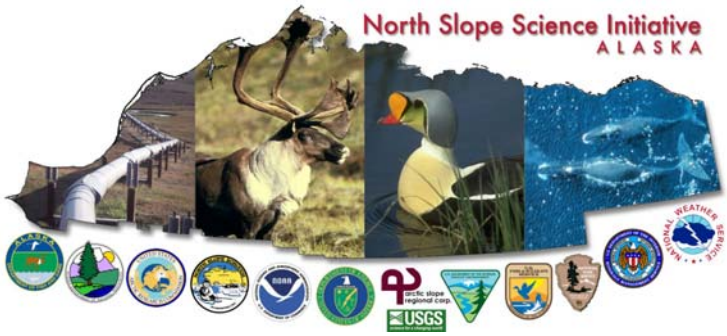

Remote Sensing-Derived Monitoring Products for the Arctic North Slope Science Initiative Workshop

Workshop Summary Report

The North Slope Science Initiative (NSSI) Remote Sensing-Derived Monitoring Products for the Arctic Workshop was held in Fairbanks, Alaska October 28-29, 2013. The workshop was convened to develop a summary of remote sensing products and activities that are available for the arctic. Eleven plenary speakers presented on discipline expertise as it relates to remote sensing or provided information on synergistic organizations and activities as they related to the goals of the workshop. Workshop participants represented a wide range of organizations from government to academic to non-profit to industry. Specifically program managers for NSSI, Arctic Landscape Conservation Cooperative (ALCC), Next-Generation Ecosystem Experiment (NGEE), Geographic Information Network of Alaska (GINA), NASA Arctic-Boreal Vulnerability Experiment (ABoVE), NASA Snow Working Group, National Academies Permafrost Remote Sensing Working Group, as well as NSSI Scenario Planning presented at the workshop. Three breakout sessions worked to develop prioritized lists of remote sensing products, both available datasets and those needed by the stakeholder community but not currently available.

A large portion of the first day was devoted to information sharing among the stakeholders. An excellent set of presentations were given on a diverse set of discipline expertise. Major synergistic programs (NGEE, Arctic LCC, ABoVE, NASA Snow Working Group, National Academies Permafrost Remote Sensing Working Group, as well as NSSI Scenario Planning) were presented and discussed. All presentations and workshop materials are posted on the NSSI website (http://northslope.org/event/products2013). The first day provided an excellent summary of what is available, what activities are currently happening, and what is planned for the future.

The first breakout session was focused on currently available remote sensing products and their usefulness for arctic monitoring. Two concurrent breakout sessions were run, with one focusing on terrestrial applications and the other on coastal and marine applications. Table A specifically documents what remote sensing products were identified as available by the terrestrial breakout group. Due to time constraints and

workshop participant expertise, freshwater color/clarity/primary productivity, specific snow parameters, and ice sheet dynamics were not discussed in the terrestrial breakout. These rows remain in the final table products.

Breakout session two was focused on what potential remote sensing products are missing. Table C documents the input from the workshop participants during the breakout session.

Breakout session three was an exercise to synthesize all of the workshop information presented and discussed for the specific application of remote sensing technology to address long-term monitoring data gaps, organized in terms of the NSSI Emerging Issues (http://northslope.org/issues/). Due to time constraints, not all Emerging Issues were discussed. Issues complementary to workshop participant expertise were selected for discussion. Nine of the fifteen issues were addressed. The results are summarized in Table D.

Workshop Findings

Specific workshop findings are detailed in Tables A-D. This includes the specific remote sensing products that are available now, and identifies other products that are needed by the North Slope stakeholder community. There were several recurring comments and themes, including the need for high-resolution DEMs and a fine-scale to Landsat-scale resolution map of landforms. The presentation on the recently-completed Landsat-derived, field validated, digital map covering the entire North Slope was well received by participants. Historically, the desire to have such a comprehensive product has been near the top of resource manager's needs. Discussions on snow and snow and ice-derived remote sensing products were found to be important to many disciplines, as well as active layer and soil moisture but concerns linger over whether remote sensing can provide measurements of these parameters. Other specific findings from the workshop include:

Technical

- We have a good technical toolbox but we don't use it well.
- Documentation of remote sensing-derived product limitations and model relationships are needed for the geographic area of interest for all data products. Specifically, error bars are needed for the MODIS products.
- Validation of satellite products are needed with in-situ data and by domain experts.

