High Spatial Resolution Commercial Satellite Imaging Product Characterization

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High Spatial Resolution Product Characterization

- Very important when using commercially obtained imagery for scientific investigations
  - Systems designed and operated outside the scientific community
- High spatial resolution (<4 m GSD) and limited swath (<17 km) allow different approaches than with coarser resolution wider swath systems
  - Designed targets are commonly used
  - Single site can be used to measure most geopositional, spatial and radiometric characteristics

Relevant High Spatial Resolution Sensors

Asset	Revisit Time	Spectral Bands/Spatial Resolution (GSD)	Swath (Standard Product)
IKONOS	1-2 days	B, G, R, NIR, Pan Nadir 3.84 m (multi) 0.86 m (pan)	11 km
QuickBird 2	1- 5 days	B, G, R, NIR, Pan Nadir 2.44 (multi) 0.61 m (pan)	16.5 km
OrbView-3	< 3 days	B, G, R, NIR, Pan Nadir 4 m (multi) 1 m (pan)	8 km

Product Characterizations & Uses

- Spatial Resolution (MTF, PSF, Edge Response)
  - Smallest object detection & identification
  - Pixel mixing
  - Image restoration

- Radiometry (Linearity, Relative, Absolute)
  - Atmospheric correction
  - Change detection
  - Sensor intercomparison

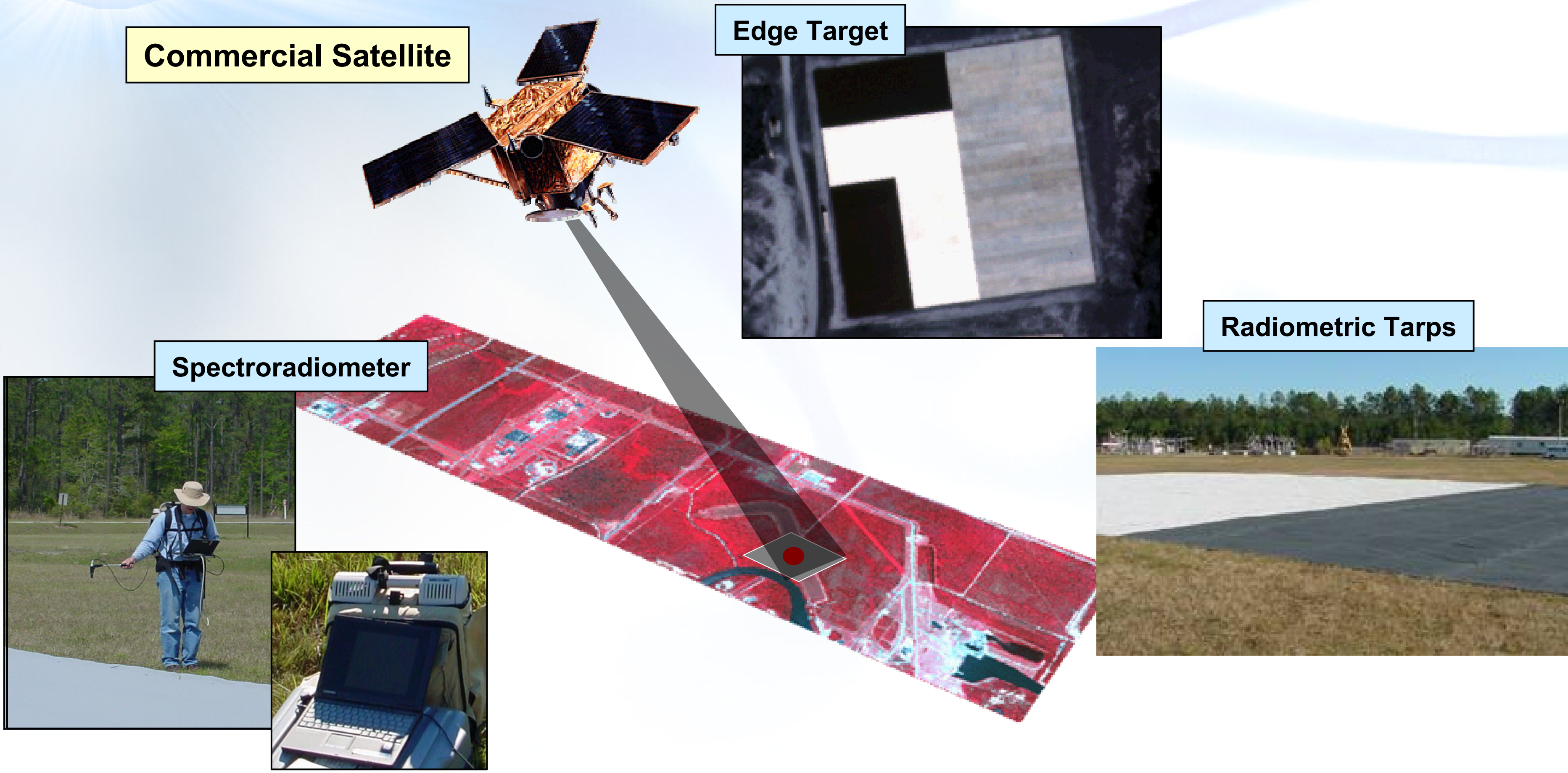
- Geopositional Accuracy (Absolute & Relative)
  - Map creation
  - Measurements
  - Repeatability for accurate change detection

Spatial Product Parameters & Targets

- Parameters of interest
  - Ground Sample Distance
  - Optical Transfer Function
    - Modulation Transfer Function (MTF)
    - MTF @ Nyquist
  - Point Source Function (PSF)
  - Edge Response
    - Slope and ringing
  - Line Spread Function
  - *Point Source Transmittance (PST) / Stray light*
- Target types
  - Edge, pulse, line and point targets

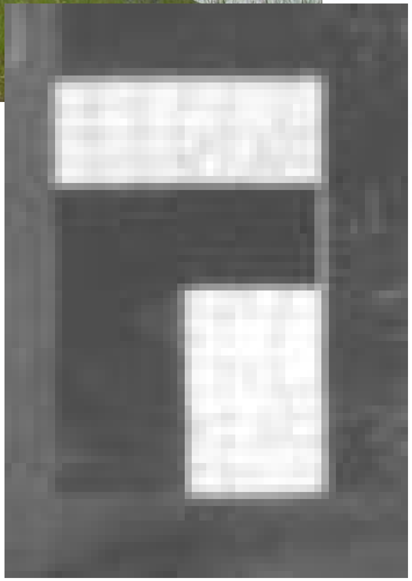
High spatial resolution allows the use of designed and man made targets

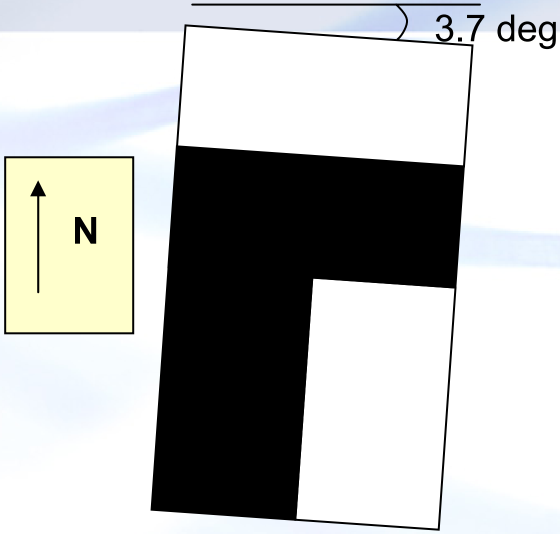
Spatial Characterization

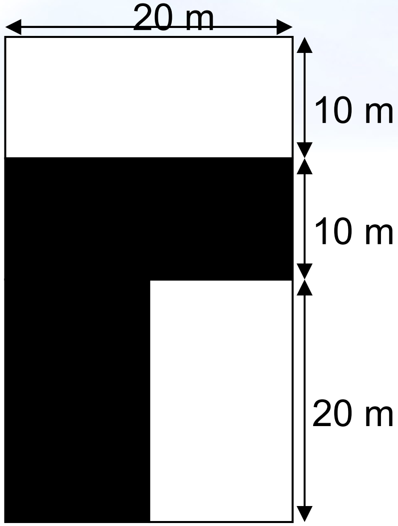


Method: Utilize edge targets (tarps, SSC concrete edge target or other man-made features such as painted runways or buildings) and ground reflectance measurements (spectroradiometer) to determine the edge response of remote sensing systems.

