Results and Recommendations from the Remote Sensing Initiative

Grand Canyon Monitoring and Research Center

Presentation Order

- **Overall Objectives**
- **Technologies Tested & Results for Specific Monitoring Requirements**
- **Summary Recommendations**

Initiative Objectives

- **Less intrusive, cost effective monitoring approaches that:**
  - **Provide acceptable accuracies**
  - **Increase capability and productivity**
  - **Expand spatial coverage**

Resources not Approachable

- **Very small or obscured features – individual plants, cave/adit deposits**
- **Chemical characteristics of water**
- **Faunal populations**
- **Fish foodbase**

Resources Approached

- **Cultural Resources**
  - **Archaeological structures**
  - **Camping sites/beaches**
- **Biological Resources**
  - **Physical characteristics of water**
  - **Aquatic habitat mapping**
  - **Terrestrial habitat mapping**

Resources Approached (*continued*)

- **Physical Resources**
  - **Sediment transport and storage**
    - **Aquatic**
    - **Terrestrial**

Archaeological Structures

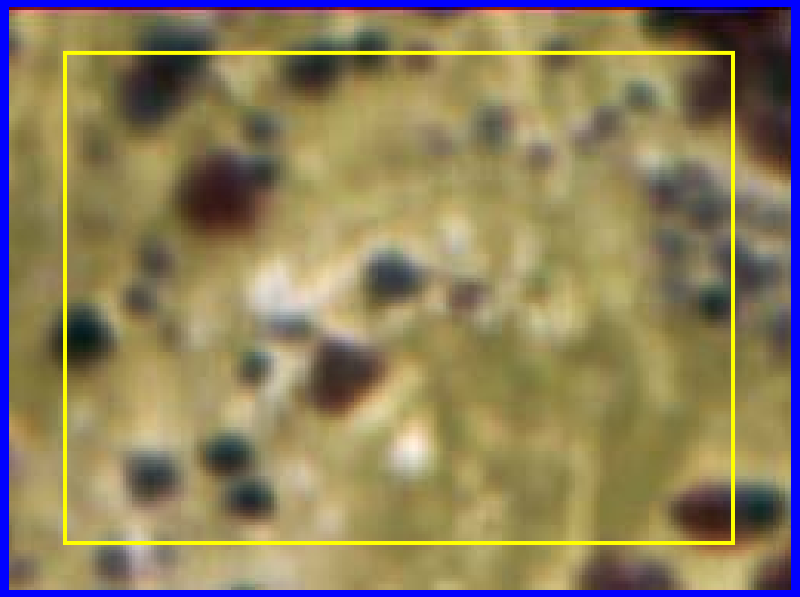
- **Requirement: detect structures and monitor modifications**
- **Technologies Evaluated:**
  - **Detection = 11-cm to 100-cm visible through thermal-infrared imagery**
  - **Measurement = 3-cm stereo photogrammetry**

    (240-m AGL; $22,000 for 4 small sites)

Detection - Results

11-cm CIR image

100-cm CIR image



- **Requires CIR with resolutions <11 cm res.**
- **Daytime TIR less effective than 100-cm CIR.**

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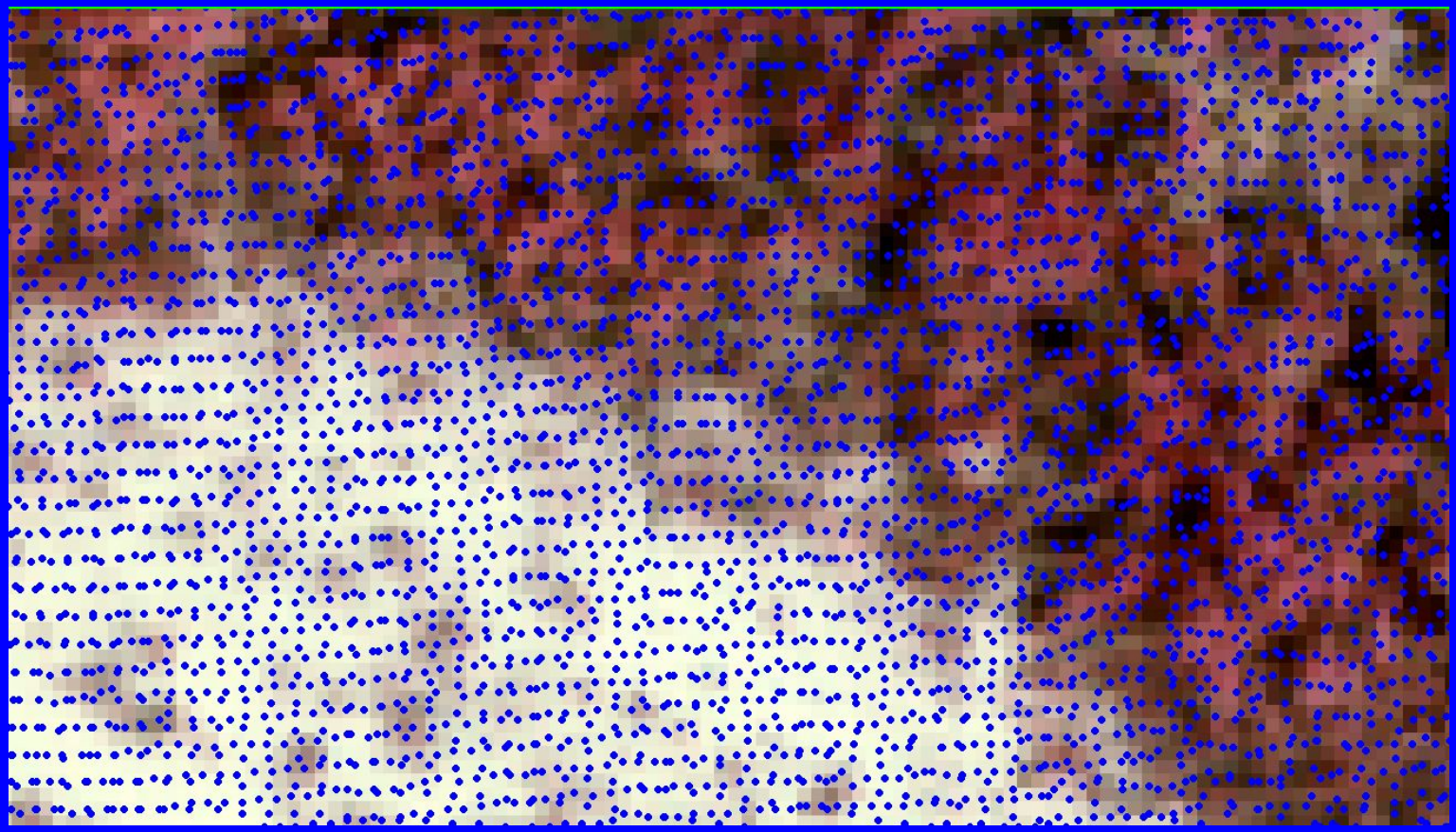
High-resolution Photogrammetry Results

- **Could not achieve the required 6 cm vertical accuracy to detect arroyo and structure modifications in post-monsoon data.**
- **Method requires control panels – still invasive**
- **Possible Alternative - very high-resolution LIDAR**
  - **17 points/m^2; 7-cm vertical accuracy; 100-m AGL; $6,200/river km ≈ 10-20 arch sites.**

Very High Resolution (0.3 m) LIDAR



0 5 m

(noninvasive; 100-m AGL; $6,200/km)

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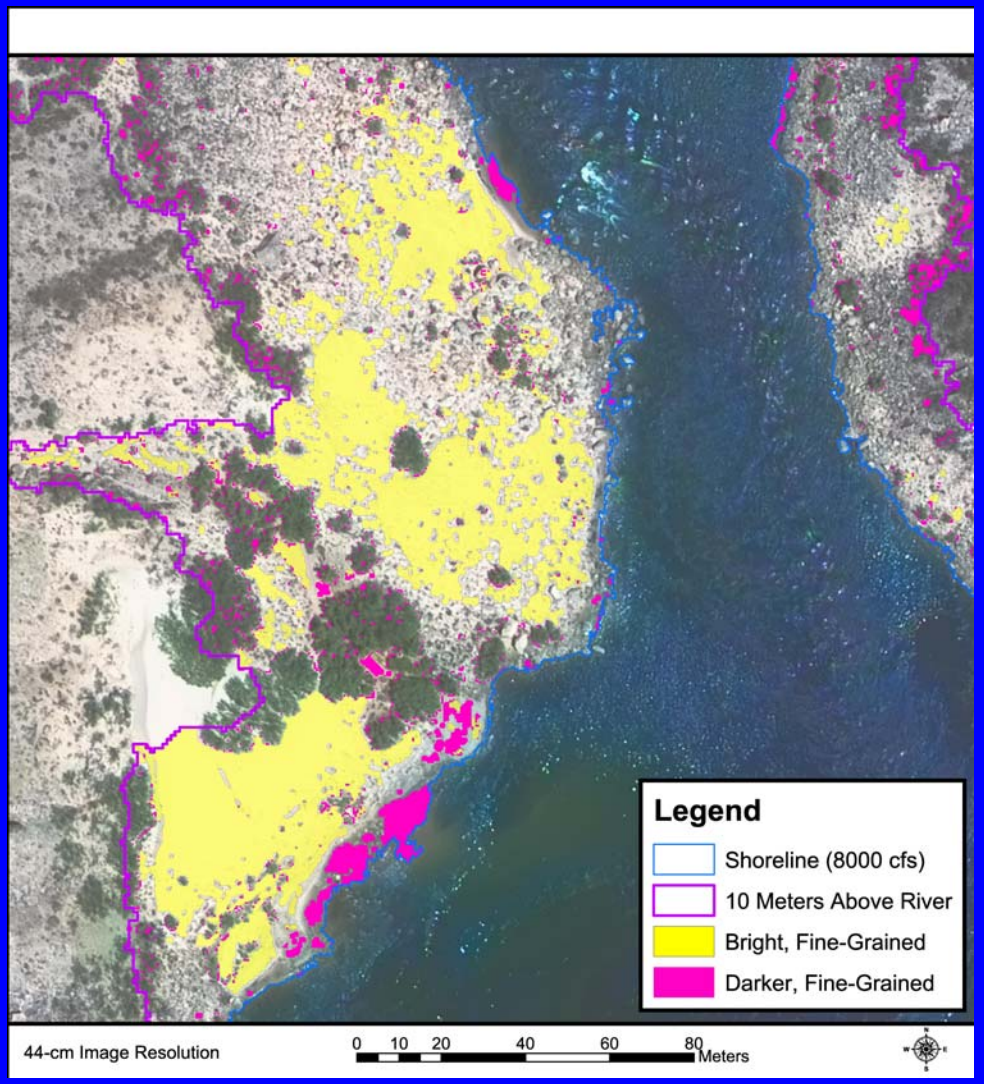
Mapping Camping Sites/Beaches

- **Requirement: Monitor quality of camp sites and beaches throughout the CRE**
  - **quality ≡ open, smooth surfaces near river, but elevated above water's edge to avoid daily fluctuations.**

- **Technologies evaluated:**
  - **44-cm, orthorectified, digital visible and near-infrared band imagery (25-cm positional accuracy).**
  - **1-m DSM data produced from 22-cm stereo imagery.**
  - **45-cm vertical accuracy; 6,100-m AGL; $625/km.**

Camping Sites/Beaches Results

- **Results**: Calibrated image color and texture and elevation data can be used to map *all* campable areas *throughout* the CRE in a matter of a few months, which is not possible by ground surveys.



