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Spectral Dark Subtraction

A MODTRAN-Based Algorithm for Estimating Ground Reflectance without Atmospheric Information

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Agenda

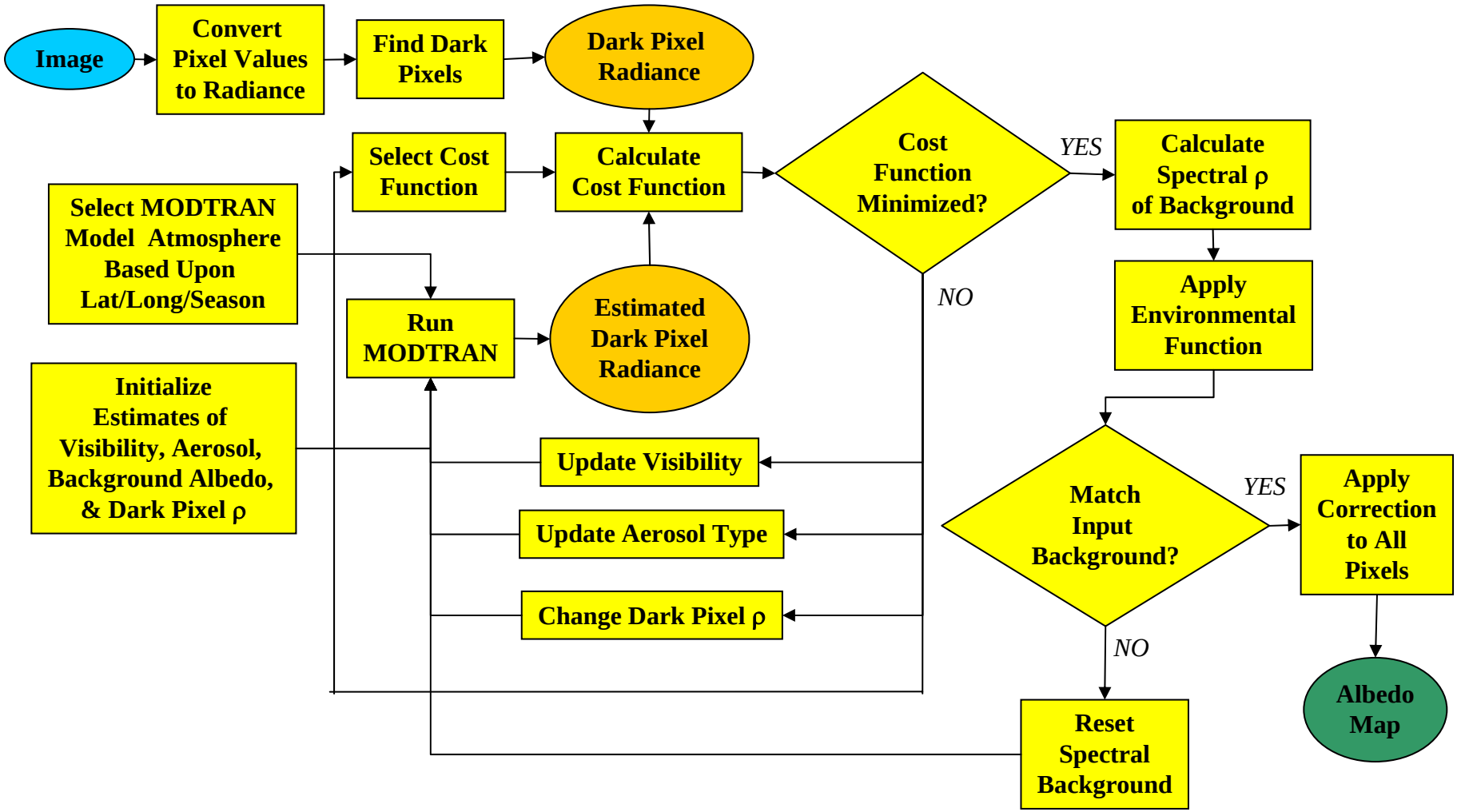
- Background
- Algorithm Overview
- Methodology/Approach
- Results
- Summary and Conclusions

Background

- In late 1990's, several systems set requirements for determining timely, ground reflectance
  - Several approaches suggested involved commercial, government and sounder-based atmospheric data
- Lockheed Martin took the approach of developing an algorithm under internal funding that did not require atmospheric knowledge
- In 2004, LM IS&S enlisted the aid of LM Stennis Space Center to enhance and evaluate the algorithm.

Algorithm Overview

Spectral Dark Subtraction Flowchart



Dark Pixel Identification

- Common Location Histogram
  - Find darkest x% of pixels in each band
  - Determine which pixels are in that portion of all of the histograms
  - Works well, but tended to identify “ringing” as dark pixels in images that had been oversharpened
- Normalized Radiance
  - Create the weighted sum of pixel values in all bands
  - Find the pixels with the lowest weighted sum
  - Effectively the darkest “color” pixel

Cost Functions

- Blue Haze Cost Function
  - Root squared difference between simulated and measured slope calculated from blue and red bands
  - Intended to emphasize shape of spectral haze rather than absolute match
    - Minimizes impact of correlated calibration errors
- Dark Dense Vegetation Cost Function
  - RMS of difference between simulated and measured values in blue and red bands
- Shadow Cost Function
  - RMS of difference between simulated and measured values in all bands

Methodology

Data Sources Used

- LM Stennis, SSAI Stennis, NASA and JACIE provided
  - Ikonos imagery and ground truth
  - Quickbird imagery and ground truth
- Landsat 7 image purchased fromUSGS
  - Ground truth provided by South Dakota State University

Images Evaluated

Location	Date	Sensor	Sensor Az/El	Ground Truth	Measured Visibility
Brookings, SD	July 3, 2001	IKONOS	281.8 / 76.2	Targets=grass ASD, ASR/MFRSR, radiosonde	49 km ASR
SSC, MS	Jan 15, 2002	IKONOS	113.0 / 77.2	Targets=3 tarps (3.5, 22, 52), grass, concrete ASD, ASR/MFRSR, pressure, radiosonde, BRDF	316 km ASR
SSC, MS	Feb 17, 2002	IKONOS	100.7 / 81.9	Targets=3 tarps (3.5, 22, 52), grass, concrete ASD, ASR/MFRSR, radiosonde, BRDF	97 km MFRSR 148 km ASR
SSC, MS	Feb 17, 2002	QuickBird	10.5 / 67.3	Targets=3 tarps (3.5, 22, 52), grass, concrete ASD, ASR/MFRSR, radiosonde, BRDF	97 km MFRSR 148 km ASR
SSC, MS	Dec 15, 2004	IKONOS	118.6/68.9	Targets=3 tarps (3.5, 22, 52), grass, concrete ASD, ASR/MFRSR, radiosonde, BRDF	300 km ASR
Brookings, SD	July 20, 2002	QuickBird	349.8 / 64.1	Targets=2 tarps (3.5, 52), grass ASD, ASR/MFRSR, radiosonde	26 km MFRSR 28 km ASR
Brookings, SD	Aug 25, 2002	QuickBird	332.5 / 70.5	Targets=2 tarps (3.5, 52), grass, concrete ASD, ASR/MFRSR	48 km ASR
Brookings, SD	Sept 7, 2002	QuickBird	191.0 / 74.9	Targets=2 tarps (3.5, 52), grass, concrete ASD, ASR/MFRSR	48 km MFRSR 36 km ASR
SSC, MS	Nov 14, 2002	QuickBird	274.8 / 79.4	Targets=3 tarps (3.5, 22, 52), grass, concrete ASD, ASR/MFRSR, pressure, radiosonde, BRDF	239 km MFRSR 221 km ASR 228 km ASR
Brookings, SD	Aug 26, 2003	Landsat 7	0 / 0	Targets=200m x 110m grass site ASD, ASR/MFRSR, pressure, temp, RH	Wx Reported 10 miles

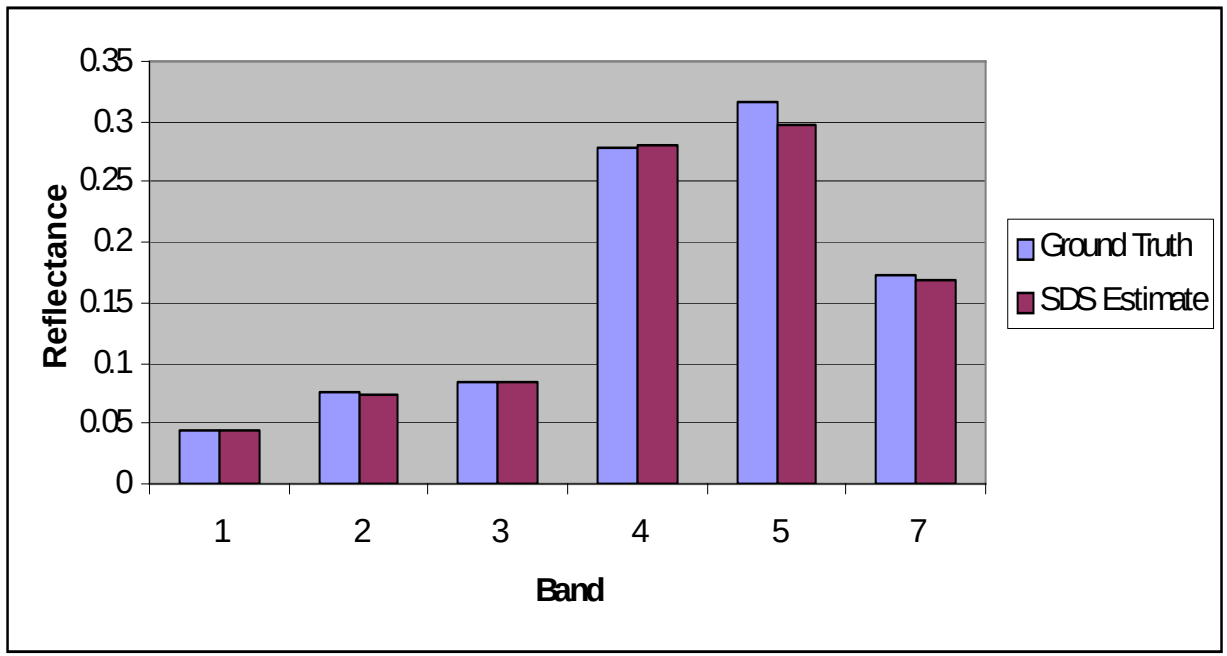
Ground Truth

- Ikonos and Quickbird
  - Specially designed 20m x 20m tarps
  - Nominal reflectances of 3.5%, 22% and 52%
  - Located at Stennis Space Center and Brookings, South Dakota
  - One image of Railroad Valley, NV
- Landsat 7
  - Carefully measured “grass” field at 3M site near Brookings

Results

Landsat Results

- Used image of Brookings, SD on August 26, 2003
  - Used a “mowed” section of farm owned by 3M
  - Ground truth provided by South Dakota State University



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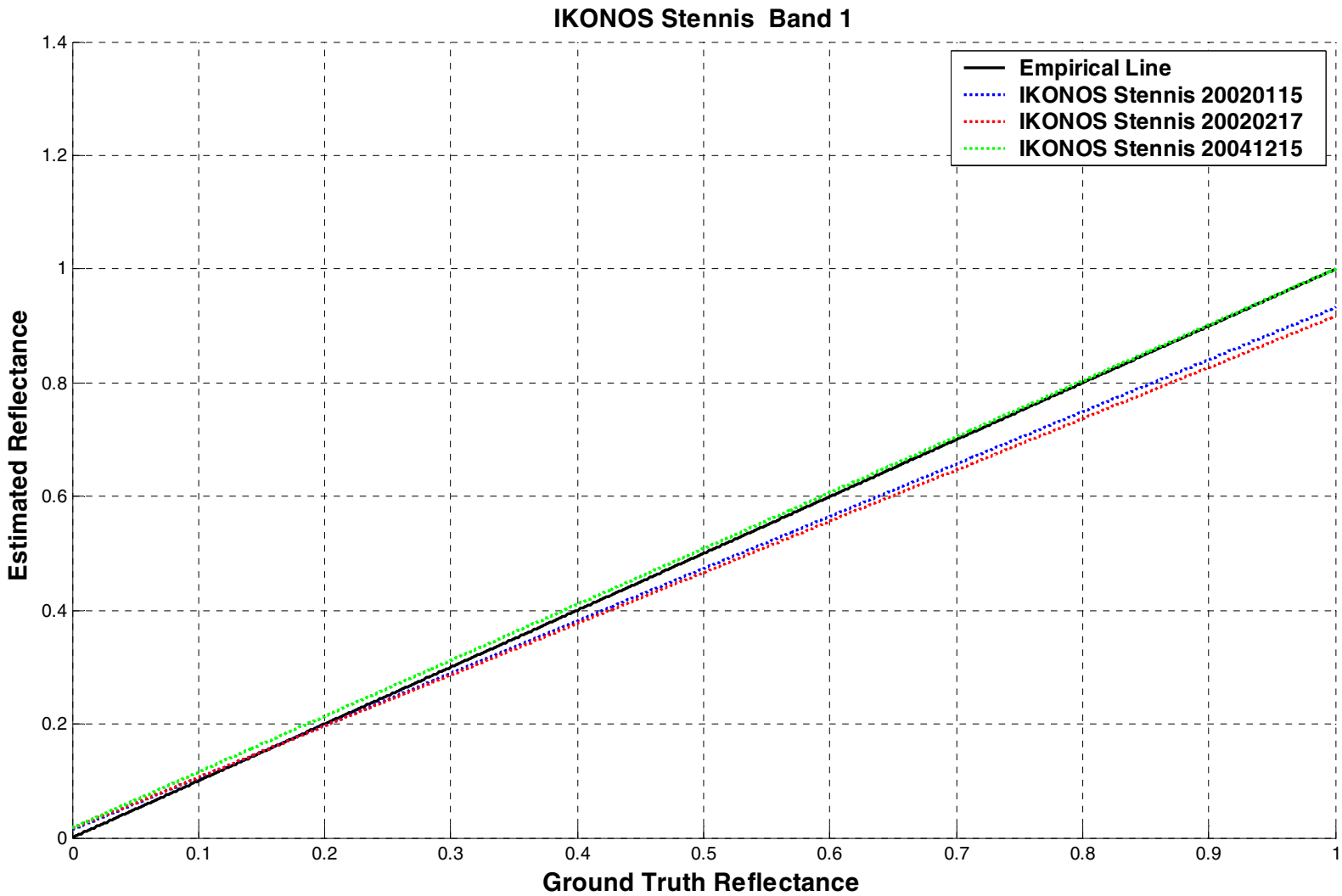
IKONOS Band 1 Results



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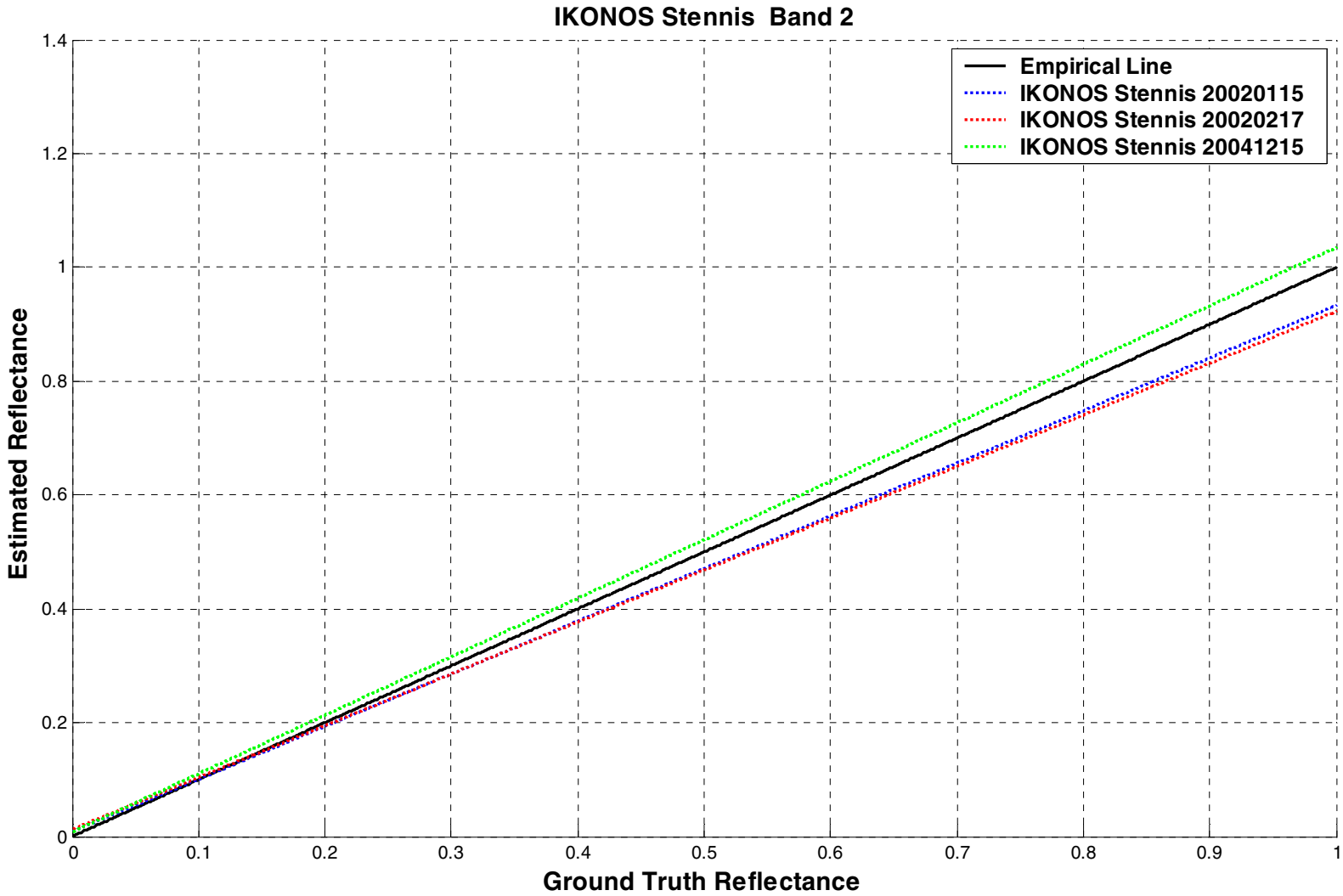
IKONOS Band 2 Results



