A Continuation of Radiometric Calibration Using the Reflectance Based Calibration Technique for High and Medium Resolution Sensor Systems

Civil Commercial Imagery Evaluation Workshop

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Goal: Radiometric Calibration

- Satellite Imagery becomes the best tool for research when the imagery can be traced back to absolute radiance units.
  - Especially critical when doing comparisons over time
  - Especially critical when comparing imagery from different sensors

- While equipment manufacturers do an excellent job of initial calibration of sensor systems, the old adage applies:

  “Things Change”

- A primary goals of the JACIE group has been to provide an independent monitor of radiometric calibration of common sensor systems and publish these results for use by satellite imagery vendors, governmental agencies, and the imagery user community.

Historical JACIE Radiometric Evaluation Team

- 3 Independent Groups
  - Stennis Space Center
  - University of Arizona (Thome)
  - South Dakota State University
- Scheduling: Base Coordination through SSC
- Diverse locations and collection seasons
  - Collections represent various times of the year
  - Collections thru different atmospheres
- Diverse target set:

  Radiance

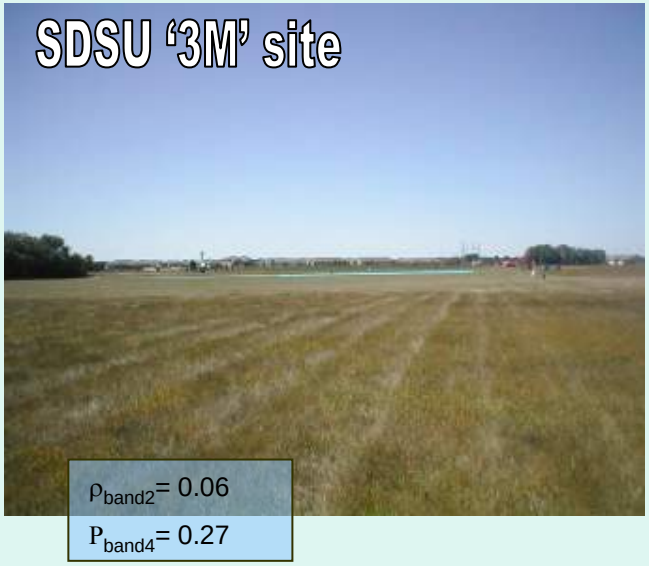
  ‘dark’ targets (vegetation)
  ‘bright’ targets (playa)
  high contrast (tarps)

  Spectral response:

  vegetation signatures
  high reflectance natural surfaces
  flat response manmade targets

Collection Sites Exhibit Varied Surfaces

Note: typical Band 2 and 4 reflectances shown



Radiometry Groups (cont)

- Similar (but certainly not identical) equipment sets
  - spectroradiometers (primarily Analytic Spectral Devices Field Spec)
  - Sunphotometers, shadowband radiometers, reference panels, etc
    - some common basis but also considerable variation/replication/modification from group to group

- Data collection: Each group has developed their own protocols

- Data reduction: Each group has developed their own techniques
  - Atmospheric modeling:
    - SDSU & SSC: all MODTRAN based
    - UOA RSG: Combination of custom code and MODTRAN

Project Completion 2005-2006

2005 was the last ‘full collection season’ for the general JACIE team

2006 SDSU (with the kind assistance of SSC) was able to access

- a limited number of ‘unused’ high resolution collections
- A limited number of ‘science collections’ (thanks GeoEye)
- Coincident AWiFS collections (thanks Bob Tetrault & USDA Satellite Imagery Archive)

SDSU SCG was able to perform a limited data collection set as part of a NASA EPSCoR Precision Agriculture/Cross Calibration.

Data processing for radiometric calibration was also performed under the NASA EPSCoR auspices.

Resources to complete the MTF assessment (D. Helder’s IP lab group) were unable to be located, thus the results are not complete and will not be reported.

Reflectance Based Calibration
Base Process:

1. Identify a target area that has uniform reflectance over a multi-pixel area
2. During satellite imaging overpass: ground level reflectance measurement
3. Hours preceding and subsequent to overpass: continually monitor select wavelengths for direct and diffuse downwelling solar radiance
4. From above: Calculate extinction parameters using Langley analysis
5. From extinctions and other atmospheric parameters calculate hyperspectral atmospheric model
6. Propagate Top of Canopy radiances thru atmosphere via above model
7. Band these Top of Atmosphere hyperspectral radiances
8. Use satellite image DN counts of target area to calculate gain

SDSU Satellite Calibration

Satellite Calibration Group:

- David Aaron
- Larry Leigh
- Sara Landau
  - (now at UA Optical Sciences)
- + IP lab Crew:
  - Dennis Helder's cast of characters

SDSU Radiometry Goals: 2006

Vegetated target collections and assessment:

Completion of radiometric assessment under the JACIE team:

- High resolution imagers:
  - QuickBird
  - OrbView 3
  - Ikonos attempted
- Moderate resolution imager:
  - AWiFS

Continuing independent investigations under NASA/USGS Landsat Science Teams:

- Landsat 5
- Landsat 7

SDSU Vicarious Calibration Process:

- ‘Simultaneous’ satellite imaging and hyperspectral measurement of upwelling radiance at grass target area (“3M” in Brookings SD).
  - ASD FS FR unit 638 with 8 degree optic
  - New 12” Spectralon 99% panel, BRDF characterized Spring 2006
- Monitor atmospheric transmittance over time interval including overpass
  - Primary monitor: 10 Channel ASR unit 30
- Use ASR Langley analysis to determine extinction values
  - Supplement with MFR Shadowband units (global/diffuse measurement)
- Populate MODTRAN using extinctions, angles, etc; optimize thru measured ASD values
  - MODTRAN 4.3.2
- Transfer (hyperspectral) Top of Canopy (TOC) to TOA using MODTRAN model
- Band hyperspectral radiances to produce in-band TOA radiance
- Calculate gain by comparing satellite DN to in-band TOA radiance values

2006 Data Collections

22-May	Landsat 5	Okay
30-May	Landsat 7	Bad
7-Jun	Landsat 5	bad
15-Jun	Landsat 7	Good
23-Jun	Orbview	cancelled
23-Jun	Landsat 5	okay
1-Jul	Landsat 7	Bad
9-Jul	Landsat 5	Good
12-Jul	Orbview	Good
15-Jul	Orbview	Good
15-Jul	AWiFS	Good
16-Jul	Ikonos	Bad
17-Jul	Landsat 7	Good
19-Jul	Ikonos	Cancelled
23-Jul	Quickbird	*Fair*
23-Jul	Orbview	*Fair*
26-Jul	Orbview	Marginal
27-Jul	Ikonos	Haze ?

2-Aug	Landsat 7	Good
8-Aug	AWiFS	Good
10-Aug	Quickbird	canceled**
10-Aug	Ikonos	canceled
10-Aug	Landsat 5	*fair*
17-Aug	AWiFS	Bad
18-Aug	Quickbird	Bad
18-Aug	Ikonos	Bad
18-Aug	AWiFS	Bad
18-Aug	Landsat 7	Bad
26-Aug	Landsat 5	*Marginal*
1-Sep	AWiFS	Bad
3-Sep	Landsat 7	Bad
25-Sep	AWiFS	*fair*
5-Oct	Landsat 7	*bust*

Continuation
Process Capability Study

- Pre 2005 Mode: Data processing is primarily ‘post season’
- Agriculture applications require ‘real-time’ reflectance correction
- 2005+ Pilot analysis of processing streams:
  - Image acquisition
  - Atmospheric correction
  - Image correction
  - Data archiving
- Continuation of quick turn-around study of atmospheric correction
  - cloud free day: 4 hours per scene analysis

“3M” Site Characteristics

200m X 180m ‘grass’ site (approx)

- rotated 6 degrees off N-S
- NW corner:
  - Lat: 44°17'31.12383"N
  - Long: 96°45'59.33636"W
- Maximum measured elevation change = 4.89 meters

Differential GPS values measured by the Stennis GRIT Staff

Maintenance Primarily mowing

- 6 ft rotary mower (rough, not finish cut) for easternmost 3/4 of site
- western 1/4 of site, finish cut

  (target area for high resolution satellite collection)

To accommodate AWiFS, markers in unmowed area

3M Site

Oct 7,2005 (OrbView)

