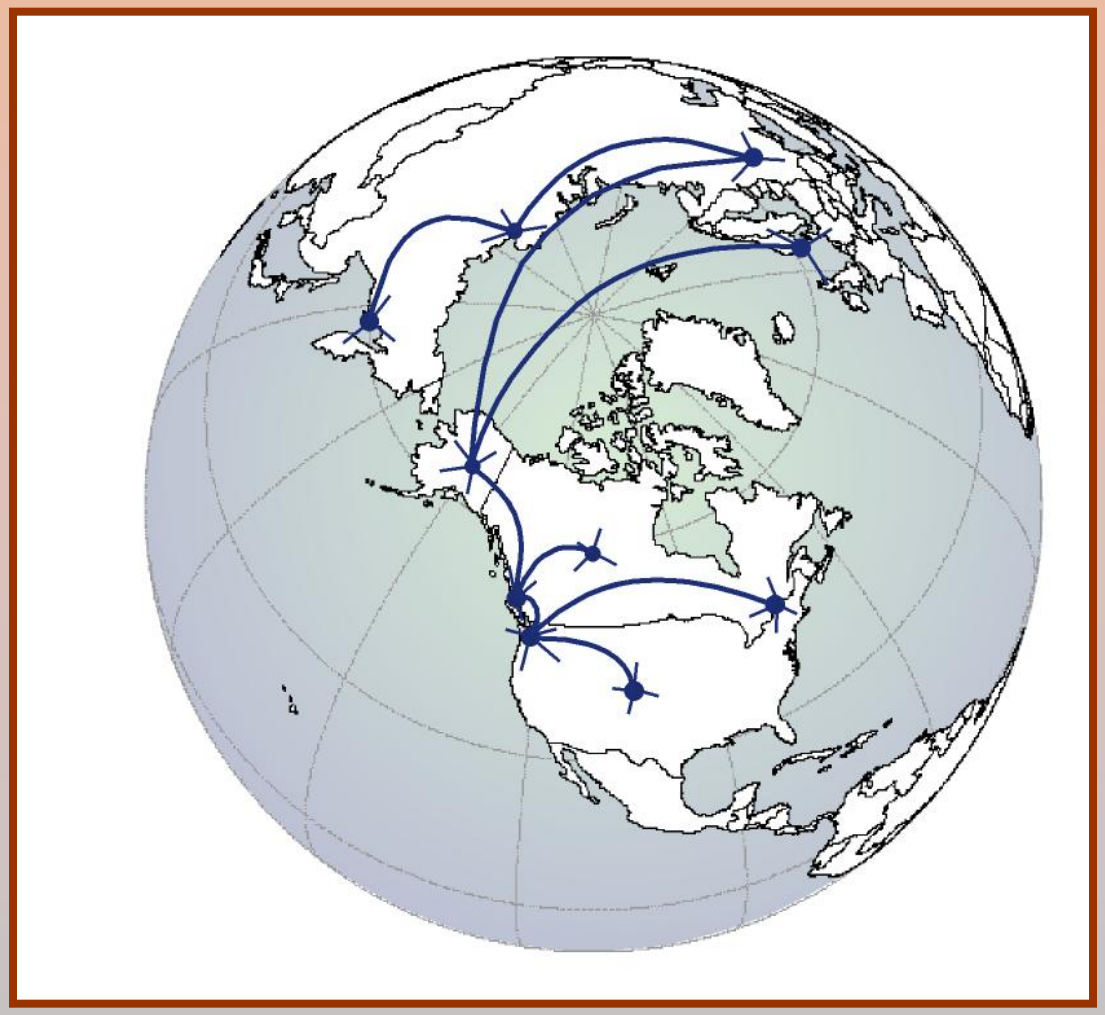
Towards a Web-based Arctic Geographic Information System:

A hierarchic GIS geobotanical atlas for the Toolik Lake-Kuparuk River region

D.A. Walker, A.W. Balser, H.A. Maier, V. Sharpton

University of Alaska Fairbanks

UAF: One node in a global Arctic Network



The University of Alaska Fairbanks: a treasurehouse of arctic geospatial information

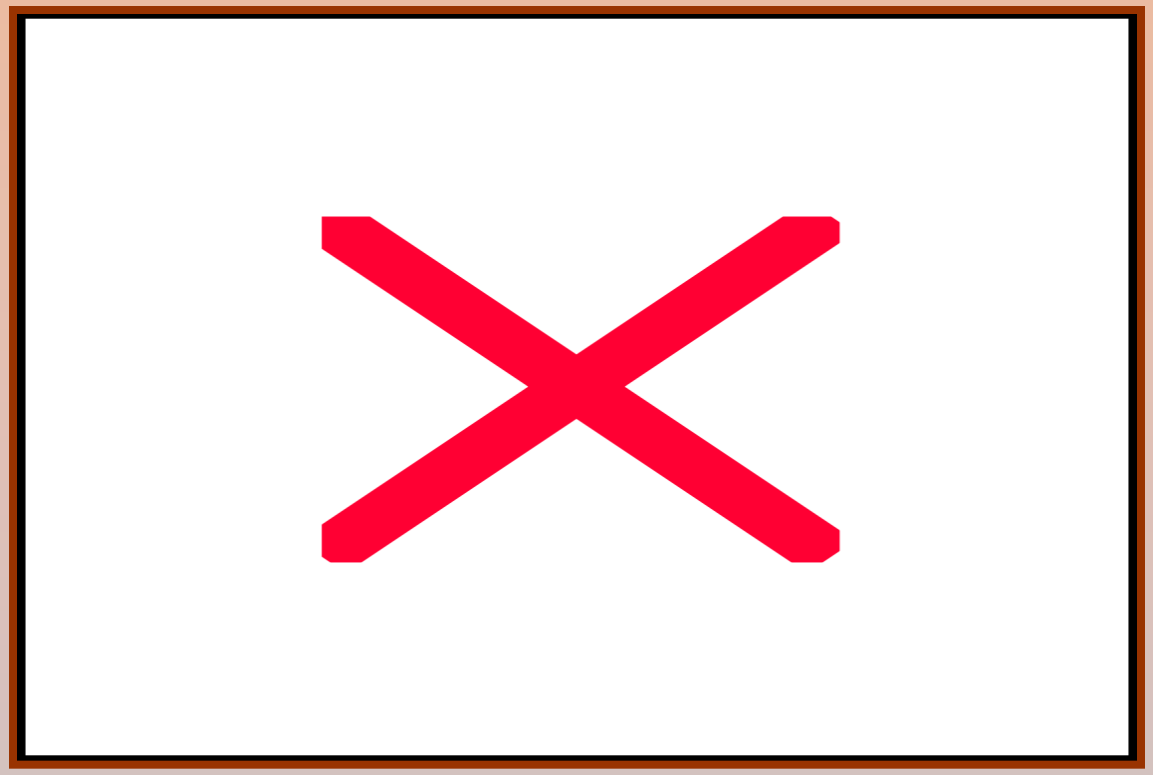
- *International Arctic Research Center (IARC)*
- *Institute of Arctic Biology (IAB)*
- *Geophysical Institute (GI)*
- *Water and Environmental Research Center (WERC)*
- *Toolik Field Station (TFS)*

We are proposing:

- *A prototype Arctic GIS network node based at the University of Alaska Fairbanks (UAF).*
- *Develop a web-based geobotanical atlas focused on the Toolik Lake Field Station and the North Slope.*

Focus on the geobotanical data sets

- *Vegetation*
- *Soils*
- *Landforms*
- *Geology*
- *Hydrology*
- *Remote sensing data*



Bundy Fiord, Axel Heiberg Island

Critical information for research and…

…science support at the Toolik Field Station and Kuparuk River region

Why Toolik Lake and Kuparuk River region?

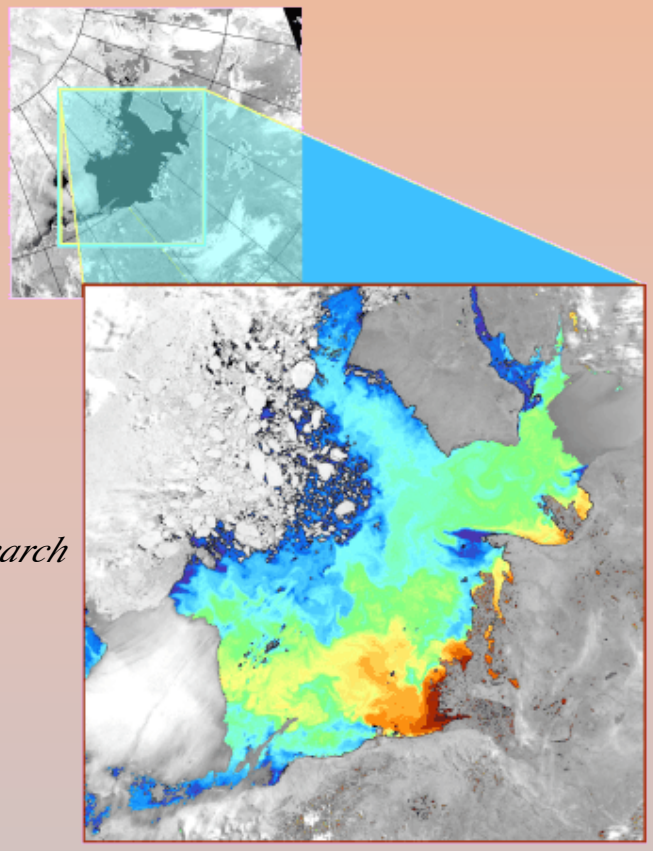
Photo: Rich Flanders

- *Long history of research associated with Arctic LTER, Imnavait Creek site, and many sites along the Dalton Highway.*
- *Prudhoe Bay and the Trans-Alaska Pipeline are within the Kuparuk River region, enhancing the applied aspects of the GIS.*
- *Availability of many types of spatial data not available elsewhere.*
- *Existing hierarchical geobotanical atlas of the region.*

Five UAF subnodes interacting to serve North Slope geospatial information

- *Geographic Information Network of Alaska (GINA)*
- *A Region Supercomputing Center (ARSC)*
- *Toolik Lake Field Station GIS*
- *Alaska Geobotany Center (AGC)*
- *Water and Environmental Research Center (WERC)*

Alaska Geographic Information Network (GINA)



Part of GINA's goals are to:

- *Integrate geospatial information and satellite image data into the university's mission of providing high-quality education and basic research opportunities.*
- *Create new capability for serving Alaska's needs to monitor natural resources, natural hazards, and the effects of climate change.*

GINA's role in the proposed node:

- *Gateway to Toolik Lake GIS, the Geobotanical Atlas, and other North Slope geospatial databases with links to other statewide, national, and circum-arctic clearinghouses.*

Arctic Region Supercomputing Center (ARSC)

ARSC
www.arsc.edu

Part of ARSC's goals are to:

- *Support high performance computational research in science and engineering with an emphasis on high latitudes and the Arctic.*
- *Provide high performance computational, visualization, networking and data storage resources for researchers within the University of Alaska (UA), other academic and scientific institutions, and government agencies.*

ARSC's role in the proposed node:

- *Provide to GINA the high speed computational, networking, and data storage resources necessary for handling massive amounts of spatial information.*

Toolik Field Station GIS Facility

Part of the facility's goals are to:

- *Support the science mission of the Station by providing high quality maps, GIS-based products, and analysis to users.*
- *Support management of the Toolik Lake natural resources.*

The facility's role in the proposed node:

- *Provide the link between users in the field and the geobotanical GIS.*
- *Fully develop the Toolik Natural Resource Tool and other tools for application of the Geobotanical GIS.*

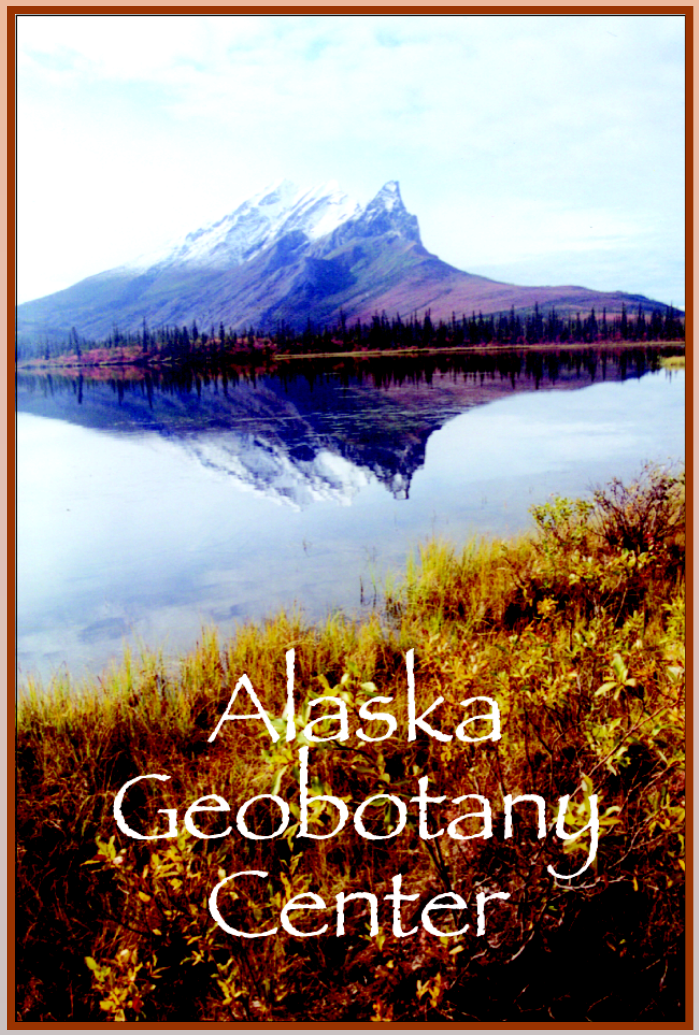
Alaska Geobotany Center (AGC)

AGC's goals are to:

- *Explore and understand global northern regions. through GIS, remote sensing, and ecosystem analysis.*
- *Educate students and the public about northern systems and issues.*

AGC's role in the proposed node:

- *Develop and manage data within the Arctic Geobotanical Atlas.*
- *Fully document the Atlas information through publications and digital metadata.*
- *Develop a web-based IMS interface for the Atlas.*



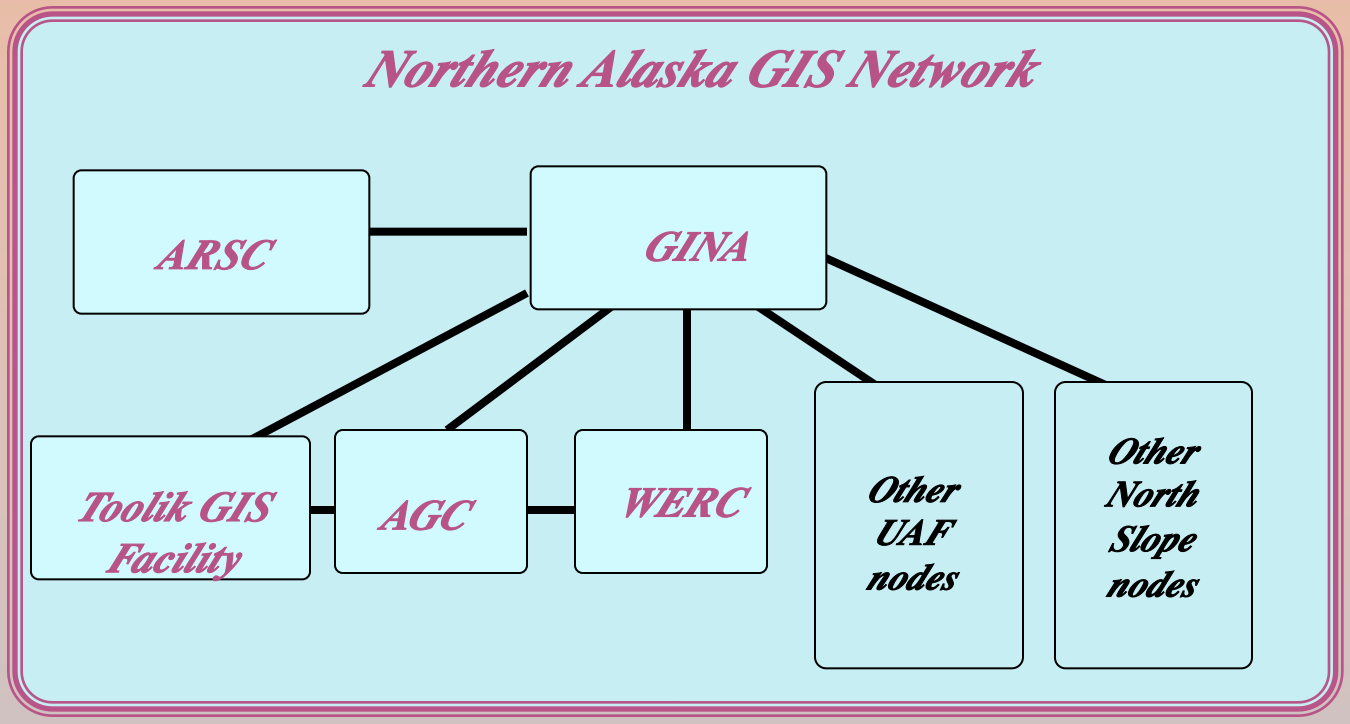
Water and Environmental Research Center (WERC)

