Characterizing Frozen Ground with Multisensor Remote Sensing

B.M. Csatho (SUNY Buffalo), C. Ping, G. Michaelson (U of Alaska), L.R. Everett. C. Tremper (BPRC, OSU) and J.M. Kimble (Soilcarbon)

Overview

- Motivations and goals
- Sensors and data sets
- Automation of mapping landscape units and geomorphological features from high-resolution DEMs
  - Non-sorted polygons, Beacon Valley, TAM, Antarctica
- Fusion of multisensor data using object-based classification
  - Sagwon, Arctic Foothills, North Slope, Alaska

Motivation and Goal

- Motivation: changing climate can cause significant changes in permafrost and cold region soil, such as
  - Increase of active layer depth
  - Increasing release of greenhouse gases
  - Changes in hydrological cycle
  - Erosion and damage to infrastructure, etc.
- Goal: Develop methods for determining soil and permafrost distribution from multi-sensor, multi-resolution and multi-temporal remotely sensed data in conjunction with point observations (soil pits, vegetation, climate, etc., data) to map and monitor changes on a regional scale.

Sensors and Data, Remote Sensing

1. Mapping and monitoring vegetation, exposed soils, components of the hydrologic cycle, surface and subsurface temperature. Imaging sensors: VIS, NIR, thermal IR, SAR, passive microwave, hyperspectral
2. Mapping and monitoring surface topography and changes: photogrammetry (analog and digital), SAR/InSAR, LIDAR

LIDAR mapping McMurdo Dry Valleys

- Hyperarid, polar desert
- Contains a variety of landscapes, some of them are very ancient
- Current research on geologic history, landscape evolution and climate with implications on the stability of the east Antarctic ice sheet and on ecosystems
- Probably the best analogue of Marsian surfaces

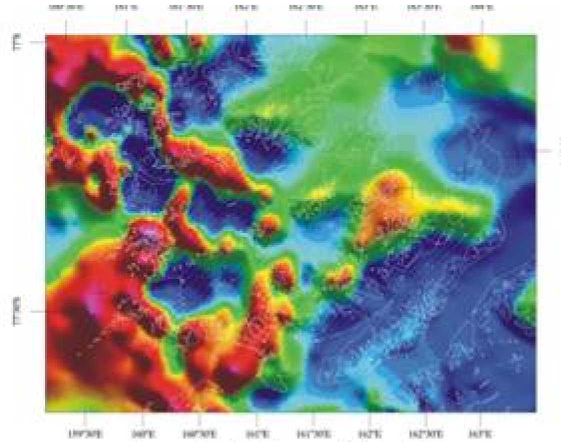
LIDAR Mapping McMurdo Dry Valleys

- Intensive exploration since Scott's Discovery expedition (proximity of McMurdo base)
- Diverse data sets and detailed maps are available
- Used as calibration/validation site for ICESat and therefore high resolution and accurate DEM (2 meter resolution, <0.1 m accuracy)

Objective:

Using approaches from photogrammetry, computer vision, remote sensing, Geographic Information System(GIS) and Artificial Intelligence (AI)

- to fuse multisensor data to map geomorphologic features, soil and landscape units



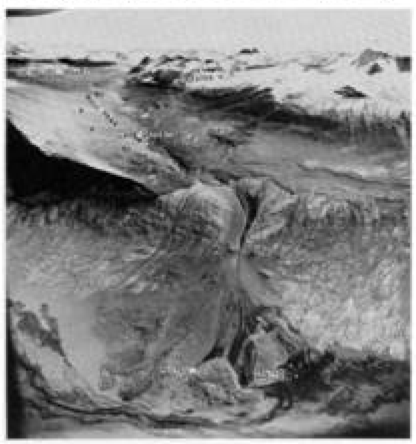
Magnetic field map of Dry Valleys with outcrops (C. Finn, USGS)

Digital aerial photographs of Webb glacier and patterned ground

Data Sets:

Multispectral satellite imagery (Landsat, ASTER)
SAR imagery
Hyperspectral imagery
Aerial photographs and digital imagery
Geologic maps
Geophysical data (gravity and magnetic field, bedrock surface)
Digital Elevation Models from 1:50,000 topographic maps

Aerial view of Bull Pass (US Navy photograph, 1958; from Calkin, 1971)



Tools:

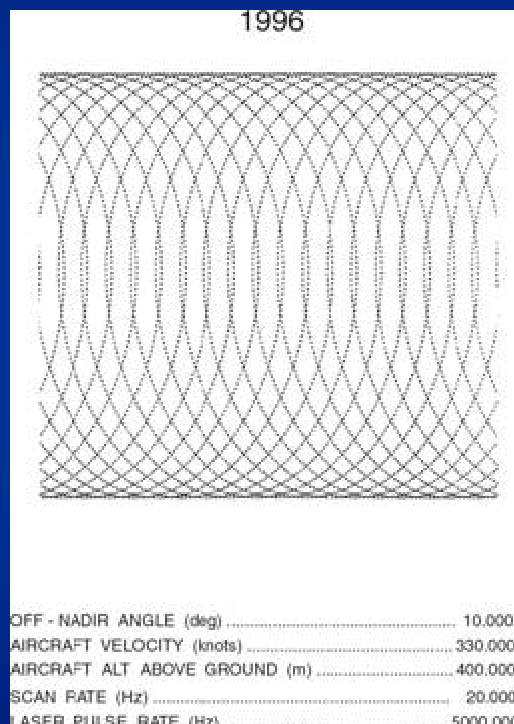
Remote and image processing: ERDAS, PCI, ENVI
GIS: ArcGIS
Pattern recognition: eCognition
Visualization: Surfer
Database: Oracle
Software tools developed by OSU photogrammetry group (Toni Schenk) in Matlab, C++ and IDL for interpolation, visualization, geocoding and segmentation

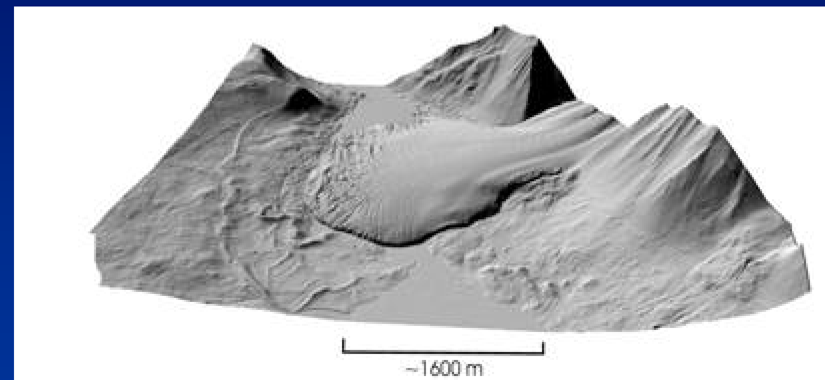
HYPERION hyperspectral satellite imagery

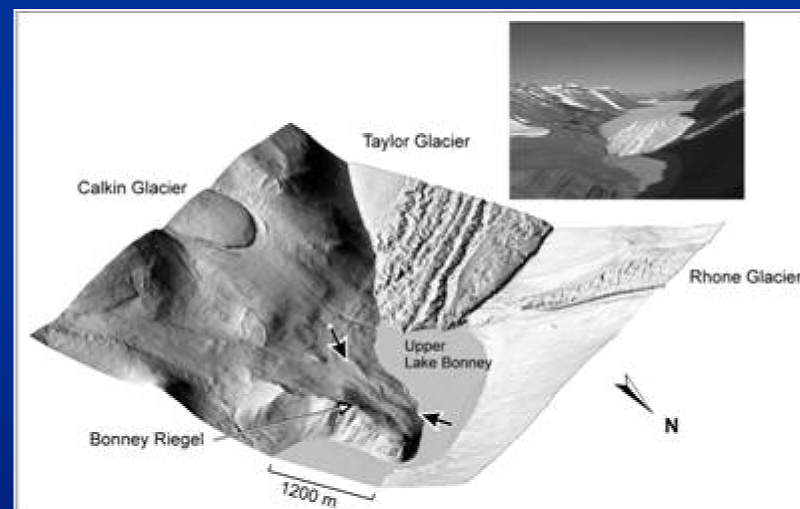
Airborne Laser Altimetry

Airborne Topographic Mapper (NASA WFF)

NASA's Topographic Mapper scanning laser system and distribution of points on the ground