SSC Concrete Edge Targets





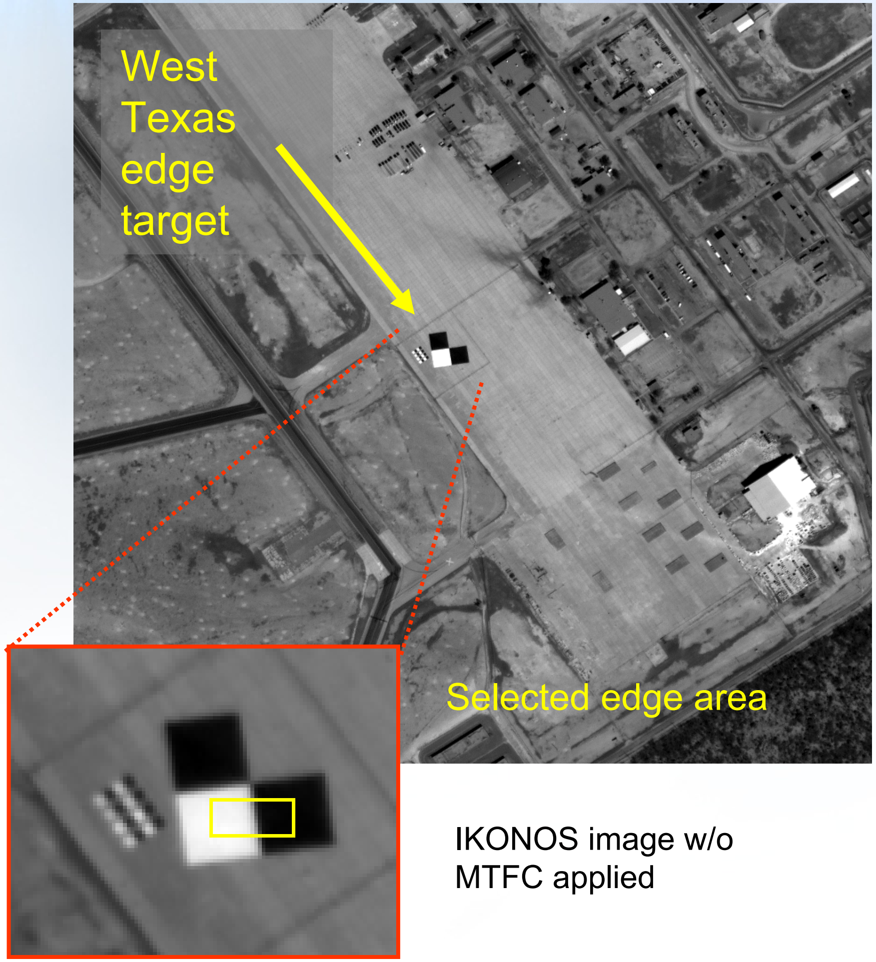


QuickBird Imagery

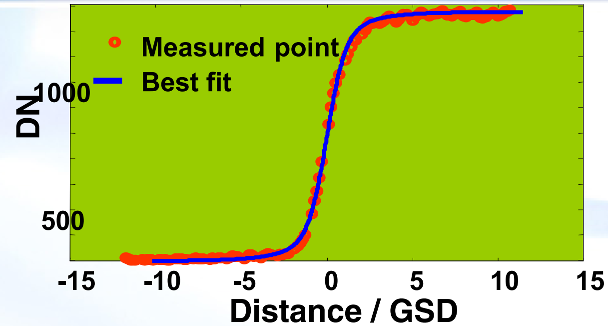
Feb 17 2002

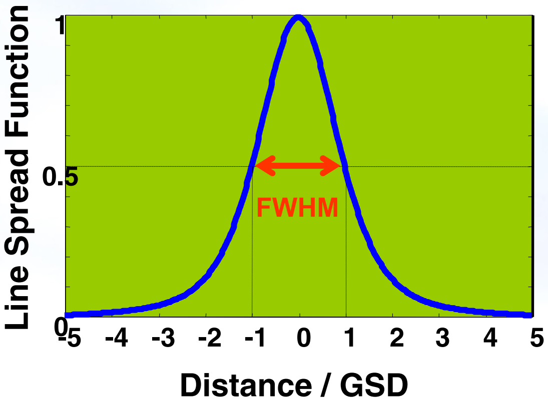
Tilted edge allows for proper sampling of the edge response

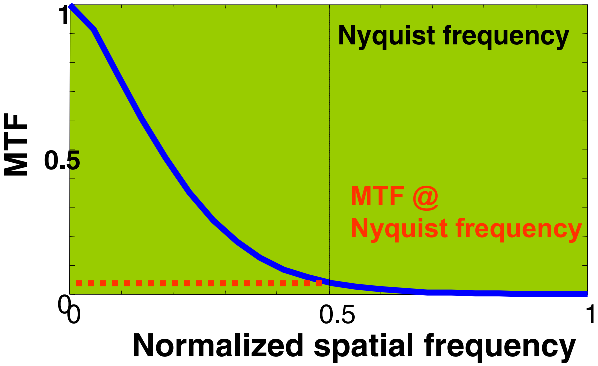
IKONOS MTF Measurements



IKONOS image w/o MTFC applied







Radiometric Product Parameters & Targets

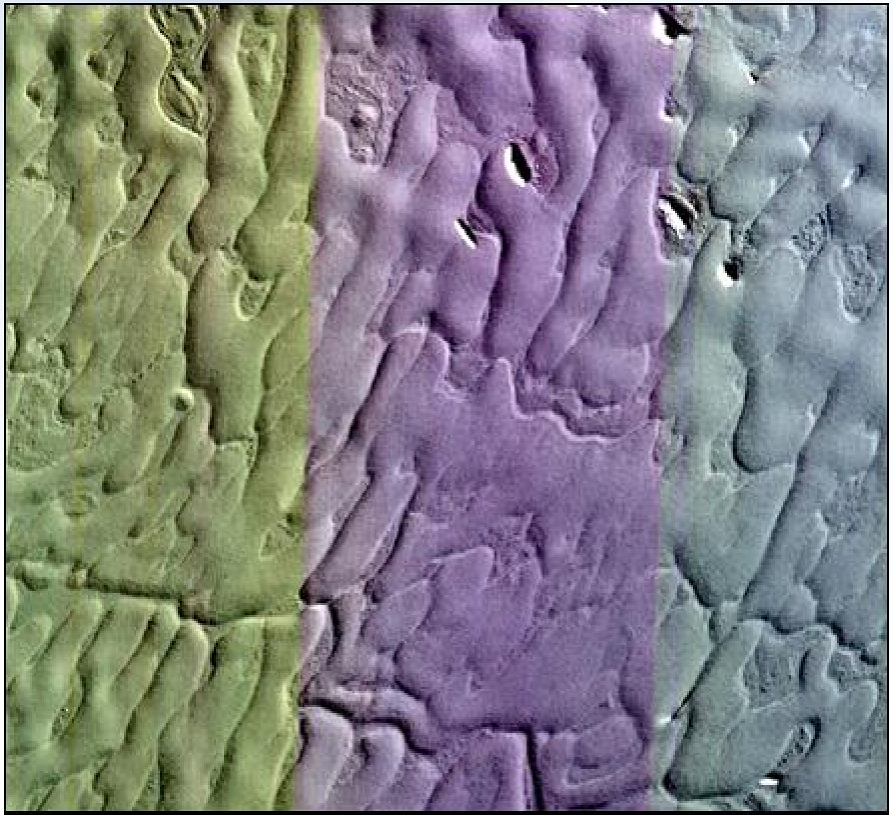
- Parameters of Interest
  - Relative radiometry
  - Absolute radiometry
  - Signal-to-noise

- Target types (Reflective Based Calibration)
  - Large bright uniform areas such as playas
  - Natural features and manmade targets
    - Grass fields, concrete parking lots, etc.
    - Engineered uniform targets

High spatial resolution allows the use of designed and man made targets.

