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NASA HEADQUARTERS
RESEARCH OPPORTUNITIES IN SPACE AND EARTH SCIENCES –2006
NASA EARTH SCIENCE DIVISION
A.16 THE INTERNATIONAL POLAR YEAR (IPY)

This synopsis is for the NASA Cryosphere Program solicitation of the NASA Research Announcement (NRA) ROSES-2006 NNH06ZDA001N-IPY. This NRA offered opportunities for research to contribute to the objectives of the International Polar Year (IPY), for the period March 2007 to March 2009. From the NASA perspective, IPY will provide an international and interdisciplinary approach to understanding the behavior of these polar regions and their role in the broader Earth System, including the oceans, atmosphere, biosphere, cryosphere, and land surface. The IPY also offered the opportunity to study the Lunar and Martian poles, as well, in the spirit of exploration and discovery that was characteristic of the earlier IPYs and IGYs (International Geophysical Years). Details of the IPY and the U.S. IPY Program are available at: http://www.ipy.org/ and http://www.us-ipy.org/ respectively.

Research was solicited under this announcement to deal with observational and modeling studies designed to understand polar processes and the links between the polar regions and the rest of the Earth System in a way that is scientifically and technologically interdisciplinary. As part of the planning for IPY, NASA solicited proposals in several areas:

1. Integrated analysis of multiple satellite data sets, enhanced validation of NASA satellite data sets in polar regions needed for improving their interpretation by models, and/or the integrated analysis of satellite and related suborbital data addressing the scientific questions defined by NASA in its *Earth Science Enterprise Strategy* (see Appendix at http://earth.nasa.gov/visions/ESE_Strategy2003.pdf) that can be addressed in the context of IPY.
2. Individual US investigator participation in field activities carried out as part of IPY, especially US participation in multinational field campaigns to take place in the primary IPY timeframe from March 2007–March 2009.
3. Integrated regional modeling of the polar regions (including the terrestrial, oceanic, atmospheric, biospheric, and cryospheric components of these regions and their interactions) that takes advantage of synergies between the enhanced international observational capabilities that will be available during the IPY time frame and NASA satellites.
4. Definition studies for potential US-led, focused IPY activities that integrate field work (typically using NASA-provided suborbital platforms), satellite data analysis, and modeling to address IPY-related science questions and provide enhanced validation for NASA satellite data products in the unique geophysical and/or biogeochemical conditions found in the polar areas.
5. Development of remote-sensing instruments suitable for implementation on uninhabited aerial vehicles (UAVs) such as are likely to be available for use during the IPY time frame (March 2007-March 2009). Such instruments

would make contributions to IPY contributing to our knowledge of the unique geophysical and/or biogeochemical conditions found in the polar regions.

NASA's implementation of IPY science is based on the concept of Earth System Science and a significant interest in making the connections between the multiple components of the Earth system, as well as in enhancing understanding of the physical, chemical, and biological connections between the polar regions and the rest of the planet. Given the large extent to which the polar regions are covered with ice, either seasonally or throughout the year, there will be a significant emphasis on cryospheric science within NASA's IPY activities, but the IPY activities will not be limited to them. Indeed, NASA is very interested in supporting interdisciplinary activities leveraging international IPY investments that address the couplings between the cryosphere and the surrounding oceans, overlying atmosphere (including radiative coupling between the atmosphere and the surface as well as polar precipitation), rivers, ecosystems, and the land surface (e.g., land cover, geologic activity) within the polar regions. Aspects of these Earth System components uniquely found in polar regions not directly related to the cryosphere are also of interest for this ROSES element. More details are available at http://nspires.nasaprs.com

Out of 92 submitted proposals, NASA selected 33 proposals for funding. The NRA forecasted that available funding levels would be approximately $6 million per year. It is currently estimated that total funding for the selected investigations will total $18 million dollars to cover three programmatic years of research activity. The Principal Investigator, institution, and investigation title are provided. Other co-investigators are not listed here. In the future, please see the THP website, http://thp.gsfc.nasa.gov, where information on these projects will be available once they have commenced.

Vladimir Aizen/University of Idaho
Estimation of seasonal snow cover, glacial and lake area changes at the Ob/Yenisey river heads during the last 40 years using NASA ESE products and in situ data

Problem statement: The Altai-Sayan mountains geographically define southern periphery of the Asian Arctic Basin. The Ob and Yenisey rivers are only Siberian rivers that are feed by fresh water from Altai-Sayan alpine glaciers. The water flowing from the Ob and Yenisey rivers accounts for 40% of the total river inflow into the Arctic Ocean. The 2340 Altai-Sayan's glaciers are receding from the middle of 19th century. There has not been done any precise estimation on the glacial and seasonal snow-covered areas changes, and the consequent changes in water resources.

Our main objective is to estimate changes in snow- glacial- and lake-covered areas, and glaciers' volume, in the head of Ob/Yenisey river basins over forty years, and to simulate and forecast consequent snow and glacial runoff variability.

Research approaches: (1) Collect and process in-situ data and NASA data products; (2) Simulate snow/glacier-and lake cover area and volume changes through developing a model; (3) Implement the snow/glacial runoff model parameters; (4) Characterize the annual to decadal variations in river runoff component and assess the climate-driven impact on future snow/glacial water resources.

Methods (1) We will check data for homogeneity and representativeness. Topographic and photo-grammetric measurements will be geo-referenced to a common coordinate system; (2) Glacial area distribution will be evaluated by Landsat and Terra ASTER data, and satellite products (IKONOS and CORONA) will be used for validation. Sub-pixel techniques using MODIS and AVHRR data will be used for snow mapping, and snow-covered area will be validated using Landsat and ASTER image data. Aerial photographs and Corona photographs and ASTER, SPOT and IKONOS images will be used for subsequent lake area changes. (3) Snow/glacier melt Runoff Model will simulate the annual mean runoff through snow distribution, snow/glacier ablation and quantifying the precipitation partitioning; Snow/glacier melt runoff models will be assimilated with MODIS Evapotranspiration products, MODIS Snow Cover, and MODIS Land Cover Science Data Product (MOD12Q1). (4) Forecast of glacier retreat will be based on the Equilibrium Line Altitude, which is determined through mean summer air temperatures and annual precipitation. Hypothetical climate-change scenarios will be imposed as an annual progression of changes in temperature and precipitation.

Value: Proposed project addresses an important unifying component of the NASA IPY Program, particularly with respect to the terrestrial components of the cryosphere in the Cold Land Regions of the Northern Hemisphere. Modeling and predicting glacier and snow cover changes is an important unifying component of the U.S. Global Change Research Program and the World Climate Research Program, and will contribute to the International Climate and Cryosphere Program, the Climate Variability and Predictability Research, and the North Eurasia Earth Science Partnership Initiative.

Robert Bindschadler/ NASA Goddard Space Flight Center
Total Antarctic Ice Sheet Discharge: An IPY Benchmark Data Set

We propose to employ new remote sensing methods applied to multiple satellite data sets (ICESat, Landsat, and InSAR) to complete the first-ever measurement of the total discharge of ice from the grounded Antarctic Ice Sheet. This will significantly reduce the uncertainty in this fundamental characteristic of the ice sheet that heretofore has been based only on the outflow of major outlets. This work will also provide the most detailed and comprehensive mapping ever of the grounding line position, as well as ice thickness and velocity along and in the vicinity of the grounding line. These products are sensitive indicators of changes and will serve as benchmark data sets of the International Polar Year suitable for subsequent comparisons to identify and quantify future changes in the ice sheet. An international team of student analysts and professional mentors will use standardized methods to accomplish these objectives. Field validation will be provided to quantify the accuracy of the results. Data products will be made publicly available through the Antarctic data portal hosted at the USGS EROS Data Center and the National Snow and Ice Data Center.

Robert Bindschadler/NASA Goddard Space Flight Center
IPY: Ocean-Ice Interaction in the Amundsen Sea: The Keystone of West Antarctic Stability

We propose integrated oceanographic and glaciological field studies linked with regional and local modeling activities to advance our ability to predict future behavior of ice sheets, particularly that portion of West Antarctica that drains into the Amundsen Sea. Our efforts are motivated by the nearly complete absence of direct observations of sub-ice shelf processes, the primary influence the ocean is having on the recent dramatic changes in ice sheet discharge, and the potential increased importance of these changes in the near future through accelerating sea level rise. The societal importance of this work is the need to predict future sea level. Without a process-based understanding of the ocean's interaction on ice-sheet discharge that is supported by measurements and is incorporated into predictive models, policy makers will have no firm basis for action that may protect society.

We will access the never-before seen ocean cavity beneath the Pine Island Glacier directly through hot-water drilling, measure the shape of the cavity by seismic soundings, monitor the properties of the underlying waters with newly developed instrumentation and visually explore the underside of the ice shelf and the seafloor. New instrumentation will monitor both the spatial and temporal variations in water properties inside and outside the sub-shelf boundary layer and associate these variations with the basal melt rate and dynamic response of the glacier. To be most useful to prognostic models, such measurements must include vertical profiling at flexible intervals and at horizontally distributed points. Our measurements link directly to the needs of new models of both ocean and ice behavior by directly measuring both horizontal and vertical fluxes across a model grid cell and we plan to assimilate these measurements into the first-ever coupled model of ice dynamics and ocean dynamics that expressly contains the interactive processes we will measure.