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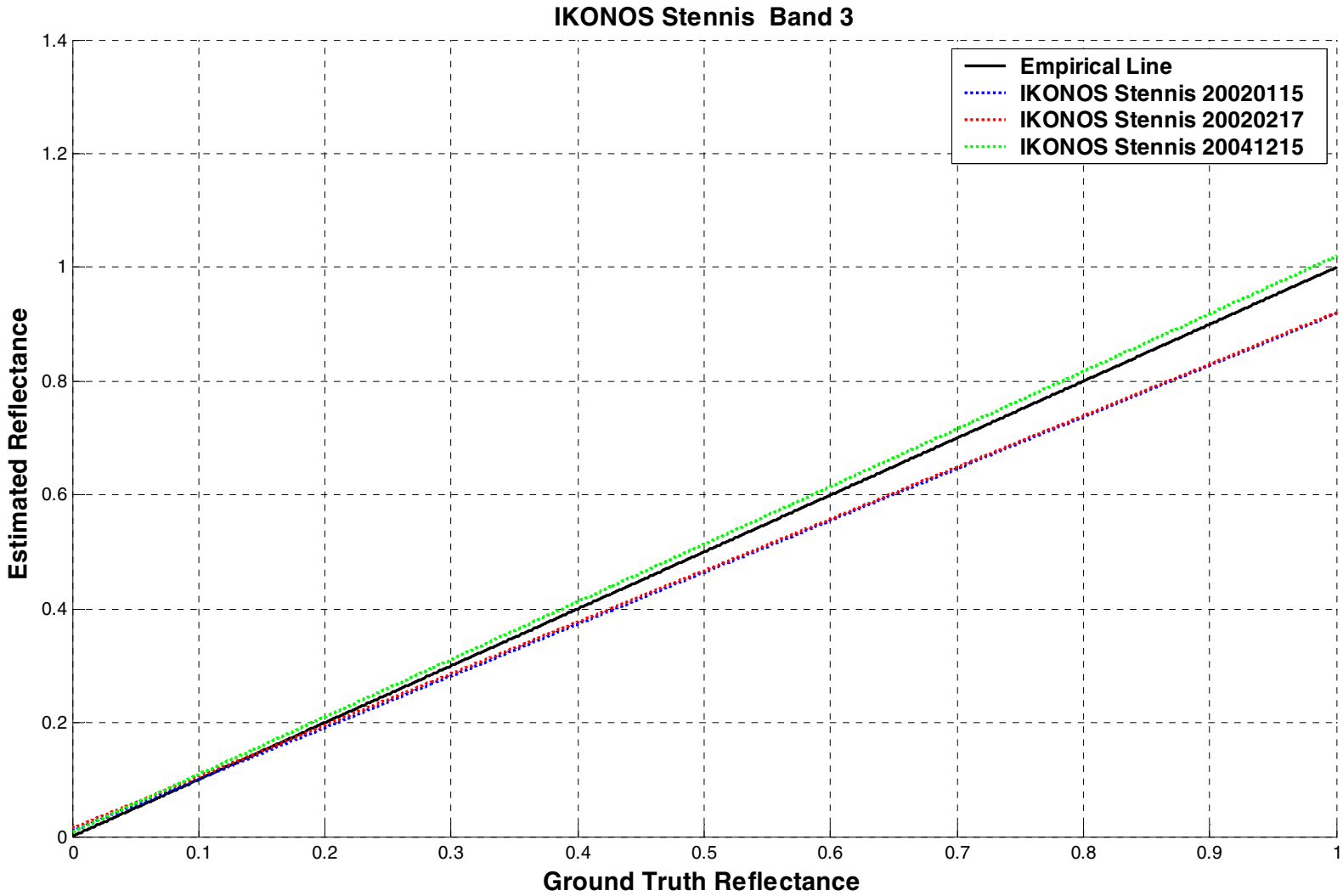
IKONOS Band 3 Results



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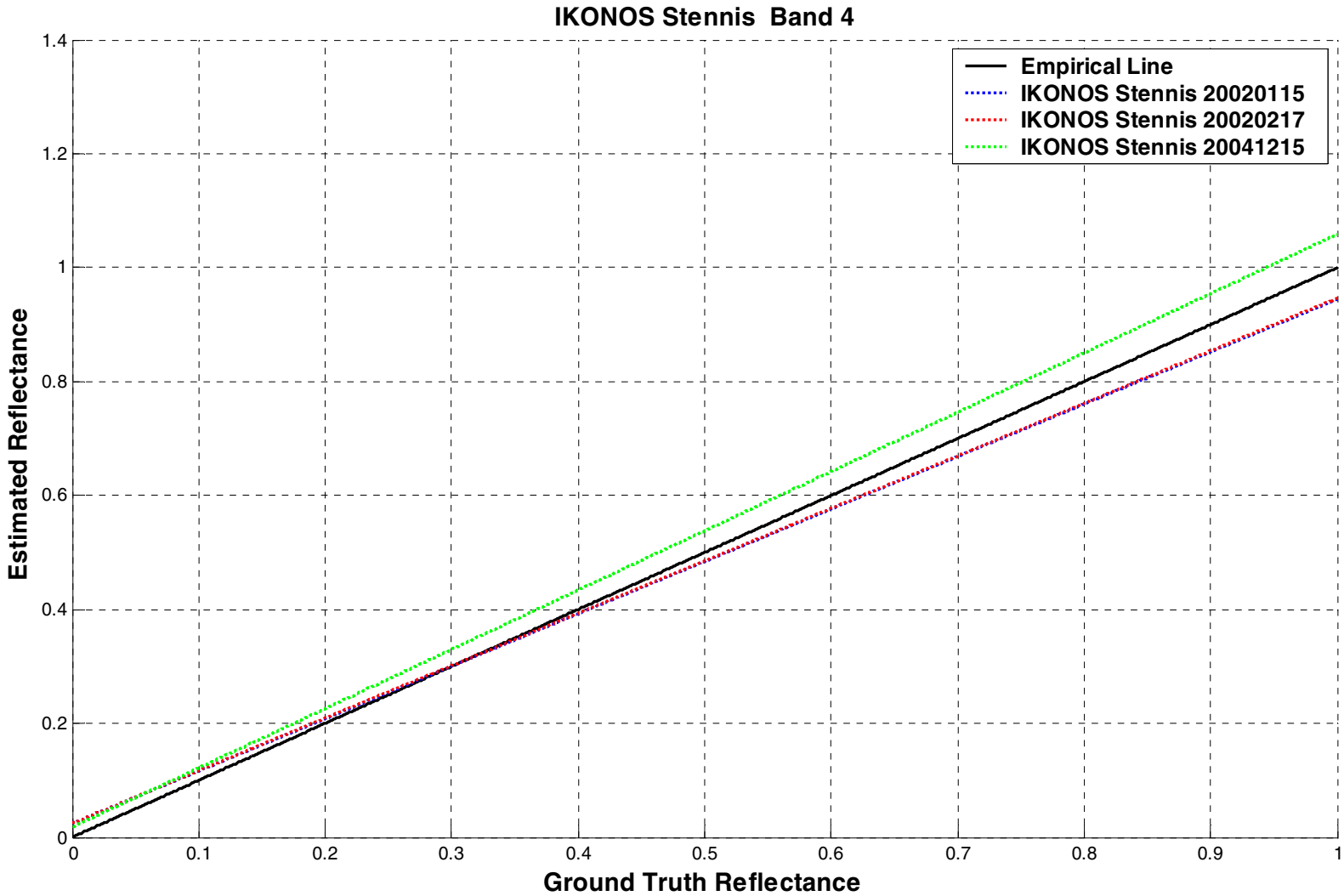
IKONOS Band 4 Results



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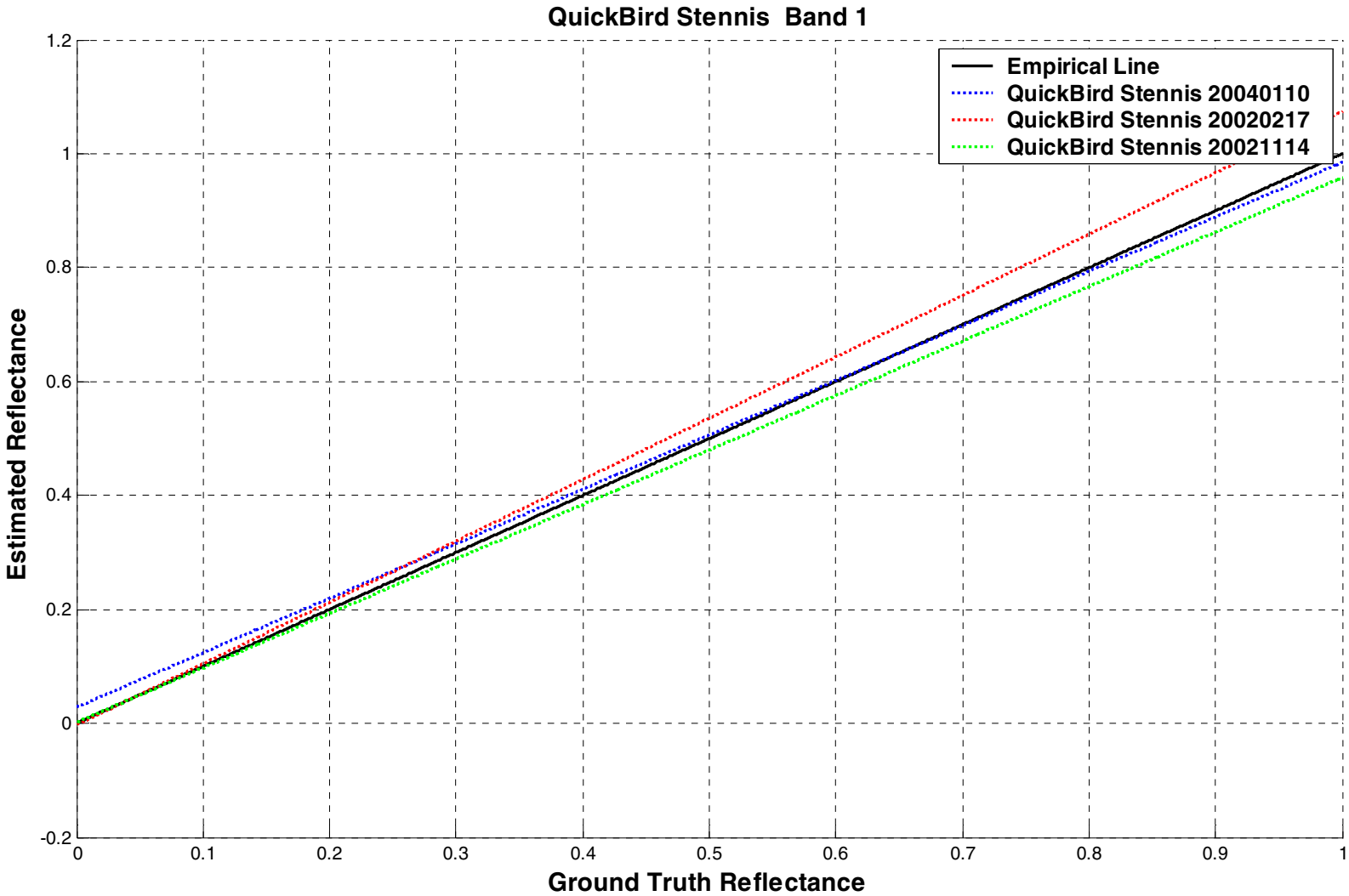
QuickBird Band 1 Results



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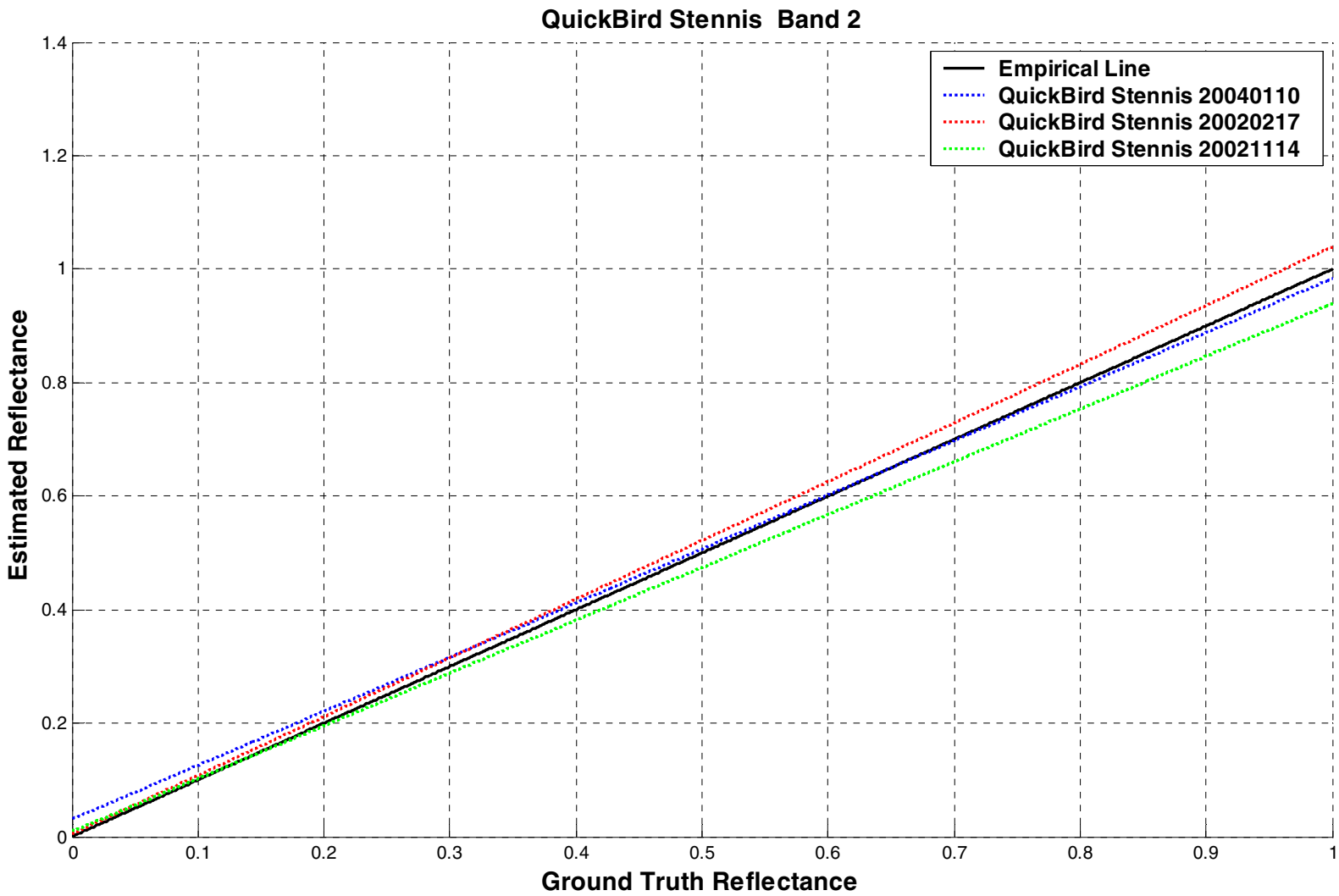
QuickBird Band 2 Results