- Locally and regionally tuned algorithms at scales of a few meters to a hundred meters are needed.

Process-based

- For many remote sensing products, we need to identify the suite of stakeholders/customers that use or could potentially use the product.
- For the data gaps, or in modifications of existing products, we need to develop a prioritized list and focus on developing products that are broadly useful beyond a limited set of end-users.
- Collaboration among several interested user groups may provide enough resources and expertise to develop targeted and useful products (e.g., improved snow products).

Needs

- More time-series maps are desired. A major strength of remote sensing is frequent image acquisition, and once an algorithm is developed, it is relatively easy to implement over frequent temporal scales. We need to map various parameters annually or seasonally instead of decadally. This effort would result in needed datasets for long-term monitoring.
- MODIS standard products (especially NDVI, vegetation phenology, and products documenting seasonal effects) are desired at Landsat spatial scale.
- Higher resolution DEMs are needed. The finer the resolution the better, but validation is necessary.
- Hierarchies of maps and data products are needed at a variety of spatial scales to examine change at multiple scales.

General

- Among the land management community, there is a lack of confidence in many existing remote sensing-derived products. If evaluation fails in a specific area (e.g., isolated land cover misclassifications), the entire data product is assumed by potential end users to be junk. This reinforces skepticism of all remote sensing-derived products.
- Remote sensing is underutilized in long-term monitoring applications. Currently only a handful of studies utilize or are primarily focused on remote sensing. Of the 123 data records in the NSSI Long-Term Monitoring Study List, only 9 have a remote sensing component.

- Synthetic Aperature Radar (SAR) is an underutilized remote sensing resource for the Arctic even though it has all-weather, day-night imaging capabilities. Many algorithms exist, but these are not currently executed over various spatial or temporal scales. Much of the use of SAR has been limited by end-user expertise in application.
- For both passive and active satellite sensors there are spatial resolution and temporal coverage problems. There are tradeoffs in terms of spatial and temporal resolution in determining the best remote sensing solution to a given problem.
- We should leverage existing in-situ data and long-term data records in the development and validation of remote sensing products. This would be especially useful for hierarchal, multi-scale studies.
- Multi-source monitoring with Light Detection And Ranging (LiDAR) and Unmanned Aerial Vehicles (UAV) are important to North Slope stakeholders. If data were available, it would be consumed.

Workshop Participants

Robyn Angliss, National Oceanic and Atmospheric Administration, Alaska Fisheries Science Center

Don Atwood, Alaska Satellite Facility

Betsy Baker, International Arctic Research Center IT Law School

Greg Balogh, Arctic Landscape Conservation Cooperative, US Fish and Wildlife Service

Keith Boggs, Alaska National Heritage Program, University of Alaska Anchorage

Gil Castellanos (Online Participant)

Jessie Cherry, University of Alaska Fairbanks

Hajo Eicken, University of Alaska Fairbanks

Dan Fehringer, Duck's Unlimited

Allison Gaylord, Nuna Technologies

Amanda Grimm, Michigan Tech Research Institute

Jess Grunblatt, North Slope Science Initiative/Geographic Information Network of Alaska

Scott Guyer, Bureau of Land Management

Tom Heinrichs, University of Alaska Fairbanks/Geographic Information Network of Alaska

Larry Hinzman, International Arctic Research Center, University of Alaska Fairbanks

Liza Jenkins, Michigan Tech Research Institute

Nicole Kanayurk, North Slope Borough

Eric Kasischke, University of Maryland

Denny Lassuy, North Slope Science Initiative

Olivia Lee, University of Alaska Fairbanks/Geophysical Institute

Wendy Loya, The Wilderness Society

Joel Lindstrom, Department of Energy, National Energy Technology Laboratory (on-line participant)

Bill Manley (Online Participant)

Philip Martin, Arctic Landscape Conservation Cooperative/US Fish and Wildlife Service

