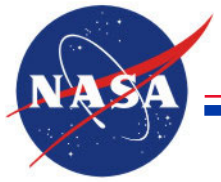

NASA Radiometric Characterization

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High Spatial Resolution Commercial Imagery Workshop
Reston, Virginia, USA
November 9, 2004

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Outline

- Characterization Overview
  - Vicarious Calibration
  - MODTRAN
- Ground Truth Data Collection
  - Stennis Space Center, MS
  - Brookings, SD
- Data Processing Methods
  - Data Processing for MODTRAN
- QuickBird Characterization
  - Data Collections
  - Results
- OrbView-3 Characterization
  - Data Collections
  - Results

Characterization Overview

- Objective
  - Perform radiometric vicarious calibrations of imagery and compare with vendor-provided calibration coefficients
- Approach
  - Use multiple, well-characterized sites
    - Sites widely used by the NASA science community for radiometric characterization of airborne and spaceborne sensors
  - Perform independent characterizations with independent teams. Each team has slightly different measurement techniques and data processing methods.
    - NASA Stennis Space Center
    - University of Arizona Remote Sensing Group
    - South Dakota State University (provided ground-truth data)

Data Providers

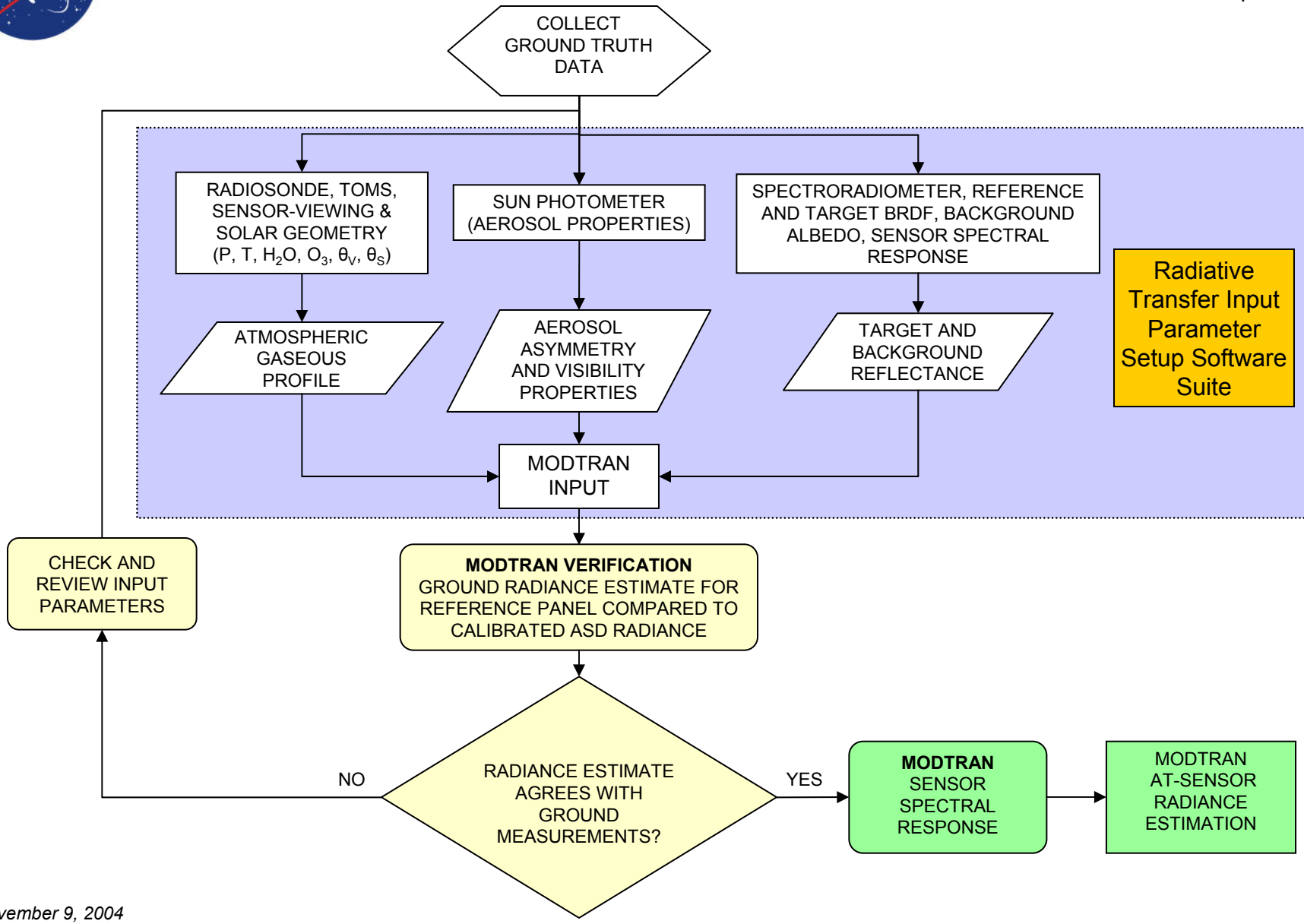
- DigitalGlobe, Inc.
  - Imagery acquired by the QuickBird sensor
  - Data purchased by NASA through the Scientific Data Purchase project
  - Independent characterization is a continuation of the previous year

- OSC/ORBIMAGE, Inc.
  - Imagery acquired by the OrbView-3 sensor
  - Data received through a Space Act Agreement among NASA, Orbital Sciences Corporation, and ORBIMAGE, Inc.
  - Independent characterization performed on pre-initial on-orbit checkout (pre-IOC) data

Vicarious Calibration Method

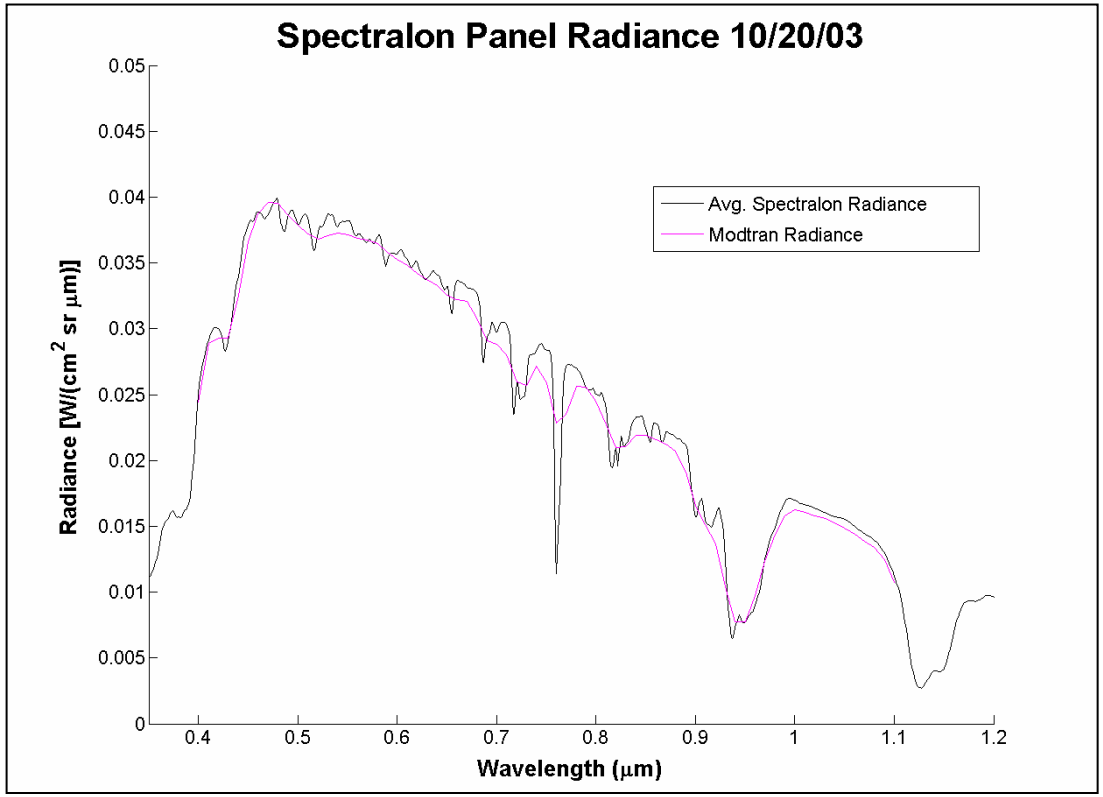
- Reflectance-based approach
  - Ground truth collection
    - Characterize target reflectance at time of satellite overpass
      - Measurements taken of target area and a 99% reflectance Spectralon® panel (Jackson BRDF model)
      - Laboratory measurements of target BRDF
    - Characterize atmosphere at time of satellite overpass
      - Radiosonde data used to determine Rayleigh scattering and water vapor extinction
      - Least squares fit of sun photometer data to determine model atmosphere parameters
  - Use MODTRAN radiative transport code to predict at-sensor radiance
  - Compare predicted at-sensor radiance to actual radiance acquired by sensor

At-Sensor Radiance Prediction Method



Comparison to Spectralon Panel

- Verification of parameters used to generate MODTRAN at-sensor radiance estimate
  - Measuring the radiance of Spectralon panel with a well-calibrated spectroradiometer is a way of measuring atmospheric global and diffuse irradiance
  - Use ground truth data and geometry modeling an ASD FieldSpec FR spectroradiometer measuring a 99% reflectance Spectralon panel as input to MODTRAN to predict radiance
  - Compare MODTRAN-calculated radiance to actual radiance measured from Spectralon panel to verify the atmospheric model



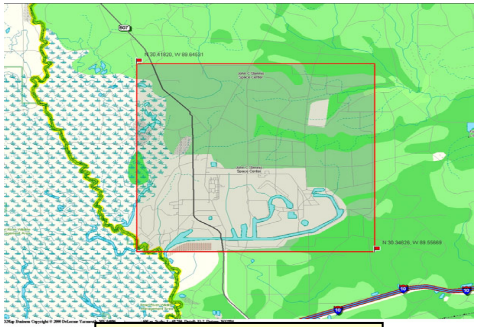
Ground Truth Data Collections

- Ground truth data collection occurred at five sites over the 2003-2004 season
  - Data collections by University of Arizona (described in previous presentation)
    - White Sands Missile Range, NM
    - Ivanpah Playa, CA
    - Railroad Valley, NV
  - Data collections by NASA
    - Stennis Space Center, MS (SSC)
  - Data collections by South Dakota State University
    - Brookings, SD

NASA Stennis Space Center, MS

- **Site:** Scattered buildings within a heavily wooded area; manmade reservoirs and canals
- **Elevation:** 5.5–10 m
- **Centerpoint:** 30.356° N, 89.62° W
- ***In-situ* Instrumentation:** Analytical Spectral Devices FieldSpec FR spectroradiometers, Yankee multifilter rotating shadowband radiometers (MFRSRs), automated solar radiometers (ASRs), Sippican radiosonde, full sky imager, 20-m x 20-m radiometric tarps, 99% reflectance Spectralon panels

General Scene



SSC Image Area
8.5 km x 8 km

OrbView-3 True-Color Imagery
September 28, 2003

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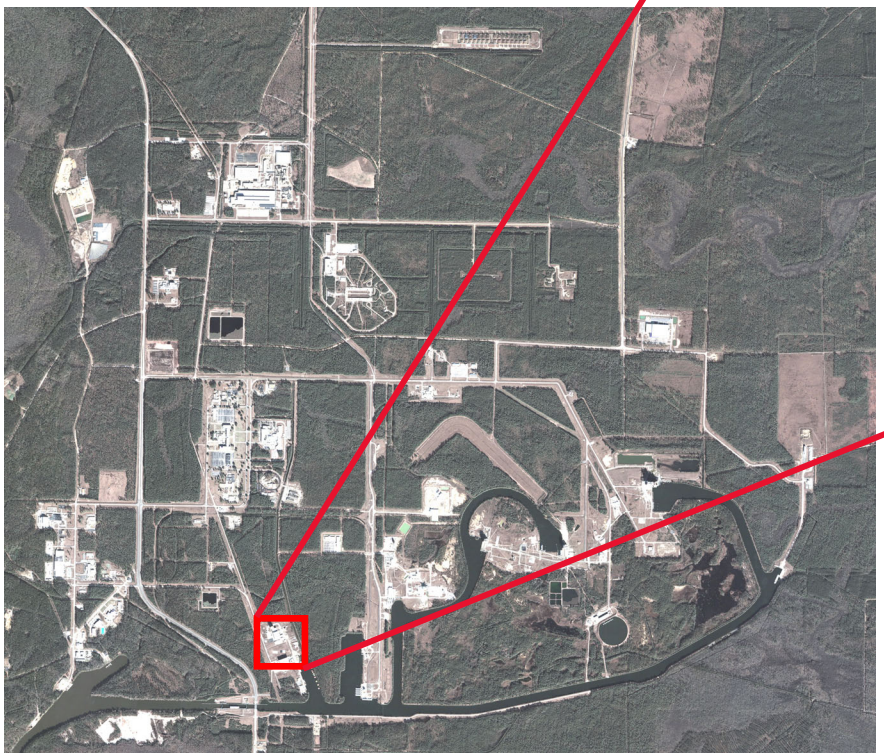
NASA SSC Target Field