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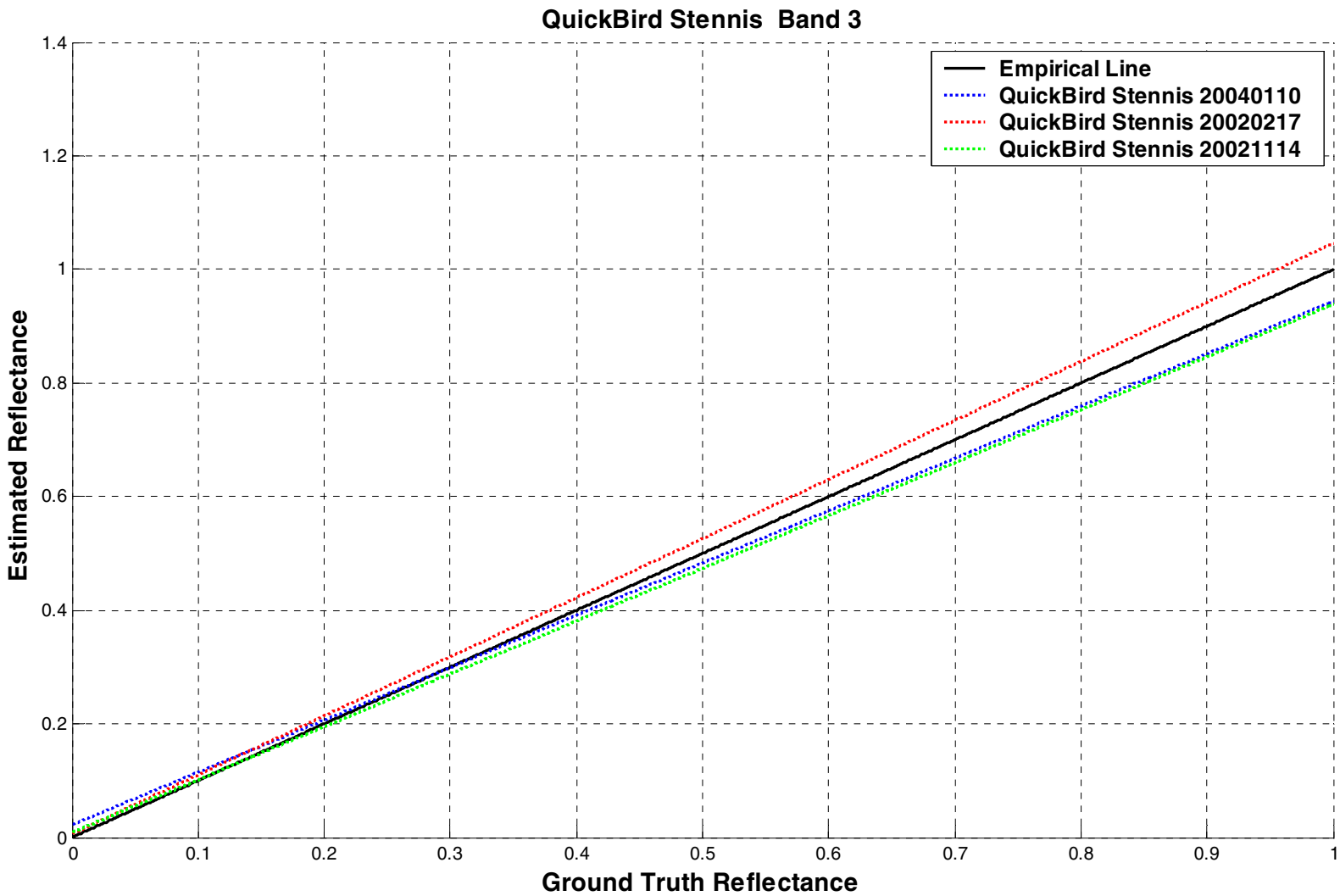
QuickBird Band 3 Results



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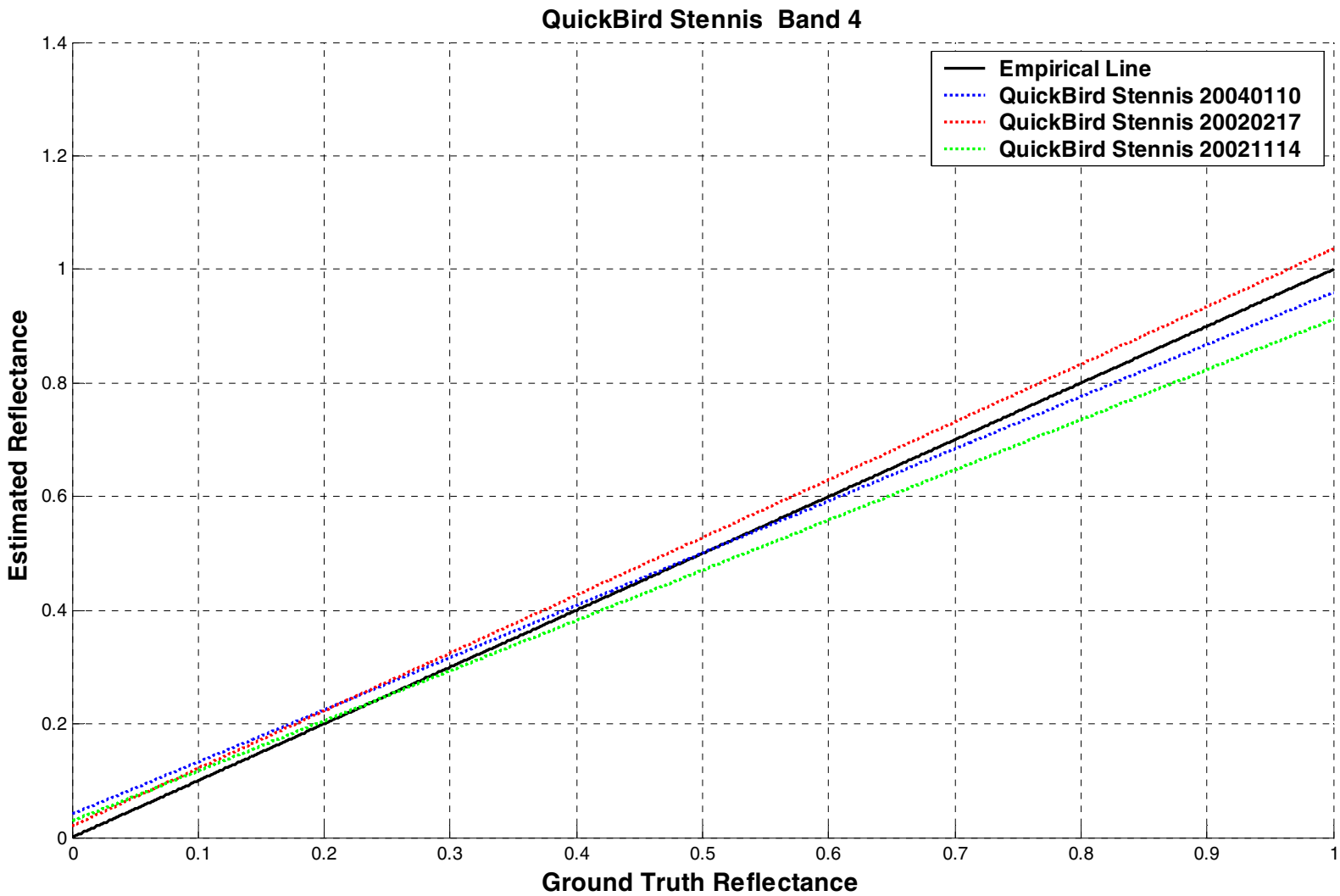
QuickBird Band 4 Results



Unusual Cases (1)

- Requested that LM Stennis find difficult atmospheres in which to test the algorithm
- Provided a collection by Ikonos at Railroad Valley, CA with smoke in atmosphere from nearby forest fires

Railroad Valley Conditions

University of Arizona Solar Radiometer #2K

7/13/2002

Langley Regression Analysis

Equivalent Visibility: 4.9 km

Channel (nm)	Optical Depth
381	1.658
400	1.557
440	1.333
521	1.037
610	0.832
671	0.713
781	0.590
871	0.486
940	1.107
1030	0.536

Smoke significantly reduced visibility

Smoke not visible in imagery due to uniformity of ground/target

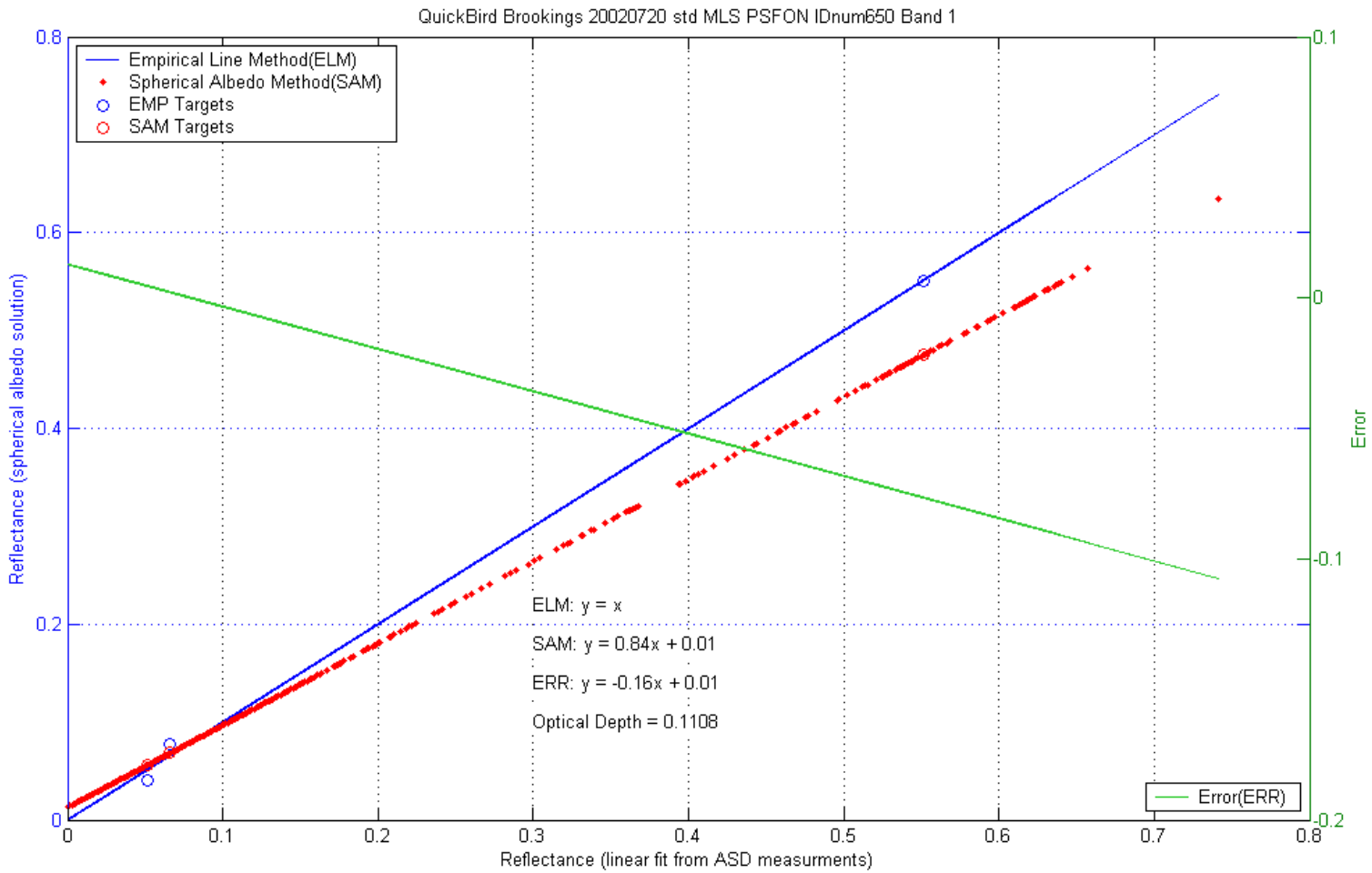
Railroad Valley Results

Cost Function	Model Atmosphere	Blue Error (%)	Green Error (%)	Red Error (%)	NIR Error (%)	Chosen Aerosol Type	Derived Visibility (km)
Blue Haze	MLS	Did not converge	Did not converge	Did not converge	Did not converge	Maritime	2
Blue Haze	MLW	Did not converge	Did not converge	Did not converge	Did not converge	Maritime	2
LS Fit Blue/Red	MLS	-6.1	-4.0	-3.1	0.2	Maritime	14
LS Fit Blue/Red	MLW	-6.4	-4.7	-4.5	-3	Tropospheric	14
LS Fit BGRN	MLS	-3.7	0.7	1.0	4.4	Tropospheric	11
LS Fit BGRN	MLW	-24.5	1.9	2.3	4.3	Rural	8.5

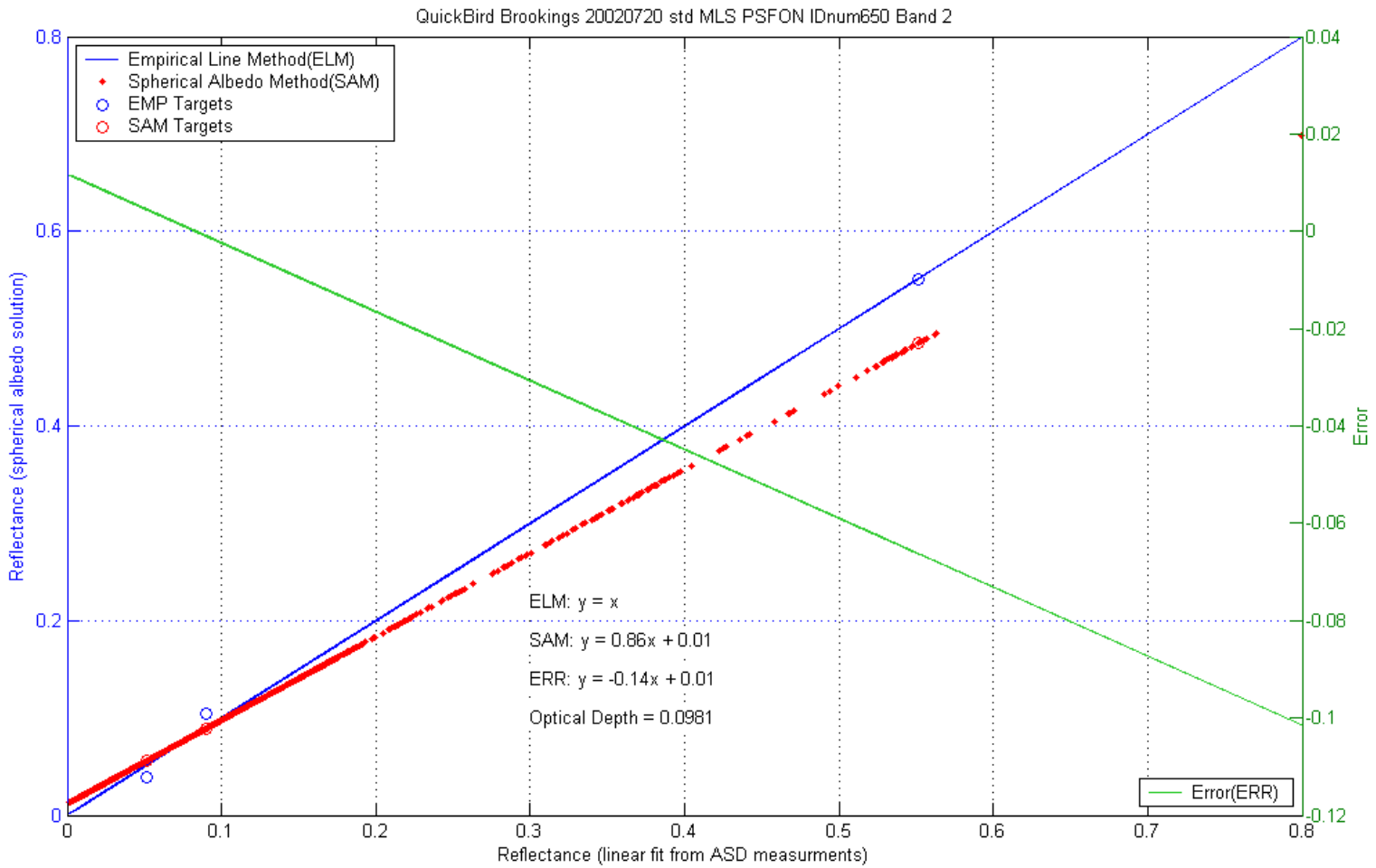
Unusual Cases (2)

- Collection by Quickbird at Brookings, SD on 7/20/2002 had unusually large errors relative to other cases.