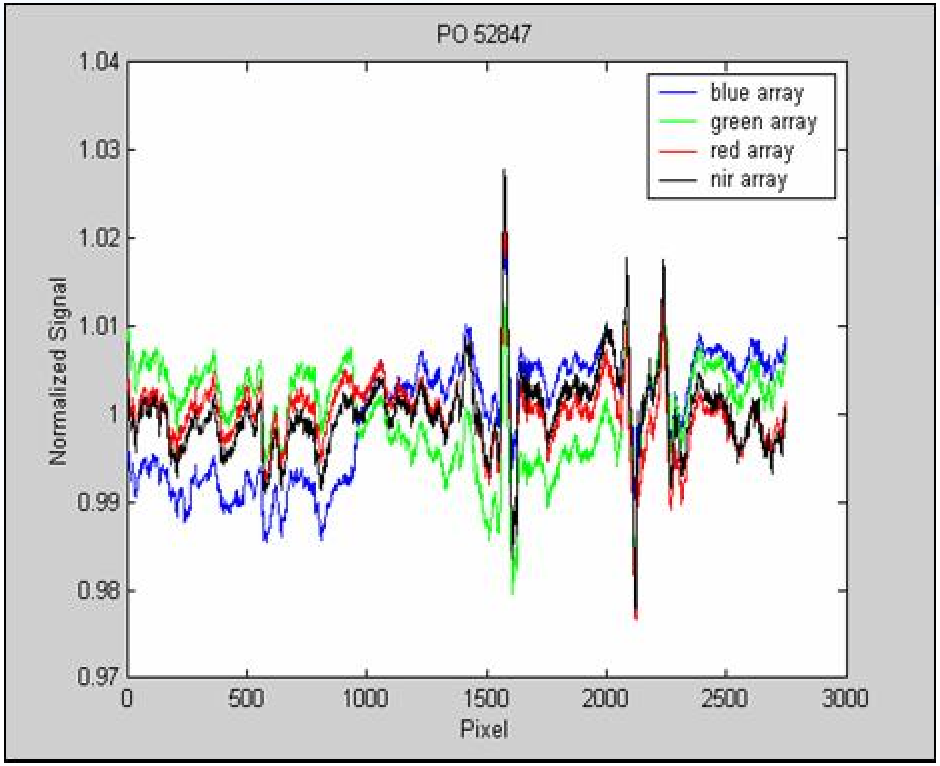
Relative Radiometry

Large uniform scenes support the determination of pixel-to-pixel uniformity and SNR estimation.



IKONOS Image of Antarctica – RGB, POID 52847

Normalized Average Row Values for Antarctica



Radiometric Calibration

Radiometric calibration is the process of converting digital imagery values to radiance

$$L_{TOA} = K\,DN + C$$

Where:

L_{TOA}	Top-of-the-Atmosphere radiance
K	Calibration coefficient
DN	Pixel digital number (Value)
C	Offset (Many times near zero)

Commercial vendors often provide calibration coefficients with C equal to zero.

Radiometric Calibration Uncertainty

$$\frac{\sigma_K}{K} = \sqrt{\left(\frac{\sigma_L}{L}\right)^2 + \left(\frac{\sigma_{DN}}{DN}\right)^2}$$

- **Bright calibration targets typically provide best accuracy**
  - **Minimizes radiative transfer errors**
  - **Maximizes SNR (Important for small targets)**
- **Uniform targets minimize DN variations**

Absolute Radiometric Characterization Reflective Region

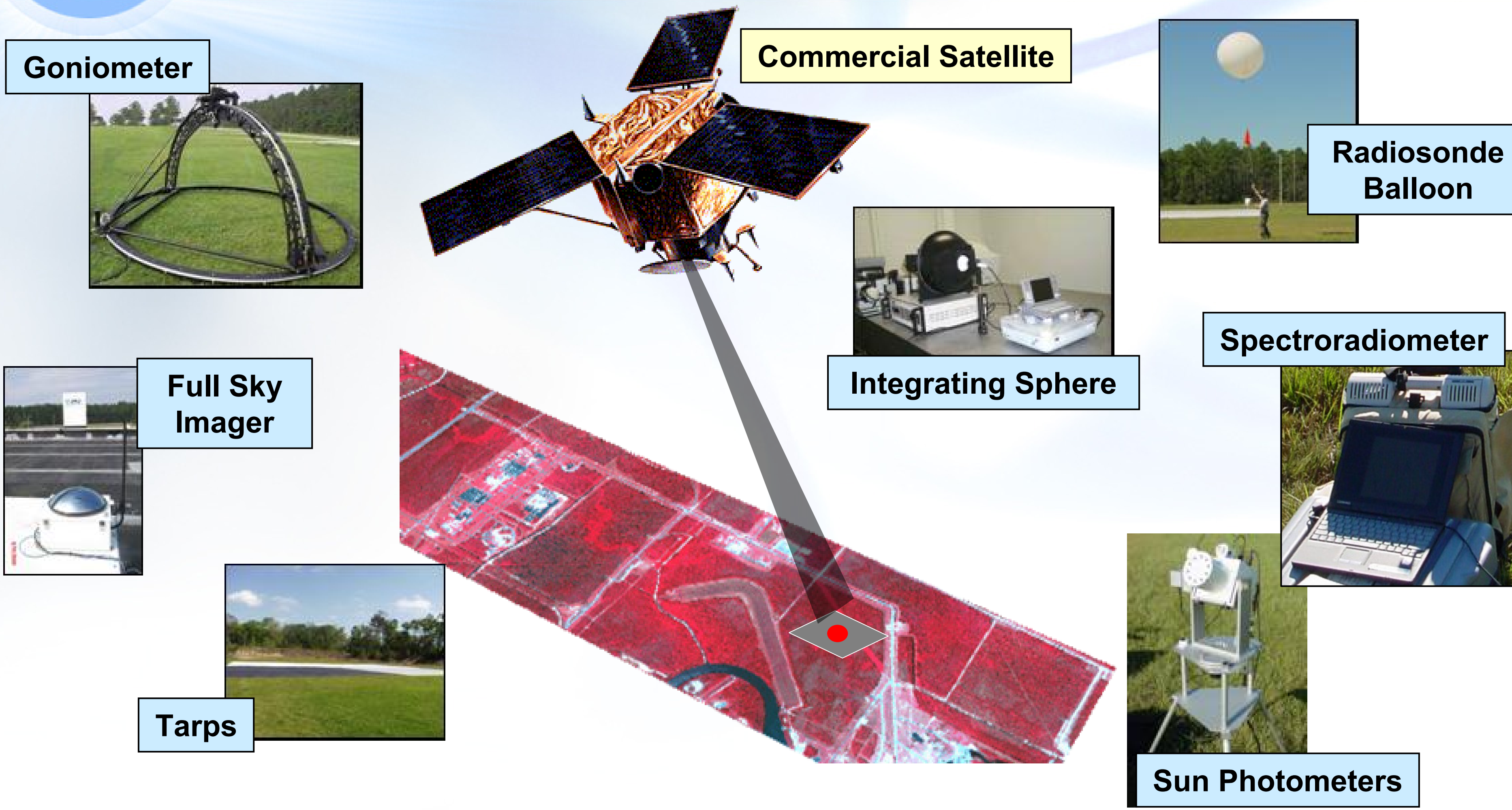
- Site Requirements
  - Uniform targets large enough to minimize finite PSF errors (5 pixels or greater)
  - Reflectance measurements
  - Atmospheric measurements
    - Aerosols
    - Water vapor
    - Ozone
- Characterization Technique
  - At time of acquisition measure:
    - Target reflectance
    - Atmospheric parameters
  - Predict at-sensor radiance using:
    - Target reflectance
    - Modeled atmosphere
    - Sensor spectral response
    - Sensor-target-solar geometry

Reflective Radiometric Characterization Sites

- Playas and other “bright” naturally occurring land features (Adjacency is not an issue)
  - White Sands Missile Range
  - Lunar Lake Playa
  - Railroad Valley Playa
  - Ivanpah Playa

- Complex sites with targets (Adjacency is important)
  - Brookings/South Dakota State University
  - Stennis Space Center and surrounding area