WERC

WERC's role in the proposed node:

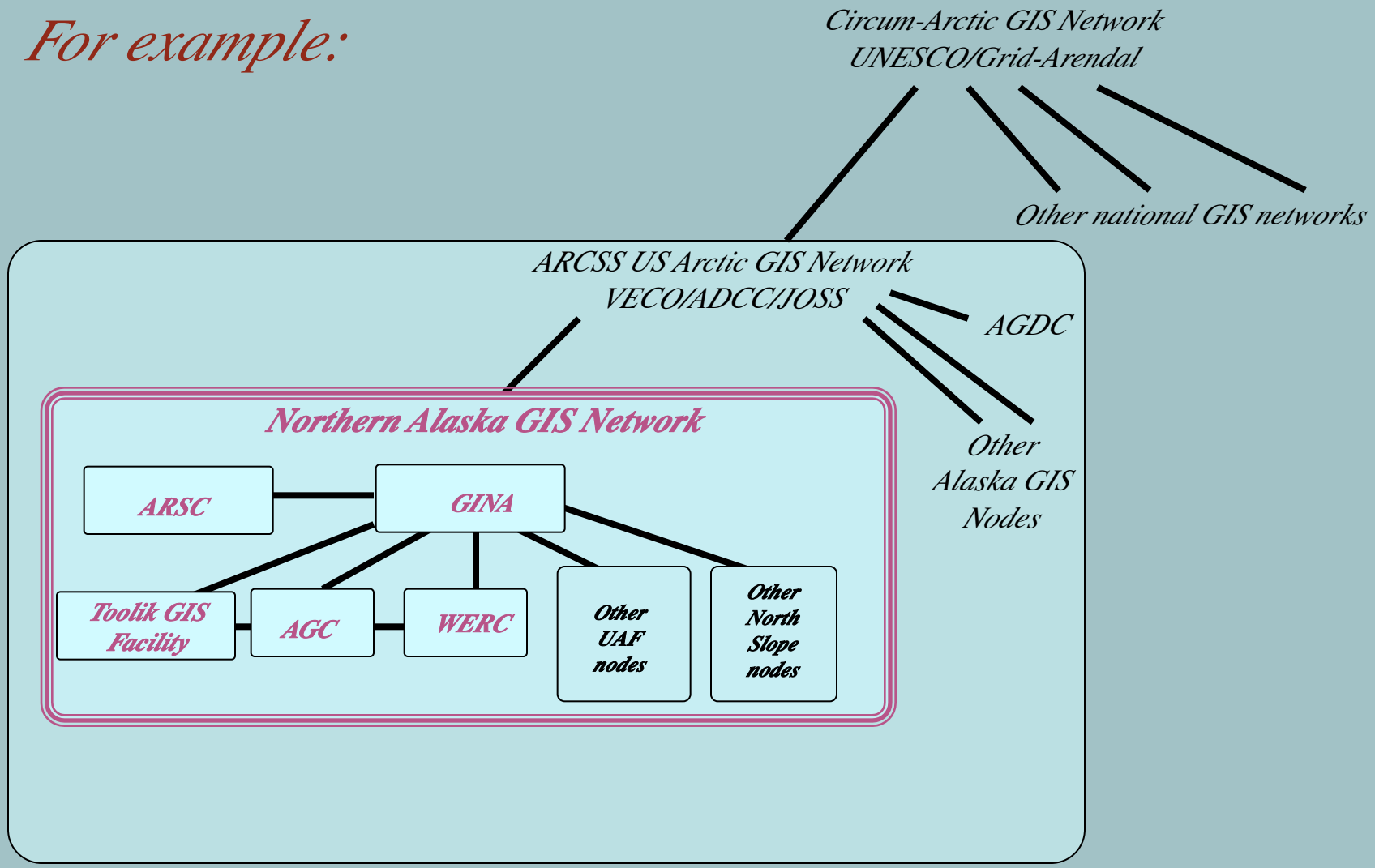
- *Help develop the visualization products of the geobotanical atlas.*
- *Provide the high resolution DEM for the Kuparuk River basin.*

Components of a UAF node

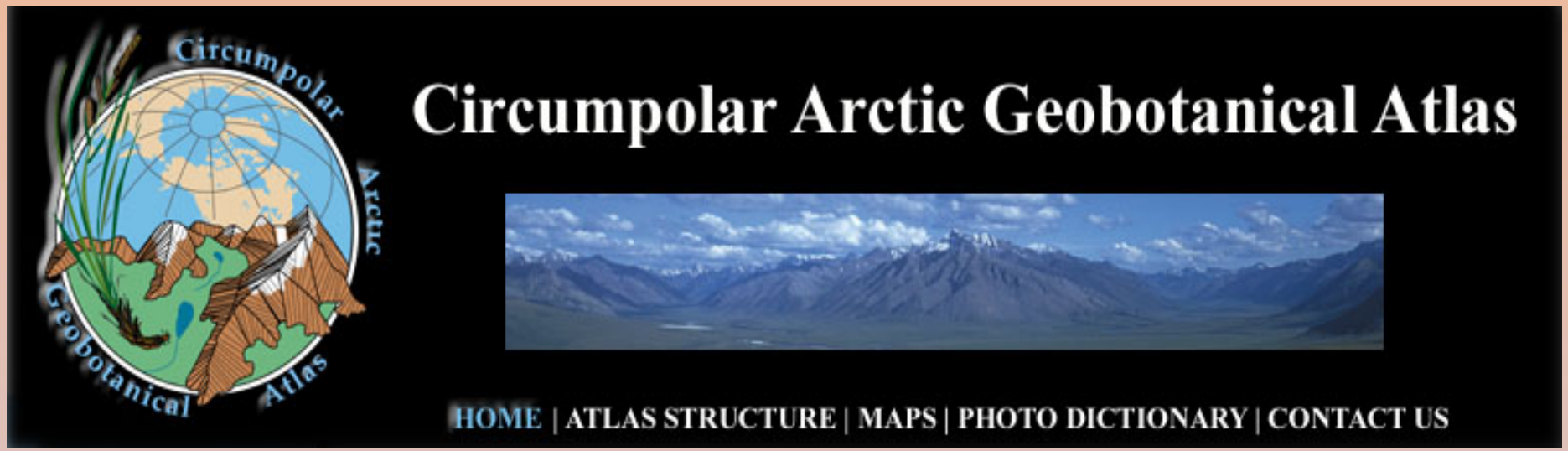


Part of an ARCSS and Circum-Arctic GIS Network

For example:



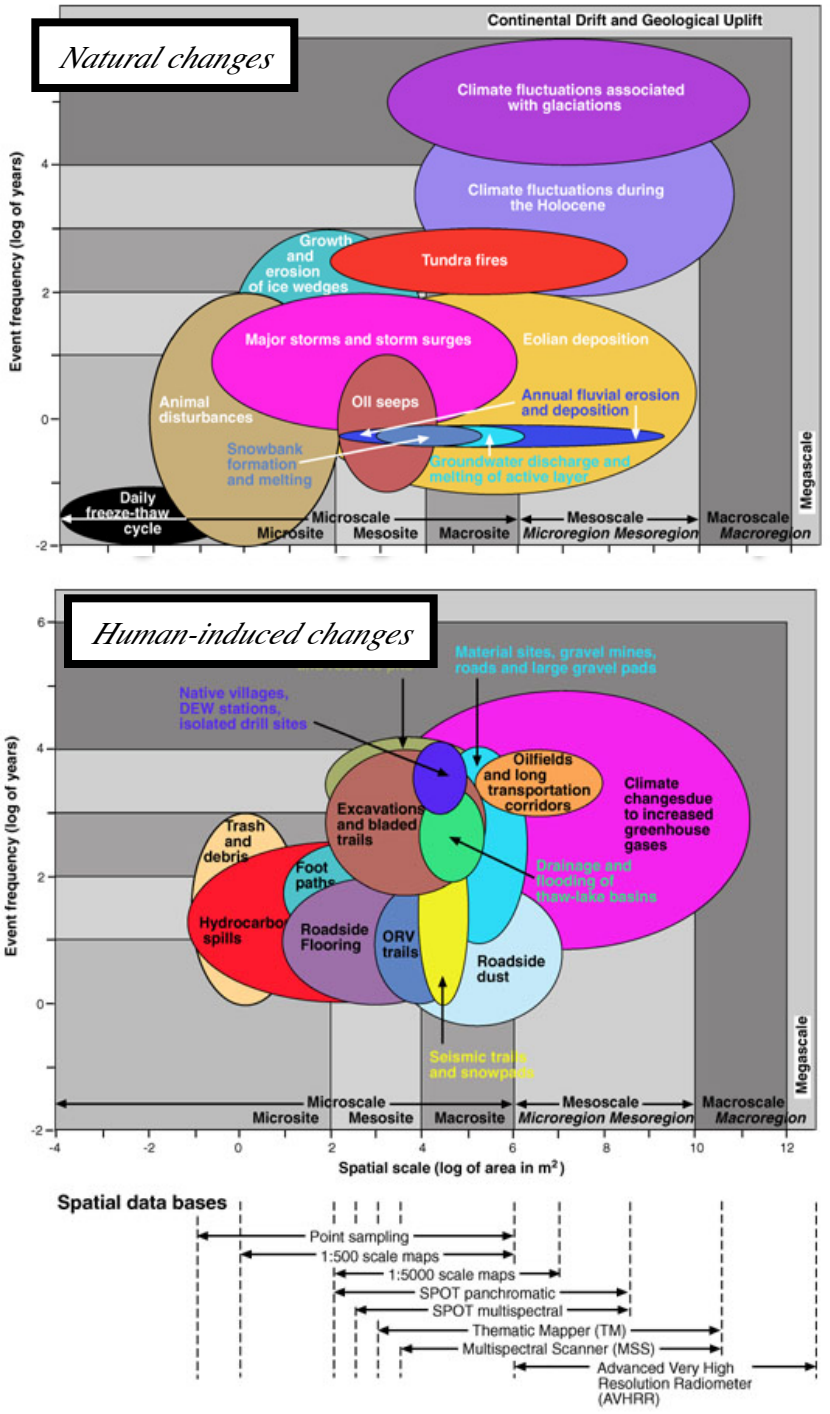
A web-based
Circumpolar Arctic Geobotanical Atlas



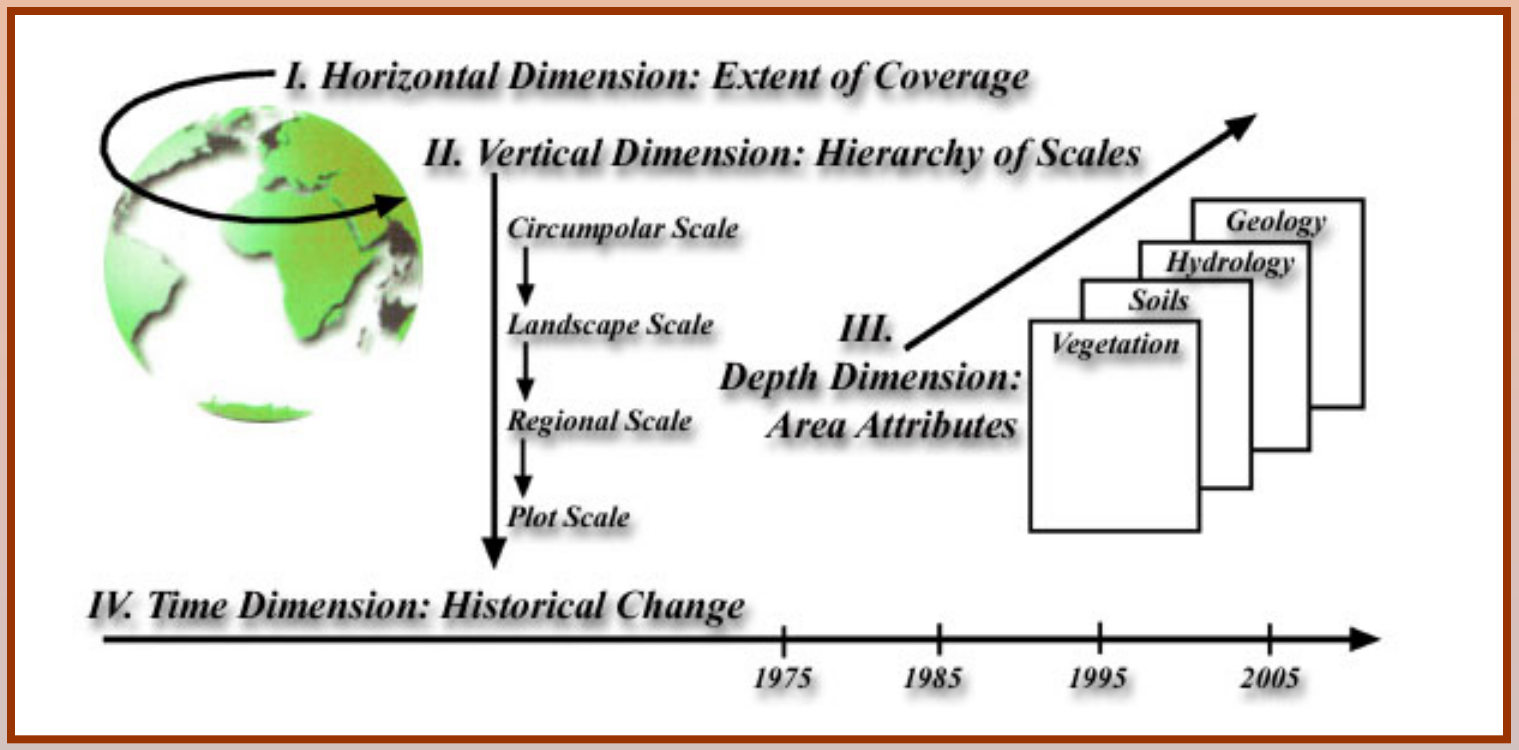
- *Collection of geobotanical maps and supporting documentation for the Arctic.*
- *Current collection is a fusion of three large GIS efforts:*
  - *Circumpolar Arctic Vegetation Mapping project,*
  - *Kuparuk River basin geobotanical atlas,*
  - *Prudhoe Bay geobotanical atlas and cumulative impact studies.*
- *Maps are currently in PDF format.*

Processes of Arctic change operate across spatial scales that differ by 15 orders of magnitude.

