Report of the NASA Arctic Boreal Vulnerability Experiment (ABoVE) Workshop – 13 to 15 June 2012, Boulder, Colorado

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Preface

Over the past several years, NASA's Terrestrial Ecology Program has sponsored several efforts to develop the scientific questions and plan for a research program that involves a new major field campaign. One of these efforts resulted in a scoping study report describing the Arctic-Boreal Vulnerability Experiment (ABoVE). This report has undergone extensive review (discussed in Appendix A), and its Executive Summary has been revised to address suggestions and recommendations made by the broader scientific community during these reviews.

To further address these suggestions and recommendations, a workshop was held in Boulder, Colorado on 13-15 June 2012. In this report, we present the findings and recommendations emerging from this workshop.

Revised Executive Summary:

The Arctic-Boreal Vulnerability Experiment

Climate change in the Arctic and Boreal Region (ABR) is unfolding faster than anywhere else on Earth, resulting in reduced volume and area of sea ice in the Arctic Ocean during summer, warming and thawing of permafrost, increases in the frequency and severity of climate-driven disturbances, and widespread changes to surface water extent, soil moisture, and vegetation structure and function. Amplification of climate warming in the ABR is particularly important as observations show that temperature variability and trends in this region tend to be larger than those for the Northern Hemisphere or the Earth as a whole. Arctic amplification is a forcing function that leads to multi-scale interactions and nonlinearities that are fundamental to understanding Arctic/boreal ecosystem processes and to constructing robust models and scenarios of ABR futures. In addition to producing significant and widespread feedbacks to climate, environmental change in this region is increasingly affecting society in a variety of ways, including impacts on forests from insects and fires, erosion of Arctic coastlines, changes to wildlife habitat and ecosystems that affect subsistence opportunities, as well as transportation infrastructure, oil, gas, and mineral development, and other economic uses. Long at the edge of our mental map of the world, environmental change in the ABR is rapidly becoming the focus of numerous policy discussions.

To more fully understand the evolving ABR environment and provide the information required to develop options for societal responses to the impacts of ABR climate change, the Arctic-Boreal Vulnerability Experiment (ABoVE) has been proposed as a NASA-sponsored field campaign. Previous and ongoing research sponsored by NASA has focused on developing the types of geospatial information products from remotely-sensed imagery and data that are critical for monitoring key environmental characteristics and processes. In addition, remotely-sensed data products are required to address scaling issues that are inherent in linking process-based research conducted at local scales over short time periods to modeling research that addresses a variety of spatial and temporal scales.

Research carried out as part of ABoVE would provide the opportunity to focus not only on key processes associated with changes to the land surface, but on important interfaces between the land and the coastal ocean and atmosphere as they interact with climate-mediated terrestrial processes. Through research that integrates and synthesizes geospatial data collected by airborne and spaceborne remote sensors with information obtained from field studies and ground-based monitoring, ABoVE would focus on addressing several key questions:

- ***What processes, interactions, and feedbacks control the vulnerability of Arctic and boreal ecosystems and landscapes to structural and functional changes in a changing Earth system?***
- ***How are people at local, regional, national, and global scales being affected by and responding to these changes?***
- ***How do changes to terrestrial processes in the ABR alter inputs to adjacent oceans?***

- ***How do changes to terrestrial processes in the ABR alter climate through exchanges of energy, water, gases, and particulate matter between the land surface and troposphere?***

The research conducted to address these questions would emphasize observations, analyses, syntheses, and modeling. This research would address questions critical to understanding the processes of climate and environmental change in the ABR, focusing on impacts to society and ecosystem services, changes to land surface processes, and interfaces with the adjacent coastal ocean and the overlying troposphere (see Figure 1). The studies conducted as part of ABoVE would provide the basis for improving the reliability of models required to predict how ABR terrestrial and coastal ecosystems and the troposphere are likely to change in the future based on different climate change scenarios. The output from these models, in turn, will provide decision makers, resource managers and other stakeholders with new information to aid in understanding the range of potential impacts on society and formulate decisions on how to respond to ABR environmental change.

ABoVE Study Plan

Research and analysis activities for ABoVE would be carried out in study sites located across western Canada and Alaska. Studies would be carried out over a range of spatial scales, including within different terrestrial ecoregions, within primary and secondary research areas, within discrete landscape units (such as a watershed or disturbance event), and within plots (at a scale of 10 m to 1 km). The exact geographic boundaries and location of study sites will be determined in the more detailed planning activities to follow, and will be influenced by collaborating programs and projects. An initial preparatory research phase would include dataset development, development of a modeling framework, and work to identify/secure/prepare needed field resources and infrastructure. The field phases of the research would be carried out during a multi-year intensive study period. The synthesis and integration phase would include final data analysis, modeling, and synthesis and integration studies making use of the data and information acquired during the intensive study period. The projects funded by NASA as part of the intensive study period would be involved in a variety of activities, focusing on the collection and analyses of airborne remote sensing data, development of new information products from remote sensing data, collection and analysis of field data, integrative analyses, and refinement, validation, and application of models.

A key component of ABoVE would be the use of spatial-temporal information products derived from remotely-sensed data. Remotely-sensed information products would be used in several ways, including providing improved maps of key characteristics (i.e., ecological, hydrological, cryospheric, biogeochemical) of the land, ocean and atmosphere in the ABR, as well as providing the means to measure variations in these characteristics over time. In some cases, remotely-sensed data products would be the primary information source for studying specific processes. In others, these products would be used as key inputs for models or used as a basis for model validation.

A rich array of international satellite and airborne data would be utilized in ABoVE. In addition to the existing satellites and their successors, many new U.S. satellite sensors will be becoming available in the planned timeframe of ABoVE. Of

these, the following would be well-suited to contribute to the scientific goals of ABoVE: Soil Moisture Active Passive (SMAP), Orbiting Carbon Observatory-2 (OCO-2), Ice, Clouds and Elevation Satellite-2 (ICESat-2), and the Joint Polar-orbiting Satellite System (JPSS). Existing remote sensing and *in situ* airborne sensors, such as NASA's AVIRIS and UAVSAR as well as several new instruments now under development, would be available and are anticipated to make strong contributions to ABoVE's observational needs and scaling objectives. Especially noteworthy are 1) the instrumentation being used and data that will be collected in the NASA EV-1 Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) in Alaska in 2012-2014 and 2) the P-band SAR capability being developed through the NASA EV-1 Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) project.

An important activity that would occur during the research conducted is the development, refinement and validation of models based on the studies and analyses being carried out for ABoVE. In order to understand the impacts of the processes that are affected by climate change, or that affect climate change, requires that different process models be linked. A key element of ABoVE will focus on developing the integrated modeling framework needed to improve the representation of key processes and to provide the mechanisms for developing model linkages, particularly via scaling of local processes to regional and larger spatial scales using multi-scale, multi-sensor remote sensing. Compiling regional and global information products would be conducted as part of the activities associated with assessments using the integrated modeling framework. An additional activity for ABoVE would be to synthesize the results from research being carried out in other Arctic/boreal regions. The results from this synthesis would be used to make further refinements of the integrated models developed as part of ABoVE. These integrated models could then be used to conduct a pan-Arctic/boreal assessment of the impacts of climate change during the final synthesis and integration phase of ABoVE or as a follow-on activity.

The development of a data and information system would be another important component for ABoVE. The ABoVE Information System would serve the field campaign as a short-term repository and clearinghouse for all data sets collected and data products generated as a result of ABoVE research. It would provide access to other datasets that would be used during ABoVE that were generated from other ABR research projects, products from land management agencies, and from long-term monitoring efforts. The ABoVE Information System would provide access to the results and assessments being produced through modeling and other analyses to a wide range of end users, and would provide support for experiment planning during ABoVE. Representatives of end users who require information from assessments of the impacts of climate change would be involved in determining the products that would be generated during ABoVE and made available through the ABoVE Information System. Long-term archive of ABoVE data sets would transition to a NASA Distributed Active Archive Center (DAAC) or other appropriate archive.