QuickBird image acquired
January 10, 2004
True-Color Pan-Sharpened



Includes material © DigitalGlobe™

Radiometric Tarps

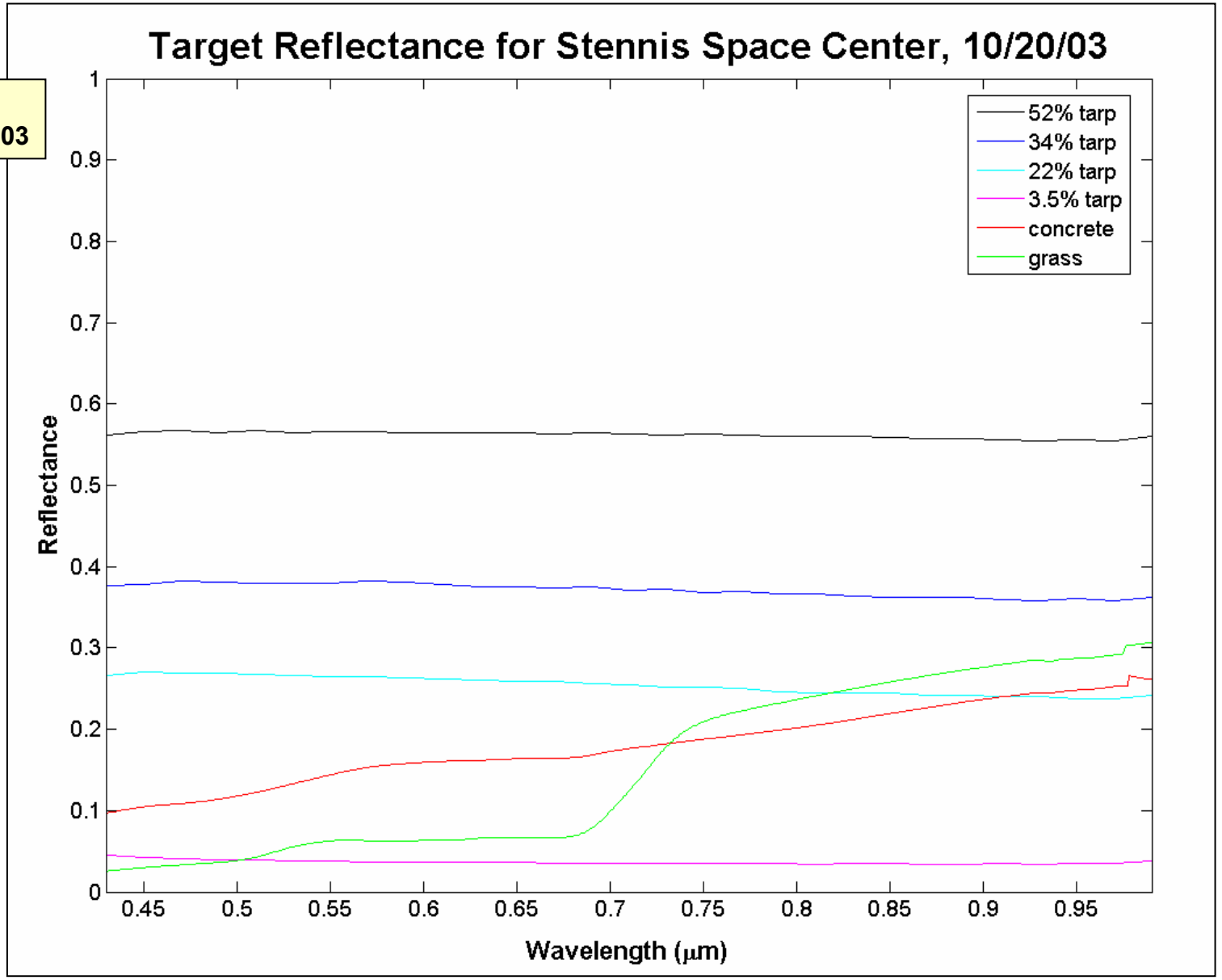
- Four 20-m x 20-m tarps with reflectance values of approximately 3.5%, 22%, 34%, and 52% within spectral measurement range
- Peak-to-peak variation in reflectance less than 10% within any 100-nm spectral band within spectral measurement range
- Less than 10% variation in reflectance values when measuring tarps from 10° to 60° off axis within spectral measurement range
- Spectral measurement range of 400 to 1050 nm
- Each side is straight to within ±6.0 cm over the 20-m length
- Each tarp has 60 square witness samples measuring 30.5 cm x 30.5 cm

ASD FieldSpec FR Spectroradiometer Measurements

- Measurements of several target areas were taken
  - ~35-m x 15-m area of a grassy field
  - ~30-m x 20-m area of a concrete parking lot
  - Up to four 20-m x 20-m radiometric tarps (3.5%, 22%, 34%, and 52% reflectance)
- Measurements were taken along transect lines (grass and concrete) or tarp perimeter
  - All measurements were taken while walking to increase spatial averaging
  - Periodic Spectralon panel measurements were taken
  - ASD FieldSpec FR spectroradiometer optimization and dark current measurements were taken before and during target measurements.
- All data were acquired within 30 minutes of satellite overpass

Spectroradiometer Data

NASA SSC
October 20, 2003

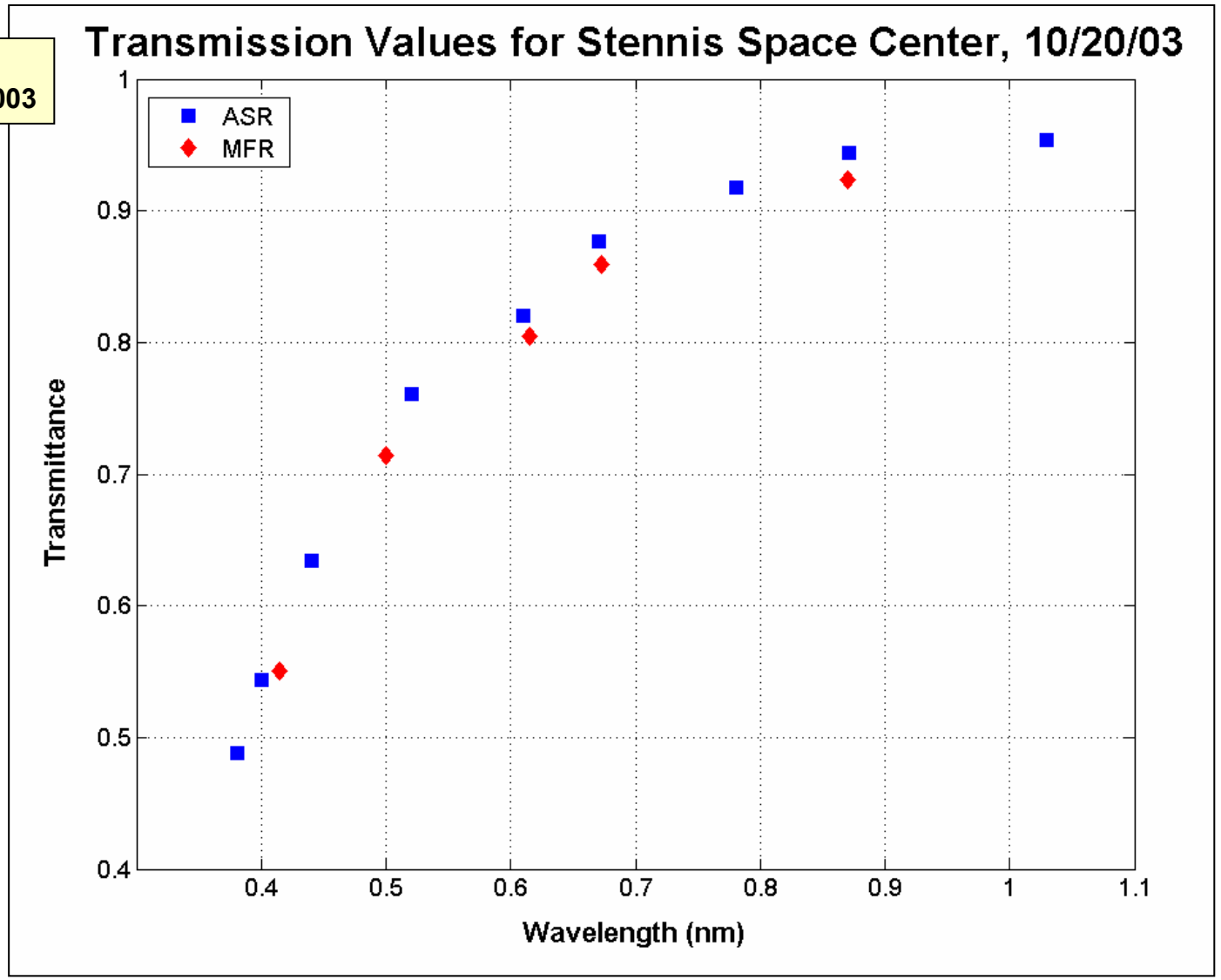


Atmospheric Measurements

- Solar irradiance data collected from early morning through post-sensor acquisition
  - One MFRSR and one ASR acquired data from the measurement field
  - One MFRSR acquired data from a building rooftop approximately 2 miles away
- Radiosonde launched near satellite overpass time
  - Data acquired up to 3 km on 9/28/03
  - Data acquired over 20 km on 10/20/03 and on 1/10/04