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Biological Resources

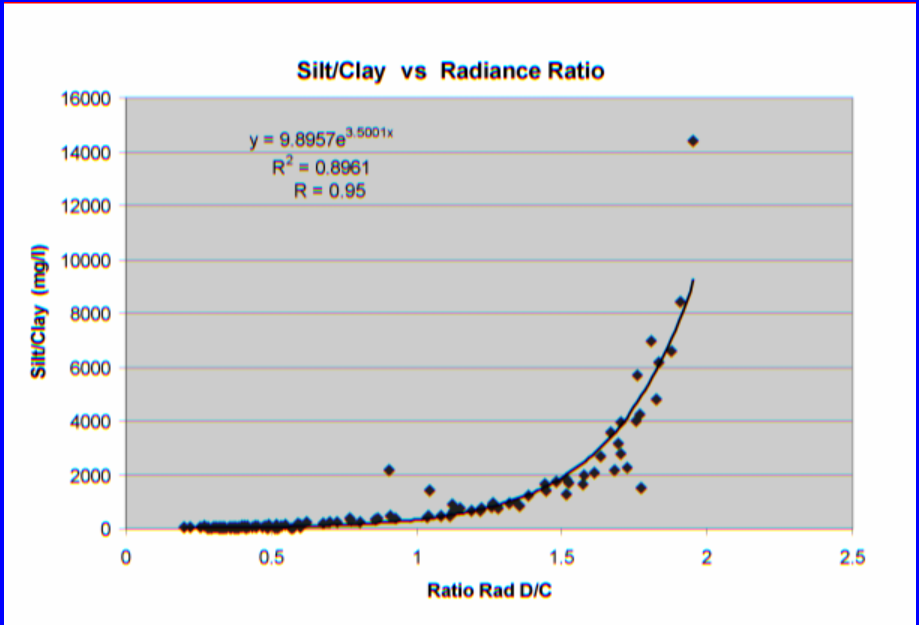
- Physical characteristics of water (also sediment transport)
- Aquatic habitat mapping
- Terrestrial habitat mapping

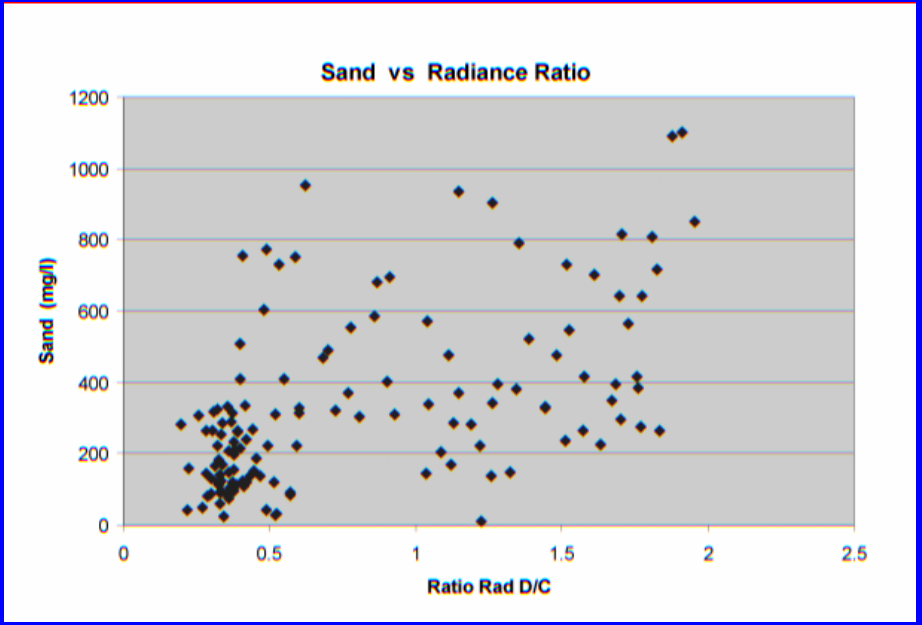
Physical characteristics of water

- **Requirement: Monitor turbidity (sediment load) of water over large regions.**

- **Technologies Evaluated: Digital 15-30 cm blue-green and green wavelength imagery (275-m AGL; $25/km *unrectified*)**

Suspended Sediment Results





- **Blue-green/green image ratio does correlate with suspended sediment.**
- **More accurate for silt/clay than sand-sized particle flux.**
- **Requires periodic ground calibration to insure accuracy.**

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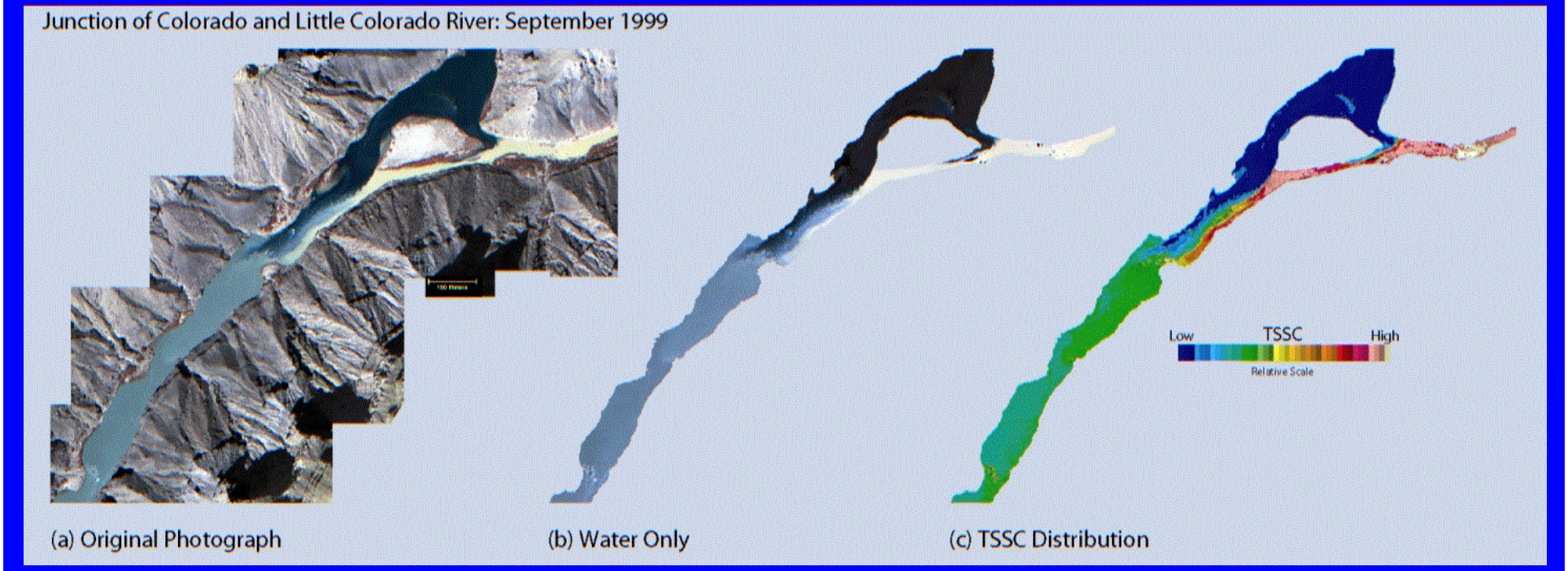
Suspended Sediment - LCR



- **Cannot approach frequency of ground measurements, but does provide instantaneous, wide-area concentration maps.**
- **Also requires digital image data that provides better water penetration and calibration than analog imagery.**

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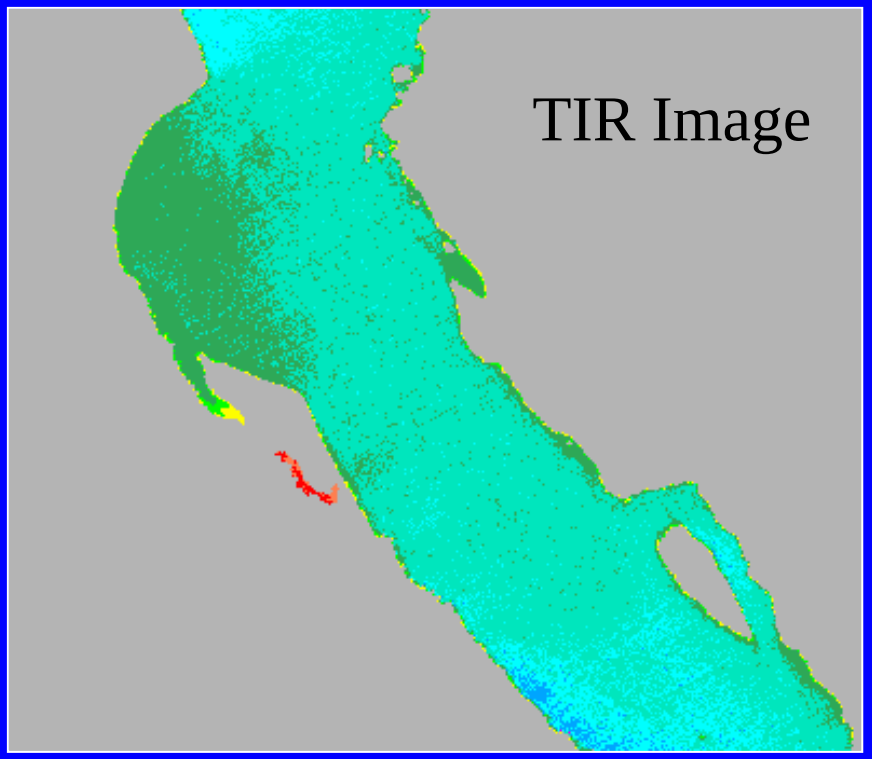
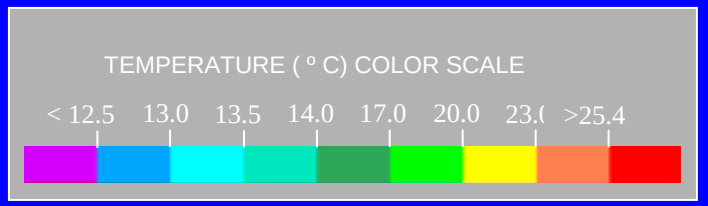
Aquatic Habitat Mapping

- **Requirements: Map the warm-water, fish habitats throughout the CRE.**

- **Technology Evaluated:**
  - **100-cm georectified, daytime thermal-infrared imagery (365-m AGL; $600/km - also provided 11 other wavelength bands for other evaluations).**

Warm-water habitats - Awatubi Canyon





Airborne thermal detector has a 0.3 degree sensitivity.

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Warm-water habitats

- **Results: Mapped all warm-water habitats for 44 river miles with a 20-minute data collection and a week of data processing.**

- ***Note*: Mapping to absolute temperature requires water-gage temperature data.**

Vegetation Monitoring

- **Requirement: Map the distribution of vegetation alliances throughout the CRE with 30-cm positional accuracy and 80% vegetation mapping accuracy for future and retrospective temporal change analyses.**

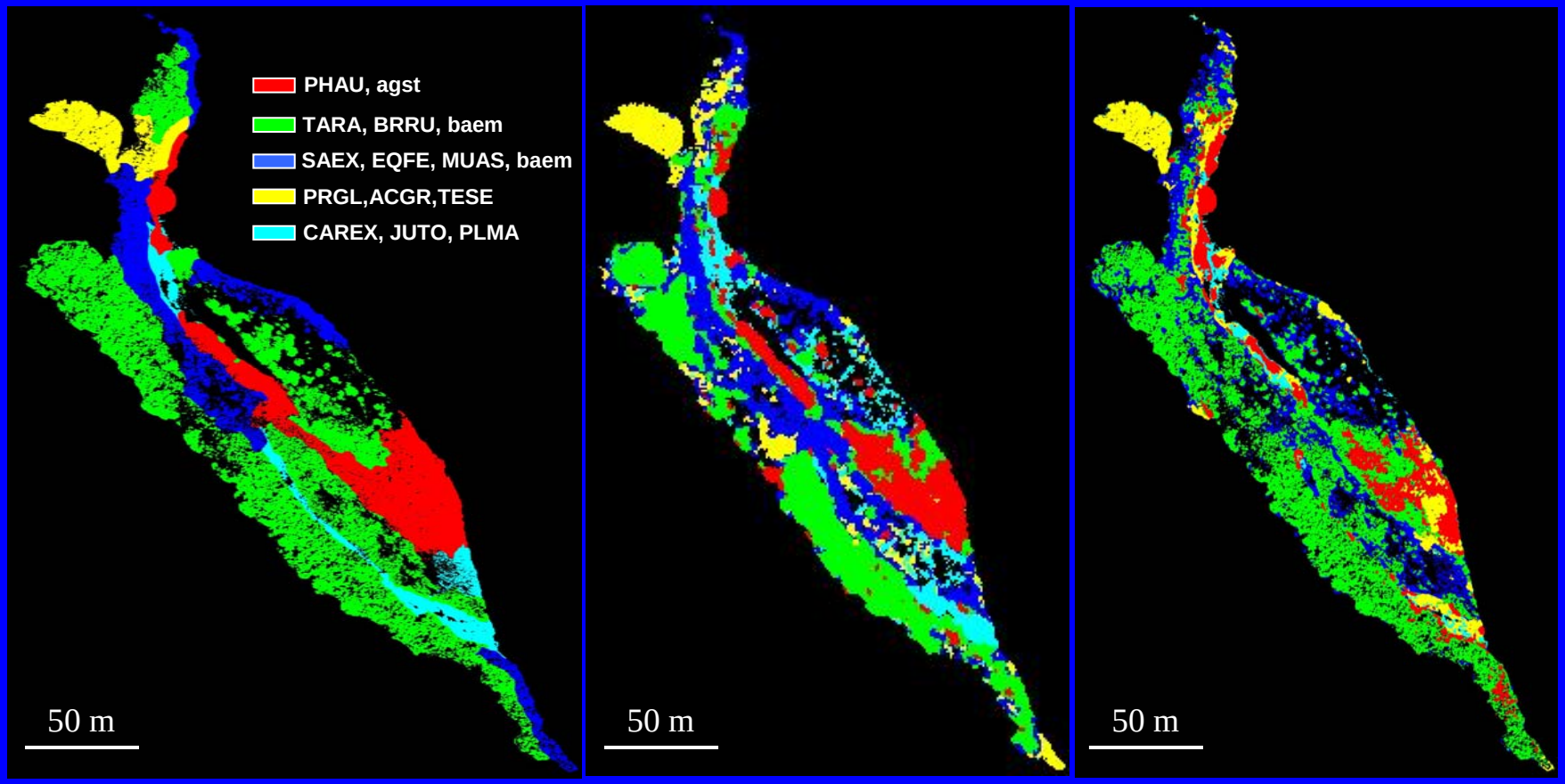
Vegetation Monitoring

- **Technologies Evaluated:**
  - **11-cm to 30-cm color-infrared film and digital imagery (730-m to 3,050-m AGL; $750/km)**
  - **44-cm digital 4-band imagery (6,100-m AGL; $625/km).**
  - **100-cm digital multispectral (11 bands) imagery (365-m AGL; $600/km).**