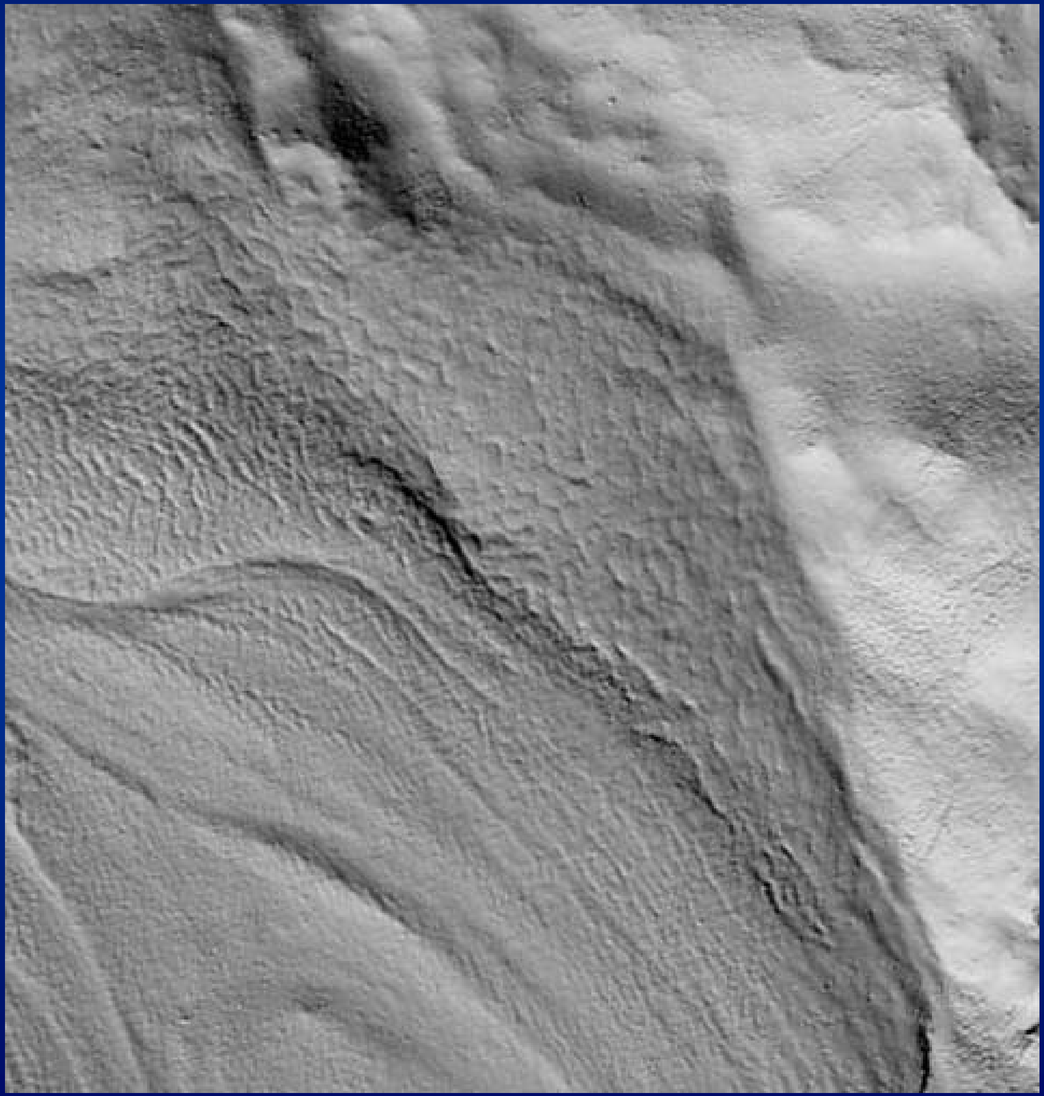




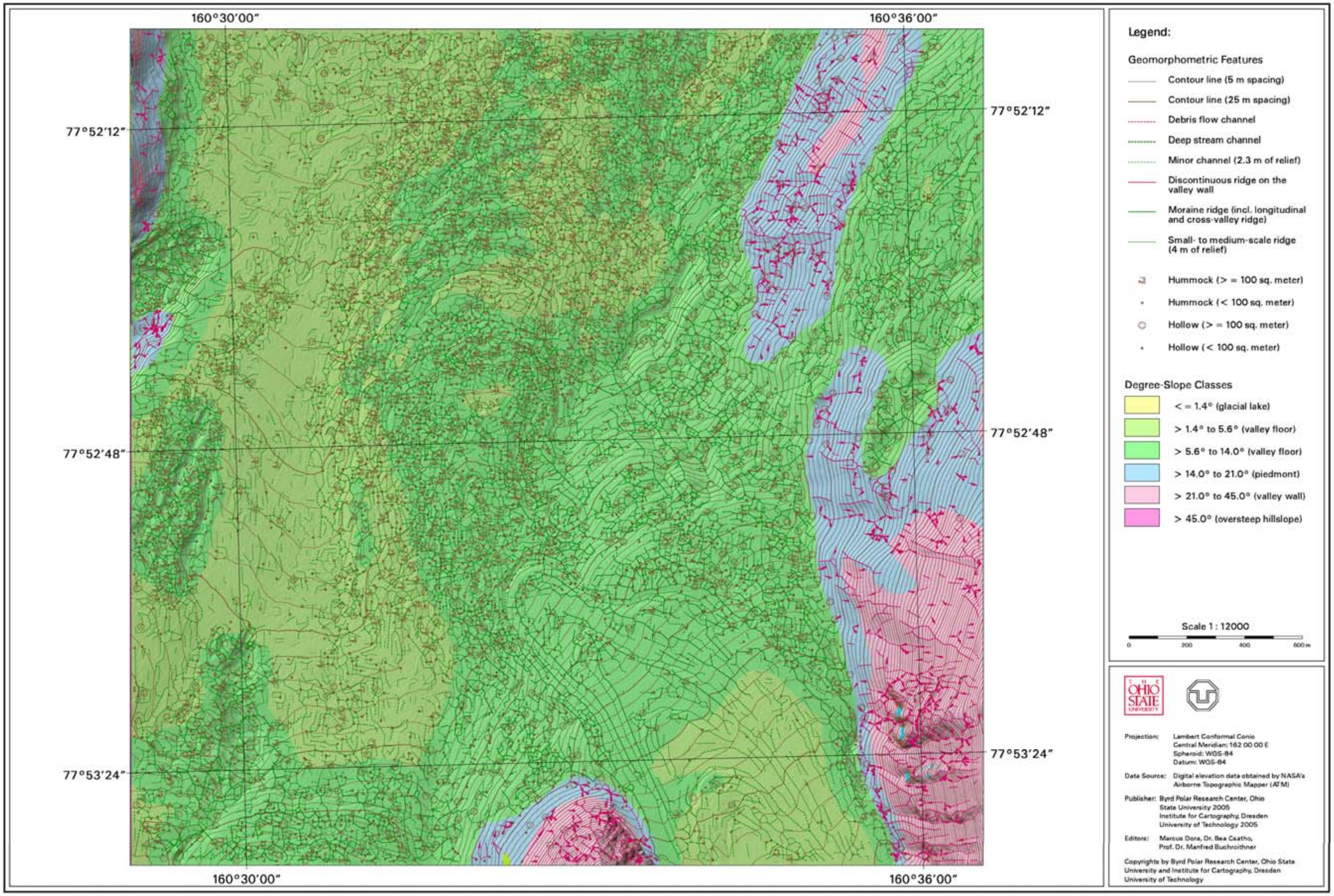
Airborne Laser Scanning for High-Resolution Mapping of Antarctica (Csatho et al., 2005, *EOS*)

Patterned Ground and Rock Glacier Beacon Valley

- Surface is composed of sand-wedge casts (relict sand wedge polygons)
- These nonsorted polygons are underlain with ice-cemented permafrost in ~100 cm depth
- Depth of sand-wedge casts suggest that ice-cemented permafrost was higher in geologic times (Bockheim, 2002)
- There is an ongoing debate about the age of the rock glaciers in Baecon Valley (> 8 Ma)
- High resolution topography is needed as input for modeling studies

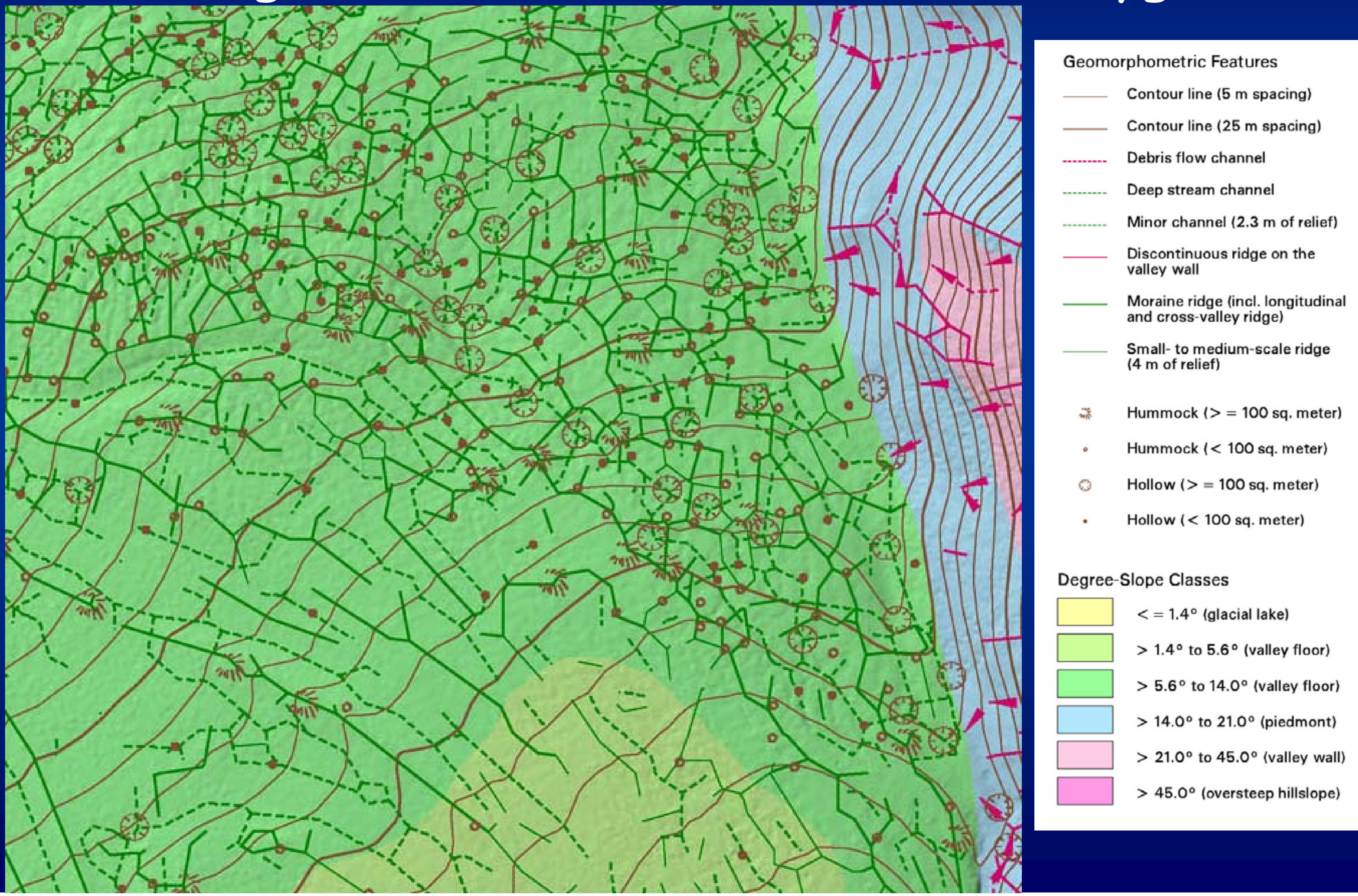


Geomorphologic Map of Beacon Valley (rock glacier and valley floor)