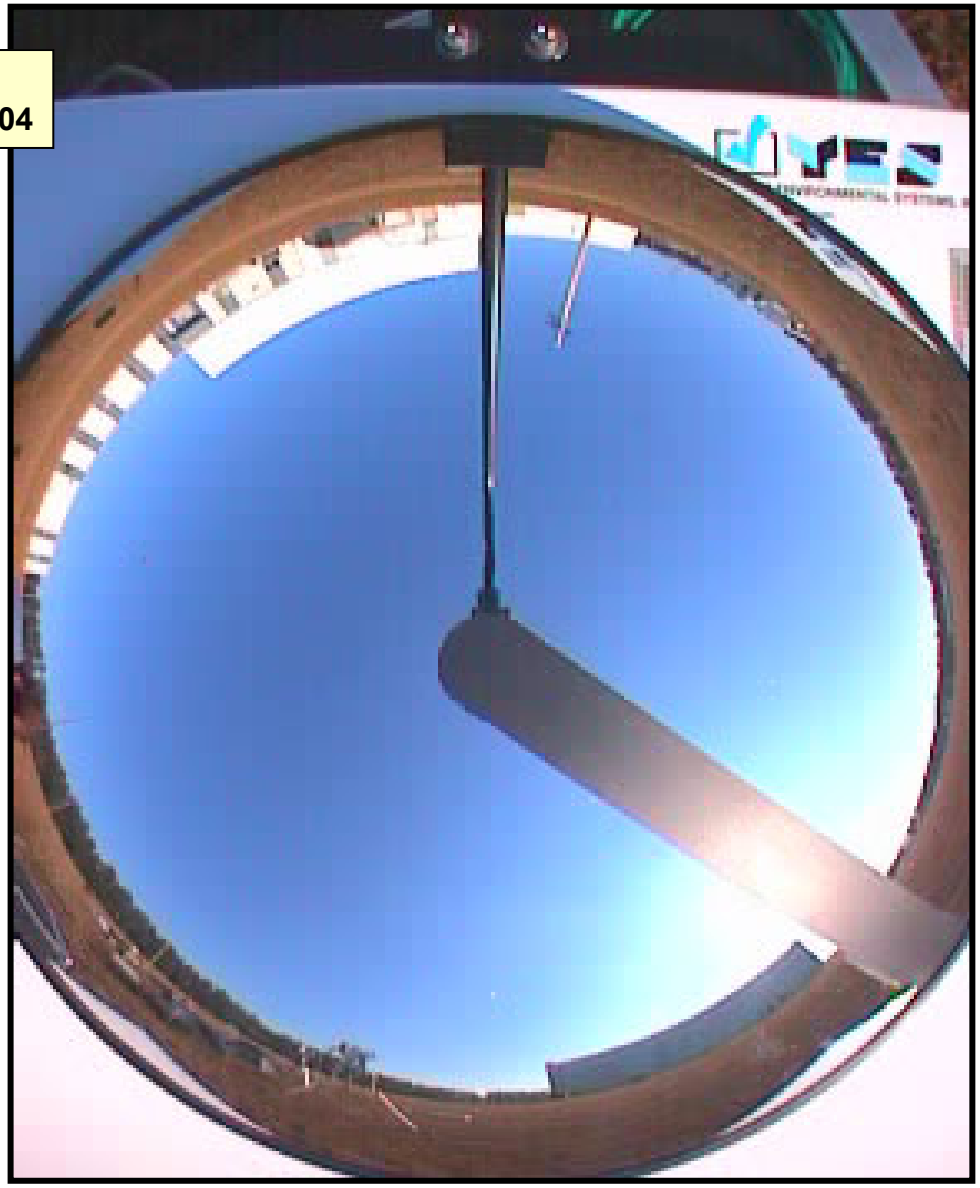
ASR/MFRSR Transmission Values

NASA SSC
October 20, 2003



Full Sky Imager

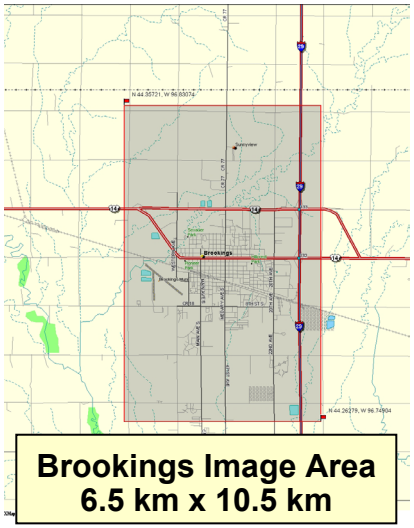
NASA SSC
January 10, 2004



Brookings, South Dakota

- **Site:** Grass field beside 3M plant on the outskirts of the city of Brookings
- **Elevation:** approx. 500 m
- **Centerpoint:** 44.3º N, 96.8º W
- ***In-Situ* Instrumentation:** ASD FieldSpec FR spectroradiometers, Yankee MFRSRs, automated solar radiometer, 20-m x 20-m radiometric tarps, 99% reflectance Spectralon panels

General Scene



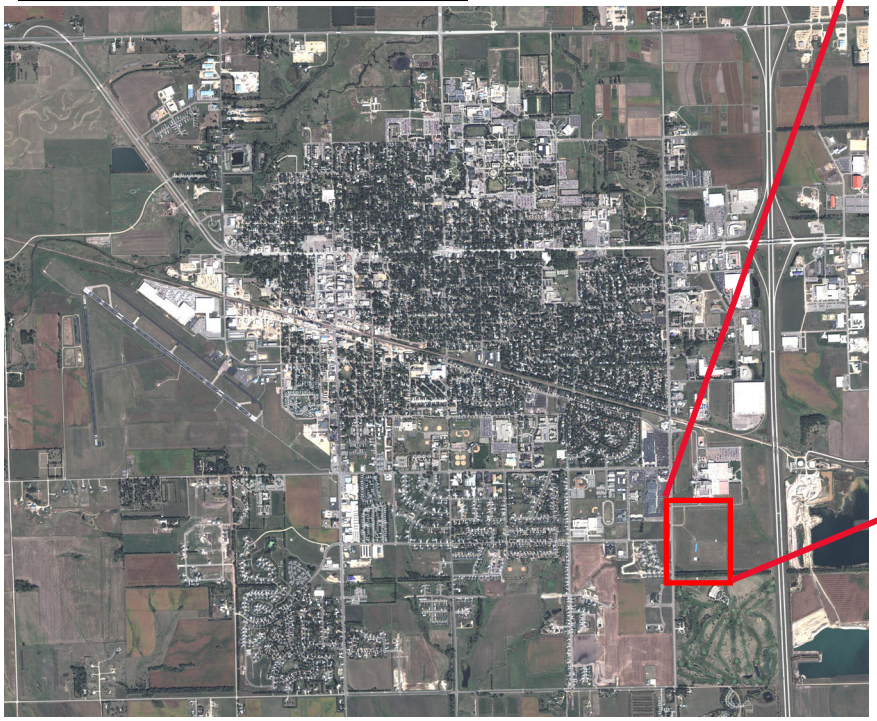
Brookings Image Area
6.5 km x 10.5 km

QuickBird Imagery
August 23, 2003

Includes material © DigitalGlobe™

Brookings, SD, Target Field

QuickBird image acquired
September 15, 2003
True-Color Pan-Sharpened



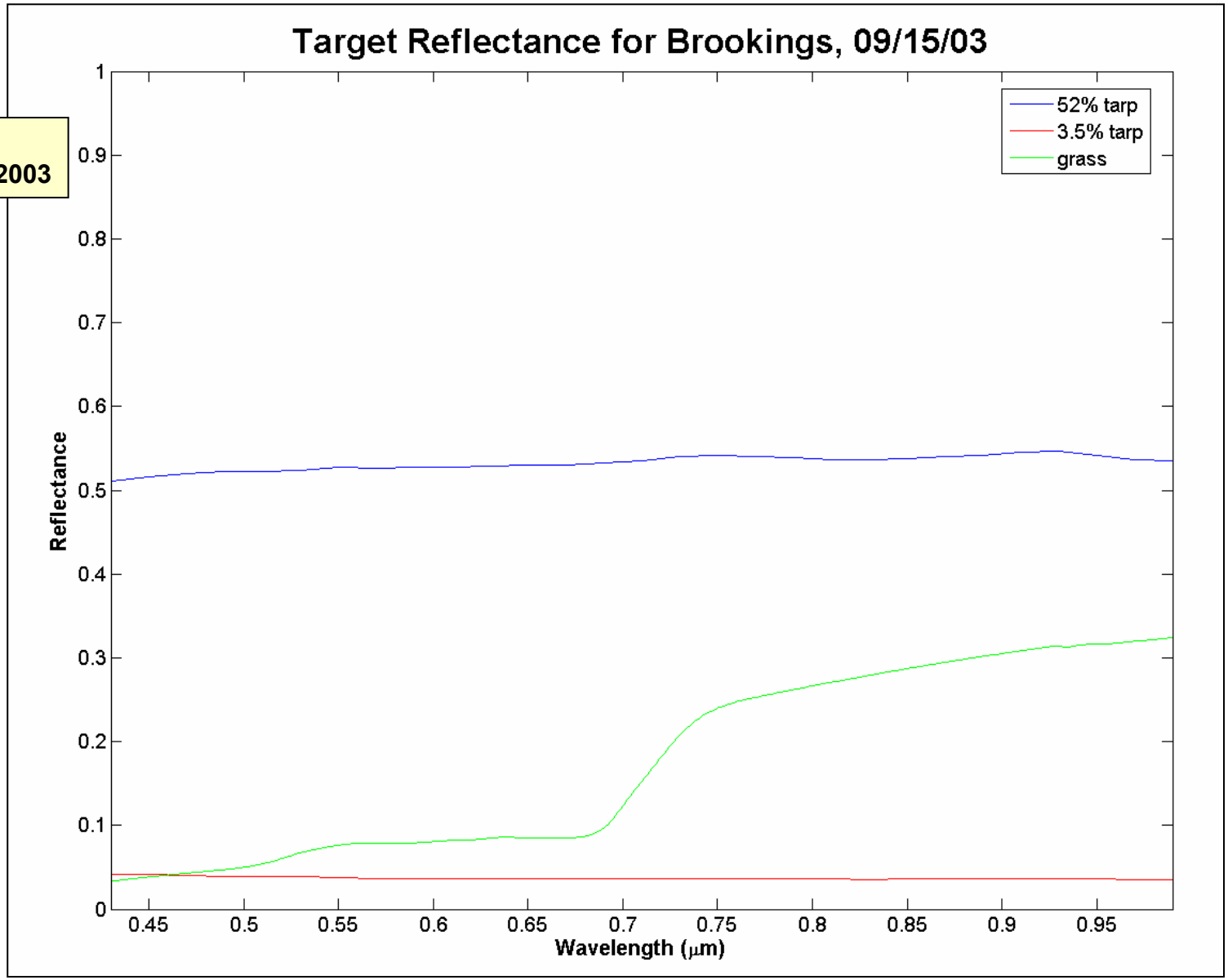
Includes material © DigitalGlobe™

ASD FieldSpec FR Spectroradiometer Measurements

- ASD FieldSpec FR spectroradiometer measurements of several targets were taken
  - ~150-m x 150-m area of a grassy field
  - Two 20-m x 20-m radiometric tarps (3.5% and 52% reflectance) for the 9/15/03 collect
- Measurements were taken along transect lines (grass) or tarp perimeter
  - All measurements were taken while walking to increase spatial averaging
  - Periodic Spectralon panel measurements were taken
  - Before and during target measurements, the instrument was optimized and dark current measurements were made
- All data were acquired within 30 minutes of satellite overpass

Spectroradiometer Data

Brookings, SD
September 15, 2003

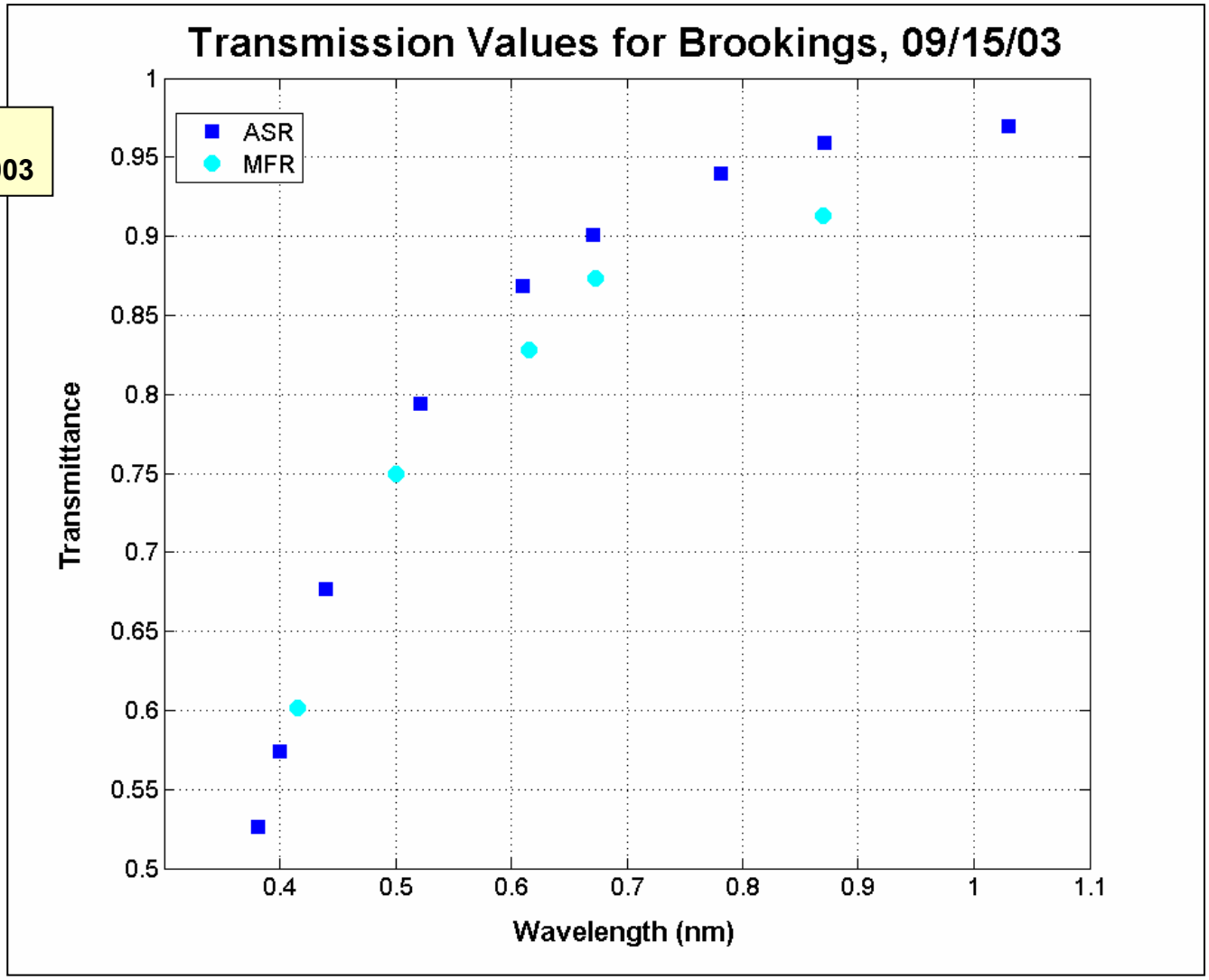


Atmospheric Measurements

- Solar irradiance data collected from early morning through post-sensor acquisition
  - Two MFRSRs acquired data in the measurement field
  - One ASR was used on 8/23/03; two ASRs were used on 9/15/03 and on 10/20/03 to acquire data in the measurement field