This proposal meets the exceptional challenges of the International Polar Year (IPY). We have assembled an elite international group of leading scientists and engineers with vast Arctic, Antarctic and modeling skills and sterling professional records of success. Our combined talents are focused on overcoming long-standing obstacles to understanding the interactions between ocean waters and ice shelves - urgently needed research in light of increased ice discharge from West Antarctica. Our collaborative approach amplifies the enhancements of linking measurements to models; satellite technology to innovative field instrumentation; modern science to exciting polar exploration; difficulties of Antarctic field work to our need to know. Working with education and outreach professionals, we believe the public will find our work inspiring and informative. Because it involves aspects directly associated with the International Polar Year solicitations of both NSF and NASA, it is submitted jointly to both agencies. Our success will significantly advance our ability to predict future ice sheet behavior and stand as a major scientific achievement enabled by the IPY.

Darek Bogucki/University of Miami/RSMAS
Estimates of Arctic air-sea CO2 transfer using QuikSCAT scatterometer

PI - D. Bogucki (RSMAS)
Co-PI: W. Drennan

We propose to address the oceanic sink of carbon dioxide in the Arctic Ocean as part of the International Polar Year (IPY). The North Atlantic and Arctic Oceans are believed to represent the largest ocean sink for atmospheric carbon dioxide in the Northern Hemisphere, yet the variability in oceanic uptake is poorly constrained. The Arctic is undergoing rapid change. The fate of vast stores of carbon previously frozen in the permafrost is a big unknown in future models. If released as carbon dioxide, will they be taken up locally? How will decreased ice cover impact the Arctic sink of atmospheric carbon dioxide? Here we propose to obtain improved fields of air-sea gas exchange in the Arctic basin. We will use QuikSCAT estimates of the Normalized Radar Cross-section (NRCS) to obtain fields of gas transfer velocity at around 10 km daily resolution. These fields will be used to quantify seasonal and interannual variability in air-sea fluxes of CO2 in the ice-free Arctic waters. We base our approach on the role of capillary waves in mediating gas transfer for intermediate wind speeds. The short capillary-gravity component, corresponding to roughly 2 cm surface waves of the wave field, usually dominates the Ku-band measurement made by QuikSCAT. In past work we have used air-sea transfer of carbon dioxide measured in situ during GasEx2001 and concurrent upwind NRCS (via the Geophysical NRCS-to-Wind Transfer Model Function) to obtain a NRCS-based transfer velocity. We found that the transfer velocity obtained from NRCS and that based on standard wind parameterizations were similar in mean and variance over the study area, indicating that they represent the same quantity. However, since the QuikSCAT upwind NRCS values are not averaged within a cell, they are obtained on a finer grid than the wind speed values. This enables us to carry out studies over shorter time scales and at finer spatial resolution than using wind, although the broad satellite coverage is conserved. Furthermore, the dynamic range of the NRCS-based transfer velocity is greater than in the wind-based estimates, indicating greater sensitivity to near-surface turbulence dynamics. In this project we will use data from two upcoming experiments with proposed involvement by the PIs (Drennan): the 2007 Canadian SOLAS Arctic program to the Arctic Archipelago and the 2008 Finnish IPY cruise to Svalbard. The CO2 flux and ancillary data will be used to (1) fine tune our algorithm and apply it to turbulent conditions and (2) to provide an estimation of air-sea exchange in Arctic basins. The expanded database will lead to a novel estimate of gas transfer based on NRCS that is uniquely applicable to conditions in the Arctic or to comparable conditions. We will validate and compare our algorithm with independent in situ measurements as well as with standard wind based parameterizations.

Charles Fowler/University of Colorado
Extension and Improvements to the AVHRR Polar Pathfiner Products

As part of the NOAA/NASA Pathfinder Program in the 1990's, NASA provided funding for the AVHRR Polar Pathfinder (APP) data products. These products included gridded and geolocated AVHRR channel radiances, clear-sky albedo and temperature, scan and solar angles, a cloud mask and surface type data at 5-km resolution, twice per day, for both the Arctic and the Antarctic. The original funding was to cover the period from fall of 1981 through 1997. Subsequent NASA funding allowed the dataset to be extended through 2000.

This submission proposes three objectives:
1.Update the original 1981-2000 dataset with improved cloud masking and clear-sky albedo algorithms;
2.Extend the APP dataset from 2001 through 2009;
3.Enhance the APP product suite during the IPY period.

By meeting these objectives, there are three areas of expected benefits:
1.A continuous and consistently produced dataset spanning 28 years, from 1981-2009, to better understand changes occurring in the polar climate;
2.The ability to assess the IPY years in relation to previous years;
3.And finally, a comparison dataset bridging the period from the older AVHRR through MODIS on Aqua and Terra, and VIIRS on NPP and NPOESS.

Albin Gasiewski/University of Colorado at Boulder
Identification of Atmosphere-Surface Interaction Mechanisms During Arctic Sea-Ice Freezup using NASA EOS and Airborne Observations

The dramatic shrinking of Arctic sea ice cover during the past few decades has enormous consequences for polar and global climate, as well as for human commercial activities. An observed increase in the Arctic melt season has been suggested as a major reason for the decrease in spatial extent and mass of Arctic pack ice. By forcing large, transitory changes in the surface energy budget (SEB) over the Arctic Ocean, late summer tropospheric synoptic and mesoscale disturbances may trigger the end of the melt season through positive feedbacks associated with these large transitory changes, suggesting the importance of these events for determining the length of the melt season.

Satellite-based sensors are incapable of providing both accurate observations of Arctic sea ice cover and type along with meteorological measurements of the mesoscale processes, which are necessary to understand the dynamics of this ice-atmosphere interaction process under these disturbance-driven conditions. A complete study of the ice-atmosphere interaction process thus requires satellite-based data augmented by regional-scale in situ data that can only be provided by airborne and ship-based sampling.

We therefore propose to integrate a ship-based meteorological campaign occurring during IPY on the Swedish ice breaker Oden with an airborne campaign using the NASA P-3B aircraft. The P-3 measurements will include high resolution microwave imagery of sea ice using the Polarimetric Scanning Radiometer (PSR) system, discrimination of fresh water meltponds using the SLFMR L-band imaging radiometer, and direct sampling of thermodynamic, kinematic, and cloud variables over wide areas using in situ cloud probes, dropsondes, and radiometric profiling. The observations will occur during August-September 2008. The uniqueness of this campaign will be to provide the first observations of late-summer Arctic sea ice and atmospheric state variables with high enough spatial resolution and three-dimensional specificity to elucidate in detail the ice-atmosphere interaction processes that occur during freezeup. The observations are required to understand the impact of mesoscale and turbulent atmospheric processes on surface-energy transition-to-freezeup conditions, along with providing critical data required to improve the AMSR-E sea ice algorithm during late-summer Arctic conditions. The simultaneous occurrence of the Oden IPY campaign and this proposed one represents a rare opportunity to combine extensive surface-based point measurements with spatial airborne measurements to validate and improve the capabilities of satellite remote sensing instruments and to address questions important for understanding recent changes in Arctic pack ice.

Joaquim Goes/Bigelow Laboratory for Ocean Sciences
Spatial and temporal variability in chlorophyll, primary production and carbon export in the Bering Sea linked to climate change

The wintertime sea-ice sheet in the Bering Sea plays a pivotal role in heat and biogeochemical transport into the Arctic Ocean. Its formation and retreat have a major influence on the baroclinic structure of the Bering Sea and in addition the timing, the intensity and the fate of its spring phytoplankton bloom. Several studies have shown that the sea ice sheet is sensitive to climate change. Over the past decade, large parts of the Bering Sea have been witnessing a year-on-year absence of sea-ice due to the steady rise in winter to summer temperatures being experienced over the entire Arctic. What do these changes portend for the Bering Sea ecosystem? These and other questions remain largely unresolved because of difficulties in making measurements of biological productivity by traditional shipboard means. The absence of biological datasets that match those available for atmospheric and oceanographic properties continues to remain a major impediment to understanding the potential consequences of climate change on the Bering Sea ecosystem. Satellites present us with an unprecedented opportunity to resolve this problem. While satellite images have helped reveal general trends in phytoplankton biomass and productivity in the Bering Sea, discrepancies still persist between satellite and field estimates that urgently need to be resolved to accurately assess the consequences of climate change on the Bering Sea ecosystem. In the coastal domain in particular, which sustains a large part of the spring bloom, ocean color signals continue to be confounded by riverine material, bottom reflection and sediment resuspension. These uncertainties in the satellite ocean color estimates in the Bering Sea suggest the need for more field bio-optical studies to improve assessments of sea-water constituents especially coccolithophores, which in recent years have been responsible for exceptionally large, anomalous phytoplankton blooms in the region. In this collaborative study between US and Japanese researchers we plan to collect bio-optical data in conjunction with measurements of phytoplankton chlorophyll and productivity, CDOM, suspended matter, coccolithophore counts and calcium carbonate in support of NASA's efforts to develop robust ocean color empirical and semi-analytic algorithms for the Bering Sea. We have been offered ship time aboard the Japanese ship T/S Oshoro Maru which will be conducting field activities as part of the Japanese contribution to the IPY program. Nutrient data collected during the field program will be utilized to fine-tune our existing algorithms for estimating sea surface nitrate and nitrate based export production. These measurements will be utilized together with other satellite derived products such as sea-ice cover, sea surface winds, sea surface temperature and sea-surface height anomaly etc. to study seasonal and long-term trends in response to climate change.

Ziad Haddad/jet propulsion laboratory
Combining measurements from CloudSat's radar, AQUA's AMSR-E and NOAA's AMSU-B to estimate precipitation in polar regions

While the CloudSat radar's capabilities are optimized to provide vertical profiles of clouds, the instrument has a large dynamic range and is therefore perfectly capable of detecting and estimating snow and light rainfall. We therefore propose to use this nadir radar's measurements to estimate precipitation over arctic and antarctic regions, where the ``A-train'' platforms' sampling is particularly frequent. By combining the measurements of CloudSat's radar with those of the AMSR-E and AMSU radiometers along the orbit track, we will derive optimal radiometer-snowrate relations for use in the wide swath of the passive microwave instruments.