During ABoVE, particular attention will be focused on those ecosystem processes and characteristics that are unique to the ABR. These include the widespread occurrence of natural disturbances, the presence of permafrost, and the existence of high levels of soil carbon in surface organic layers and frozen soils. At local scales, some Arctic and Boreal ecosystems are resistant or resilient to longer-term changes in climate

and episodic perturbations; however, ongoing climate change in the ABR may be crossing important threshold points that push or tip ecosystems and landscapes into new biophysical states. A key focus of ABoVE is to conduct the research necessary to identify factors that influence vulnerability, as well as to enable identification and understanding of potential tipping points that produce state changes in ecosystem processes and functional attributes.

Society and Ecosystem Services

The motivation for the research proposed for ABoVE is to provide scientific information needed by policy makers, resource managers and other stakeholders to develop policies and approaches that most effectively respond to the climate-driven environmental change in the ABR. While human land use activities are not as extensive as in other regions, a number of human activities directly contribute to environmental change in the ABR. Research on human activities would focus on activities related to the fire regime (human ignitions and fire suppression), oil, gas, and mineral resource exploration and development, and salvage activities in disturbed forests. Research on human impacts and responses would focus on developing an improved understanding of how climate change directly and indirectly affects society and the natural resources that it utilizes (including ecosystem services). This would include studies on the impacts of environmental change on the habitats (including food webs) for key fish, mammal, and migratory bird populations, the use of subsistence and recreational resources by native and non-native populations, harvesting of forest resources, and the impacts of permafrost degradation on resource development, coastal erosion, and human health. By design, research conducted on the impacts of environmental change on the society and ecosystem services will be integrated with research on other processes being affected by climate change. *As a result, all research carried out as part of ABoVE will be guided by the need to address questions of how society is affected by and responds to the impacts of environmental change in the ABR.*

Land Surface Processes

ABoVE would provide the opportunity to conduct research on climate-driven processes that are forcing changes to ABR terrestrial and aquatic ecosystems and land surfaces, in particular changes to disturbance regimes, permafrost warming and thawing, and hydrologic processes. ABoVE research would focus on how changes to these processes are driving changes to ecosystem dynamics and the cycling of soil carbon. This research would also focus on connections, interactions, and feedbacks between the land and the near-shore coastal oceans and troposphere

Climate-driven, natural disturbances impact large areas within the ABR and their frequency has been increasing over the past two decades. Research on disturbance would focus on improving the understanding of controls on and impacts of natural disturbance regimes, including fire, insects, disease, and the formation of thermokarst and other land features associated with thawing of permafrost, and erosion of coastlines. Such research would include investigations on the responses of terrestrial ecosystems to changes in climate, disturbance regimes, surface hydrology and permafrost, including

changes to terrestrial and aquatic ecosystems, and soil microbial processes that drive heterotrophic respiration.

In areas with permafrost, the large reservoirs of soil carbon and hydrological processes are intrinsically linked. Studies of soil carbon would offer the opportunity to investigate the responses of carbon stocks in organic and mineral soil layers to the direct and indirect impacts of climate change. For land systems, research would focus on linking surface-based inventories of soil carbon stocks with land surface features that can be mapped using remote sensing (vegetation cover, locations of wetlands and peatlands, disturbance location and severity, surface hydrology, topography and microtopography) and that control variations in soil carbon, and carbon cycling processes. For permafrost, studies would focus on understanding how variations in climate, surface characteristics (e.g., topography, soils, vegetation type and structure, organic soil depth, surface hydrology) and disturbance history, interact to control the distribution of permafrost as well as the rates of permafrost warming and degradation.

Studies of hydrological processes are not only critical to understanding terrestrial and aquatic ecosystem processes and characteristics in the ABR, but also the processes controlling the exchange of water between the land and coastal oceans and troposphere (discussed below). Research on terrestrial hydrology would provide the opportunity to conduct investigations on the processes and factors controlling landscape and regional-scale variations in the patterns of surface and subsurface water (including soil moisture) over multiple time scales. Because permafrost and seasonal thawing of frozen grounds are important to surface hydrology, this research would be closely linked to research being conducted on permafrost. Studies on the factors controlling variations in water discharge from Arctic/boreal river systems as well as the amounts of suspended and dissolved matter being transported are important from several perspectives. First, these discharges provide inputs of sediments and nutrients to near-shore coastal waters, critical information for understanding coastal ocean processes. Second, water and sediment flow are important for the formation and maintenance of the large delta and estuarine ecosystems found on coastlines. Thus, research on factors controlling river discharges would be important to studies of coastal ocean chemistry and biological processes.

Research on coastal erosion would offer the opportunity to quantify the rates of erosion of Arctic coastlines, and to understand the processes that interact to mediate or intensify this erosion, including sea level rise, formation and loss of seasonal ice cover, coastal currents, storms, and changes to permafrost. Studies would also focus on processes controlling the growth and/or loss of land and changes to vegetation cover within major deltas, estuaries, and salt marshes in the ABR region (e.g., Yukon, Kuskokwim, and Mackenzie Rivers), including the role of river discharge, sea level rise, and increased wave energy resulting from changing coastal and coastal-zone ice cover and changing storm patterns.

Studies of land surface-atmosphere interactions would focus on improving understanding of the key feedbacks and linkages between the land surface/ocean surface and the atmospheric boundary layer/troposphere in the ABR. This research would include studies of factors controlling the reflectivity of the land surface in the ABR, in particular on how variations in snow, vegetation, water, and ice coverage

directly change albedo, as well as the role of disturbance in controlling variations in surface processes (e.g., vegetation, snow, and water dynamics) that influence land-surface reflectivity. In addition, this research area would include studies on how atmospheric deposition of soot and black carbon influences snow dynamics and snow albedo. The research would provide the opportunity to integrate research on the processes responsible for exchanges of carbon dioxide and methane between the land and coastal oceans and the atmosphere. This work could build upon the results from NASA's CARVE project. In a similar fashion, studies would also investigate how variations in vegetation cover, vegetation dynamics, permafrost, and surface hydrology regulate the exchange of water between the land surface and atmosphere. Results from disturbance studies would offer the opportunity to quantify the levels of emissions from wildland fires that are common across the ABR and that contribute to additions of aerosols and particulate matter to the atmosphere.

Coastal Ocean Processes

The Arctic coastal oceans represent a key transition zone between the land and deep ocean basins, and thus are influenced by both terrestrial and oceanic processes. Arctic oceans may be heavily influenced by coastal erosion and by the water, nutrients, and particulate and dissolved organic and inorganic materials originating from river discharge. The terrestrial end members relevant to ocean processes could be studied during ABoVE, thus informing studies of ocean processes, if suitable partnerships can be established with one or more ocean research programs. Such studies could include the processes controlling rates of net ecosystem production (NEP) in the adjacent coastal oceans, in particular the role of ocean circulation and upwelling and nutrient availability; the role NEP plays on fluxes of carbon between the ocean and the atmosphere; and the marine food web. Studies of ocean acidification could examine factors regulating changes in dissolved carbon dioxide, which in turn, control the pH of coastal waters. Research could also be conducted on how changes to ocean acidity interact with ocean productivity to influence the marine food web. Studies could focus on factors controlling near shore circulation, including coastal currents, upwelling, and storms, and the relationship of physical oceanographic processes to permafrost warming, nutrient and sediment transport, and reshaping Arctic coastlines. Research could include studies on how patterns of ice cover influence coastal wave formation and propagation during storms, as well as processes controlling the formation and loss of shoreline ice cover during the spring and fall and interactions between ice cover and temperature-mediated processes in adjacent terrestrial ecosystems (e.g. tundra productivity).