- *Documenting and predicting change requires a broad range of map scales.*
- *The hiearchy of maps in the Atlas cover scales spanning 11 orders of magnitude.*

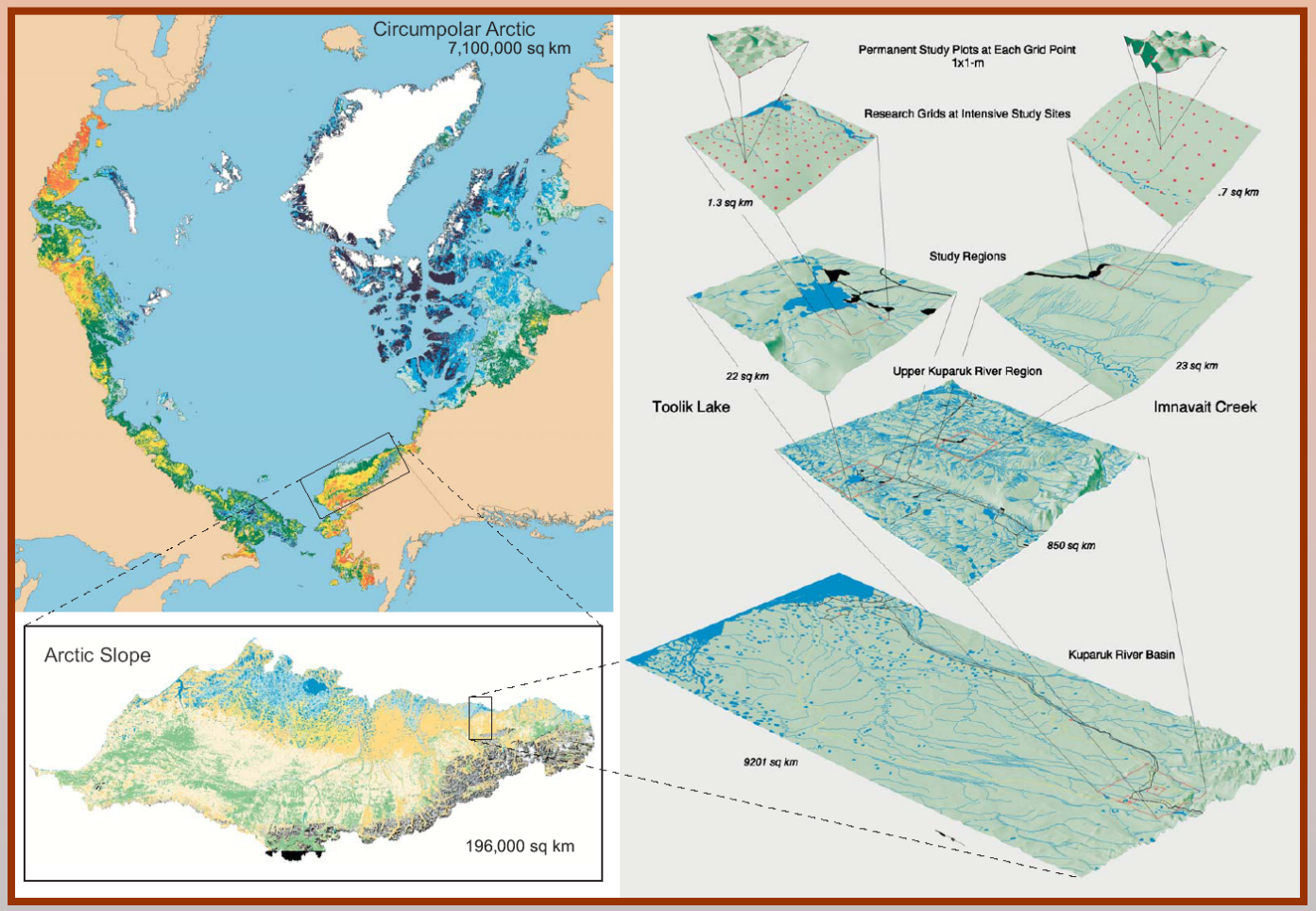


The 4-Dimensional Framework of the Arctic Geobotanical Atlas

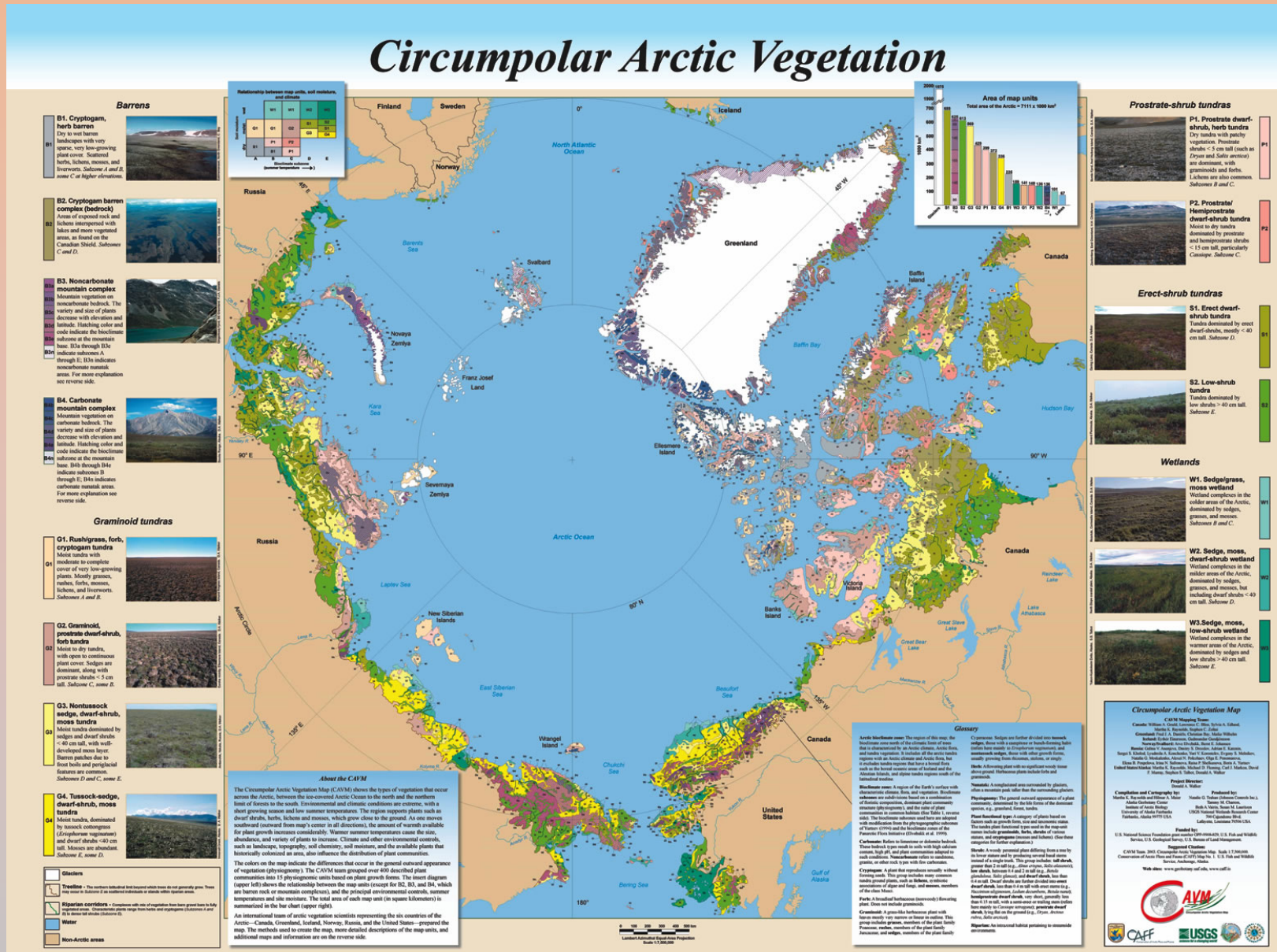


Hierarchy of map scales

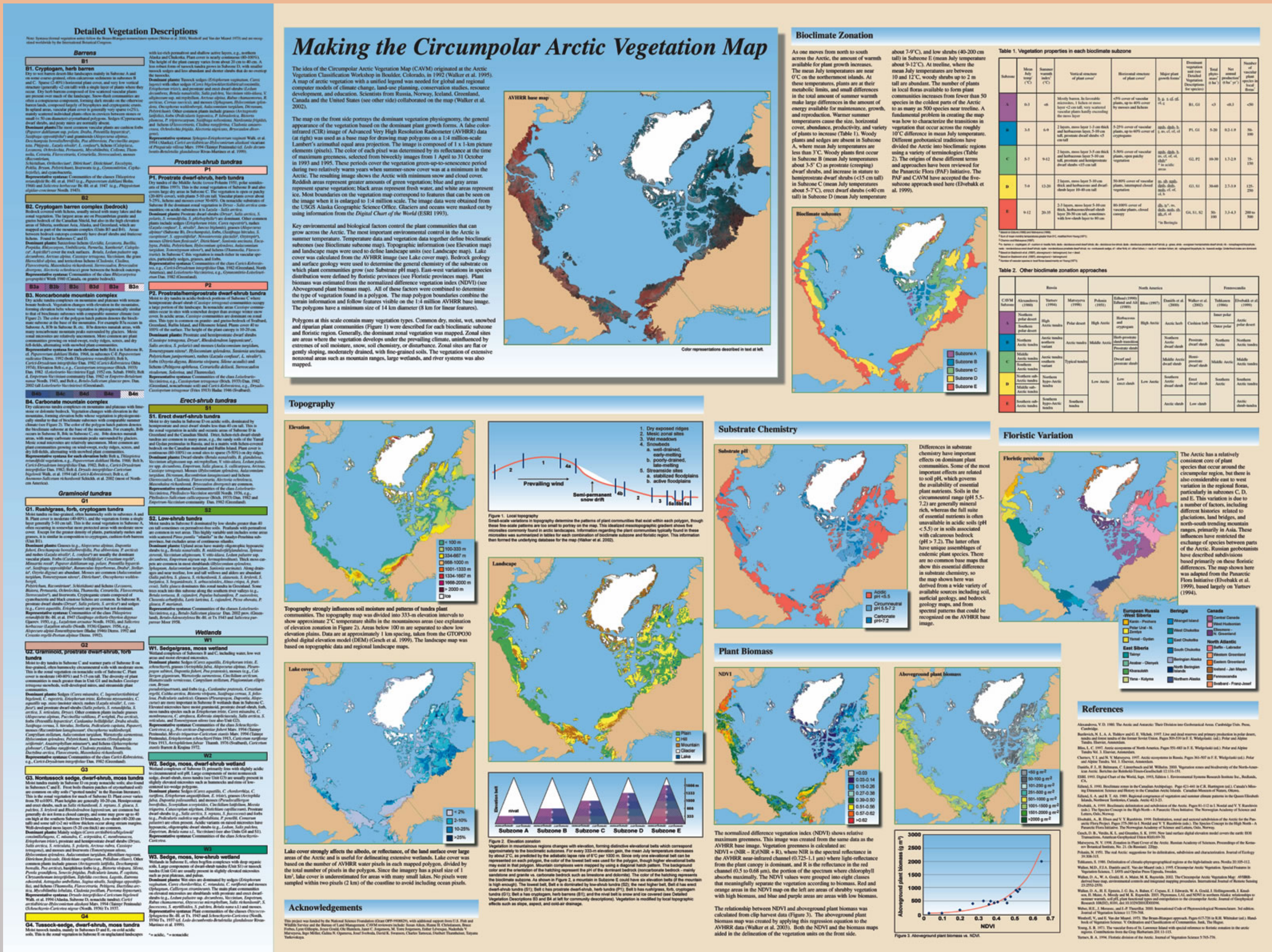
- *Planet to plant scales: 8 scales in all for some areas of the Kuparuk River basin.*