Vegetation Monitoring

- **Initial Evaluation: Determined mapping accuracies for various vegetation alliances within the vegetation LTM sites using the spectral and textural information provided by each type of image data for the vegetation alliances.**

Kwagunt Marsh



Field mapping

100-cm multispectral
67% accuracy

11-cm CIR
63% accuracy

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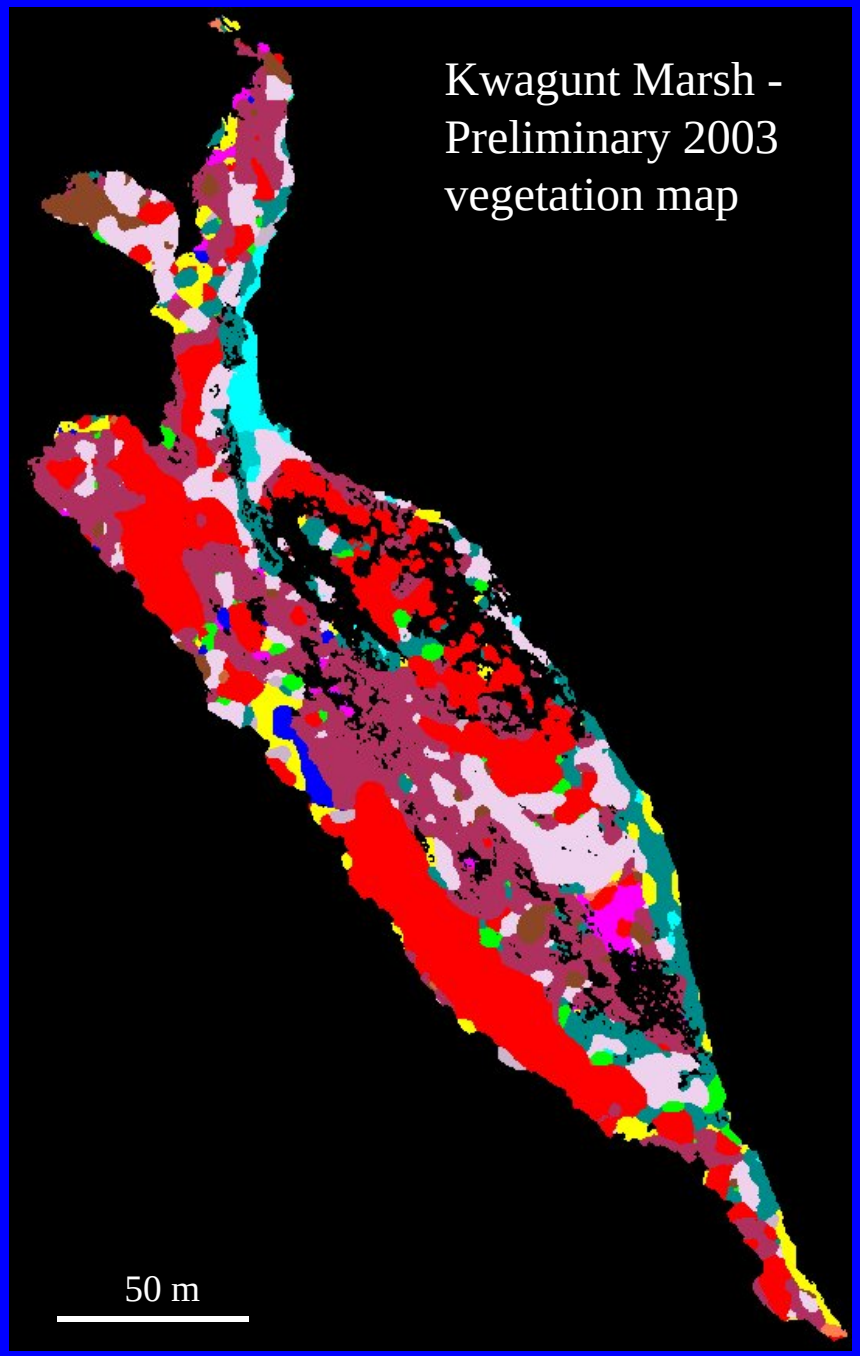
Initial Results for Sites

- **Accurate mapping requires data that can be calibrated for large regions = digital imagery.**
- **MS data produces higher accuracies, but at visual verification difficult at 100-cm resolution.**
- **CIR data approaches MS mapping accuracies, only using vegetation texture, which diminishes at resolutions > 30 cm and is non-existent at 100-cm resolution.**

2002-3 CRE Inventory

- **Employed a "calibrated," digital system that acquired 4-band imagery at 44 cm and b&w imagery at 22-cm and a DSM at 1 m cell size.**
- **Acquired at 6,100-m AGL at $625/km in 6-8 days for entire CRE.**
- **Automated rectification to 25 cm positional accuracy.**



Current mapping using 44-cm digital, orthrectified 4-band imagery

- PRGL (Mesquite)
- ACGR (Catclaw acacia)
- FAPA (Apache plume)
- Seasonally dry grass
- CERE (Hackberry)
- BAxx (Baccharis)
- Wetlands
- CLMA (Sawgrass)
- EQFE (Horsetail)
- Litter
- FONE (New Mexican olive)
- SAGO (Gooding willow)
- SAEX (Coyote willow)
- QUTU (Live oak)
- TARA (Salt cedar/Tamarix)
- Sparse shrubs (ACTA, LATR)
- TESE (Arrowweed)

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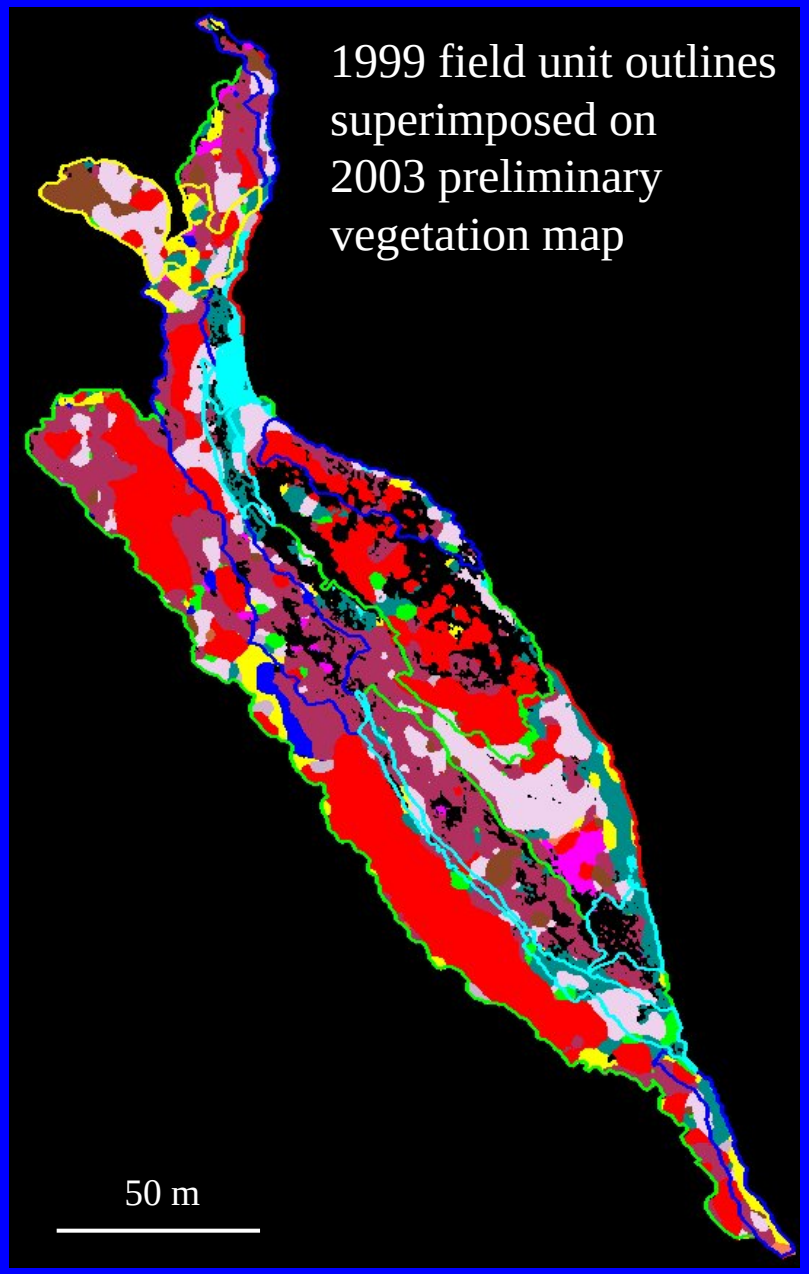

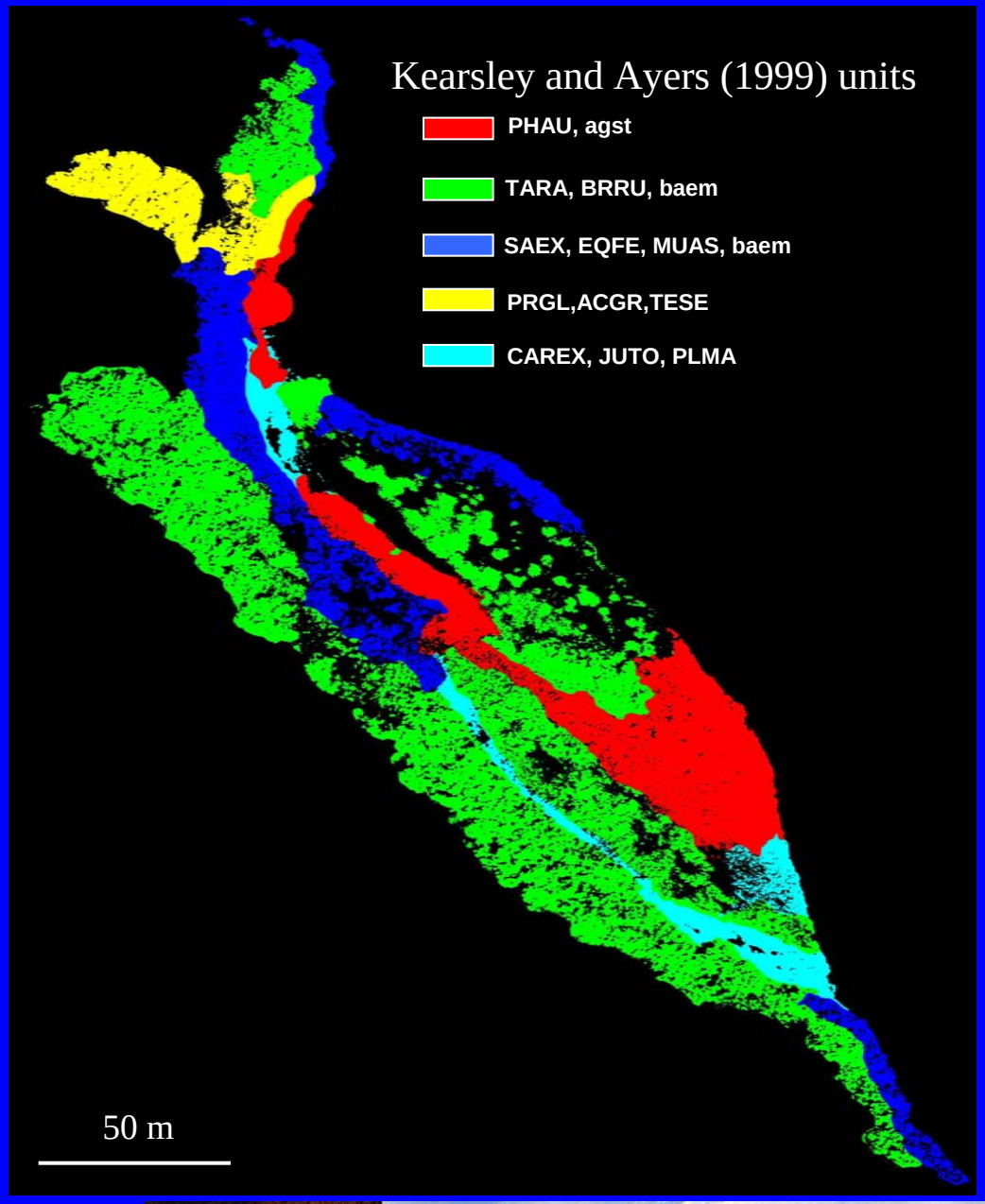

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Vegetation Inventory Results