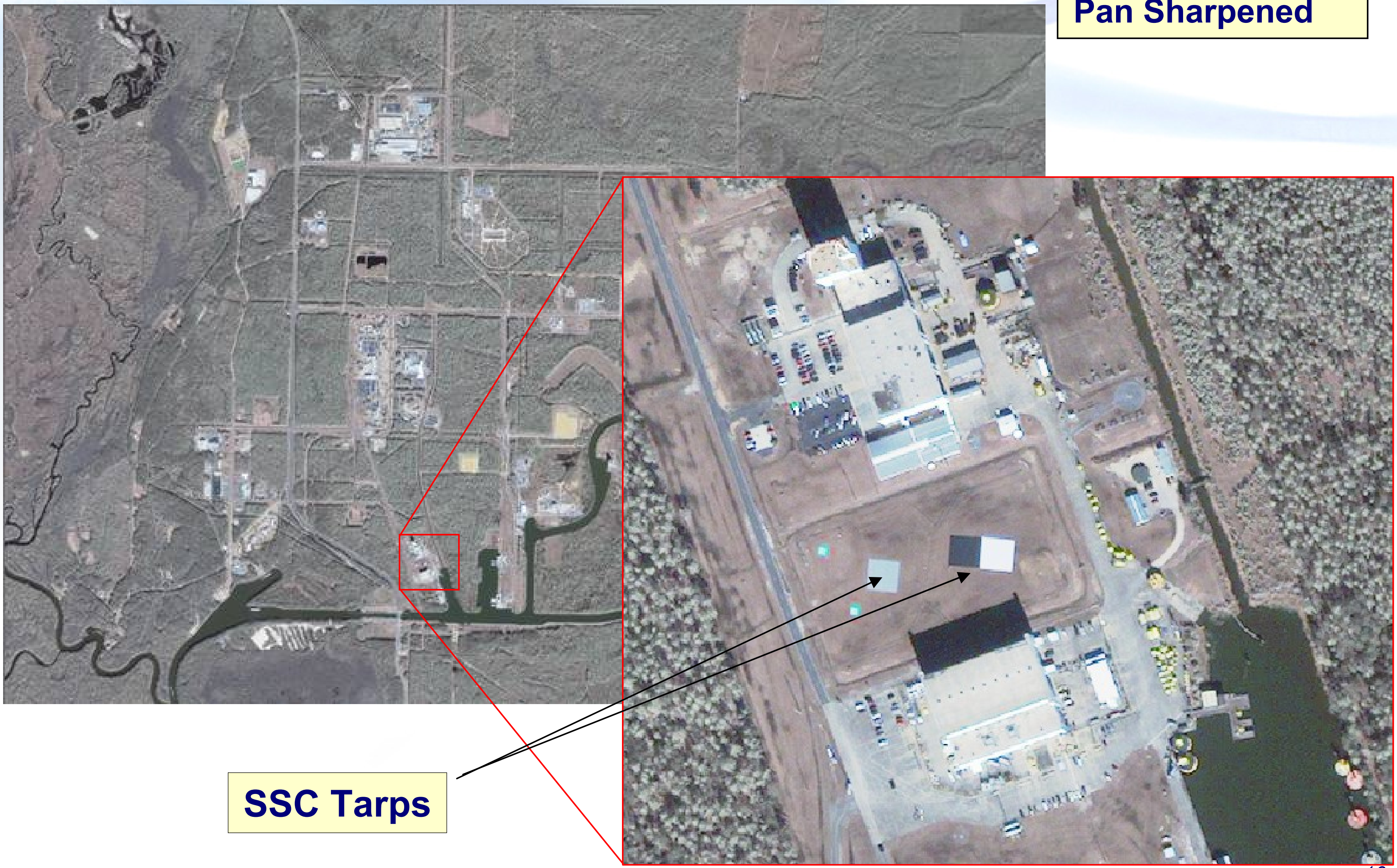
Reflective Radiometric Characterization



Method: Utilize ground reflectance measurements (Spectroradiometer) and atmospheric measurements (Sun Photometer and Radiosonde) to determine radiometric accuracy of remote sensing systems.

IKONOS Image of NASA SSC

January 15, 2002
Pan Sharpened



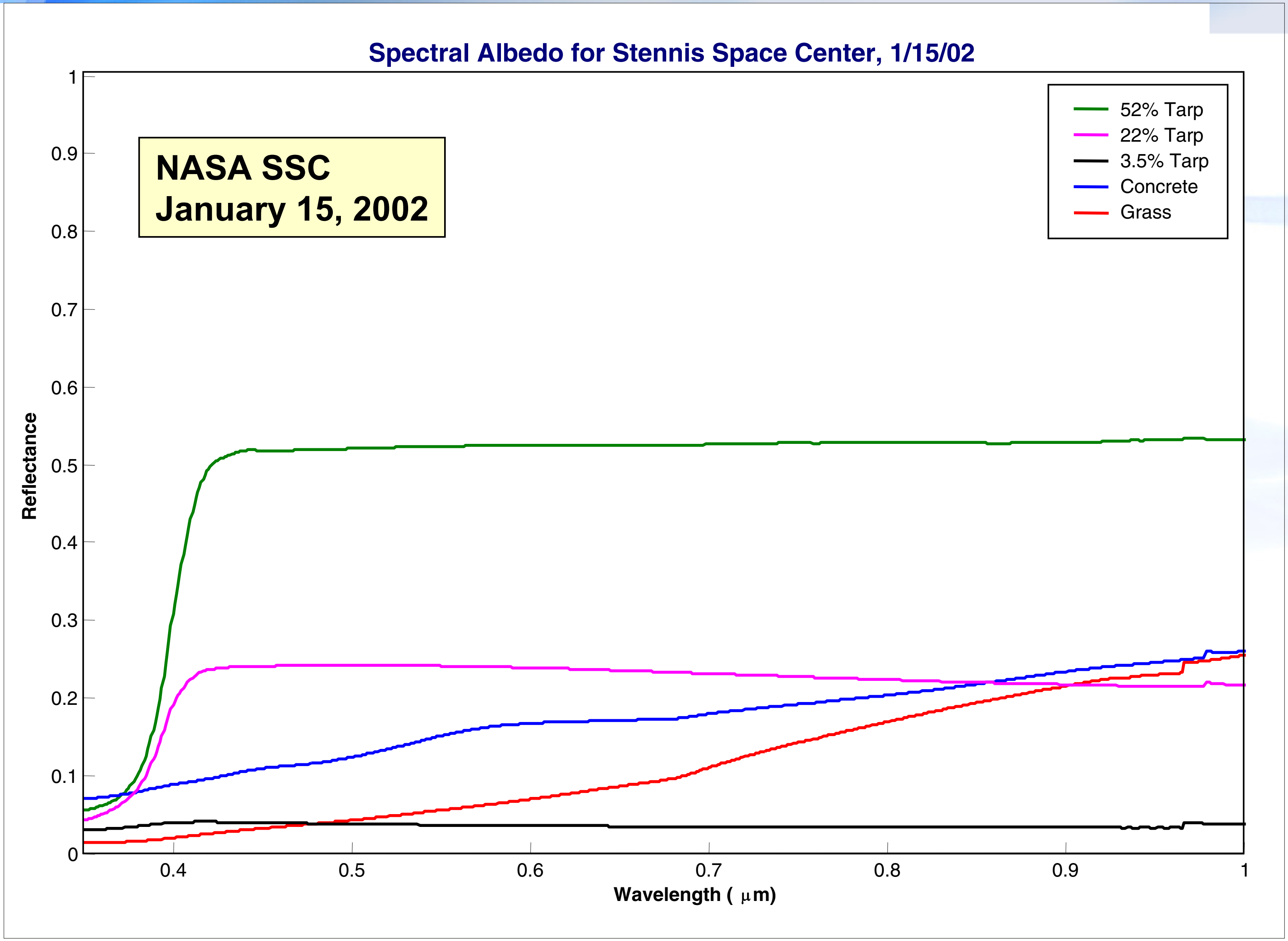
SSC Tarps

Includes material © Space Imaging LLC

20-Meter Reflectance Tarps

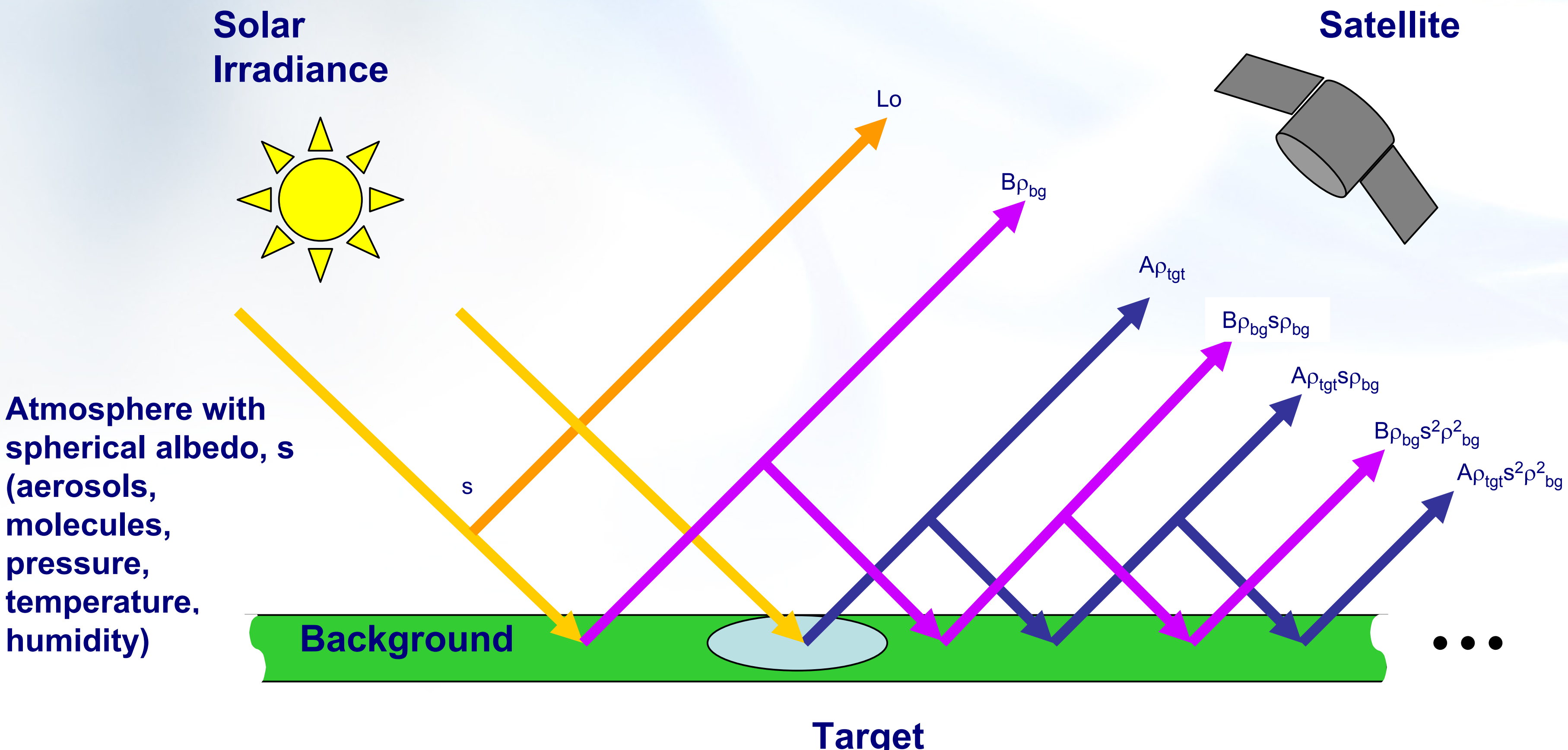
- Four 20 m x 20 m tarps; reflectance values:
  - less than 5%
  - between 20% and 25%
  - between 30% and 40%
  - between 50% and 55%
- Spectral measurement range of 400 to 1050 nm
- Standard deviation about average reflectance, less than 1% spatially
- Peak to peak variation in reflectance less than 10% (within any 100 nm spectral band)
- When measuring tarps from 10 to 60 degrees off axis, less than 10% variation in reflectance values
- Each side is straight and within ±6.0 cm over the 20 m length
- Each tarp panel has 60 square witness samples measuring 30.5 cm x 30.5 cm