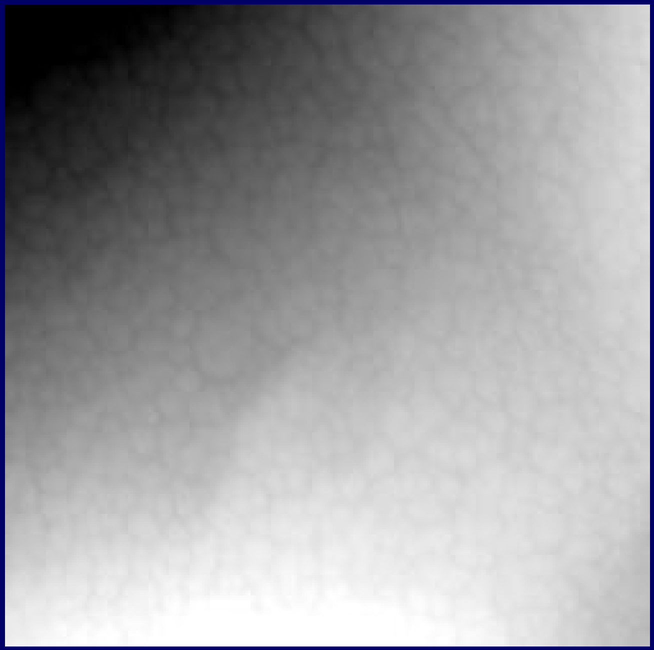


Marcus Dora, MS Thesis, 2003; University of Dresden

Geomorphologic Map Does not Provide Explicit Information about the Geometry of Higher Level Features such as Polygons



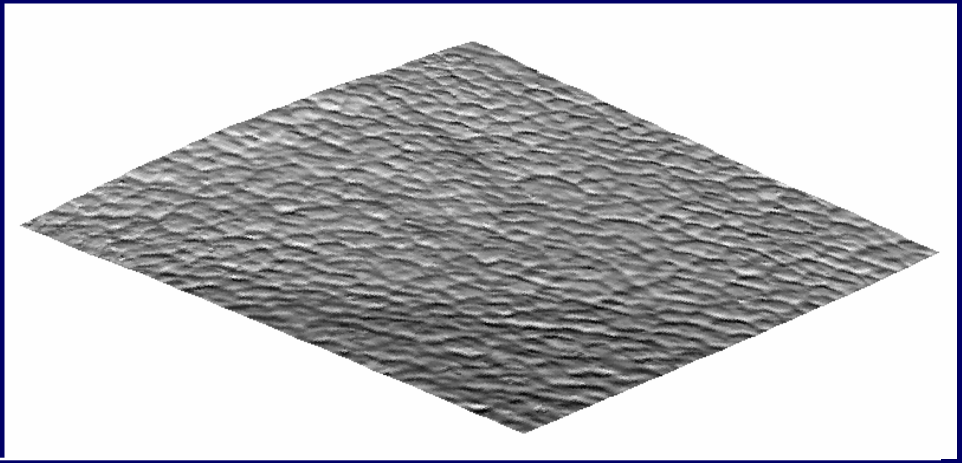
DEM



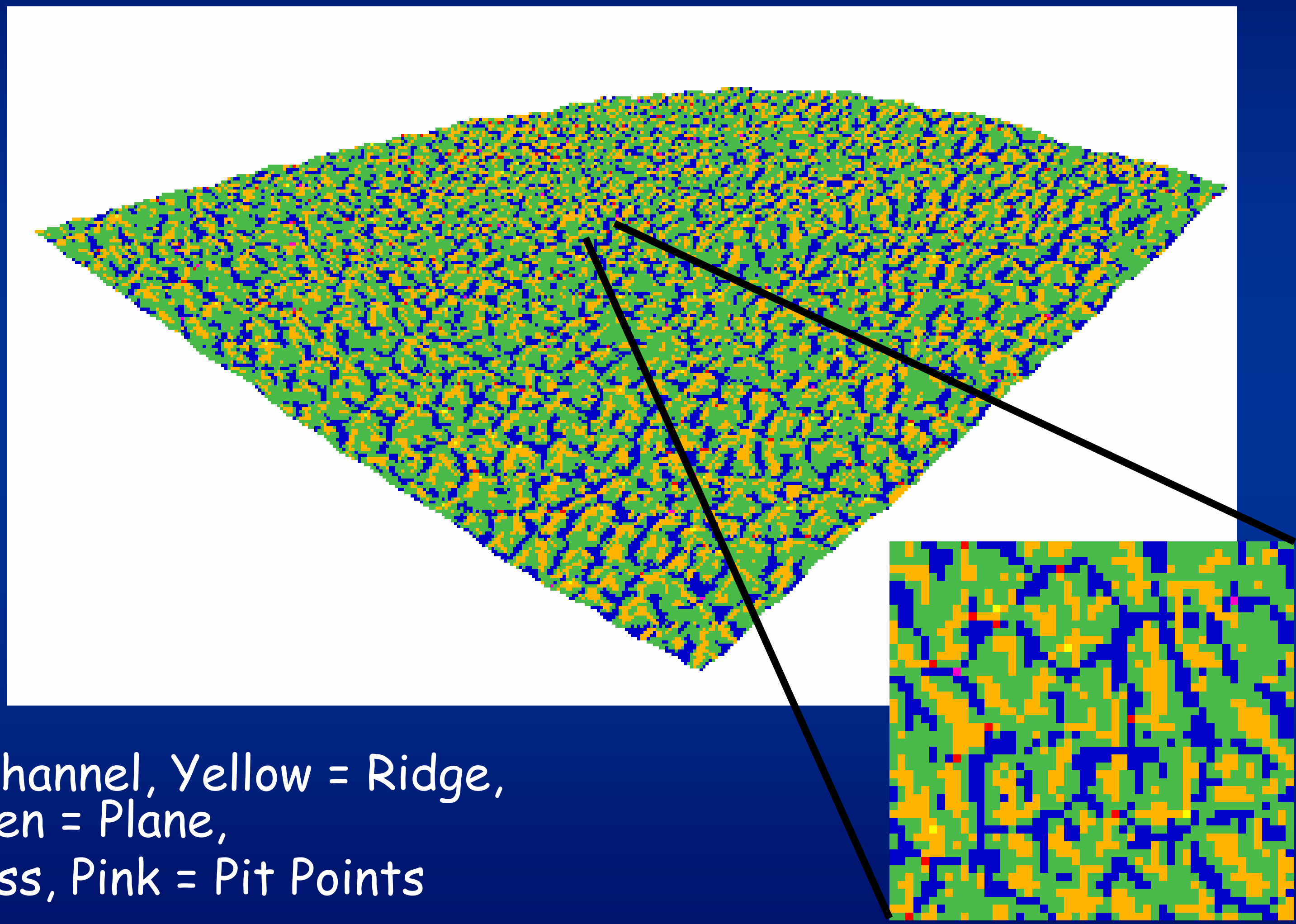
500 m * 500 m
2 m grid cell size
Elevation ranges from 1537 → 1566 m

Digital Aerial Photograph

Visualization of DEM as shaded relief



Geomorphometric Features Extracted from DEM



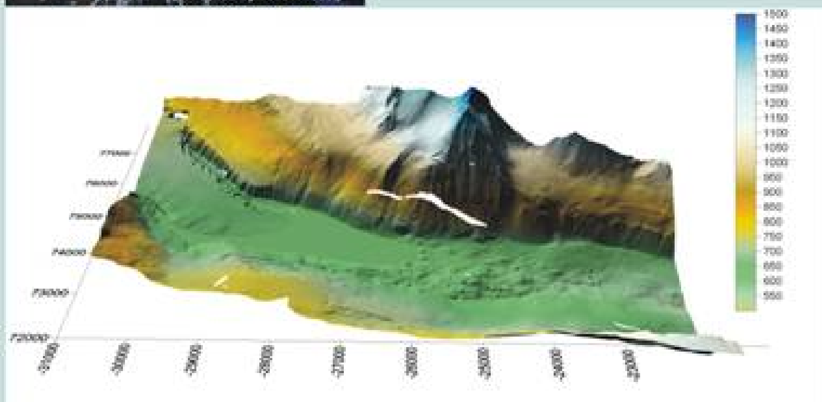
Blue = Channel, Yellow = Ridge,
Green = Plane,
Red= Pass, Pink = Pit Points

Alternative Approach for Extracting and Reconstructing Polygons

- Computing trend surface and high frequency surface component using spatial or frequency domain operations
- "Closing" the channels around the polygons by using morphological filtering of high frequency component of the surface
- Invert the surface so that channels become ridges
- Using a modified watershed algorithm to find enclosed basins → each basin correspond to a polygon

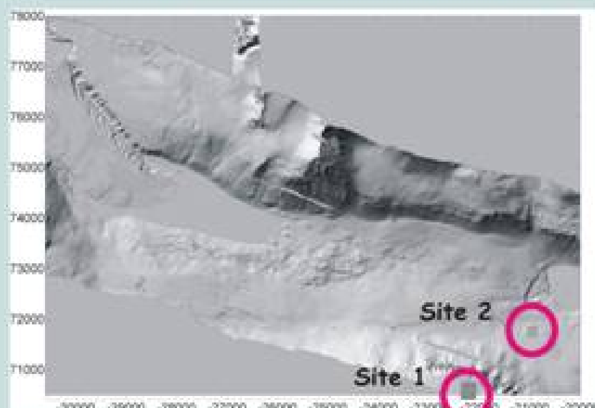
Characterizing Patterned Ground Using High-resolution DEMs

Digital aerial photographs of patterned ground in Barwick Valley

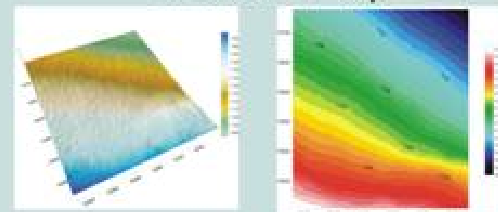


(color code is elevation in meter, LCC coordinates in meter)

3D and shaded relief views of 2 meter resolution DEM with study sites



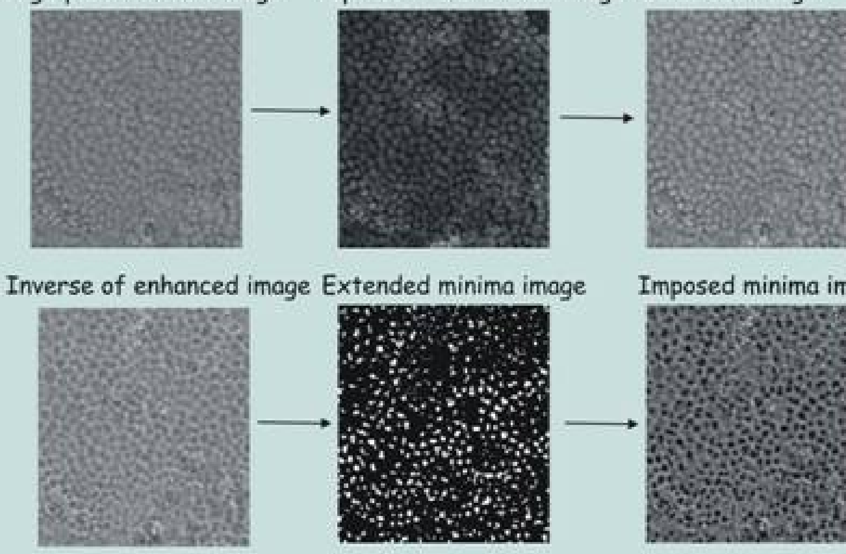
Enlarged detail of patterned ground from DEM in 3D and on contour map