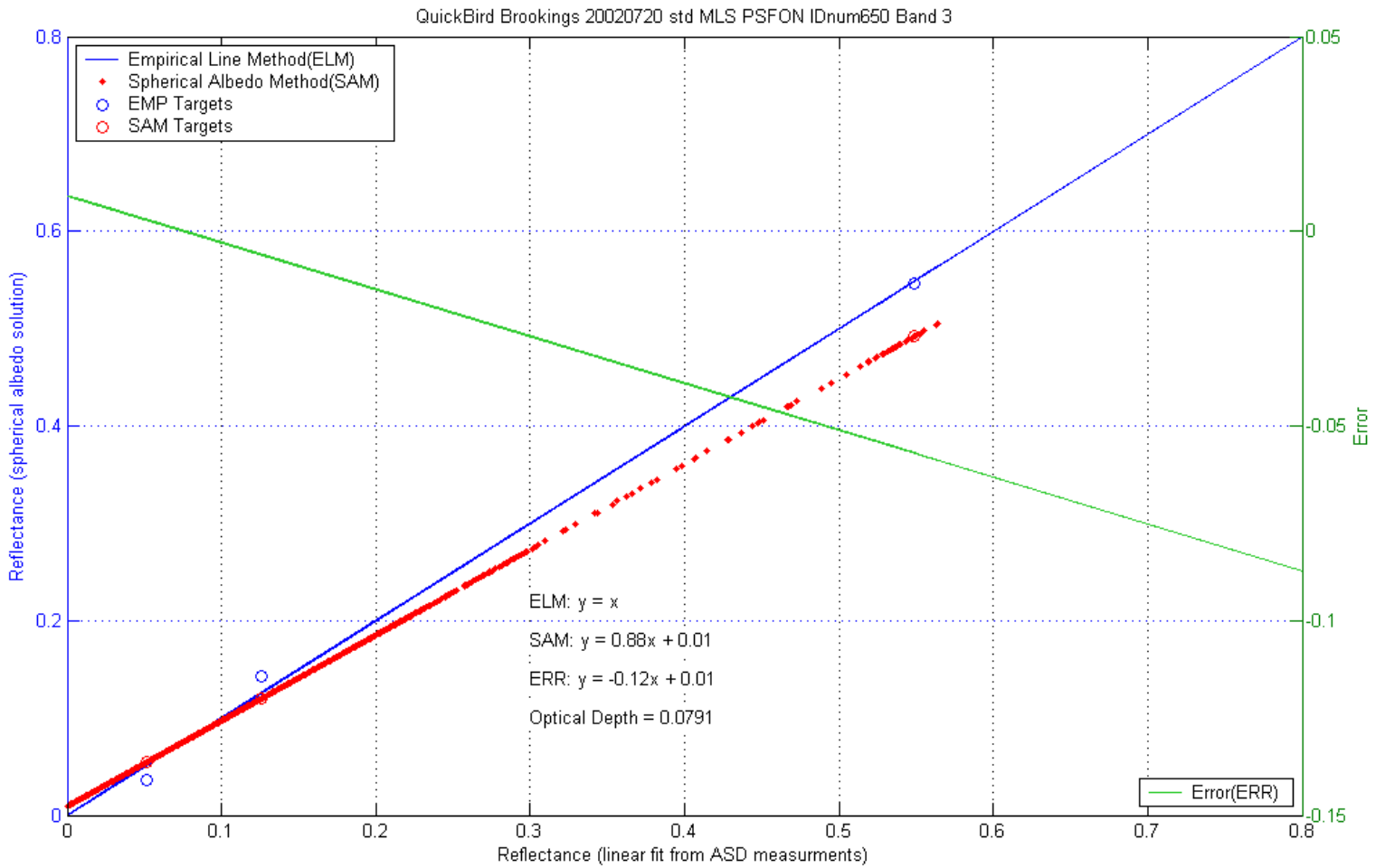
Empirical Line Method / Spherical Albedo Method
QuickBird Brookings 07/20/2002
Blue Band



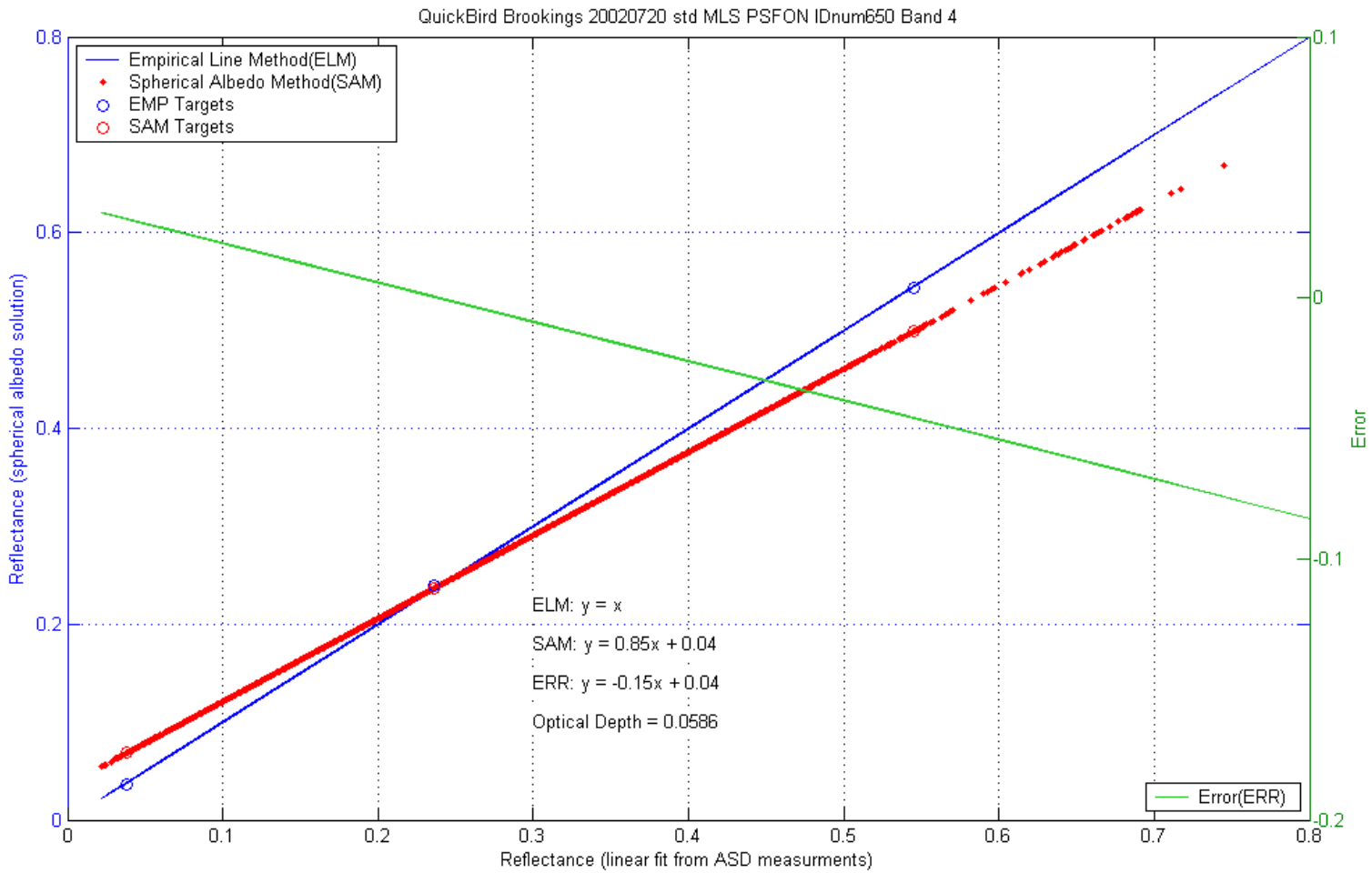
Empirical Line Method / Spherical Albedo Method
QuickBird Brookings 07/20/2002
Green Band



Empirical Line Method / Spherical Albedo Method
QuickBird Brookings 07/20/2002
Red Band



Empirical Line Method / Spherical Albedo Method
QuickBird Brookings 07/20/2002
NIR Band



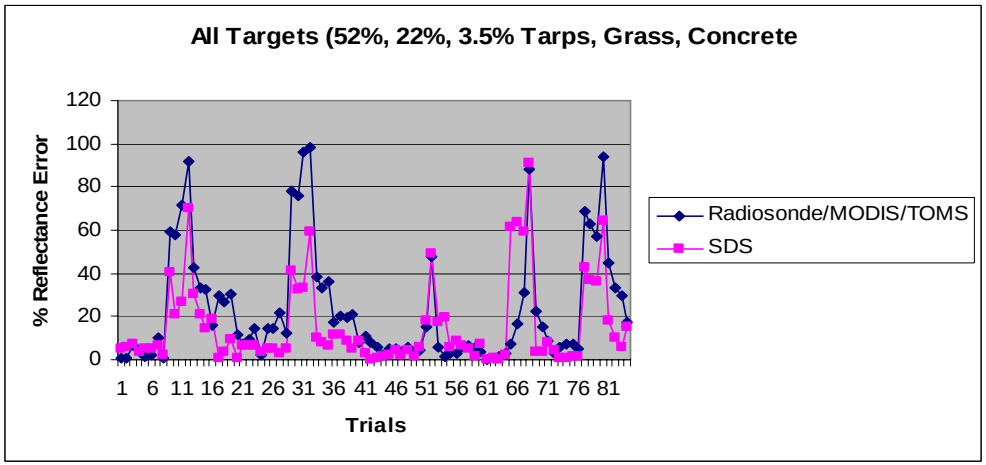
Followup of Poor Brookings Results

- Originally speculated that the Spectralon reference panel used for ground truth was not cleaned properly
- Contacted Professor David Aaron at South Dakota State
  - Responsible for ground truth collections
- Reference Spectralon panel was clean
- Atmospheric conditions were marginal to poor
  - Record setting day in Brookings
    - Temperature: 104F
    - Dew point: 77F
    - “The sky had a few cirrus ‘wisps’, but mostly wasn’t really blue. Rather it was humid enough so the sky was pushing well toward ‘white’ (i.e. just a lot of water vapor scattering).”

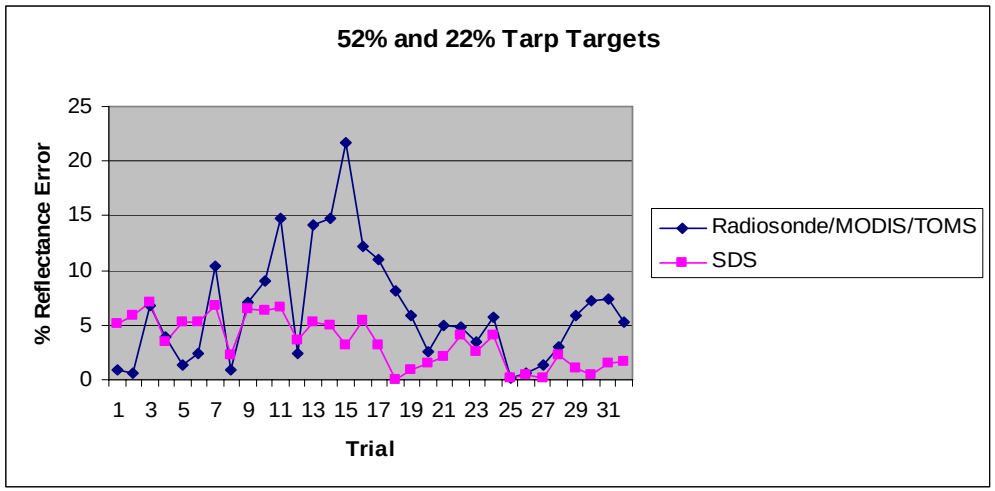
Comparison of SDS to Traditional Method

- NASA sponsored a study of reflectance retrieval of the same targets in the same images used for the SDS study
- Retrieval to be performed using MODTRAN 4 with data from radiosondes launched on-site, TOMS (ozone) and MODIS MOD 04 and MOD 05 products (aerosol and water vapor estimates) collected within 20 minutes of image collection
- One to one comparison performed between results using both methods

Algorithm Results Comparison



SDS produces more accurate results than traditional atmospheric data 71% of the time against all targets in all bands



SDS produces more accurate results than traditional atmospheric data 78% of the time against all 22% and 52% calibration targets in all bands

Conclusions and Summary

- Spectral Dark Subtraction (SDS) provides good ground reflectance estimates across a variety of atmospheric conditions with no knowledge of those conditions
- The algorithm may be sensitive to errors from,
  - Stray light
  - Calibration
  - Excessive haze/water vapor
- SDS seems to provide better estimates than traditional algorithms using on-site atmospheric measurements much of the time

Backup Slides

Blue Haze Cost Function

$$\varepsilon = \sqrt{\left[\frac{R_{Haze}(sim, blue)}{R_{Haze}(sim, red)} - \frac{R'_{Haze}(meas, blue)}{R'_{Haze}(meas, red)} \right]^2}$$

$R_{Haze}(sim, band) =$ Haze calculated from MODTRAN

$R'_{Haze}(meas, band) =$ Haze derived from dark pixel characteristics

$R'_{Haze}(meas, band) = R_{dark\_pixel}(band) - \rho_{dark\_pixel}(band) \cdot R_{100}(band)$

$R_{dark\_pixel} =$ Measured TOA radiance of the dark pixel

$\rho_{dark\_pixel} =$ Reflectance of the dark pixel

$R_{100} =$ Estimated TOA radiance for a 100% reflective target (no atmosphere)

Other Cost Functions

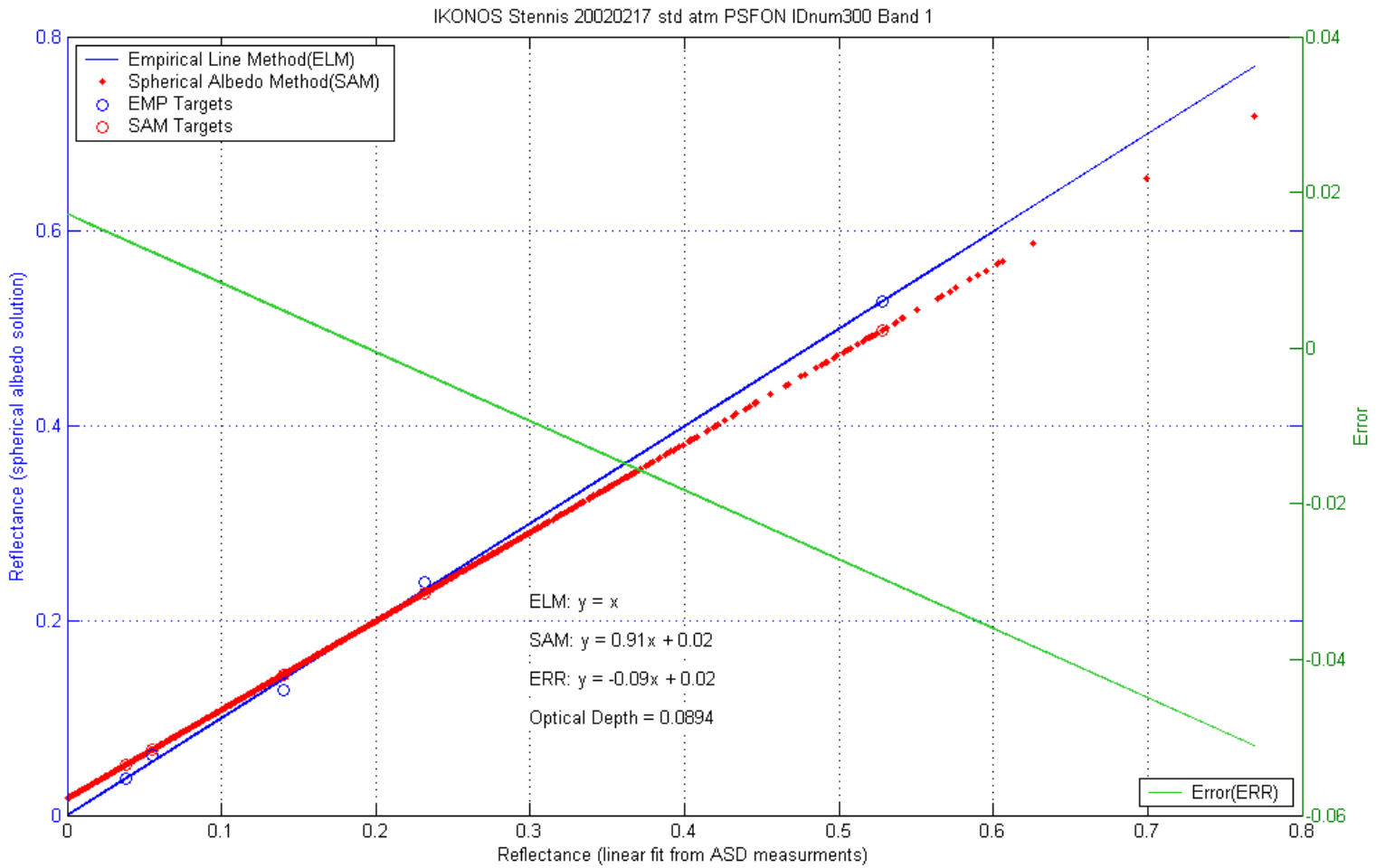
Dark Dense Vegetation RMS Cost Function:

$$\varepsilon = [R_{Haze}(sim, blue) - R_{Haze}(meas, blue)]^2 + [R_{Haze}(sim, red) - R_{Haze}(meas, red)]^2$$

Shadow RMS Cost Function:

$$\varepsilon = \sum_{i=1}^{4} [R_{Haze}(sim, band(i)) - R_{Haze}(meas, band(i))]^2$$

Empirical Line Method / Spherical Albedo Method
IKONOS Stennis 02/17/2002
Blue Band