- **Although totally acceptable for most CRE monitoring requirements, the 3 visible and 1 near-infrared band provided by the 2002 overflight *does not* provide enough species or alliance identification to dramatically reduce field mapping.**

- **A sensor with additional near-infrared (possibly short-wave infrared) bands is necessary to reduce field mapping. Most such instruments can only achieve a 1-m resolution (possibly 50 cm); 1-m data will not be useful for other monitoring requirements.**

Canopy Volume

- **Requirements: Provide estimates of vegetation volumes within the CRE with 80-90% accuracy. Data used to model carbon budget for aquatic environment and to provide relative measure of quality of habitats for birds.**

Topography – Summary

Method	Accuracy Bare	Accuracy Veg.	Precision	Invasiveness	Cost/km
Ground Surveys	5 cm	5 cm	unknown	very	>$5,000
Manual Photogrammetry	32 cm	54 cm	unknown	panels every 200 m	$3,000
Automated Photogrammetry	44 cm*	129 cm	unknown	panels every 15 km	$625
Low-res. LIDAR	45-100 cm*	30-200 cm	unknown	None	$575
Mod.-res. LIDAR	15-40 cm *	60-280 cm	25-30 cm	None	$1,785
High-res. LIDAR	17 cm	*71 cm***	6 cm	None	$2,100
Very high-res. LIDAR	8 cm	*133 cm***	4 cm	None	$6,200

* have vertical offsets, some variable

** better processing may reduce these values

Canopy Volume - Results

- **Low and moderate resolution LIDAR and automated photogrammetry too inaccurate (>40% error) for estimating canopy volume.**
- **Manual photogrammetry approaches 80% accuracy, but processing very difficult, time-consuming, and expensive.**
- **Higher resolution LIDAR data still to be evaluated.**

Physical Resources

- **Requirement: monitor and model sediment transport and storage in the aquatic and terrestrial environment.**

- **Technologies Evaluated:**
  - **Detection = 7-cm to 44-cm digital visible and near-infrared imagery**
  - **Measurement = photogrammetry and LIDAR**

Channel Substrate

- **Requirements: (1) distribution of fine- and coarse-grained sediment and (2) substrate topography (bathymetry).**

- **Approaches: 7-cm, high-gain color imagery (275-m AGL; $25 *unrectified)*, 22-cm high-gain, b&w (1,100-m AGL; $1,250 *rectified*), and photogrammetry.**

Channel Sediments – northern 100 miles

positional accuracy = 30 cm.

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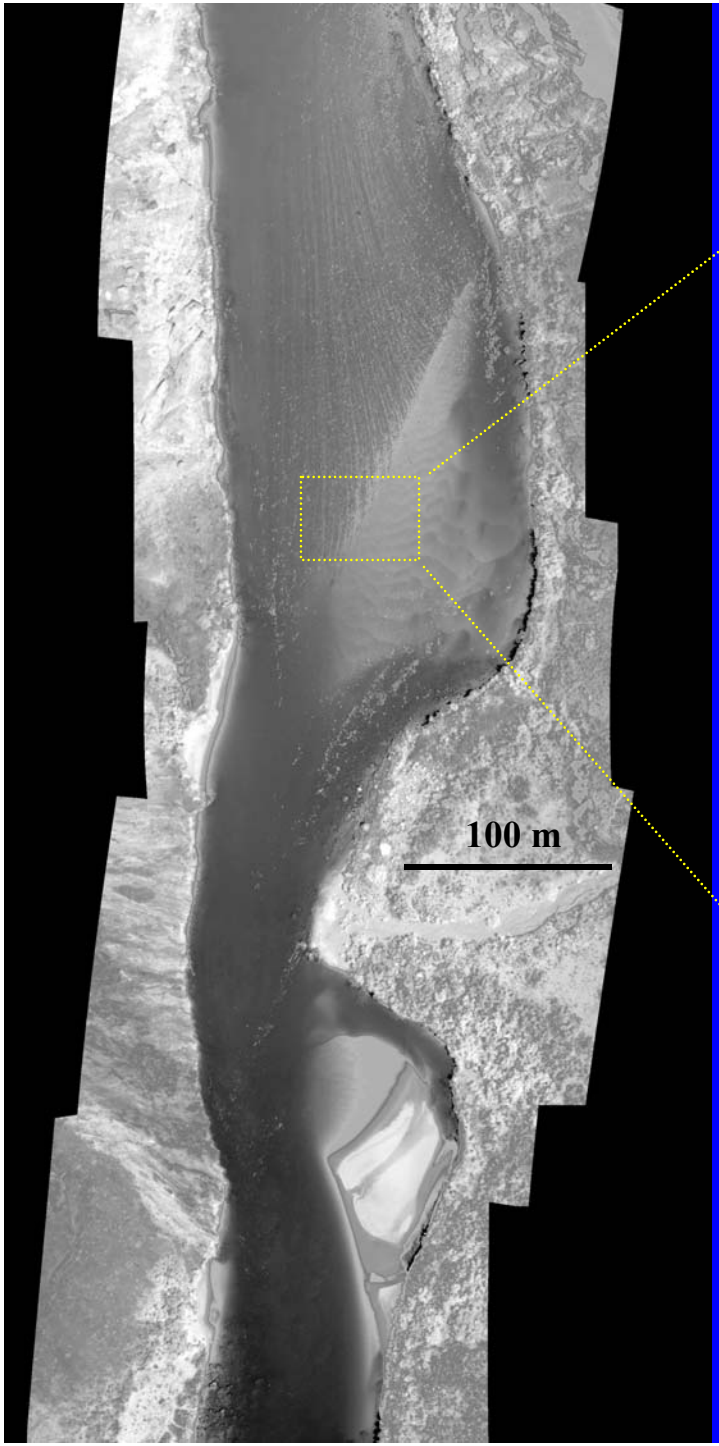
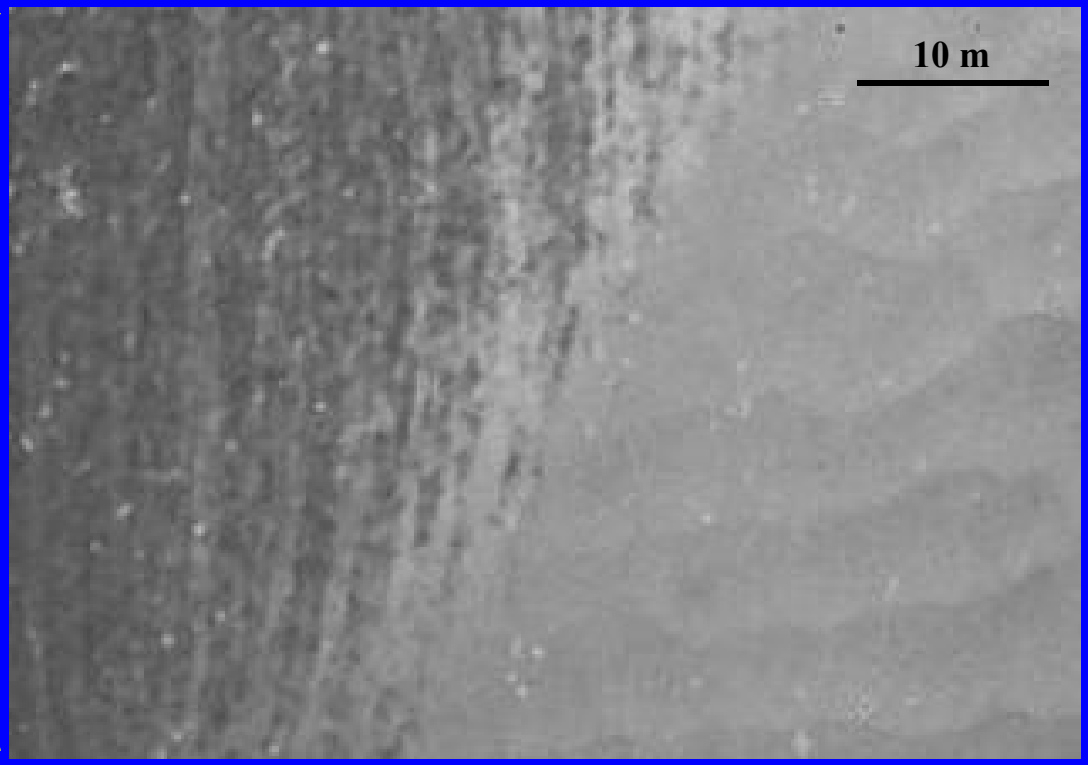
Channel Sediments





7-cm, georectified, digital blue-green imagery acquired with a high-gain state in May, 2003

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Channel Morphology

- **Results: High-gain capability provided by digital cameras can map sediment distribution and grain size on channel substrate, but uncertain at this time what size ranges can be discerned.**

- ***Note*: Method limited by water clarity and depth, both of which attenuate light. Image rectification of inexpensive data to 1 m positional accuracy without accurate GPS/IMU information requires about 2 hours processing per image or about one-half year for 100 miles of 7-cm imagery.**

Bathymetry – channel topography

- **Photogrammetry is unable to model the channel topography due to a lack of surface texture on sediment deposits.**

- **SHOALS (green and NIR LIDAR) now worth testing; recent developments allow mapping to 20 m in turbid water and 40-50 m in clear water. The 2-m point spacing provided by SHOALS is adequate for modeling and the digital camera on the SHOALS system can also map grain size at the 7-cm level (same camera shown previously).**

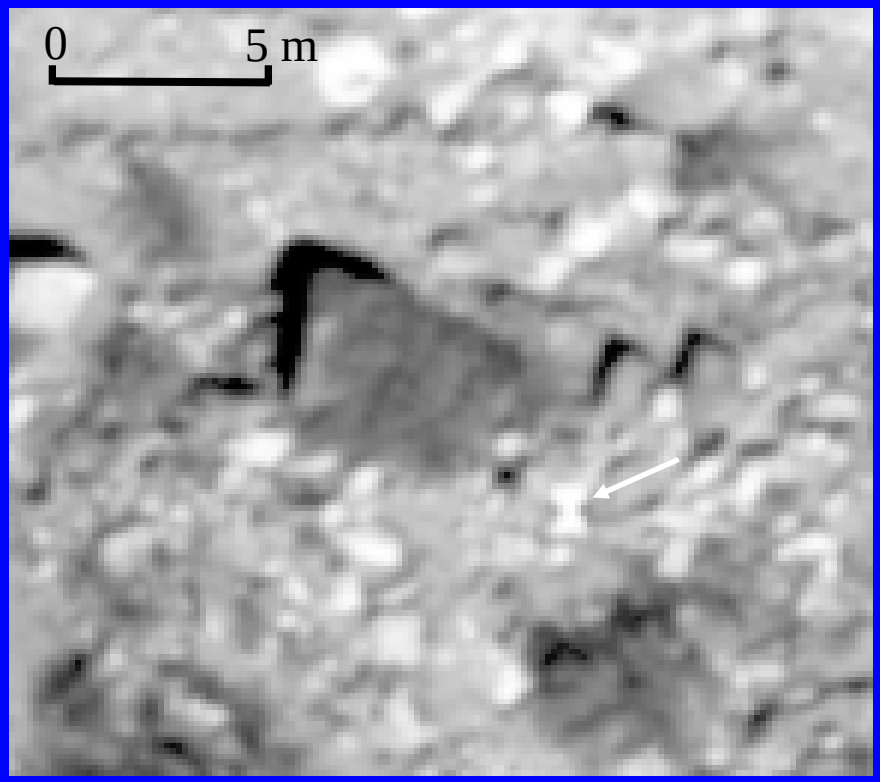
Terrestrial sediment deposits

- **Requirements:**
  - **Map spatial distribution, geomorphology, and volume of fine- and coarse-grained sediment deposits.**
  - **Initially, believed required image resolution near 6 cm provided by aerial photography**
  - **30-cm positional accuracy**
  - **Topography ≤ 25 cm vertical accuracy.**