John Payne, North Slope Science Initiative

Scott Pegau, Oil Spill Recovery Institute

Robert Shuchman, Michigan Tech Research Institute

Jamie Trammell, Alaska National Heritage Program, University of Alaska Anchorage

Tim Viavant, Alaska Department of Fish and Game

Matthew Vos, Bureau of Land Management /North Slope Science Initiative

Skip Walker, University of Alaska Fairbanks

Michelle Wienert, Michigan Tech Research Institute

Dave Yokel, Bureau of Land Management

TABLE A: Breakout Session I, Terrestrial: What's available and is it useful

Current Satellite Product	Application	Is this useful in present form?	Priority (High, Medium, Low)	Modifications needed?/Remarks
NDVI (at 1 km scale)	Vegetation greenness index	Yes, at the global/regional scale & by ecoregion, and to look for long term trends	High	Projection to support pan-Arctic; Address mixed pixel issues related to surface water; Normalize product between sensors; Improved latitudinal calibration
NDVI (at 30 m scale)	Vegetation greenness index, specific habitat mapping,	Yes, for smaller-scale features and landscape level changes	High	Projection to support pan-Arctic; Address mixed pixel issues related to surface water; Normalize product between sensors; Improved latitudinal calibration. Not yet available North Slope-wide at 30 m, but generation of such a product is not technology-limited (imagery archive already exists)
SINDVI	Seasonally integrated vegetation greenness index	Yes	High	Projection to support pan-Arctic; Address mixed pixel issues related to surface water; Normalize product between sensors; Improved latitudinal calibration
Vegetation phenology (SOS, EOS, DOS)	Start/end/duration of growing season, monitoring/modeling change	Yes	High	Lack of confidence in current products for Arctic.
Gross primary productivity	Quantifying carbon budgets, change monitoring	Maybe	Low	Limits to accuracy of current product, less useful until the relationship between spectral characteristics and GPP is better understood, better documentation needed of testing/applicability/uncertainty specifically for the North Slope (*last remark true for all MODIS-derived products*)
Leaf area index	Carbon & water cycle modeling, habitat mapping/modeling	Maybe	Low	Limits to accuracy of current product, less useful until the relationship between spectral characteristics and ground features is better understood

TABLE A: Breakout Session I, Terrestrial: What's available and is it useful

Current Satellite Product	Application	Is this useful in present form?	Priority (High, Medium, Low)	Modifications needed?/Remarks
Land cover (at 1 km scale)	Global/regional land cover mapping	Yes	High	Useful input for spatially explicit models that can't handle finer scale data; Classes not consistent among sources; No standard language for cover classes – need closer collaboration with regional experts; Periodic remapping needed
Land cover (at 30 m scale)	Regional- or landscape-scale land cover mapping	Yes, more so than 1 km for the North Slope scale	High	Classes not consistent among sources; No standard language for cover classes – need closer collaboration with regional experts; Periodic remapping needed; Cover classes need to follow a hierarchical classification, National Land Cover Database (NLCD) is not sufficient
Land surface temperature		Yes	High	Better/further calibration for different land cover types
Soil moisture		Maybe	Medium	Lack of faith in current measurements – needs further validation, esp. for Arctic; A believable regional algorithm would potentially be very valuable; Soil Moisture Active Passive (SMAP) will be useful but at a very coarse scale; many North Slope applications would need finer-resolution data
Surface water mapping	Habitat mapping, flood mapping, long-term trends	Yes	High	More useful in some contexts than soil moisture
Albedo	Climate modeling, Fire, Monitoring	Yes	Medium	Product more useful for researchers/modelers than for land managers