Role of ABoVE in ABR Research

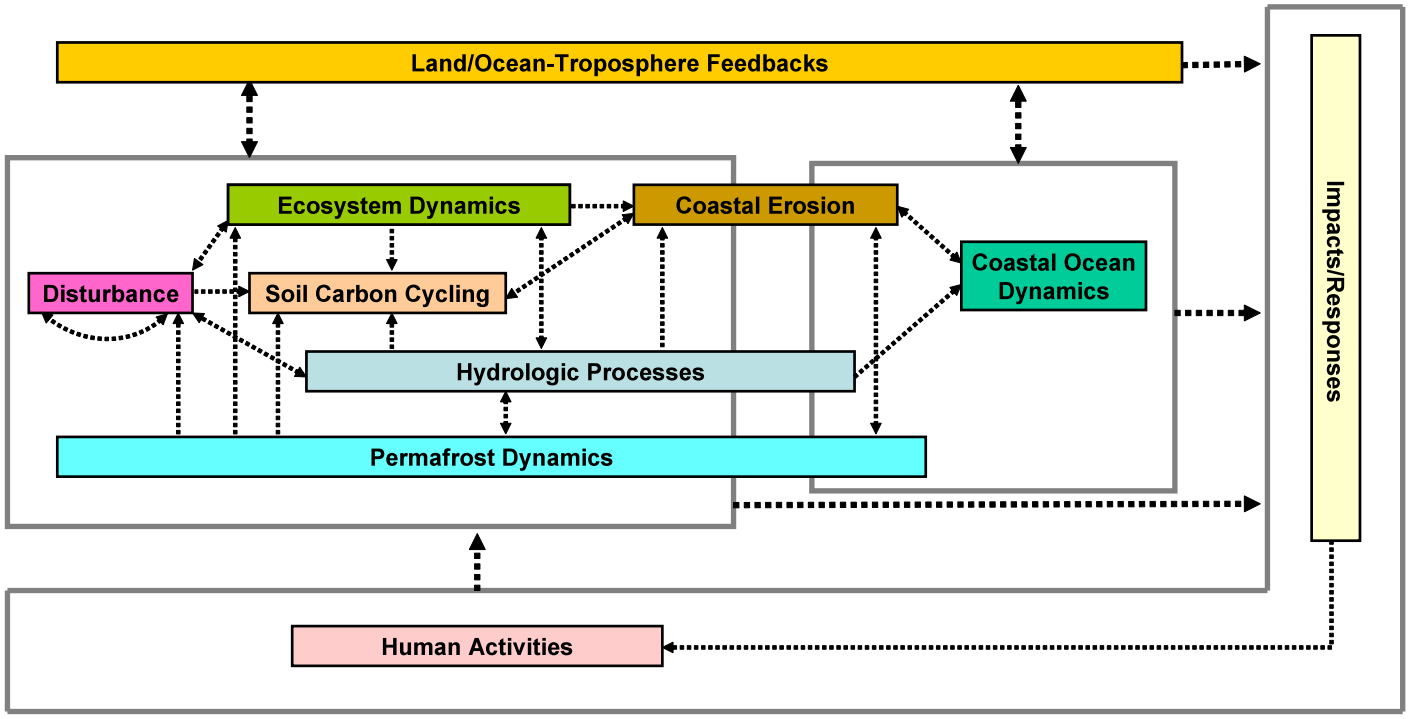
ABoVE would become a new contribution to an existing body of research on northern high-latitude systems and environmental change in the ABR. There is wide-spread recognition that climate change is unfolding faster in the ABR than anywhere else on the Earth, and there is growing appreciation of the imperative to understand its effects on Arctic and boreal systems and the consequences for society. It is also apparent that understanding interactions among major system components, across environmental boundaries and spanning multiple spatial and temporal scales, will be

major challenges in deriving understanding of change in the ABR and its consequences. It would provide the opportunity for coordination of research and monitoring activities on the impacts of climate change in the ABR and to catalyze synthetic and integrative studies building on the foundation of what is known and what is being learned.

A successful ABoVE field campaign will need to build partnerships with other programs, agencies, and nations conducting research in the ABR. NASA will need to leverage, coordinate with, and/or build upon recent and ongoing projects being sponsored by research and resource management agencies in other nations, especially Canada and Japan, as well as those in the U.S., both at the state and federal levels, and with non-government organizations. Within these organizations, there is a substantial amount of ongoing and planned research, monitoring, and assessment activities that focus on the questions and issues being addressed by ABoVE. Discussions with scientists and managers across a range of organizations in Canada, Japan, and the U.S. have revealed there is strong interest in ABoVE and in carrying out coordinated, collaborative research activities. These initial contacts have been made with the Department of Energy regarding their Next Generation Ecosystem Experiment (NGEE), the National Ecological Observatory Network (NEON), the National Science Foundation regarding the Study of Environmental Change in the Arctic (SEARCH), the Department of Interior, and several state and local organizations within Alaska. ABoVE has been discussed with representatives of the Canadian government involved in the Canada-Mexico-U.S. CarboNA program. Many other important contacts have yet to be initiated. A key activity for ABoVE would be to work with other organizations sponsoring activities focused on climate and environmental change in the ABR to develop an integrated approach to the sponsored research and create a management framework to facilitate data sharing, coordination of field activities, and collaborative analyses.

Equally important will be activities to broaden the disciplinary scope and build partnerships for coordinated multi-disciplinary research so that a full range of important ocean, land and atmosphere interactions can be addressed. In particular, to fully tackle research questions in the areas of coastal ocean dynamics and land-ocean-atmosphere feedbacks, partnerships with ocean- and atmospheric-oriented programs will be required.

Figure 1. Key Processes in the Arctic-Boreal Region that Provide the Focus for ABoVE Research



Report of the NASA Arctic Boreal Vulnerability Experiment (ABoVE) Workshop – 13 to 15 June 2012, Boulder, Colorado

1. Introduction

On 13 to 15 June 2012, a workshop was convened to discuss refinements to the scope of research and science questions to be addressed via a new field campaign sponsored by NASA's Terrestrial Ecology Program, focused on Arctic and boreal ecosystems in northwestern Canada and Alaska. The participants in this workshop discussed the societal issues and needs that could be addressed by the proposed research, and identified critical next steps that needed to be carried out in the near term to prepare for the writing of a concise experiment plan. The workshop was characterized as a last opportunity to obtain community inputs on the scientific and societal importance of ABoVE prior to the identification of a Science Definition Team and initiation of detailed study design planning.

There was a consensus among the workshop participants that: (1) the scientific issues and questions identified in the ABoVE Scoping Study report (as summarized in the revised Executive Summary) were highly relevant to understanding the causes and impacts of global warming in the arctic/boreal region (ABR); (2) that utilizing data collected by NASA remote sensing instrumentation, and further developing the expertise needed to exploit these data, is critical for not only understanding changes that are occurring in the ABR, but also providing the needed to project the impacts of future climate change; and (3) the research conducted through ABoVE could have high societal value because it would provide a clearer understanding of the impacts of climate change in the ABR in a number of areas important to decision makers, resource managers, and individuals with interests in the ABoVE study region while also improving our understanding of feedbacks to the climate system.

The ABoVE workshop attendees were asked to address the following questions:

1. Is the science of ABoVE, as described in the revised Executive Summary (and backed by the ABoVE Scoping Study report) compelling and of high priority?
    a. Are the science questions compelling? Do they convey the strongest/ most important science priorities? Do they capture the societal imperative for this project? If not, how can they be improved?

b. How do the ABoVE science questions compare to those of related research programs and recommendations of the U.S. NRC, USGCRP, and other national and international entities interested in environmental change in Arctic/Boreal systems? Should we take steps to align ABoVE more closely with the other questions?
c. What ABoVE research best addresses key interactions and linkages among the land, atmosphere and coastal oceans?