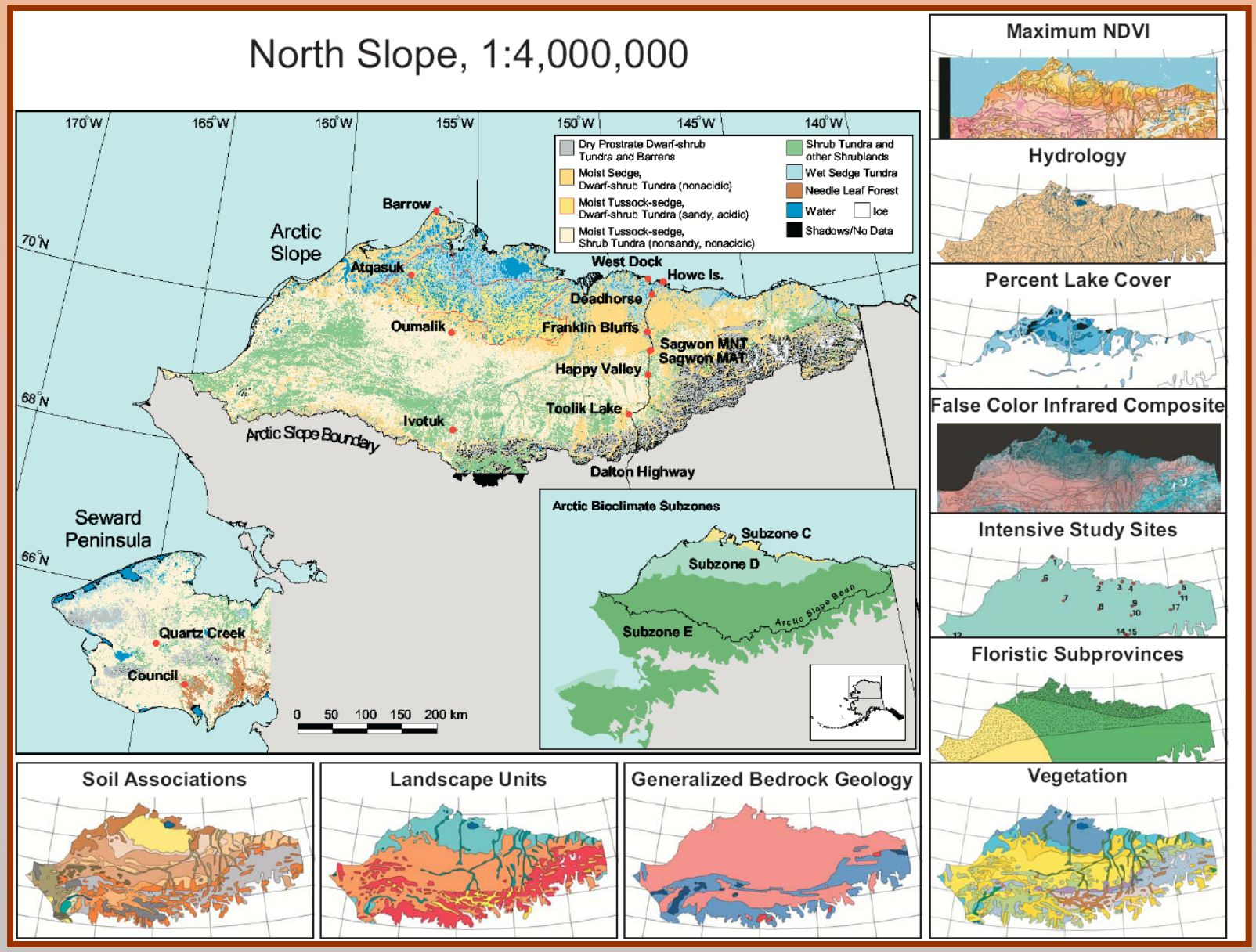
Global-scale: the CAVM



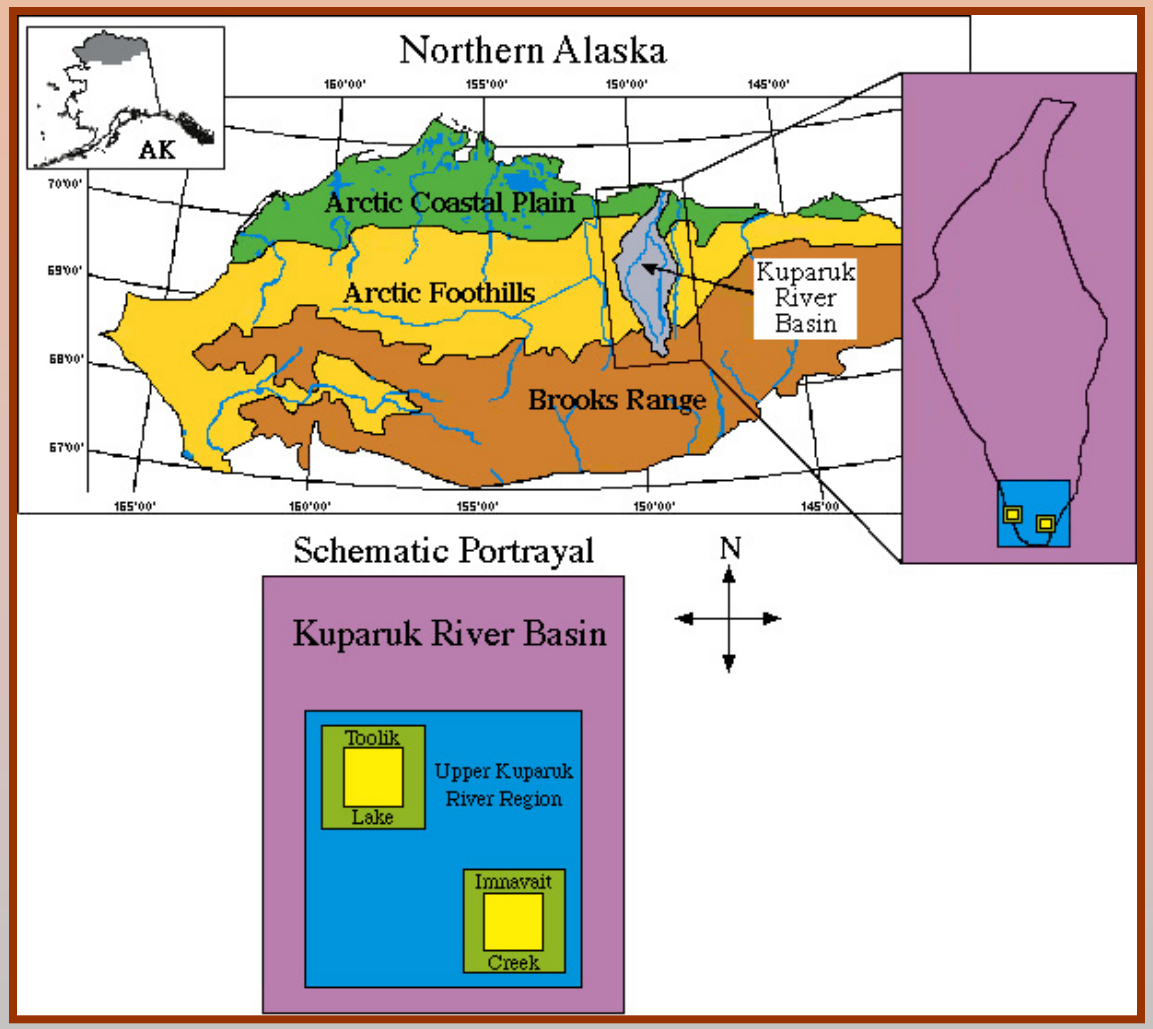
Vegetation plus 8 ancillary data sets



Information available from the CAVM for northern Alaska



Hierarchy of Databases for the Kuparuk River basin



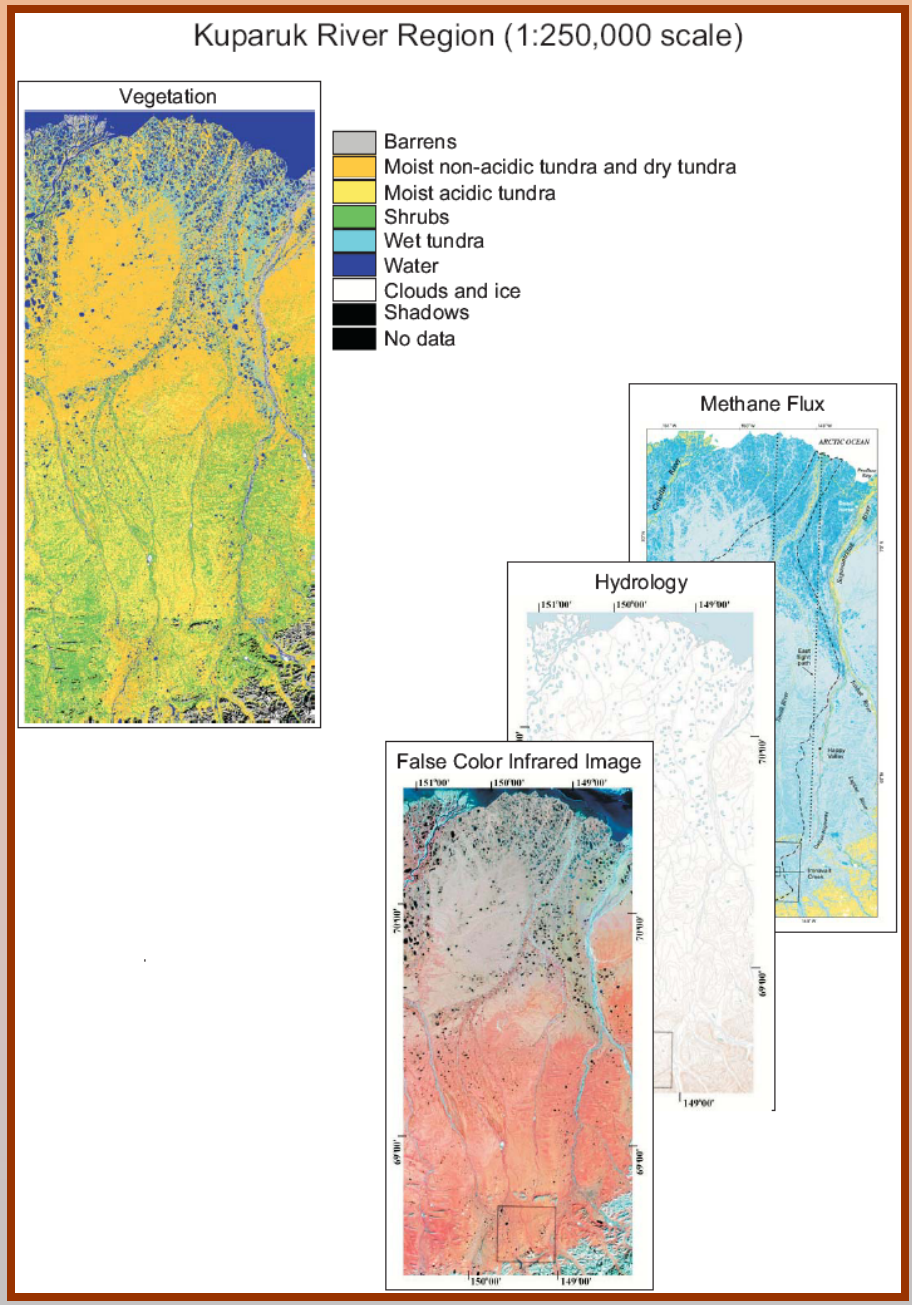
The regional scale: Some Kuparuk River Basin databases

- *Current data bases include:*
  - *Topography*
  - *Hydrology*
  - *Vegetation*
  - *NDVI*
  - *Active layer depth*
  - *Methane flux*

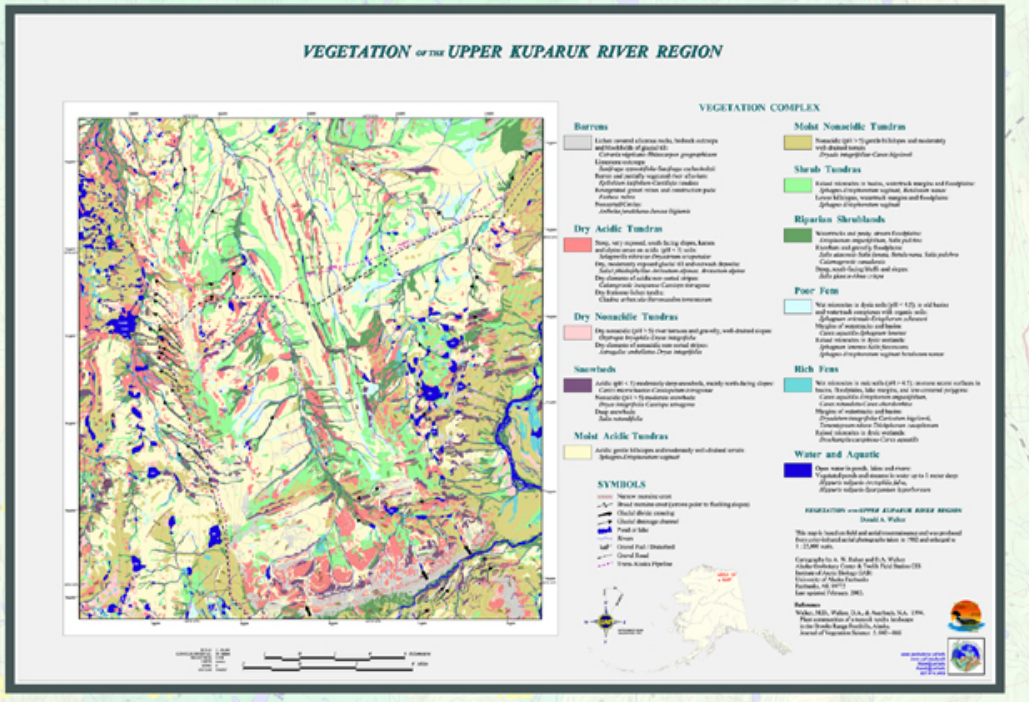
- *Most are derived from remote-sensing data, Landsat MSS.*

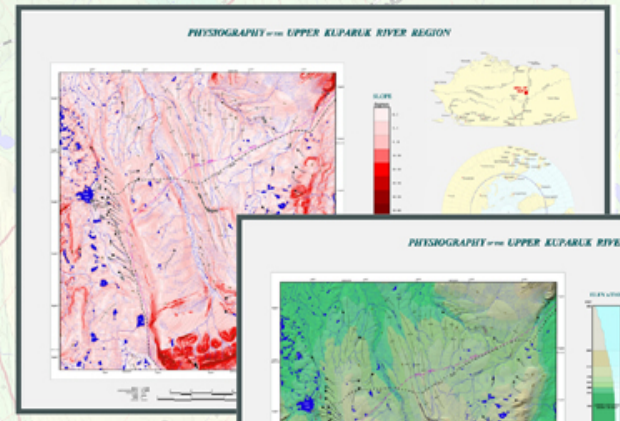
- *Geobotanical maps are needed at this scale.*

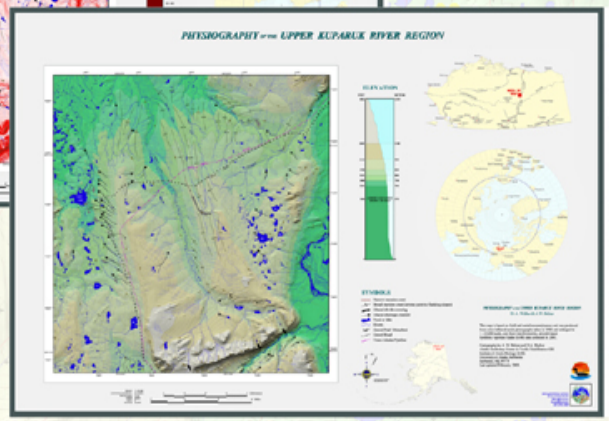
- *Maps at the this scale and all other scales within the basin need to be co-registered to a common high-resolution topographic base map.*

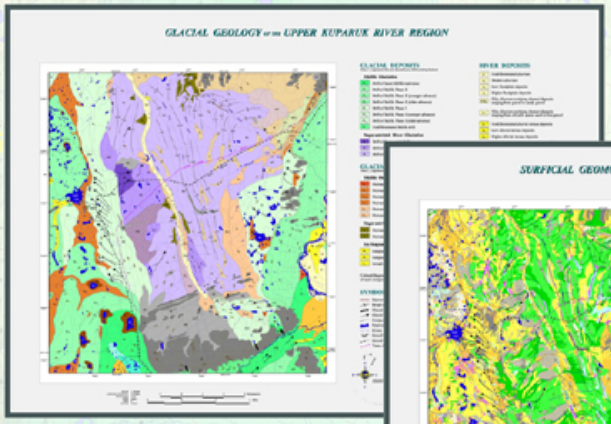


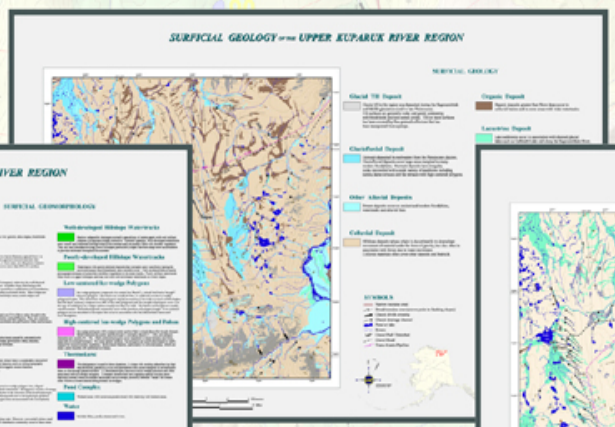
Upper Kuparuk River Basin databases

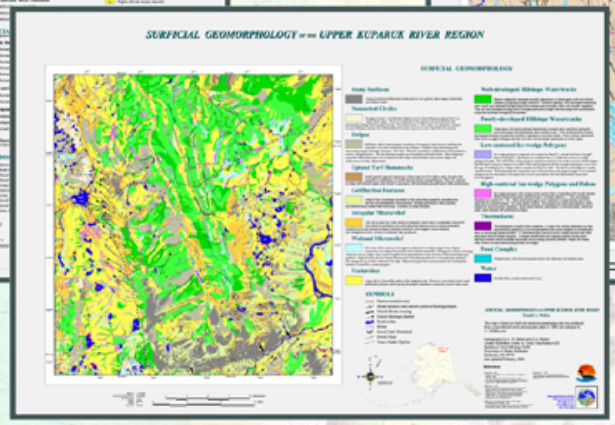


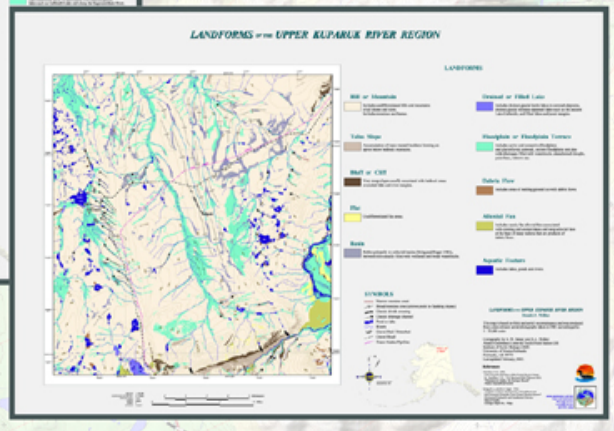












Recent application of 1:25,000-scale database

Vegetation of the Upper Kuparuk River Region in relationship to glacial geology and surficial geomorphology

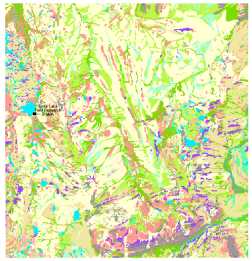
A Research Experience for Undergraduates (REU) project

C.A. Munger and D.A. Walker, Alaska Geobotany Center, Institute of Arctic Biology, University of Alaska Fairbanks

Poster presented at the 54th Arctic Science Conference, Fairbanks, AK, September 22-24, 2003.

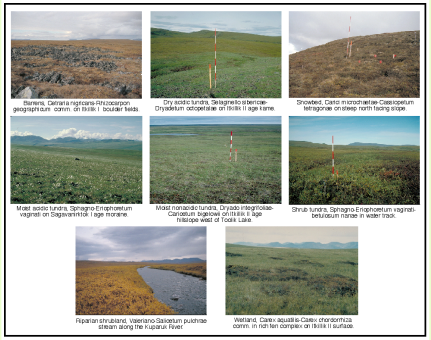
Introduction: The main factors controlling mesoscale vegetation patterns in the Upper Kuparuk River Region are landscape age and surficial geomorphology. The complex topography of the region is the result of glacial deposits from three major glaciations: the Sagavanirktok (mid- Pleistocene), Itkillik I, and Itkillik II (late Pleistocene). Surficial geomorphological features are created through alluviation, colluviation, and periglacial processes . This poster examines the relationship between vegetation, glacial geology, and surficial geomorphology in the Upper Kuparuk River Region through area analyses of the three maps.

Vegetation Complexes (Walker unpublished)



Vegetation

The vegetation of the region is divided into eleven vegetation complexes, which are subdivided into 33 plant community types and 17 subtypes (M.D. Walker, et al 1994; Walker and Walker 1996; Walker unpublished). The zonal climax vegetation is tussock tundra, Sphagno-Eriophoretum vaginatum consisting of tussock cottongrass, Eriophorum vaginatum, a mixture of dwarf shrubs, and mosses. Dryas integrifoliae-Caricetum bigelowii, is common on nonacidic surfaces.



Barrens, Cetraria nigricans-Rhizocarpon geographicum comm. on thicke (boulder fields

Dry acidic tundra, Salicpanicto-sterricae-Dryadetum octopetalae on Itkillik II age kame.

Snowbed, Carex microchaetae-Cassiopetum tetragonae on steep north facing slope.

Moist acidic tundra, Sphagno-Eriophoretum vaginati on Sagavanirktok I age moraine.

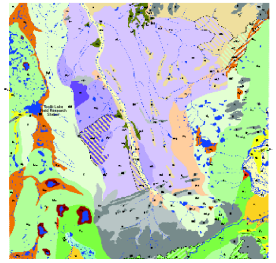
Moist nonacidic tundra, Dryado integrifoliae-Caricetum bigelowii on Itkillik II age hillslope west of Toolik Lake.

Shrub tundra, Sphagno-Eriophoretum vaginati-betulosum nanae in water track.

Riparian shrubland, Valeriano-Salicetum pulchrae stream along the Kuparuk River.

Wetland, Carex aquatilis-Carex chordorrhiza comm. in rich fen complex on Itkillik II surface.

Glacial Geology (Hamilton 2003)



Vegetation and Glacial Geology

The Upper Kuparuk River Region was shaped by repeated glacial advances during the middle and late Pleistocene.

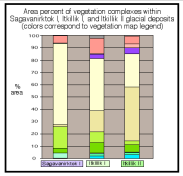
- Sagavanirktok I surfaces, which make up most of the Upper Kuparuk watershed, including the Imnavait Creek watershed, are characterized by rounded, gently rolling hills rising less than 100 m from valley bottom to ridge crests, and have few glacial erratics.
- Itkillik I surfaces have a more irregular topography, steeper slopes, and have many small glacial lakes, kames, and moraines.
- Itkillik II surfaces are the youngest, the most heterogeneous, and are characterized by rocky terrain, only slightly flattened moraine crests, and steep flanks.