TABLE A: Breakout Session I, Terrestrial: What's available and is it useful

Current Satellite Product	Application	Is this useful in present form?	Priority (High, Medium, Low)	Modifications needed?/Remarks
Topography (DEM)	Many	Yes but not adequate	Highest Priority Identified	The finer resolution the better; Accuracy/validation is of high importance; Repeat measurements important, ex. for permafrost and erosion applications; Required across all of North Slope
Infrastructure (land use)	Development rate, anthropogenic footprint, impacts on wildlife, landscape integrity/fragmentation	Yes	Regionally high	Both as a land cover category and distinguishing among classes Classes within infrastructure useful for looking at impacts Time series, repeat mapping needed Improvements in distinguishing between bare ground/other land uses needed Potential use for high-res LiDAR/radar and multispectral fusion
Burned area (at 1 km scale)	Land management, carbon estimates,	Yes	High	Can be easier to work with than higher-resolution burn product
Burned area (at 30 m scale)	Land management, carbon estimates,	Yes	High	Captures smaller North Slope fires, historical fire data would be extremely useful BAER program produces other burned area products, limited accuracy in Alaska
Snow cover area	Model changes in albedo, monitor long-term trends, habitat mapping	Yes	High	High confidence in current product What spatial resolution is needed? Is that need being met?
Snow albedo	Climate modeling	--	--	Workshop participants not especially familiar with this parameter
Snow depth	Wildlife movements, habitat	Yes	High	Could be very useful, Little confidence in measurements, timing of measurements would be important

TABLE A: Breakout Session I, Terrestrial: What's available and is it useful

Current Satellite Product	Application	Is this useful in present form?	Priority (High, Medium, Low)	Modifications needed?/Remarks
Snow water equivalent/wetness	Water availability/balance	--	--	Workshop participants not especially familiar with this parameter
Snow melt rates	Temporal version of snow area, predict flooding / ice jams etc.	Yes	High	
River ice characterization	Monitoring, flood modeling, wildlife movements	Yes	Medium	Freeze/thaw, freeze-up/breakup timing and trends important
Lake drying	Water balance, monitoring	Yes	High	
Lake freeze/thaw	Waterbird habitat, ice roads, fish habitat	Yes	High	Freeze depth
Ice sheet melt index	--	--	--	Workshop participants not especially familiar with this parameter
Ice sheet melt extent	--	--	--	Workshop participants not especially familiar with this parameter
Ice volume	--	--	--	Workshop participants not especially familiar with this parameter
Freshwater color – Chlorophyll, Dissolved organic carbon (doc), Suspended minerals (sm)	--	--	--	Workshop participants not especially familiar with this parameter
Freshwater primary productivity	--	--	--	Workshop participants not especially familiar with this parameter

TABLE A: Breakout Session I, Terrestrial: What's available and is it useful

Current Satellite Product	Application	Is this useful in present form?	Priority (High, Medium, Low)	Modifications needed?/Remarks
Freshwater shallow water bathymetry	--	--	--	Workshop participants not especially familiar with this parameter
Freshwater clarity (kd, kpar, photic zone)	--	--	--	Workshop participants not especially familiar with this parameter

TABLE B: Breakout Session I, Coastal and Marine: What's available and is it useful?

Current Satellite Product	Sensor	Application	Is this useful in present form?	Customer	Priority (High, Medium, Low)	Modifications needed?/Remarks?
Surface wind speeds (to 2 m/s)	-Scatterometers -SAR	Marine safety, wave modeling, coastal circulation, coastal erosion	Yes, but only to climate modelers; No from the standpoint of operations	-Climate modelers -Mariners -Emergency response -Industry -Coastal engineers	High (if available real-time or within hours)	-Finer resolution needed -Temporal coverage -4 times a day SAR 5 km grids
Wave height (to 0.5 m)	-SAR -Altimeter	Marine safety, wave modeling, coastal circulation, coastal erosion	Yes	-Climate modelers -Mariners -Emergency response -Industry -Coastal engineers -Ocean transportation	High (if available real-time or within hours)	More temporal and spatial coverage needed
Wavelength and direction	SAR	-Coastal circulation -Coastal erosion	Not used presently (in the US)	-Environmental -Coastal engineers -Emergency responders	High (if available real-time)	Temporal coverage
Ocean currents (dynamic height method)	Altimeter	Currents	Yes (Jason-1 data, esp. for longer open water season)	-Climate modelers -Emergency response	High (if available real-time)	Revisit usefulness of altimeter data for characterizing currents
Ocean frontal boundaries	-MODIS -MERIS -VIIRS	-Fisheries -Modelers -Weather -To indicate currents -Navigation -Environmental	Yes	-Fishing fleet -Researchers -Regulatory	High (paying customers already)	Cloud dependent

TABLE B: Breakout Session I, Coastal and Marine: What's available and is it useful?