Empirical Line Method / Spherical Albedo Method
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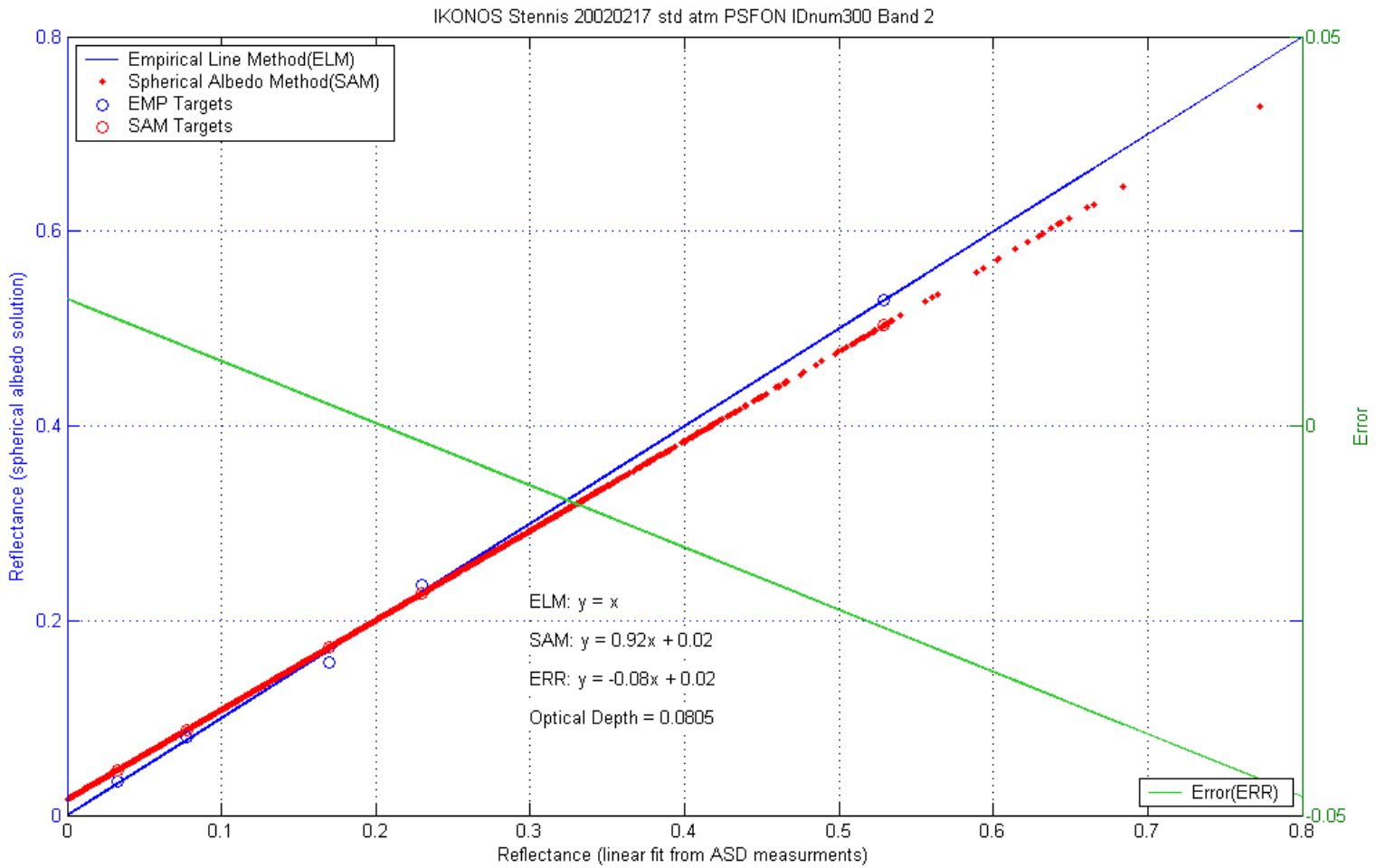
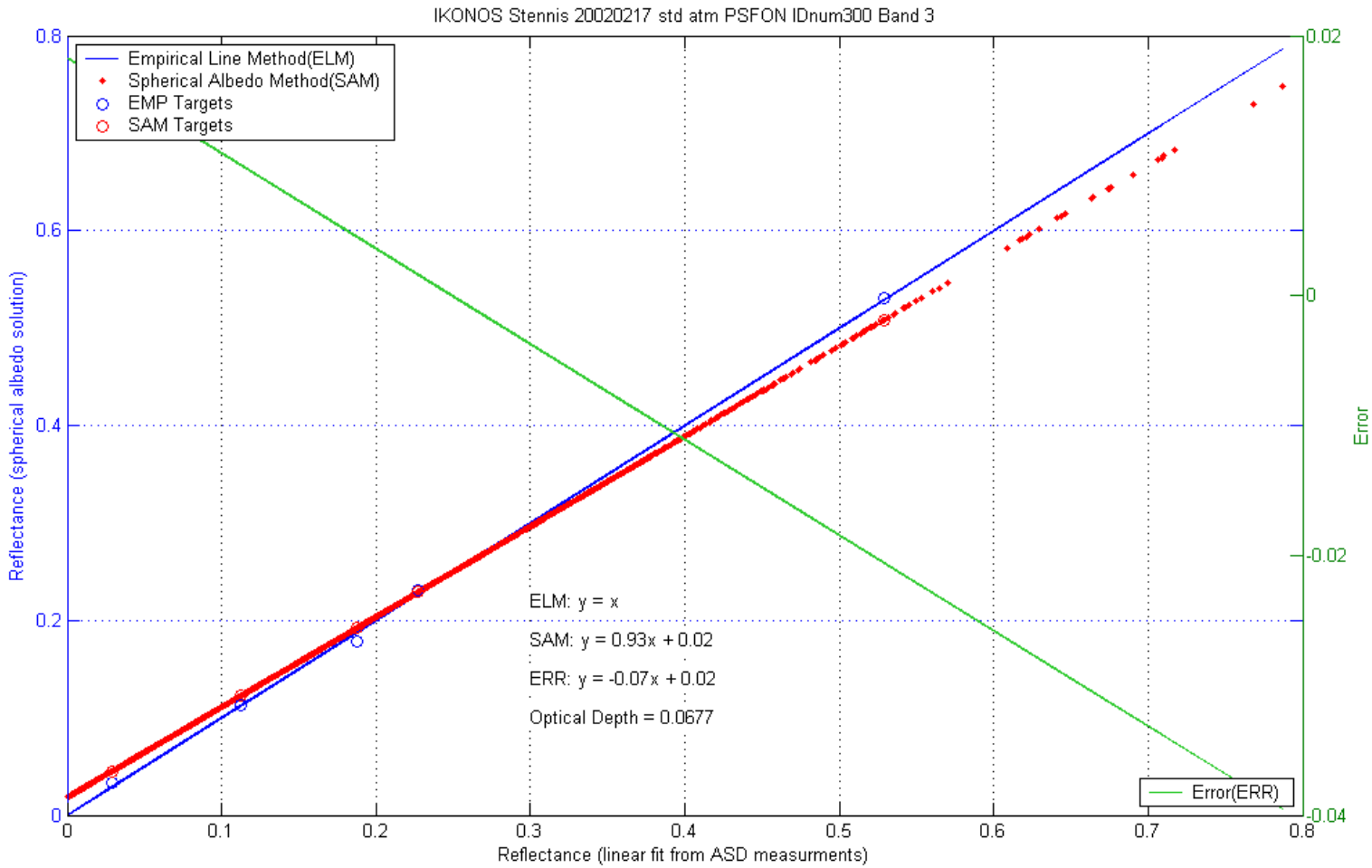
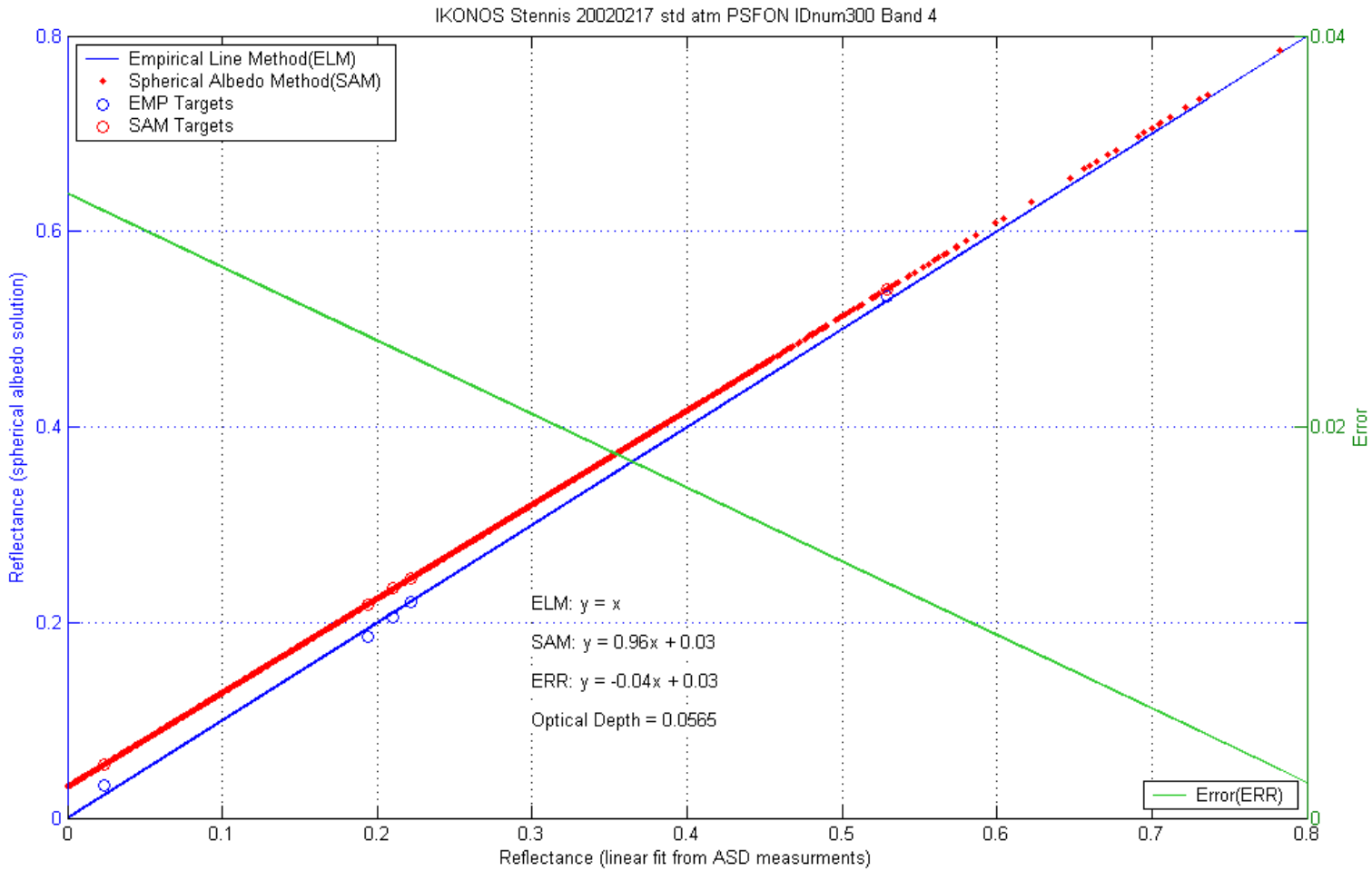
Green Band



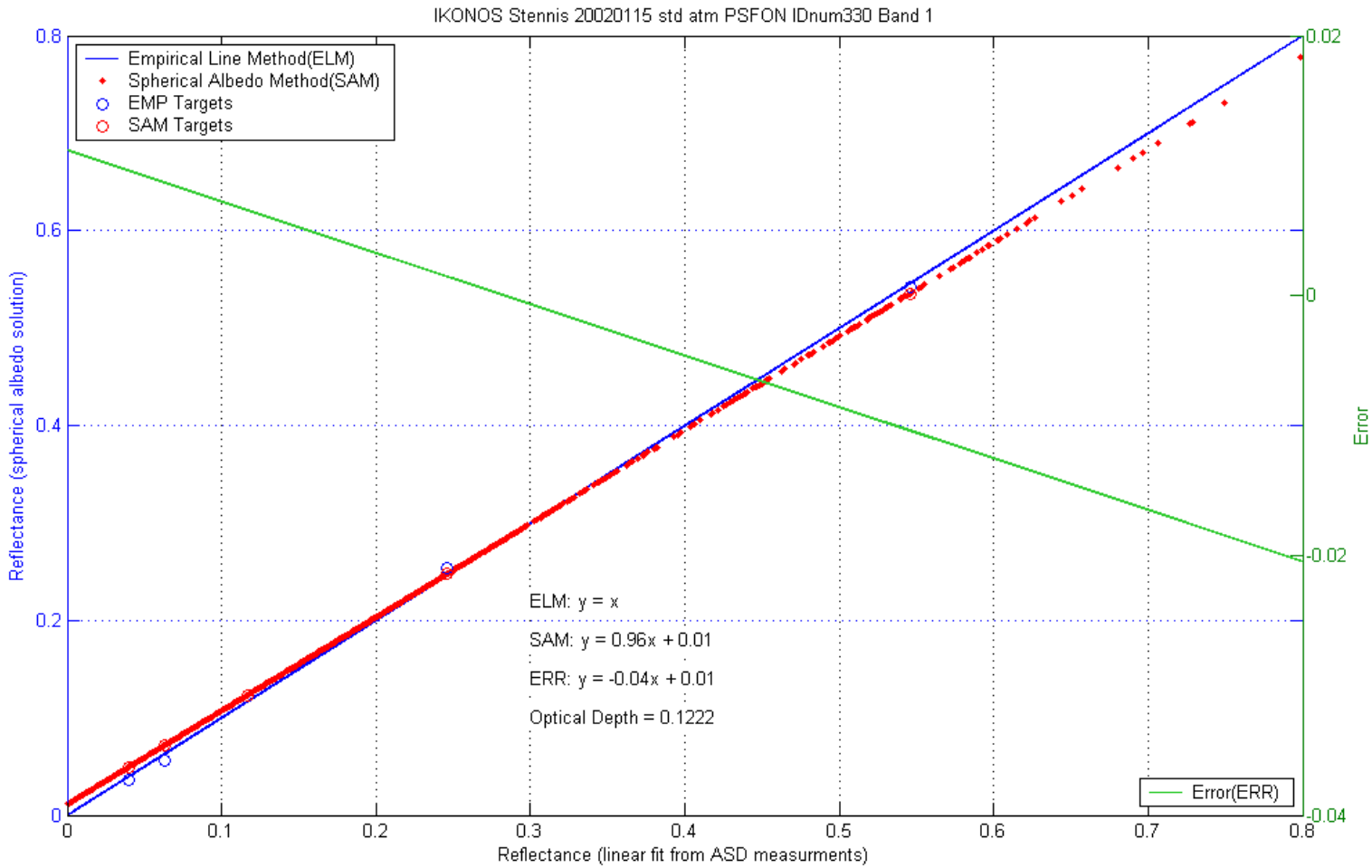
Empirical Line Method / Spherical Albedo Method
IKONOS Stennis 02/17/2002
Red Band



Empirical Line Method / Spherical Albedo Method
IKONOS Stennis 02/17/2002
NIR Band



Empirical Line Method / Spherical Albedo Method
IKONOS Stennis 01/15/2002
Blue Band