Processing steps

High pass filtered image → Top-hat transformed image → Enhanced image

Inverse of enhanced image → Extended minima image → Imposed minima image



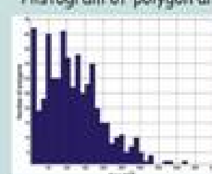
Results

Site 1

Segmented image

330 by 300 meters

Histogram of polygon areas

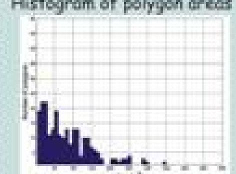


Site 2

Segmented image

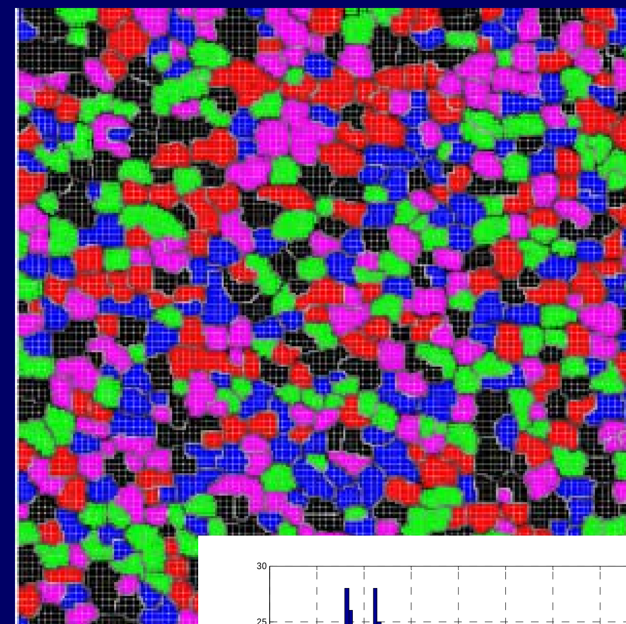
200 by 200 meters

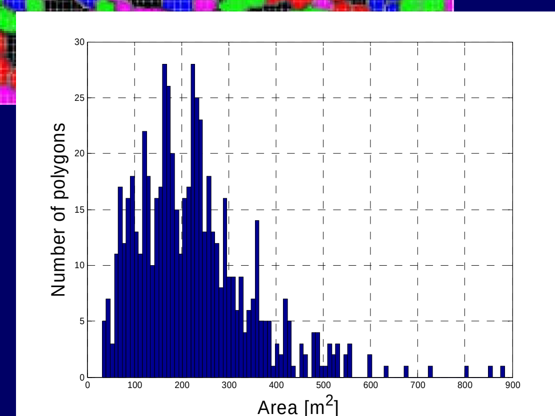
Histogram of polygon areas



Extracting and Reconstructing Polygons

- Result:
  - Polygon boundaries described by chain-code for each polygon
  - Analytical surfaces (2nd order) fitted to each polygon
- Advantages:
  - Direct input for modeling and statistics
  - Edges and boundaries are ideal for fusion with other sensory data





Differentiation of Rocks and Unconsolidated Materials from Spectral Measurements from Space

Results

Spectra of tills and bedrock from HYPERION hyperspectal satellite imagery

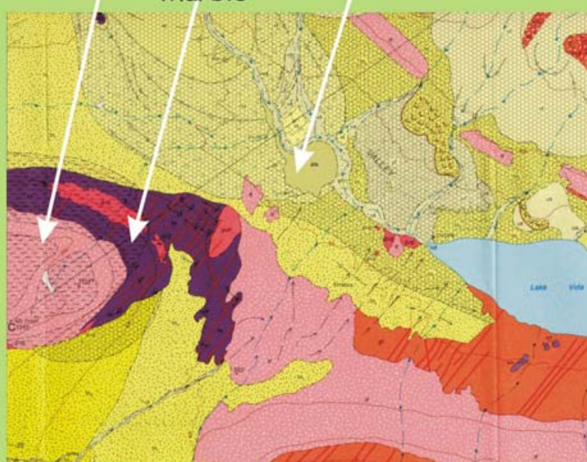
Upper panel: spectra of tills with varying amounts of boulders, cobbles, sand, and silt have similar shape but different amplitude

Lower panel: spectrumof marble shows flat reflectance in visible and high reflectance in NIR, while dolerite has an has darker color and larger absorption, especially in higher wavelength. Till spectrum is a linear mixture of ingredients.

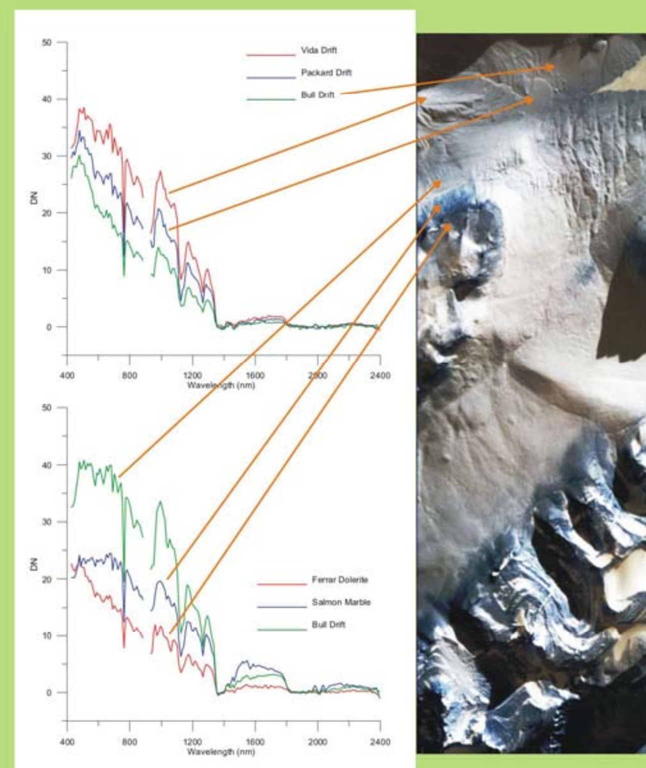
Dolerite

Tills

Marble



Enlarged part of HYPERION imagery with sites of spectra



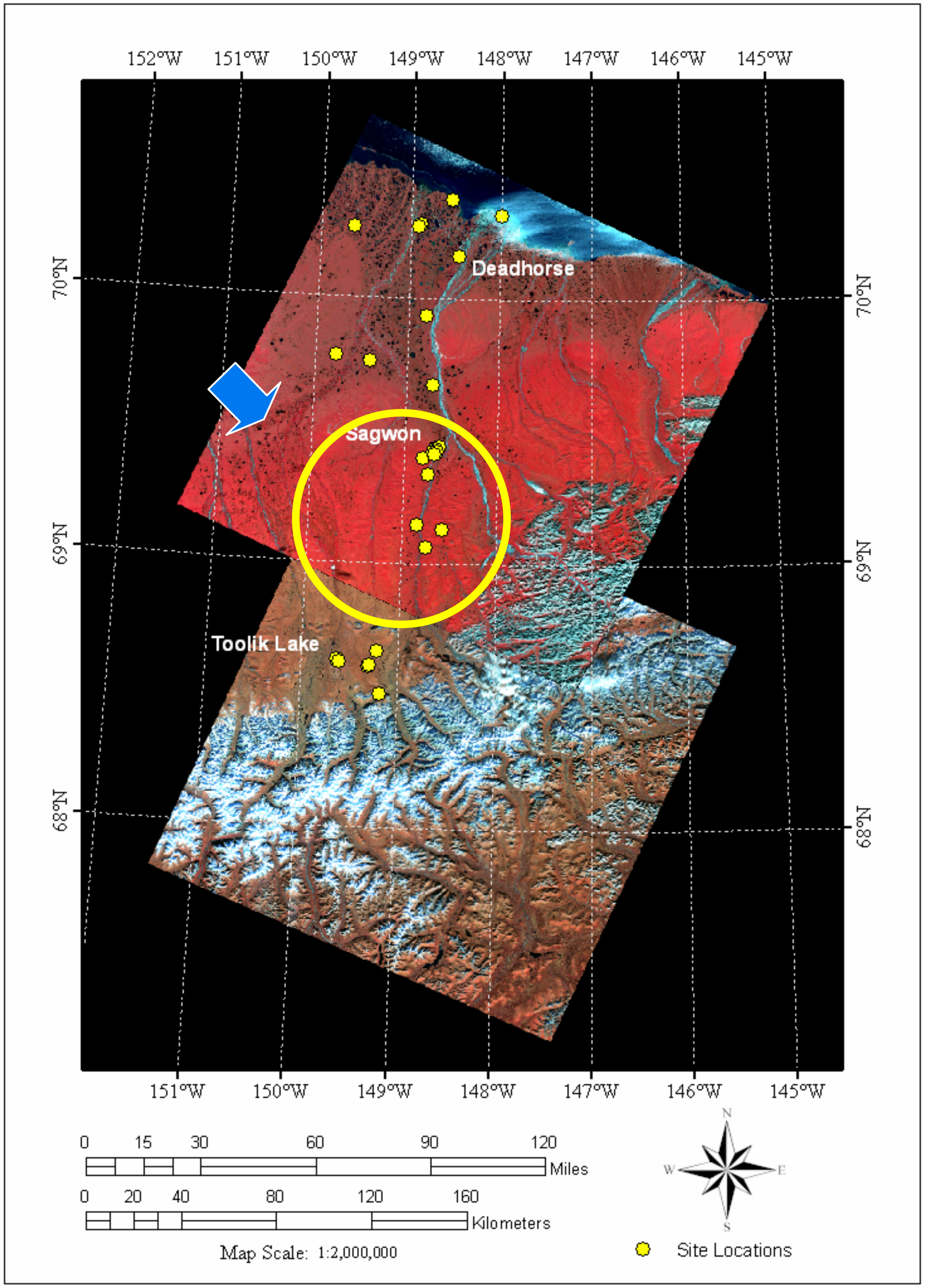
Spectra in DN, no atmospheric correction
Data from USGS, EROS Data Center