ASR/MFRSR Transmission Values

Brookings, SD
September 15, 2003

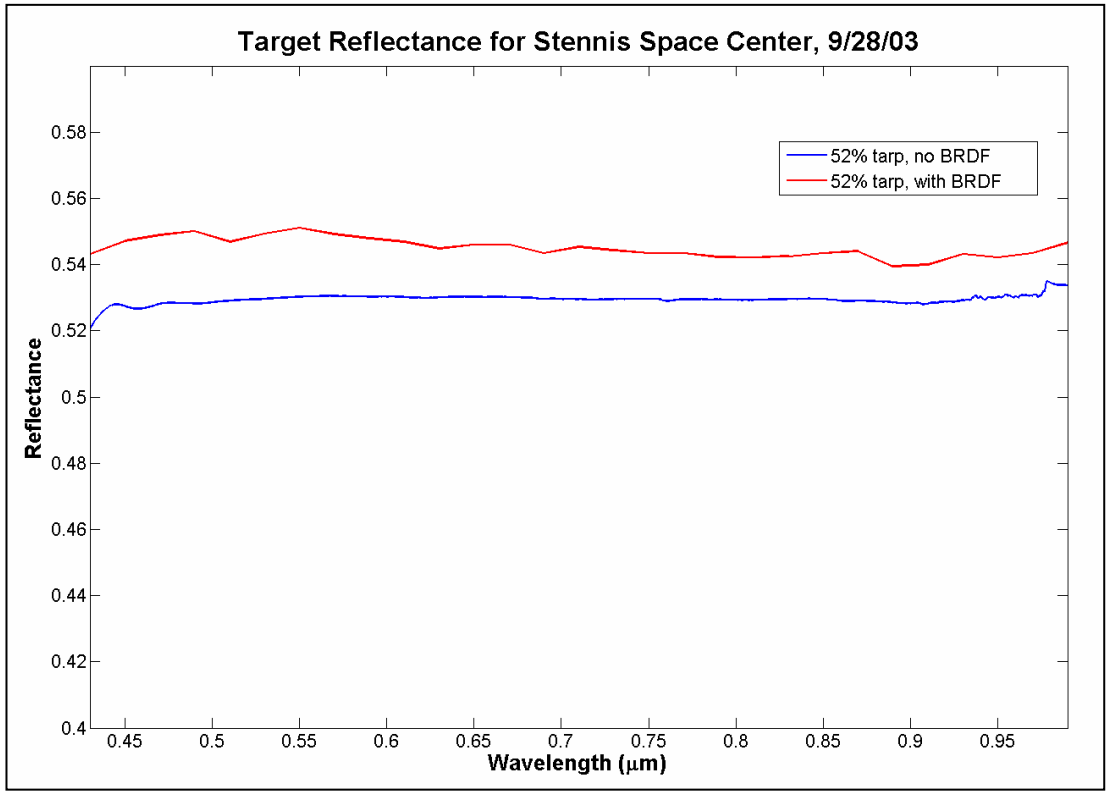


Additional Data Processing

- Data processing to calculate additional MODTRAN input parameters
  - Incorporation of laboratory-measured target BRDF
  - Estimation of visibility
  - Estimation of aerosol asymmetry

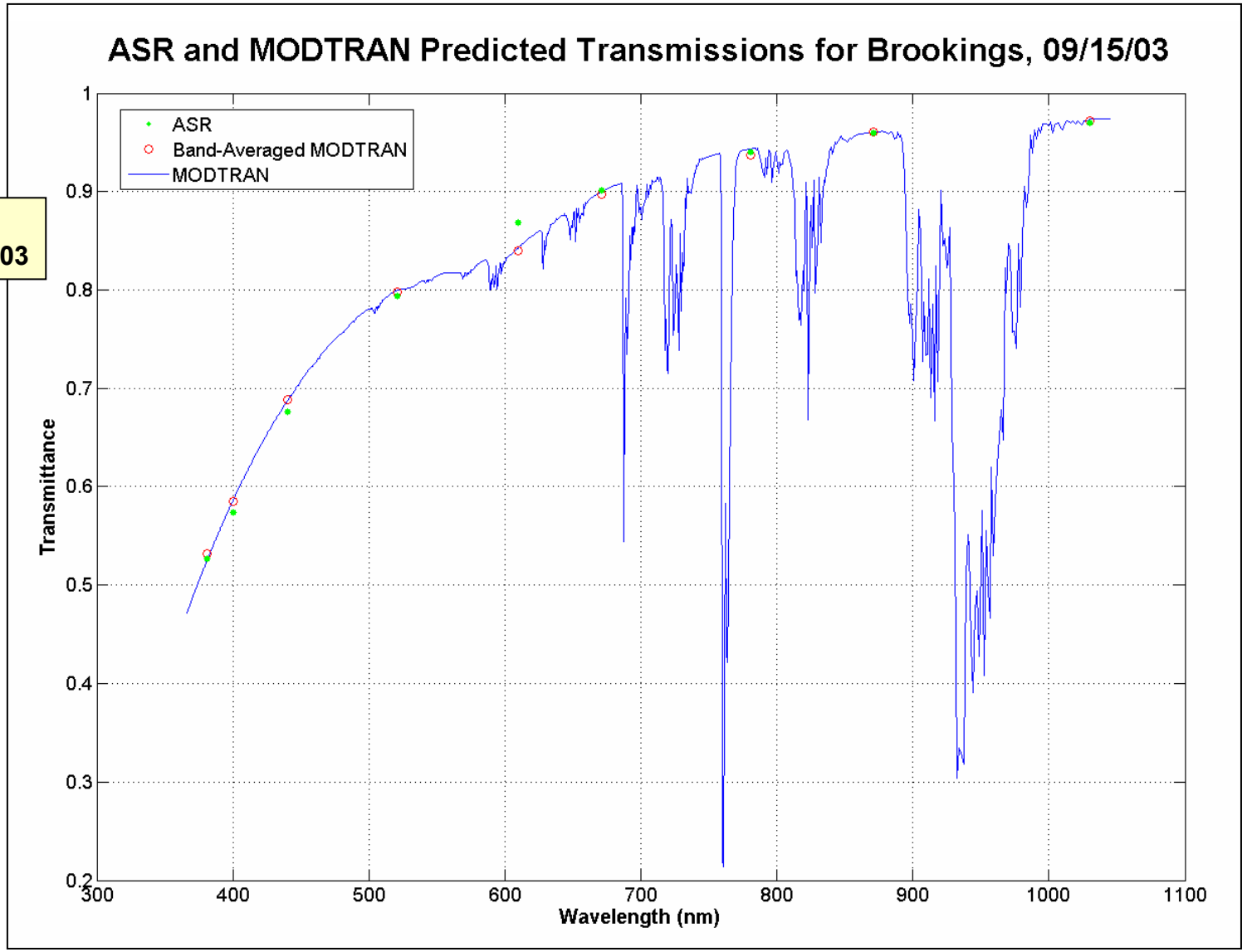
BRDF Correction

- BRDF of radiometric tarp witness samples measured in laboratory
  - Witness samples removed from tarps after ground truth data collection
  - Sun and satellite geometry recreated in the laboratory to determine BRDF correction factors for each radiometric tarp
- Calculated correction factors incorporated into reflectance data files



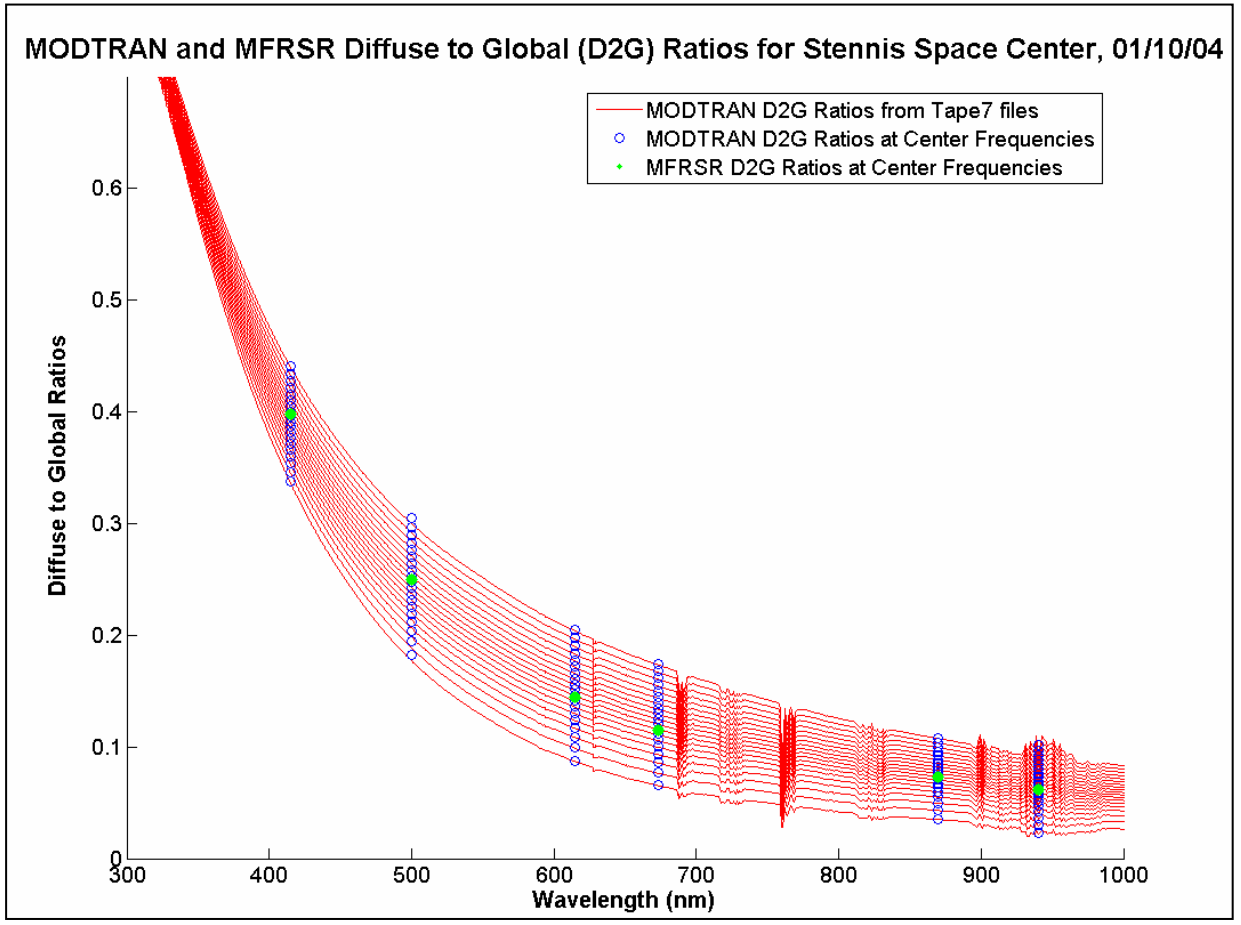
Visibility Estimation

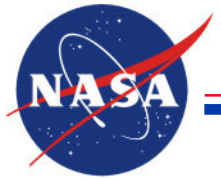
Brookings, SD
September 15, 2003



Aerosol Scattering

- The asymmetry factor for the aerosol scattering phase function is estimated by comparing MODTRAN output diffuse-to-global ratio values to MFRSR measured diffuse-to-global ratio values