Target Reflectance Data



Spherical Albedo Approximation for Radiometric Calibration Analysis

The spherical albedo approach approximates the signal observed by the satellite as the summation of successive scattering terms. Useful for estimating uncertainty.



$$L_{TOA} = L_o + A\rho_{tgt} + A\rho_{tgt}s\rho_{bg} + A\rho_{tgt}s^2\rho_{bg}^2 + \ldots + B\rho_{bg} + B\rho_{bg}s\rho_{bg} + B\rho_{bg}s^2\rho_{bg}^2 + \ldots$$

Spherical Albedo Formulation, cont'd

Case I Target and background are the "same"

$$L_{TOA} = L_o + \frac{(A+B)\rho_{tgt}}{1 - s\rho_{tgt}}$$

Where:

ρ_{tgt} = Target reflectance

L_{TOA} = Target radiance signal observed by the satellite

A, B, s, and L_o = Constants that depend on atmospheric properties and geometry

•Adjacency (background reflectance) is not significant
•High reflectance targets provide the highest accuracy results

Spherical Albedo Formulation, cont'd

Case II Target and background have different reflectances

$$L_{TOA} = L_o + \frac{A\rho_{tgt}}{1 - s\rho_{bg}} + \frac{B\rho_{bg}}{1 - s\rho_{bg}}$$

Where:

ρ_{tgt} = Target reflectance

ρ_{bg} = Effective reflectance of the area surrounding the target (background) that contributes to the observation of the target via an atmospheric scattering

L_{TOA} = Target radiance signal observed by the satellite

A, B, s, and L_o = Constants that depend on atmospheric properties and geometry

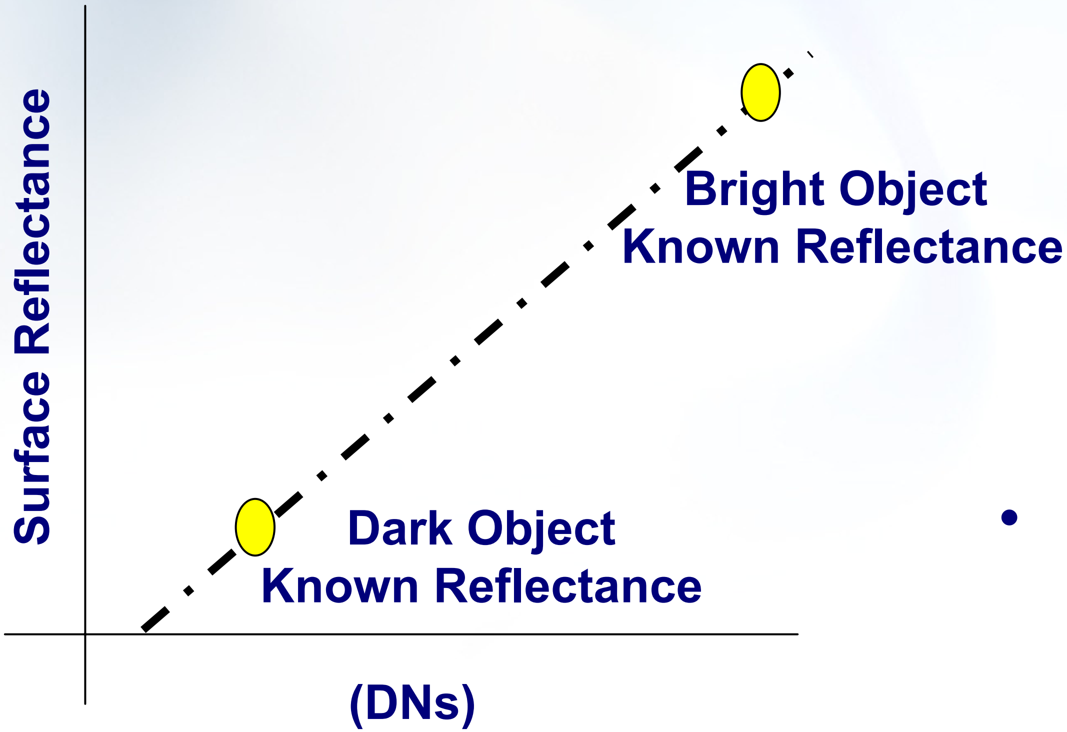
- **Adjacency (background reflectance) needs to be accounted for.**
- **High reflectance targets provide the highest accuracy results.**

Radiometric Error Associated With Adjacency

- Spherical Albedo approximation of TOA radiance estimates for geometries of interest agreed with MODTRAN estimates to better than 0.6%.
- For low visibility days (<25 km), B coefficient can be almost 50% the value of the A coefficient
  - Most measurements made with > 100 km visibility
- Ignoring adjacency effects (by modeling an infinite sized target) can lead to TOA radiance errors greater than 20% when large differences exist between target and background reflectance.
  - e.g., 52% tarp against largely vegetative background in the blue band
  - Reasonable knowledge of background reflectance required

Empirical Line Method for Estimating Background Reflectance

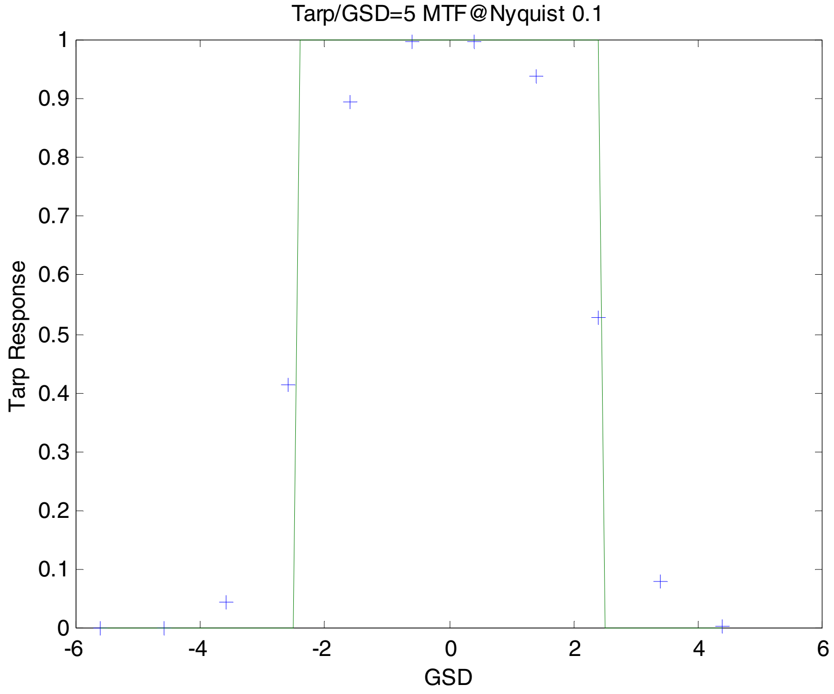
$$\rho = \left(\frac{\rho_{Bright} - \rho_{Dark}}{L_{Bright} - L_{Dark}}\right) DN + Offset$$