Pilot Study: inferring soil and permafrost distribution from remotely sensed data, North Slope, Alaska

Data: Landsat EMT+. ASTER, USGS DEM (ongoing), airborne laser scanning, Hyperion, etc. (planned)

Ground truth:

Soil pedons and geobotanical data collected for NSF Land-Atmosphere-Ice Interaction Flux (LAII-FLUX), Arctic Transitions in the Land-Atmosphere System (ATLAS)

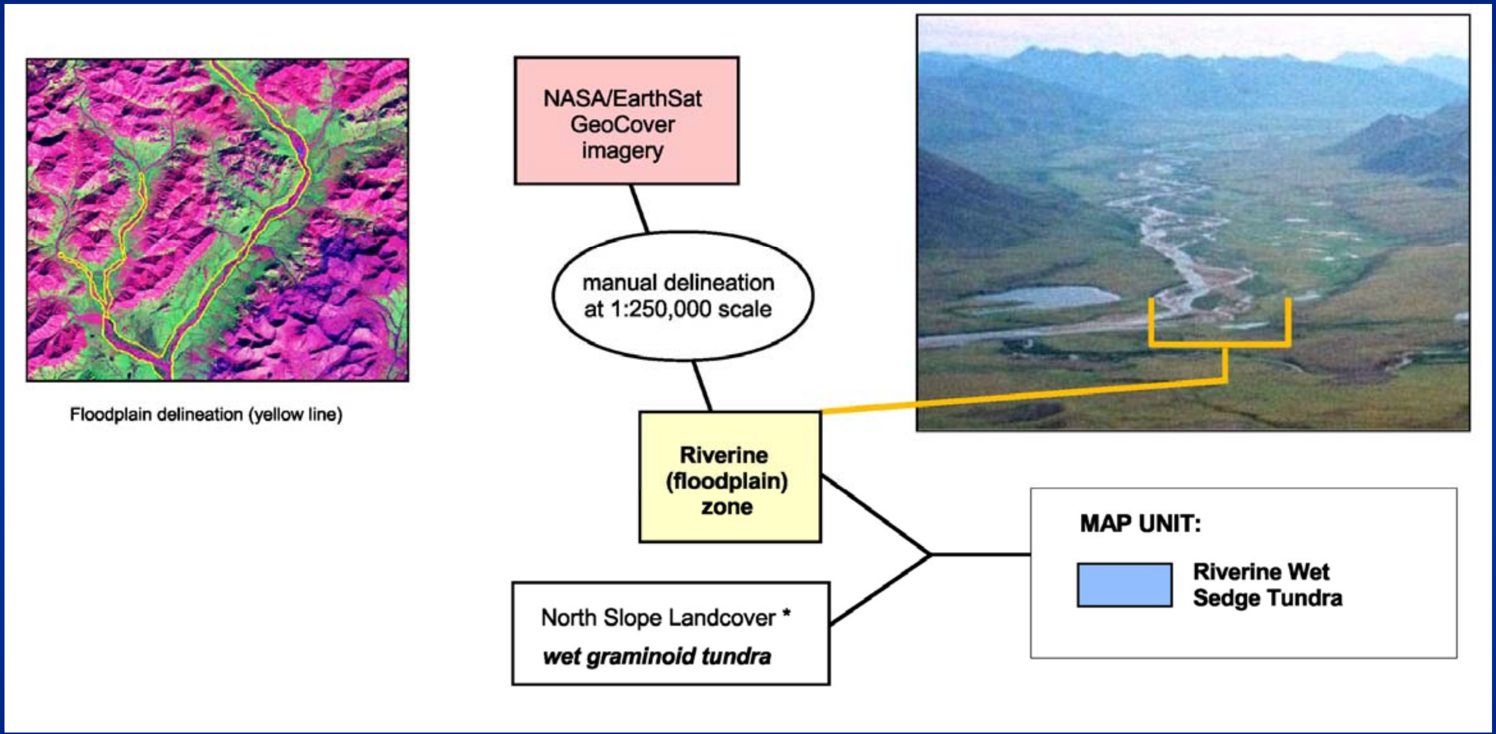


Interpretation of Remotely Sensed Data

- Permafrost is located below the penetration depth of most remote sensing methods
- Therefore indirect methods, such as surface indicators (periglacial phenomena, vegetation cover, etc.,) are usually used for mapping permafrost distribution
- Traditional solution: photointerpretation of stereo aerial photographs
- Currently used: Landcover classification, hydrologic modeling and manual delineation from remote sensing data, different information layers are "fused" in GIS

Example for Modeling Approach

Ecosystems of Northern Alaska (Jorgensen and Heiner)

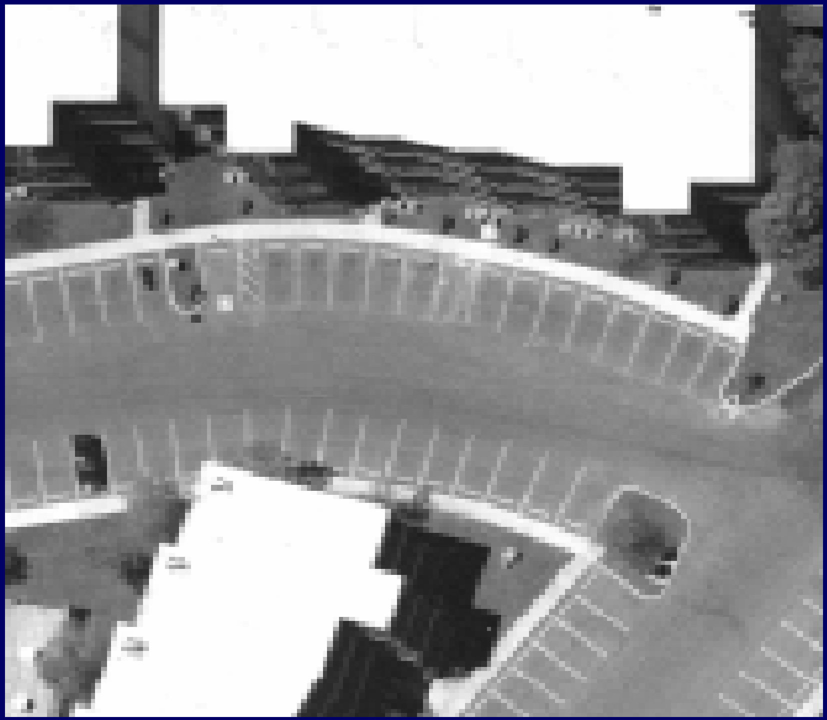


Floodplain delineation (yellow line)

- Modeling was based on pixel based classification of satellite imagery and manual delineation of landscape units
- Disadvantage: no synergism between spatial and spectral processing; only 3 bands were used for photointerpretation

Spatial extent, Peephole Example

- 3 x 3

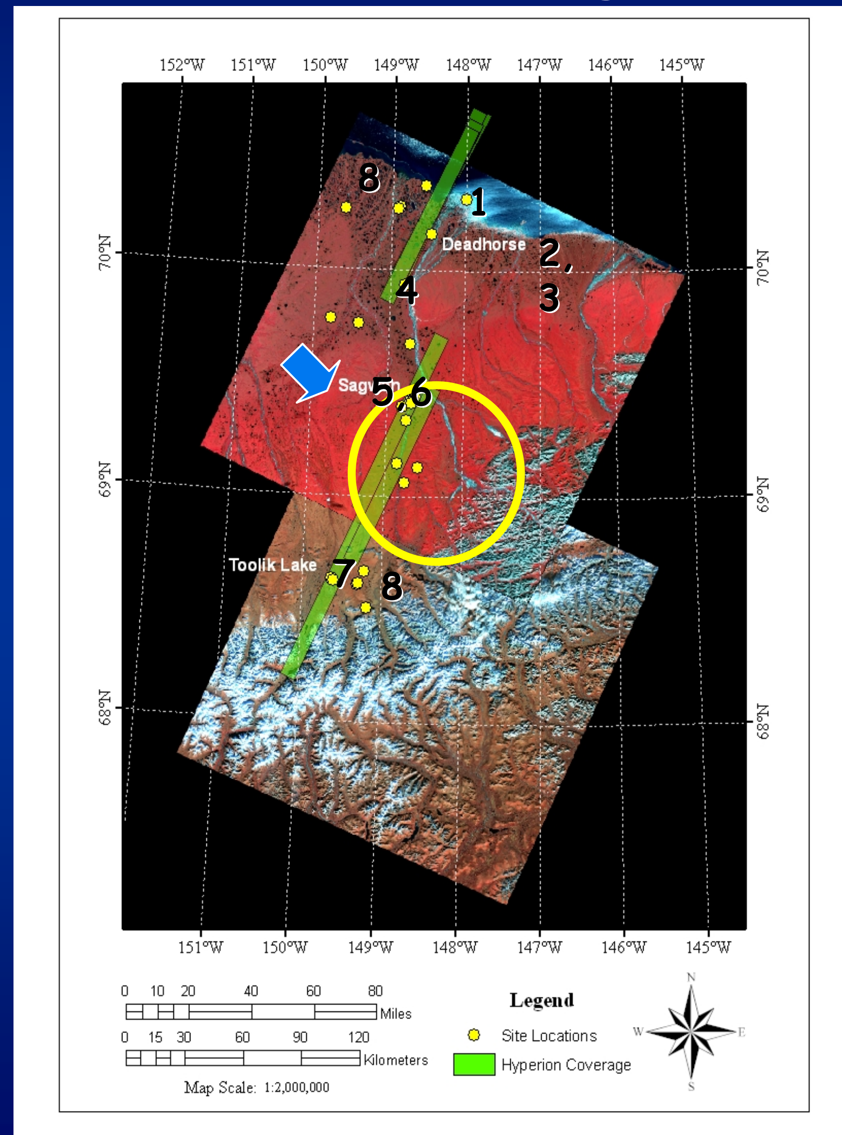


- Most remote sensing techniques use spatial "units" that are determined by sensor characteristics and not by the application or object (e.g. IFOV and pixel)
- A single, uncalibrated pixel has almost no information about the material of the surface or about the object it belongs to