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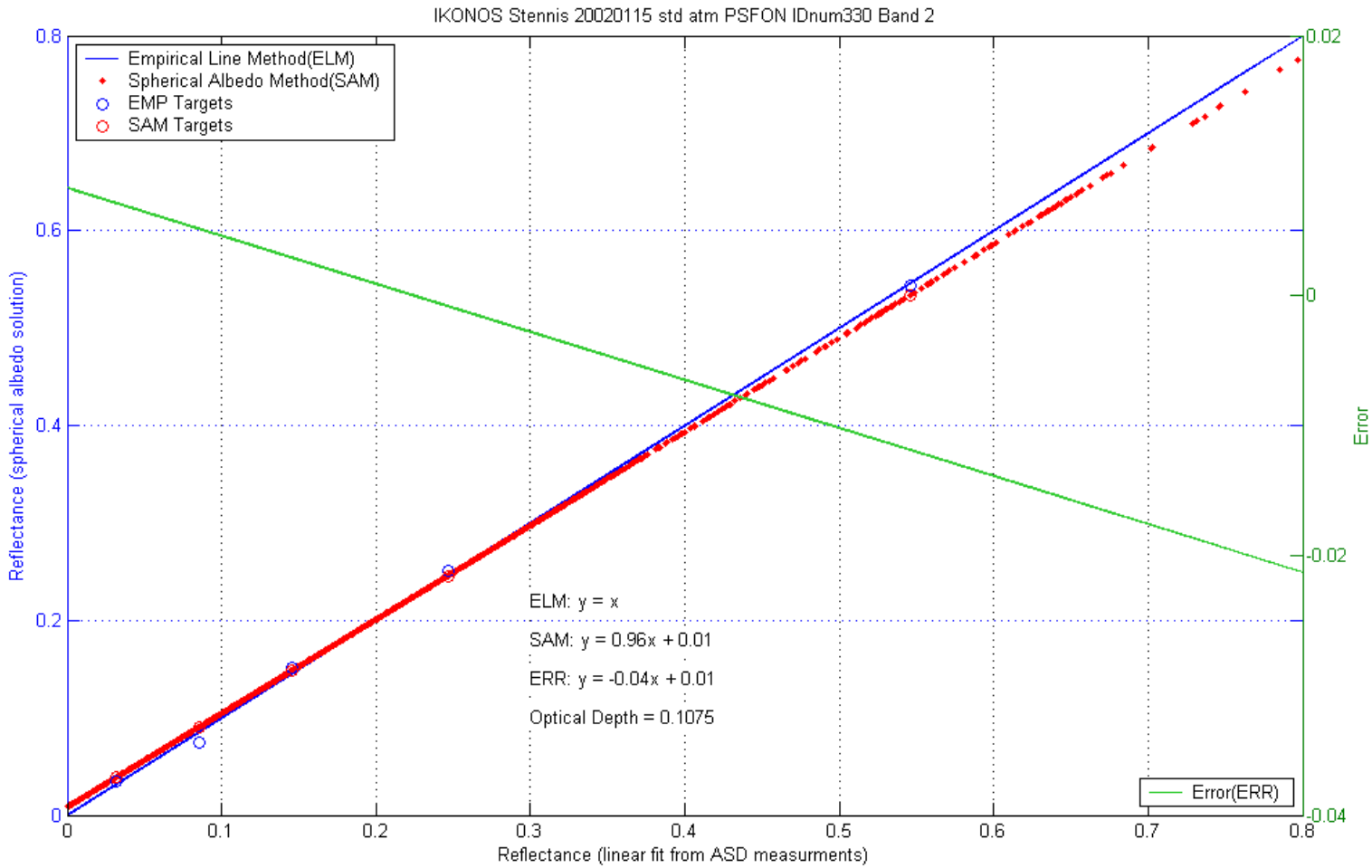

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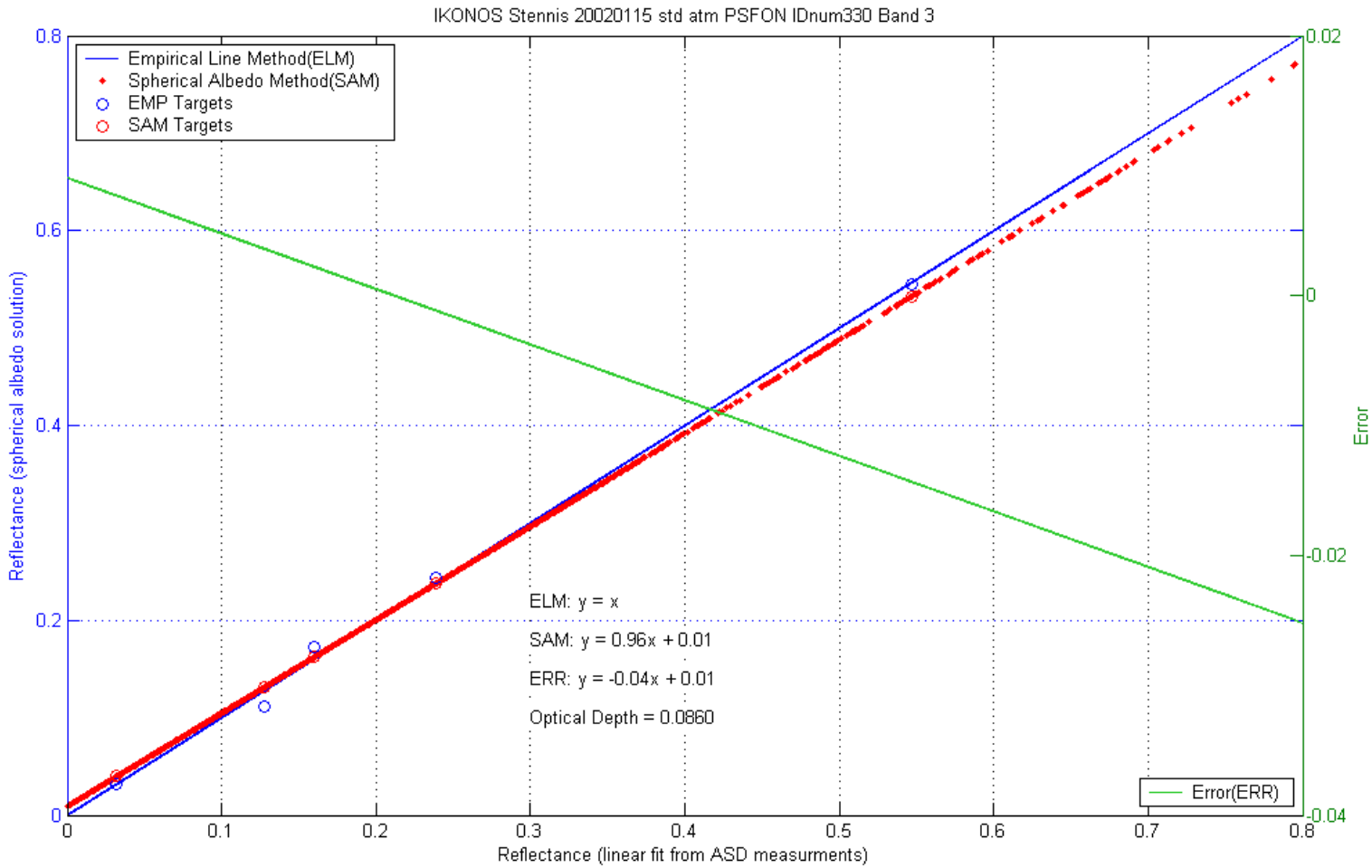

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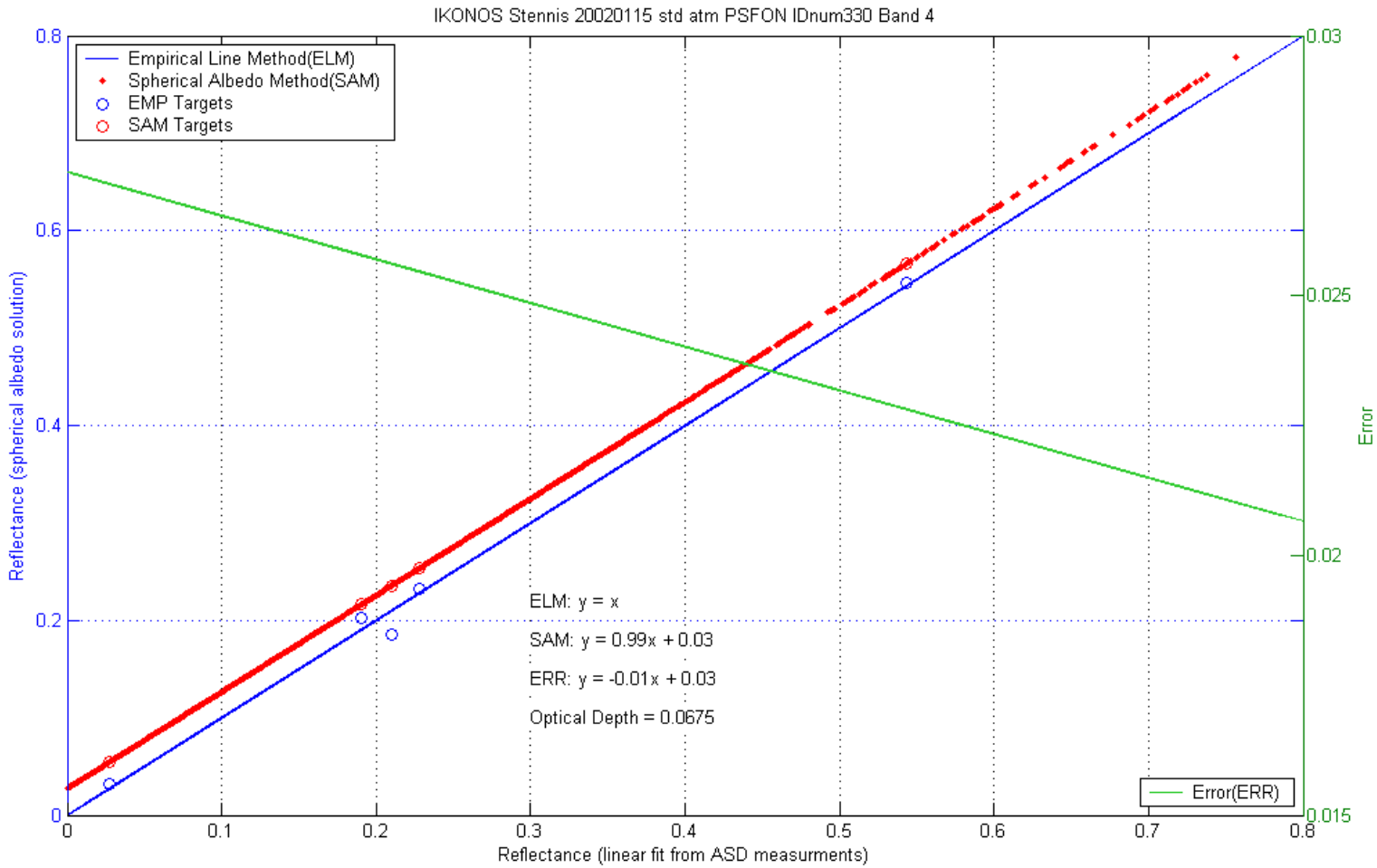
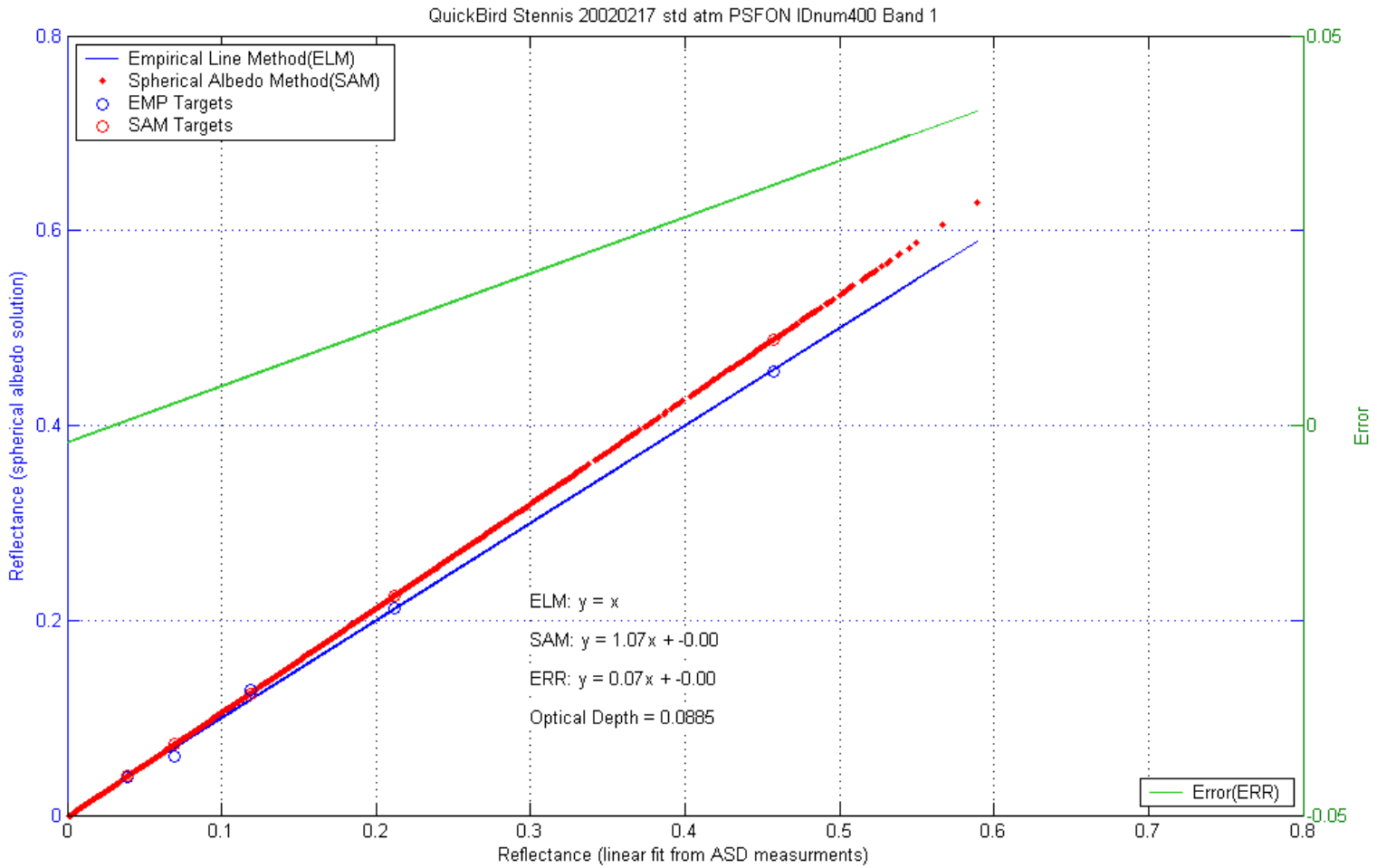
NIR Band



Empirical Line Method / Spherical Albedo Method
QuickBird Stennis 02/17/2002
Blue Band



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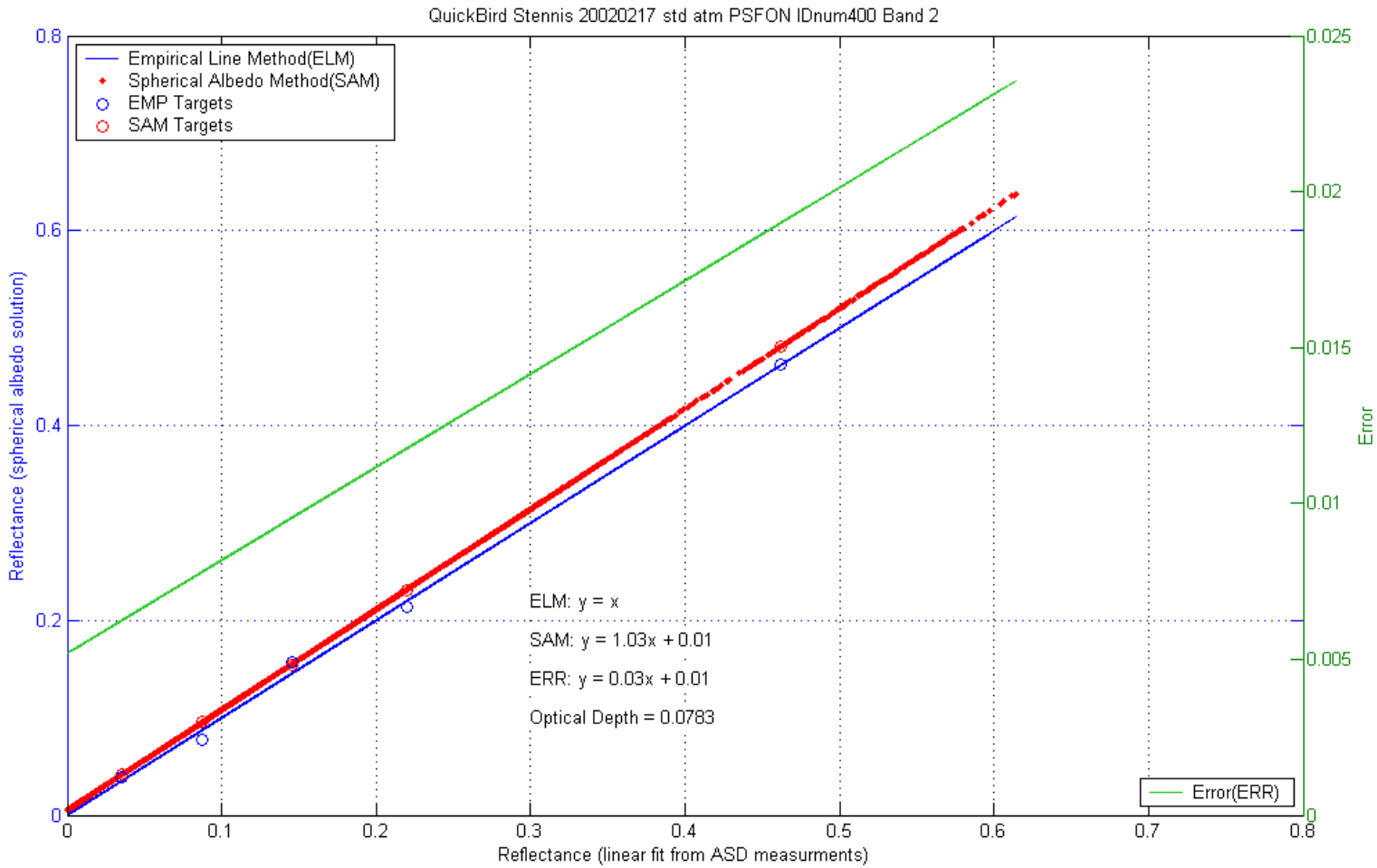