2. What are the most significant and pressing societal issues associated with current and projected environmental change in the ABoVE study region (permafrost-influenced and peatland areas of Alaska and Western Canada) and which are amenable to study in an ABoVE-like project?
    a. How well do the top tier (Tier 1[1]) questions capture our commitment to integrating such work into ABoVE? Do we need one or more top tier questions that better capture this?
    b. How many and which different societal impacts/responses should we consider addressing? How can we validate which will offer greatest value/utility to key end users? And who are those key stakeholders?

3. What near-term (within 1 year) actions will be required to mature the ABoVE science plan and prepare for the field campaign(s)?
    a. What do we need to do to establish the scientific foci that will inform study design (detailed science questions/studies to do; remote sensing and *in situ* measurements to make; selection of field sites/infrastructure; etc.)?
    b. What do we need to know about existing and planned research, data sets, and field activities to inform ABoVE planning?
    c. What are the most important practical considerations needed to guide study design?
    d. What are the high priority partnerships/collaborations to pursue?

In this report, we present a summary of the discussions, findings, and recommendations from the ABoVE Boulder Workshop. Including this introduction, this report contains five sections that summarize these findings and recommendations. Section 2 discusses the societal importance of research on terrestrial ecosystem processes in the ABoVE study region, and suggests societal needs for information that could be productively addressed in ABoVE. Section 3 presents the recommendations regarding the scientific scope for the ABoVE field campaign. Section 4 includes a review of key research activities (previous, ongoing, planned) in the ABoVE study region. Section 5 identifies critical next steps for implementing the ABoVE field campaign.

[1] The Tier 1 questions are the four questions presented in the Executive Summary. Tier 2 questions are associated with the ABoVE Science Themes (Figure 1) and are presented in the ABoVE Scoping Study Report.

2. Societal Importance of ABoVE Research

The rapid rate of climate change in the ABR has already resulted in significant changes in terrestrial ecosystem processes (for example, permafrost warming, increased disturbance, etc.). These environmental changes, in turn, have combined to alter key land surface characteristics that have had a wide range of impacts on society and ecosystem services that are likely to continue, if not expand, in the near future. In addition, changes to the ABR are very likely to exert strong feedbacks onto the global climate system and may impact the future trajectory of global climate change.

One of the key challenges in providing information important to society on the impacts of climate change in the ABR is to determine which ecosystems are resilient to the impacts of climate change (resilience is the capacity of a system to maintain its function, structure and feedbacks in the face of a perturbation) and which are vulnerable (vulnerability is the degree to which a system is likely to undergo significant change in structure and function following a specific perturbation). In particular, information is needed on how the impacts of climate change may tip ecosystems into new states where novel dynamics emerge. Conducting the research needed to identify these vulnerabilities and tipping points is necessary for understanding how climate change will alter Arctic and boreal ecosystems in ways that affect society.

The effects of environmental change in the ABR on people and society are both direct and indirect. These effects include direct impacts on human health (e.g., reduction in air quality from fires, mobilization of mercury stored in soils and sediments, and changes in the quantity and quality of freshwater supplies, damage to infrastructure from melting permafrost). Additional impacts are associated with changes to services that are provided by ABR ecosystems (e.g., changes to fish and wildlife that affect subsistence harvesting, changes to forest productivity).

Feedbacks to the climate system due to changes in the land surface and ecological functioning of the ABR are likely to be of global significance. Potential positive feedbacks (including changes in the energy, water and carbon budgets of the ABR) could trigger large scale releases of CO_2 and CH_4 into the atmosphere. These may be counterbalanced by negative feedbacks caused by the warming and drying of land

surfaces, which could also increase plant production and decrease production or increase consumption of CH_4, reducing carbon emissions to the atmosphere. There are currently large uncertainties in the direction and strength of feedbacks that are likely to occur in the ABR in response to continued climate change.

Breakout Session 2 of the Boulder ABoVE Workshop focused on addressing the societal issues and scientific information needs that would be carried out as part of ABoVE research. The three breakout groups focused primarily on three sets of questions that were suggested by the organizing committee:

(1) What are the most significant and pressing societal issues associated with current and projected environmental change in the ABoVE study region? Which are amenable to study in an ABoVE-like project?

(2) Who are those key stakeholders (impacted by environmental change in the ABR)?

(3) How well do the top tier questions capture our commitment to integrating such work into ABoVE? Do we need one or more top tier questions that better capture this?

What are the most significant and pressing societal issues associated with current and projected environmental change in the ABoVE study region? Which are amenable to study in an ABoVE-like project?

The breakout groups stressed the extreme significance, degree, and diversity of current and projected changes to the environment at local and regional scales and identified the following impacts of ABR environmental change that are of great concern to society, not only locally and regionally in the ABR, but around the world as well:

1. Impacts of permafrost degradation (long-term and seasonal, natural and human caused) on infrastructure (local stakeholders)
2. Changes to the quantity and quality of freshwater resources (local and regional stakeholders)
3. Impacts of disturbances on forest resources and on regional and local communities (local and regional stakeholders)
4. Impacts of coastal/riverine thermal erosion and sea level rise (local and regional stakeholders)
5. Changes in the extent, frequency, and severity of disturbances from fires and insects/disease (regional stakeholders)
6. Impacts of changes to bird, fish, and mammal populations from changes in habitat (local, regional, and global stakeholders)
7. Changes in carbon, water and energy cycles with multi-scale interactions and regional to global scale implications for climate.

8. Impacts of changes to near-shore coastal regions on food webs, fisheries, ice thickness, hunting/fishing, and shipping (local, regional, and global stakeholders)
9. Impacts on environmental contaminants (especially mercury) stored in soils from fire, coastal flooding, and permafrost thaw (local and regional stakeholders)
10. Impacts of saltwater salinization on near-coastal ecosystems (local and regional stakeholders)
11. Impacts on agriculture (local and regional stakeholders)
12. Changes in forest productivity (local and regional stakeholders)

Several breakout groups emphasized the diversity of impacts of climate change in the ABR region. In particular, climate warming may have positive as well as negative impacts, including increasing forest productivity, expanding the area available for agriculture, increasing microbial methane consumption, and reducing climate-related impediments to oil, gas, and mineral exploration. Resource managers and policy makers must take both types of impacts into account in their decision making. Research to inform such decisions must do the same.

In addition to identifying the different societal impacts of ABR climate change, the breakout groups identified the need to improve capabilities to forecast and predict trajectories of change in important land characteristics (e.g., vegetation, permafrost, surface hydrology) and processes (stream and river flows, fire risk assessment, insect outbreaks). They also identified the need to model both transient and long-term impacts, and effectively communicate the risks of these impacts to the affected stakeholders.

It was also agreed that understanding the interactions and feedbacks between terrestrial ecosystems and the climate system represents a key information requirement for scientists and decision makers. While recent global warming has been the greatest in the ABR due to ice-albedo feedbacks in the Arctic Ocean, there have also been other positive negative and feedbacks between the Earth's surface and atmosphere which are less well understood.

There was debate among the workshop participants on the most important and pressing societal issues that research conducted as part of ABoVE would address. Some argued that the most relevant issue was developing a more complete understanding of the feedbacks and interactions between the land surface and the atmosphere/climate

system in the ABR, in particular to address whether the Arctic amplification would increase in the future as a result of large releases of soil carbon and changes to surface albedo. Others argued that understanding integrated, whole ecosystem responses at the regional scale would have enormous value to local, state, regional, and national decision makers tasked with adapting to or mitigating the effects of climate change – as well as providing a first example of what types of changes to expect and of how society acts to meet the challenge of responding in a system undergoing rapid changes driven or exacerbated by global climate change. The majority of participants, however, felt that they were both of high importance. Many felt these two perspectives are inextricably linked because studies of processes at regional scales are required to understand the mechanisms driving feedbacks between the Arctic/Boreal region and the Earth system. Of the issues identified above as of importance to society for understanding the impacts of environmental changes, there was consensus among the three breakout groups that issues 1 to 7 above are of high priority for an ABoVE-like project[2].