Object-Based Data Fusion

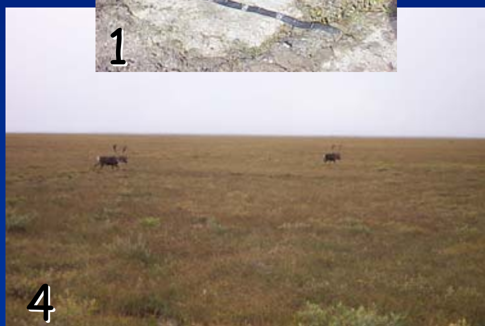
- Object-based techniques
  - are based on identification of natural units of the environment, for example buildings or landscape units
  - they provide robust solutions by considering both spatial and feature-space relationships
  - they are ideal for fusing multi-scale data and for using model and topology based rules

Pilot Study
Arctic Foothills, Sagwon



Howi Island, nonsorted circles (spotted tundra)

Patterned ground formation



Arctic Coastal Plain

High-centered and flat polygons

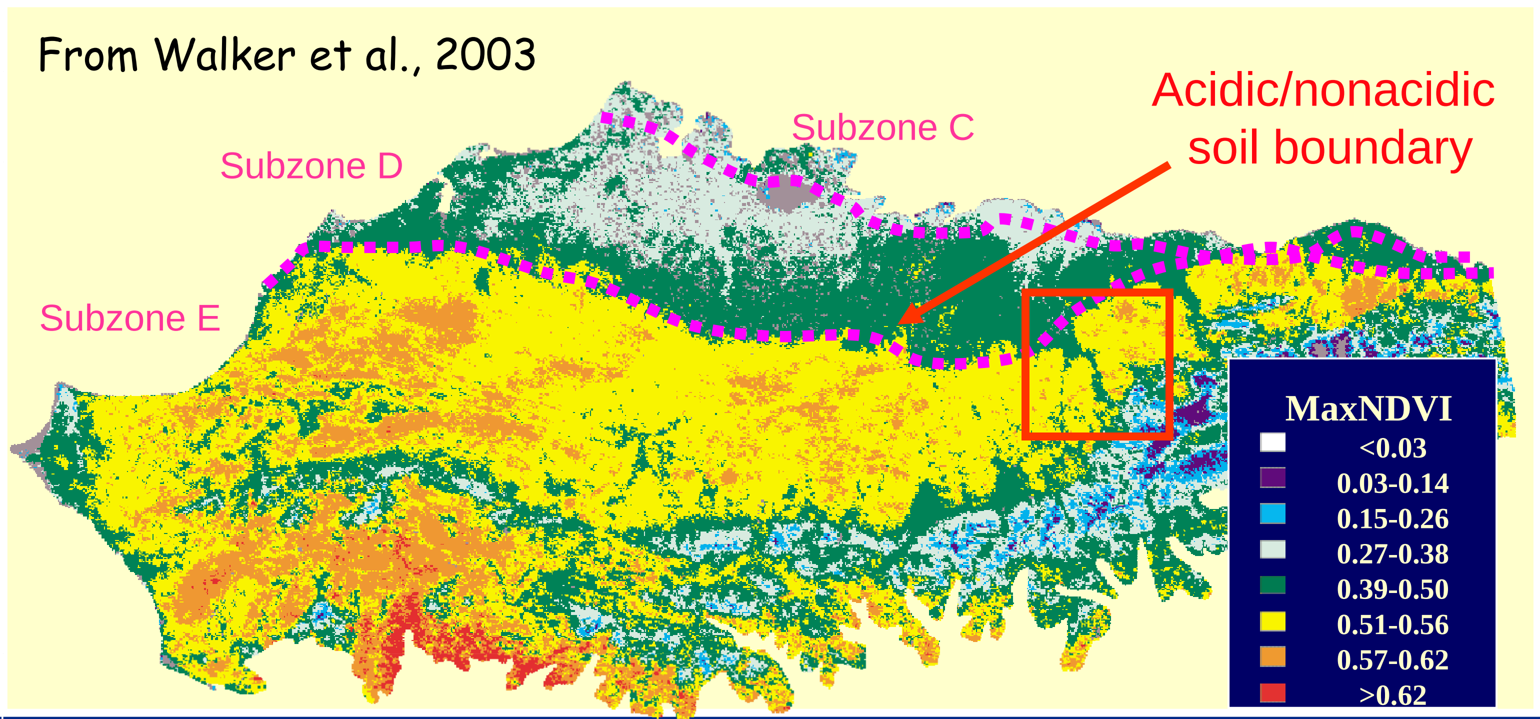
Sagwon Hill - Arctic Foothills

Sagwon Hill - nonacidic tundra

Periglacial features, Toolik Lake

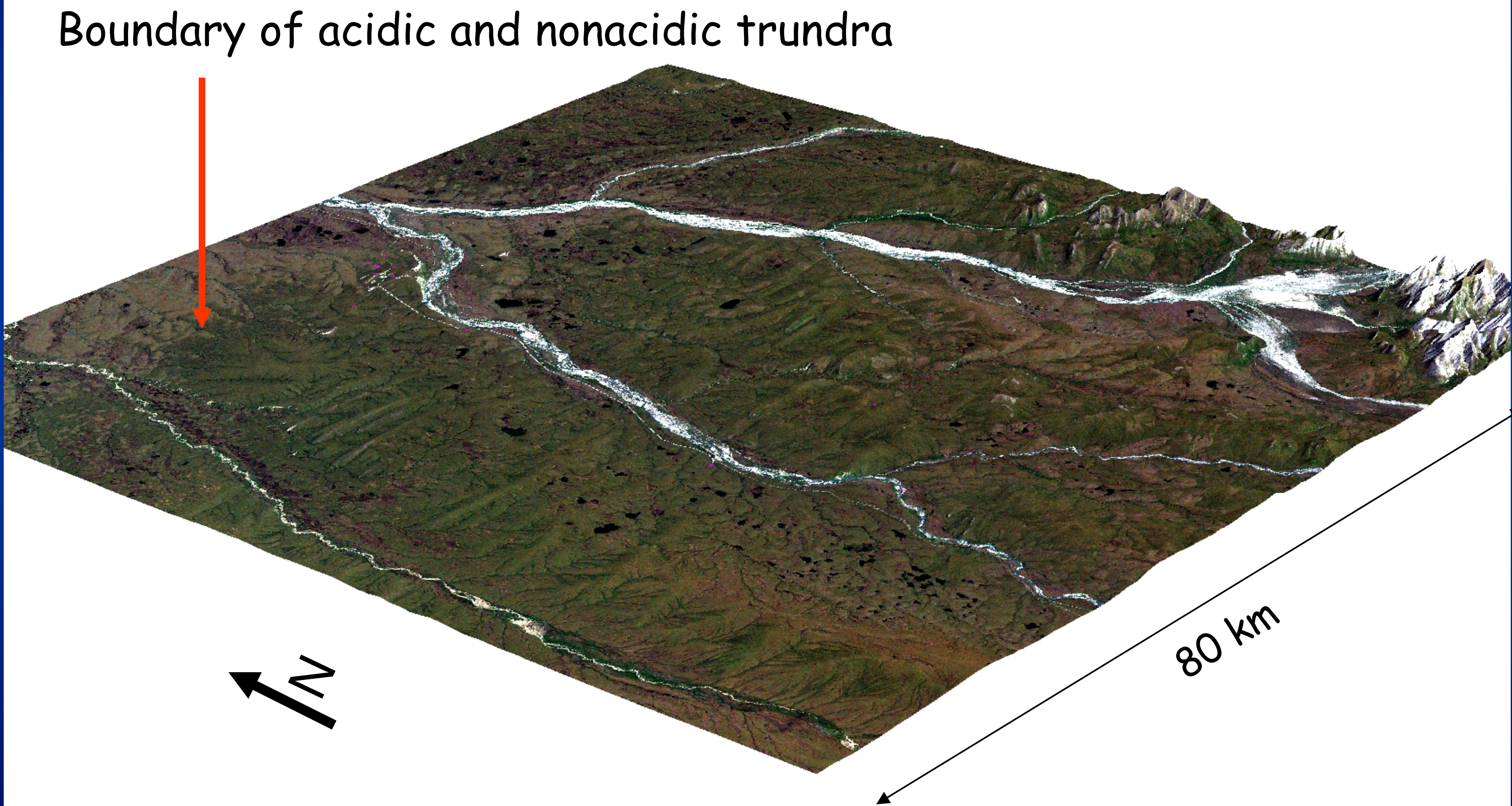
Arctic Foothill

Map of the maximum NDVI in northern Alaska derived from AVHRR (Advanced Very High Resolution Radiometer) composite images



Areas with higher MaxNDVI are generally greener. The boundary between the yellow and green colors is between primarily acidic tundra to the south and nonacidic tundra to the north. Yellow areas are mainly tussock tundra. Green areas are mainly, moist nonacidic tundra with higher soil pH, more frost boils, fewer erect shrubs, and shorter plants.

