of some species. A change in vegetation cover will change surface energy budgets through changes in albedo and transpiration, just to mention a few. We might expect to see changes in surface water. The Arctic coastal Plain is riddled with shallow ponds and lakes and what is the fate of these? A change in winter precipitation will also induce changes in albedo causing feedback loops through sensible and latent heat.

These are just a few of the many examples of change we might expect to see. There is the possibility of negative as well as positive feedbacks. Can we constrain our predictions given what we already know of biophysical processes or is our knowledge limited? Are we maximizing the information we can get from paleorecords and can we use this knowledge along with what we know of the biophysical processes to constrain our predictions. Are the models doing a good enough job?

Let’s start the discussion with what we think are some of the probable pathways of change and future states of arctic land surfaces.