The most notable relationship between landscape age and vegetation is the increase in moist acidic tundra and decrease in moist nonacidic tundra over time. Moist acidic tundra (MAT) covers 27% of the total Itkillik II area, 43% of the Itkillik I areas, and 66% of total Sagavanirktok I areas. Moist nonacidic tundra (MNT) covers 44% of the Itkillik II areas, 17% of total Itkillik I areas, and only 1.5 % of the Sagavanirktok I areas.

The development of acidic tussock tundra depends on long-term site stability. This is explained by a hypothesis of vegetation succession by which peat formation (paludification) and ice aggradation lead to restricted drainage, a general acidification of the soils, and the introduction of Sphagnum mosses to wet hill slopes. The mosses gradually change the soil chemistry, hydrology, and soil thermal properties resulting in continued peat formation, acidic mires in colluvial basins, extensive water track development, and tussock tundra on gentle hill slopes (Walker and Walker 1996).

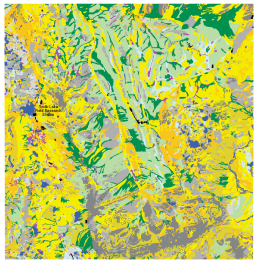
Glacial sequence in the Central Brooks Range. Modified from Hamilton (2003).

Age	Glaciation	Phase
Holocene	Neoglaciation	
Late Pleistocene	Itkillik II	Latest Itkillik II readvance (idi)
		Younger advance (ida)
		Older advance (ida)
	Itkillik I	Phase B (idi)
		Phase A (idi)
Middle Pleistocene	Sagavanirktok River	Late phase (sdi)
		Main phase (sdi)
Early Pleistocene	Anaktuvuk River	-------
Late tertiary	Gunsight Mountain	-------



Acknowledgments:
Thanks to Tako Raynolds, Hilmar Maier, and Christine Martin for all their help. This project was funded through NSF grant OPP 9908829.

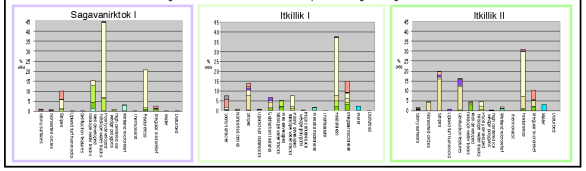
Surficial Geomorphology (Walker unpublished)



Vegetation, Glacial Geology, and Surficial Geomorphology

Sagavanirktok I, Itkillik I, and Itkillik II glacial deposit surfaces each have characteristic surface geomorphological features. Older surfaces tend to have more well developed and poorly developed hillslope watertracks, shrub tundra, and poor fens than younger surfaces. Younger surfaces have more lakes, nonsorted circles, gelifluction features, stripes, and snowbeds. All of these patterns are a reflection of a trend towards more peaty, wetter upland surfaces and infilling of lakes in lowland sites.

Percent of vegetation complexes on each surficial geomorphology unit for the three glacial surfaces. Colors on the bars correspond to the vegetation legend.



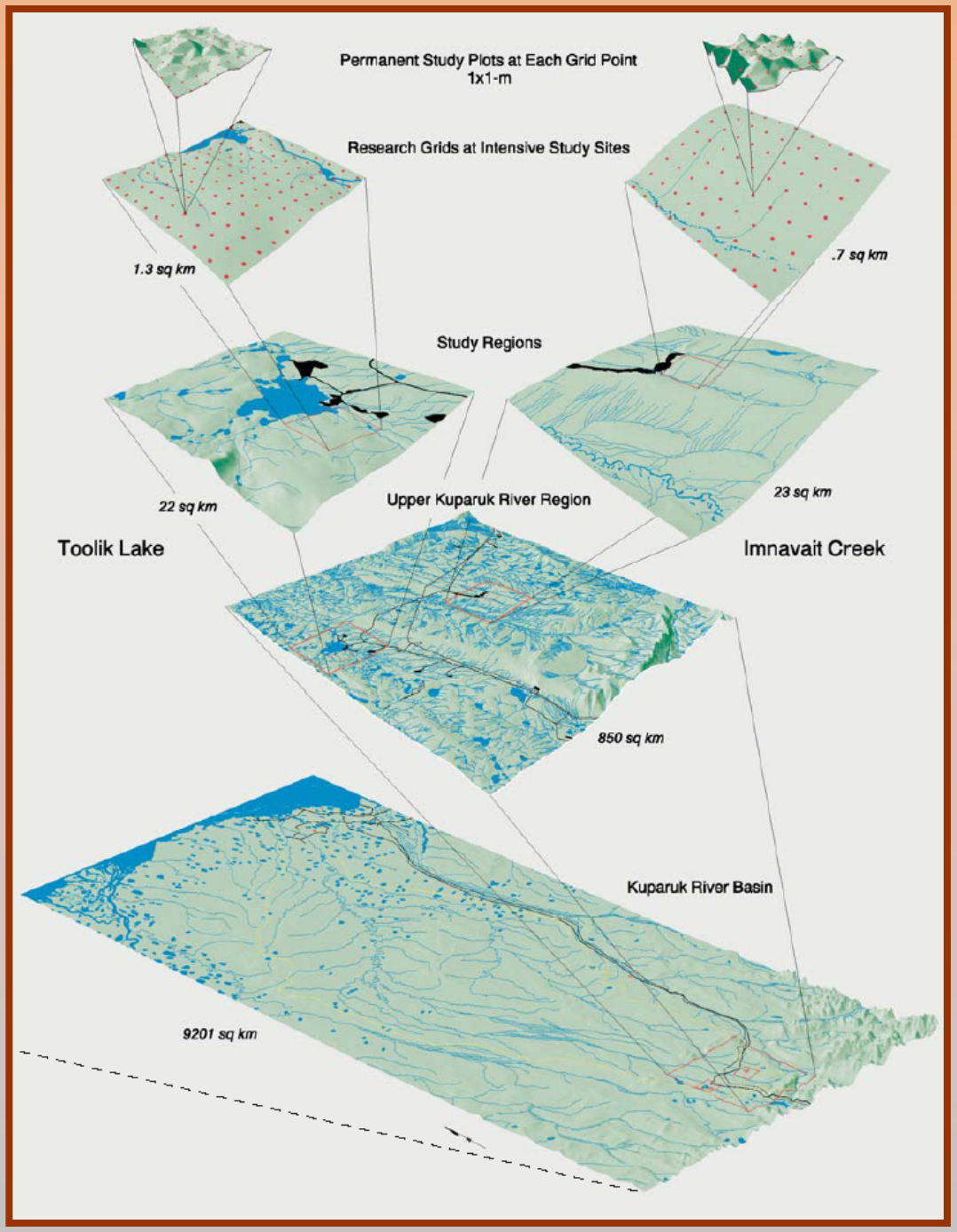
Conclusions

1. The patterns of vegetation and microrelief are clearly different on the three different aged surfaces. Older surfaces are wetter, more peaty with acidic tundra; whereas the younger surfaces are drier with nonacidic vegetation and more snowbed vegetation.
2. There are more watertracks on the older surfaces and more stony areas and irregular microrelief on the younger surfaces.
3. The relationship between landscape morphology and vegetation likely have major significance to a wide variety of terrestrial and aquatic ecosystem properties, such as carbon storage, trace-gas production, wildlife use, and stream chemistry.

Literature cited:

Hamilton, T.D. 2003. Glacial Geology of the Toolik Lake and Upper Kuparuk River Regions: A contribution to the Geobotanical Atlas of the Kuparuk River Region. Biological Papers of the University of Alaska 26, Institute of Arctic Biology, University of Alaska, Fairbanks.
Walker, D.A., M.D. Walker, and N.A. Auerbach. 1994. Plant communities of a tussock tundra landscape in the Brooks Range Foothills, Alaska. Journal of Vegetation Science **5**:843-866.
Walker, D.A. and M.D. Walker. 1996. Terrain and Vegetation of the Imnavait Creek Watershed. Ecological Studies **120**:73-108.
Walker, D.A. Unpublished database. Hierarchic GIS of the Kuparuk River Region. www.geobotany.uaf.edu. Alaska Geobotany Center. University of Alaska, Fairbanks.

REU Student project poster presented at the 54th Arctic Science Conference Fairbanks, AK, 21-24 Sep 2003



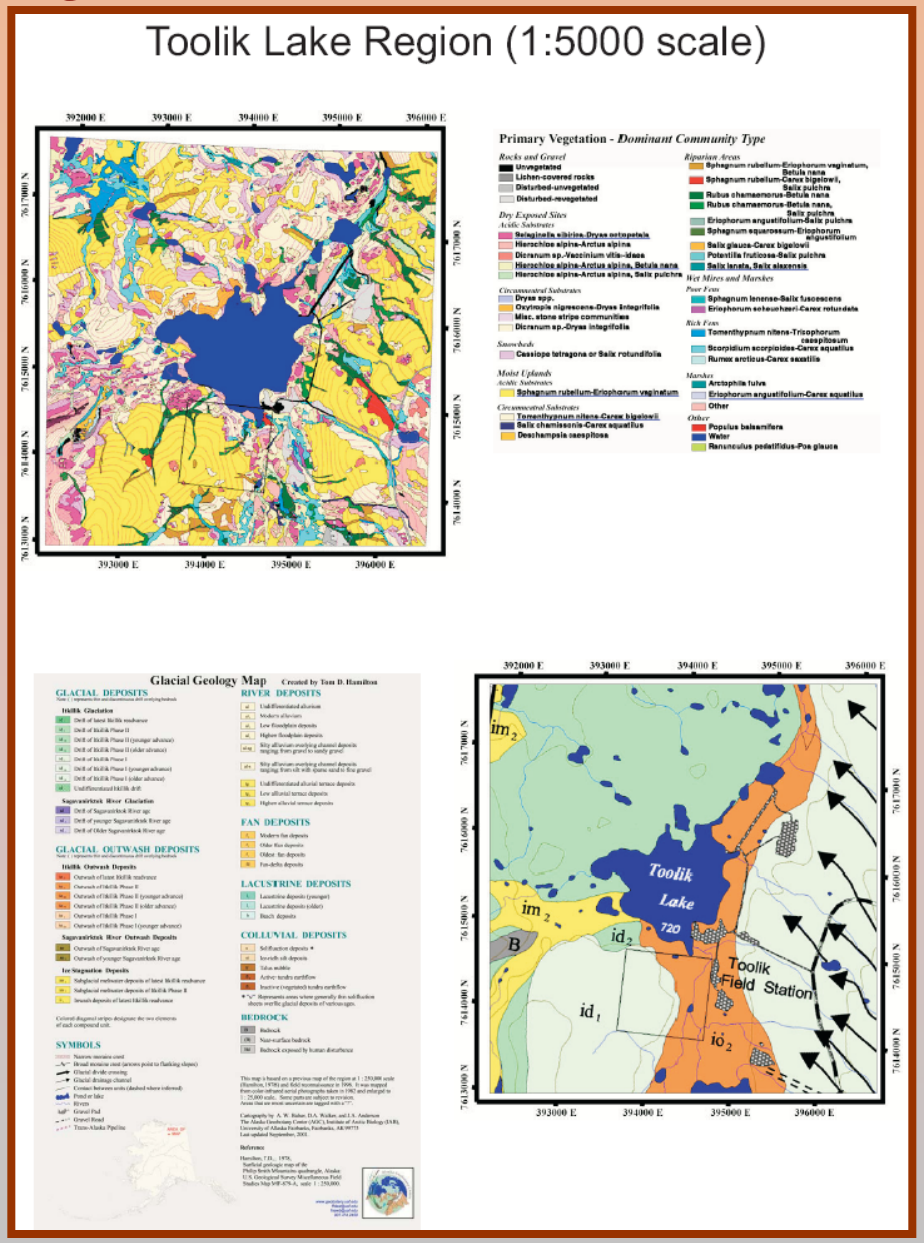
Kuparuk River basin: hierarchy of map scales

Landscape scale: Geobotanical maps of the Toolik and Imnavait Creek regions

- *Databases include:*
  - *Vegetation (primary, secondary, tertiary)*
  - *Landform*
  - *Surface geomorphology*
  - *Glacial geology*
  - *Percent water cover*
  - *Topography*
  - *Hydrology*
  - *NDVI*

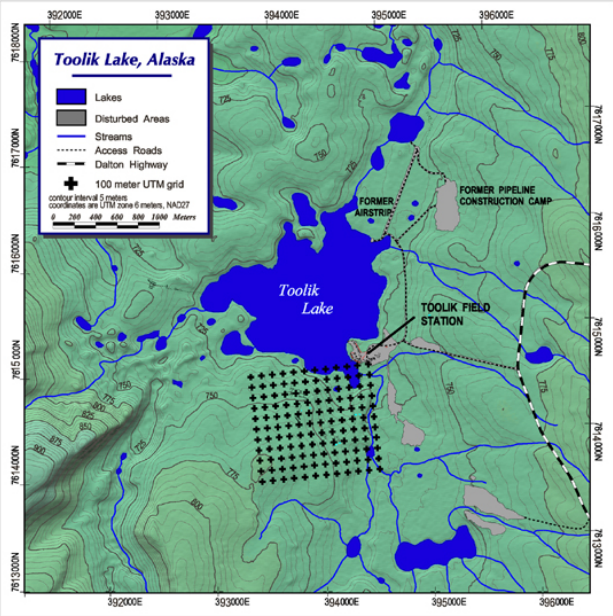
- *Information registered to an orthophoto topographic map.*

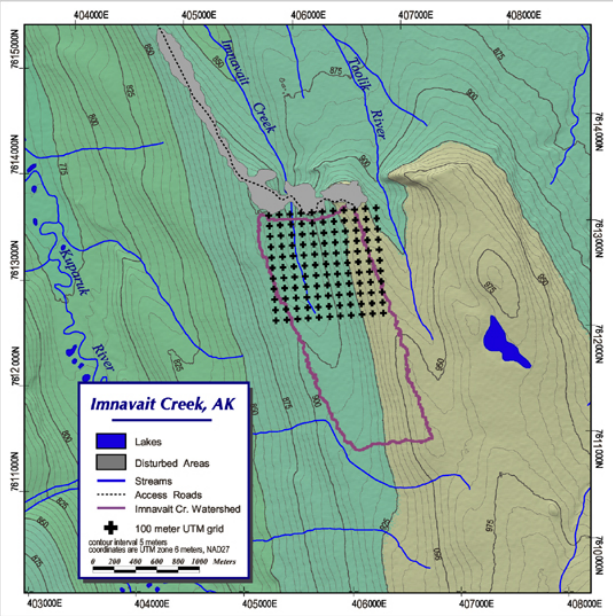
- *Legend terminology and color schemes are compatible and hierarchical at all scales.*



ARCSS/ CALM Grids

Toolik Lake & Imnavait Creek 1:5,000 scale ARCSS Grids





- *1 x 1 km grids with 100-m grid point spacing, registered to orthophoto topographic maps and CIR aerial photographs.*
- *Similar CALM grids exist at Toolik, Imnavait Creek, Prudhoe Bay West Dock, Betty Pingo, Barrow, Atqasuk, Council, Quartz Creek and other international sites.*
- *Additional grids are needed at Franklin Bluffs and Sagwon to examine the full bioclimate gradient in northern Alaska.*

Geobotanical maps of the ARCSS/CALM grids

- *Geobotanical data include vegetation and 8 ancillary data sets.*

- *Currently, geobotanical maps available for the grids at Imnavait Creek and Toolik Lake.*