The workshop participants included a mix of scientists from academic institutes, government laboratories, and resource management agencies whose geographic areas of responsibilities are in northern high-latitude regions. There was a strong consensus within the latter group of workshop participants that much of the research proposed for ABoVE would have particularly high value for addressing information requirements on the impacts of climate change on the natural resources and ecosystem services in the ABR region. They also emphasized the need to identify the societally important information that would be generated by ABoVE and to identify the mechanisms required to generate information products based on the results from ABoVE that are needed by resource managers and decision makers. Suggestions for meeting these objectives included organization of periodic Users Community Workshops to bring together ABoVE scientists with stakeholders to review progress and to chart future activities, as well as forming a Users Advisory Panel composed of stakeholders, end-users, community members to provide guidance on development of information products.

[2] All three breakout groups identified Issues 1 to 7 as being of high importance, while 2 out of 3 breakout groups identified Issues 8-12. The issues are not ranked in order of importance.

The working groups observed that many of these key impacts of climate change in the ABR affect stakeholders at multiple spatial scales. For example, information on changes to bird, fish, and mammal populations from changes in habitat (including vegetation and the extent and quality of freshwater bodies) is important to: (1) the local stakeholders dependent on these resources for subsistence or recreation; (2) the regional stakeholders in state/provincial/ territorial/national land management agencies who are responsible for developing and implementing policies; and (3) to international regulatory agencies who develop agreements for the management of migratory bird, mammal, and fish species. Because of this, understanding the impacts of climate change on society requires development of approaches to measure and assess environmental change in the ABR over a range of spatial and temporal scales. Research carried out as part of ABoVE will provide the opportunity to not only develop and implement methods to measure key changes to the land surface in the ABR using remotely-sensed data, but also provide data sets needed as input parameters to models used to assess the current and future impacts of environmental change that are important to society. Using remotely-sensed data products developed during ABoVE will provide the ability to analyze large-scale changes for local and regional stakeholders who require information on the impacts on key ecosystem services (such as the impacts on wildlife habitat) or changes that affect infrastructure (such as the impacts of permafrost thawing on roads, buildings, etc.). As a result, much of the research that would be carried out as part of ABoVE would address a variety of societal issues at multiple-spatial scales.

Who are those key stakeholders (who need information on the impacts of environmental change in the ABR)?

The breakout groups agreed that the key stakeholders could be divided into three groups based on different types of information needs: global, regional, and local. Regardless of spatial scales, all groups agreed there was a need for a strong educational component for ABoVE that would provide stakeholders with reliable information in a timely fashion, while going well beyond presenting results at scientific meetings and in journal articles.

Stakeholders interested in large-scale (global/regional) information about the ABR) include the scientific modeling and assessment community, in particular the Intergovernmental Panel on Climate Change (IPCC), regulatory agencies, and the business community. The IPCC in particular has responsibility for informing national policy makers about significant threats to the global climate, identifying the impacts of climate change on society, and providing recommendations for mitigating climate change and adapting to its impacts. IPCC's Working Group I requires improved information on the societal, geophysical, and biological drivers of climate change, and incorporation of any gains in scientific knowledge into Earth System models (ESMs) to provide more reliable predictions of future climate. Working Group II needs information on the impacts of climate change in order to understand the vulnerability of ecosystems and possibilities for adaptation, and Working Group III needs information on how society can mitigate the impacts of climate change. A number of international regulatory agencies deal with the large numbers of migratory fish, animal and bird populations found in the ABR region, and thus require information on how these populations will be impacted by climate change, in particular, how these populations will be directly impacted by changes to climate as well as by changes in habitat.

Regional stakeholders include policy makers, managers and scientists in government agencies (federal/national, state/provincial/territorial), and native corporations/organizations, businesses, and non-government organizations. A large number of land management agencies at all levels of organization already have programs dedicated to monitoring, measuring, and studying the impacts of ABR climate change (including participants at this workshop) and have expressed interest in collaborating with ABoVE research or sharing the information products and results that would be generated during ABoVE (e.g., the Canadian Forest Service, the North Slope Science Initiative, and the Landscape Conservation Cooperative program of the U.S. Department of the Interior).

Local stakeholders include government and private organizations and businesses, as well as individuals, who are directly impacted by environmental changes. The working groups noted that a particularly important group of local stakeholders are members of communities (both native and non-native) located throughout the ABR who use the natural resources of this region for subsistence, whose economies are based on

natural resources that are likely to be impacted by climate change, or whose infrastructure (including availability of freshwater and sewage disposal facilities) will be affected by climate change.

How well do the top tier questions capture our commitment to integrating such work into ABoVE? Do we need one or more top tier questions that better capture this?

The workshop participants agreed that only one Tier 1 question was needed to address the societal issues that ABoVE research will address. However, all three breakout groups suggested that changes be made to Question 2 of the Executive Summary (*How are people at local, regional, national, and global scales being affected by and responding to these changes?*). Suggestions for changes included the following:

How are/will people at local, regional, national and global scales being/be affected by and respond to environmental change in the ABR region, and how are those human responses in turn feeding back to the system?

What are the spatial and temporal patterns of change that impact people and at local, regional, national, and global scales and how can ABoVE inform decision making at these scales?

What changes are likely to occur in the ABR that are most likely to affect society and economics at local, regional and global scales?

3. Scientific Scope of ABoVE

The scope, relevance, importance and focus of the science to be conducted as part of ABoVE was addressed by three breakout groups (Land, Water, Atmosphere) on the afternoon of the first day of the workshop. The charge to the groups was to address the science focus and scope described in the revised Executive Summary. The primary emphasis of the breakout group discussions was to:

(1) Revisit the science questions of the original scoping study report, particularly the overarching "Tier 1" questions, to ensure they are compelling, convey the most important science priorities, and capture the societal imperative for the project (and if they do not to suggest possible reformulation of the questions);

(2) Consider how the science questions align with those of related research programs and recommendations of the U.S. National Research Council, U.S. Global Change Research Program, and other national and international entities addressing

environmental change in Arctic/boreal systems (and if not how to better align them); and

(3) Identify and prioritize the key interactions and linkages among the land, atmosphere and coastal oceans, as suggested by the panel tasked with reviewing the original scoping study and associated community comments.

The science questions and their alignment with other programs

Each of the breakout groups focused on the Tier 1 questions and also delved substantially into the Tier 2 questions presented in the ABoVE Scoping Study Report (all of the questions were provided to participants as handouts). There was general consensus among the groups that the Tier 1 questions were of appropriate scope, with respect to asking the "big questions" and focusing on land-atmosphere interactions and net feedbacks to climate, ecosystem resilience and vulnerability, societal impacts and responses, and linking to the adjacent oceans. However, there was a good deal of discussion about how the questions might best be formulated and ordered, whether some of them might be combined, as well as how they could be modified to emphasize remote sensing, scaling, models and forecasting.

The Land Group debated differing reformulations of the questions. Some specific rewording was considered of insufficient scope (more process oriented), while others were considered to be too all-encompassing (i.e. trying to capture all changes rather than the higher order changes of most relevance, for example land-atmosphere interactions and climate feedbacks). Together the group emphasized the importance of proper sequencing of the questions and suggested specific rewording and reordering they considered appropriate. The Land Group collectively felt implementing a NASA-led field campaign in the ABR was important and would help to coordinate research efforts among disciplines, but suggested a number of specific modifications intended to emphasize the application of remote sensing technologies and the insights that can be gained via iterative observations and analyses. A number of points were also made in the context of discussing the Tier 2 questions that address specific topics either missed or inadequately represented in the scoping study, such as interactions among multiple disturbances (e.g. insects and fire), remote sensing of permafrost and thermokarst features, implications of composition changes on ecosystem processes, and several others.