Ground Hyperspectral data collection

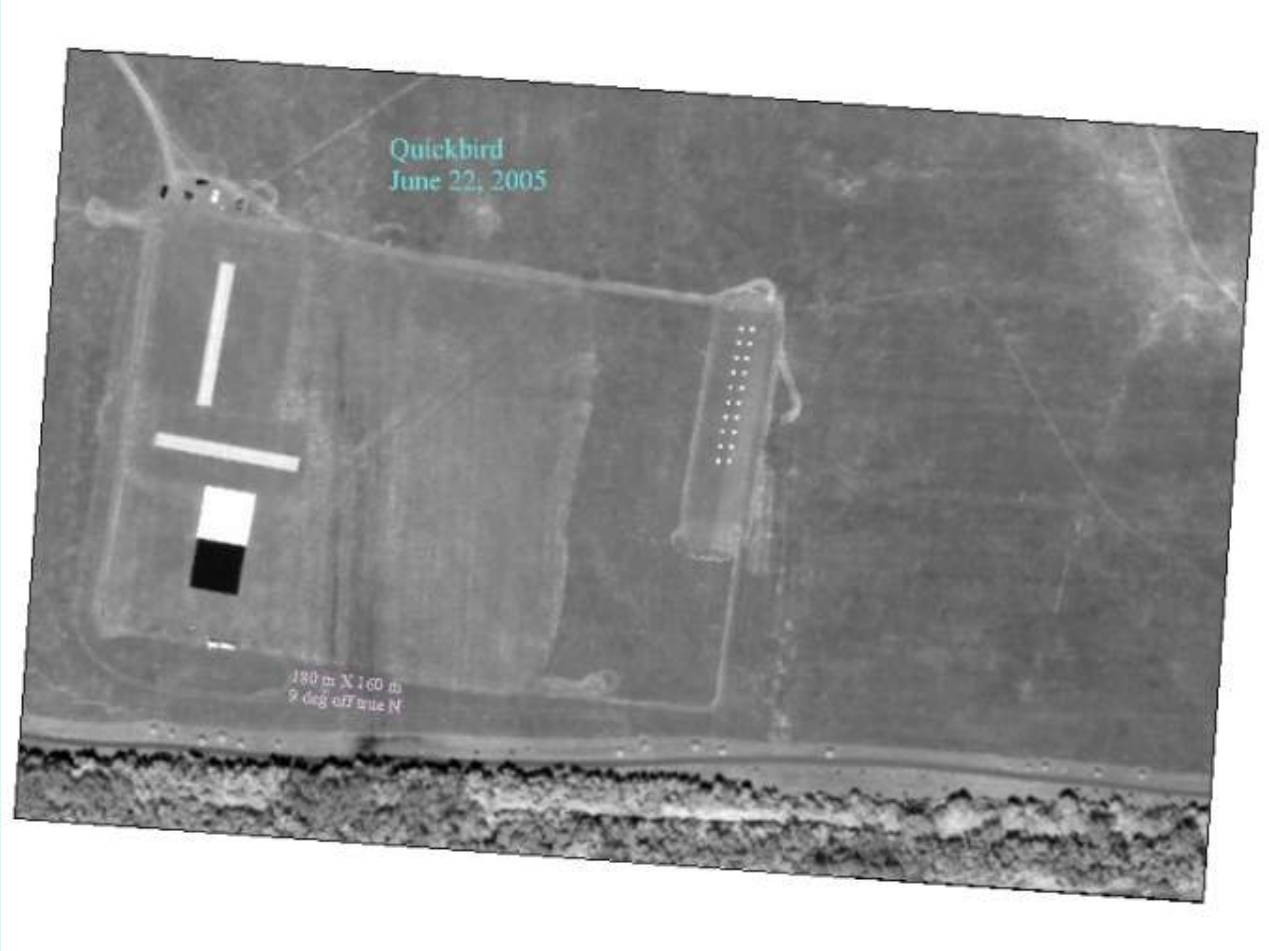
ASD FS FR with 2 meter cable

- 8 deg optic on pole held 1.5 to 2 m above ground
  - Nadir view (~25cm diameter sample area)

- Collect while walking ASD along 150 m N-S rows
  - 20 spectra/file, 10 files/save
    - Results in 60 files per row so about 600 files per collection
    - ~ 20 minutes for 10 row collection

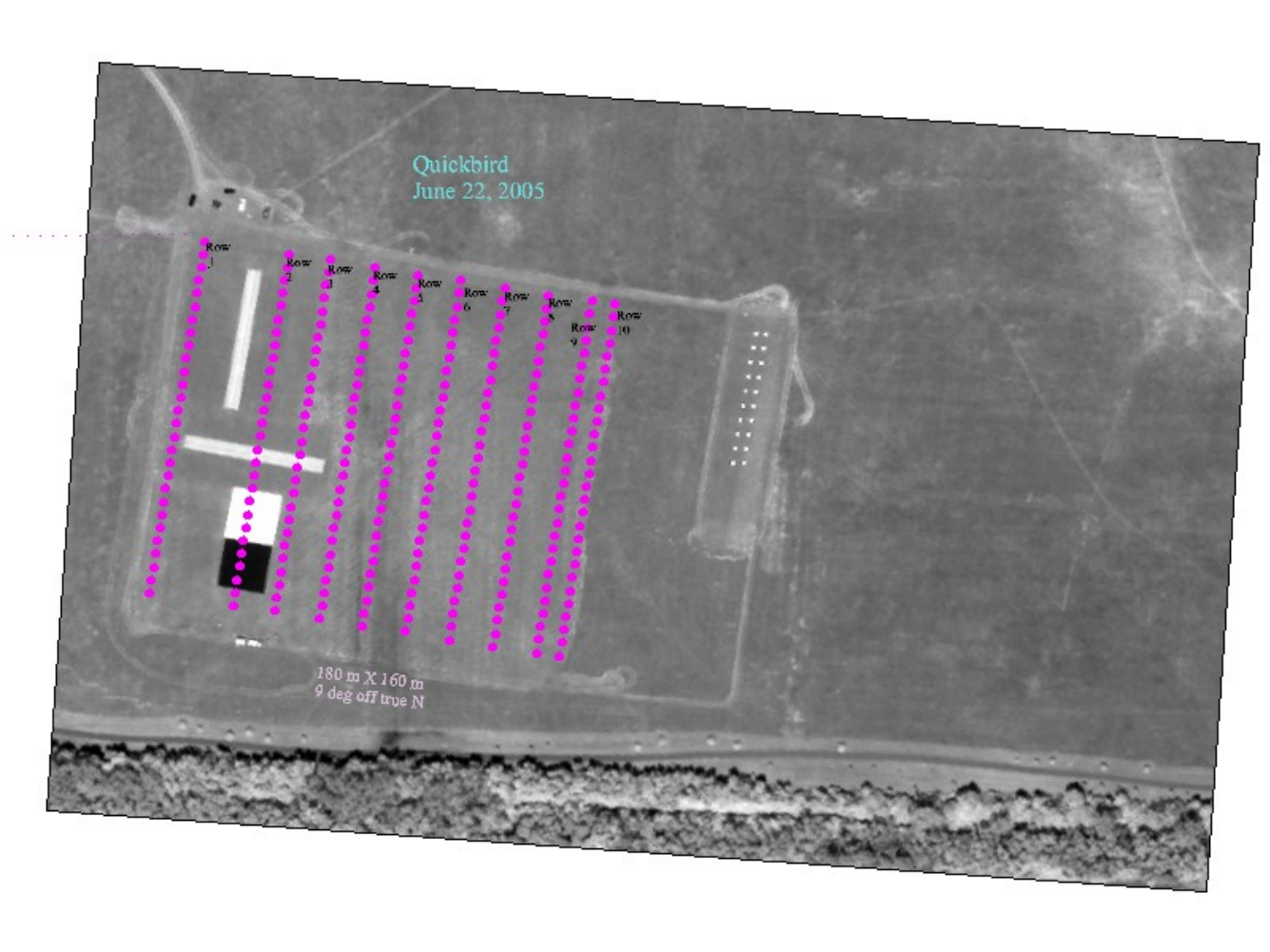
- White reference at end of each row pair (north end)
  - Calculated reflectances are time interpolated between white reference pairs.