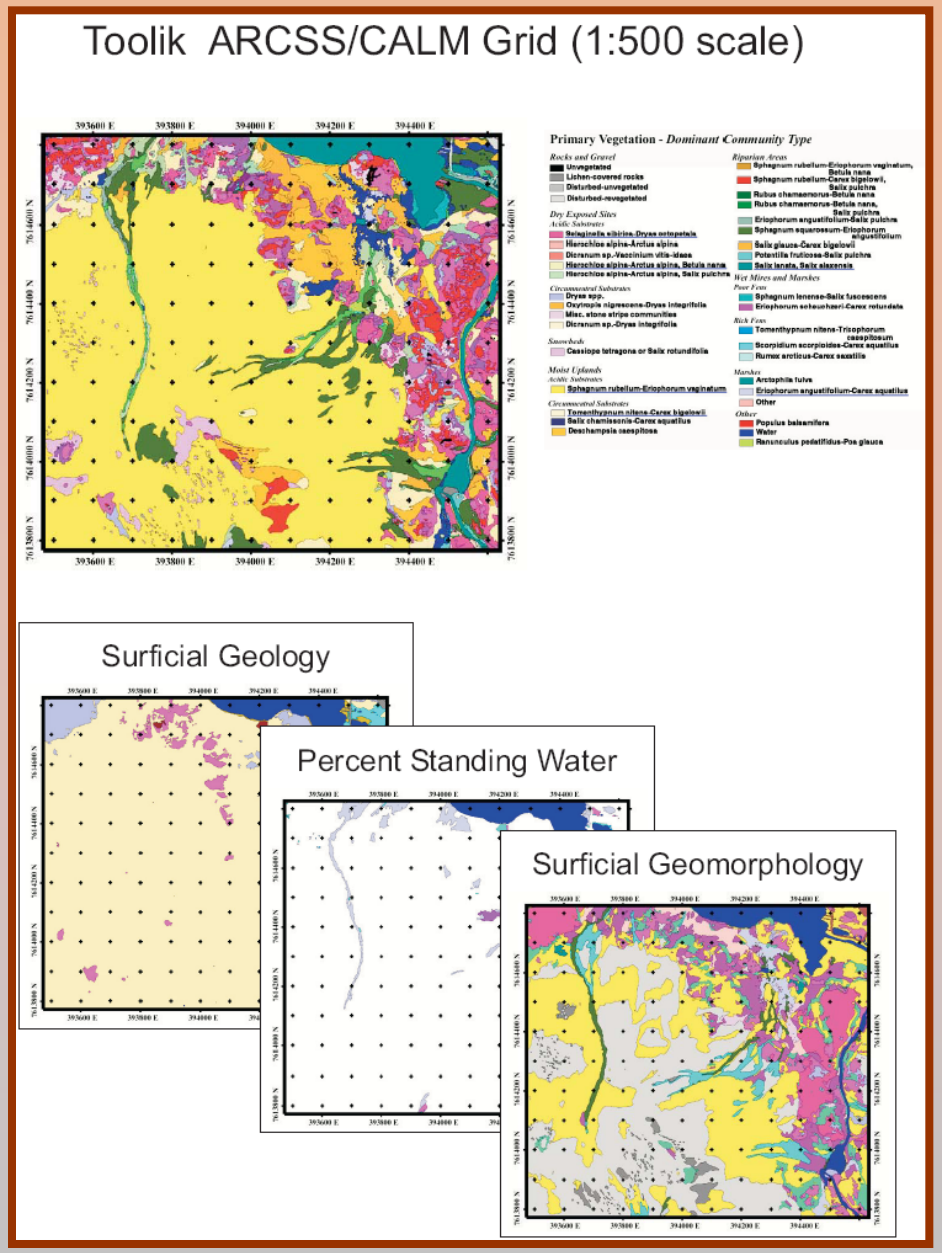


Photo Dictionary: links to map legends

GPD - Community Types: Moist Uplands http://www.geobotany.uaf.edu/arcticgeobot/dctmstup.html#sphrub_e...

Geobotanical Photo Dictionary

HOME | ATLAS STRUCTURE | MAPS | PHOTO DICTIONARY | CONTACT US

Community Type:

Moist Uplands

I. ACIDIC SUBSTRATES

II. CIRCUMNEUTRAL SUBSTRATES

I. MOIST UPLANDS: ACIDIC SUBSTRATES

Sphagnum rubellum-Eriophorum vaginatum *Close up:*

I. MOIST UPLANDS: CIRCUMNEUTRAL SUBSTRATES

Tomenthypnum nitens-Carex bigelowii *menthypnum nitens-Carex bigelowii*

Close up:

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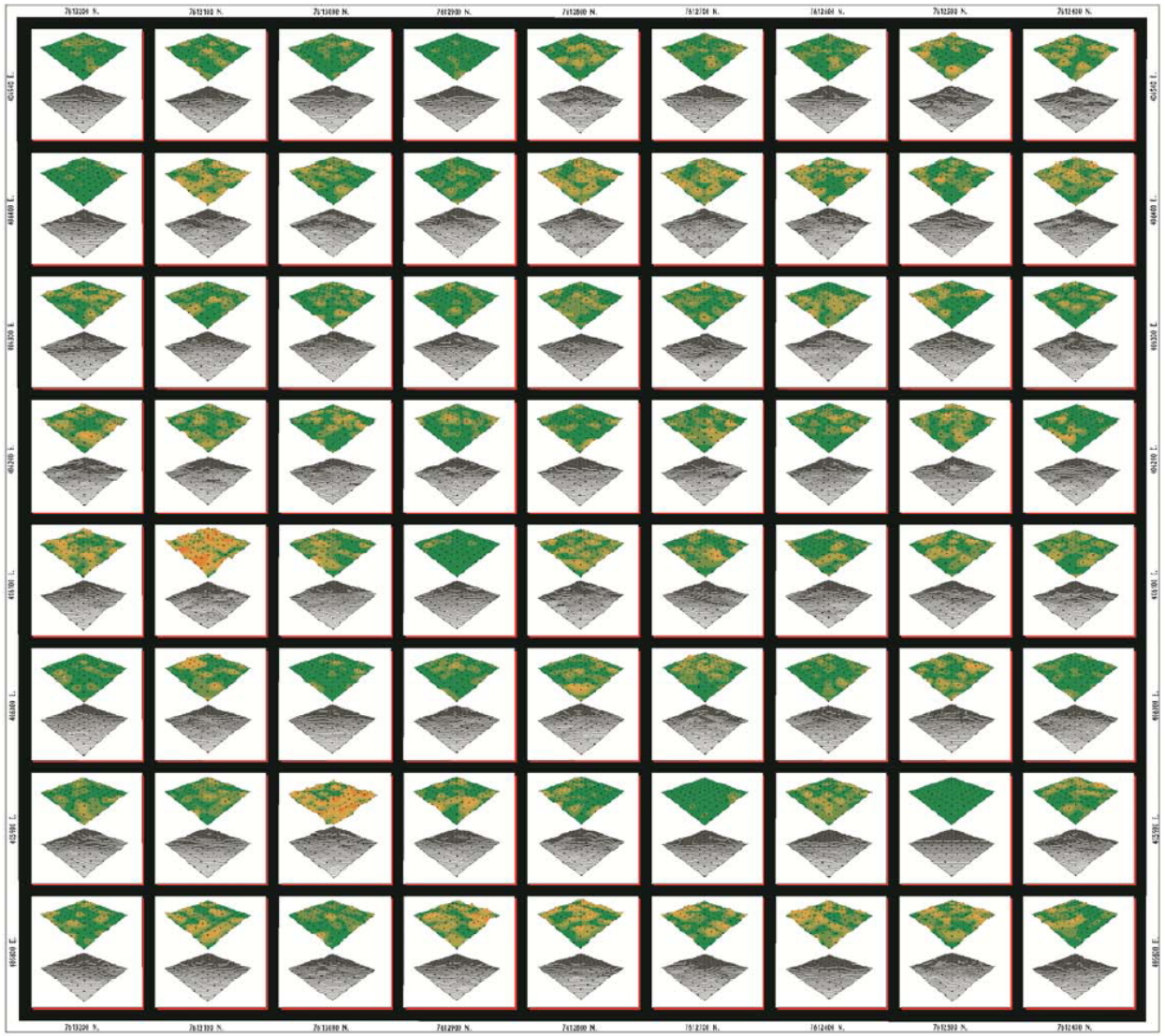
- *Photos and descriptions of legend units.*
- *Plans call for similar links to PDF files of critical literature, and Excel files for the supporting plot information (vegetation, soils, site factors).*

Plot-scale: 1x1-m plots at grid points

Microtopography of Toolik Lake Grid



1989 Microsite Topography and Canopy Structure

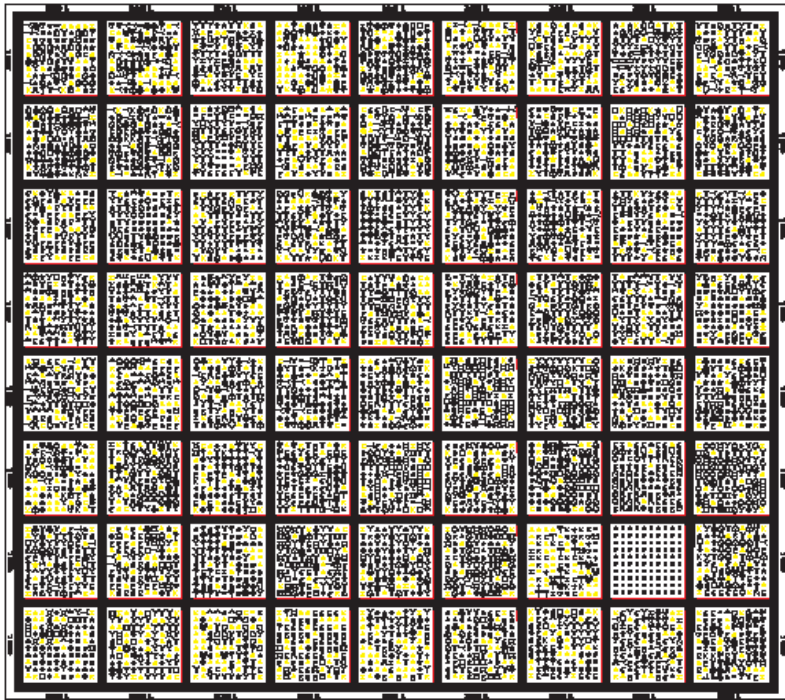
Explanation:
This matrix of plots shows the microtopography and vegetation structure at the 72 1 x 1-m plots at the gridpoints of the Imnavait Creek Grid. The lower layer in each pair of plots shows microtopography of the ground surface. The upper layer shows the height of the vegetation canopy at each of the 100 points in the plots. The colors portray the microtopography height classes according to the legend below.

- 30 –40
- 20 –30
- 10 –20
- 5 –10
- 2 –5
- 0 –2
- Sample point

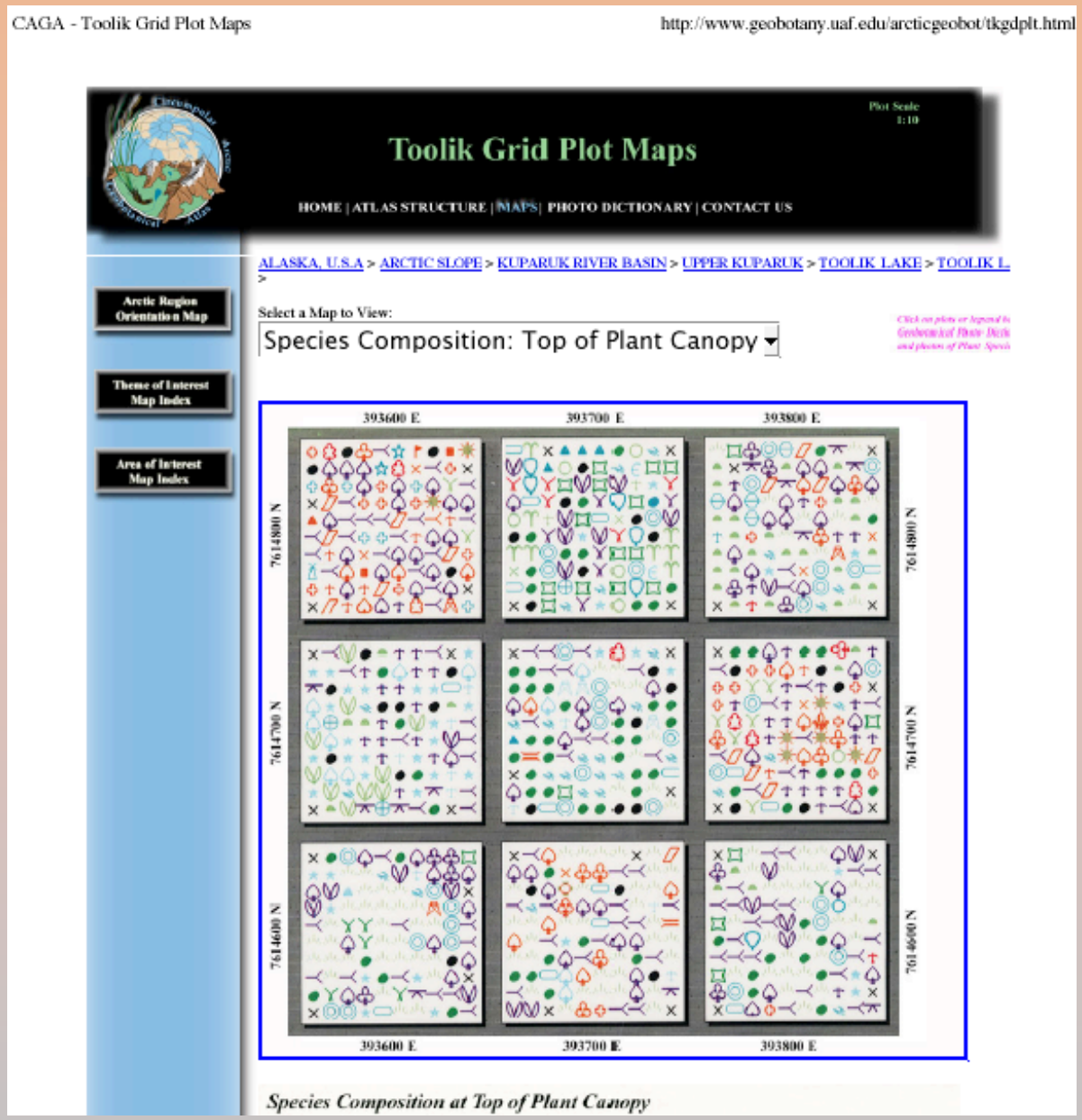
N

Plant species within 1-m plots

- *10-cm intervals, top and bottom of the plant canopy.*
- *Plots are permanently located so individual points can be resampled over time.*
- *Toolik and Imnavait Creek grids have been resampled at 6 year intervals to record changes in plant canopy structure and species composition.*



Detail of species maps



- *Colors represent plant functional types.*
- *Shape and color represent plant species.*

Map legend also has links to the Photo Dictionary for species photos

Species Composition at Top of Plant Canopy

This matrix of plots portrays the species at the top of the plant canopy at 100 points in each 1 x 1-m plot. Colors represent the growth form and the symbols plus color represent species.