Terrestrial Sediment Morphology

- **Detection Technologies Evaluated:**
  - **Photographic and digital b&w, true-color, and color-infrared imagery at resolutions ranging from 6 cm to 30 cm.**

Geomorphology - Eminence



- **Results: Natural-color better than b&w imagery for distinguishing surface materials and surface texture.**

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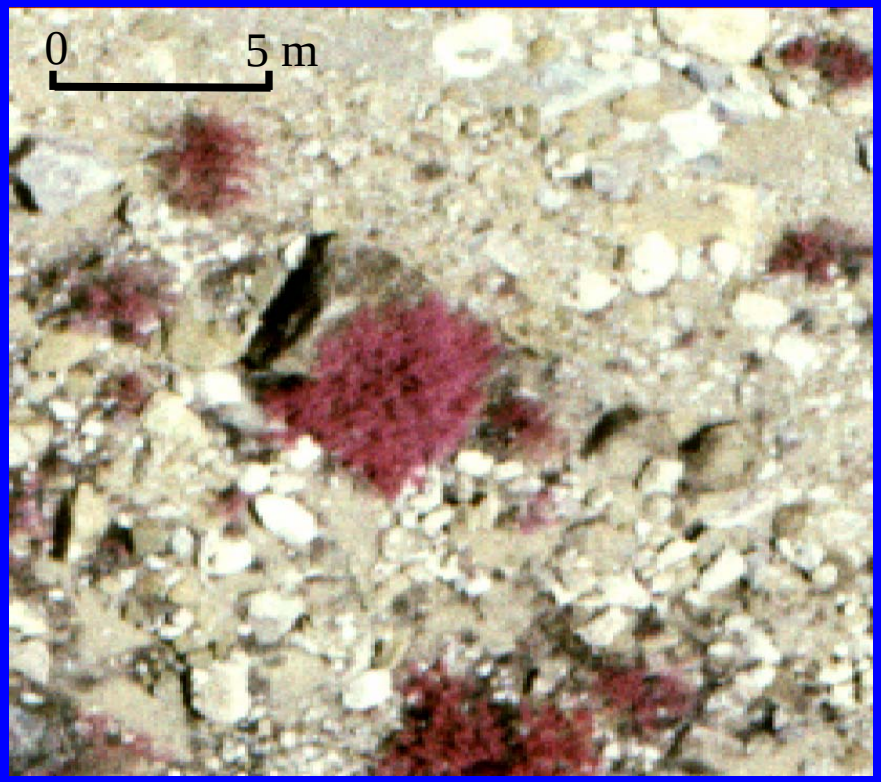
Geomorphology - Eminence



- **Results: CIR imagery provides more unambiguous vegetation identification, which allows better and more unsupervised texture analyses, which is an important attribute of sediment deposits.**

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Geomorphology Results

- **For most GCMRC mapping applications, image resolution near 20-25 cm is acceptable to scientists. In fact, they appear to use the 44-cm image data.**

- **This result opened the door for digital sensors, which cannot obtain 6 cm resolution, but can provide calibrated, orthorectified data at 25 cm for many monitoring requirements.**

Topography – Data Evaluated

Method	Accuracy Bare	Accuracy Veg.	Precision	Invasiveness	Cost/km
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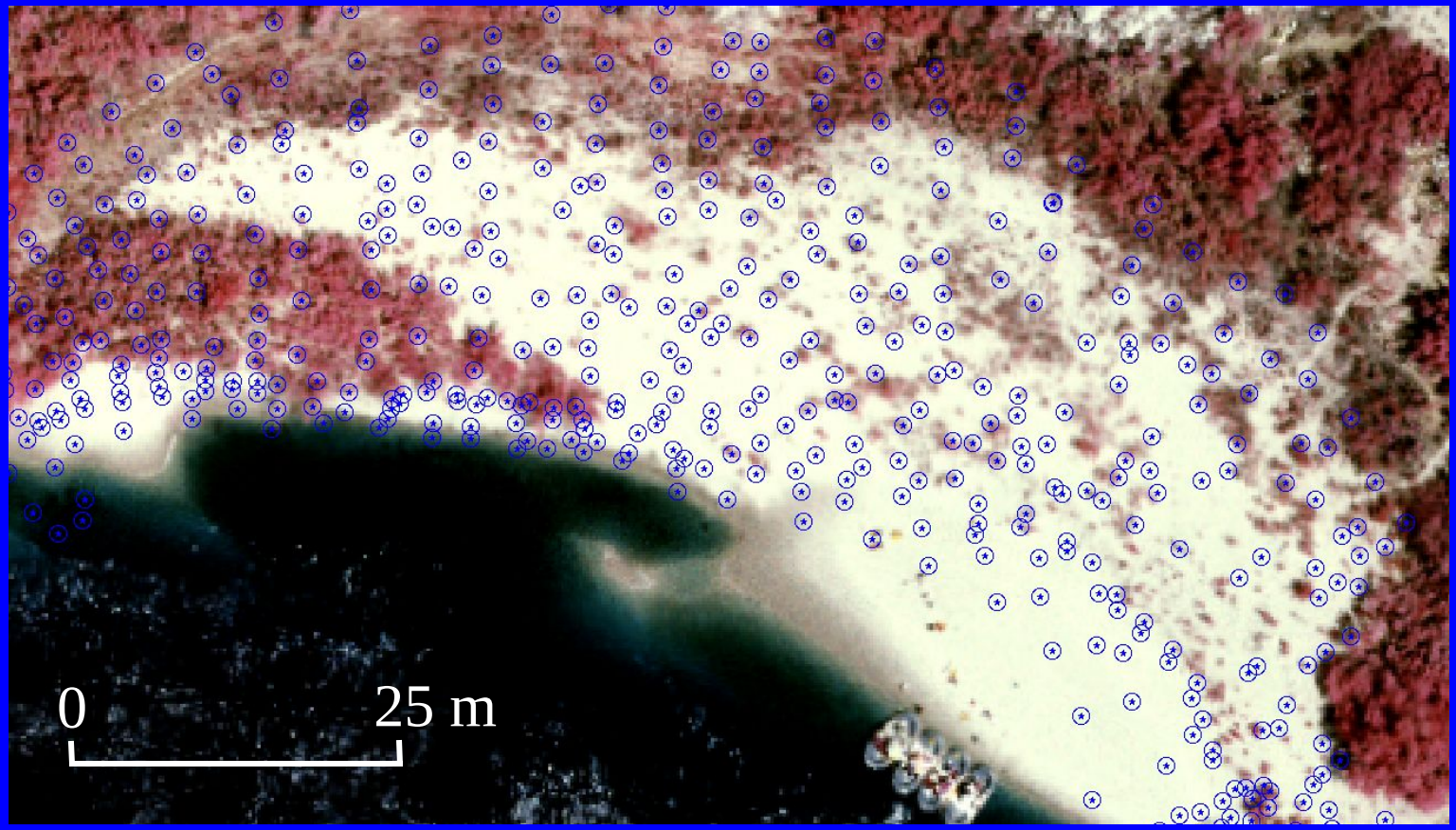
* have vertical offsets, some variable

** better processing may reduce these values

Ground Survey (2-3 m point spacing)



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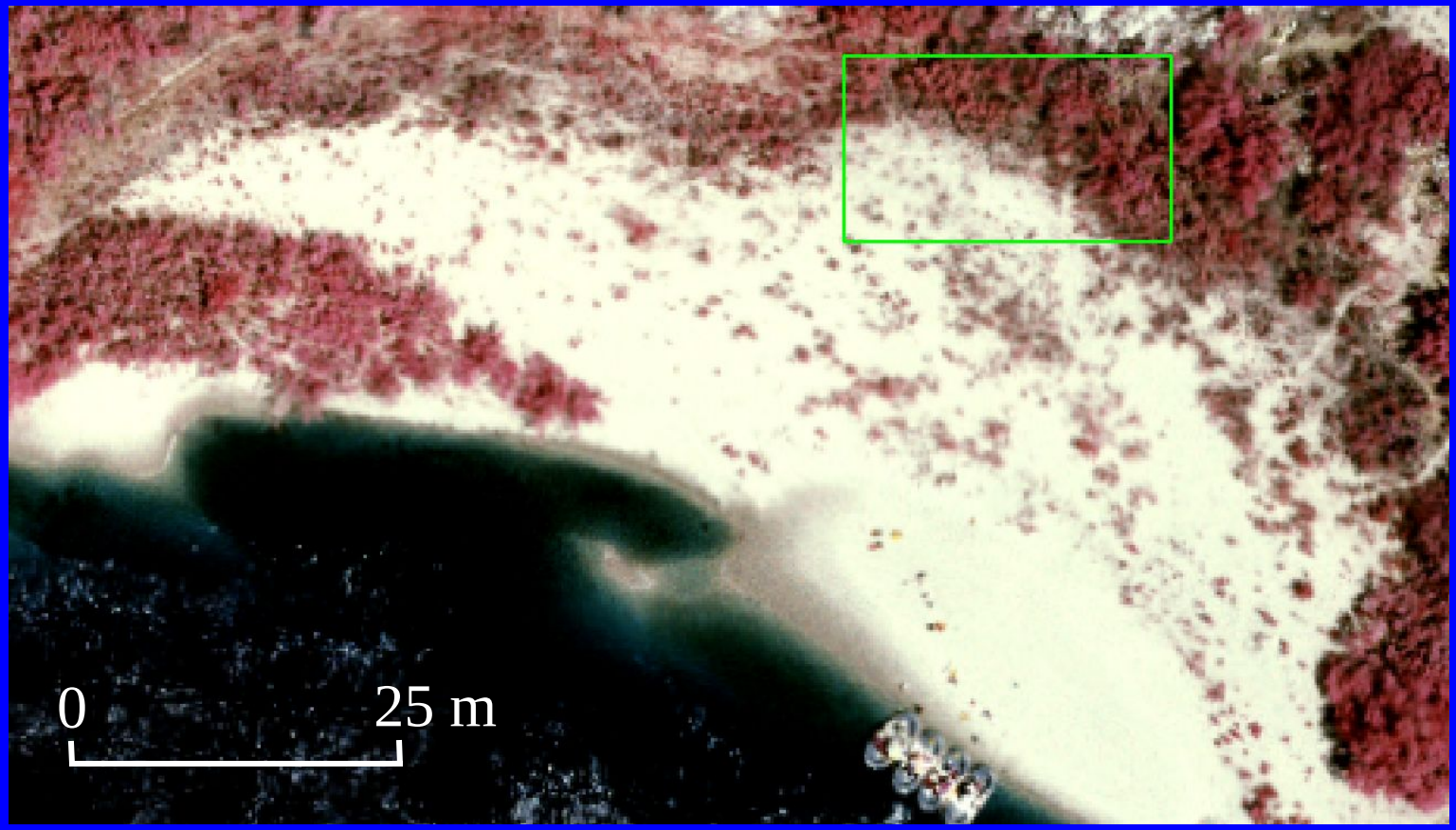
Subarea for DSM/LIDAR