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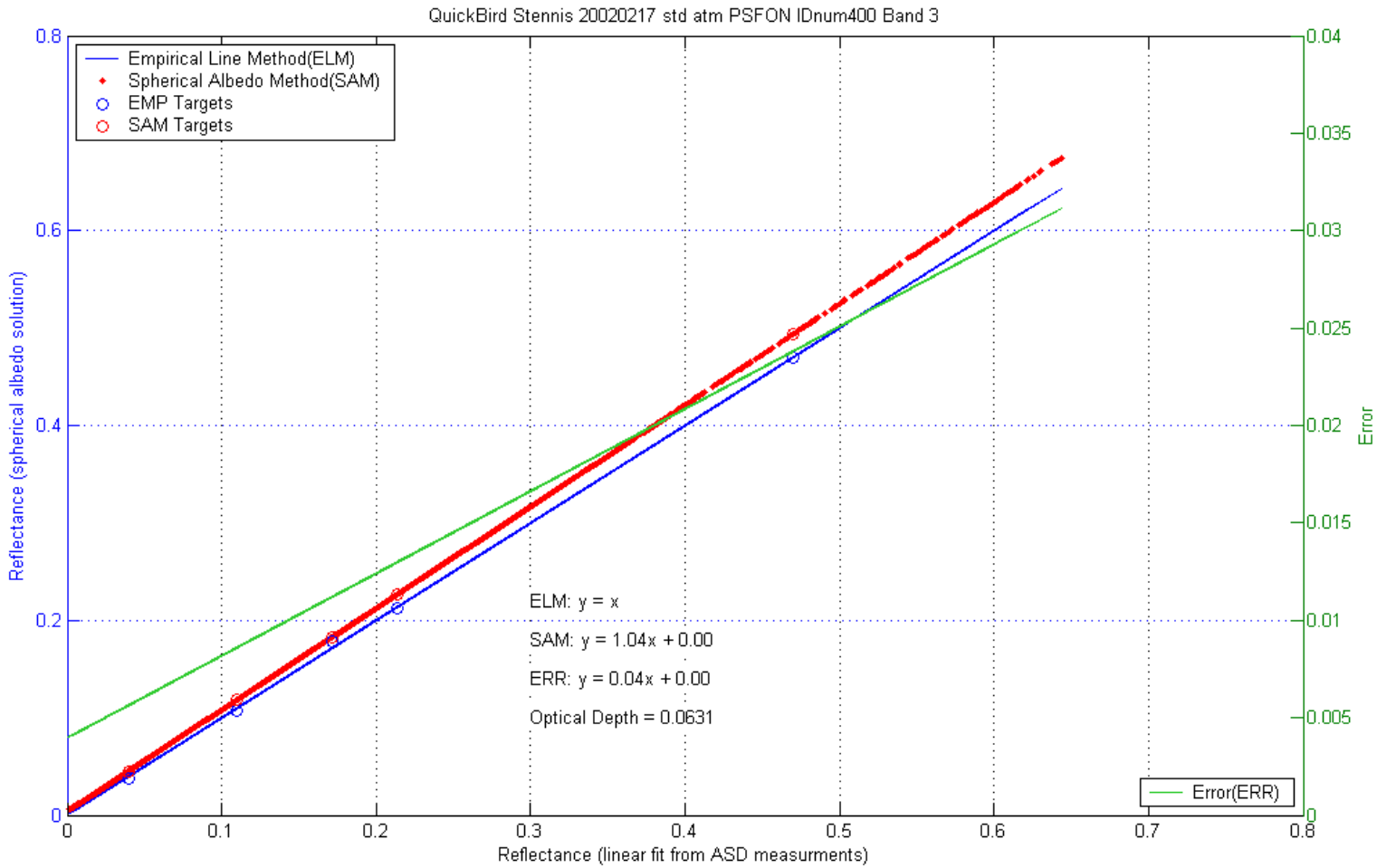
Red Band



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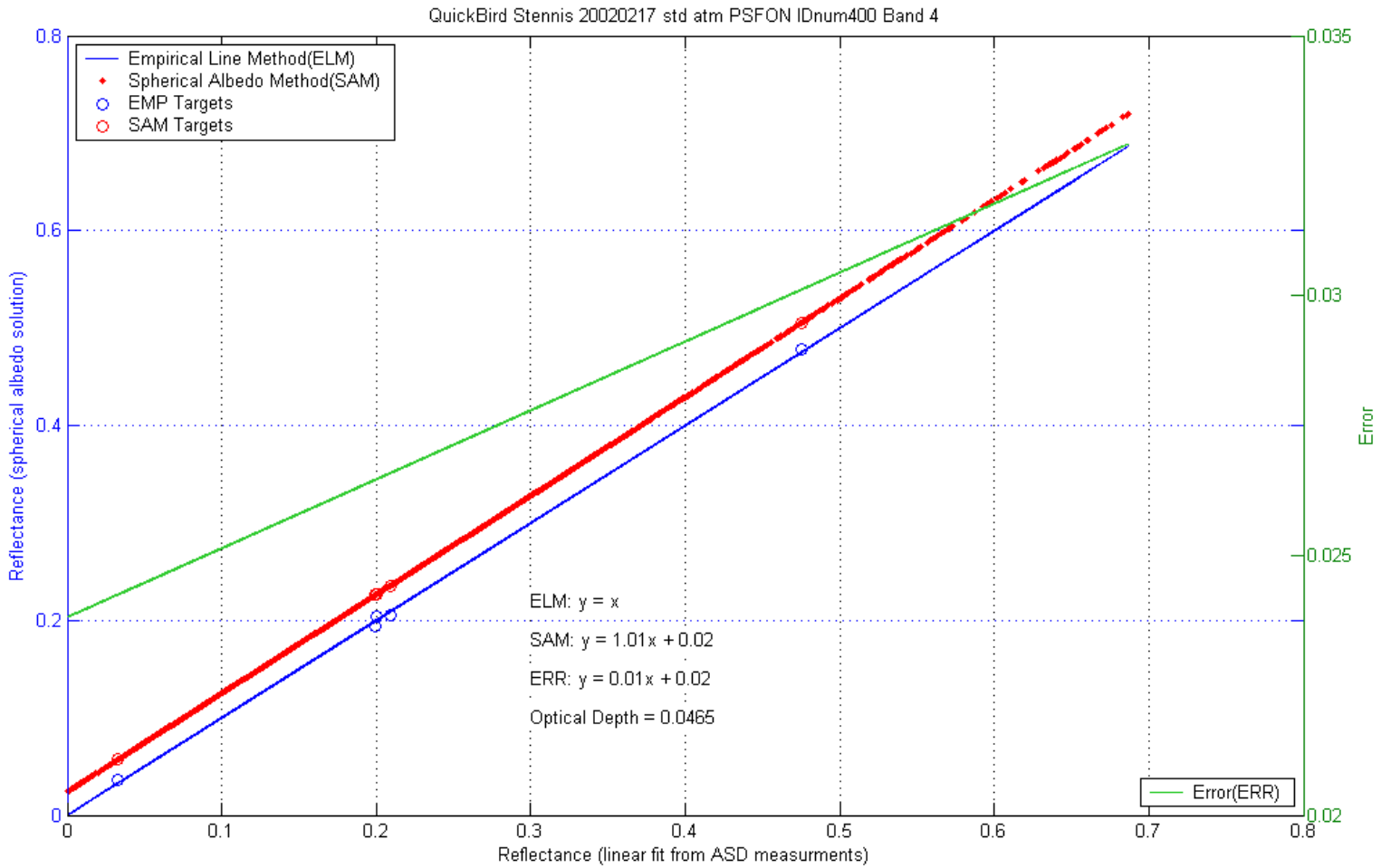
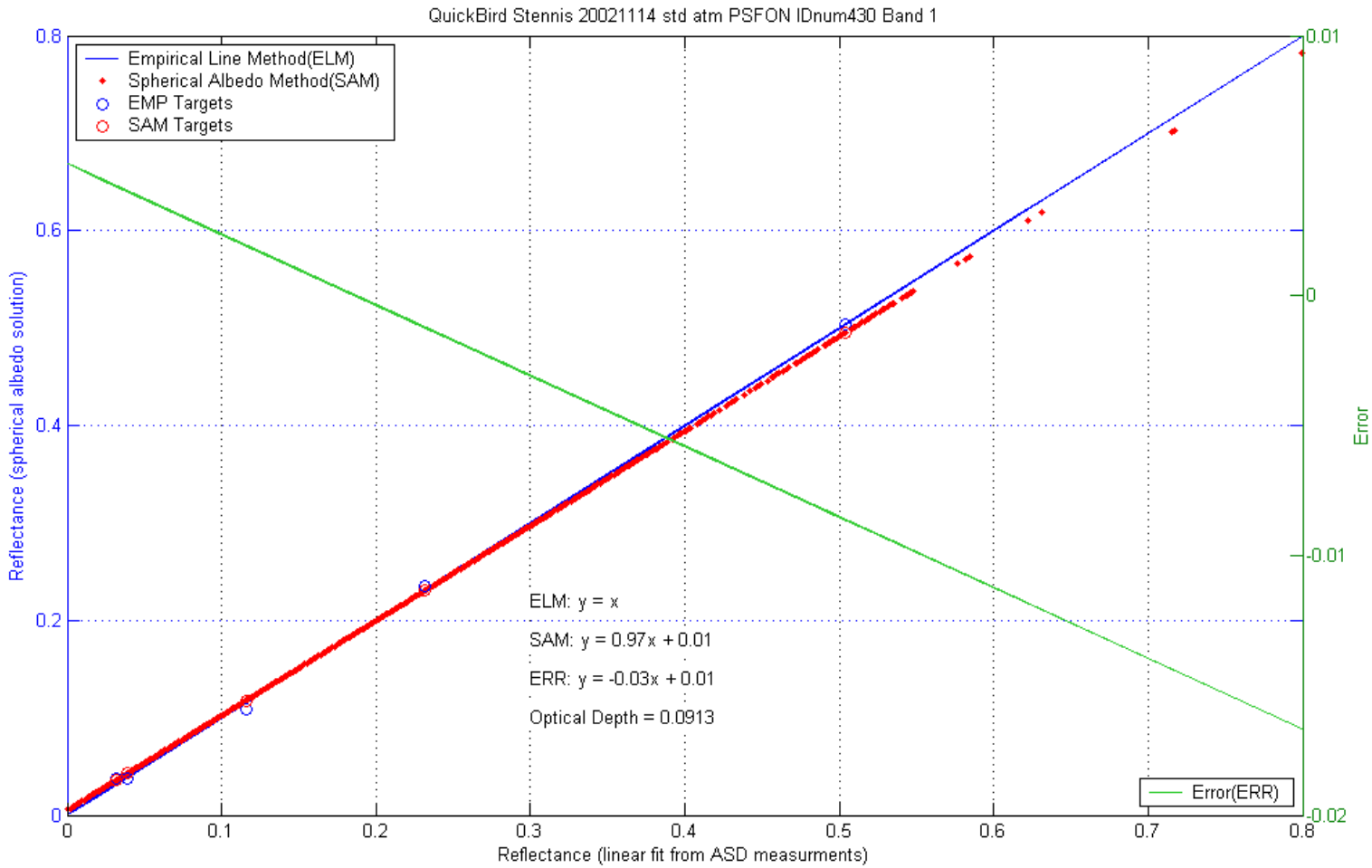


Empirical Line Method / Spherical Albedo Method
QuickBird Stennis 11/14/2002
Blue Band



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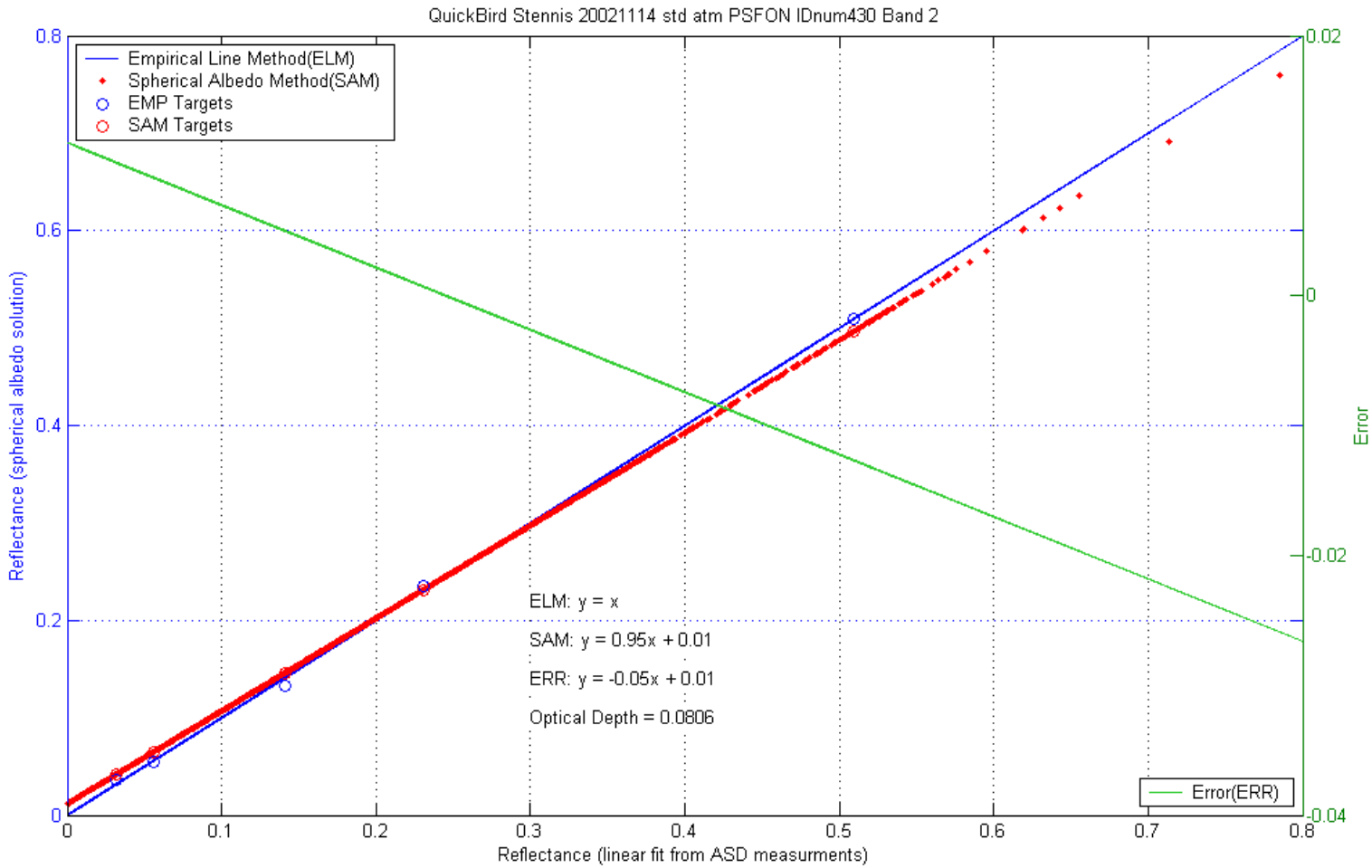
Green Band



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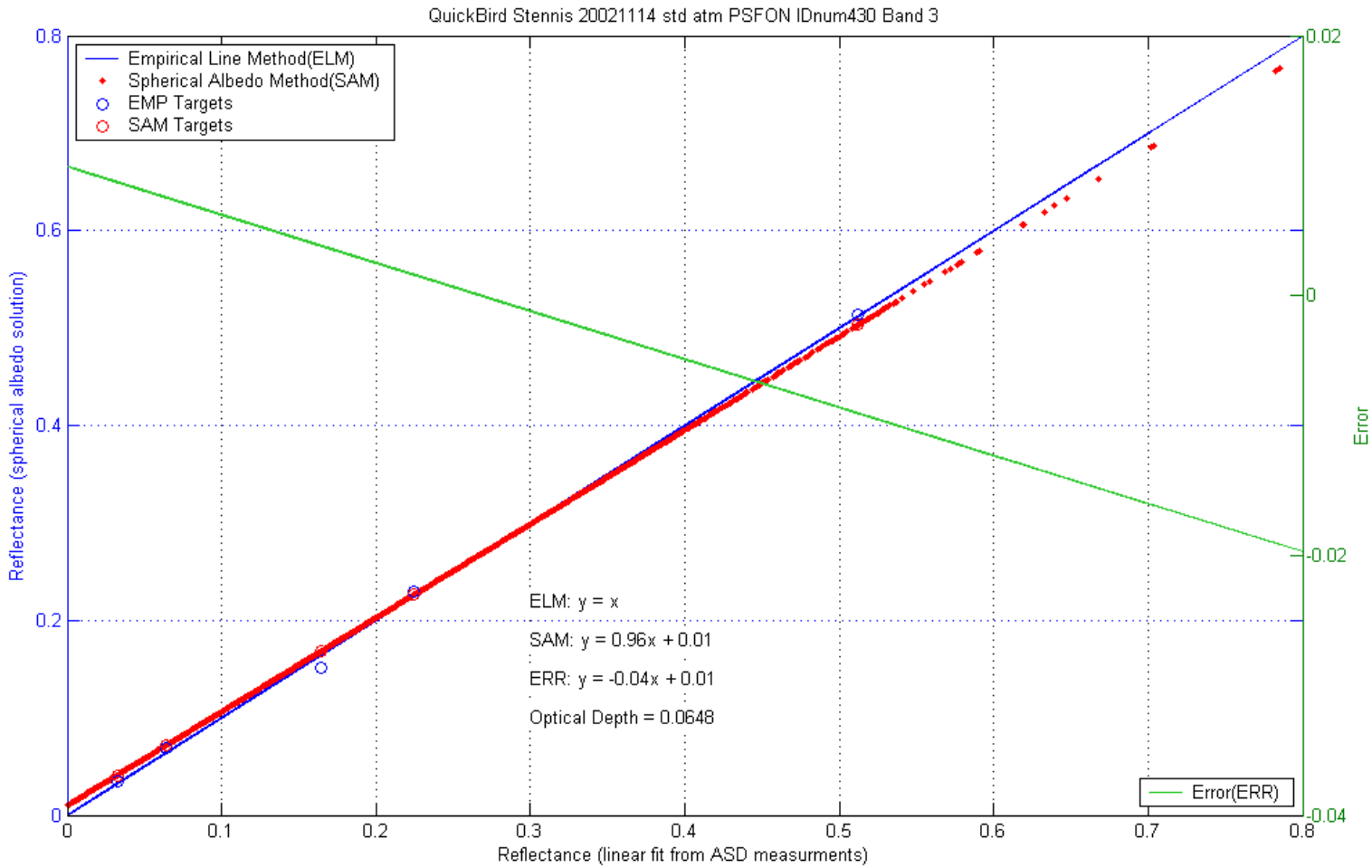
Red Band