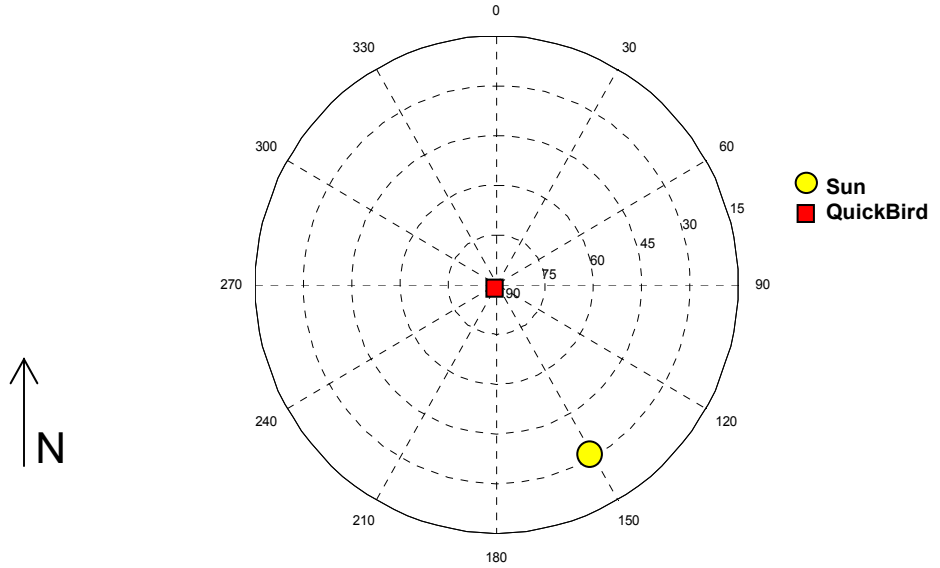


QuickBird Radiometric Characterization

Data Acquisitions: SSC

Date	Overpass Time (UTC)	Satellite Elevation	Satellite Azimuth	Sun Elevation	Sun Azimuth
Jan 10, 2004	16:30	89.2 deg	230.7 deg	32.3 deg	152.2 deg

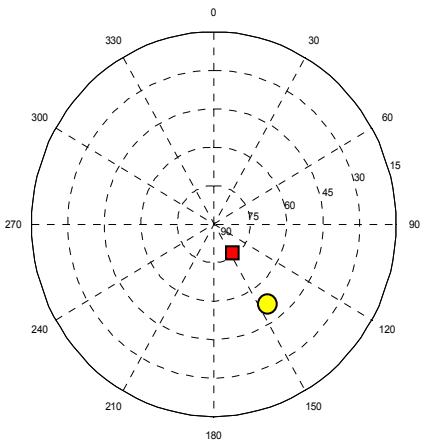
Standard imagery
4x4 Cubic Convolution resampling algorithm



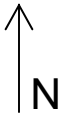
Data Acquisitions: Brookings

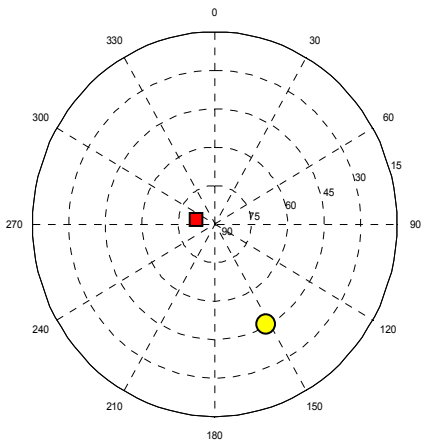
Date	Overpass Time (UTC)	Satellite Elevation	Satellite Azimuth	Sun Elevation	Sun Azimuth
Aug 23, 2003	17:07	76.8 deg	148.3 deg	52.8 deg	145.2 deg
Sept 15, 2003	17:12	83.3 deg	285.3 deg	46.1 deg	154.3 deg
Oct 21, 2003	17:11	81.3 deg	279.5 deg	33.5 deg	162.1 deg

Standard imagery
4x4 Cubic convolution resampling algorithm

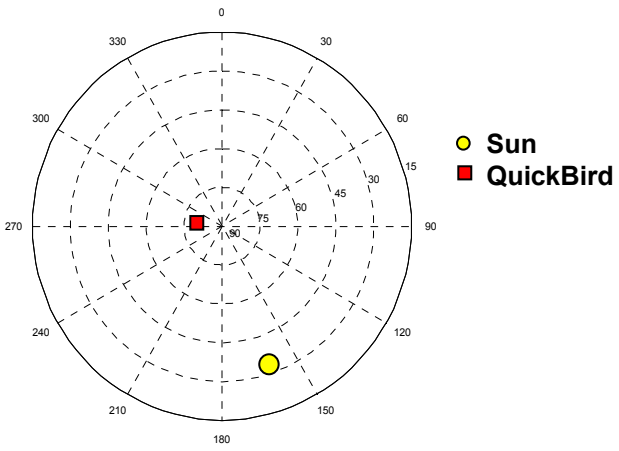


Brookings, SD, 8/23/03





Brookings, SD, 9/15/03



Brookings, SD, 10/21/03

QuickBird Spectral Response

- DigitalGlobe provided the QuickBird system effective spectral quantum efficiencies that were converted to system spectral response