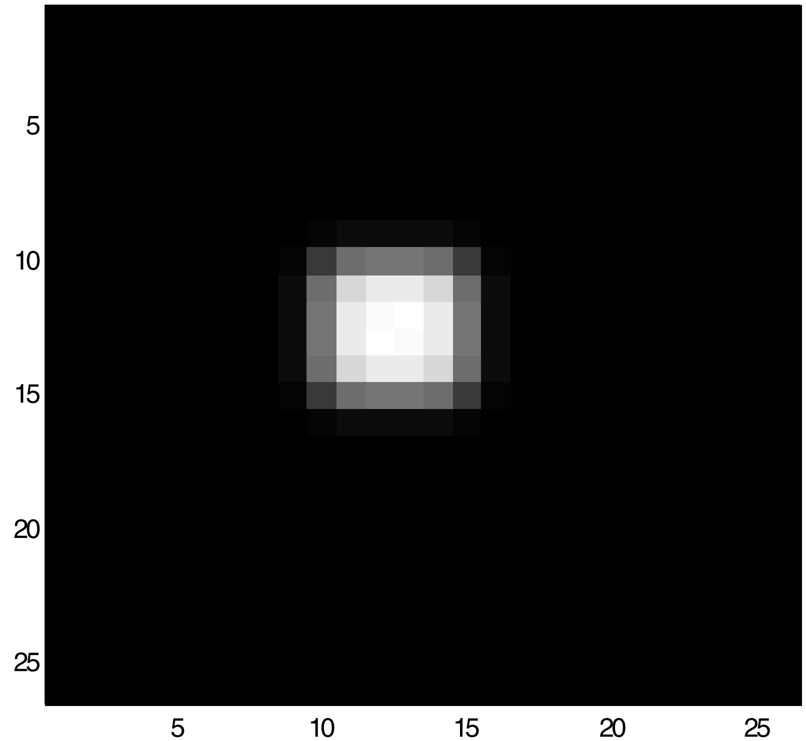
- DNs and target reflectance are “linearly” related.
- Effective background reflectance is estimated through empirical line method and weighting pixels using the atmospheric Point Spread Function
- Reduces adjacency uncertainty to < 1%

Radiometric Error Associated with Finite Size Tarp

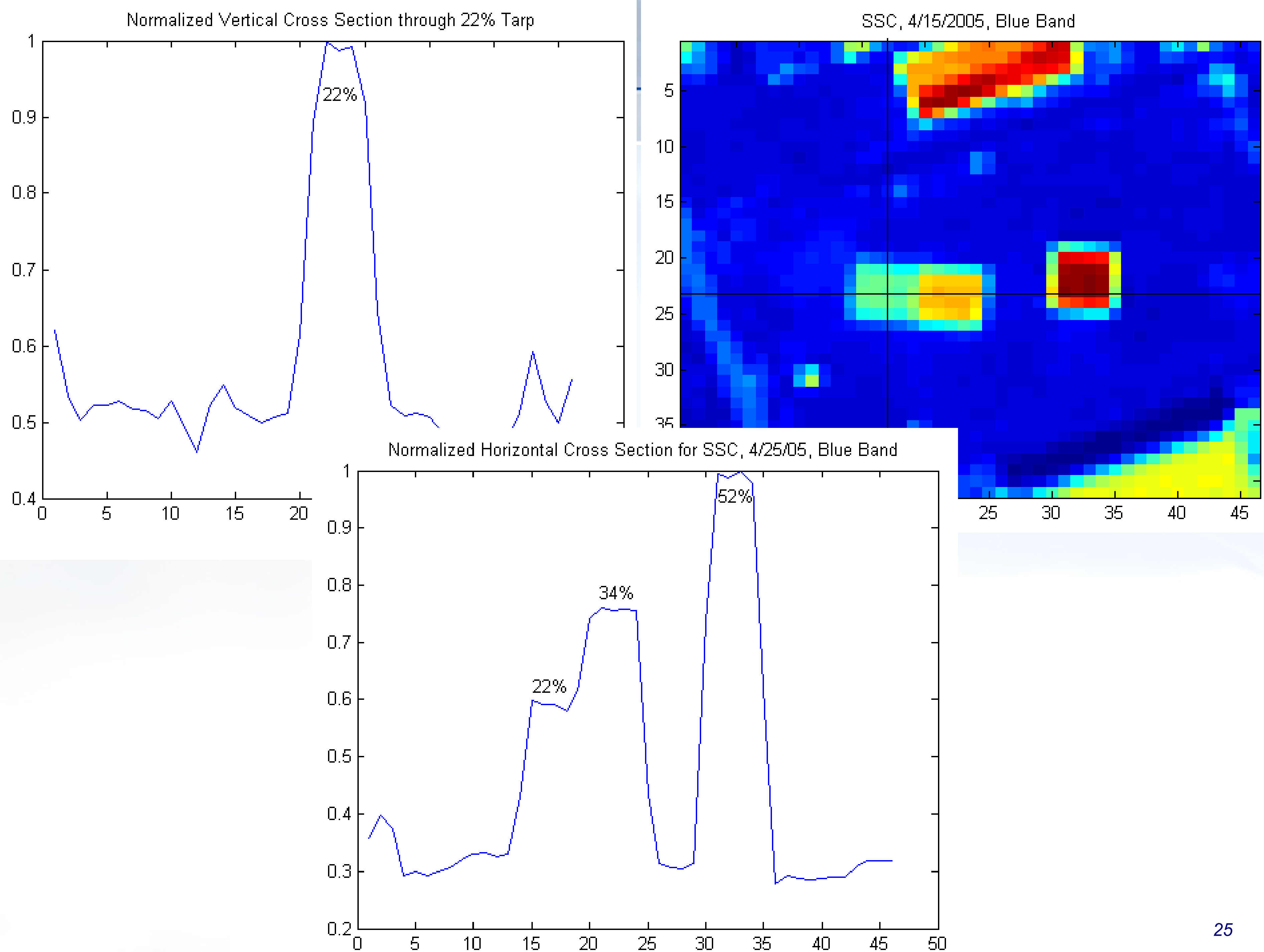
Cross Sectional Plot of Response



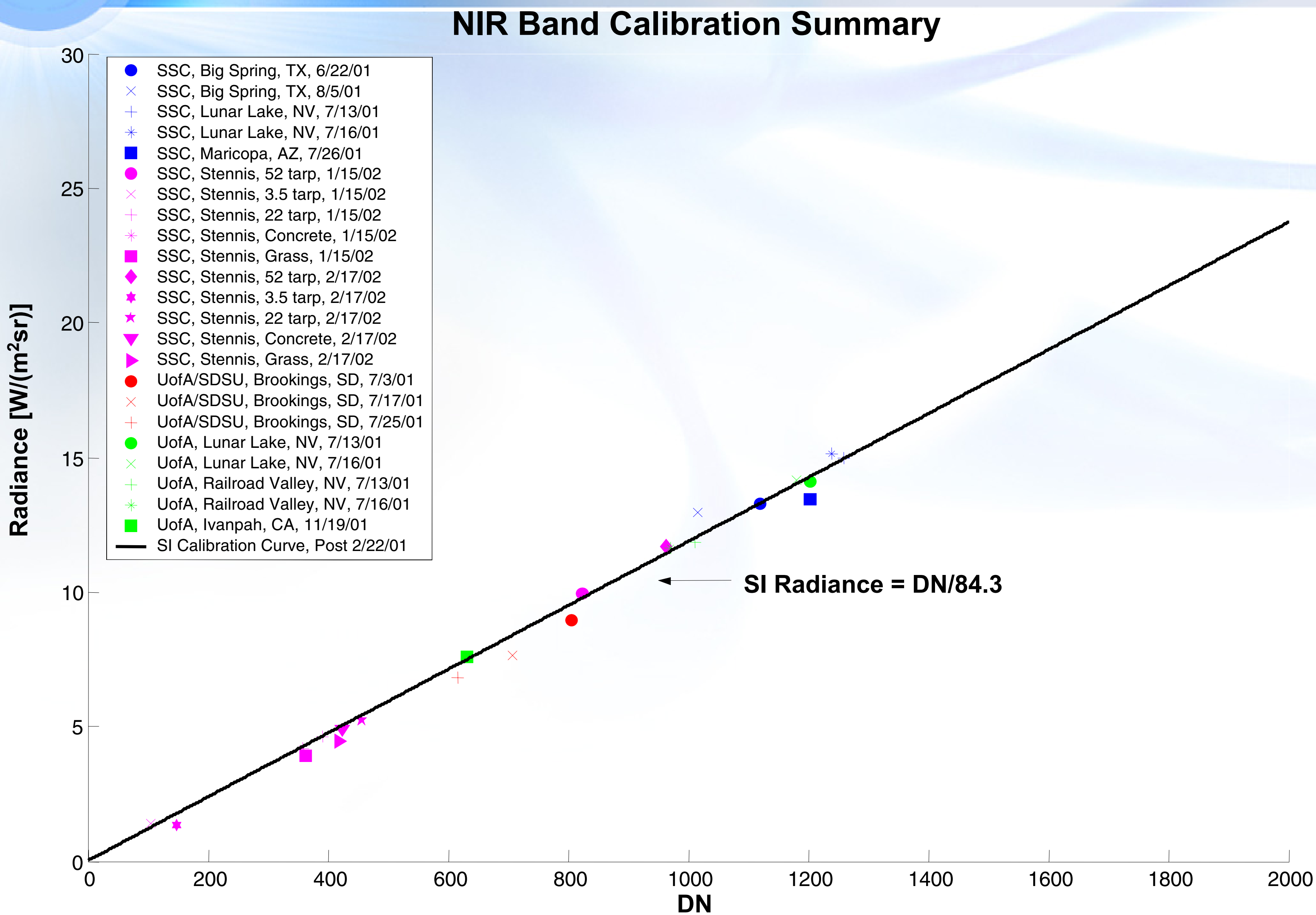
Simulated 20 m Tarp Image with 4 m GSD with MTF @ Nyquist of 0.1