Brookings ‘3M’ Grass Site
Shown with targets deployed



Standard ASD Data Acquisition Paths

(note: When SSC tarps deployed, Row 2 is skipped)



Landsat 5

VICARIOUS CALIBRATION RESULTS

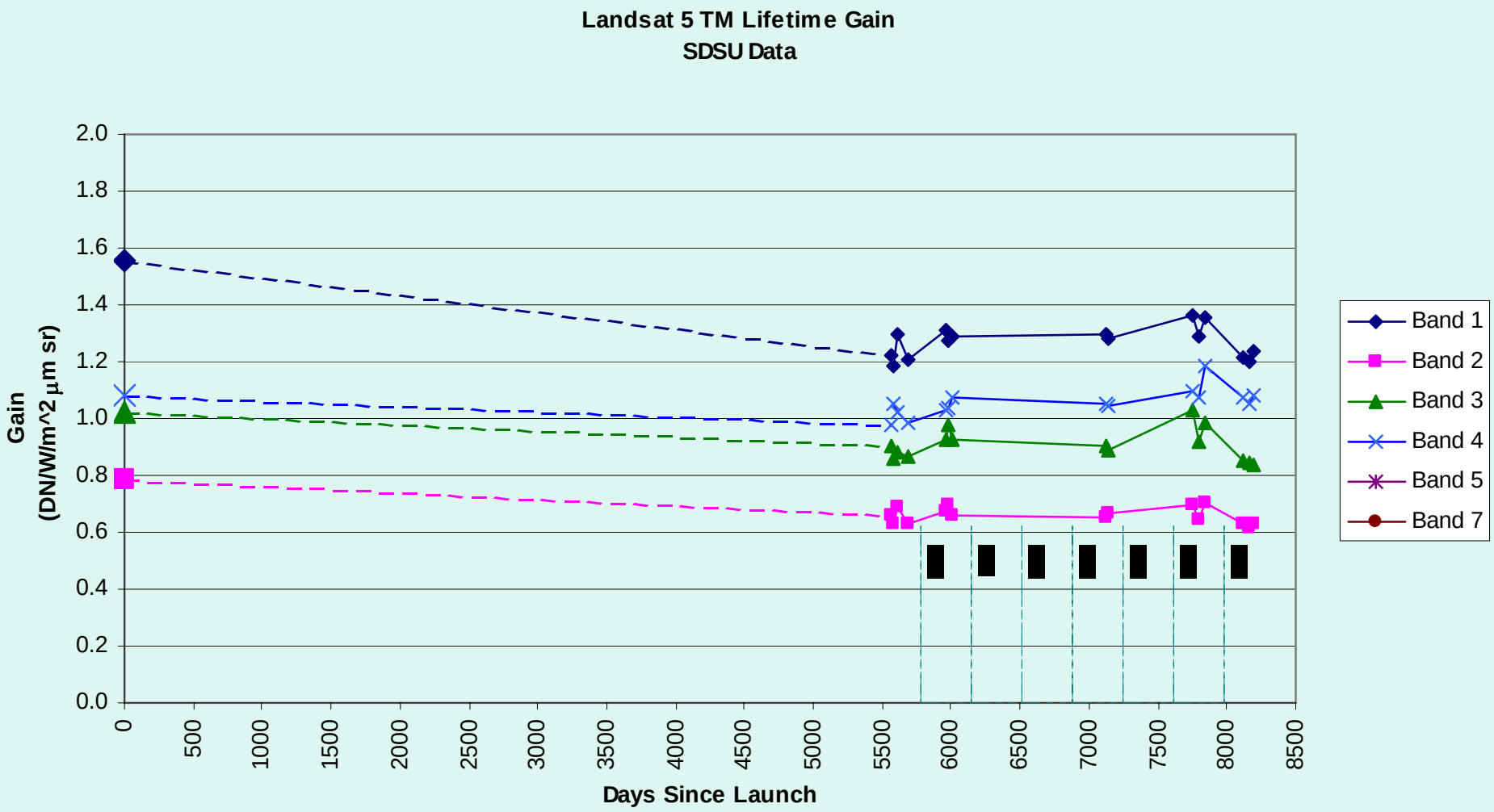
SDSU

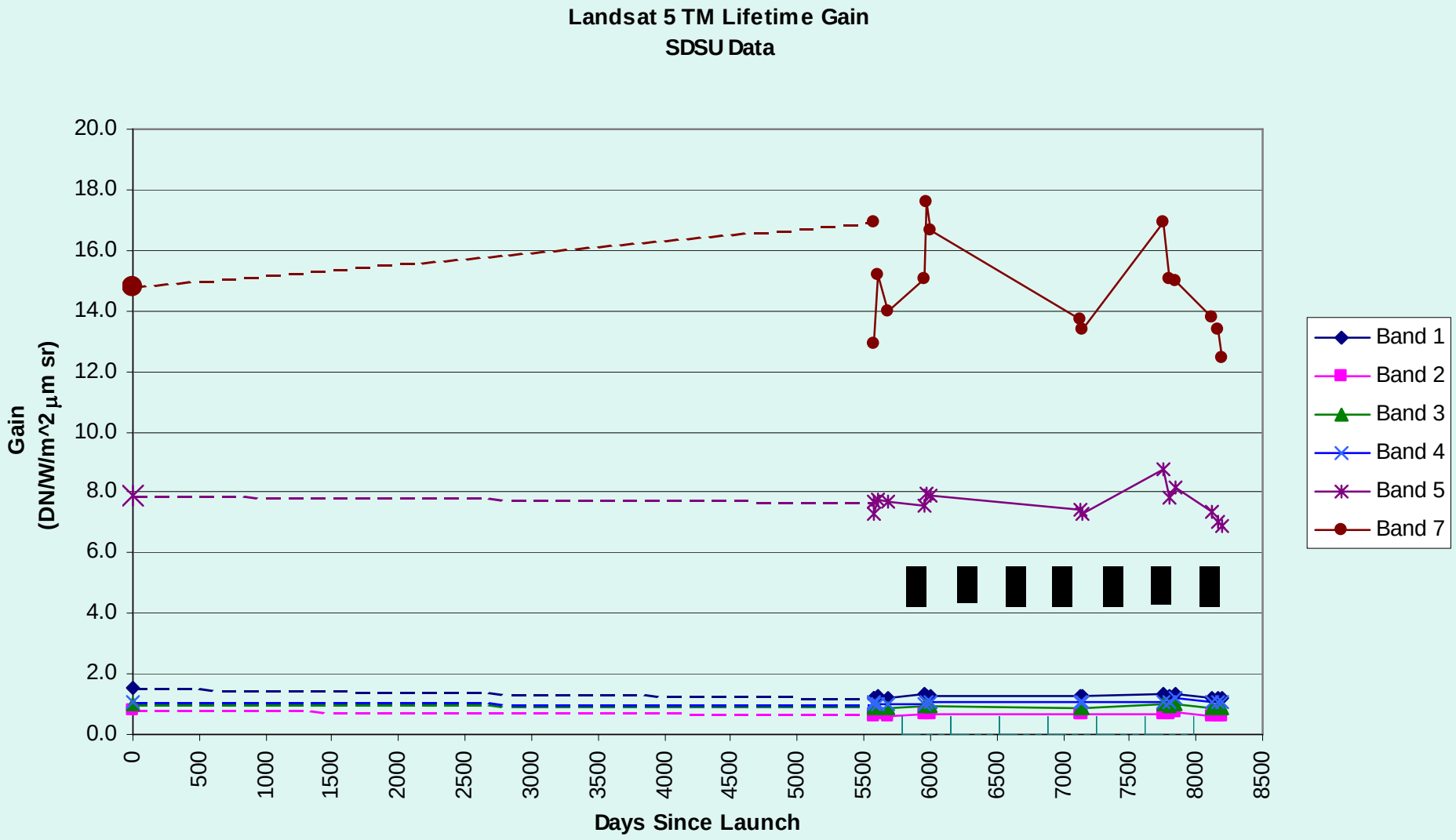
2006

Landsat 5: 2005-06 Data Points
SDSU

(reprocessed 2005 to follow consistent process flow)

	Date	DSL	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 7**
			(m^2 μm sr)/W	(m^2 μm sr)/W	(m^2 μm sr)/W	(m^2 μm sr)/W	(m^2 μm sr)/W	(m^2 μm sr)/W
			DN/Rad	DN/Rad	DN/Rad	DN/Rad	DN/Rad	DN/Rad
2005	19-May	7750	1.365	0.696	1.028	1.095	8.742	16.943
	6-Jul	7798	1.290	0.644	0.917	1.072	7.850	15.065
	23-Aug	7846	1.357	0.703	0.982	1.189	8.144	15.016
2006	**22-May**	**8118**	**1.218**	**0.630**	**0.852**	**1.074**	**7.344**	**13.757**
	9-Jul	**8166**	**1.199**	**0.614**	**0.845**	**1.048**	**7.021**	**13.365**
	10-Aug	**8198**	**1.235**	**0.630**	**0.840**	**1.083**	**6.898**	**12.446**


Landsat 5 TM Lifetime Gain
SDSU Data
Gain
(DN/W/m^2 µm sr)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
Days Since Launch
Band 1
Band 2
Band 3
Band 4
Band 5
Band 7


Landsat 5 TM Lifetime Gain
SDSU Data
Gain
(DN/W/m^2 µm sr)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
Days Since Launch
Band 1
Band 2
Band 3
Band 4
Band 5
Band 7