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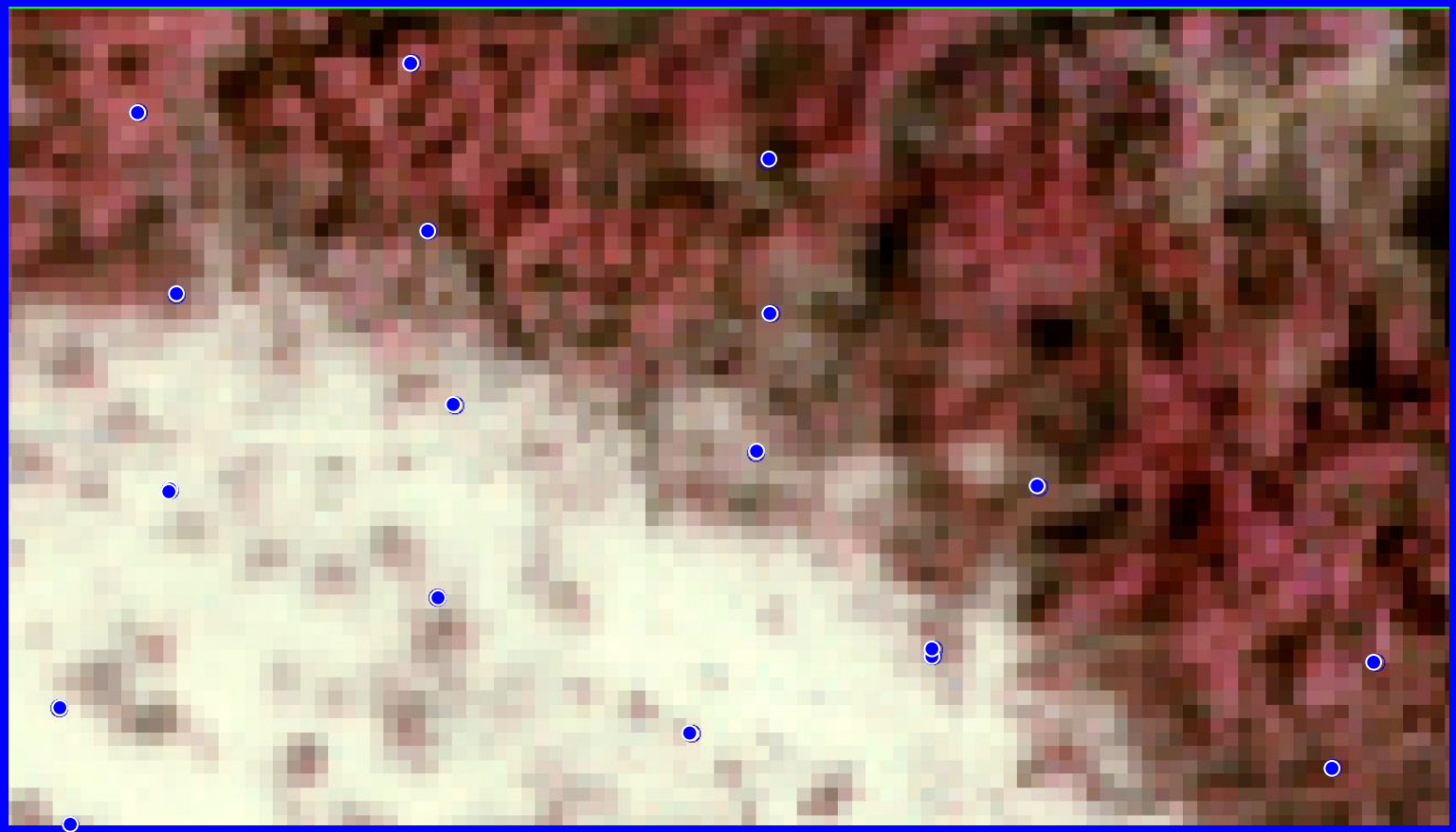
Ground Survey (2-3 m point spacing)



0 5 m

(invasive, $1,000/km)

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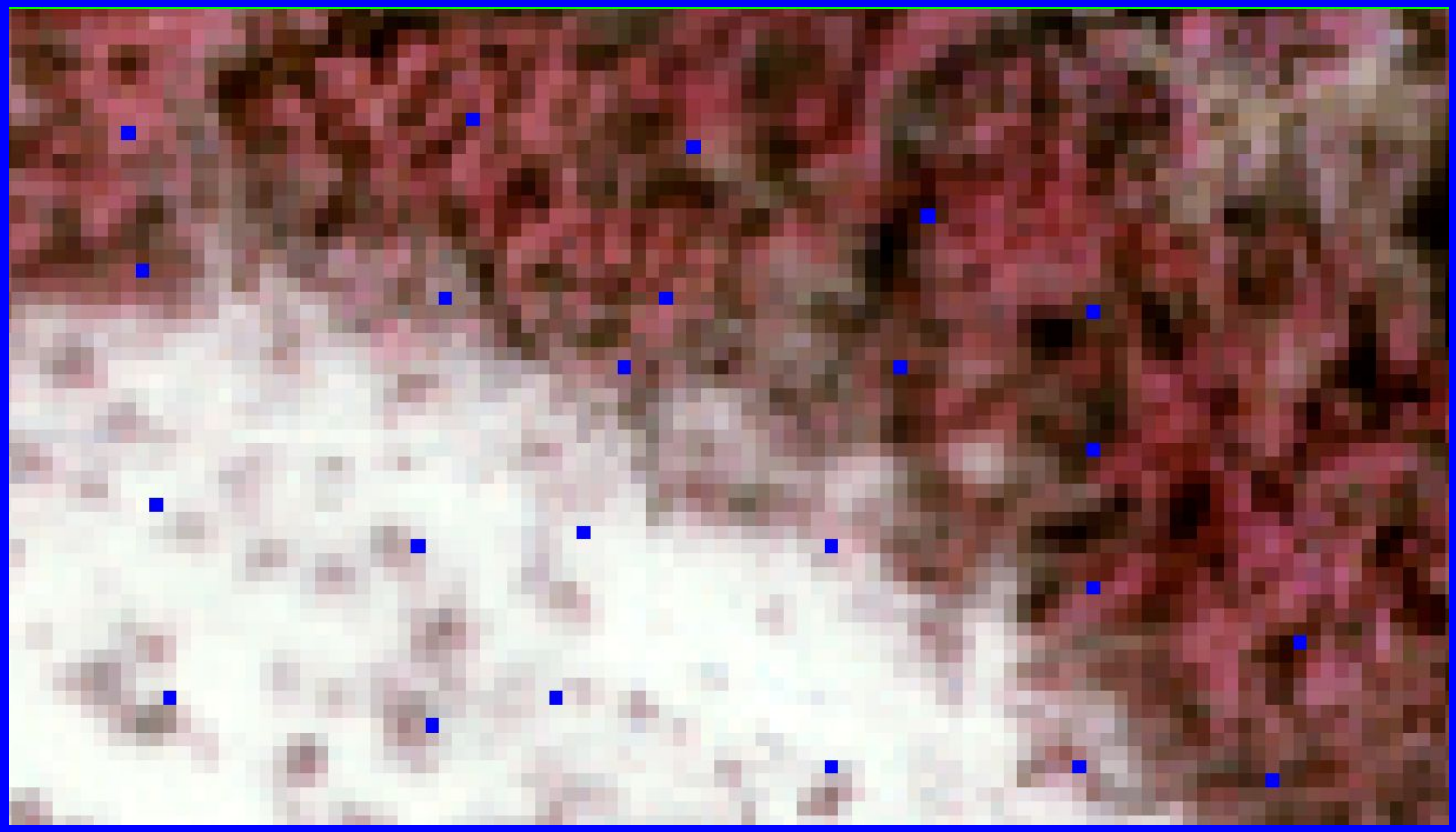
Low Resolution (3.75 m) LIDAR



0 5 m

(noninvasive; 3,000-m AGL; $575/km)

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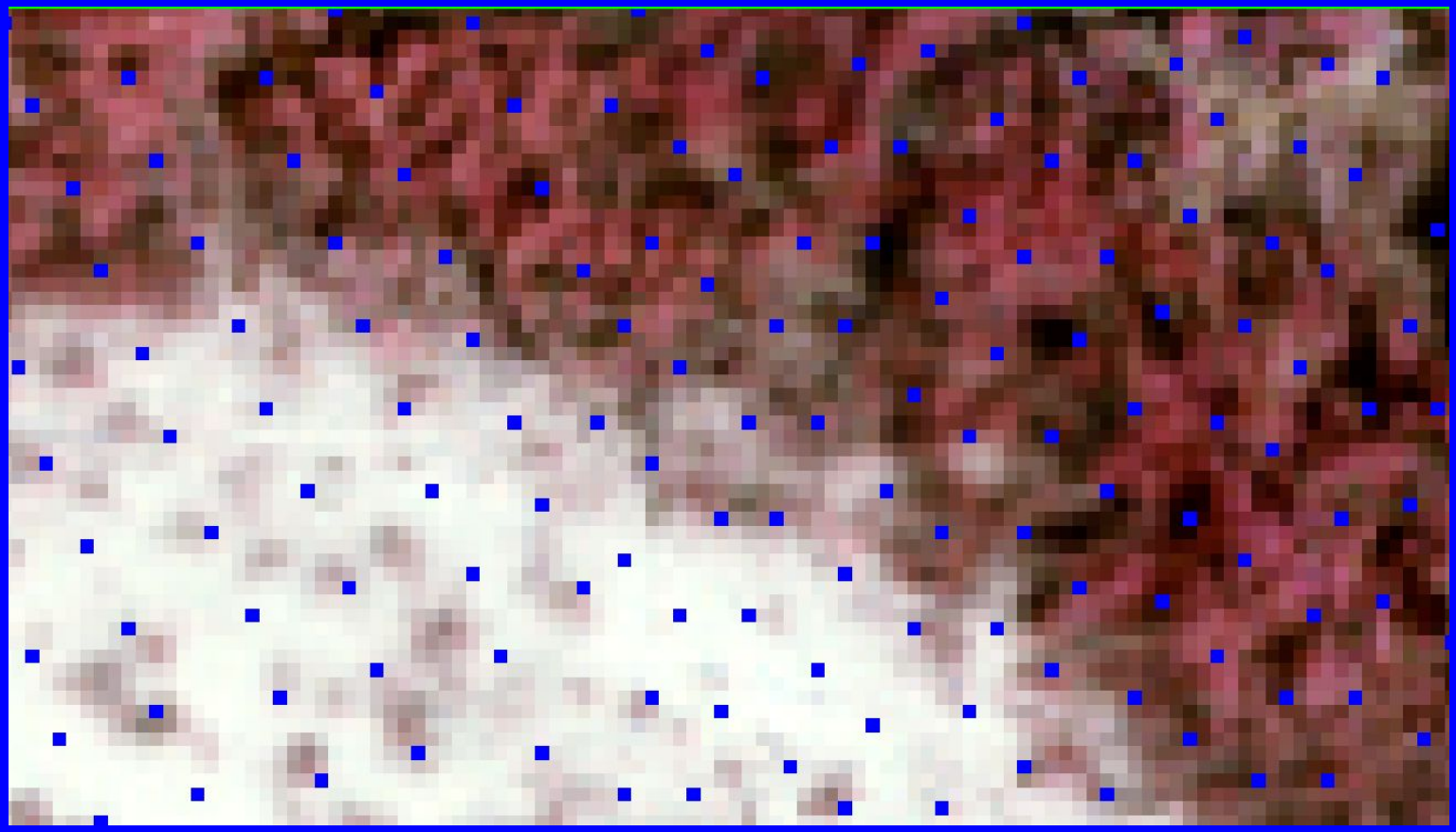
Moderate Resolution (1.5 m) LIDAR



0 5 m

(noninvasive; 1,500-m AGL; $1,785/km)