Richard Honrath/Michigan Technological University
A study of biomass-burning and anthropogenic impacts on arctic tropospheric chemistry using measurements at Summit, Greenland as part of the POLARCAT International Polar Year project

Although it is a remote region, the Arctic is impacted by boreal biomass-burning and anthropogenic emissions that significantly alter tropospheric composition, affecting levels of ozone and ozone precursors and causing radiative and air quality impacts. These impacts have large seasonal and interannual variability and are expected to respond to climate change, as a result of dependencies on boreal wildfire emissions and the state of the North Atlantic Oscillation. To quantify these impacts, information on the ozone-precursor families nitrogen oxides and non-methane hydrocarbons (NMHC) is needed. However, continuous in-situ high-altitude measurements are required for this purpose and are not available at any arctic station.

We propose to make continuous year-round measurements of total reactive nitrogen oxides, PAN, NOx, and NMHC at the high-altitude (3208 m) GEO-Summit station in Greenland, for a period of 2 years. These measurements will be analyzed in conjunction with FLEXPART transport modeling and simultaneous observations of CO, ozone, and black carbon to identify sources and impacts of both anthropogenic and biomass-burning emissions, with a focus on impacts on arctic tropospheric ozone, ozone precursors, and OH levels and consideration of potential feedbacks upon snowpack photochemistry.

This proposal responds to the ROSES-2006 A.16 (International Polar Year) solicitation for individual US investigator participation in multinational field activities carried out as part of IPY. The proposed research is part of the multinational IPY POLARCAT study. Integration with POLARCAT will make available FLEXPART and other modeling and satellite products that will increase the value of the proposed measurements, and the Summit observations will provide seasonal and interannual context for intensive measurements associated with POLARCAT. The results will contribute to multiple NASA strategic science goals involving understanding and predicting current and future atmospheric composition as it relates to climate forcing and air quality.

Kenneth Jezek/The Ohio State University
Glacier and Ice Sheets Mapping Orbiter: Airborne Validation Experiments

Through a NASA Instrument Incubator Project, we are evaluating a concept for a spaceborne radar system designed to measure the surface and basal topography of terrestrial ice sheets and to determine the physical properties of the glacier bed. Our primary objective is to develop this new technology for obtaining spaceborne estimates of the thickness of the polar ice sheets with an ultimate goal of providing essential information to modelers estimating the mass balance of the polar ice sheets and estimating the response of ice sheets to changing climate. Our new technology concept employs VHF and P-band interferometric radars using a novel clutter rejection technique for measuring surface and bottom topographies of polar ice sheets from aircraft and spacecraft. Our approach will enable us to reduce signal contamination from surface clutter, measure the topography of the glacier bed at better than 1 km intervals with an accuracy of 20 m, and paint a picture of variations in bed characteristics. As part of the NASA Instrument Incubator Program, we are presently funded to evaluate the conceptual design (summarized in section 2) through simulations and airborne field experiments. We will be conducting preliminary airborne experiments in May 2006 using a commercial Twin Otter aircraft. In this proposal we request additional flight hours and equivalent operational costs on the NASA P-3 aircraft to conduct experiments in 2007 and 2008 as part of the IPY. Scaling analysis shows that the higher operating altitude of the P-3 will enable us to better test our technique. The increased range will allow us to test the instrument over portions of the ice sheet where basal water content is known to be changing. The research complements IPY science objectives outlined in the IPY umbrella program for spaceborne observations titled the Global Inter-Agency IPY Polar Snapshot (GIIPSY).

Jeffrey Kargel/University of Arizona
Collaborator Research: Satellite, Airborne, and Ground-based Assessment of Cryospher Changes in the Copper River/Chitina Basins and Adjoining Ranges (Alaska) from Late Glacial Maximum to Now

The Copper River Basin-- now a region of discontinuous permafrost rimmed by glaciated mountains, which drain to the Gulf of Alaska-- was once dammed; a large, poorly studied ice-dammed lake formed, called Glacial Lake Atna (over 5,000 square kilometers). Lake Atna may or may not have undergone a period of evaporitic, hypersaline conditions, but groundwater compositions suggest that this may have been the case. We do not know whether the lake was perennially covered by lake ice or glacier ice, but this is a possibility we shall investigate. Lake Atna may serve as a now-de-iced model of lake Vostok in Antarctica and may be a useful analog of Martian lakes in glacial and permafrost environments. As the region's glaciers retreated into nearby mountains, Lake Atna drained. A series of ice-dammed lakes have formed higher in the mountains during the retreat phase, and this type of lake continues to be important in the region's hydrology. The evolution of glaciers and lakes in this region from the Late Glacial Maximum to now is a natural model of what may elapse in parts of Greenland and Antarctica. As for the future of this region of Alaska, the thawing cryosphere of the modern European Alps offers a possible analog. We shall investigate the current state of glaciers and recent glacier fluctuations in the mountains rimming the Copper River Basin and produce 3-D models of the temporal evolution of glaciers and regional hydrology from the Late Glacial Maximum to now. Tasks: (1) Satellite image and other data collection and GIS integration, manipulation, and display. (2) Land cover classification of images and integration into GIS database. (3) Field validation and GPS tracking of interannual changes. (4) 3-D glacier modeling (former Late Glacial Max up to the present). (5) Glacier and lake change assessment, including change in ice damming from the Late Glacial Maximum to the present. (6) Implications of temporal changes in glaciers for near-future evolution of glacier lakes, surging glaciers, hanging glaciers, artesian springs and mud volcanoes. The project includes separate budgets for the University of Arizona and U.S. Geological Survey, plus unfunded foreign collaborations. This project is to be conducted with the U.S. Geological Survey (Co-PI, Bruce Molnia) and his associates.

William Krabill/NASA/GSFC Wallops Flight Facility
IPY Airborne Laser-altimeter Surveys in Collaboration with Multinational Polar Campaigns

This proposal is primarily to acquire accurate measurements of surface elevation of glaciers and ice sheets using NASA’s Airborne Topographic Mapper (ATM). The goal is to help for improve our understanding of the mass balance of these ice masses. Data acquired during the IPY would be used for our own ongoing research, primarily in Greenland, and in collaborative research with other IPY investigators. We have previously established such collaborations with both US and international groups, using ATM data from Greenland, Iceland, the Canadian Archipelago, Svalbard, and Alaska in the arctic and, with Chilean collaboration, from the Antarctic Peninsula and West

Antarctic glaciers flowing into the Amundsen Sea, as well as from the northern and southern ice fields of Patagonia. We propose to continue such collaborations during the IPY, and to work with other successful IPY investigations to acquire and analyze specific data sets. We are aware of several scientists who will be proposing to IPY solicitations for use of the ATM in their investigations.

Although ice-sheet elevation data are available from satellite radar and laser altimeters, large differences between radar-derived mass balance in Greenland and estimates from other techniques suggest possible problems with interpretation of the radar data; and failing power indicates that ICESat laser measurements are unlikely to continue much into the IPY time frame. This leaves a gap in our measurement capability, with CryoSat not scheduled for launch until 2009 at the earliest, and a follow-on for ICESat not yet planned. Its existing track record makes ATM a strong candidate for continuing ice-sheet surveys that are focused on regions likely to be undergoing rapid change.

In addition to research investigations, we propose to use ATM data for validation of elevations and their rates of change derived from altimetry data from other sensors, such as those from ICESat and ERS and future light-weight altimeters designed for UAV (unmanned airborne vehicle) operations. In the past, ice-penetrating radars have been operated by other investigators in tandem with the ATM, and we expect this to be the case during IPY.

Ronald Kwok/Jet Propulsion Laboratory
Satellite Observations of Sea Ice: Pan-Arctic ice export and assessment of sea ice models

We propose to address two topics that are of importance for understanding the role of the Arctic Ocean in global climate: Pan-Arctic sea ice export and the efficacy of Arctic Ocean sea ice models. The sea ice outflow through Fram Strait has been generally accepted as the largest component of the total mass export; outflow through other passages have been assumed to be small and inconsequential. Recently estimates by Kwok [2005] and Kwok et al. [2005] at Nares Strait and the passages into the Barents Sea indicate that the export at these gates are highly variable and could represent up to one-fifth of the total Fram Strait outflow. First, we propose to construct the first-ever estimate of Pan-Arctic sea ice export using ice motion and thickness estimates from satellite active and passive microwave sensors, ICESat, and in-situ measurements. Available satellite datasets provide sufficient spatial and temporal extent to allow for estimates of the mean and variability of contemporary Arctic sea ice export. Second, we propose to participate in the assessment of sea ice simulations from the on-going Arctic Ocean Model Intercomparison Project (AOMIP). AOMIP's major objectives are to use a suite of sophisticated models to simulate the Arctic Ocean circulation for the periods 1948-2004 and 1901-2004 to examine the ability of Arctic Ocean models to simulate variability on seasonal to interannual scales, and to qualitatively and quantitatively understand the behavior of different Arctic Ocean models. In particular, we will focus on the evaluation of ice kinematics from daily-to-interannual time scales. Assessment will be on the motion and deformation near the grid scale of these models as well as ice export.

Spatial patterns of ice thickness from ICESat and model output will be compared. Both efforts are relevant to IPY: the ice export work will provide a benchmark dataset of the International Polar Year and suitable for subsequent comparisons to identify and quantify future changes in the Arctic Ocean; the assessment work will allow for better understanding of the limitations and performance of sea ice models used for Arctic climate analysis and for future climate projections.