Current Satellite Product	Sensor	Application	Is this useful in present form?	Customer	Priority (High, Medium, Low)	Modifications needed?/Remarks?
Ocean temperature (SST)	-MODIS -MERIS -VIIRS	-Fisheries -Modelers -Weather -Indicate -Currents -Navigation -Environmental	Yes	-Fishing fleet -Researchers -Regulatory	High (paying customers already)	Cloud dependent
Sea surface salinity	-SMOS -Passive radiometer	-Climate modelers -Fisheries -Acidification -Runoff	Not yet operational	-Researchers -Modelers -Regulators	High (when available)	Data experimental and waiting for operational capability
Water color / Chlorophyll	-MODIS -MERIS -VIIRS	Water Quality	Yes	-Researchers -Fisheries -Regulators for pollution and setting fish stock and understanding the food web (ecosystem)	High	-Validation of products at ice edge is an issue -Helps with Arctic Report Card -Relevance to coastal pollution
Primary productivity	-MODIS -MERIS -VIIRS	-Carbon budget -Ecosystem change -Fisheries	Yes	-Researchers -Fisheries -Regulators for pollution and setting fish stock and understanding the food web (ecosystem)	High	-Validation of products at ice edge is an issue -Helps with Arctic Report Card -Relevance to coastal pollution

TABLE B: Breakout Session I, Coastal and Marine: What's available and is it useful?

Current Satellite Product	Sensor	Application	Is this useful in present form?	Customer	Priority (High, Medium, Low)	Modifications needed?/Remarks?
Water color – Dissolved organic carbon (DOC)	-MODIS -MERIS -VIIRS	-Runoff -Bacteria -Water quality -Ecosystem health	Yes	-Researchers -Fisheries -Regulators for pollution and setting fish stock and understanding the food web (ecosystem)	High	-Validation of products at ice edge is an issue -Helps with Arctic Report Card -Relevance to coastal pollution
Water color – Suspended minerals (sm) Turbidity	-MODIS -MERIS -VIIRS	-Runoff -Bacteria -Water quality -Ecosystem health -Tourism	Yes	-Researchers -Fisheries -Regulators for pollution and setting fish stock and understanding the food web (ecosystem)	High	-Validation of products at ice edge is an issue -Helps with Arctic Report Card -Relevance to coastal pollution
Water clarity (K_d, K_d(PAR), photic zone)	-MODIS -MERIS -VIIRS	-Water quality -Ecosystem health -Tourism	Yes	-Researchers -Modelers -Regulators	High	Cloud dependent
Shallow water bathymetry	-Airborne LiDAR -Multispectral (commercial)	-Water depth -Navigational safety -Coastal infrastructure -Modeling storm surge	Yes	-Mariners -Industry -Emergency planners -City/borough planners -Researchers -Modelers -Regulators -Subsistence users -Fisheries	High	-Need more of it -Cheaper -Limited by water clarity

TABLE B: Breakout Session I, Coastal and Marine: What's available and is it useful?

Current Satellite Product	Sensor	Application	Is this useful in present form?	Customer	Priority (High, Medium, Low)	Modifications needed?/Remarks?
Bottom substrate	-Airborne LiDAR -Multispectral (commercial)	Coastal infrastructure Ecology Navigation	Yes	-City planners -Researchers -Subsistence	High	-Water clarity an issue -Feasibility needs to be demonstrated
Oil spills and surfactants	-SAR -IR -MSS	-Long-term -Ecosystem health -Triage (real-time disaster response)	Yes	-Emergency response -Regulators -Subsistence users	High	-Right now SAR data is expensive with inadequate temporal coverage (dearth of sensors) -Problems detecting oil in / under ice
Sea ice concentration	-Passive Microwave -SAR -MODIS (when available and light permitting) -VIIRS (when available and light permitting)	-Climatology -Coastal Planning -Industry -Ecosystem health -Long-term climate forecasting -Marine shipping	Yes	-Mariners -Industry -Emergency planners -Researchers -Modelers -Regulators -Subsistence users -Fisheries	High	-Higher resolution for passive -SAR temporal resolution -Cheaper access for SAR
Sea ice dynamics	-Passive Microwave -SAR -MODIS (when available and light permitting) -VIIRS (when available and light permitting)	-Climatology -Coastal planning -Industry -Ecosystem health -Long-term climate forecasting -Marine shipping	Yes	-Mariners -Industry -Emergency planners -Researchers -Modelers -Regulators -Subsistence users -Fisheries	High	-Higher resolution for passive -SAR temporal resolution -Cheaper access for SAR

TABLE B: Breakout Session I, Coastal and Marine: What's available and is it useful?