The Atmosphere Group also noted that research in the ABR was a high priority, but felt that the Tier 1 questions (particularly Q4) needed to better address how atmospheric processes and measurements can help to understand measurement and observations of key terrestrial ecosystem processes. The atmosphere is an integrator, just as rivers integrate biogeochemical signatures of watersheds, but attributing atmospheric (or river) measurements to specific physical and biogeochemical processes represents a key research challenge. This need could be partly addressed through development of high spatial resolution information (mostly derived from remote sensing) of the land surface properties and processes with which the atmospheric models can be "challenged." Seasonal and temporal information is particularly important, so there is a need to invest in flux (eddy covariance) towers, as well as airborne eddy flux measurements (not just concentrations) to help extend from the site level (tower) to regional scales. The Atmosphere Group also noted that while aircraft measurements were essential, ABoVE activities could also be used to evaluate new satellite sensor concepts relevant to providing input parameters for ecosystem process models and linking to physical climate / Earth system models. A number of suggested changes to Tier 2 questions were discussed and are captured in the session notes.

The Water Group, which included experts in terrestrial hydrology as well as oceanography, did not focus a great deal on addressing the current formulation of the science questions and instead focused most of their effort (appropriately) on discussion of the interactions between the land and the coastal ocean (below). They did, however, suggest some wording changes to both Tier 1 and Tier 2 questions, noted a need to strengthen wording related to the integration of field and remote sensing measurements for scaling to include reference to mountain glaciers and groundwater hydrology, and to point out that NASA is in a unique position to address the ABoVE science questions; therefore the questions should emphasize the aspects of ABoVE that play to NASA's strengths.

This last point was a common theme to the other groups as well, with much discussion as to the specificity of the questions to NASA, and how they might be tailored to emphasize core strengths of NASA. Some thought that tailoring the questions to NASA was important whereas others thought less specificity could be advantageous with

respect to broadening inter-agency support, particularly in the context of land-ocean interactions.

Overall, the questions posed as part of ABoVE thus far were considered consistent with various ongoing and evolving programs focused on climate change more broadly, and changes in the ABR more specifically, although each group recognized that the science questions will continue to be refined (next by the Science Definition Team).

Addressing linkages among the land, atmosphere and coastal oceans

The external review panel of the scoping study report included the statement that "the potential for major scientific advances and societal payoffs seems much greater if the study addresses the entire system." This challenge was partly addressed by the groups in their discussion of how linkages might be made to study these systems synergistically, while also recognizing that the scoping study was focused on NASA's Terrestrial Ecology program and that this broader focus would logically require a much broader level of NASA and inter-agency support.

Ocean-land interactions were not extensively discussed by groups other than the Water Group (possibly because it was the 3rd of three questions they were tasked with addressing and time was limited). The Atmosphere Group focused heavily on land-atmosphere interactions, and suggested flux aircraft and tower site measurements across a broader spatial domain, including eastern as well as western Canada (note ABoVE was scoped to focus on western Canada and Alaska). One proposal was for a "ring of tall towers" that could partly serve this purpose. This group suggested that a carefully-designed network of atmospheric sounding and profiling measurements of CO_2 and CH_4, augmented by flux aircraft, could also help determine the large scale patterns of carbon sinks and sources. They also indicated that current model simulations constrained by these concentration and flux measurements could be used to help define optimal site selection. Related aspects of their discussion are summarized in the previous section (science questions) and revisited again in the next section (overarching issues).

The Water Group focused on the process interactions and feedbacks that control ecosystem vulnerability, noting that ABoVE should not focus so much on the oceans *per se* but rather on the terrestrial ecological and hydrological processes that influence

coastal ocean processes – particularly river chemistry and export. There was some discussion of how coastal ocean processes (e.g. circulation) and physical properties (e.g. temperature) would influence land processes (e.g. productivity, seasonality). They felt the boundary defining "coastal ocean" was not entirely clear, but could be defined by bathymetric contour lines (isobaths). Much of the land processes relevant to the coastal ocean were focused on closing the water balance and various aspects of terrestrial hydrology (e.g. identifying water flow paths and how they interact with soils and vegetation to define biogeochemical processes, the influence of permafrost thaw and thermokarst features, remote sensing of permafrost and soil moisture, snow-shrub interactions, changes in lake extents and distributions, incorporating lateral transport in models). The group also noted that river connectivity affects the quality and quantity of water output from basins, and the seasonality of connectivity strongly influences the quality of the water exported. Permafrost thaw, in particular, changes the relative proportion of vegetation cover types, which in turn influences hydrological functions including the volume and timing of runoff (export). There were previous studies in the region that could provide some historical reference and data addressing these topics, but those were not focused on capturing change dynamics.

Overarching issues and knowledge gaps

Among all groups, there were concerns expressed as to whether sufficient emphasis was being placed on identifying and improving upon the weaknesses of models (ecosystem / biogeochemistry models and physical climate system / Earth system models). Most participants felt that a well-defined modeling strategy, coupled with a strong data/portal system, would be key to making ABoVE's impact more than the sum of its individual studies. The Land Group identified several areas in which ecosystem / biogeochemistry models could be improved with observational / remote sensing data sets and vetted products, but there was a strong sense that ABoVE needed a well-defined modeling strategy. This was also emphasized by the Atmosphere Group in the context of physical climate system models and a desire to ensure that the more local-to-regional scale measurements, remote sensing and ecosystem / biogeochemistry models would be sufficiently representative of, and/or could be spatially scaled to be representative of, pan-Arctic/boreal processes in the context of global climate change.

The group noted “modelers need source/sink patterns of CO_2, CH_4 and energy balance and fluxes in time and space.” Others noted that these observational data sets and derived products alone were extraordinarily valuable for capturing processes and understanding dynamics and linkages to seasonal and inter-annual variability in land-atmosphere interactions and climate feedbacks.

There was also some debate regarding the plans for ABoVE (as presented in the scoping study report versus the “expanded scope” recommended by NASA's review panel and described in the expanded Executive Summary) to address key issues of societal importance in the region, including collaboration with resource management agencies and local stakeholders, while also addressing the needs of Earth system models focused primarily on broader global climate change research objectives. NASA and the Science Definition Team formed for ABoVE (to be determined) will clearly need to consider an appropriate balance and the extent to which research conducted in a regional field campaign (whatever its ultimate spatial extent) can inform not only local and regional decision-making and management needs, but also provide the fundamental information needed to drive global models, scale from site to regional, continental and even pan-Arctic/boreal extents, and inform physical climate and integrated Earth system models. No field campaign can be expected to fully meet all these needs – regardless of the spatial extent or intensity of measurements - but ongoing efforts can be leveraged, synergies emphasized, and scaling efforts based on field-calibrated remote sensing products prioritized.

Overall, there was consensus that the possible contributions of NASA through ABoVE include scaling field measurements and process understanding to larger areas using remote sensing, taking advantage of emerging remote sensing technology and new missions, and improving models of ecosystem processes and land-atmosphere interactions. All of the breakout groups strongly felt the Arctic/boreal region was a high priority focus and that the science objectives were compelling and highly relevant to NASA, as well as to other national and international programs focused on climate and the Arctic/boreal systems, particularly the cross-disciplinary nature of the land-atmosphere-water interactions. There was also a general consensus that there was a great deal of research in the proposed study domain that could be leveraged and that the synthesis aspect was particularly important. Related, there was recognition that

synthesis is the most challenging part of interdisciplinary research, but that it should be a priority for ensuring that ABoVE is ultimately greater than the sum of its parts, i.e. much more than a series of non-coordinated studies. In this regard, there was consensus that a 10-year study was appropriate and valuable for ensuring that synthesis could be emphasized and thereby captures the processes driving the rapid changes taking place across the region.