Dennis Lettenmaier/University of Washington
Use of International Polar Year Circumpolar Permafrost Data to Understand Long-Term Water and Carbon Cycle Changes in the Terrestrial Arctic Drainage Basin

Major hydrologic changes have been observed over much of the Eurasian Arctic over the last half century. These include widespread increases in permafrost active layer depth, changes in the extent of lakes and wetlands, and increased river discharge, especially in winter. A number of causes have been suggested for these trends, including thawing of permafrost, construction of dams, land cover change, and melting of land ice. In most cases, coincident changes in precipitation have not been observed.
These changes motivate the overarching science question for this proposal:: "To what extent are changes in permafrost characteristics, as compared with seasonal patterns of snow cover extent, reservoir storage, and land cover change responsible for observed changes in the discharge of major Arctic rivers over the second half of the Twentieth Century?" We intend to address this question through intensive use of IPY permafrost data to be collected as part of IPY project #125, Thermal state of permafrost, with which we will coordinate closely. We will use land surface modeling, incorporating new in situ and remote sensing data sets to be acquired as part of IPY activities, as well as recent advances in representation of the hydrologic effects of permafrost, improved modeling of snow cover dynamics over large areas, land cover change, and water management. We will further utilize our land surface model in cooperation with TSP PI (NSF funded project) Vladimir Romanovsky to help identify portions of the pan-arctic domain where additional permafrost borehole measurements will be most useful. Through representation of these potential change agents in long term (50-75 year) simulations of streamflow for the major Eurasian Arctic river basins and their largest tributaries, and comparison with observed streamflow records, we expect to understand the relative effects of these various changes, as well as the direct effects (e.g., through earlier onset of spring snowmelt) of climate change over the last half to three-quarter century.
Our overall approach will be as follows. We will perform retrospective simulations with the Variable Infiltration Capacity (VIC) macroscale hydrology model and a suite of other land surface models in our multi-model hydrologic simulation system over the Eurasian Arctic study domain. Via examination of simulated river discharge in comparison with observations, we will infer the relative magnitudes of long-term (last 50-75 years) changes attributable to each of the proposed change agents – specifically, permafrost active layer depth, climate and hydrologic response (e.g., changes in amount, timing, and location of precipitation and snowmelt), vegetation changes, and the effect of reservoirs. The proposed project will contribute directly to one of the central questions posed by the NAS 2001 report "Enhancing NASA's contributions to polar science", specifically under responses to change, we will address the question posed by the NAS report "How will

land surface hydrology and energy exchanges be influenced by the climate-induced changes to vegetation structure and distribution across the polar regions?" This proposal further responds to the second element of the NRA requesting proposals for "Integrated regional modeling of the polar regions … that takes advantage of synergies between the enhanced international observational capabilities that will be available during the IPY time frame and NASA satellites".
This proposal is a slight variation of a proposal by the same PI and co-PI submitted to the NASA NEWS call in December, 2004. We are submitting this proposal to the IPY call at the recommendation of the NASA Terrestrial Hydrology Program Manager, Jared Entin. This proposal focuses more directly on issues specified in the IPY call (notably permafrost, and a connection with the IPY Thermal State of Permafrost project) than does the NEWS submission.

Varavut Limpasuvan/Coastal Carolina University
The Roles of Gravity Waves in the Polar Atmosphere

Flow over topography, latent heating associated with polar fronts, and jetstream fluctuations can generate gravity waves (GWs) that propagate into the stratosphere. While the coupling processes between near-surface disturbances and those in the middle atmosphere are still unclear, GWs are thought to play a key role in interacting with planetary-scale flows and distributing energy at different parts of the atmosphere. Damping of GW can significantly alter the stratospheric circulation, distorting the polar vortex and the underlying planetary-scale disturbances. Anomalous changes in the polar vortex have been suggested to bias near-surface climate conditions. Perturbed polar dynamics on mesoscale and planetary scales can have significant implications in the formation of polar stratospheric clouds (PSCs) which could facilitate stratospheric ozone destruction.

The goal of this study is to investigate the roles of GWs in coupling the polar troposphere to the stratospheric evolution. The study aims to better understand the dynamical connection between GWs and planetary waves, to access GW forcing on the polar vortex, and to examine the role of GWs in PSCs formation. As such, our objectives are (1) to characterize the sources/properties of GWs in the polar region and their propagation into the stratosphere, (2) to assess the interactions between GWs and planetary-scale disturbances in the polar region, and causes of wave intensification, and (3) to estimate impacts of GW perturbations on the formation of PSCs in the lower stratosphere.

Methods: To achieve these objectives, GW simulations will be performed using the ARPS weather model (extended up to the mesosphere) to explicitly resolve GWs of horizontal scales greater than 50 km. Focus will be placed on events in which synoptic disturbances significantly raise the tropopause. These cases are often associated with enhanced cloudiness (in the troposphere and the stratosphere) and strong GW generation. Model results will be compared with satellite observations like NASA AIRS radiance to elucidate wave properties and their sources. Gravity wave forcing of the polar stratosphere in relation to planetary waves will be analyzed using model results and reanalyses data from GEOS-4. In assessing the impact of gravity waves on PSC formations, model results are used to diagnose and interpret simultaneous satellite observations of temperature, water vapor, and PSCs, including those from Aura HIRDLS, ENVISAT SCIAMACHY, Aura MLS, and local soundings. The cloud occurrence frequency generated with/without the presence of gravity waves will be compared to quantify overall wave impacts in various meteorological conditions

Significance: Improved understanding of GW can provide further insights on the formation of PSC (linked directly to ozone depletion) and the polar stratosphere (which are coupled to tropospheric climate). By shedding light on GW source/characteristics and influence on the polar stratosphere, this study can improve how GW effects are incorporated in global climate models and thereby increase the models' effective in assessing climate variability and changes. To this end, the proposed study addresses two scientific questions raised by NASA Earth Science Enterprise Strategy: "how will future changes in atmospheric composition affect ozone and climate?" and "how can predictions of climate variability and change be improved?" Importantly, the proposed investigation will complement and be enhanced by several IPY projects on modeling, observations, and data assimilation, in conjunction with ice clouds over the polar region. Like these projects, our objectives address the IPY themes of: (1) "Current state of the [polar] environment", (2) "Change in the polar regions", (3) "Polar-global linkages/teleconnections", and (4) "Exploring new frontiers [in polar science]".

Michael Mahoney/Jet Propulsion Laboratory, California Institute of Technology
A UAV Microwave Temperature Profiler (MTP) for IPY

The objective of this proposal is to integrate an existing Microwave Temperature Profiler (MTP) on a UAV in time to participate in potential International Polar Year (IPY) UAV field campaigns. The Jet Propulsion Laboratory (JPL) MTPs are small, light-weight, easily-integrated, and fly autonomously; hence, they are well suited for UAV integration. In more that two decades of airborne research, JPL MTPs have accumulated 4175 flight hours during 739 flights on 46 field campaigns -- probably more than any other instrument. Most importantly, they have an enviable performance record since they have had very few failures.

The proposed work would involve building a fairing to mount the MTP Sensor Unit on the UAV, and then integrating the MTP Data Unit with the payload, including interfaces for power, control, and access to navigation data (time, pitch, roll, etc.) We have proposed to fly MTPs in the past on Global Hawk, Pathfinder, and Perseus, but could also be easily integrated on Predator, Altair, and other UAVs that NASA and other organizations are considering.

The UAV MTP measurements will contribute directly to two of the three areas identified in the IPY solicitation. First, the MTP observations were recognized as being needed for all Aura validation field experiments, and they would fulfill this role of calibration and validation when flying on a UAV during IPY. Second, the proposal will show that MTP measurements provide important information that complements that available from satellite sensors. They do not contribute to the third area solicited -- demonstration of instrumental approaches for future satellites -- because microwave satellite temperature sounders already operate like an MTP. The MTP however obtains much better vertical resolution than a satellite sounder, because it scans in both frequency and elevation angle, something that a satellite sounder cannot do.

Michael Mahoney/Jet Propulsion Laboratory, California Institute of Technology
MTP Support for ORACLE-O3 Activities

ORACLE-O3 is a European-led project comprising fifteen Expressions of Interest (EoI) submitted to the International Polar Year (IPY) organization, which is co-sponsored by the ICSU and WMO. The ORACLE-O3 project includes 15 EOIs representing 117 researchers from 67 institutions in 22 countries. It has already received a conditional endorsement from the IPY. The Jet Propulsion Laboratory (JPL) Microwave Temperature Profiler (MTP) team is a part of the ORACLE-O3 project. The objective of this proposal is to obtain support to participate in ORACLE-O3 planning activities related to the deployment of the Geophysica high-altitude research aircraft (under EoIs #566 and #919) in the Arctic and Antarctic. This is necessary because what can be done is subject to pending approval of proposals submitted to national funding agencies, which is on-going at this time.

The proposed work under EoIs #566 and #919 would involve participation in an Arctic field campaign based out of Longyearbyen, Spitzbergen, and in an Antarctic field campaign based out of Ushuaia, Argentina, aboard the Russian Geophysica high-altitude research aircraft. The JPL MTP is the only US instrument to have flown on the Geophysica, and is the only instrument capable of measuring temperature profiles in these radiosonde-sparse regions of the world.

EOI#566 aims to provide new scientific knowledge on the evolution of ozone, polar stratospheric clouds (PSCs), and cirrus clouds in the stratosphere and upper troposphere in a changing climate. The MTP measurements aboard the Geophysica will contribute to this understanding because temperature profiles are essential for understanding the microphysics of PSC and cirrus cloud formation, which play a key role in ozone chemistry. The MTPs ability to "see" mountain lee waves (by converting a temperature curtain to isentropic surfaces on which air parcels flow) will also allow the role of these waves in PSC formation to be understood relative to PSC formation from large scale subsidence.