Landsat 7

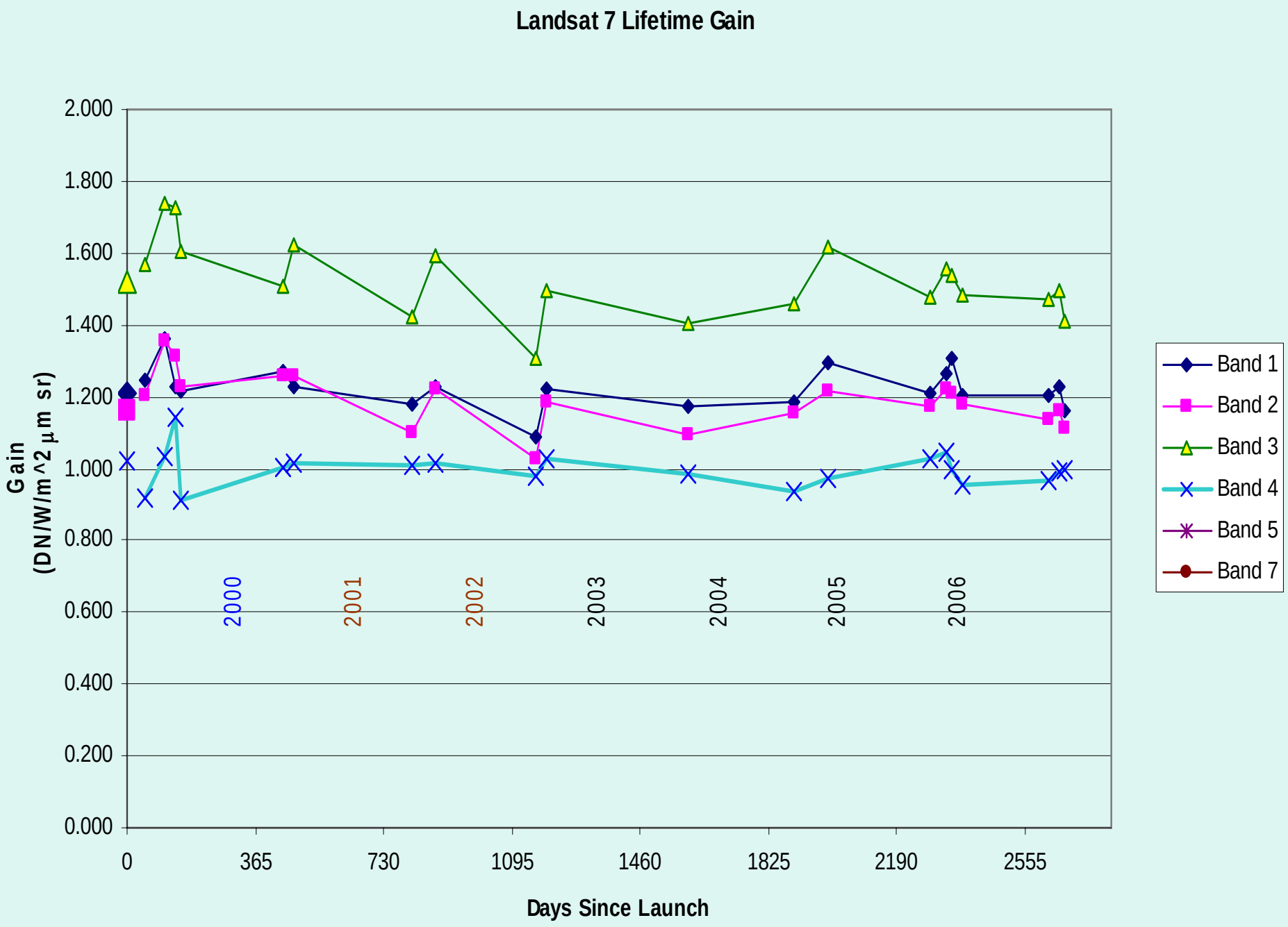
VICARIOUS CALIBRATION RESULTS

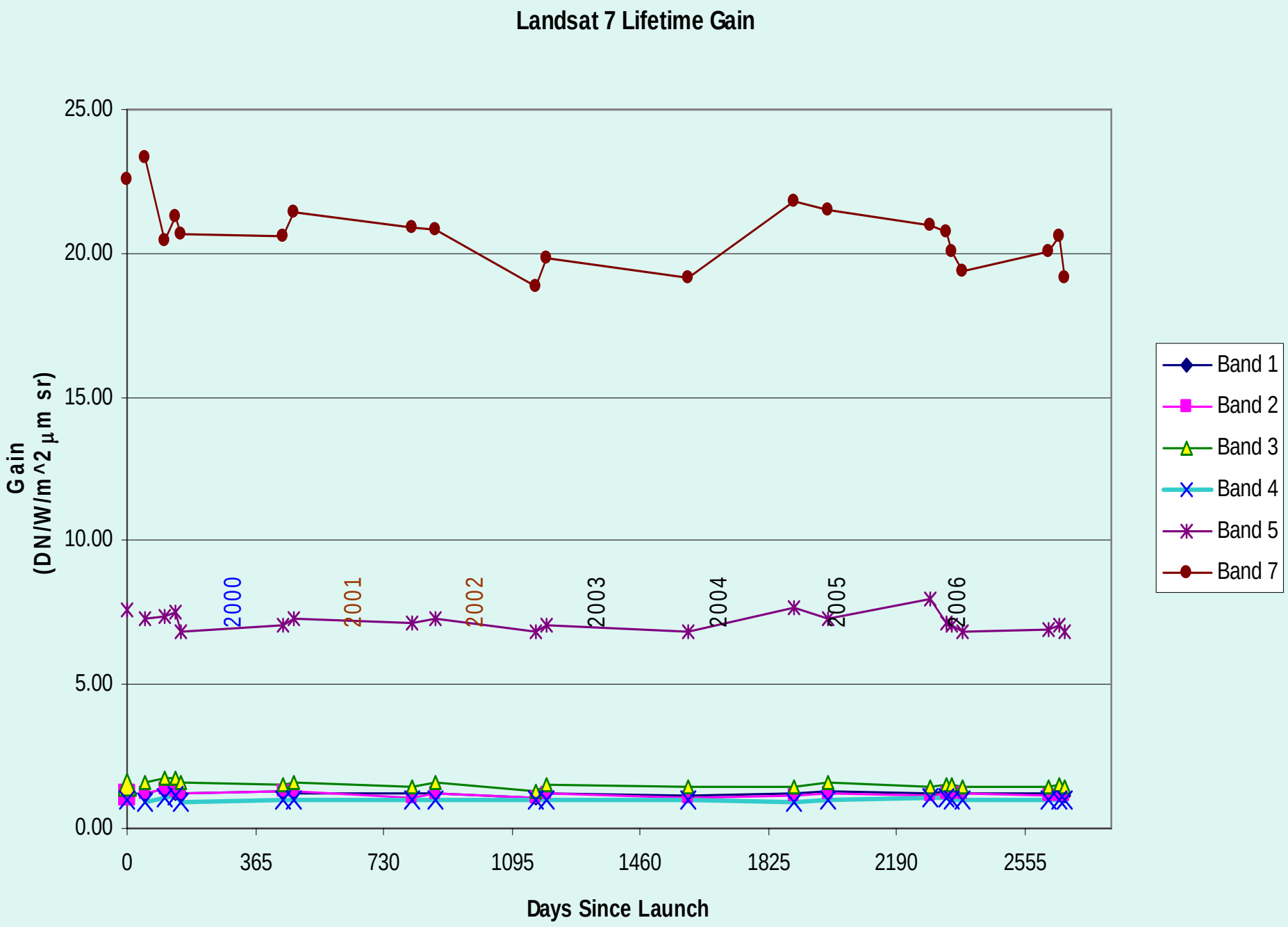
SDSU

2006

Landsat 7: 2006 Data Points
SDSU

Date		DSL	**Band 1** (m^2 μm sr)/W DN/Rad	**Band 2** (m^2 μm sr)/W DN/Rad	**Band 3** (m^2 μm sr)/W DN/Rad	**Band 4** (m^2 μm sr)/W DN/Rad	**Band 5** (m^2 μm sr)/W DN/Rad	**Band 7** (m^2 μm sr)/W DN/Rad
15-Jun	good	**2619**	**1.201**	**1.135**	**1.472**	**0.967**	**6.914**	**20.038**
17-Jul	good	**2651**	**1.227**	**1.163**	**1.496**	**0.991**	**7.084**	**20.568**
2-Aug	cirrus	**2667**	**1.162**	**1.110**	**1.412**	**0.996**	**6.821**	**19.154**


Landsat 7 Lifetime Gain
Gain
(DN/W/m^2 µm sr)
2.000
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0
365
730
1095
1460
1825
2190
2555
Days Since Launch
2000
2001
2002
2003
2004
2005
2006
Band 1
Band 2
Band 3
Band 4
Band 5
Band 7