Current Satellite Product	Sensor	Application	Is this useful in present form?	Customer	Priority (High, Medium, Low)	Modifications needed?/Remarks?
Ice type (age)	-Passive Microwave (multi-year) -SAR -MODIS (when available and light permitting) -VIIRS (when available and light permitting)	-Climatology -Coastal Planning -Industry -Ecosystem health -Long-term climate forecasting -Marine shipping	Yes	-Mariners -Industry -Emergency planners -Researchers -Modelers -Regulators -Subsistence users -Fisheries	High	-Higher resolution for passive -SAR temporal resolution -Cheaper access for SAR
Albedo	-MODIS -VIIRS	Radiation budgets	Yes	-Modelers -Climatologists	High	Only available for cloud-free conditions
Detailed ice movement and rheology	-SAR -InSAR	-Shipping -Subsistence users -Marine -Fisheries	Yes	-Modelers -Climatologist -Coastal engineers -Subsistence fishing	High	Revisit time for Interferometric Synthetic Aperture Radar (InSAR)
Leads	-SAR -MODIS	-Radiation budget -Shipping -Research vessels -Subsistence hunting -Sea bird wintering habitat -Whaling	Yes	-Subsistence hunters -Mariners -Regulators	High	Clouds for MODIS Revisit time for SAR
Marginal ice zone (MIZ)	-SAR -Passive Radiometers -Altimeters	-Radiation budget -Shipping -Research vessels -Subsistence hunting -Sea bird wintering habitat -Whaling	Yes	-Subsistence hunters -Mariners -Regulators	High	Revisit time for SAR

TABLE B: Breakout Session I, Coastal and Marine: What's available and is it useful?

Current Satellite Product	Sensor	Application	Is this useful in present form?	Customer	Priority (High, Medium, Low)	Modifications needed?/Remarks?
Land fast ice	-SAR -InSAR -Commercial multispectral	-Subsistence hunting -Marine mammal habitat -Whaling -Coastal engineering	Yes	-Subsistence hunters -Mariners -Regulators	High	Revisit time for SAR
Melt pond distribution	-SAR -Optical	-Changes albedo -More PAR -Deeper photic zone	No product development yet – Research only	-Modelers -Climatologists -Biologists	High	-Need a standard product -Resolution limited
Ice free-board (0.3 m)	-Altimeter -LiDAR -IceSAT	-Modeling -Navigation -Climatology	Under development	-Mariners -Modelers -Climatologists	High	-Need better techniques needed - Cloud and land Elevation Satellite (IceSAT-II)

TABLE C: Breakout Session II: What's missing?

Data Gap	Application/ Rational	Parameter to Measure (unit)	Customers	Priority (High, Medium, Low)	Spatial Scale Required	Temporal Scale Required (Daily, Monthly, Yearly, 5-year, etc.)	Form of Products (GIS data layers, maps, etc.)	Remarks
Land cover change	Change detection	Pixel/spectral change, CVA, or classification change	Land managers Researchers Many others	High	Match existing products scales	Yearly; Every 5 (or 10) years	GIS data layers, yearly change maps and stats	Requires validation
DEM	Many	Elevation	Many	Very High	cm LiDAR scale desired	Decadal or more	GIS Layers	Validation needed Polar geographic article 50cm releasing in November
Fine scale geomorphological maps (Landform)	Hydrology Habitat modeling Future potential vegetation Separation of polygonal terrain mapping	Polygon delineated areas	Land managers Integrated land management modelers	Very High	30-100m	One time mapping effort to start	GIS Layer	See Arctic Geobotanical Atlas for definition and example Limited algorithm to date

TABLE C: Breakout Session II: What's missing?