EOI#919 will focus on the early phase of the ozone seasonal cycle and on processes which can be significantly affected by future changes in stratospheric temperatures. The Antarctic Geophysica flights will study the occurence of "NAT rocks," which have only been detected in the Arctic, but which are extremely efficient at de-nitrification, and hence increased ozone loss. Unlike the Arctic, the Antarctic ozone hole developes very predictably in mid-May. MIPAS satellite measurements indicate that mountain waves trigger the formation of small NAT (nitric acid trihydrate) particles during the cold phase of these waves. The MTP measurements aboard the Geophysica will help in understanding how the small NAT particles become "rocks," because this likely depends on the temperature history. Also, the MTP's ability to "see" mountain lee waves will allow the role of these waves in the formation of small NAT particles to be understood.

James Maslanik/University of Colorado
Sea Ice Roughness as an Indicator of Fundamental Changes in the Arctic Ice Cover: Observations, Monitoring, and Relationships to Environmental Factors

Sea Ice Roughness as an Indicator of Fundamental Changes in the Arctic Ice Cover: Observations, Monitoring, and Relationships to Environmental Factors

Since the macro-scale (meters to 10's of meters) roughness characteristics of sea ice are a function of a combination of dynamical and thermodynamical processes and conditions, observations and monitoring of ice roughness could provide new insights into such basic issues as the magnitude and distribution of ice thinning, changes in the nature and amount of ice of different ages, and modifications of the ice cover in ways that might enhance or reduce the effects of rising air temperatures. On a larger scale, sampled via aircraft or satellite, monitoring of the distributions of ridged and rubbled ice would help address questions such as the degree to which changes in Arctic ice mass reflect melting or less growth versus redistribution of mass into regions such as areas north of the Canadian Archipelago.

The proposed research combines the use of a variety of remote sensing methods, including satellite observations and uninhabited aerial vehicles, to provide fundamental new insights into ice roughness on the scale of meters to 10's of meters in the context of larger-scale environmental forcings. Our intent is to be able to relate scattering and emission properties to surface roughness and hence to geophysical properties that are difficult or impossible to observe directly. Fine scale and in situ observations are essential to understanding physical processes at work, but it is necessary to know how processes aggregate over the scale of the types of spaceborne observations that we must rely upon for regional and hemispheric-scale monitoring. In keeping with this, the proposed work has three main goals:

- Determine the degree to which ice-roughness monitoring via remote sensing can detect basic changes in ice conditions such as ice thickness and ice age;
- Investigate relationships between ice roughness and factors affecting the loss or maintenance of the perennial ice cover;
- Determine how roughness varies as a function of different kinematic conditions and ice properties.

As part of IPY, the proposed work would provide fundamental new insights into important but difficult-to-observe aspects of the ice cover and would complement other planned and proposed IPY projects. The nature of the proposed research would further the contribution of satellites as tools for long-term monitoring and observations, and thus help solidify the role of spaceborne remote sensing as a key element of IPY.

Matthew McGill/NASA Goddard Space Flight Center
Lidar Measurements from a UAV Platform in Support of International Polar Year Activities

The upcoming International Polar Year (IPY) activities will provide a unique opportunity to demonstrate airborne measurement capabilities using Unmanned Aerial Vehicles (UAVs). For several years the Cloud Physics Lidar (CPL) instrument has provided valuable measurements of cloud and aerosol properties from the ER-2 aircraft platform. Based on the success of the ER-2 CPL, and given the future direction of NASA airborne platforms, we have been constructing a duplicate of the CPL instrument for use on a UAV. We propose to fly a duplicate of the CPL instrument (called UAV-CPL, for lack of a better name) in support of IPY activities. Like CPL, the UAV-CPL is a multi-wavelength elastic backscatter lidar designed specifically for sensing cirrus, sub-visual cirrus, and aerosols. The UAV-CPL will provide profiling at 1064, 532, and 355 nm with 30 m vertical and 1-second temporal resolution. Data products from the UAV-CPL include cloud/aerosol structure and variability, cloud/aerosol boundaries, cloud/aerosol layer optical depth, depolarization ratio, and, when possible, extinction profiles. To support the UAV-CPL activities we request funding support to complete the instrument assembly and integration, for in-field operations, and for subsequent data analysis. It is understood from the research announcement that flight costs will be covered separately by NASA.
In addition to providing scientifically important measurements over the polar regions, measurements from UAV-CPL will permit validation and calibration of satellite instruments, most notably those in the so-called A-Train. The UAV-CPL data has particular application to validation of the following A-Train sensors: the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), CloudSat, the Moderate Resolution Imaging Spectroradiometer (MODIS), the Atmospheric Infrared Sounder (AIRS), the Ozone Measuring Instrument (OMI), Microwave Limb Sounder (MLS), and the High Resolution Dynamics Limb Sounder (HIRDLS). The ability for one airborne instrument to contribute to the (near-simultaneous) validation of so many satellite sensors is unprecedented and clearly illustrates the value of the UAV-CPL to NASA. Further, the ability to fly the UAV-CPL in polar regions will provide a unique opportunity for satellite validation over regions where validation is normally not possible

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Delwyn Moller/jet propulsion laboratory
An Interferometric Ka-band Synthetic Aperture Radar: A New Technique for Glacier and Ice-sheet Topography Mapping

The estimation of the mass balance of ice sheets and glaciers on Earth is a problem of considerable scientific and societal importance. A key measurement to understanding, monitoring and forecasting these changes is ice-surface topography, both for ice-sheet and glacial regions. As such NASA identified "ice topographic mapping instruments capable of providing precise elevation and detailed imagery data for measurements on glacial scales for detailed monitoring of ice sheet, and glacier changes" as a science priority for the most recent Instrument Incubator Program opportunities. Funded under

this opportunity is the technological development for a Ka-Band (35GHz) single-pass interferometric synthetic aperture radar (InSAR). Unique to this concept is the ability to map a significant swath impervious of cloud cover with measurement accuracies comparable to radar and lidar altimeters.
While the IIP addresses the development of the major technology challenges, this proposal demonstrates the phenomenology of the measurement by adapting the NASA-funded UAVSAR system for Ka-band interferometric operation. This will directly achieve two of the stated IPY objectives; 1) "development of remote-sensing instruments suitable for implementation on UAVs" and 2) "providing early demonstration of instrumental approaches that may be suitable for use on future satellites". The comprehensive infrastructure of UAVSAR will be utilized requiring only pod and simple RF modifications for this program. In this manner we can capitalize on the vast resources already in-place including aircraft integration, data-acquisition system and processor.
A key question to be answered as part of this program is "what is the penetration depth of the radar signal into the snow?" for which little to no measurements currently exist. To address this issue in May 2008, we will fly aboard the UAVSAR platform over regions of Greenland in May 2008. The primary flight plan entails flying a grid over Jakobshavn glacier, then a transect from the coast to Swiss Camp ending at Greenland's Summit. Over a period of 4-5 weeks at the beginning of the melt season, these flight missions will be repeated at least 4 times in different snow/ice conditions. The flight data will be compared with airborne laser altimetry, field observations (GPS data at Swiss Camp, Summit), and climate data from the AWS network (snowfall, corrected for densification). Topography is an essential piece of information for glaciology and a high-quality topographic map (tens of cm height accuracy over 10m pixels) will be useful to any glaciologists studying the area. At present, such high-precision, dense topography is not available. This map will also form an IPY reference for measuring future changes in ice elevation. Finally, our experiment will pave the way to making more topographic products available to glaciologists and design a spaceborne mission capable of delivering similar products at the continental scale.

Son Nghiem/Jet Propulsion Laboratory
The State of Arctic Sea Ice Cover: Integrated Decadal Satellite Observations of Properties and Processes in a Changing Environment

Drastic change has occurred over the Arctic sea ice cover in the past decade. In the spring of 2006, perennial sea ice is almost completely depleted from the East Arctic (0-180^{o}E). In view of recent profound Arctic change, we submitted the IPY Full Proposal (FP) 95 entitled "The state of the Arctic sea ice cover: Physical and biological properties and processes in a changing environment". Recognized as "a prominent and valued part of the IPY program", the FP 95 was selected for the full endorsement by the ICSU/WMO Joint Committee for the IPY Program.

As a critical component of the FP 95, satellite remote sensing provides large-scale basic parameters for observing properties and processes characterizing the state of the Arctic sea ice cover. In this regard, the objectives our NASA IPY proposal are to develop, coordinate, enhance, and integrate NASA satellite datasets in the Arctic region including satellite wide-swath active microwave (AM) and passive microwave (PM) data for Arctic observations and model assimilation. We focus on obtaining a suite of products from AM scatterometer data for one decade (1999-2009) including: ice extent, ice classes, melt onset, melt season length, melt zone, freeze-up timing, and wind vector. We develop and implement methods to blend different AM and PM datasets such as ice motion and ice concentration to improve accuracy and consistency of Arctic data products. We use existing and future IPY field experiment results to verify and validate the satellite products. We will assimilate these products into physical and climate models to understand and forecast sea ice change. We integrate the decadal combined data products in the University of Alaska Arctic Sea Ice System (ASIS) by enhancing the network to ingest, archive, and disseminate the decadal NASA satellite products to IPY and other users.

This proposal is crucial to the success of the FP 95, and directly and specifically addresses the first IPY Scope of the Program: "Integrated analysis of multiple satellite data sets, enhanced validation of NASA satellite data sets in polar regions needed for improving their interpretation by models, and/or the integrated analysis of satellite, etc." This research contributes to answering the NASA strategic questions: "How is the global Earth system changing?" by the satellite monitoring of the Arctic identified as an important component in the Earth system, "What are the primary causes of change in the Earth system?" by investigating possible dominant causes of Arctic change, "What are the consequences of change in the Earth system for human civilization?" such as the potential opening of a seasonal Arctic sea route in diminished Arctic ice conditions that may revolutionize global maritime and commerce, and "How will the Earth system change in the future?" by improving the understanding and thus forecast of Arctic change.