Evergreen Shrubs
- *Andromeda polifolia*
- *Cassiope tetragona tetragona*
- *Diapensia lapponica ssp. obovata*
- *Dryas integrifolia integrifolia*
- *Empetrum nigrum hermaphroditum*
- *Ledum decumbens*
- *Oxytropis microcarpus*
- *Vaccinium uliginosum*
- *Vaccinium vitis-idaea minus*

Deciduous Shrubs
- *Arctostaphylos alpina*
- *Arctostaphylos rubra*
- *Betula nana exilis*
- *Rubus chamaemorus*
- *Salix arctica*
- *Salix glauca*
- *Salix lanata richardsonii*
- *Salix phlebophylla*
- *Salix pulchra*
- *Salix reticulata reticulata*

Forbs
- *Anemone parviflora*
- *Arnica frigida*
- *Cardamine hyperborea*
- *Draba sp.*
- *Epilobium latifolium*
- *Lagotis glauca minor*
- *Oxytropis maydelliana*
- *Oxytropis nigrescens s.l.*
- *Pedicularis oederi*
- *Pedicularis sp.*
- *Petasites frigidus*
- *Polygonum bistorta plumosum*
- *Polygonum viviparum*
- *Pyrola grandiflora*
- *Saussurea angustifolia*
- *Senecio atropurpureus frigidus*
- *Stellaria longipes*

Sphagnum
- *Sphagnum angustifolium*
- *Sphagnum balticum*
- *Sphagnum fuscum*
- *Sphagnum girgensohnii*
- *Sphagnum lenense*
- *Sphagnum rubellum*
- *Sphagnum sp.*
- *Sphagnum squarrosum*
- *Sphagnum teres*
- *Sphagnum warnstorfii*

Graminoid Monocots
- *Arctagrostis latifolia*
- *Calamagrostis sp.*
- *Carex aquatilis s.l.*
- *Carex bigelowii*
- *Carex microchaeta*
- *Carex misandra*
- *Carex nardina*
- *Carex podocarpa*
- *Carex rariflora*
- *Carex rotundata*
- *Eriophorum brisle*
- *Eriophorum vaginatum*
- *Hierochloe alpina*
- *Poa arctica*
- *Tofieldia coccinea*

Non-Sphagnum Bryophytes
- *Anastrophyllum minutum*
- *Aulacomnium palustre*
- *Aulacomnium turgidum*
- *Blepharostoma trichophyllum brevirete*
- *Calliergon stramineum*
- *Caloscopium nigritum*
- *Climaceum dendroides*
- *Dicranum acutifolium*
- *Dicranum angustum*
- *Dicranum elongatum*
- *Dicranum groenlandicum*
- *Dicranum scoparium*
- *Distichium capillaceum*
- *Ditrichum flexicaule*
- *Drepanocladus revolvens*
- *Drepanocladus uncinatus*
- *Fissidens osmundioides*
- *Hylocomium splendens oblusifolium*
- *Hypnum bambergeri*
- *Lophozia sp.*
- *Paludella squarrosa*
- *Pleurozium schreberi*
- *Pogonatum alpinum*
- *Polytrichum juniperinum*
- *Polytrichum piliferum*
- *Polytrichum sp.*
- *Ptilidium ciliare*
- *Ptilium crista-castrensis*
- *Racomitrium lanuginosum*
- *Rhytidium rugosum*
- *Scapania simsonii*
- *Tomenthypnum nitens*
- Unknown moss

Lichens and Fungus
- *Alectoria nigricans*
- *Alectoria ochroleuca*
- *Arahinea chrysantha*
- *Cetraria cucullata*
- *Cetraria islandica*
- *Cetraria nivalis*
- *Cladonia amaurocraea*
- *Cladonia arbuscula*
- *Cladonia ecmocyna*
- *Cladonia gracilis*
- *Cladonia mitis*
- *Cladonia pocillum*
- *Cladonia pyxidata*
- *Cladonia rangiferina*
- *Cladonia sp.*
- *Cladonia uncialis*
- *Cornicularia divergens*
- *Dactylina arctica*
- *Dactylina beringica*
- *Dactylina ramulosa*
- *Lobaria pseudopulmonaria*
- *Masonhalea richardsonii*
- *Nephroma arcticum*
- *Nephroma expallidum*
- *Ochrolechia frigida*
- *Parmelia sp.*
- *Peltigera aphthosa*
- *Peltigera canina*
- *Peltigera polydactyla*
- *Pertusaria dactylina*
- *Pertusaria sp.*
- *Psoroma hypnorum*
- *Solorina spongiosa*
- *Sphaerophorus globosus*
- *Stereocaulon alpinum*
- *Thamnolia subuliformis*
- Unknown crustose lichen
- Unknown crustose lichen black
- Unknown fungus
- Unknown gelatinous lichen

Non-Living
- Caribou scat
- Litter
- Ptarmigan scat
- Registration marker
- Rock
- Soil
- Water

Pteridophytes
- *Equisetum arvense*
- *Equisetum scirpoides*

GPD - Lichens http://www.geobotany.uaf.edu/arcticgeobot/dsplichen.h

Geobotanical Photo Dictionary

HOME | ATLAS STRUCTURE | MAPS | PHOTO DICTIONARY | CONTACT US

Plant Species:

Lichens and Fungus

Cetraria cucullata

Dactylina arctica

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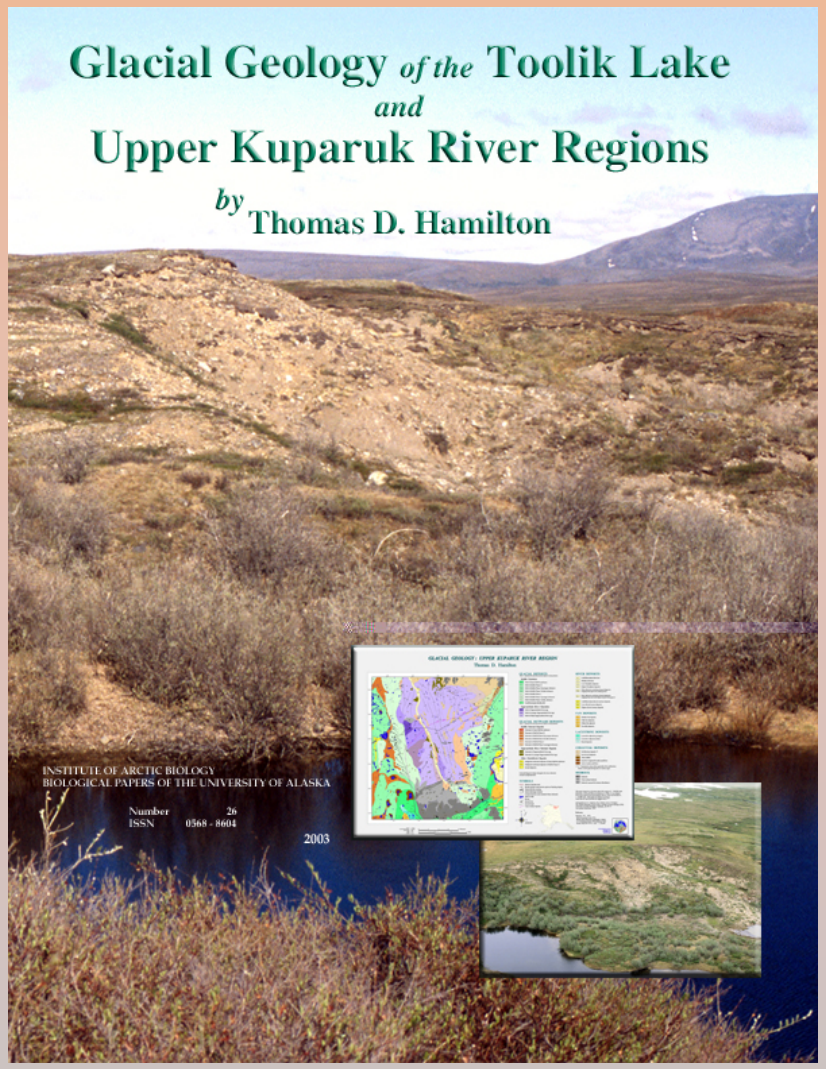
Metadata



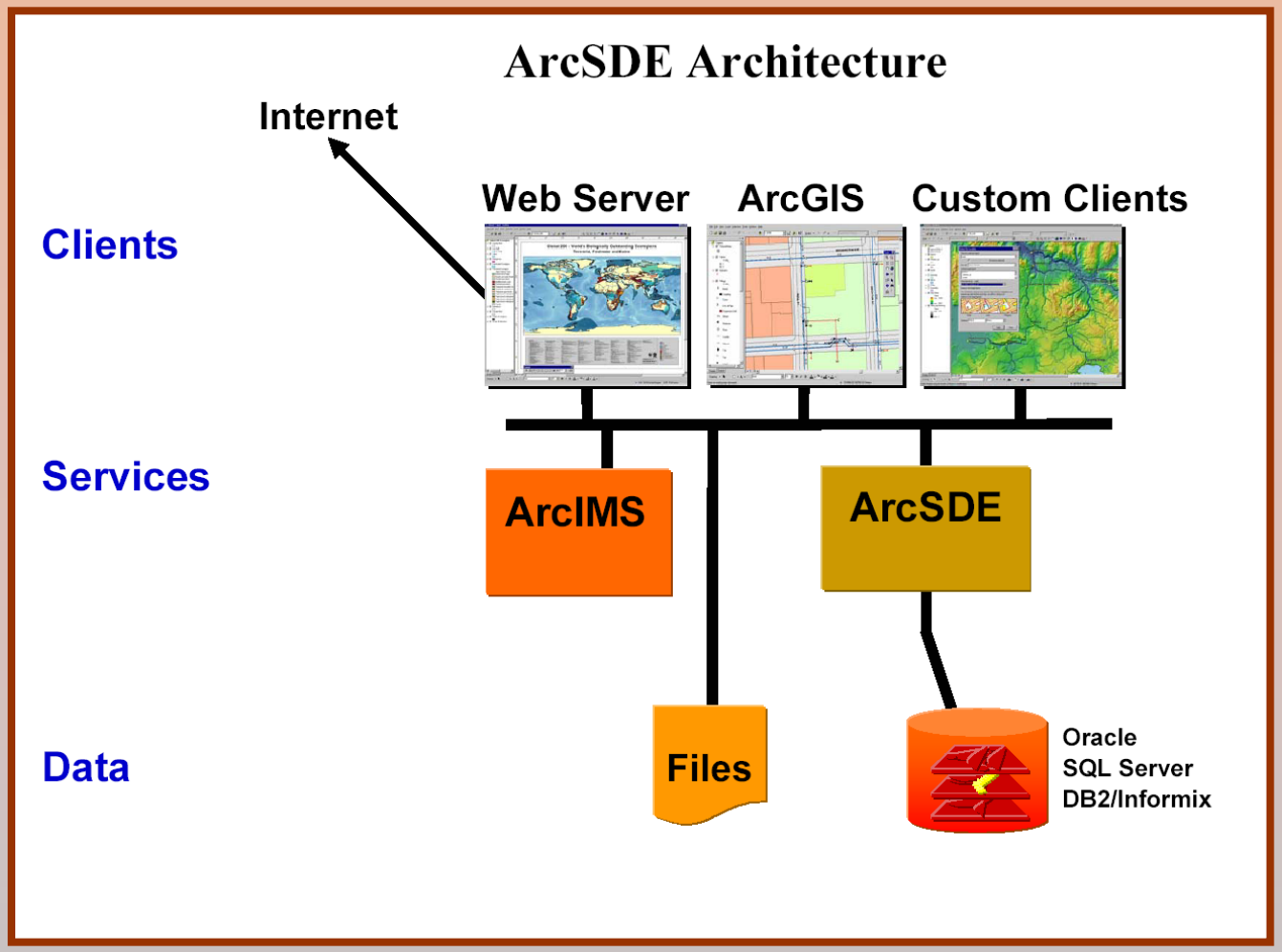
- *Thorough documentation of mapped information in peer-reviewed literature. (For example, Hamilton's description of glacial geology units, IAB Biological Papers Series No. 26)*

- *Documentation of GIS files to National Standards (Content Standard for Digital Geospatial Metadata, CSDGM).*

Consultation with ESRI…

Help with:

- *IMS interface,*
- *System architecture,*
- *Hardware.*



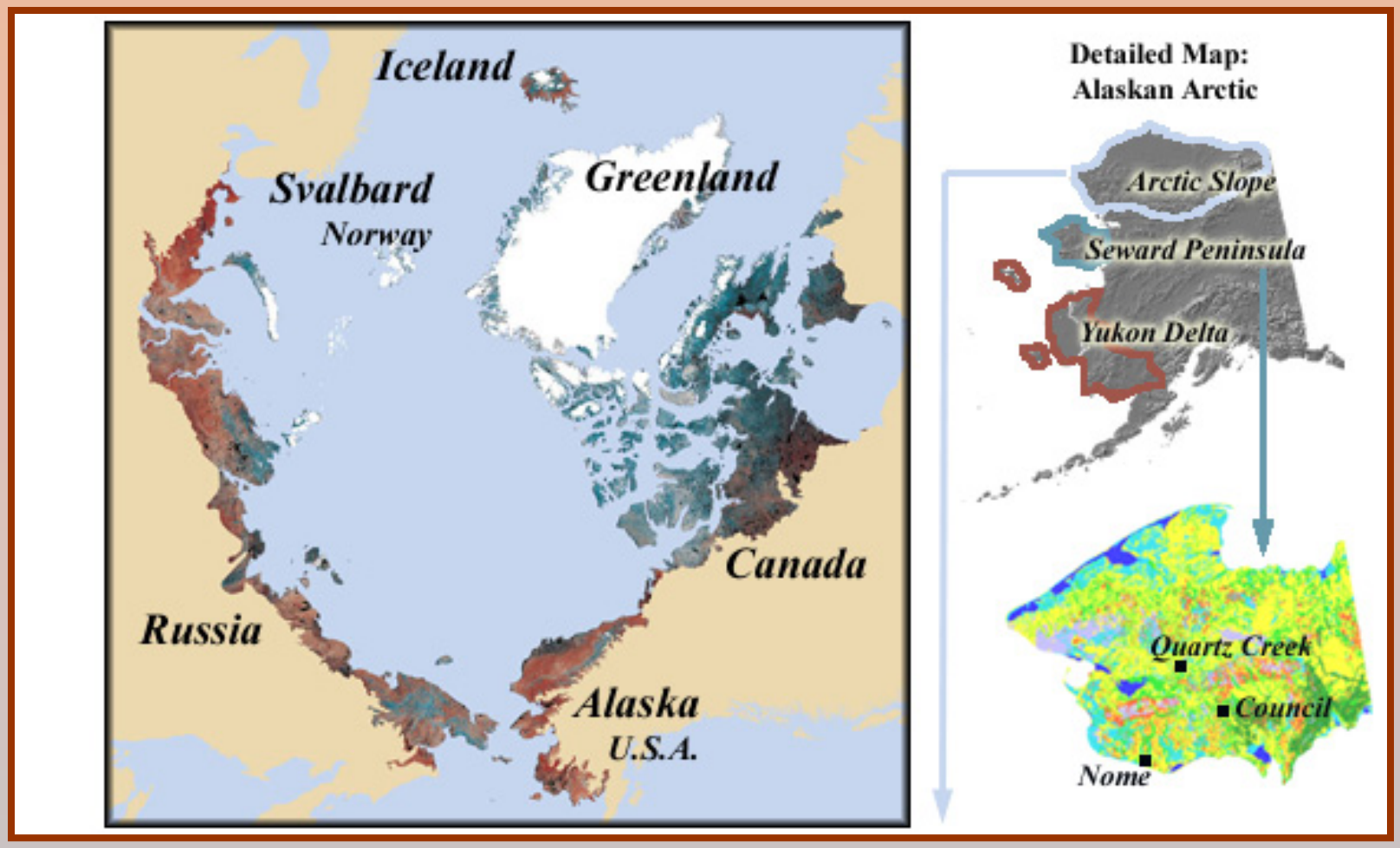
Vision for a Web-based Toolik-Kuparuk River Geobotanical Atlas

- *Link GINA, ARSC, Toolik GIS facility, and AGC to form a northern Alaska node of the Arctic GIS.*
- *Develop a highly interactive, high-speed, fully functional web-based hierarchic geobotanical GIS to serve the research needs of the Toolik Field Station and others working within the Kuparuk River Basin.*
- *Convert the existing maps from PDF files into ArcIMS files so the data are available and fully functional over the Web. A major task to accomplish this is to co-register all maps to a common high-resolution topographic base map.*
- *Develop the research tools, applications and analyses needed by researchers to access and use data. Fully develop the Toolik Natural Resource Tool.*
- *Develop visualization products and user friendly interfaces for the public and schools to access and use the Atlas.*
- *Fully document the data within the Atlas through publications and Federal metadata standards.*

Possible prototype for GISs at other Arctic locations…

…Emphasis on the nodes.