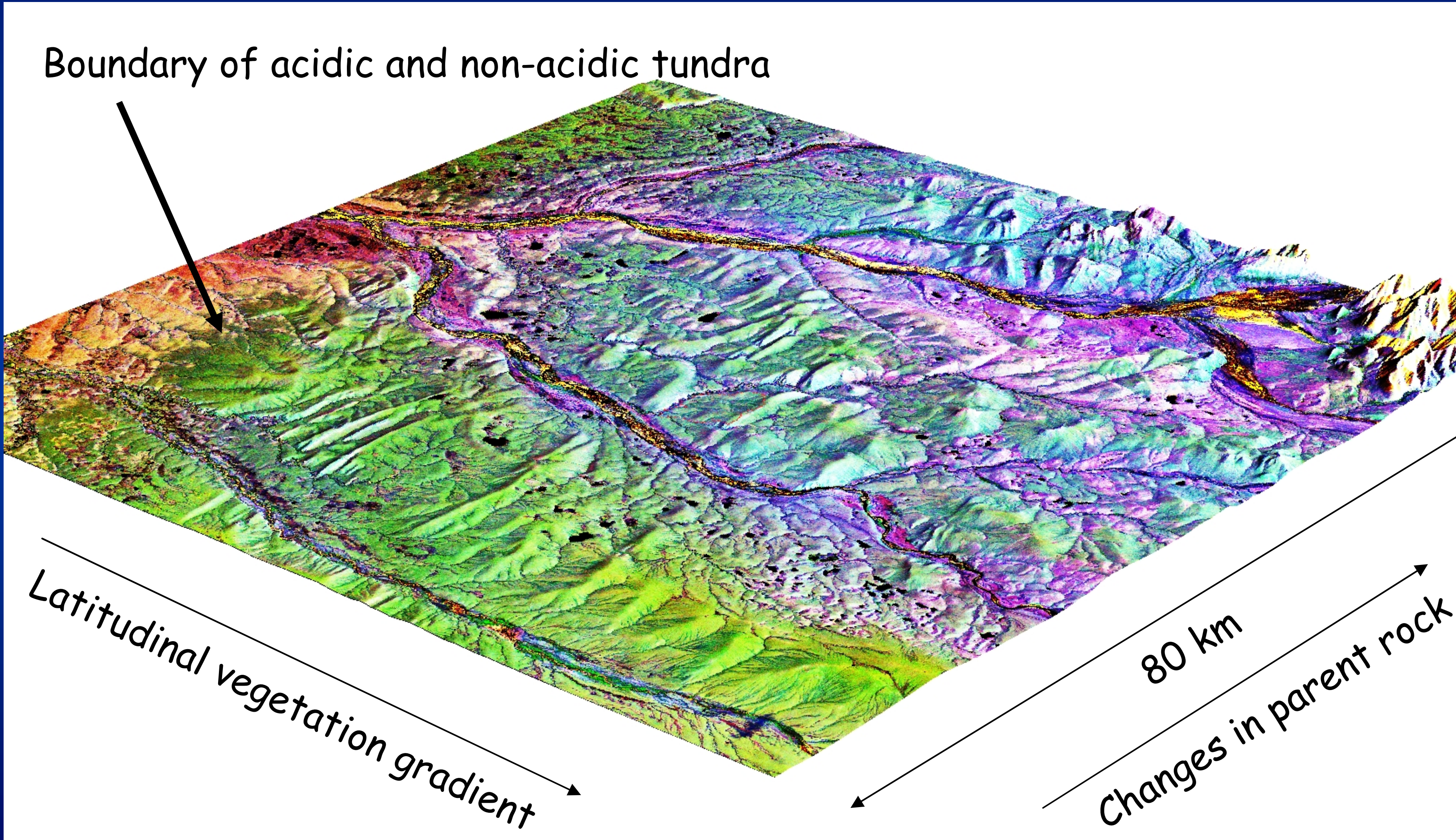
Natural Color Composite of Landsat ETM+ bands 3, 2, 1 Draped on USGS DEM



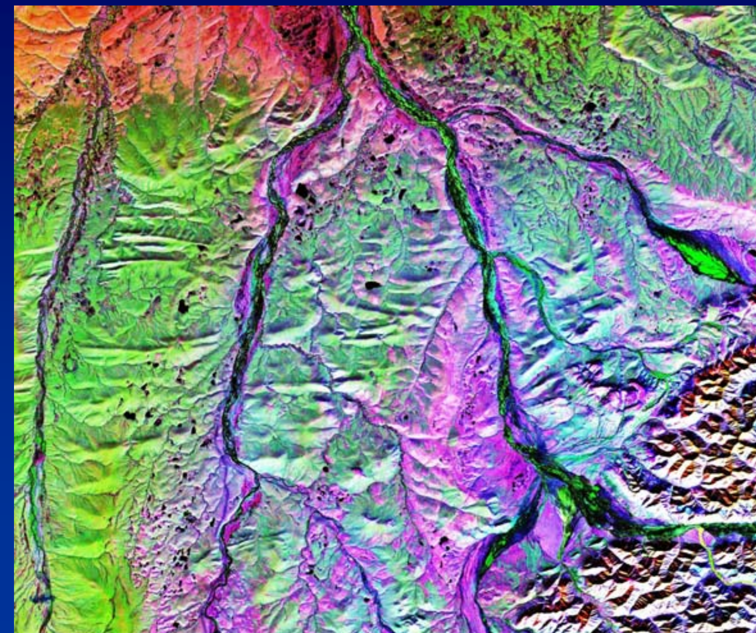
Typical Object Based Classification Workflow (eCognition, Definiens)

- Visualization
- Creating object hierarchy by using a multi-dimensional, multi-resolution, multi-scale segmentation
- Validation of object creation, compilation of vector objects and computation of object features
- Classification of objects
- The process can be performed in a loop and complex relationships, based on real world knowledge, can be defined between objects

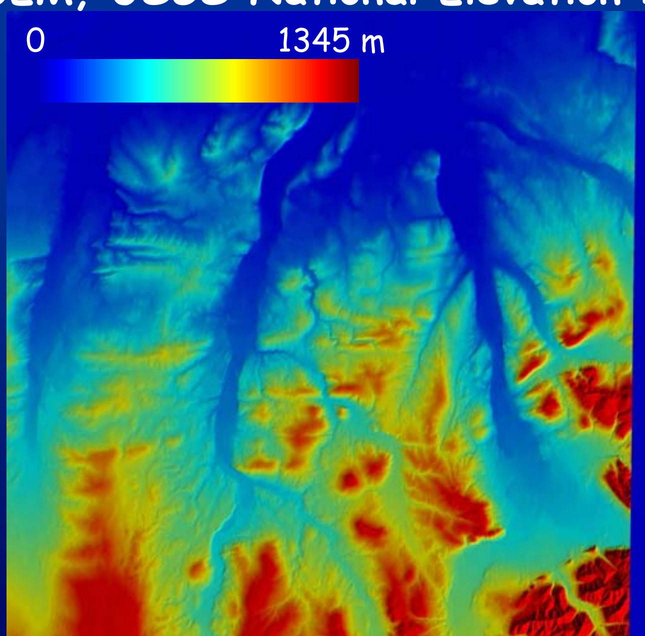
Layer Mixing of Landsat ETM+ Bands 2,3,4,5,61,62 and 7, Draped on DEM