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Fire severity	Land Management Carbon Modeling Rehabilitation Hazard protection near infrastructure Rehab	Pixel/spectral DNBR Tasseled cap Other severity indices	Modelers	Medium Not a lot of resources will be put on this	30m	Annual	GIS Data layers Maps	Need to learn more to see how it will affect the North Slope Other ways to characterize this information
Insect/pathogen impacted area, severity	Land Management	Multispectral change		Low (Hard to do with remote sensing)				No proven technique
Invasive Species		Area Presence/absence		Low			Map	May become an issue Not enough info right now
Thermokarst	Monitoring disturbance Habitat	Area	Industry Researchers Land Managers Subsistence users	Med	Finer than 30m	Decadal	GIS Layer	Monitoring needed post-disturbance Part of integrated ecosystem monitoring

TABLE C: Breakout Session II: What's missing?

Data Gap	Application/ Rational	Parameter to Measure (unit)	Customers	Priority (High, Medium, Low)	Spatial Scale Required	Temporal Scale Required (Daily, Monthly, Yearly, 5-year, etc.)	Form of Products (GIS data layers, maps, etc.)	Remarks
Thaw slumps	Monitoring disturbance Habitat	Depth (cm)	Industry Researchers Land Managers Subsistence users	Med	Finer than 30m 1m	Decadal	GIS Layer	Monitoring needed post-disturbance
Lake expansion/ draining	Monitoring disturbance Habitat	Area	Industry Researchers Land Managers Subsistence users	Med	30m	Decadal	GIS Layer	
Active layer depth	Monitoring	Depth (cm)	Hydrologists Industry Researchers	High	100m limited using current technology	Yearly, multiple years of sampling to get one point		Monitoring needed post-disturbance Remote sensing derived using SAR is experimental

TABLE C: Breakout Session II: What's missing?

Data Gap	Application/ Rational	Parameter to Measure (unit)	Customers	Priority (High, Medium, Low)	Spatial Scale Required	Temporal Scale Required (Daily, Monthly, Yearly, 5-year, etc.)	Form of Products (GIS data layers, maps, etc.)	Remarks
Human disturbances - roads, infrastructure, exploration	Landscape fragmentation Wildlife habitat	Infrastructure classes; Area		High priority data layer, depending on how we get it	Fine 5m (DOT standards), or less	Yearly with updates	GIS Data Layers Palmer, map makers provides quarterly updates – pulling from industry and the state	Time series would be valuable Biggest problem is institutional
Soil moisture	Hydrology Vegetation Fire		Hydrologic Modelers	Low	3km SMAP	2 days is more than enough		Available at SMAP scale (3km) – more than enough Validation is key Monitoring needed post-disturbance; lack of faith in current measurement, regional algorithms needed

TABLE C: Breakout Session II: What's missing?

Data Gap	Application/ Rational	Parameter to Measure (unit)	Customers	Priority (High, Medium, Low)	Spatial Scale Required	Temporal Scale Required (Daily, Monthly, Yearly, 5-year, etc.)	Form of Products (GIS data layers, maps, etc.)	Remarks
Surface water inundation	Habitat, water budget accounting	Area Depth/Volume	Hydrologic Modelers Wildlife habitat (birds/fish) Infrastructure	High	30m	Every two weeks	GIS Data layers	
Subsidence	Monitoring landscape change Surrogate to determine ice content Permafrost dynamics	Change (cm)	Permafrost researchers Industry Wildlife researchers Coastal change monitoring	Med	100m	Monthly	GIS Data Layer	Need twice a year, for a couple of years to start
Vegetation height	Carbon estimates Characterizing disturbance Wildlife management Habitat modeling	Height (m)	Researcher Land managers Modelers	Med	30m or less	Decadal	GIS Data layers	Time series change needed

TABLE C: Breakout Session II: What's missing?

Data Gap	Application/ Rational	Parameter to Measure (unit)	Customers	Priority (High, Medium, Low)	Spatial Scale Required	Temporal Scale Required (Daily, Monthly, Yearly, 5-year, etc.)	Form of Products (GIS data layers, maps, etc.)	Remarks
Vegetation biomass	Carbon studies	Mass of Carbon	Researcher Land managers Modelers	Med	30m	Decadal	GIS Data Layers	Time series change needed Biomass potential obtained from Normalized Difference Vegetation Index (NDVI) datasets
Snow depth		Inches/cm	Field biologists	High	1km Higher in select corridors	Seasonal Monthly		Accurate and reliable methodology needed Experimental products available Ground Pentrating Radar (GPR) We need a technique This is a requirement

TABLE C: Breakout Session II: What's missing?