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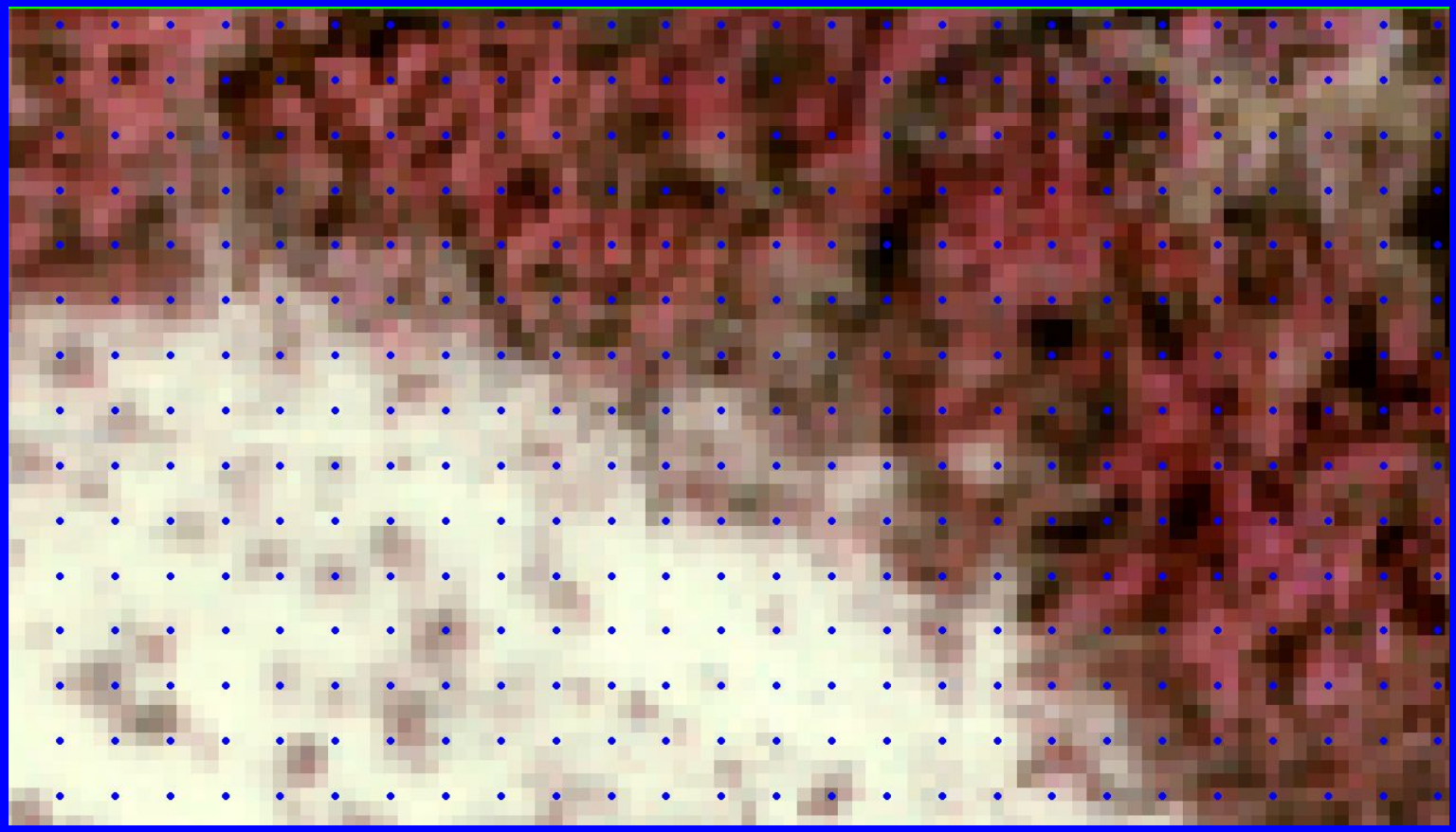
Automated Photog. (1 m) DSM



0 5 m

(~invasive; 2,400-m AGL; $625/km)

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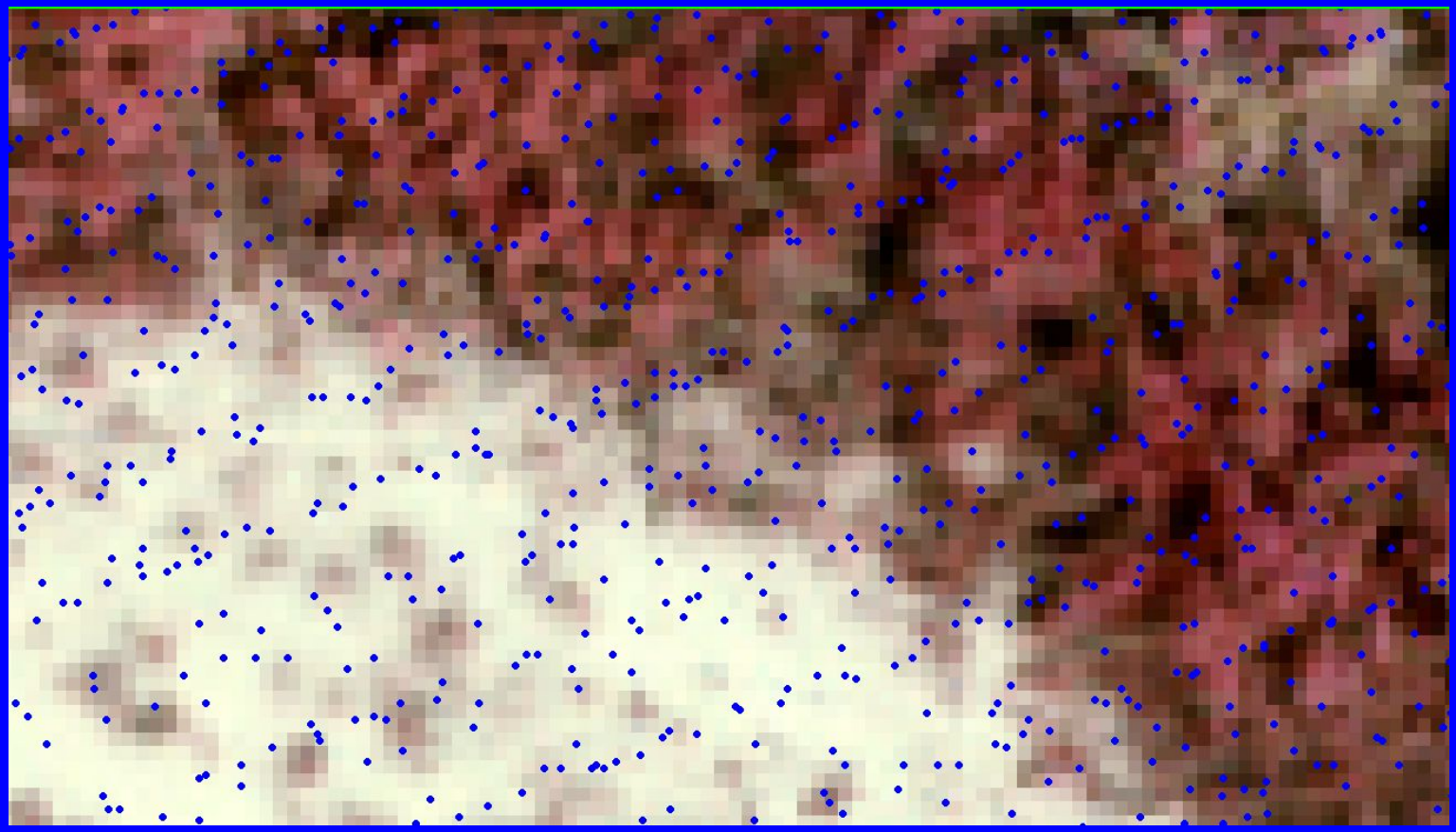
High Resolution (0.8 m) LIDAR



0 5 m

(noninvasive; 1,800-m AGL; $2,100/km)

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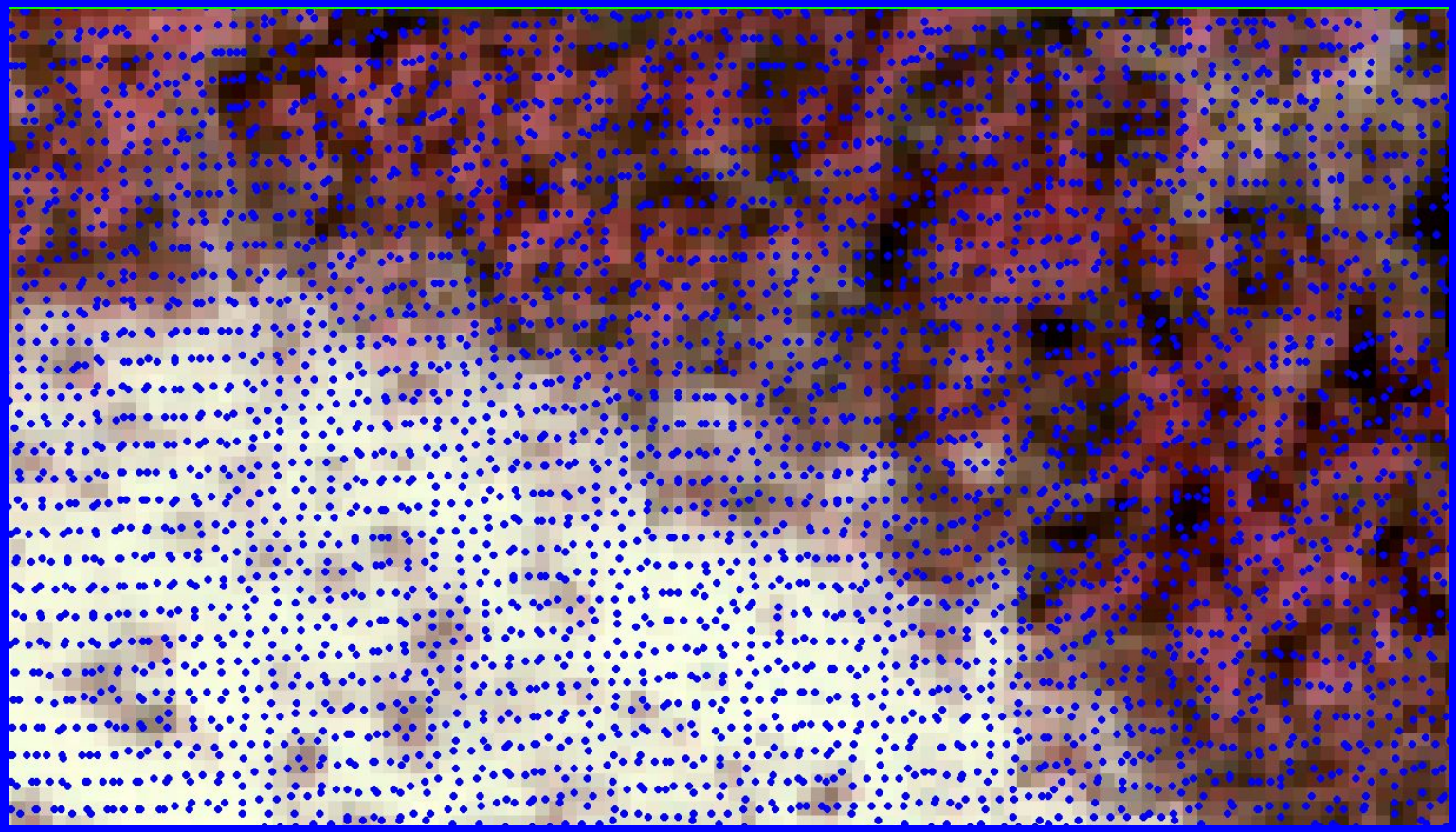
Very High Resolution (0.3 m) LIDAR



0 5 m

(noninvasive; 100-m AGL; $6,200/km)

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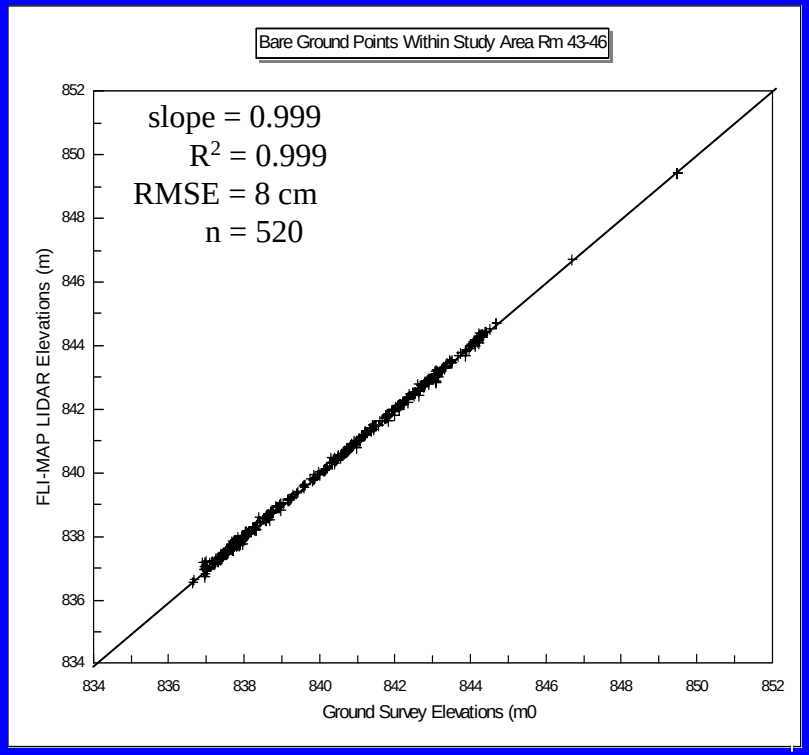
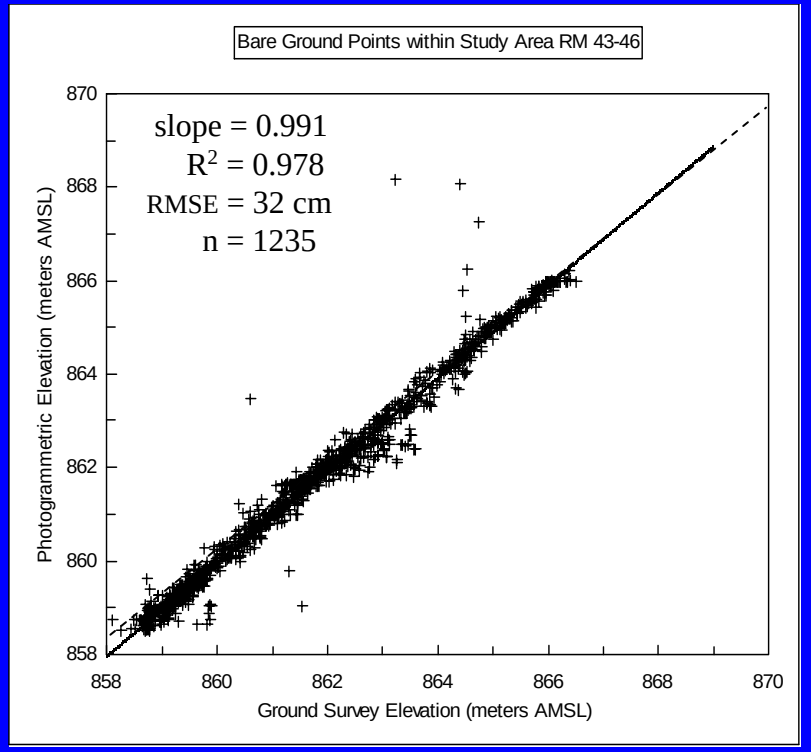
Results on Bare Ground