Jon Ranson/NASA's GSFC
Assessing Forest-Tundra Transition Zone In The Northern Hemisphere With Multi-Sensor Satellite Data

Assessing Forest-Tundra Transition Zone In the Arctic With Multi-Sensor Satellite Data

ABSTRACT
In response to NASA International Polar Year Solicitation for “integrated analysis of multiple satellite data sets, … in polar regions addressing the scientific questions defined by NASA in its Earth Science Enterprise Strategy”, the proposed study will map and characterize the current forest-tundra transition zone, and reveal its changes during the last several decades with multi-sensor satellite data and field observations for portins of the circumpolar ecotone.
Monitoring the dynamics of the circumpolar boreal forest and Arctic tundra boundary is important for understanding the causes and consequences of changes observed in these areas. This ecotone, the world’s largest, stretches for over 13,400 km and marks the transition between the northern limits of forests and the southern margin of the tundra. Because of the inaccessibility and large extent of this zone, remote sensing data can play an important role for mapping the characteristics and monitoring the dynamics. Current

land cover maps produced from AVHRR, VEGETATION, and MODIS data are not consistent along this forest-tundra transition zone, and do not provide enough detailed information on vegetation structure changes across the transition zone. Our previous studies in Ary-mas, Siberia showed that the taiga-tundra transitional area can be characterized using multi-spectral Landsat ETM+ images, multi-angle MISR red band reflectance images, RADARSAT images with larger incidence angle, or multi-temporal and multi-spectral MODIS data. Because of different resolutions and spectral regions covered, the transition zone maps derived from different data types were not identical, but the general patterns were consistent.

In this study we will incorporate the 3rd dimension in the characterization for the tundra-forest ecotone using existing lidar measurements and develop a benchmark for the midpoint of the ecotone along a substantial portion of the ecotone. We will use of multi-sensor data fusion to identify the existing forest-tundra ecotone, characterize the spatial patterns of forest-tundra mosaic, and investigate its changes. The specific objectives and tasks in the proposed study include:

1. Map tree abundance and land cover types using high resolution data in intensive study sites along the forest-tundra transition zone and characterize the spatial patterns of tree-tundra mosaic across the boundaries. These data include Landsat-7, ASTER, radar (ERS, JERS-1, RADARSAT, ENVISAT ASAR) and ALOS PALSAR and Panchromatic Remote Sensing Instrument for Stereo Mapping (PRISM).
2. Investigate the potential of GLAS waveform data and MISR data for characterization of vegetation structure across the forest-tundra transition zone.
3. Produce benchmark maps at 500m pixel size for forest-tundra transition zone by validating and improving the continuous tree cover maps and MODIS 1-km classification map from MODIS 250m or 500m data using training data generated in tasks 1 and 2, and
4. Quantify the changes of tree density and advance of “tree line” in intensive study sites using historical satellite data and field observations.

This study will result in a benchmark map of the circumpolar Arctic forest-tundra transition zone, and verified methods for periodic mapping of this ecotone using multi-sensor satellite data.

Richard Ray/NASA Goddard Space Flight Center
Tides in the Polar Seas

A number of NASA and ESA satellite measurements over the polar seas are confounded by inadequate knowledge of the tides. Several examples of high-resolution mass-flux estimates from GRACE have been found to be contaminated by spurious tidal signals. Likewise, radar and laser altimeter measurements over some regions, especially Antarctic ice shelves, are affected. Because high-inclination satellites necessarily alias some tidal signals to long period, inadequate knowledge of tides creates false climate-like signals. Reduction of these errors is becoming crucial to the success of several remote-sensing missions, including those contributing fundamentally to the International Polar Year.

We propose to attack the problem of polar tides with a variety of traditional and non-traditional data types, all of which will be assimilated into a nonlinear hydrodynamic tidal model. The large variety of measurement types is necessary because of the general lack of high-quality measurements that are normally available for studying tides in non-polar oceans. Among non-traditional data are gravity measurements from GRACE and from a number of Earth-tide gravity and geodetic stations. GRACE will provide, at least for some constituents, long-wavelength tide corrections. We propose to investigate more thoroughly the use of retracked ERS and Envisat altimetry, including data over ice shelves, for determination of tides. This requires modifications to standard tidal analysis algorithms. Initial efforts show that regulatization procedures can partially overcome the complex aliasing problems associated with sun-synchronous altimetry; extended studies with assimilation techniques and inverse methods are called for.

To improve resolution of aliased solar tides, and to make the best use of the relatively limited data available in polar regions, the Oregon State Tidal Inversion Software (OTIS) will be modified to allow more tightly coupled simultaneous assimilation of multiple tidal constituents, and to allow incorporation of novel data types such as Earth-tide data and long-wavelength GRACE estimates. The newer data types will be combined with traditional tide-gauge measurements, GPS measurements on floating ice, and radar measurements over open water to yield tidal solutions that satisfy both the data and the nonlinear hydrodynamics built into OTIS. The latter are dependent on accurate knowledge of bathymetry, so we will incorporate any improvements to those data as they become available.

This proposal responds to NASA Strategic Goal 3A, studying the Earth to advance scientific understanding and to meet societal needs.

Rick Reynolds/Scripps Institution of Oceanography, UCSD
Carbon dynamics in the Beaufort Sea from field and satellite observations.

Under the auspices of the International Polar Year, we propose to participate in a joint oceanographic study of the carbon cycle within the Arctic Ocean. This study will entail an interdisciplinary collaboration between several French, Canadian, and U.S. institutions, with the goal of determining and understanding the sizes and transformation rates of carbon reservoirs within the Beaufort Sea. Our primary role in this collaboration will be to characterize the dynamics of the particulate organic carbon (POC) pool within the upper ocean, including the determination of geographical distributions and variability from weekly, seasonal, to interannual time scales. Our approach utilizes a combination of field measurements and satellite data. We will participate in a research cruise on the French vessel Marion Dufresne in the Beaufort Sea covering both the Mackenzie Shelf region and offshore oceanic waters in July and August 2007. A broad suite of measurements will be used to quantify the inherent and apparent optical properties of the ocean and properties of suspended particle assemblages. The analysis of field data will focus on discerning the relationships between seawater constituents, inherent optical properties, and surface spectral reflectance (ocean color). These relationships, in conjunction with radiative transfer modeling, will be used to develop and parameterize bio-optical algorithms for POC, phytoplankton pigments, and other parameters of biogeochemical significance such as total suspended matter and light absorption by dissolved organic matter. We will apply these algorithms to satellite ocean color data to derive basin scale maps of POC distributions within the upper ocean, and analyze the spatial and temporal variability of this reservoir within the context of physical forcing, biological processes, and the relationship of POC to other components of the oceanic carbon cycle. This analysis will be done for the entire operational period of SeaWiFS and MODIS ocean color satellite sensors. The results of our field and satellite studies, combined with those of our collaborators studying other aspects of carbon biogeochemistry, will provide a comprehensive framework for understanding the dynamics of carbon transformations in the Arctic Ocean, and allow the assessment of potential responses of this ecosystem to changes in climate.

Eric Rignot/Jet Propulsion Laboratory
HF radar sounding of glaciers in Greenland and Antarctica for force and mass balance calculations.

Glaciers in Greenland and parts of Antarctica are accelerating in response to climate warming, triggering an increase in their contribution to global sea level rise far earlier and larger than anticipated from numerical models of ice sheet evolution. The mass loss of Greenland glaciers doubled in the last decade and may double again in the next decade. Yet, we still lack basic thickness data near the ice fronts of many glaciers, so that interpretations of observed glacier changes remain approximate and incomplete. Predicting the future is even more challenging. Southern Greenland glaciers are deeply entrenched in narrow terminal valleys, with broken up surfaces, and possibly warm ice at depth that challenge conventional radar sounders operating in the 60-150 MHz range. Here, we propose to employ a HF radar sounder (2.5 MHz) successfully tested over 1800-m deep temperate ice in the Bagley icefield, Alaska in March 2006. The radar system will be deployed in Greenland in complement with NASA/Wallops ATM (airborne laser topographic mapper) and Kansas University 150 MHz ice sounding radar to measure complete thickness profiles of key glaciers that accelerated in recent years (Jakobshavn Isbrae, Kangerdlugssuaq, Helheim, Koge Bugt) and key glaciers in the east and northwest due to accelerate in the near future (Daugaard-Jensen, Rinks Isbrae, Upernavik, Steenstrup, Kong Oscar). In collaboration with our partners, ice thickness data, combined with velocity and ATM data, will be used to improve ice discharge and mass balance estimates of the glaciers, calculate their force balance near the grounding line, how the forces changed during acceleration, and in turn address the causes of the glacier changes, such as the role of glacier ungrounding versus enhanced lubrication or changes in lateral resistance, and how far upstream changes may propagate. This exercise will be applied to other glaciers that did not yet accelerate, using observed thinning rates and climate forcing, to determine their potential for imminent acceleration and contribution to sea level. In the 2nd year of the project, we will collect thickness data along the rapidly changing Wilkes Land sector of East Antarctica (Cook, Ninnis, Mertz, Zelee, Astrolabe, Francais, Charcot, Dibble and Frost glaciers) in collaboration with French/Italian partners to constraint ice discharge and force budget estimates. The data acquired for this project will be distributed to other scientists through the IPY core projects ICEMACH-GIS in Greenland and AISAD in Antarctica. The results will contribute to NASA's Science Mission Directorate objective of improving our understanding of the evolution of the Earth's land ice and its contribution to sea level change.