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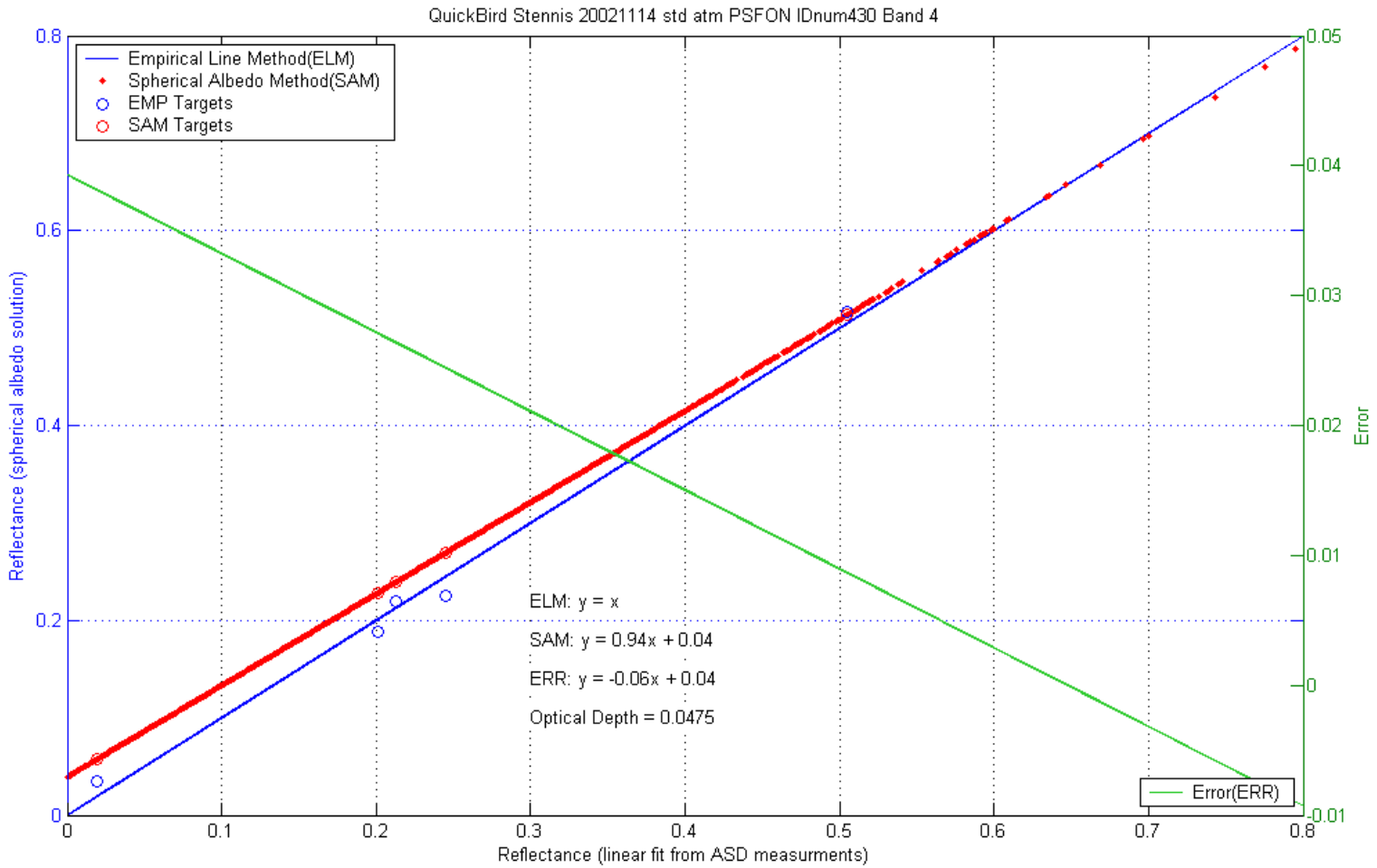
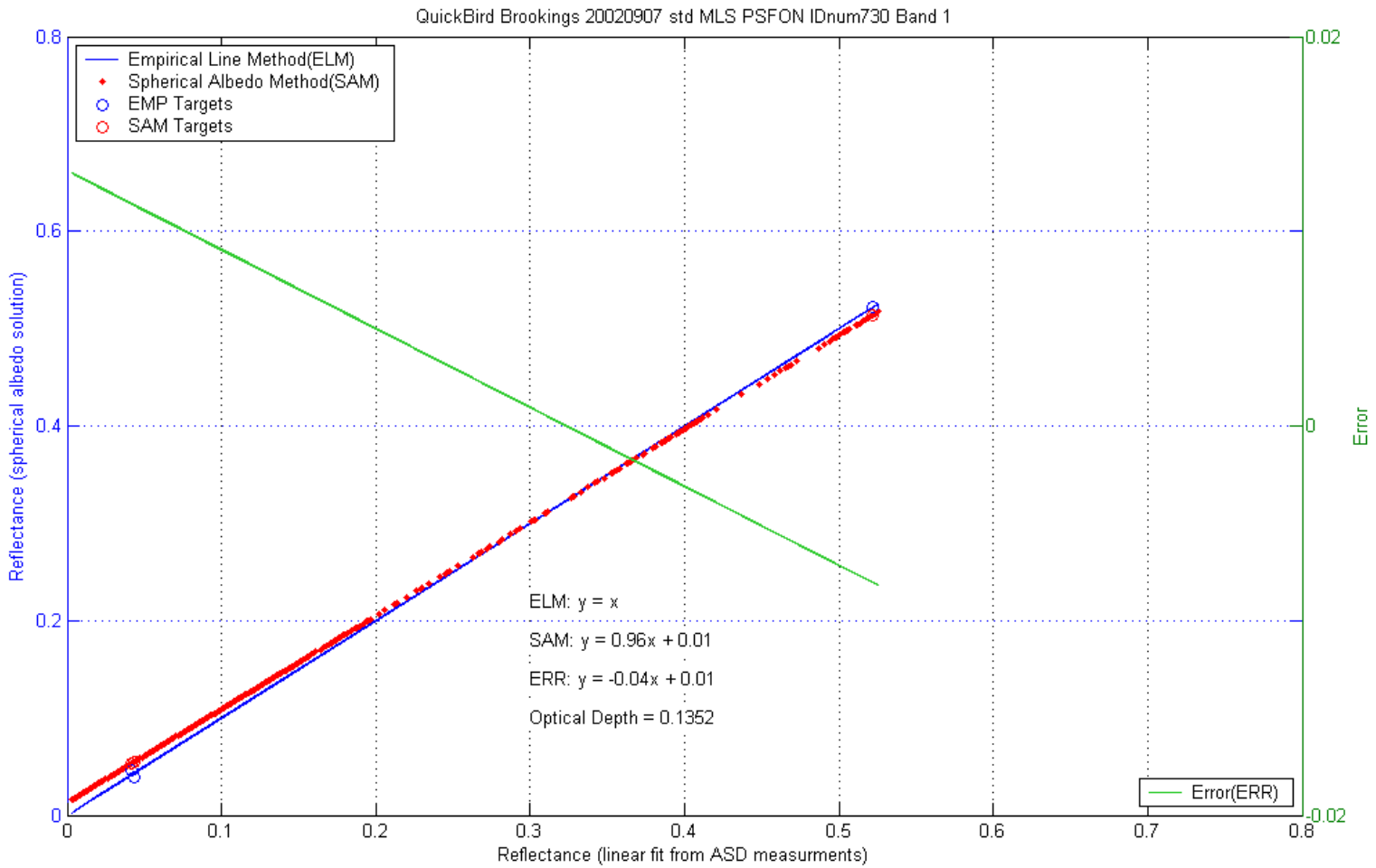


Empirical Line Method / Spherical Albedo Method
QuickBird Brookings 09/07/2002
Blue Band



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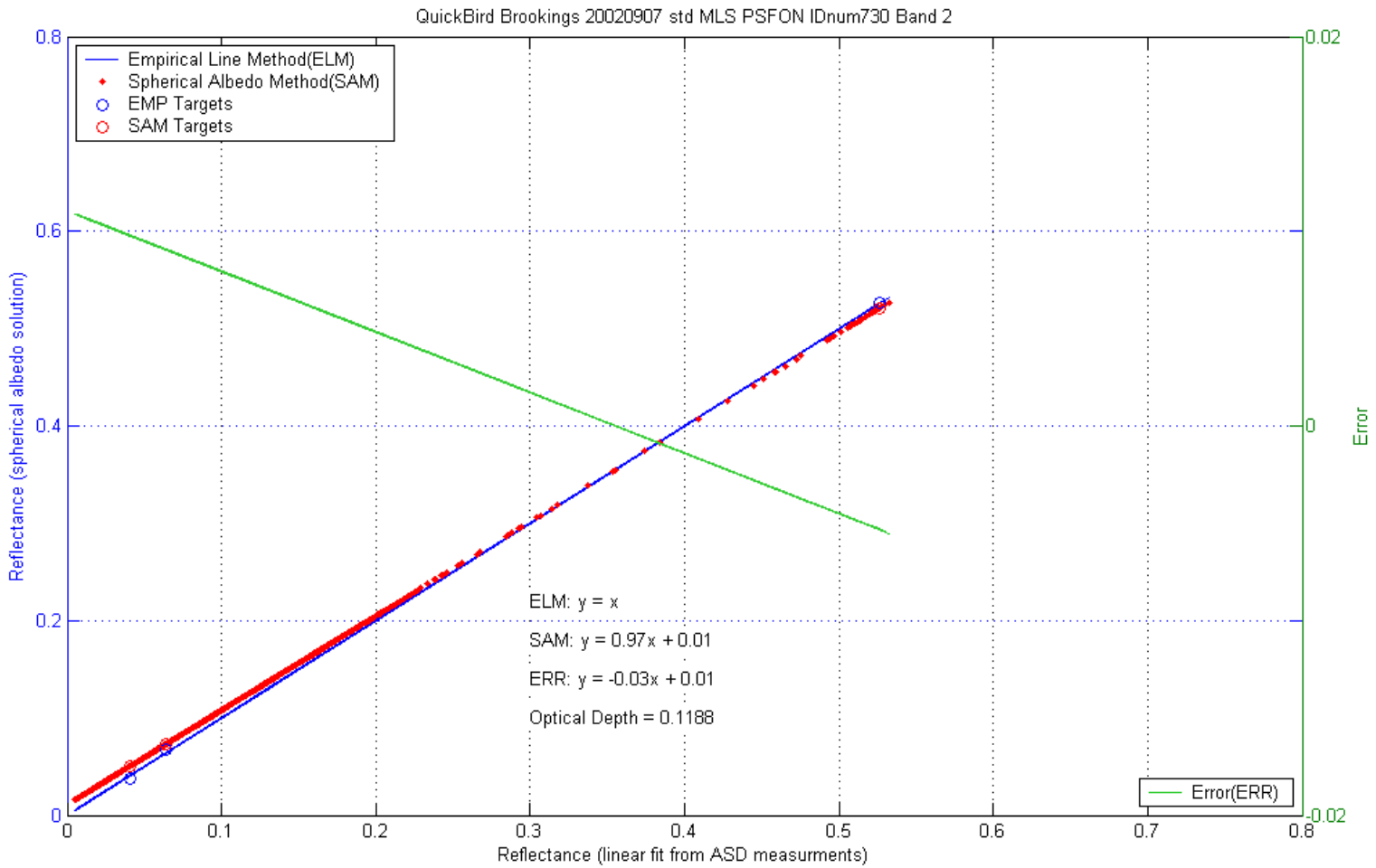

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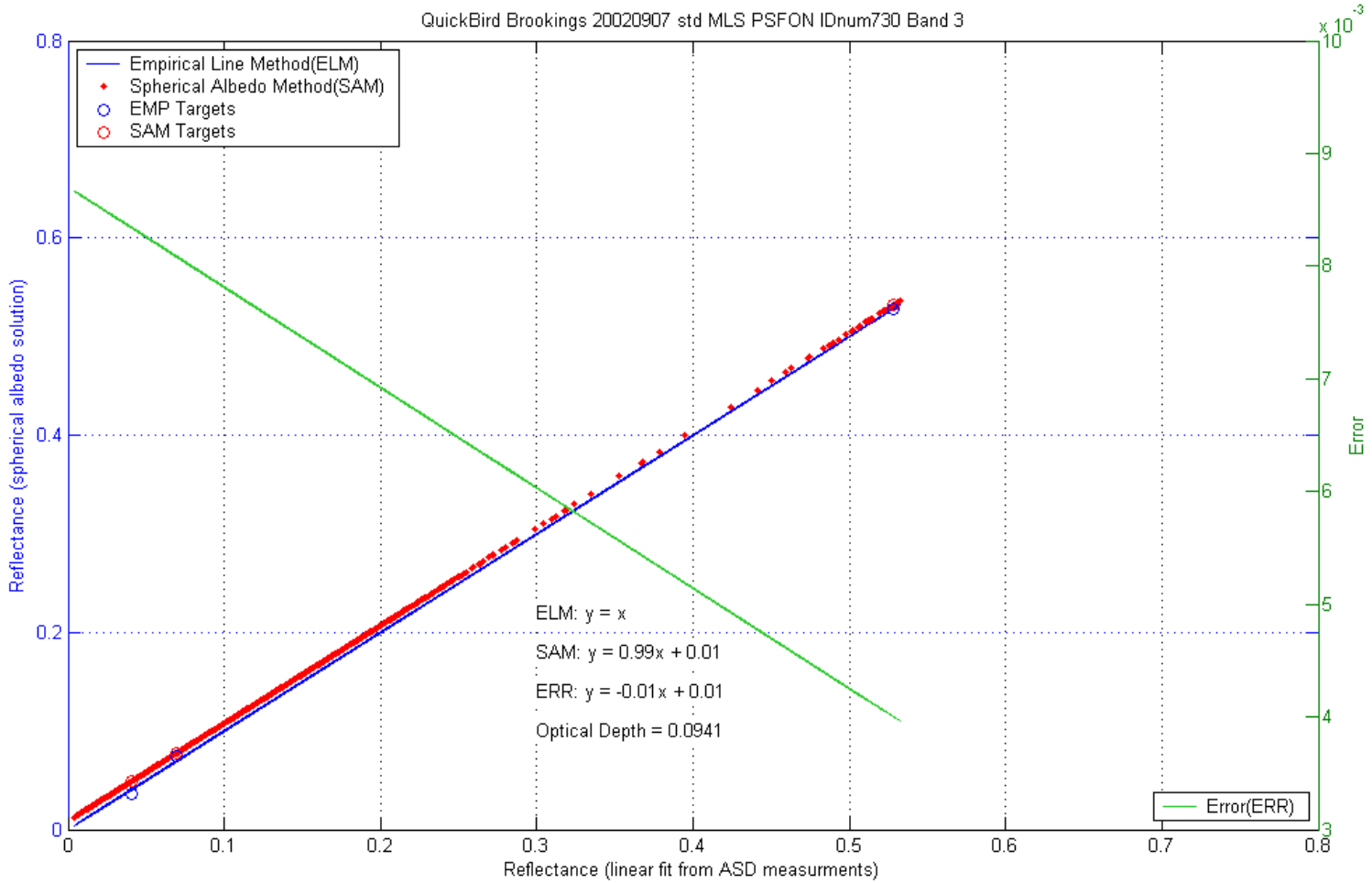

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