$$R(\lambda) = \frac{Q(\lambda) \cdot \lambda}{h \cdot c}$$

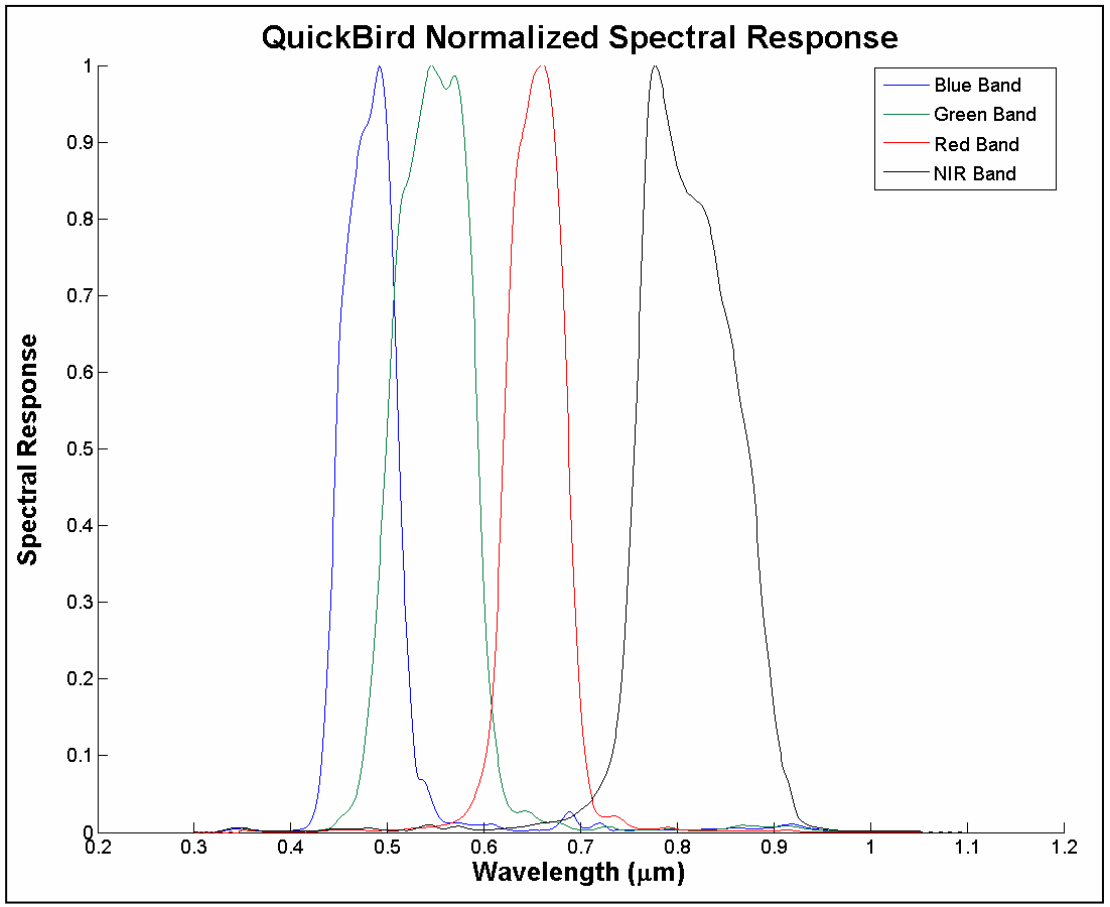
$R(\lambda)$ = spectral response

$Q(\lambda)$ = quantum efficiency

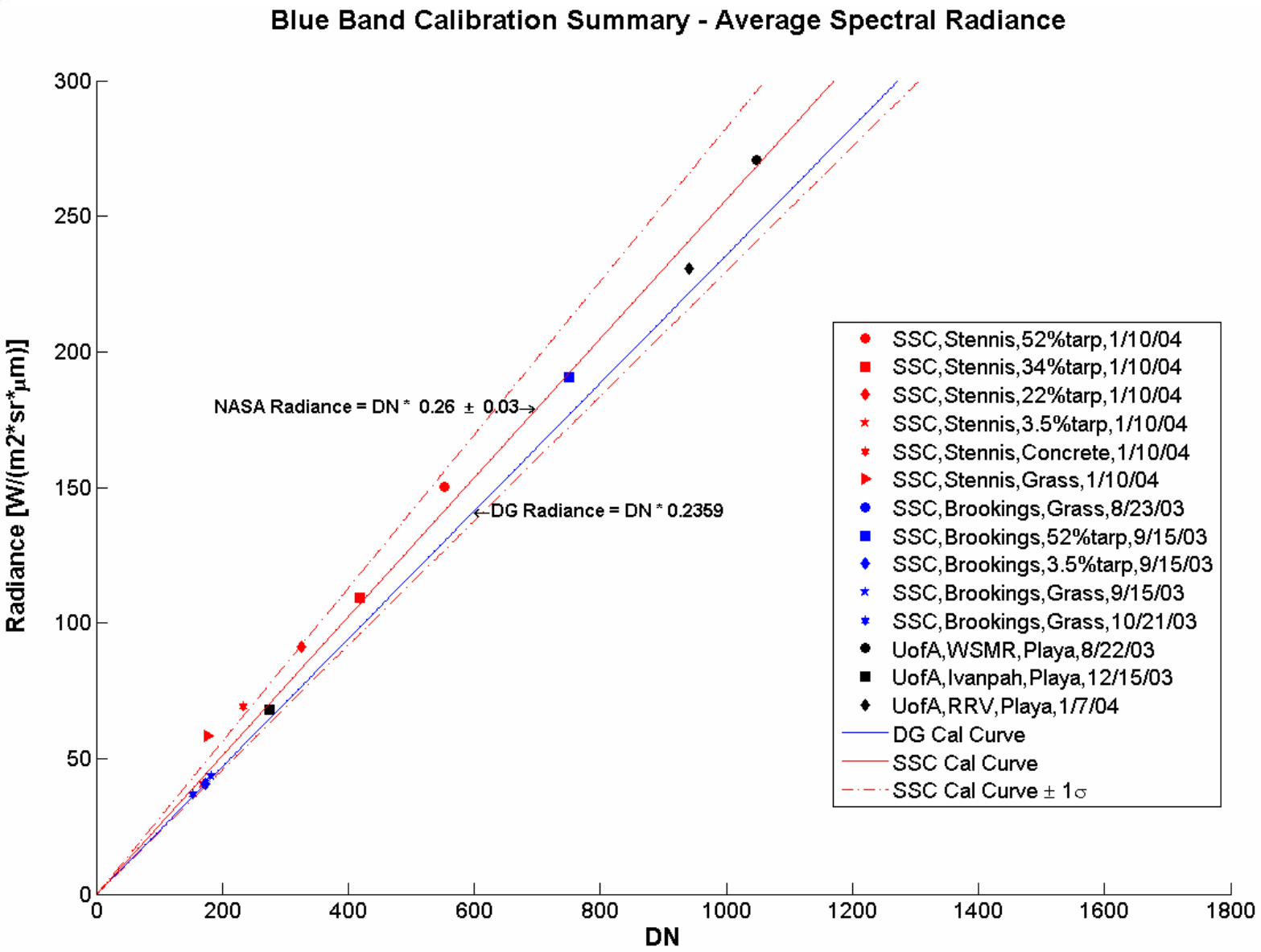
λ = wavelength

h = Planck's constant

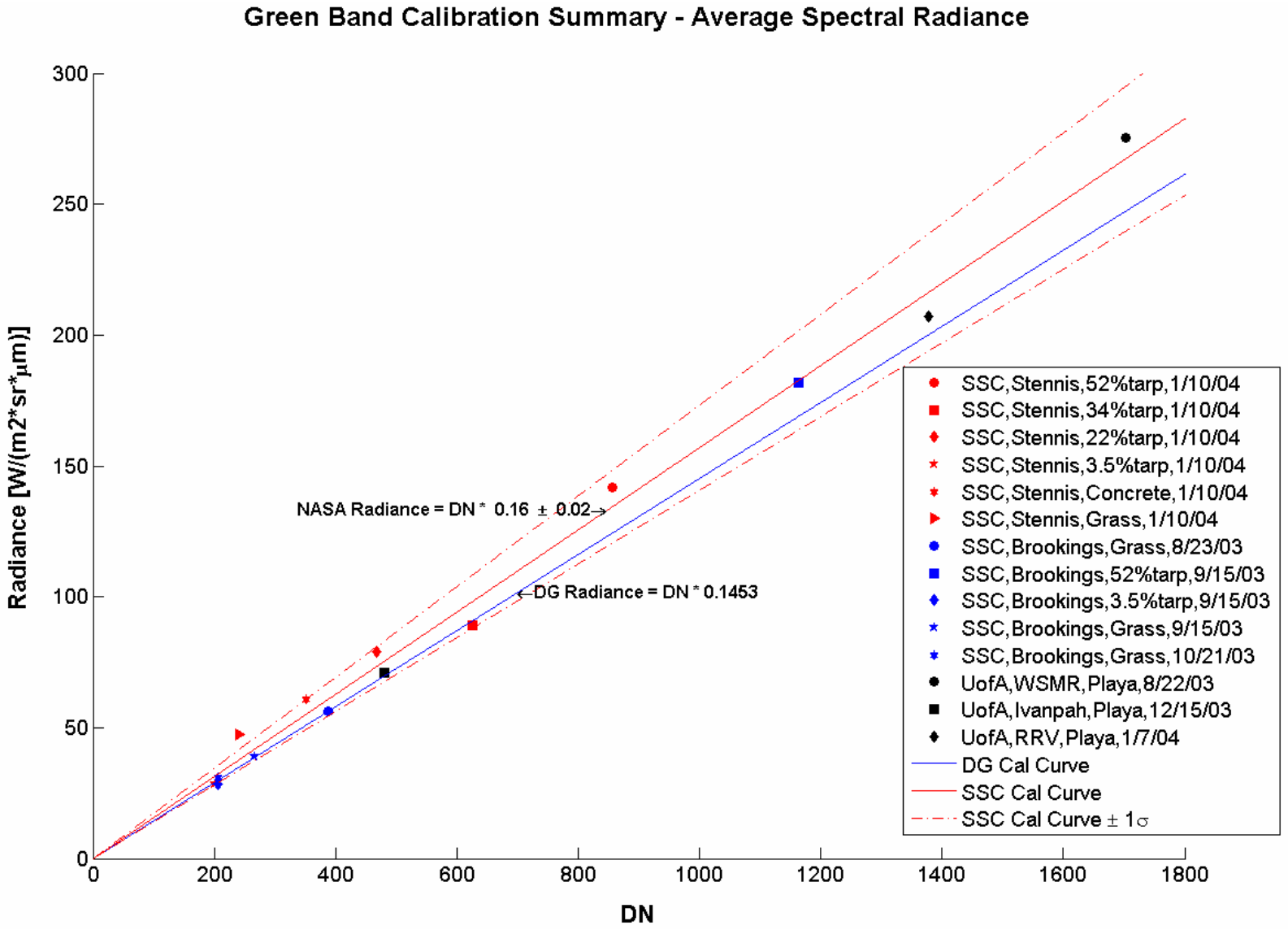
c = speed of light



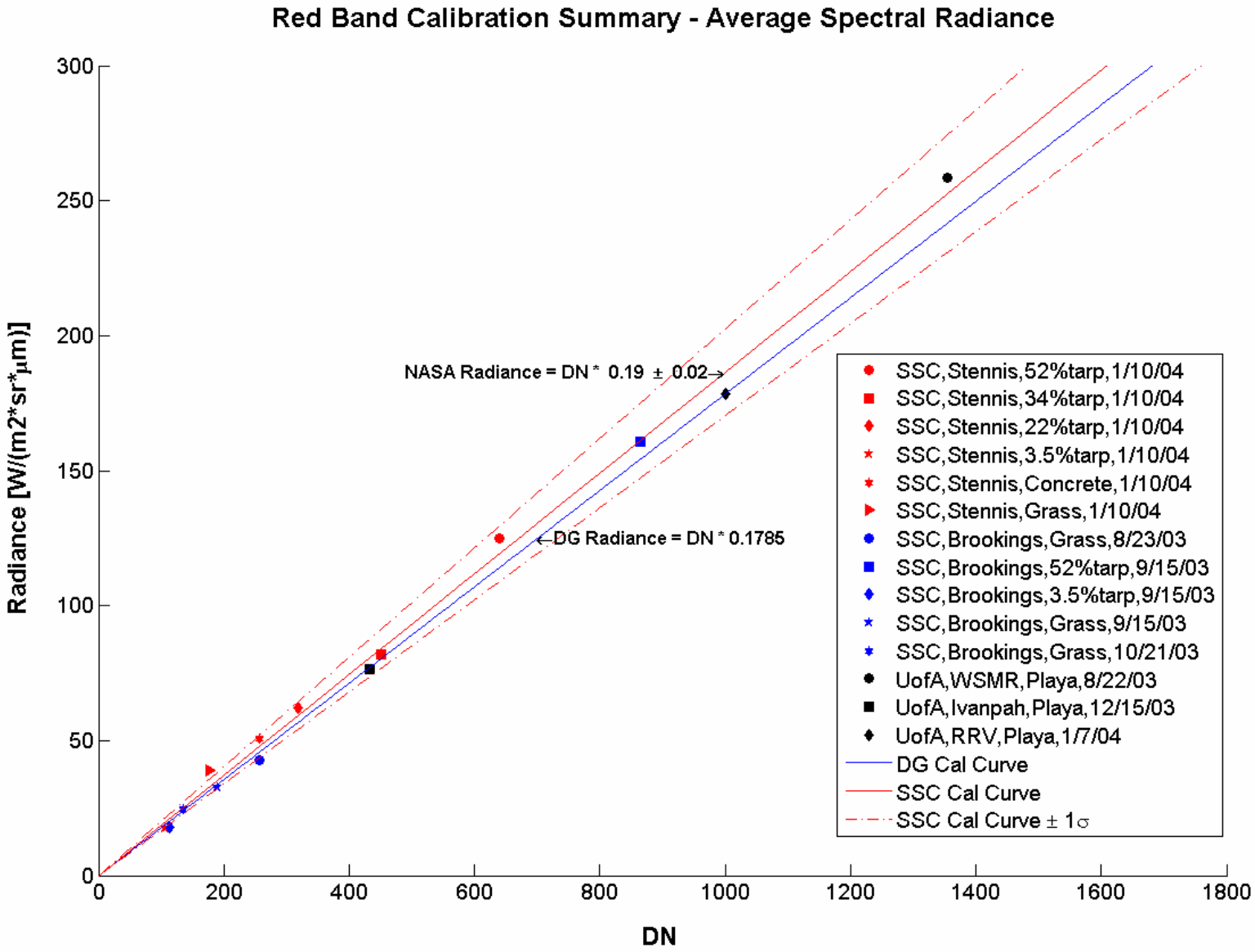
QuickBird Blue Band Calibration Summary



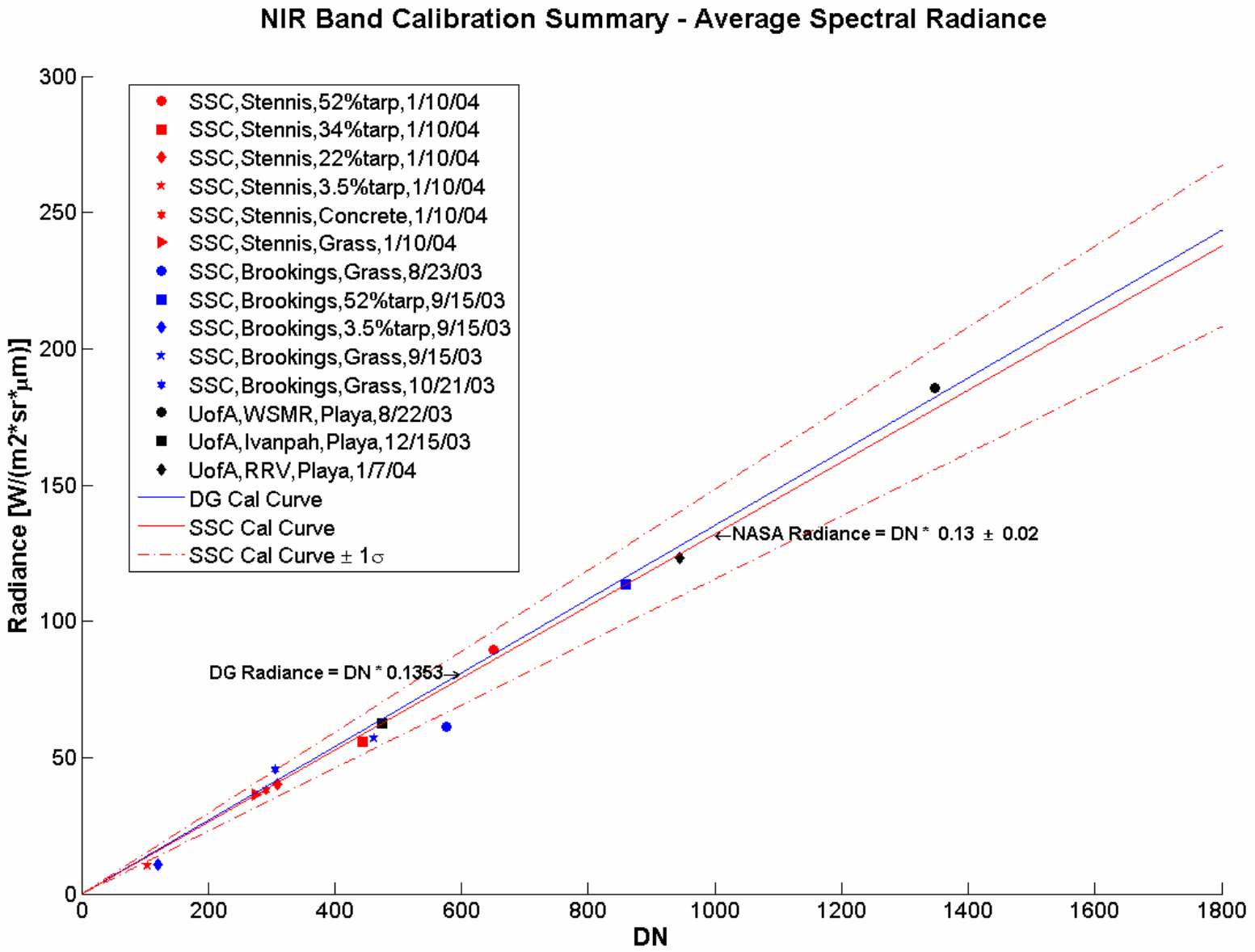
QuickBird Green Band Calibration Summary



QuickBird Red Band Calibration Summary



QuickBird NIR Band Calibration Summary



QuickBird Radiometric Assessment

Average Spectral Radiance Calibration Coefficients

Bandwidth FWHM (μm)		NASA Estimate (W/m^2 sr μm DN)	DigitalGlobe Provided (W/m^2sr μm DN)	% Difference
1	0.445 - 0.510	0.26 ± 0.03	0.236	9.2%
2	0.500 - 0.595	0.16 ± 0.02	0.145	9.4%
3	0.620 - 0.690	0.19 ± 0.02	0.179	5.8%
4	0.755 - 0.875	0.13 ± 0.02	0.135	- 3.8%