Ignatius Rigor/University of Washington
Assessment of Sea Ice Thickness Estimates Obtained from Satellites using Submarines, and Other In Situ Observations

Research on the variability of Arctic sea ice requires reliable observational data on sea-ice extent and thickness. While sea-ice extent can be readily obtained from satellites, we are only now developing our capability to remotely monitor thickness. The most promising satellite technique is altimetry to measure freeboard and estimate thickness from freeboard. The sea-ice thickness estimates obtained from satellite altimetry require careful validation, very little of which has been done to date. We plan to compare sea-ice freeboard and estimated thickness from satellites (ICESat in combination with RADARSAT, e.g. Kwok et al. 2004) with in-situ observations. The sources of in-situ data will include (a) spatial profiles of ice draft measured during submarine cruises under the sea ice, (b) time series of draft from moored upward looking sonar, (c) ice thickness surveys from electromagnetic instruments flown over the sea ice, (d) ice and snow measurements during a field camp in 2007, and (e) snow and ice thickness plus thermal and dynamic history of the ice pack from drifting buoys. Many of these datasets will be provided through collaborations with other institutions. The submarine draft measurements are derived from classified data and are a unique product which only our research group is currently capable of producing. Primary goals of this research are to: 1. Extend the public record of sea-ice draft measurements from submarines through 2007 (currently only available to 2000); 2. Compare in situ observations with satellite derived sea-ice freeboard and thickness obtained from ICESat to assess sources and degree of uncertainty in the satellite estimate; 3. Assess methods of improving the satellite estimate of thickness; 4. Study the variability of Arctic sea-ice thickness. Specifically, how do new submarine measurements of ice thickness compare to the longer record in light of moderate/low AO conditions during the past few years?

Christopher Shuman/NASA/Goddard Space Flight Center
Stability, Scale, and Context of Subglacial Lakes: Analysis of Antarctic lake features from integrated remote sensing and field data

Subglacial Water - Origin, Storage, Movement, Potential Impact
Subglacial water plays a crucial role in the overall stability of major ice sheets. An estimated 22,000 km^3 of water is currently stored within Antarctica's subglacial lakes (Siegert et al., 2005;). Movement of this water is ongoing through a complex and largely inferred drainage system in both East and West Antarctica (Wingham et al., 2006; Gray et al., 2005). Catastrophic drainage is possible (Lewis et al, 2006) from even the largest subglacial lakes situated in the relatively stable interior of the East Antarctic ice sheet (Erlingsson, 2006). Further, there is an apparent close connection between a recently defined set of significant subglacial lakes and the formation of at least one ice stream (Bell et al., in prep).

Ice streams are major flow systems that draw ice from the interior of continental ice sheets downslope towards grounding lines that contact with the world's oceans. Studies of the large ice streams in West Antarctica have highlighted the importance of basal lubrication by water and sediments to the onset of fast flow that characterizes ice streams (Kamb, 2001). The movement of this subglacial water has been identified via relatively large and local, surface elevation changes in East and West Antarctica (Gray et al., 2005; Wingham et al., 2006). Although the movement of such water volumes could influence existing ice stream flow by reducing bed resistance; to date, no linkage between subglacial hydrology and changes in the dynamic behavior of ice streams has been identified in Antarctica.

However, our preliminary analysis of the Recovery Lakes region suggests a direct linkage between lakes and streaming ice flow, specifically the 600 km long Recovery Ice Stream (RIS) and its tributaries. Located just upslope of the RIS, the Recovery Lakes Region (RLR) is composed of three well defined lakes and a fourth, ambiguous, 'lake-like' feature. In contrast to most other large subglacial lakes that are situated with 200 km of an ice divide, the RLR is over 600 km from a major ice divide. While other large lakes have a localized impact on ice surface slope, the RLR lakes are coincident with an abrupt regional change in the ice sheet surface slope. Satellite imagery demonstrates that the downslope margin of this lake area contains distinct flow strips and crevasses: both indicative of increasing ice velocities. These flow stripes directly connect to the RIS while flow features from the RAMP ice stream connect to the ambiguous "lake-like" feature, just to the south of the other lakes. We believe that the flux of water from subglacial lakes is an important mechanism for initiating rapid ice flow in the interior of the ice sheets. These large onset lakes may also play an important role in the modulation of the ice stream velocity over time possibly through the periodic injection of lake water into the ice stream or via the modification of the basal thermal regime over the lake.

Irina Sokolik/Georgia Institute of Technology
Impact of Aerosols on the Arctic Hydrological Cycle

Title: Impact of Aerosols on the Arctic Hydrological Cycle PIs: I. Sokolik and J. A. Curry

Variations in atmospheric aerosol characteristics have the potential to modulate the Arctic cryosphere through their impact on precipitation, radiation fluxes, and surface albedo. Atmospheric aerosols influence the nucleation of cloud particles, which affects directly the cloud cover and precipitation processes. Aerosols (particularly carbonaceous and dust) can directly influence surface albedo of snow/ice. Aerosols also affect the surface radiative fluxes through direct and indirect radiative forcing. Biomass burning in the northern forests, pollution aerosol, biogenic aerosol, and desert dust have been proposed as significant sources of Arctic aerosol. The overarching science question addressed by this proposal is:

What are the effects of variations in aerosol characteristics in the Arctic on cloud properties, the surface radiation budget, precipitation, and surface snow cover?

The PIs have submitted an interdisciplinary IPY proposal to the WMO/ICSU entitled "Hydrologic Impacts of Arctic Aerosol (HIAA)" that has been endorsed by the International IPY Planning Group. This large project is part of an international effort to coordinate atmospheric aerosol science associated with clouds, radiation, surface hydrology and cryospheric research efforts, including co-location of field measurements. In coordination with the WMO/ICSU HIAA project, the goal of the proposed project is to develop an understanding and predictive capability of the interactions and feedbacks associated with aerosol forcing of the arctic hydrological cycle. This goal is accomplished through a synthesis of surface-based and suborbital observations and regional modeling activities being undertaken during the IPY in conjunction with A-Train observations. Specific objectives of the proposed research are:

- Evaluation of A-Train data products associated with aerosols, clouds, precipitation, and surface energy balance using ground based, aircraft and UAV measurements near Barrow, AK, Prudhoe Bay, AK and other sites in Canada, Europe and Russia;
- Integrated analysis of the relevant A-Train data with surface-based and suborbital data to address the overarching science question targeted by this proposal;
- Evaluation of the regional modeling capability being developed under the PI's NASA MAP project for the different regions in the Arctic and for different conditions of aerosol forcing;
- Conduct sensitivity studies by perturbing aerosol characteristics for the different regions being studied to develop an improved understanding of the effects of variations in aerosol characteristics on arctic hydrological cycle and the cryosphere.

We also propose to deploy the Aerosonde UAVs. The main period of field investigations is targeted for 2008, and we anticipate requesting resources from the Suborbital Program to deploy the Aerosonde during Spring 2008 in the Barrow/Prudhoe region

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Leslie Tamppari/Jet Propulsion Laboratory
Antarctic Dry Valley Soil/Ice History and Habitability

The key objectives of this proposal are to (1) investigate the chemical and physical characteristics of the soil and ice in the Antarctic Dry Valleys as a function depth, (2) investigate the variability in these characteristics as a function of elevation and soil material, and (3) to build models of the formation and habitability of the area.

To accomplish these objectives, we will perform the following:
- Collect and analyze, in the field and in the laboratory, soil samples from a variety of locations in and near the Antarctic dry valleys that range in elevation from sea-level through the "snow-zone" to 2 km and soils that have formed from different parent materials (i.e., volcanic, granitic, sandstone).

- Solution chemistry measurments of soils and ice to understand their pH, electrical conductivity (EC), and soluble components
- Pyrolysis and combustion experiments to characterize the volatile-bearing mineralogy and biogenic elements necessary for life (C, H, N, O, P, S)
- Thermal and electrical conductivity measurements on the soils exposed in the soil pits to understand the diffusive properties and measure the amount of unfrozen water within the dry layer and at the boundary
- Optical microscopy and atomic-force microscopy on collected samples to understand more about the sample material and the shapes, size distributions, and fracture patterns of the grains

This investigation of the Antarctic Dry Valleys is significant in that it will allow us understand the signature of climate variability as written into the soils and to quantify the abundance of life's building blocks there and at the ice-soil boundary. We provide a thorough examination of the Dry Valley's physical and chemical nature, using an integrated analysis of multiple data sets. Since the Antarctic dry valleys are among the coldest, driest places on Earth, they are an end-member environment that can be used for comparison to less harsh regions on Earth and more extreme environments on other planets. To that end, we leverage the mission return of the currently funded NASA Phoenix Mars mission, which will land between 65-72º N during the International Polar Year, by providing a direct comparison of the two analogous regions. The proposed project also highly complements Phoenix, as it will enhance the validation of two instruments, thereby strengthening the Phoenix data interpretation and perhaps allowing for an increased understanding of the different evolutionary paths of these two planets.

Yuhang Wang/Georgia Institute of Technology

A study of tropospheric halogen chemistry and its environmental impact in the Arctic spring through modeling analysis of in situ and remote sensing measurements: Chemical/physical processes and interannual variability

The Arctic is an area particularly sensitive to climate change. Measurements during the past several decades revealed unique chemical and physical processes in the region, which lead to extensive halogen driven chemistry in spring. The halogen chemical processes have significant ramifications on the Arctic environment. There is a critical need to understand better these processes and their links to regional climate variability and changes. As a result, a large number of multi-national and multi-platform measurements will take place during IPY 2007 and 2008. We propose to make use of BrO measurements from 4 different satellites (including OMI onboard Aura) and leverage the spatial and temporal coverage of satellites to integrate surface, ship, balloon, and aircraft measurements in a consistent framework of 3-D chemical transport modeling. We will further extend the improved process-based understanding into the analysis of decade-long BrO measurements from GOME and investigate the factors driving the observed interannual variability in the context of regional climate variation and changes. We align our research objectives to Goal 3A in the 2006 NASA Strategic Plan and address research problems in three areas of the NASA IPY program.