Landsat 7 Lifetime Gain
Gain
(DN/W/m^2 µm sr)
25.00
20.00
15.00
10.00
5.00
0.00
0
365
730
1095
1460
1825
2190
2555
Days Since Launch
2000
2001
2002
2003
2004
2005
2006
Band 1
Band 2
Band 3
Band 4
Band 5
Band 7

QUICKBIRD

VICARIOUS CALIBRATION RESULTS

SDSU

2004 AND 2005

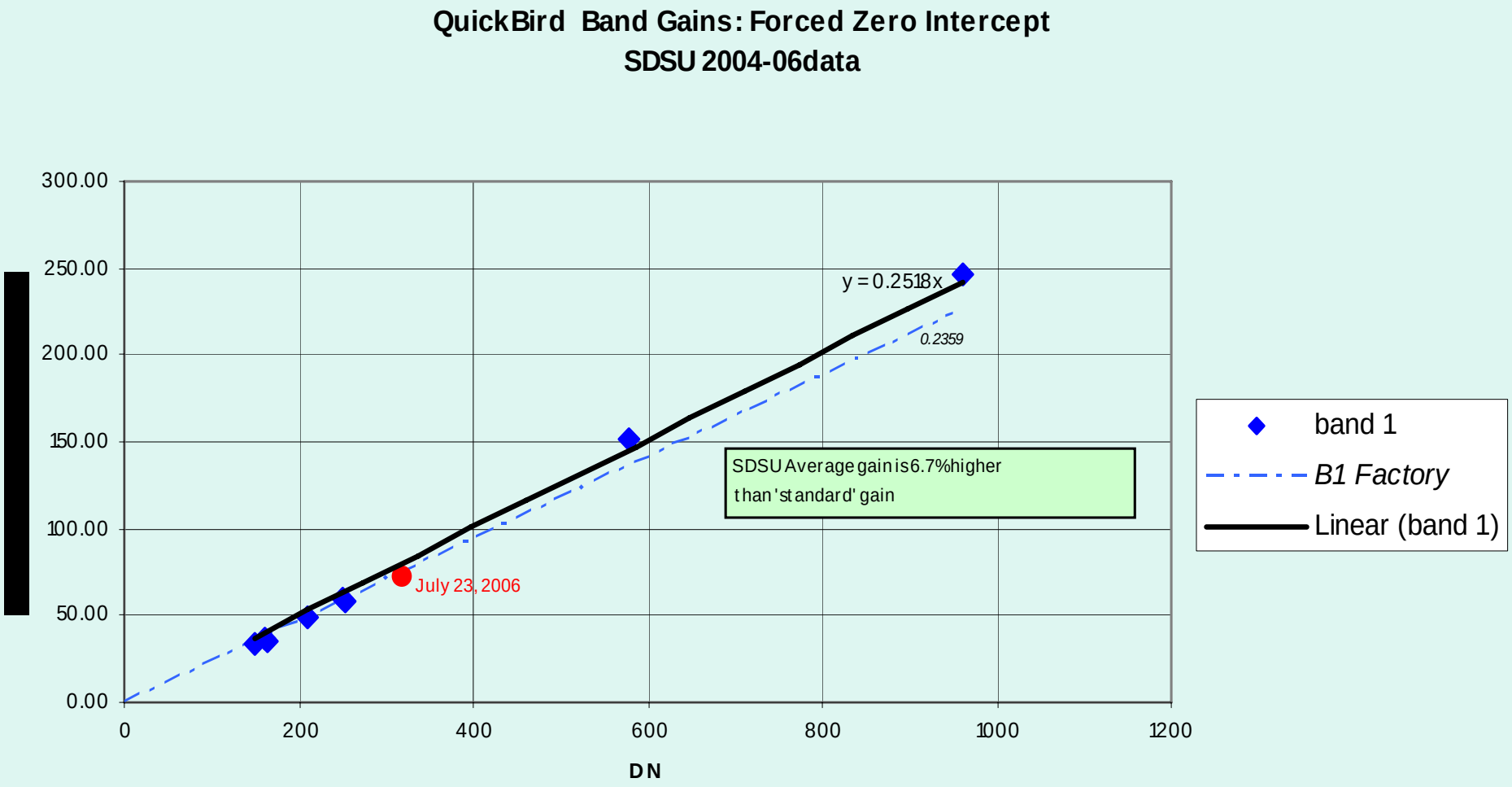
July 23, 2006
Quickbird

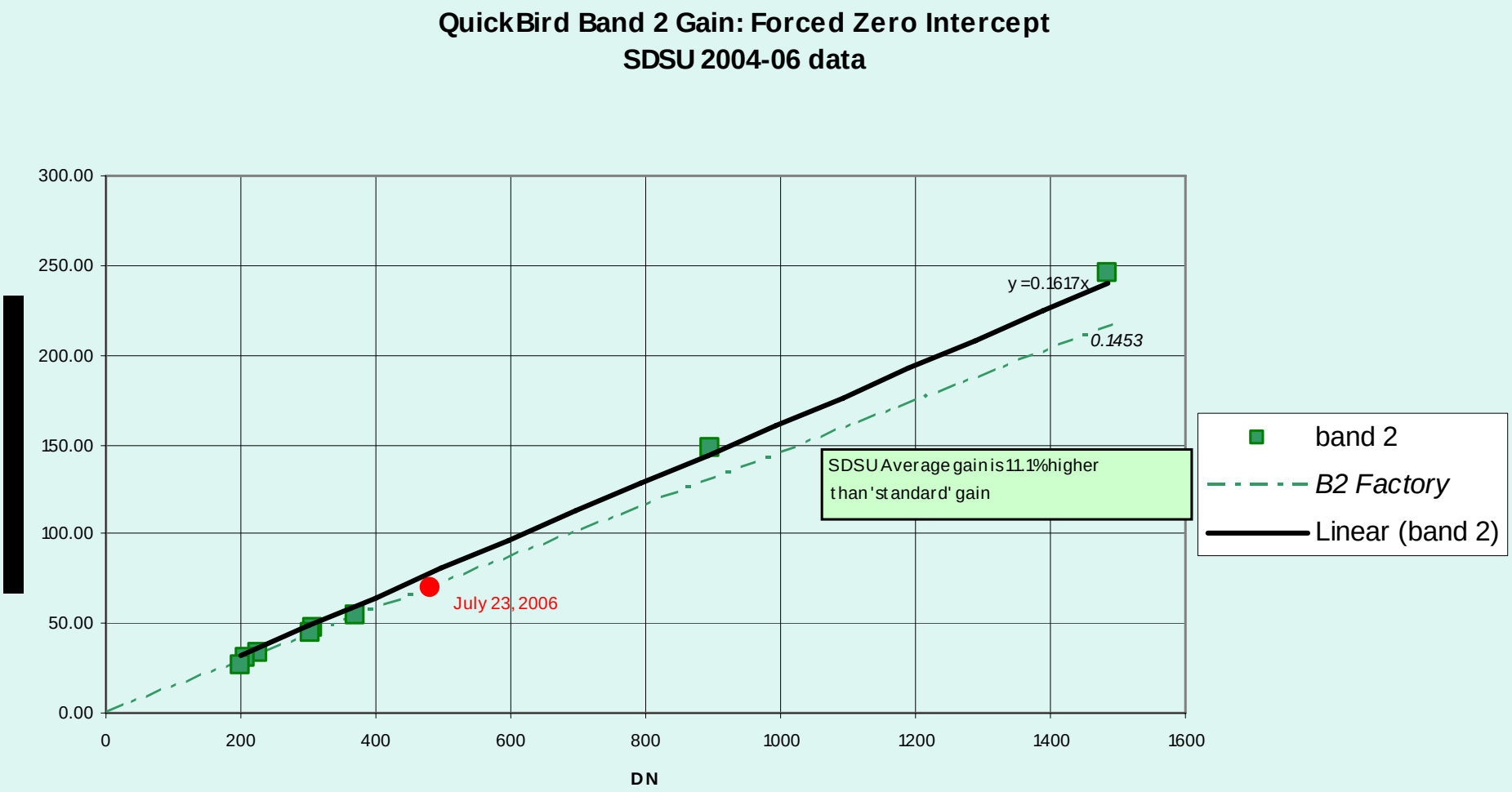
QuickBird Band Gains: 2004-2006

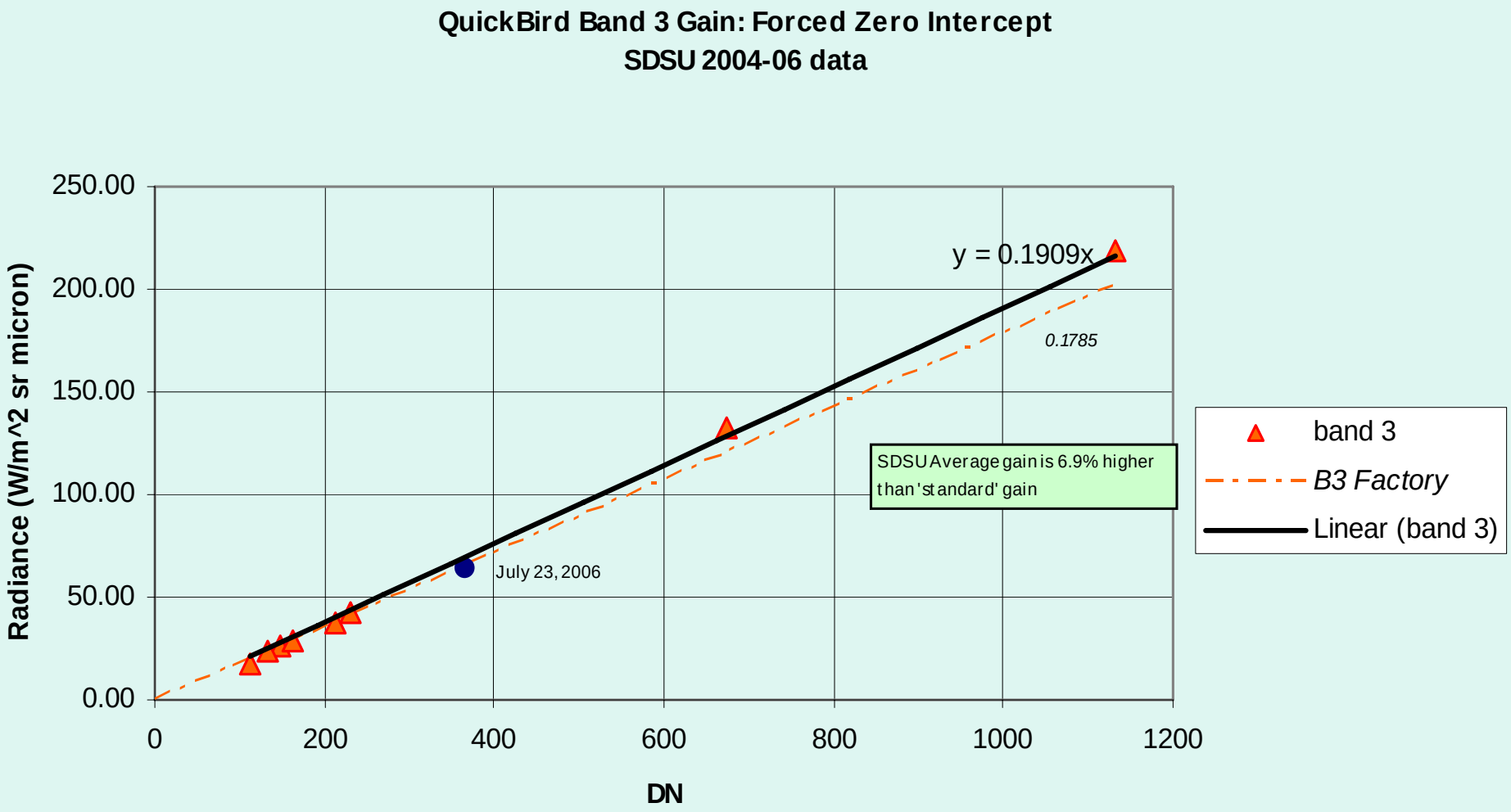
Basic Radiance(W/m^2 sr μm) to DN ratio

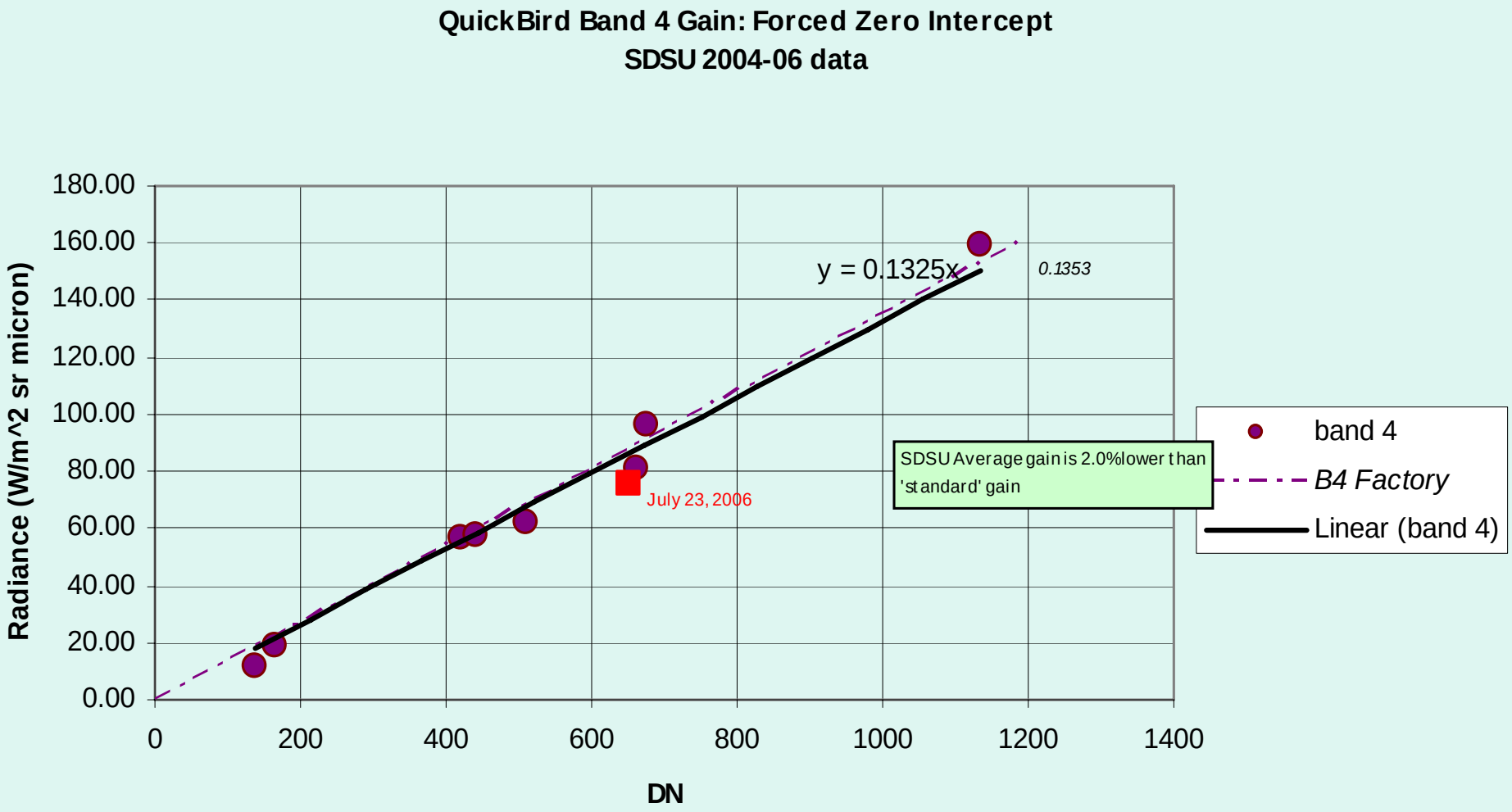
3M Grass	Band 1	Band 2	Band 3	Band 4
Aug 30 2004	0.234	0.156	0.174	0.122
Oct 5 2004	0.232	0.146	0.174	0.135
Jun 22 2005	0.236	0.149	0.183	0.123
Oct18 2005	0.227	0.146	0.179	0.130
July 23, 2006	**0.227**	**0.144**	**0.175**	**0.116**
52% Tarps				
Jun 22 2005	0.256	0.165	0.193	0.141
Oct18 2005	0.263	0.165	0.196	0.143
3.5% tarps				
Jun 22 2005	0.230	0.146	0.174	0.116
Oct18 2005	0.220	0.131	0.150	0.083

average	0.236	0.150	0.178	0.123
standard deviation (1 sigma)	0.014	0.011	0.013	0.018


QuickBird Band Gains: Forced Zero Intercept
SDSU 2004-06data
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0
200
400
600
800
1000
1200
DN
y = 0.2518x
0.2359
SDSU Average gain is 6.7% higher than 'standard' gain
July 23, 2006
band 1
B1 Factory
Linear (band 1)


QuickBird Band 2 Gain: Forced Zero Intercept
SDSU 2004-06 data
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0
200
400
600
800
1000
1200
1400
1600
DN
y =0.1617x
0.1453
SDSU Average gain is 11.1% higher than 'standard' gain
July 23, 2006
band 2
B2 Factory
Linear (band 2)