Percent difference is calculated by (1 - DigitalGlobe/NASA)

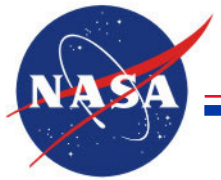
QuickBird Temporal Stability

Average Spectral Radiance Calibration Coefficients

Bandwidth FWHM (μm)		NASA 2003 Estimate (W/m^2 sr μm DN)	NASA 2004 Estimate (W/m^2sr μm DN)
1	0.445 - 0.510	0.26 ± 0.01	0.26 ± 0.03
2	0.500 - 0.595	0.16 ± 0.01	0.16 ± 0.02
3	0.620 - 0.690	0.19 ± 0.01	0.19 ± 0.02
4	0.755 - 0.875	0.14 ± 0.02	0.13 ± 0.02

QuickBird Results Summary

- The QuickBird calibration coefficients continue to agree well with the NASA estimate (within 10%)
- The QuickBird sensor appears to be temporally stable
- The JACIE team will continue to assess QuickBird radiometry

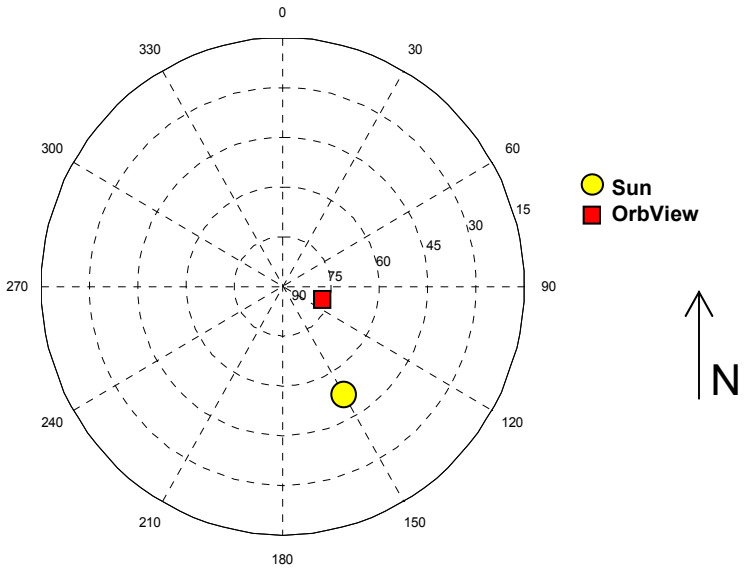


OrbView-3 Radiometric Characterization (pre-IOC)

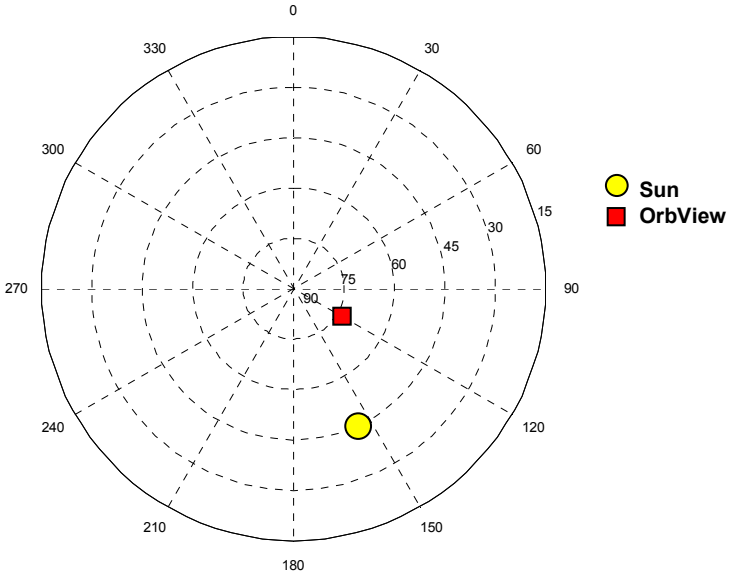
Data Acquisitions: SSC

Date	Overpass Time (UTC)	Satellite Elevation	Satellite Azimuth	Sun Elevation	Sun Azimuth
Sept 28, 2003	16:40	78.6 deg	107 deg	53.7 deg	149.8 deg
Oct 20, 2003	16:40	74.4 deg	122 deg	46.6 deg	157.0 deg