The specific research objectives are as follows. (1) Intercompare and synthesize BrO column measurements by GOME, SCIAMACHY, OMI, and GOME-2 and construct a combined high quality dataset of tropospheric BrO for spring 2007 and 2008; examine the uncertainties in the satellite measurements and establish the reliability of GOME BrO column measurements in Arctic spring since 1996. (2) Integrate satellite measurements with IPY surface, ship, balloon, and aircraft measurements using a regional 3-D chemical transport model (CTM) to investigate the distributions, sources, sinks, and cycling of BrOx and ClOx radicals in the Arctic and sub-Arctic regions in spring 2007 and 2008 and examine the effects of halogen chemistry on tropospheric chemical composition over the Arctic. (3) Integrate GOME BrO column measurements since 1996 with long-term surface and balloon ozone measurements in spring using the 3-D CTM to understand the factors contributing to the interannual variability of tropospheric BrO and consequent ozone losses in the Arctic and explore the links of halogen chemistry and its environmental impact to regional climate variation and changes.

In this project, we will (1) deliver a high quality dataset of tropospheric BrO column for IPY 2007 and 2008 springs; (2) establish a decade-long Arctic tropospheric BrO record based on GOME column measurements since 1996; (3) improve our understanding of satellite measurement uncertainties of BrO; (4) identify and constrain the critical processes of halogen sources, sinks, and chemical cycling based on integrated modeling analysis of surface, ship, balloon, aircraft, and satellite measurements; (5) identify key uncertainties that call for critical laboratory and field measurements; and (6) establish key factors driving the interannual variability of observed tropospheric BrO column and consequent ozone losses and examine the implications for the impact of climate change on halogens and other environmentally important chemicals in the Arctic spring.

Xiaoping Wu/Jet Propulsion Laboratory
Ice Mass Variations from Multi-Satellite and Interdisciplinary Data

Polar ice, sea level, and global water mass variations are important parts of the global change process. They are also sensitive indicators of the climate system with significant feedback impact and profound implications on the livelihood of the world community. The variations involve a multitude of seasonal, interannual to secular trend time scales, and result in distinct signatures of gravity, topography changes, geocenter motion, and Earth orientation variations. The revolutionary GRACE gravity and altimetry missions, and continuous ground geodetic tracking stations with ever-increasing global coverage and density have breakthrough capabilities in measuring global surface mass transport with high resolution and accuracy. Currently, no single technique can provide a complete spatiotemporal spectrum of the change processes. The secular trends in the measurements are further complicated by the postglacial rebound (PGR) process since the viscoelastic solid Earth responds to both present-day and historical ice load variations. Comparison and combination of multi-satellite and interdisciplinary data of differing physics, overlapping and complementary information will not only facilitate calibration and validation but also have the best chance of resolving ambiguities and increasing accuracy and resolution.

We will estimate present-day seasonal, interannual, secular and historical ice and water mass variations over Greenland, Antarctica and other areas by integrating multi-satellite gravity, topography, geocenter motion and Earth orientation data (GRACE, ICESat, Topex/Jason and other data assimilated ocean bottom pressure models, GPS, Satellite Laser Ranging, Very Long Baseline Interferometry), historical relative sea level (RSL), and glacio-geological data with geophysical models in our global inverse algorithms. We will coordinate our research with, and explore data, analysis results and synergies created by activities of international collaborators during the International Polar Year. These include International Terrestrial Reference Frame ITRF2005 combination effort; Polar Earth Observing Network (POLENET) activities; Reprocessing a decade of global GPS data with up-to-date dynamic and measurement models; Improving global PGR knowledge using interdisciplinary data and models; an international funded research and education cooperation project on global surface mass variations. We will adapt and evaluate concepts and realization of ITRF to suit the new geodetic reality of global change for consistent and accurate measurement and dynamic models, geocenter motion results, and long-term reference frame stability. Our rigorous inverse approaches will target distinct time scales with complete spectrum coverage, a simultaneous solution of present-day ice and other mass trends, ice history and Earth rheology profile, with realistic quantitative assessments of uncertainties.

Howard Zebker/Stanford University
Multiwavelength InSAR Properties of the Polar Ice Sheets

Remote sensing is a critical technology for study of the Earth's polar ice sheets. Lack of accessibility, harsh environmental conditions, and the vast size of the ice sheets make microwave observation from space or aircraft especially useful for polar research. Radar methods in particular have proven very helpful in observing and constraining ice velocities, dynamics, discharge and accumulation processes. Spaceborne platforms available for polar work have mainly used the C-band (6 cm wavelength) part of the radio spectrum, as it provides a strong backscatter from the topmost 20 m of the firn, ideal for surface velocity measurements. Other radar systems have been proposed at longer and shorter wavelengths to meet objectives of other disciplines, especially solid Earth crustal deformation studies. Experimental understanding of the interaction of these other frequencies with ice is limited, as no significant and comprehensive data set exists at frequencies other than C-band.

Our goal here is to acquire and analyze data at L, C, and X band (24, 6, and 3 cm) over the ice sheets and determine the mechanisms at each wavelength for microwave interaction with the ice. We will begin with a model for scattering that has been proven using C-band data, and apply it at the other wavelengths so that we may understand what physical characteristics of the surface and subsurface are reflected in the data. For example, longer L-band wavelengths will penetrate further into the ice than C-band, so that we may be sensitive to motions or structure 100's of meters deep rather than to the surface. Using both wavelengths, velocity profiles of the ice might be obtained, adding insight to the flow of glaciers and ice streams. It may also be true that some wavelengths will simply not be sensitive to parameters of interest, so that one of the outcomes of this work will be to recommend instrumentation for future space missions.

Data at C and X band wavelengths are available from multiple satellite platforms, but little data is available at L-band. While the ALOS PALSAR will deliver data from the polar regions, its long repeat time and scarce scheduling time will limit its application to this problem. Therefore we propose to use the UAVSAR instrument now being developed at JPL to collect L-band data. Most of the UAVSAR project goals are highly compatible with ours, but we will have to ensure that imaging geometries and data processing return the data products we need. This may entail some changes to the nominal data processing algorithms and strategy, but we expect a sizable data set that will validate our scattering models at the longer wavelength.

The concentrated activities of IPY provide a focus on this work and will result in many field experiments that will aid in verifying our modeling and analysis. Without this comprehensive set of contemporaneous in situ investigations, we would not be able to adequately validate our methods and the conclusions would only be conjectures.

Charlie Zender /University of California at Irvine
Black Carbon Impacts on Cryospheric Climate Sensitivity and Surface Hydrology

The prevalence of bright surfaces (snow, glaciers, sea-ice, and clouds) make the cryosphere uniquely susceptible to radiatively induced effects of black carbon (BC) such as ice-albedo feedback amplification. We will advance current understanding of cryospheric BC climate impacts by integrating effects of post-deposition BC (i.e., dirty snow) with the direct effects of atmospheric BC. This project's primary objective is to understand BC effects on cryospheric climate sensitivity and surface hydrology.

We have integrated satellite-derived BC emissions into a unified modeling framework, where we will forecast and hindcast contemporary and 21st century climate with and without atmospheric and surface BC effects. These simulations rely on our SNow, ICe, and Aerosol Radiative model (SNICAR) embedded in the Community Climate System Model (CCSM) forced by the MODIS-derived Global Fire Emissions Database (GFED). We ask three types of questions:

First, how do timing and location BC emissions affect Arctic surface reflectance and atmospheric processes? BC increases atmospheric absorptance in clear and cloudy conditions and this helps warm and thus darken snowpack. However, snowpack is also very sensitive to temperature feedbacks triggered by the vertical distribution of soot in the snowpack itself. Using alternating years of high and low boreal soot emissions from the GFED, we will test how atmospheric and surface soot contribute to improving model agreement with MODIS-derived spectral surface reflectance.

Second, what are the relative roles of surface and atmospheric BC forcing on Arctic climate sensitivity including sea-ice? Atmospheric BC cools the surface by backscattering and absorbing incident sunlight. Snowpack BC heating compounded by snow-albedo feedback can exceed atmospheric BC surface cooling in strong fire years. We will assess how BC mixing state affects top-of-atmosphere albedo (from CERES), surface spectral reflectance (from MODIS), and sea-ice extent (from AMSR-E).

Third, how does BC alter surface water seasonality such as soil moisture, snowpack depth and extent, depth to permafrost, and runoff to the Arctic? Concentration and scavenging of seasonally deposited BC within snowpack can significantly alter partitioning of spring thaw processes between sublimation to the atmosphere and melt/percolation to surface water. We will use in situ snowpack BC profiles measured during IPY activities to improve BC scavenging in SNICAR and CCSM. Snow water equivalent, extent, and liquid surface soil moisture (from AMSR) and spring discharge to the Arctic Ocean (from gauge data and GRACE) will test our global simulations.

Relevance to NASA's Strategic Objectives:
The project outcomes meets NASA Strategic Goal 3.1 ("Study planet Earth from space to advance scientific understanding and meet societal needs") and IDS Subelement 5 objectives by using space-based remote sensing and global models to improve understanding and prediction of the role of black carbon in affecting clouds, precipitation, and the hydrologic cycle. Our improved understanding and predictions of the cryospheric hydrologic cycle will be incorporated via CCSM into the IPCC AR5 report to help society understand, plan for, and mitigate BC effects on cryospheric climate.