QuickBird Band 3 Gain: Forced Zero Intercept
SDSU 2004-06 data
Radiance (W/m^2 sr micron)
250.00
200.00
150.00
100.00
50.00
0.00
0
200
400
600
800
1000
1200
DN
y = 0.1909x
0.1785
July 23, 2006
SDSU Average gain is 6.9% higher than 'standard' gain
band 3
B3 Factory
Linear (band 3)


QuickBird Band 4 Gain: Forced Zero Intercept
SDSU 2004-06 data
Radiance (W/m^2 sr micron)
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
200
400
600
800
1000
1200
1400
DN
y = 0.1325x
0.1353
July 23, 2006
SDSU Average gain is 2.0% lower than 'standard' gain
band 4
B4 Factory
Linear (band 4)

ORBVIEW-3

VICARIOUS CALIBRATION RESULTS

SDSU

2004 - 2006

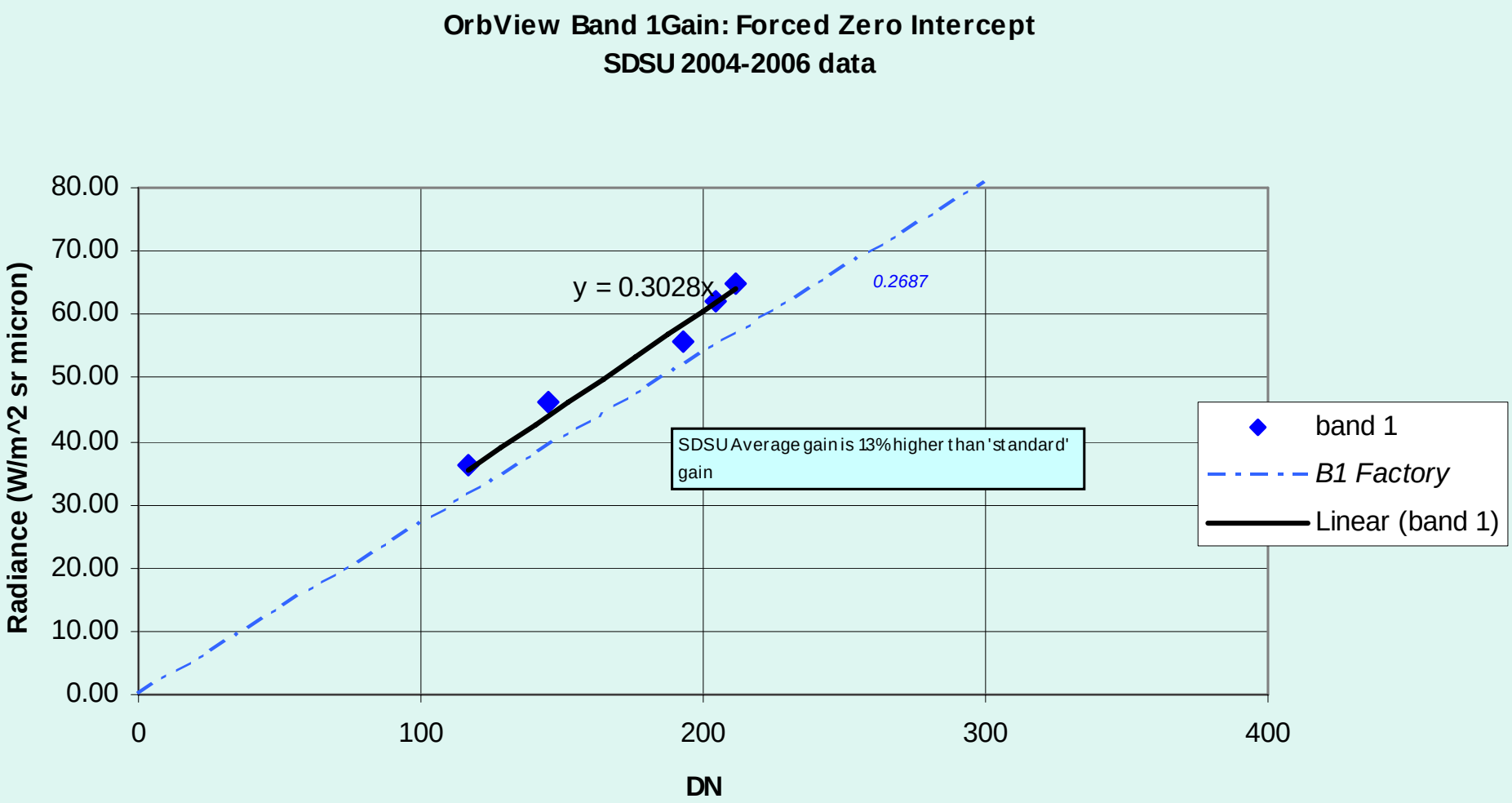
July 15, 2006
OrbView (MS)