Basic imagery

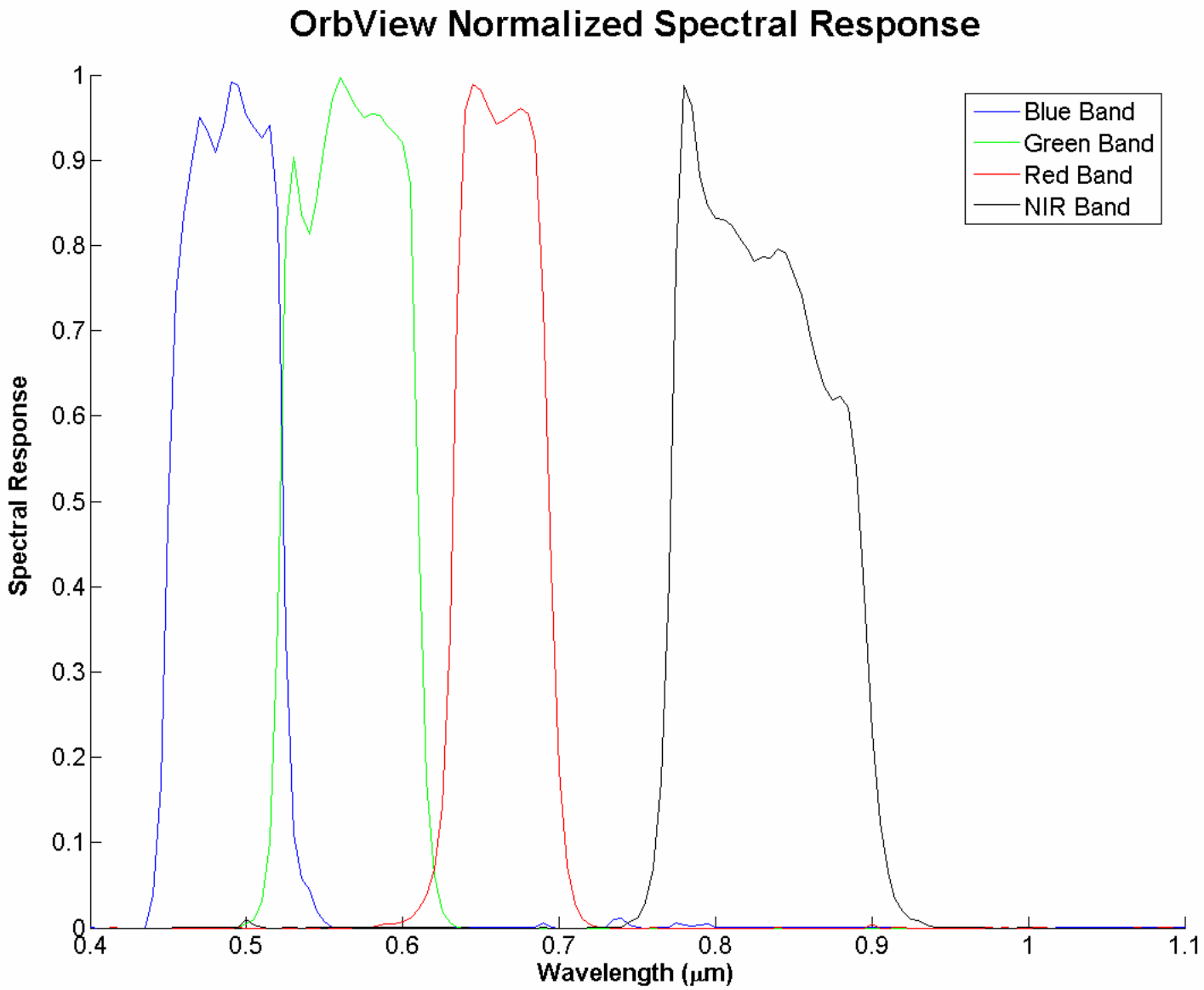


Stennis Space Center, MS, 9/28/03

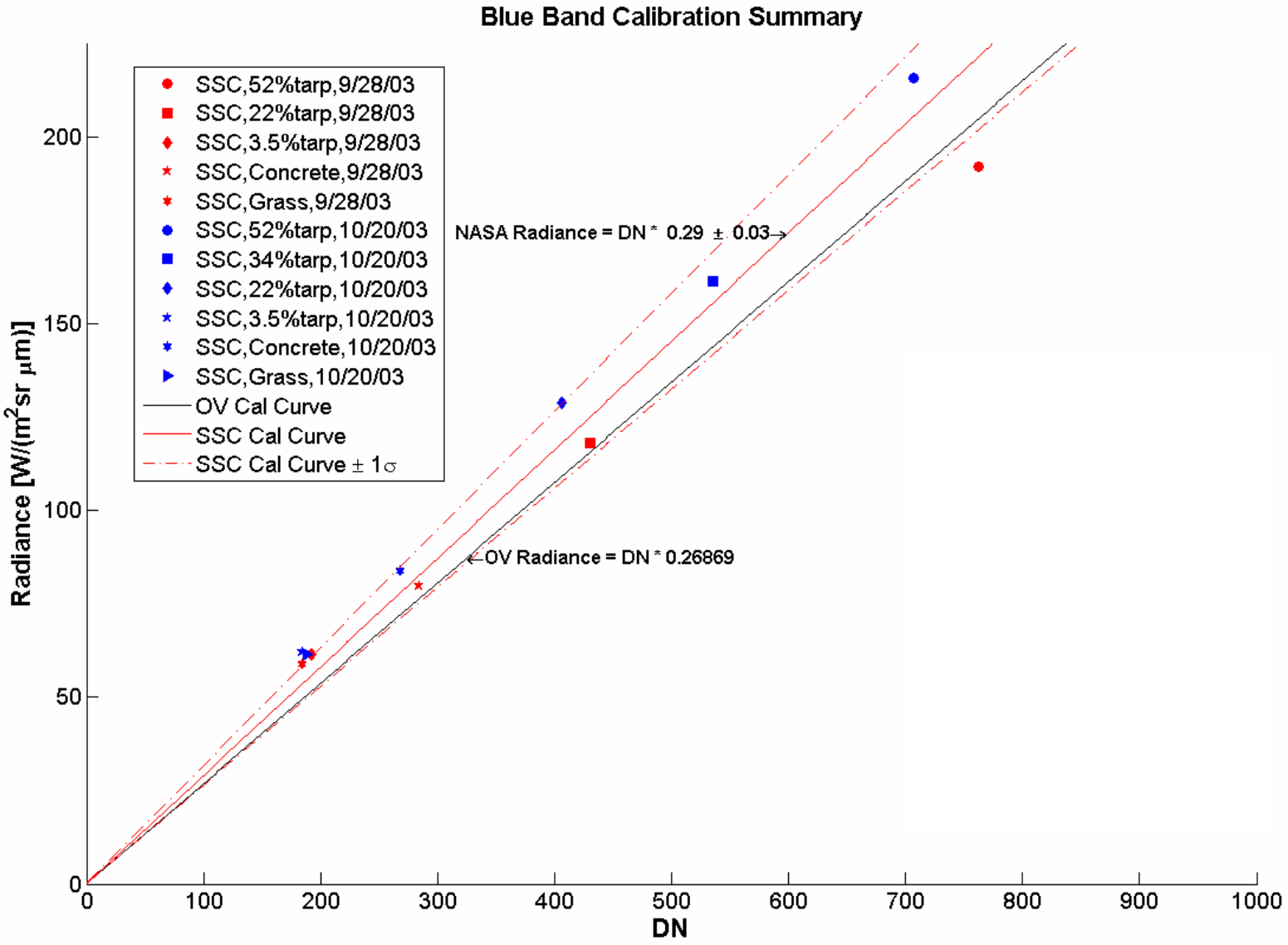


Stennis Space Center, MS, 10/20/03

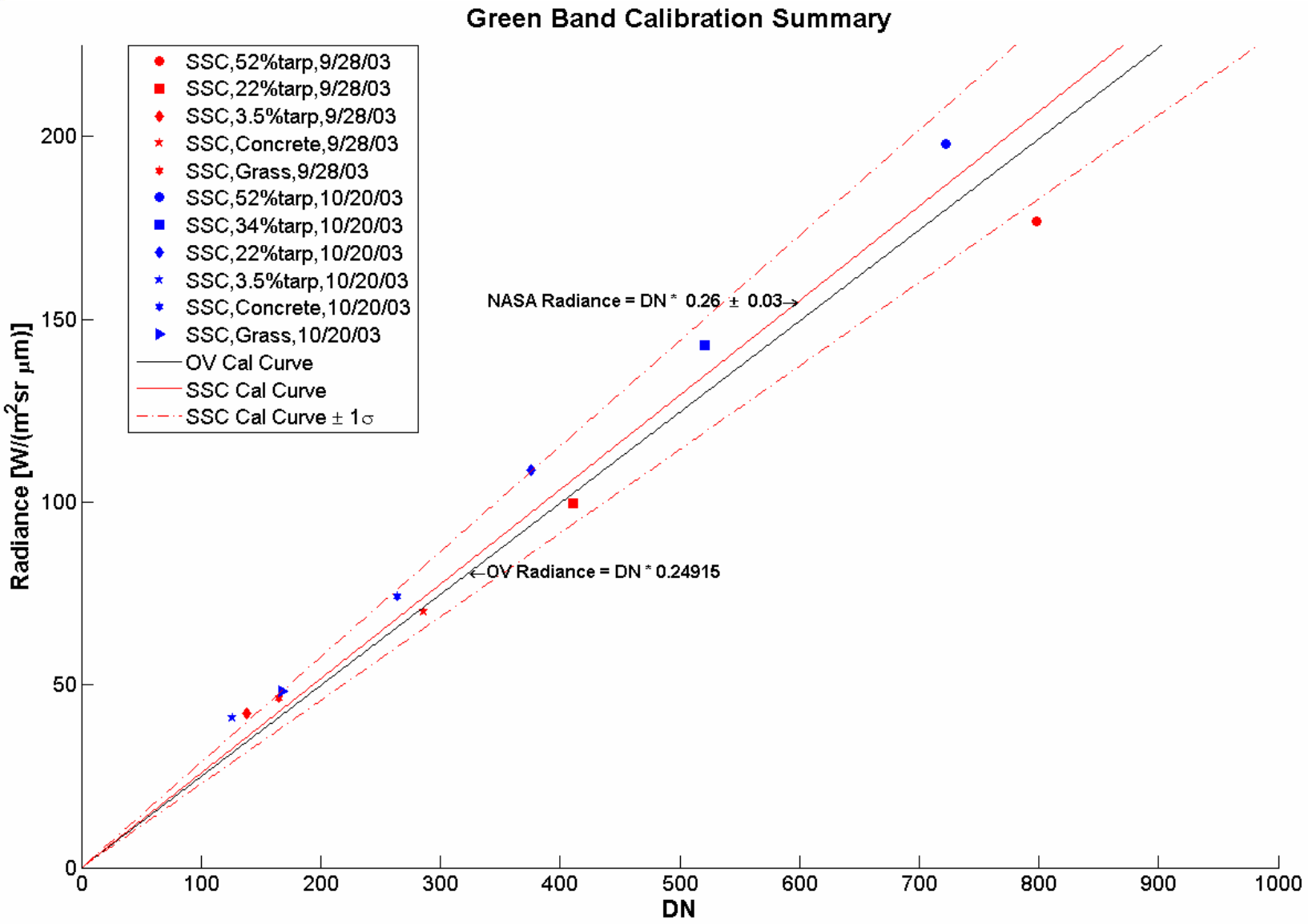
OrbView-3 Spectral Response



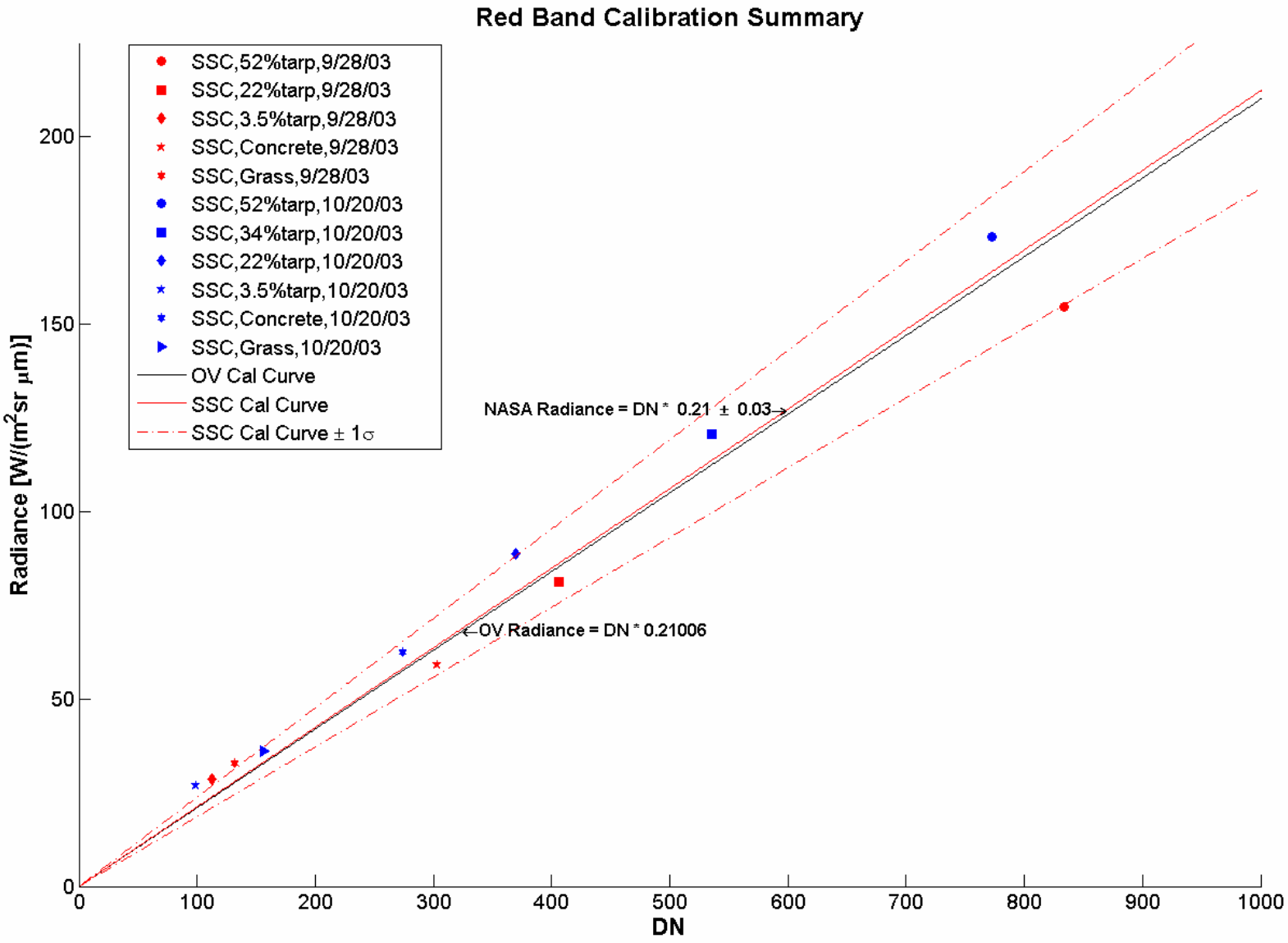
OrbView-3 Blue Band Calibration Summary



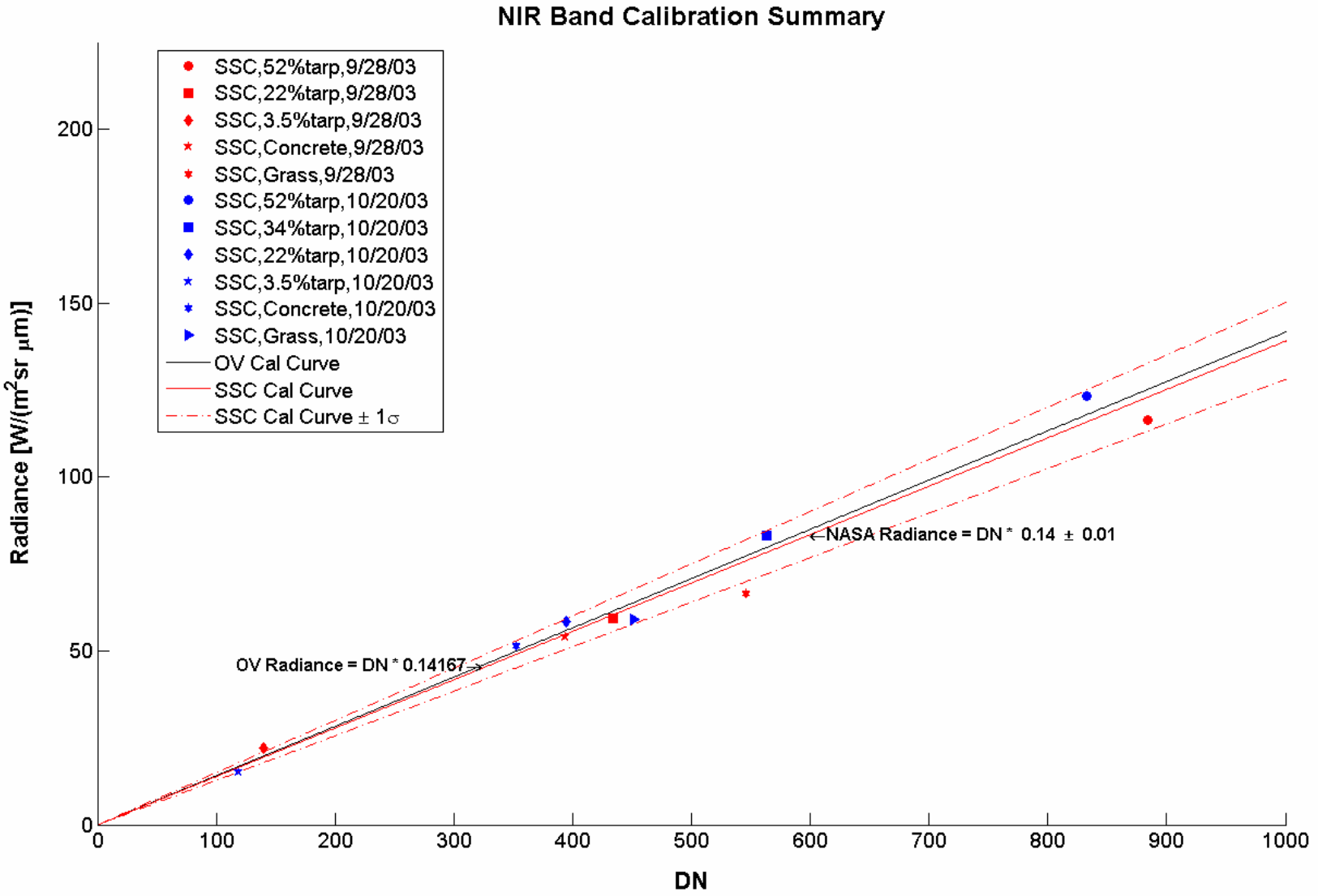
OrbView-3 Green Band Calibration Summary



OrbView-3 Red Band Calibration Summary



OrbView-3 NIR Band Calibration Summary



OrbView-3 Radiometric Assessment

Average Spectral Radiance Calibration Coefficients

Bandwidth FWHM (μm)		NASA Estimate (W/m^2 sr μm DN)	ORBIMAGE Provided (W/m^2sr μm DN)	% Difference
1	0.450 - 0.520	0.29 ± 0.03	0.269	7.2%
2	0.520 - 0.600	0.26 ± 0.03	0.249	4.2%
3	0.625 - 0.695	0.21 ± 0.03	0.210	0.0%
4	0.760 - 0.900	0.14 ± 0.01	0.142	- 1.4%

Percent difference is calculated by (1 - ORBIMAGE/NASA)

OrbView-3 Results Summary

- Pre-IOC results, based on only two data collects, are inconclusive
  - More data collects are needed before conclusions regarding OrbView-3's radiometric accuracy can be made

- The JACIE team will continue to characterize OrbView-3's radiometry