- Finite size of tarp limits radiometric accuracy
- Error at the center pixels will be less than a percent, for typical background/tarp reflectances
- MTF @ Nyquist is specified to be greater than 0.2 for most commercial multispectral bands


Normalized Vertical Cross Section through 22% Tarp
22%
SSC, 4/15/2005, Blue Band
Normalized Horizontal Cross Section for SSC, 4/25/05, Blue Band
22%
34%
52%

Absolute Radiometry Example



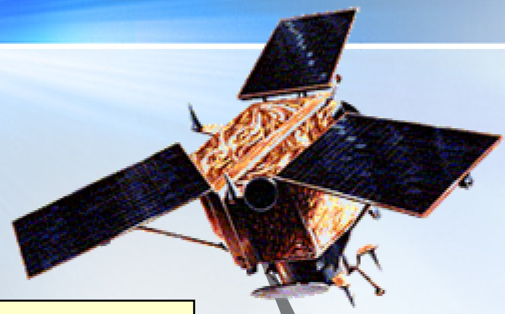
Geopositional Product Parameters & Targets

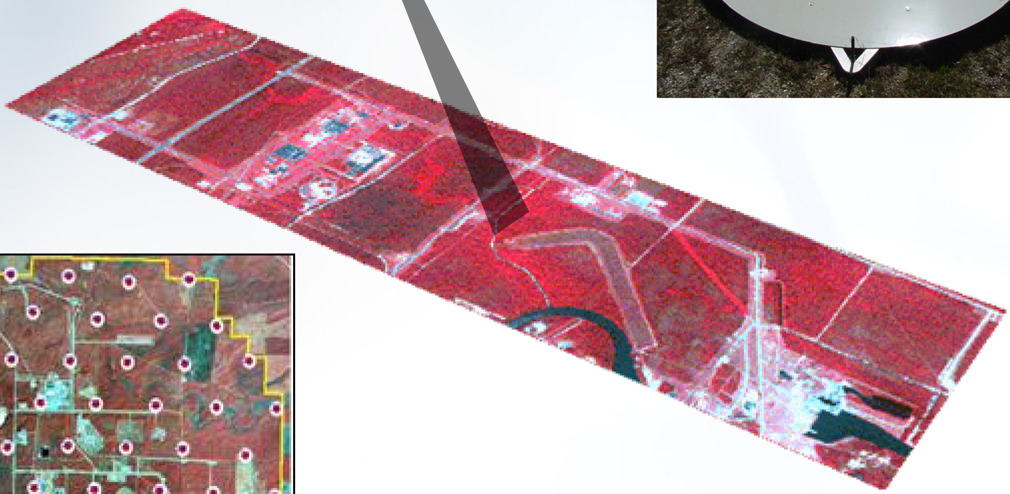
- Parameters of Interest
  - CE90
  - RMS
  - LE90

- Target types
  - Array of positionally known and identifiable points
    - Evenly positioned throughout the image acquisition area
    - Location known to be an order of magnitude better than the spatial resolution of the system being characterized

High spatial resolution allows the use of designed and man made targets.

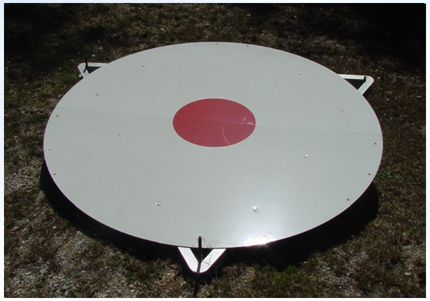
Geopositional Characterization





Commercial Satellite

Geodetic Targets



Painted Manhole Covers

GPS Instrument
Trimble 4000

Target Layout

Method: Utilize geodetic targets and GPS instrumentation to determine the geopositional accuracy of remote sensing systems.

SSC Geolocation Targets

Painted Manhole Covers:

- Approximately 136 painted manhole covers
  - ~ 0.65 paint reflectivity
  - 0.6- to 2.9-m diameter
- Target centers geolocated by GPS to within 6 cm horizontal accuracy and 9 cm vertical accuracy

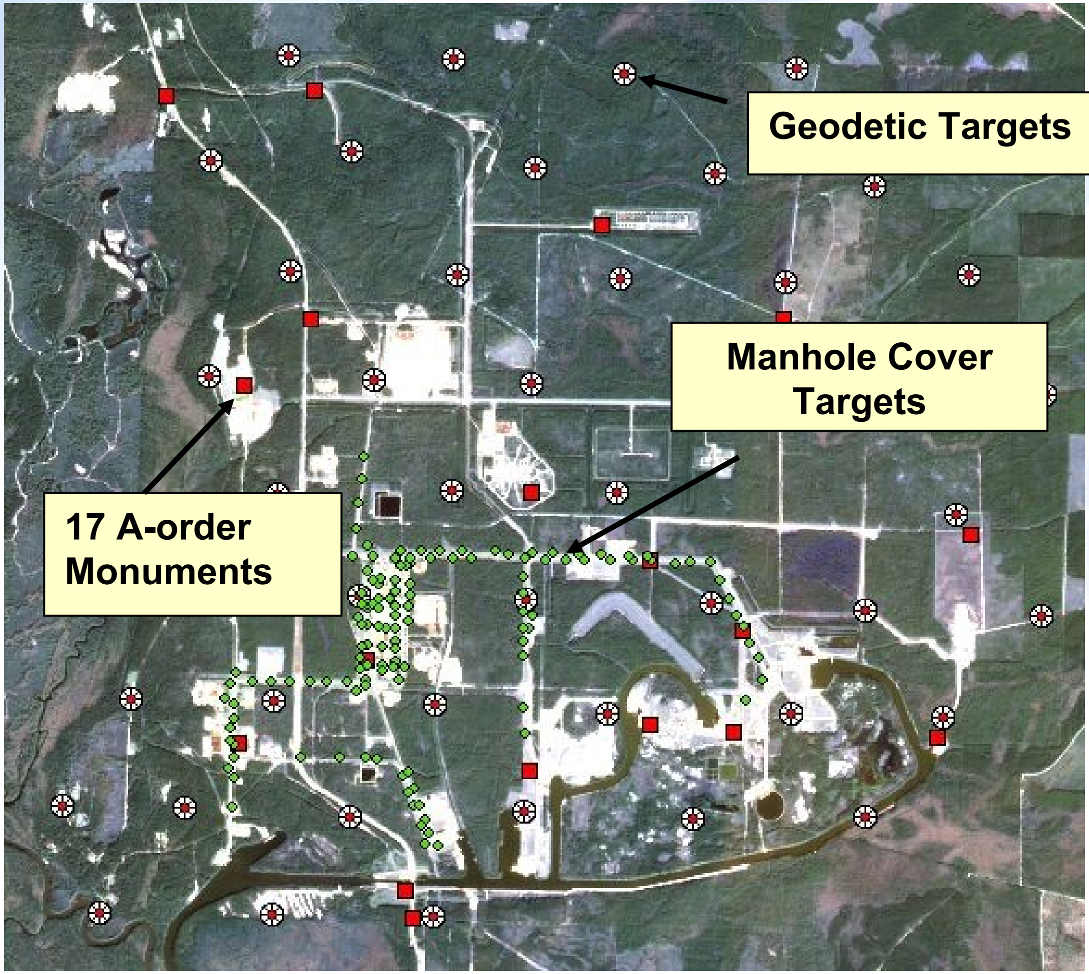
SSC Geodetic Targets:

- 44 targets currently deployed
- 2.44-m diameter painted white
- 0.6-m diameter center painted red
- Additional targets being procured (minimum of 45)
- Target centers geolocated by GPS to within 6 cm horizontal and 9 cm vertical accuracy

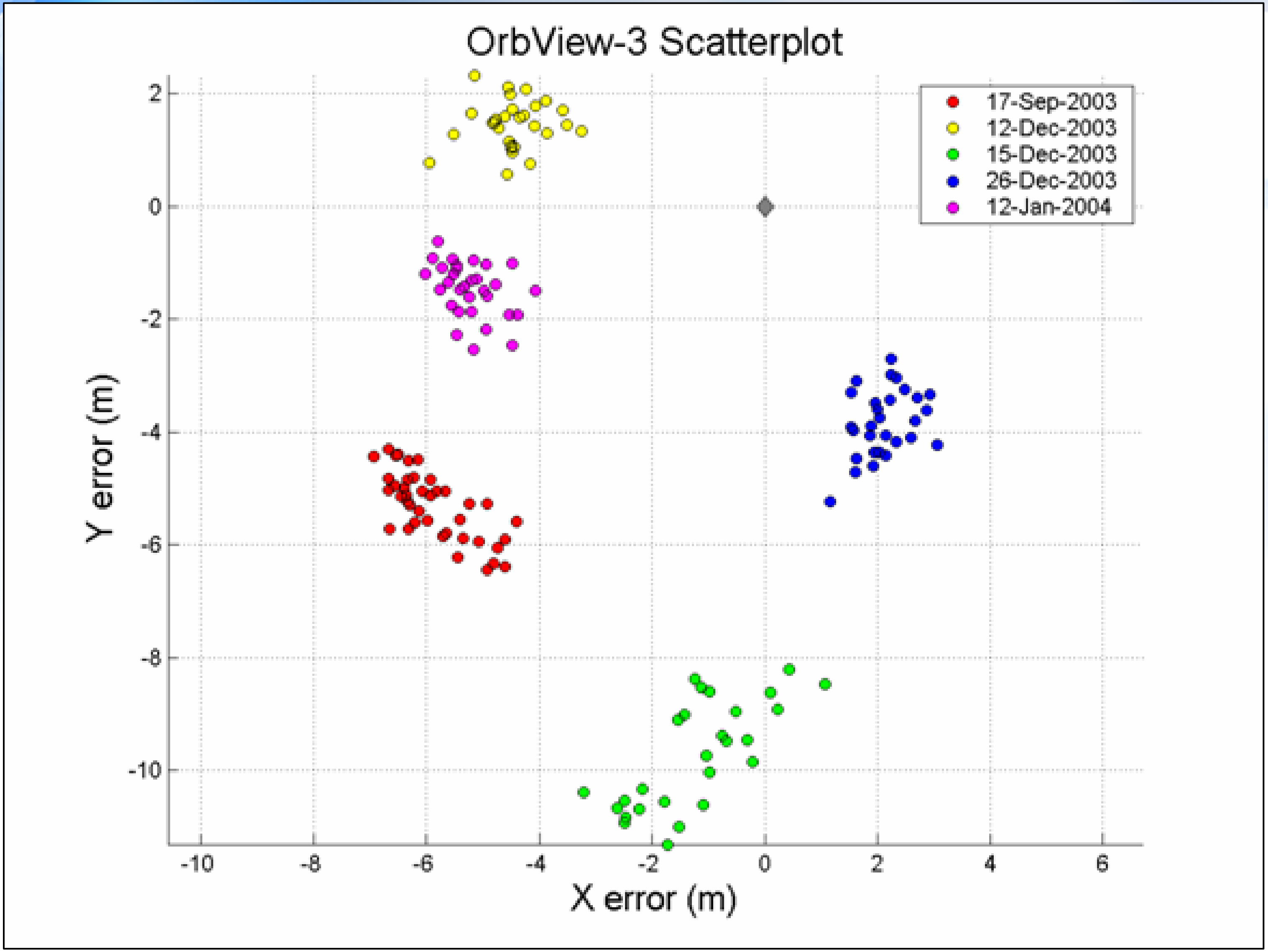
CE90 Geolocational Accuracy

- A standard metric often used for horizontal accuracy in map or image products is circular error at the 90% confidence level (*CE90*). The National Map Accuracy Standard (NMAS) established this measure in the U.S. geospatial community. NMAS (U.S. Bureau of the Budget, 1947) set the criterion for mapping products that 90% of well-defined points tested must fall within a certain radial distance.

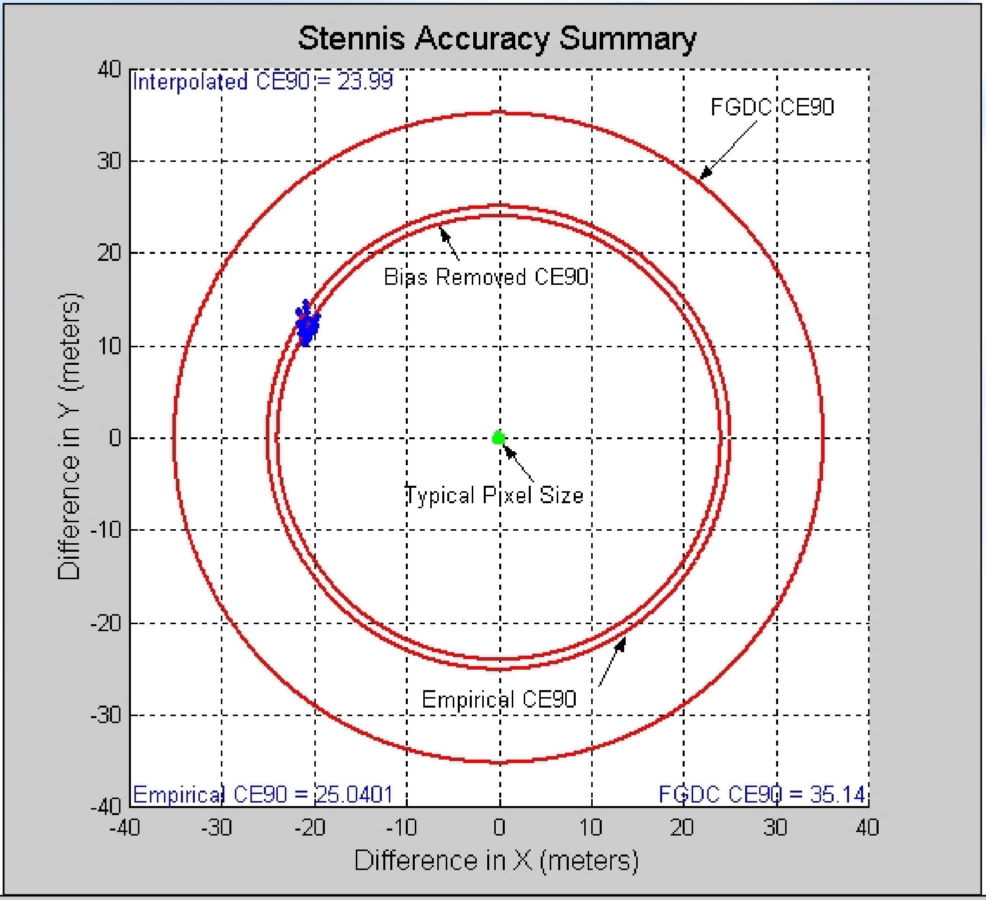
SSC Geopositional Targets



Geolocational Accuracy Example



Geolocational Accuracy Example



Data scatter plot showing the geolocational errors present in this imagery. Additionally, the CE_{90} (calculated by the FGDC standard method and by a percentile method) and the typical pixel size are shown on this plot.

Summary

- Single sites are capable of performing a wide range of spatial, radiometric and geolocation characterizations
- Spatial Resolution
  - Variety of parameters can be determined with a variety of targets
- Radiometry
  - Single acquisitions can be used to characterize the linearity and dynamic range of a system
  - Radiometric targets need to be at least 5 pixels to find pure pixels (for typical MTF imaging performance)
  - Complex sites require adjacency correction
  - Relative radiometry and SNR estimates benefit from very large uniform scenes
- Geopositional
  - Small swath enables a relatively small site with easily identifiable targets to characterize products

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14. ABSTRACT
NASA Stennis Space Center's Remote Sensing group has been characterizing privately owned high spatial resolution multispectral imaging systems, such as IKONOS, QuickBird, and OrbView-3. Natural and man made targets were used for spatial resolution, radiometric, and geopositional characterizations. Higher spatial resolution also presents significant adjacency effects for accurate reliable radiometry.

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