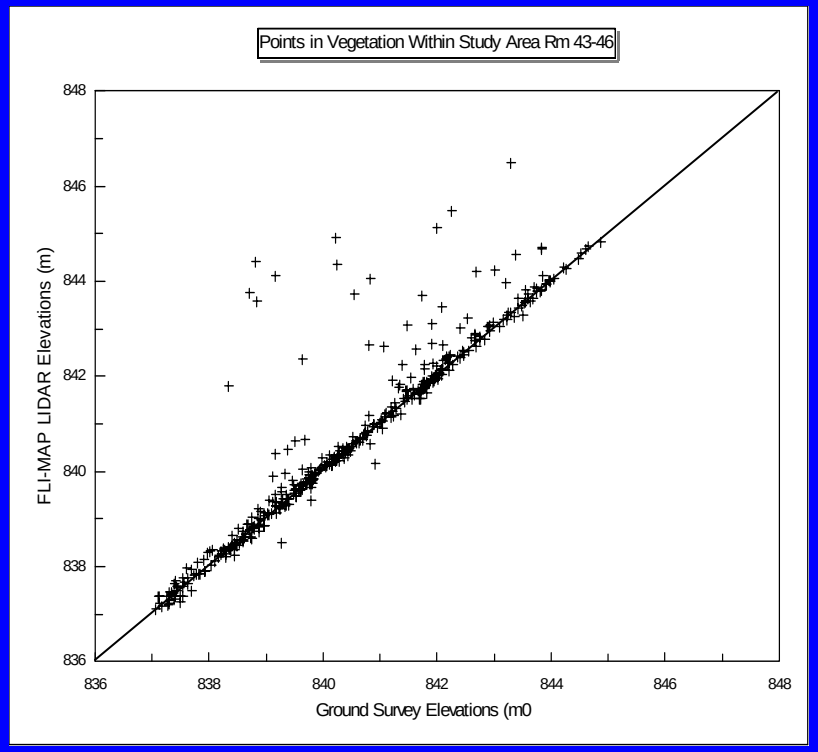


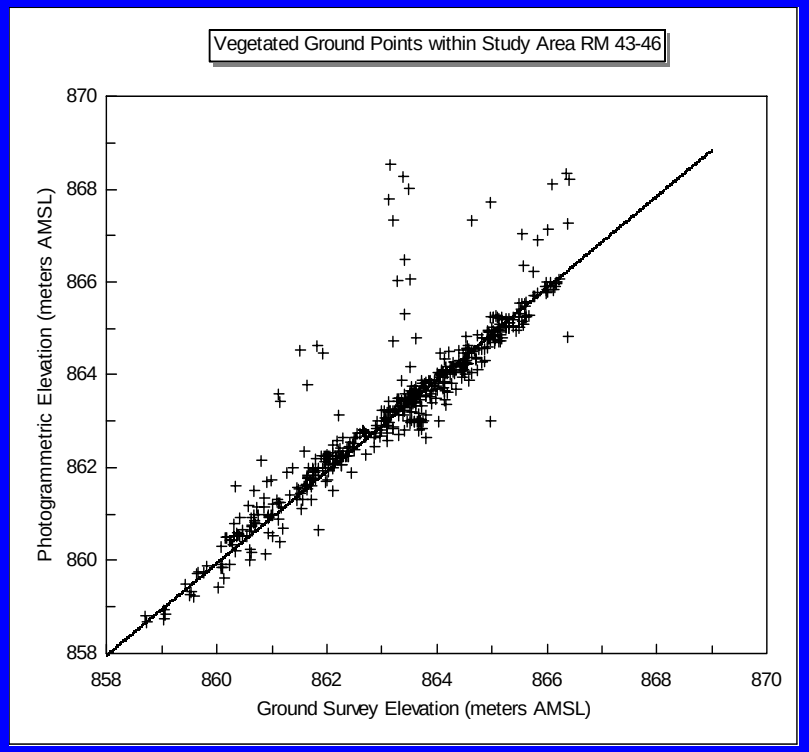


Very High Res. LIDAR (noninvasive; 100-m AGL; $6,200/km)

Manual Photogrammetry (invasive; 610-m AGL; $3,000/km)

Results on Vegetated Ground





Very High Res. LIDAR

Manual Photogrammetry

Topography – Comments

- ***Manual photogrammetry***
  - **Acceptable accuracies**
  - **Invasive (requires control panels)**
  - **May not provide acceptable accuracies during winter months due to extensive shadows**
- ***Automated photogrammetry***
  - **Inexpensive DSM data for monitoring system-wide small-scale changes**
  - **Not appropriate for sediment monitoring**
  - **Invasive (requires control panels)**
  - **Not appropriate during winter months**

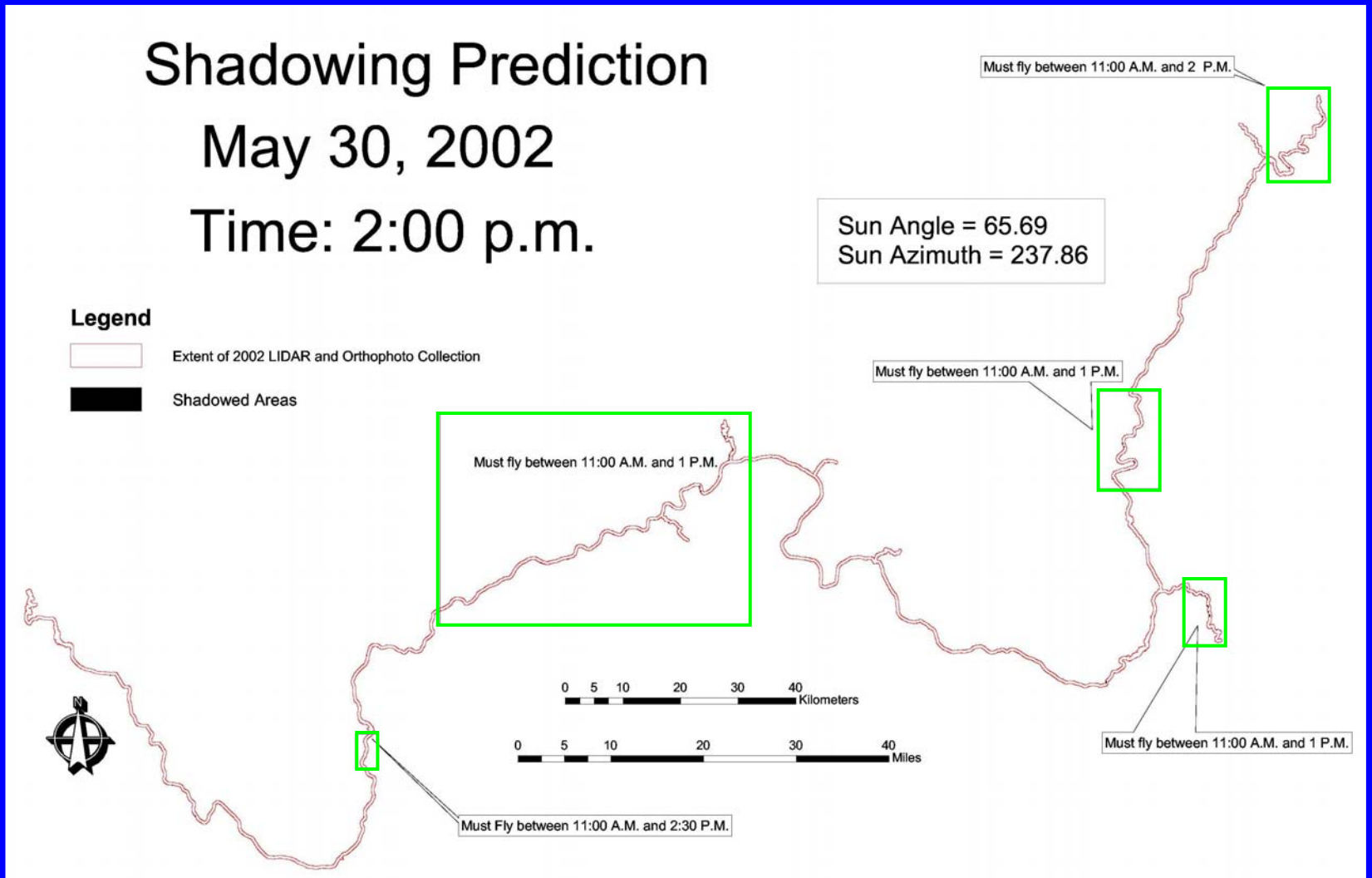
Topography – Comments

- ***High and very high resolution LIDAR –***
  - **Acceptable accuracies**
  - **Completely non-invasive**
  - **Not effected by shadows or cloud cover**
  - **Accuracy of very high resolution LIDAR data close to the accuracy of ground surveys**
  - **Very high resolution may be useful for Archaeology requirements.**
  - **Improved data processing might produce much higher accuracies within vegetation and may also provide accurate canopy volumes.**

Recommendations for Future Data Acquisition and Testing

Minimum Imagery Protocols

- **For most applications:**
  - **Spatial resolution 20-25 cm (archaeology ≤ 6 cm; TIR = 100 cm)**
  - **If analog imagery, scanned at 15 microns**
  - **GPS/IMU instrumentation (φ, κ, α for analog data)**
  - **Dual sensors/aircraft to insure against weather and equipment failures; 50% reduction in collection time (only 15% more cost)**
  - **Accurate and complete metadata**
  - **Acquired under TOD flight restrictions predicted by GCMRC shadow models to minimize shadows**



Boxes indicate areas with restricted time windows for airborne data collection to *minimize* shadows with the riparian zone.

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Optimum Imagery Protocols

- **Image bands:**
  - **Biennial data collections - Color-infrared**
  - **Warm-water habitat mapping – Thermal infrared**
  - **Vegetation mapping surveys will require green, red, and at least two near-infrared bands, possibly some short-wave infrared bands, but best resolution may be 50-100 m.**

- **Calibrated, digital sensors (12-16-bit data preferred for vegetation and aquatic monitoring) – assumes variable detector gains**

- **Orthorectified to 30-cm positional accuracy**

Elevation Data Protocols

- **Terrestrial sediments (≤ 25 cm accuracy)**
  - **Minimum (change detection) = high resolution LIDAR**
  - **Optimum (baseline) = very high resolution LIDAR**
- **Archaeology (≤ 6 cm accuracy)**
  - **very high resolution LIDAR (limited area – possibly 24 100-m sites for $7,000)**
- **Canopy Volume (≤ 50 cm accuracy)**
  - **High or very high resolution LIDAR (but more limited area coverage at very high resolution)**

Elevation Data Protocols

- **Channel (≤ 15 cm accuracy)**
  - **Minimum = acoustic multi-beam**
  - **Potential = SHOALS LIDAR**
    - ***In clear*, *calm* water to depths 20-40 m - 20 m depth penetration in *turbid* water.**
    - **In the rapids, there will be data gaps due to the water's mirror surface.**
    - **Provides both channel and terrestrial topography and digital 3-band image data appropriate for channel morphology.**