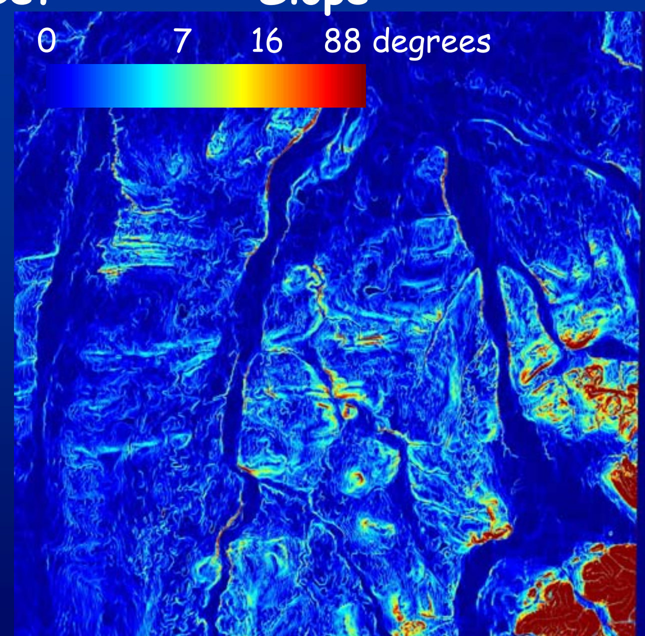
Landsat ETM+



DEM, USGS National Elevation Data Set

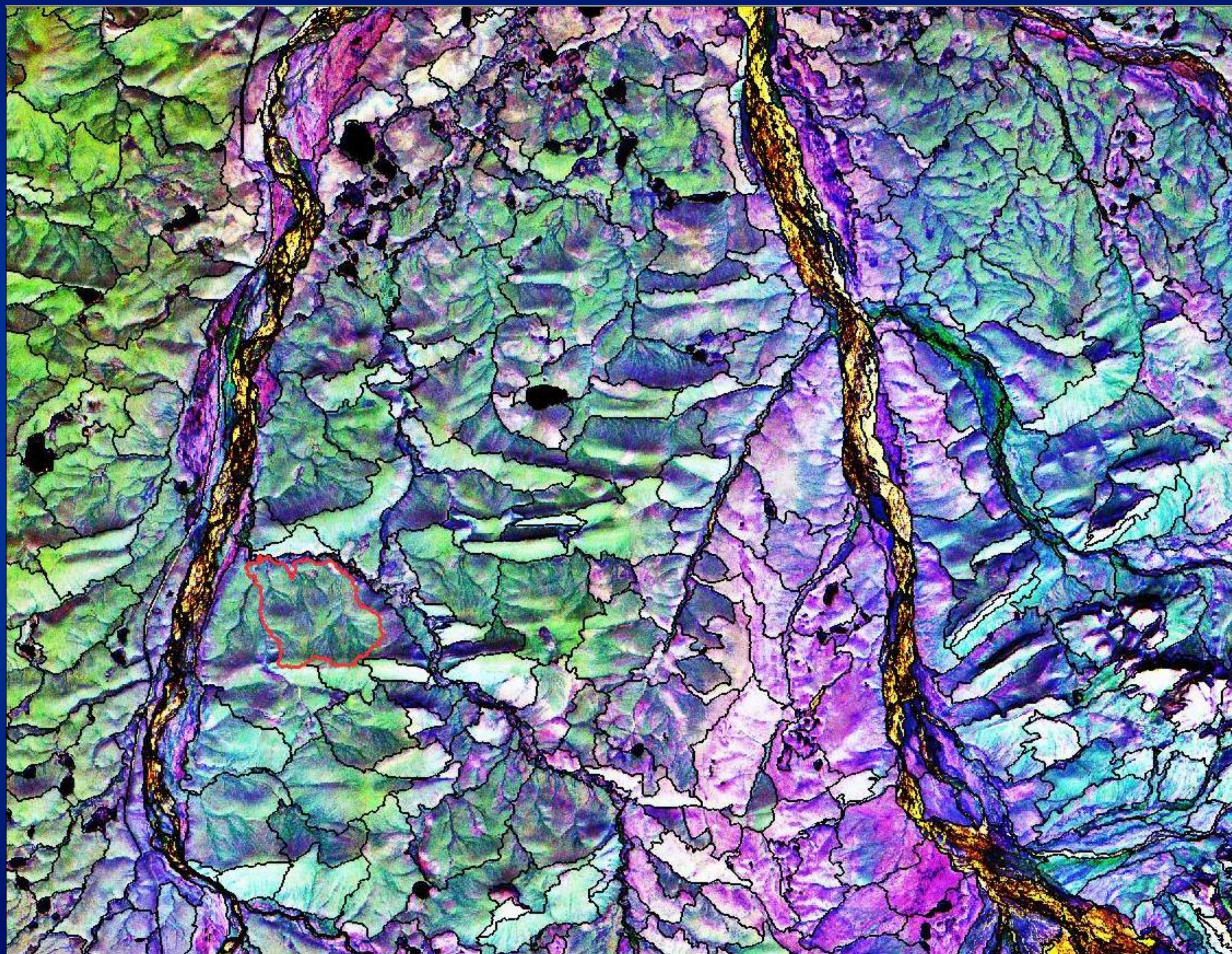


Slope



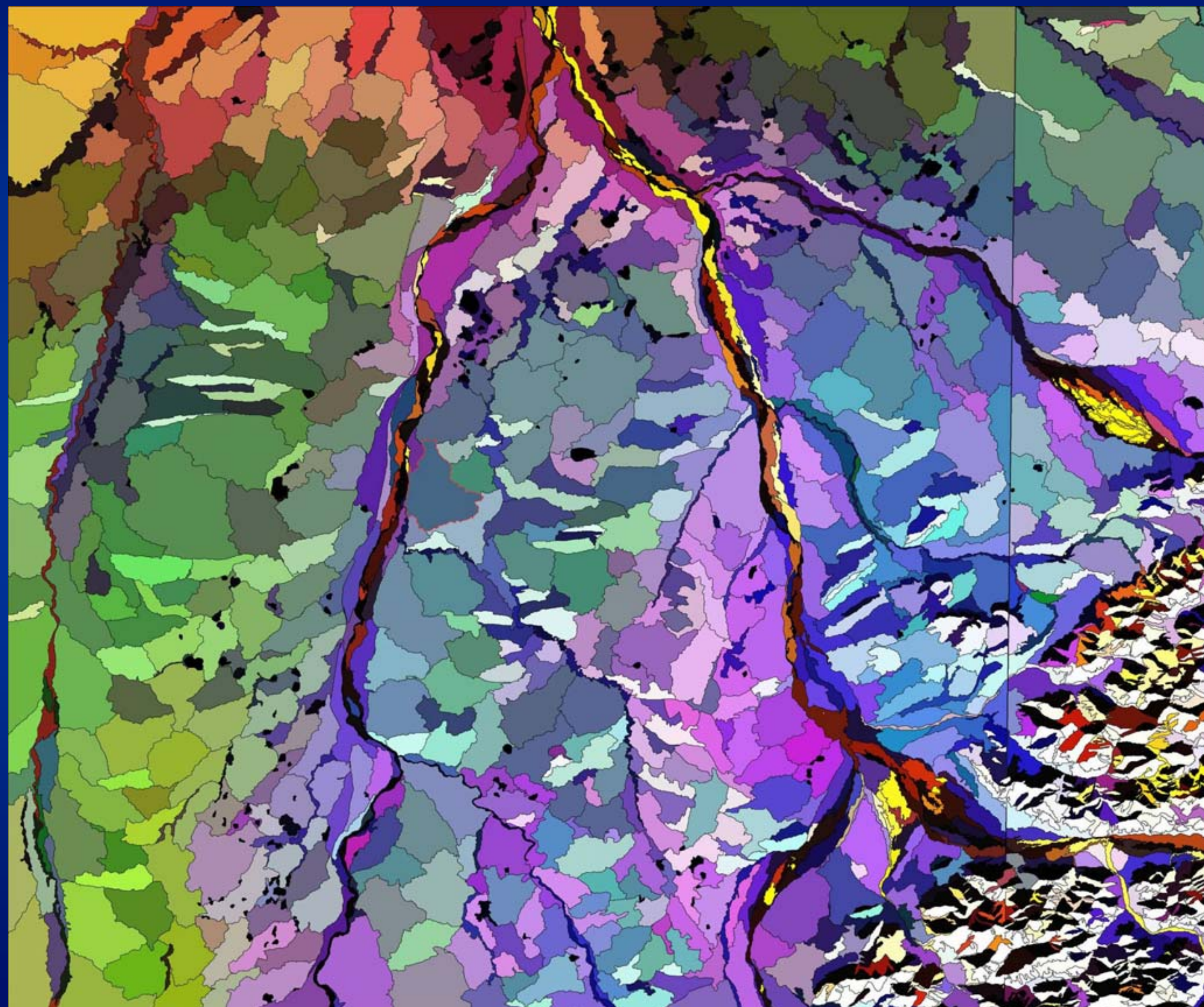
2o km

Segmentation of Landsat ETM+ Bands and Slope using Object Oriented Approach



Layer Mixing of Landsat ETM+ Bands 2,3,4,5,61,62 and 7: Plane View

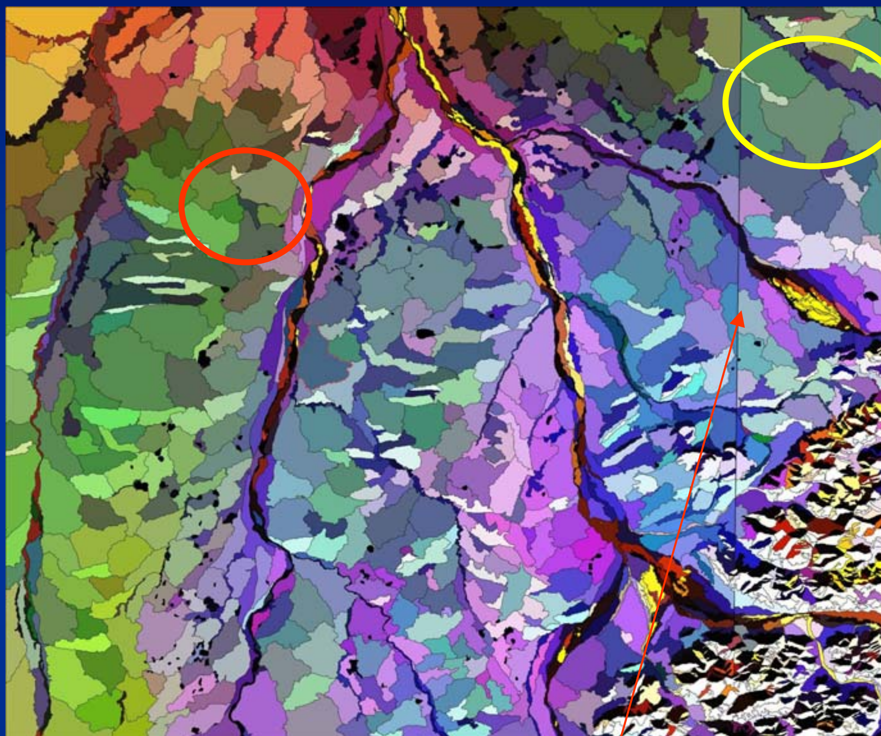
Segmented Landsat ETM+ Imagery and Terrain Slope

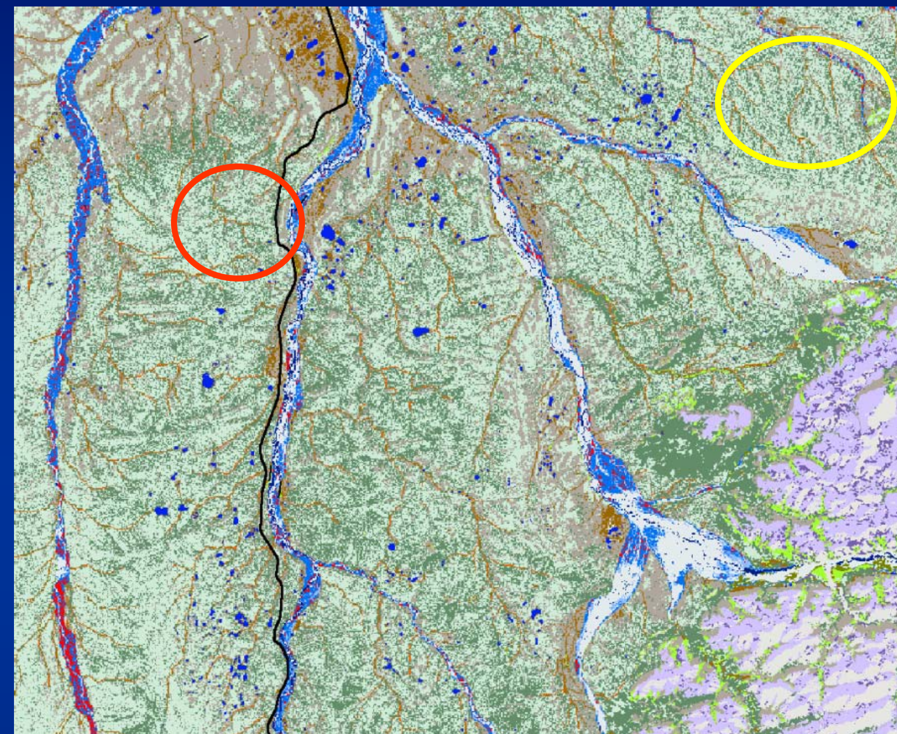


20 km

OBC Segmentation Landsat ETM+ and Slope

Ecosystems of Northern Alaska (Jorgensen and Heiner)





20 km

- Upland Low Birch-Willow Shrub Tundra
- Upland Shrubby Tussock Tundra
- Upland Dryas Dwarf Shrub Tundra:
- Upland Moist Sedge-Shrub Tundra
- Lowland Wet Sedge Tundra
- Riverine Moist Sedge-Shrub
- Riverine Wet Sedge Tundra
- Riverine Barrens
- Riverine Low Willow Shrub Tundra
- Riverine Waters:

Boundary of inclusion of slope into segmentation
Left: with slope; right: without slope

Outlook, Future Research

- Higher spatial, spectral and temporal-resolution data sets are needed to develop and test new approaches
- New sensors, for example LIDAR and hyperspectral imaging, should be used together with proven technology
- Data acquisition campaigns should include coordinated ground, airborne and spaceborne measurements to provide groundtruth and for exploring the spatial scaling of the measurements.

Outlook, Future Research

- Data interpretation, fusion should move from low level to high level processing; data → information → knowledge
- Geoscience applications can benefit from multidisciplinary approaches from photogrammetry, remote sensing, data fusion, GIS, etc.

Acknowledgements:

We thank W. Krabill, NASA WFF for providing ATM data. Landsat EMT+ imagery is from GLFC Geocover.