4. Inventory of Research Efforts Relevant to ABoVE

Prior to the ABoVE Workshop in Boulder, staff of NASA's Carbon Cycle & Ecosystems Office continued the effort begun by the authors of the ABoVE Scoping Study to identify programs, projects, data, and field sites relevant to ABoVE. The goal was to summarize existing and proposed research projects that could contribute to addressing the key science questions, as well as archives that provide relevant data, and identify key collaborations for ABoVE to seek. Sources of these included the appendices of the ABoVE Scoping Study; comments solicited from the general community and from peer reviewers; planning documents and white papers from other Arctic/boreal programs; and web-based searches.

An inventory of more than 293 Programs and Projects; 74 Data Centers and Portals; and 898 Field Sites in 23 networks, was reviewed by workshop participants, who identified additional elements included in the appendices of this Workshop Report. These serve as a resource to the Science Definition Team which will create a concise interdisciplinary experiment plan for ABoVE (Appendix C).

5. Critical Next Steps

For the third breakout session (Thursday afternoon, June 14), the workshop participants were tasked with the question: "What do we need to be ready?" Groups were asked to discuss the near-term actions required to "mature" the ABoVE science and implementation plan for the campaign. The breakout groups converged on similar issues related to 1) Goals, Questions and Hypotheses; 2) Partners and Stakeholders; 3) Data Management; 4) Implementation and Logistics; and 5) Modeling Efforts. In addition, there were several issues that arose in just one group and emerged as

important discussion topics during the last plenary session on Friday morning (June 15). The latter included the role of Canadian researchers in the near-term actions, the spatial extent of the ABoVE study region, and discussions on emphasizing evaluation of regional vulnerabilities to climate change and informing local/national-scale decision making versus an emphasis on improving global climate change projections and informing national/international-scale decision making.

Goals, Questions and Hypotheses

All breakout groups converged on the need for refining the overarching questions (i.e., Tier 1 questions) of the Executive Summary. There were differences in opinion among groups as to whether this activity should come before the identification of a Science Definition Team (SDT), which will write the Concise Experimental Plan, or alternatively, whether this would be the first task of the SDT. One group suggested that the current leadership rephrase the Tier I questions based on input from workshop participants with the goal of making them more saleable to a general scientific audience and to policy makers. Another group suggested that the Tier 1 questions be prefaced by a vision statement or meta-question emphasizing the overall scientific importance of the campaign to global biogeochemical cycles and climate and the relevance of the science goals to human health and welfare. Finally, a group suggested that the Executive Summary emphasize the unique capacity of NASA's Terrestrial Ecology Program for developing a field campaign to address the ABoVE goals and science questions, including the capacity of integrating novel remote and airborne sensing technologies, legacy remote sensing data sets, field measurements and modeling.

Discussion of the constitution of the SDT generated a diversity of opinions in the Friday morning plenary session. One group stated repeatedly that Canadian researchers and scientists needed to be included on the SDT to ensure adequate coverage of Canadian interests and sites and provide motivation or leverage for Canadian organizations to contribute to the campaign. Another group emphasized the importance of including broad technical expertise in the key interdisciplinary areas of near-shore oceanic and tropospheric processes, economics and risk assessment, policy relevance, and socio-ecological systems.

Partners and Stakeholders

All breakout groups agreed that following refinement of the Tier 1 questions, the key next step should be establishing connections with science and management groups involved in observational and experimental activities in the ABoVE study region. NASA's Carbon and Ecosystems Office is compiling a database of relevant research programs and organizations in the ABoVE region (see Section 4); this will be used to identify relevant datasets and partner researchers or organizations. In light of the likelihood for cross-agency and cross-border partnerships, it was recommended that the leadership of ABoVE garner political support and initiate formal arrangements (e.g., Memorandums of Understanding) with other agencies and governments.

Partner organizations discussed included DOE's NGEE project in Alaska, NSF's LTER network, NEON, a variety of Canadian research groups (CFS, NSERC, CSA), JAXA, ESA, and Coastal/Marine Groups (e.g. ART, OCB). Several models for integration were suggested, including the International Polar Year campaign, BOREAS and LBA. To facilitate connections and inform the policy makers who might also facilitate connections, it was suggested that NASA's Carbon and Ecosystems Office develop a crisp briefing brochure and/or PowerPoint presentation with regional imagery.

In the plenary session, there was enthusiasm for visioning the educational scope of ABoVE via outreach with stakeholders, local educational organizations, and the institutions associated with the scientists involved. Suggestions included local stakeholders such as residents of rural communities in Alaska and Canada. There was emphasis on the importance of initiating a dialog and establishing a liaison with the residents of the region. Also discussed was the scientific legacy of graduate and undergraduate students who will be trained as part of the campaign; an educational specialist could also design a formal, interdisciplinary program for graduate training as part of the project.

During breakout session 2 on the societal importance of ABoVE research, several breakout groups recommended that a series of workshops or a working group be organized to discuss and identify societal information requirements on the impacts of climate change. In particular, the working group/workshops should focus on

information requirements from the resource management and economic forecasting and risk management communities. The workshop could identify specific information products and the best avenues for providing these products to the stakeholders.

Data Management

The breakout groups identified access to existing and planned research products and datasets relevant to the ABoVE region as crucial for moving forward. One group suggested that metadata, at the least, be made available through a tool or portal so that it is accessible to the SDT and to those writing proposals. There was also agreement that researchers and scientists sponsored through ABoVE work from a unified suite of base maps/datasets (e.g., digital elevation maps, climate downscaling, surficial geology in common projection, resolution, and format).

All groups lobbied for definition of the ABoVE data system as a high priority, near-term action, suggesting that data and computer systems personnel should receive dedicated financial support and be engaged from the start of the program. Authorization of a standing working group was suggested, as was a workshop organized to design the data system functionality. By engaging science investigators and data-sharing agencies, this working group could develop a data policy and a data management plan and a data policy to facilitate data preparation, sharing, discovery, integration, and analysis. The Friday morning plenary group discussed some lessons learned from previous large field campaigns, suggesting that retrospective analysis might help avoid the data management pitfalls previously encountered.

Implementation and Logistics

The breakout groups agreed that a plan for implementation and logistic support should be developed concurrent with the Concise Experimental Plan. This will enable recruitment of partners and costing of logistics support. They noted the implementation plan needs to be balanced between enough structure for logistics planning, but not so much structure that potential partners or proposers would feel constrained or excluded. An activity that should be carried out in conjunction with the implementation plan is the development of a business plan and a cost-estimate analysis. The latter will be

important for prioritizing resources among ground, remote sensing, modeling and human dimensions research activities.

Site selection was a key topic discussed by the breakout groups and in plenary. One group recommended that an access map be developed that would include current infrastructure (e.g., *in situ* measurement sites, roads, airports, evacuation points, hospitals) and regulation of travel (e.g., closed airspace, winter-access roads).The efficacy of access should be carefully considered as part of the experimental design. In addition, a watershed or airshed approach to site selection could facilitate interdisciplinary connections between terrestrial ecology and tropospheric or oceanic studies. Once sites are identified, it will be necessary to apply for research permits from land management agencies in Alaska (BLM, AKDOF, FWS, NPS) and in Canada, as well as seeking permission for access to sites on lands owned by native corporations. Because the permitting process can take over a year in some cases, it will be important for the implementation plan to include a timeline for permitting. When sites are identified, it will also be important to establish dialogs with rural village and First Nation groups in Alaska and Canada. Finally, the working groups suggested that the implementation plan include measurement protocols that are consistent with established protocols from other large-scale networks, such as AmeriFlux or NEON.