The horizontal dimension: Location



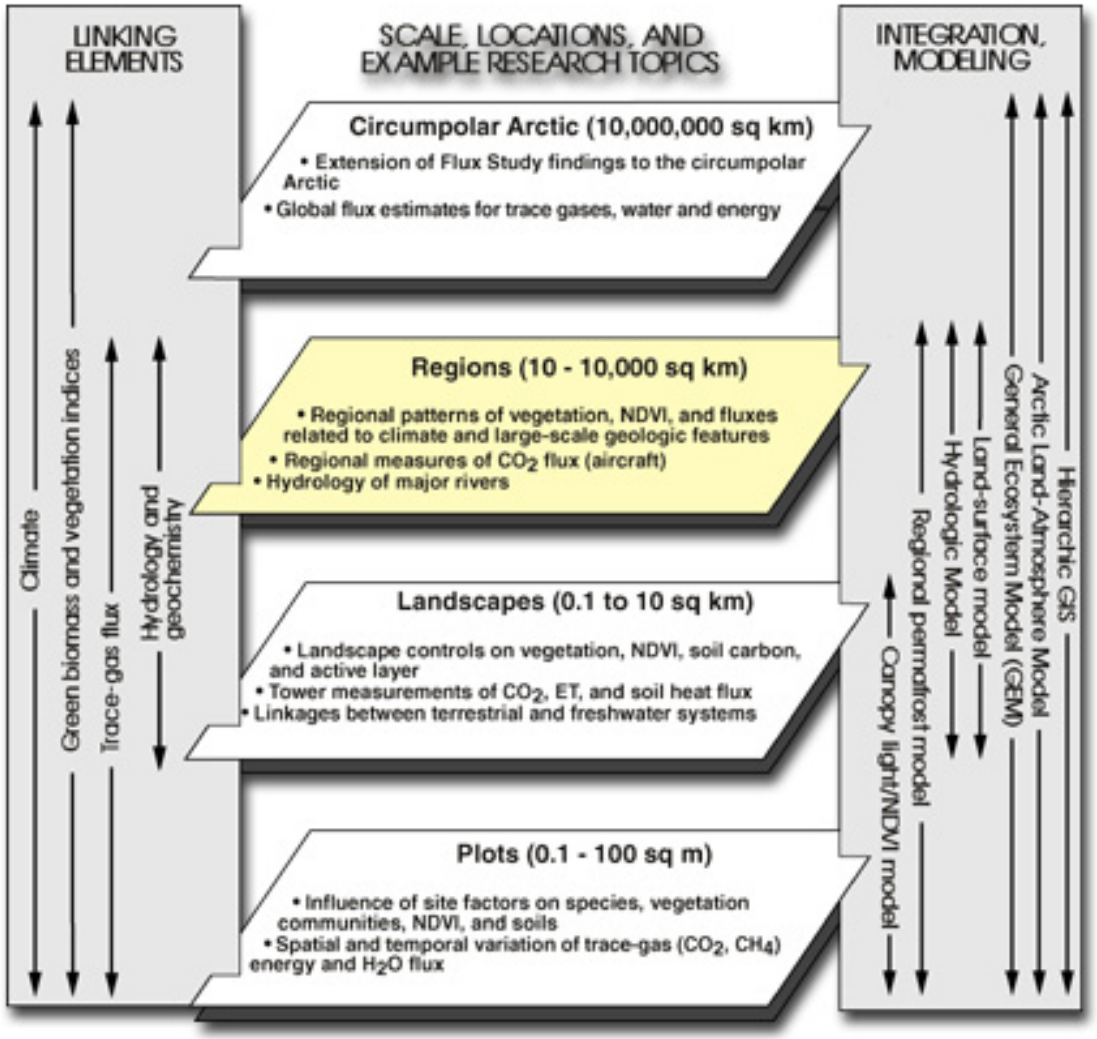
Vertical dimension: scale of maps

Macroscale Megascale
Macroregion

Mesoscale
Microregion Mesoregion

Microscale...
Mesosite Macrosite

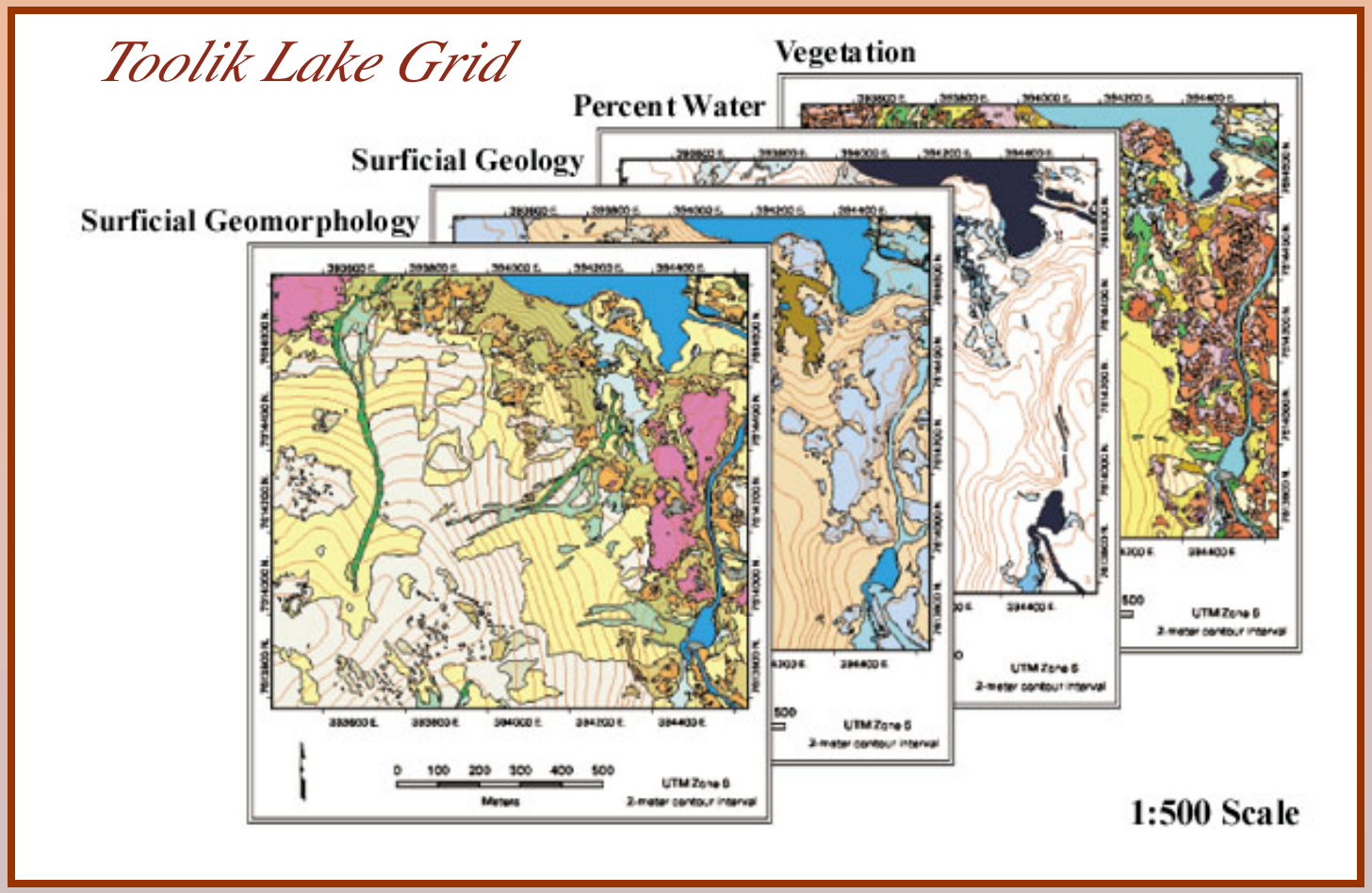
...Microscale
Microsite



(Delcourt and Delcourt, 1988)

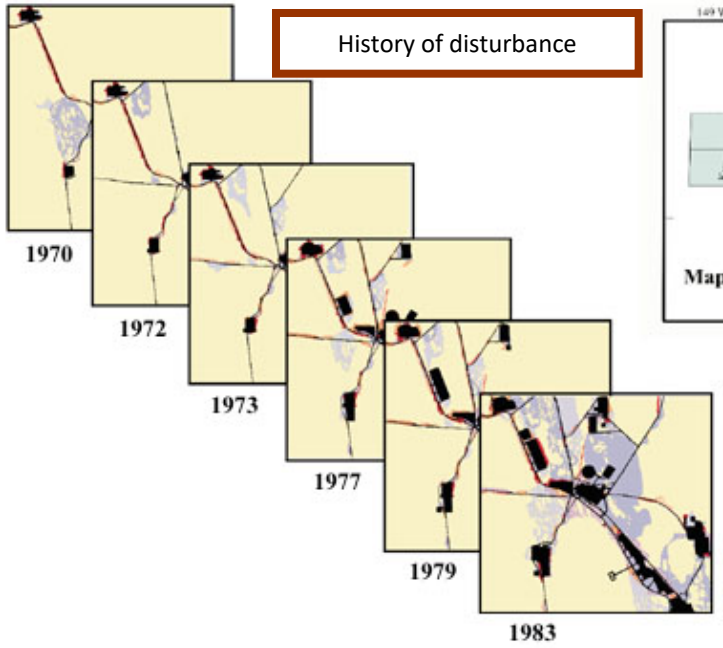
(Walker and Walker, 1991)

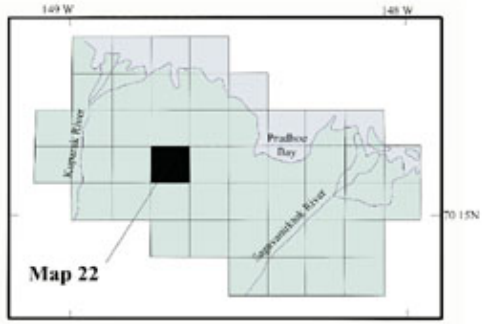
Depth dimension: Map themes or attributes



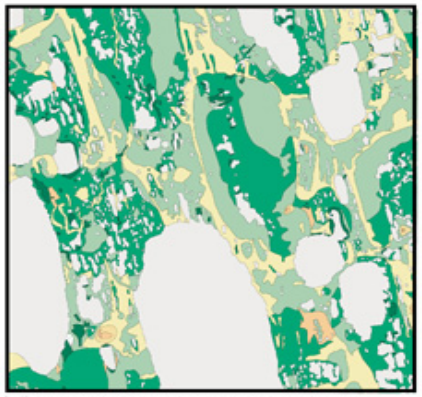
Time dimension: Historic changes

History of disturbance

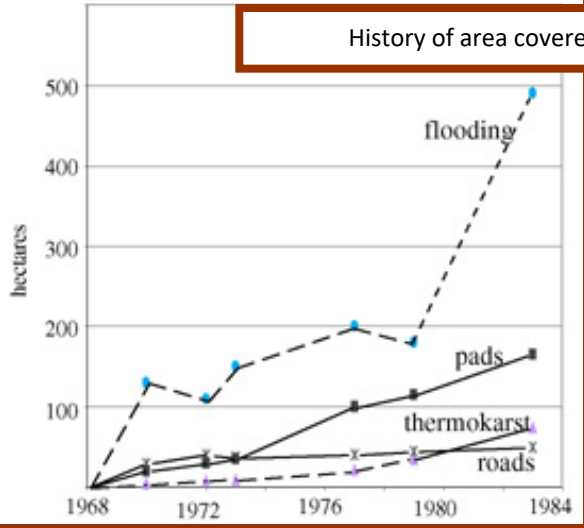




Predevelopment vegetation

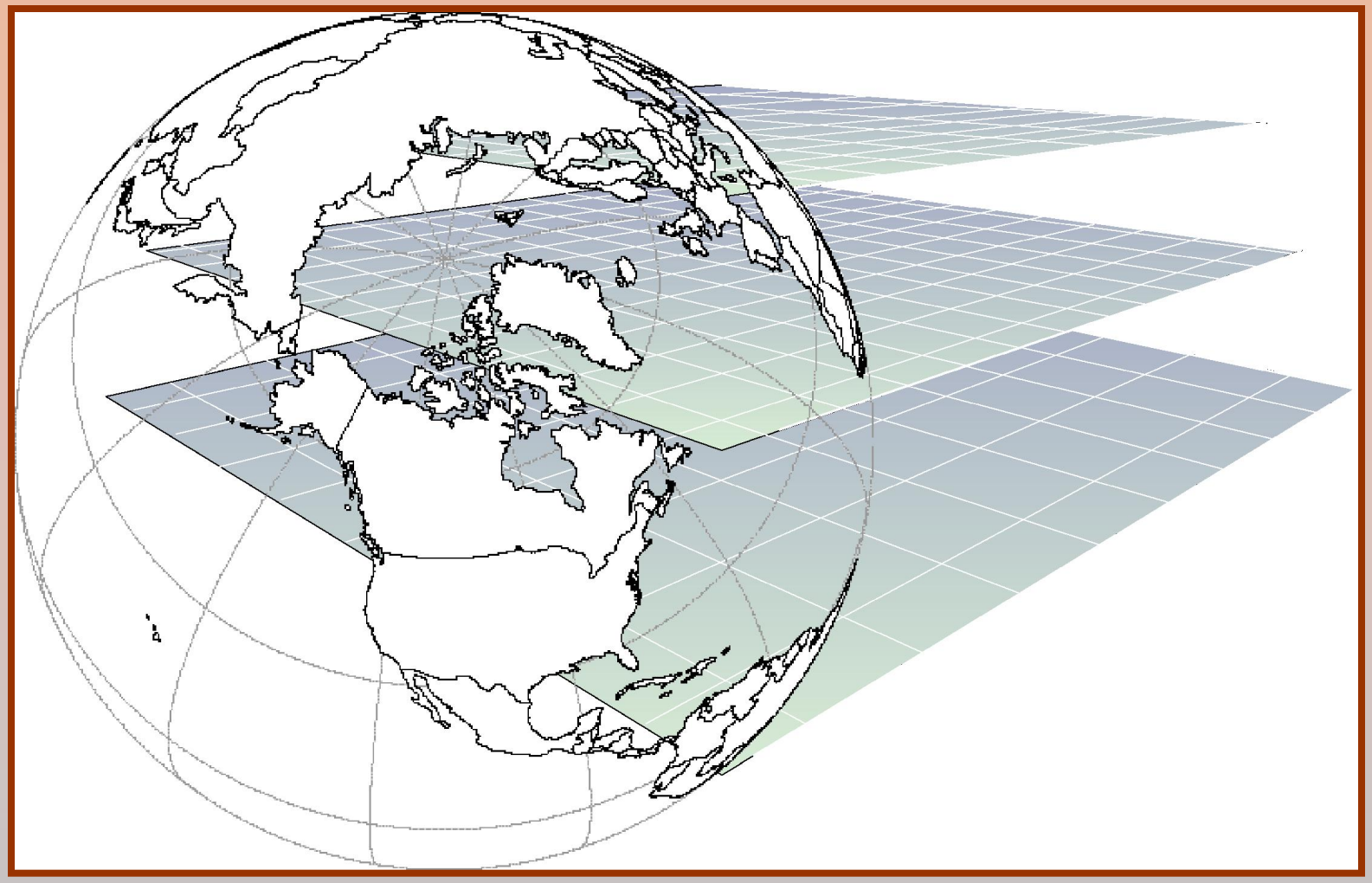


History of area covered by four disturbance types



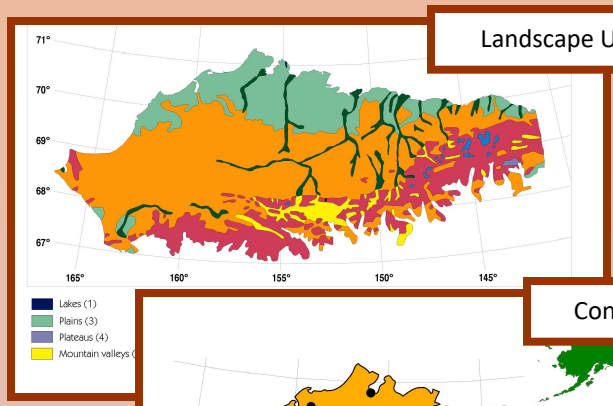
- *1:6000-scale mapping of the Prudhoe Bay Oil Field*
- *Cumulative impacts of oil field development*

GIS: A means to bring the pieces together

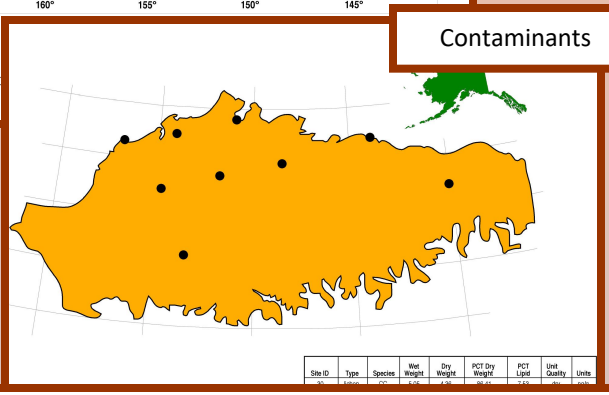


GIS is key tool for answering scientific and societal questions

Societal concerns regarding caribou



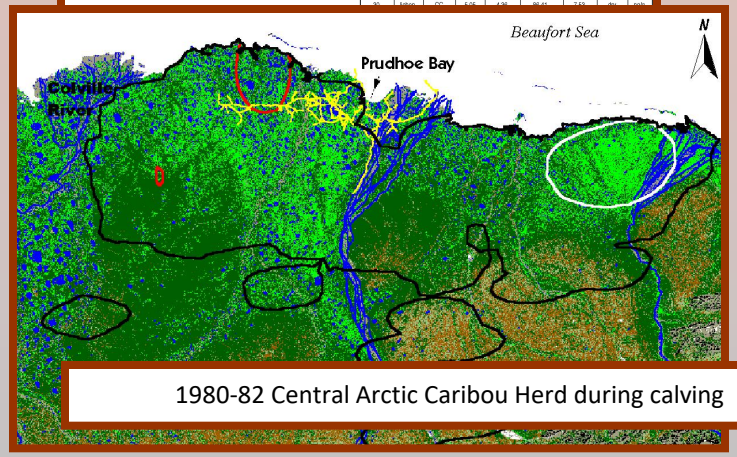
Landscape Units



Contaminants

For example:

- *Is there a relationship between vegetation, water cover, topography and caribou calving success?*
- *Is the distribution of atmospherically-transported contaminants controlled by the Arctic Front? And are levels of contaminants related to phytogeographic subzones?*
- *Is there any danger from contaninants in eating caribou hunted during the migration of the Central Arctic Herd?*



1980-82 Central Arctic Caribou Herd during calving