Data Gap	Application/ Rational	Parameter to Measure (unit)	Customers	Priority (High, Medium, Low)	Spatial Scale Required	Temporal Scale Required (Daily, Monthly, Yearly, 5-year, etc.)	Form of Products (GIS data layers, maps, etc.)	Remarks
Snow Water Equivalent		Inches/cm	Field biologists	High	1km Higher in select corridors	End of season		Desirable parameter but current technology limits mapping
Erosion	Coastline and river monitoring	Length and area	Coastal engineers Local residents Community planners	High	High resolution	Decadal (depending on location), possibly finer	GIS layer	Monitoring needed post-disturbance Animal tracking
Salinity	Ecosystem dynamics Ground freezing	Salinity	Hydrologists Habitat Mappers Biologists Subsistence Industry	Low	30m	Yearly	GIS Layer	No proven capability

TABLE D: What remote sensing products can be used by the long-term monitoring community to increase monitoring capabilities for each NSSI Emerging Issue

NSSI Emerging Issue	Satellite remote sensing applications	Ability of remote sensing to help (high, medium, low)
Weather and Climate	--	Medium
Increasing Marine Activity	Ice cover; Circulation and currents; Oil spill detection and response; Wind speed/direction; Waves	Medium
Changing Sea Ice Conditions	--	High
Permafrost	--	Medium
Coastal and Riverine Erosion	--	High
Hydrology and Lake Drying	Lake drying & draining Lake color Active layer depth (ERS 1&2) Discrimination of floating aquatic vegetation around lake edges vs. changing lake size Land cover Hydrography DEM Freeze/thaw timing PRISM precipitation data	High
Coastal Salinization	Coastal erosion Subsidence Wind speed, wave height Sea ice Land cover	Low
Contaminants	--	Low

TABLE D: What remote sensing products can be used by the long-term monitoring community to increase monitoring capabilities for each NSSI Emerging Issue

NSSI Emerging Issue	Satellite remote sensing applications	Ability of remote sensing to help (high, medium, low)
Fire Regime	MODIS & Landsat burned area maps Albedo Land surface temperature Land cover, vegetation change Soil moisture Length of snow cover *Remark: we don't really understand the natural fire regime on North Slope – need to determine the return interval*	High
Vegetation Change	Land cover Vegetation change (Landsat/satellite + ground-based products) DEM Phenology NDVI & other indexes Localized habitat change (rare ecosystems)	High
Species of Interest: Migratory Birds	Habitat mapping Saltwater intrusion Lake ice thickness / grounding (shallow vs. deep lakes) Snow melt timing & rate data Land fast ice extent & leads Phenology, green up, etc. Lake drying, lake depth Vegetation response to waterfowl grazing Water temperature Lake primary productivity Ice off dates Land surface temperature	Low

TABLE D: What remote sensing products can be used by the long-term monitoring community to increase monitoring capabilities for each NSSI Emerging Issue

NSSI Emerging Issue	Satellite remote sensing applications	Ability of remote sensing to help (high, medium, low)
Species of Interest: Caribou	Snow cover NDVI, other veg indexes Phenology Habitat/land cover mapping DEM Air temperature Freeze/thaw River ice Infrastructure	Low
Species of Interest: Marine Mammals and Their Prey	Sea surface temperature maps Ice cover & thickness (nearshore & open ocean) Leads Circulation/thermal boundaries Chl/PP maps, DOC, suspended sediments Upwelling events Winds Lake ice grounding, river ice Snow cover DEM	Low
Species of Interest - Fisheries	Sea surface temperature maps Ice cover & thickness Circulation/thermal boundaries Chlorophyll /Primary Production maps, DOC, suspended sediments Upwelling events Winds Lake ice grounding, river ice	Low
Social and Economic Dimensions of North Slope Communities	--	Low