Finally, there was substantial discussion in the plenary session about the geographic domain of the ABoVE study region with emphasis on the need to determine an appropriate balance between local and global issues in this regional-scale campaign. Refining the Tier 1 questions will help constrain the geographic scope of the campaign. It was suggested that with ABoVE field activities restricted to Alaska and northwest Canada, modeling could be efficiently used to explore the applicability of findings to the pan-Arctic/boreal region. The question of scale was also raised: different study goals and questions require different scales, and it was not clear to some of the participants whether the current regional scope would be adequate to test all questions (e.g., those related to the continental-scale tropospheric processes represented in atmospheric inversion models). Other participants felt that expansion of the geographic domain of the field campaign would dilute the ability to understand ecological processes and regional patterns in the highly heterogeneous landscapes of the ABR. Moreover, an

expanded geographic range would increase costs and risks of providing logistic support to scientists in the field.

Modeling Efforts

The breakout groups agreed that the key first step for the modeling component of ABoVE will be identifying the gaps and problems with the performance of current models. Several efforts, listed in Appendix C, highlight the need to link some of the observational goals of ABoVE with allied efforts to directly address model weaknesses. It was suggested that either new or ongoing activities to calibrate and compare large scale, gridded models could serve this purpose. Modeling activities, if carried out prior to the field campaign, could be used to identify core ground based measurements needed for resolution of modeling issues. In addition, participants suggested that the SDT should prescribe a modeling strategy for the campaign, determining the types of models needed and the study design necessary to calibrate and evaluate those models. Change in the ABoVE region is likely to have important consequences for global biogeochemistry and climate, and modeling will be our primary avenue for the prediction of these consequences.

List of Acronyms and Abbreviations

ABoVE	Arctic-Boreal Vulnerability Experiment
ABR	Arctic and Boreal Region
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AKDOF	Alaska Division of Forestry
ART	Arctic in Rapid Transition
BLM	Bureau of Land Management
BOREAS	Boreal Ecosystem-Atmosphere Study
CarboNA	Canada-U.S.-Mexico Carbon Program in North America
CARVE	Carbon in Arctic Reservoirs Vulnerability Experiment
CCEO	NASA Carbon Cycle & Ecosystems Office
CFS	Canadian Forest Service
CSA	Canadian Space Agency
DAAC	Distributed Active Archive Center
DOE	Department of Energy
EOS	American Geophysical Union's EOS magazine
ESA	European Space Agency
FIFE	First ISLSCP Field Experiment
FWS	Fish and Wildlife Service
ICESat	Ice, Clouds and Elevation Satellite
IPCC	Intergovernmental Panel and Climate Change
IPY	International Polar Year
JAXA	Japanese Space Agency
JPSS	Joint Polar-orbiting Satellite System
LBA	Large-scale Biosphere-Atmosphere Experiment in Amazonia
LCC	Landscape Conservation Cooperative
LTER	Long Term Ecological Research
NEON	NSF National Ecological Observatory Network
NEP	Net Ecosystem Production
NGEE	Next Generation Ecosystem Experiment
NPS	National Park Service
NRC	National Research Council
NSERC	Natural Sciences and Engineering Research Council of Canada
NSF	National Science Foundation
NSSI	North Slope Science Initiative
OCB	Ocean Carbon & Biogeochemistry
OCO	Orbiting Carbon Observatory
SAR	Synthetic-Aperture Radar
SDT	Science Definition Team
SEARCH	Study of Environmental Change in the Arctic
SMAP	Soil Moisture Active Passive
TE	Terrestrial Ecology
UCAR	University Center for Atmospheric Research
USGCRP	U.S. Global Change Research Program
VuRSAL	Vulnerability and Resiliency of Arctic and Sub-Arctic Landscapes

Appendix A – Timeline of Activities Associated with the Arctic-Boreal Vulnerability Experiment (2009-2012)

In June of 2009, a scoping study funded by NASA's Terrestrial Ecology Program was initiated to develop the scientific rationale for a new field campaign to follow previous NASA-sponsored campaigns (FIFE, BOREAS, and LBA). The title of the proposal for this scoping study was - *Vulnerability and Resiliency of Arctic and Sub-Arctic Landscapes (VuRSAL) - the Role of Interactions between Climate, Permafrost, Hydrology, and Disturbance in Driving Ecosystem Processes*. The goals for this scoping study were to: (1) identify the science question(s) and issues to be addressed through the field campaign; and (2) develop a plan for a research program to address these questions and issues that includes a field experiment/campaign. In addressing goal 1, the scoping study was to also discuss the current state-of-the-science, identify the potential for a major, significant scientific advancement, and explain the central, critical role of NASA remote sensing. In addressing goal 2, the scoping study was to describe the essential scientific components of the study and why coordinated teamwork is required in their implementation, develop an overall study design identifying the required observational (e.g., spaceborne, airborne, and/or supporting in situ observations) and analytical (e.g., models, data, and information system) infrastructure, and assess the feasibility of the proposed field campaign, both technical and logistical. In carrying out the scoping study, efforts to engage the broader research community were to be undertaken in order to seek feedback on the ideas and to assess interest. Finally, the scoping study was to identify the disciplinary skills needed to conduct the study and engage potential partners in their planning activities.

An initial workshop was organized and conducted at the University of Alaska in August 2009. The attendees of this workshop provided the members of the scoping study team with suggestions for the research themes that would be addressed during the proposed field campaign, the important scientific questions that required addressing, and the key elements of the research needed to address these questions. Based on the suggestions from the workshop, the name for the proposed field campaign was changed to the Arctic-Boreal Vulnerability Experiment (ABoVE). Using the inputs provided from

the workshop participants, the scoping study report (*The Arctic-Boreal Vulnerability Experiment (ABoVE): A Concise Plan for a NASA-Sponsored Field Campaign*) was generated. A draft copy of this report was made available for review by the broader scientific community in the summer of 2010. Based upon comments received, the draft report was revised, and the final report submitted to NASA in October 2010.

In the spring of 2011, an article on the ABoVE scoping study was published in the American Geophysical Union's EOS weekly newsletter (Goetz et al. 2011). In the summer of 2011, NASA's Terrestrial Ecology Program solicited comments

The NASA Terrestrial Ecology Program (TE) requested community input on the Arctic-Boreal Vulnerability Experiment (ABoVE) plan that was submitted in October 2010. Comments were sought from the research community (via community-wide email request and TE Web site request) regarding:

1. The scientific value, importance and priority of the research questions; and
2. The appropriateness of the scientific implementation approach and methods.

These comments were then provided to the Terrestrial Ecology Field Campaign Working Group, which provided an integrated evaluation of the merits of the ABoVE concept, and made specific recommendations for next steps based on a workshop held in August 2011. The working group found that the proposed study had high merit, but required a modest amount of further study/planning before being ready for partnership discussions and more detailed planning of the study design. The working group recommended that NASA should move ahead with the ABoVE field campaign concept, but consider broadening its scientific scope to allow for a more whole-system (land-ocean-atmosphere-humans), integrative study of change in the High Northern Latitude region of western North America. They also recommended that a single, compelling overarching goal statement that makes clearer the societal importance of the study was needed. The complete report from the Terrestrial Ecology Field Campaign Working Group is included as Appendix B to this report.

During the spring of 2012, the Executive Summary of the ABoVE scoping study report was revised based on these recommendations, and a workshop was organized to evaluate these revisions and suggest next steps for the ABoVE field campaign. This

workshop was convened at the University Center for Atmospheric Research (UCAR) in Boulder, Colorado, on June 13-15, 2012.

Appendix B

NASA Terrestrial Ecology Field Campaign Working Group

Summary of NASA Review of ABoVE Scoping Study Report and Recommended Next Steps

Appendix C

Inventory of Research Efforts Relevant to ABoVE

Appendix C1: Field sites overview

Appendix C2: Projects and programs

Appendix C3: Data centers and portals

Appendix C4: Annotated bibliography

Updated content may be found at:

http://cce.nasa.gov/terrestrial_ecology/above/index.html