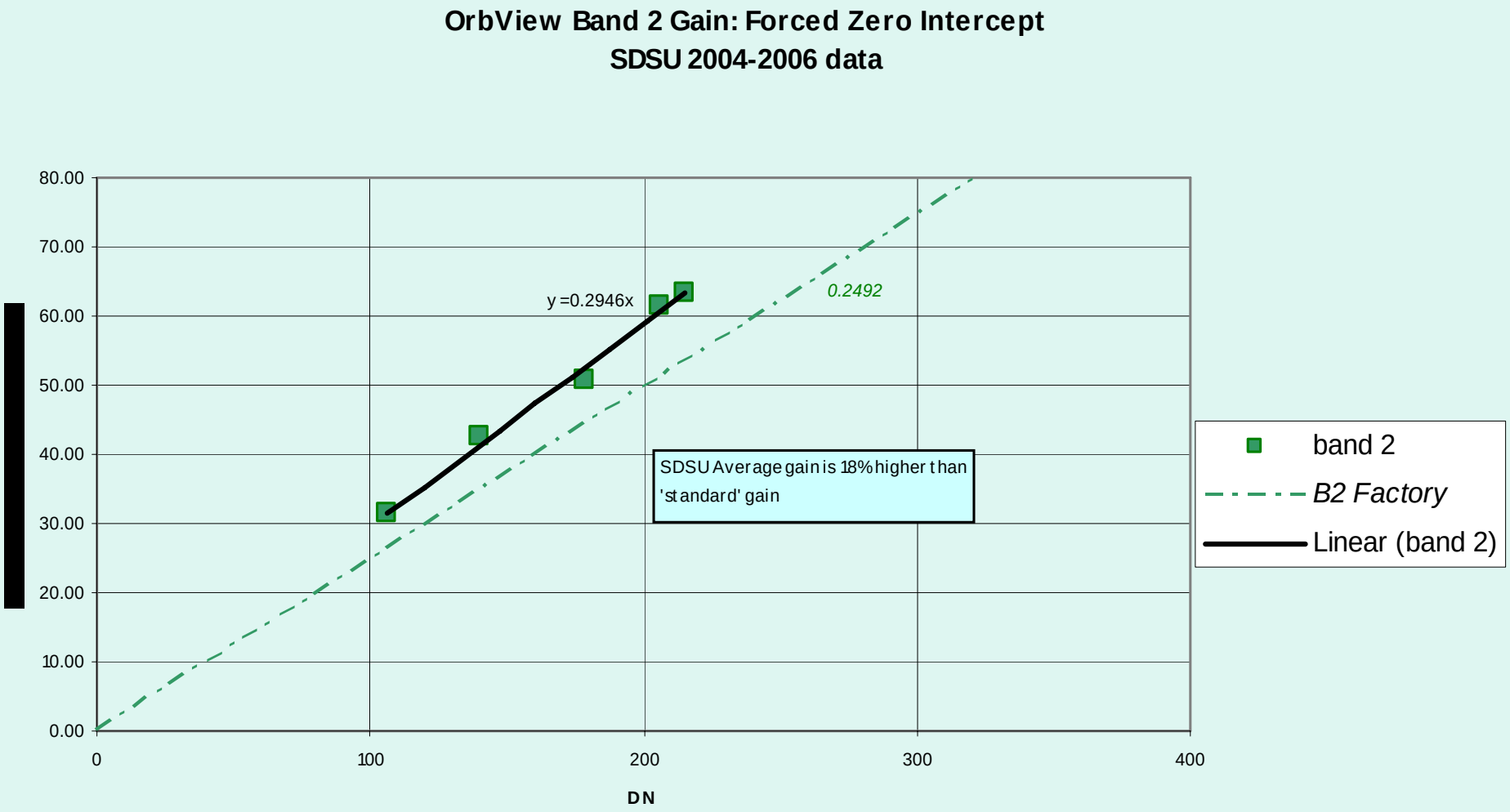
OrbView Band Gains: 2004-2006

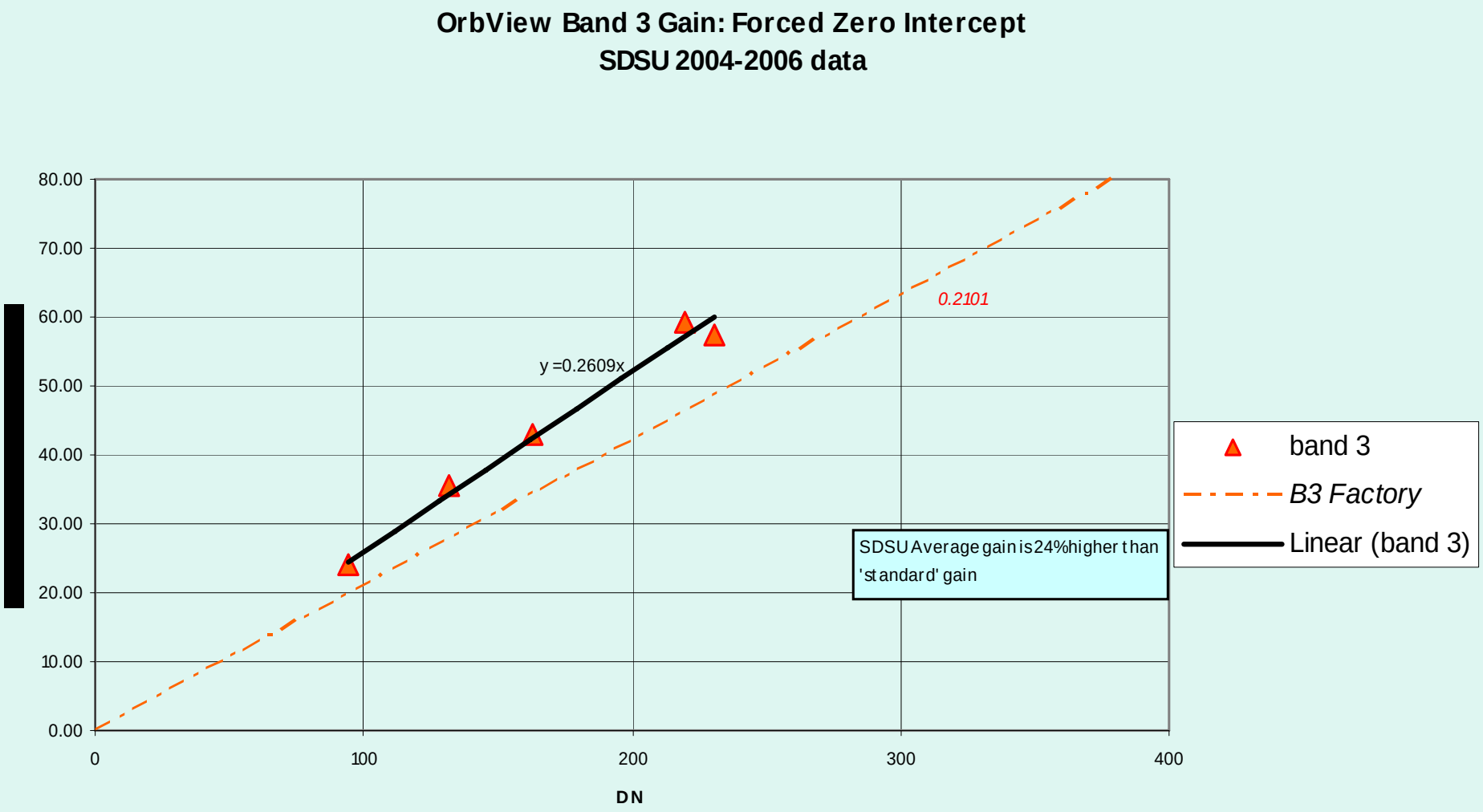
Basic Radiance(W/m^2 sr μm) to DN ratio

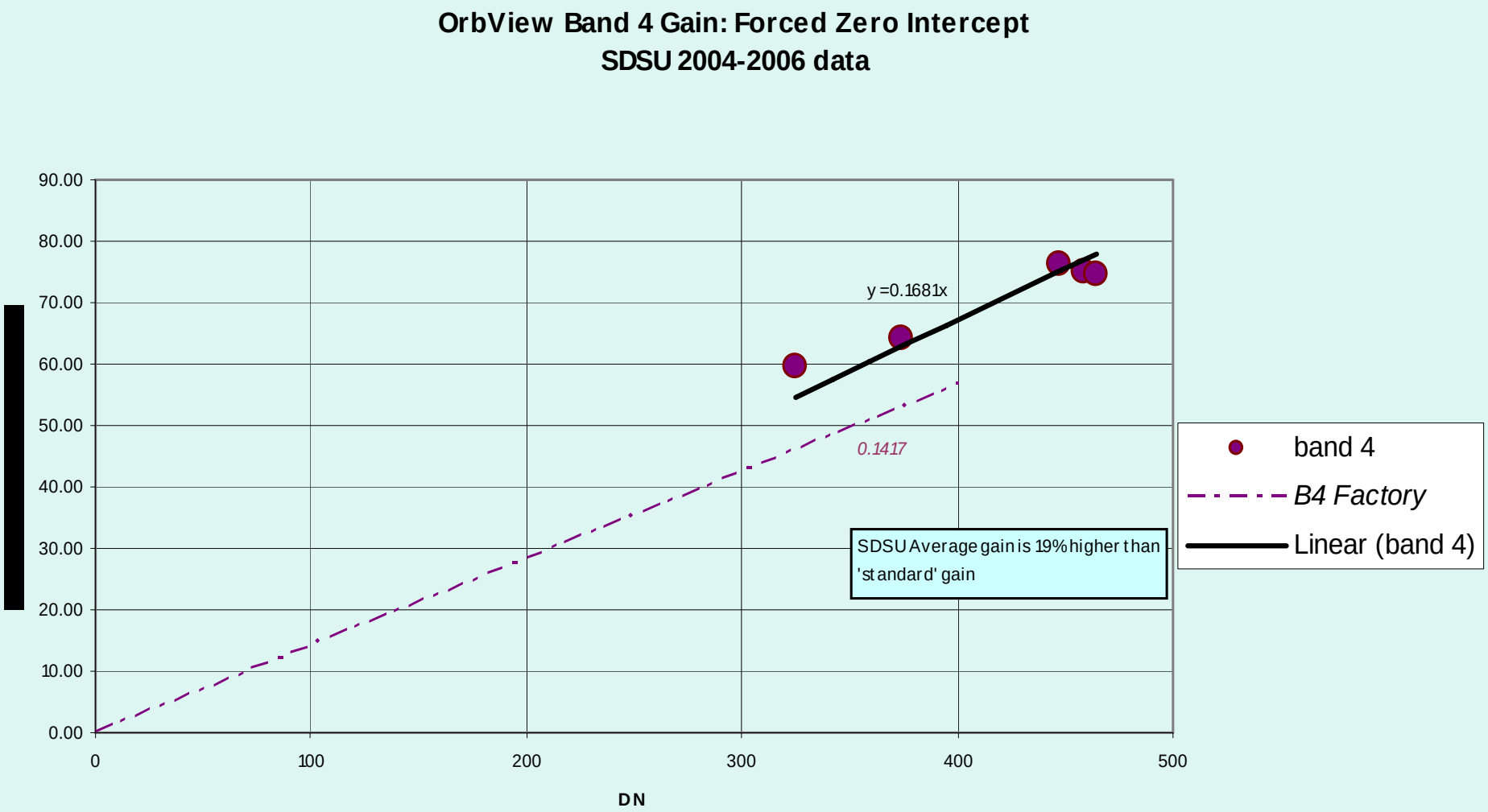
3M Grass	Band 1	Band 2	Band 3	Band 4
Aug 30 2004	0.317	0.304	0.269	0.172
Oct 8 2004	0.310	0.295	0.256	0.183
July 15 2006	0.305	0.295	0.250	0.163
July 23 2006	0.303	0.298	0.269	0.161
July 26 2006	0.288	0.284	0.264	0.171

average	0.305	0.295	0.262	0.170
standard deviation (1 sigma)	0.011	0.008	0.009	0.009


OrbView Band 1Gain: Forced Zero Intercept
SDSU 2004-2006 data
Radiance (W/m^2 sr micron)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
100
200
300
400
DN
y = 0.3028x
0.2687
SDSU Average gain is 13% higher than 'standard' gain
band 1
B1 Factory
Linear (band 1)


OrbView Band 2 Gain: Forced Zero Intercept
SDSU 2004-2006 data
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
100
200
300
400
DN
y =0.2946x
0.2492
SDSU Average gain is 18% higher than 'standard' gain
band 2
B2 Factory
Linear (band 2)


OrbView Band 3 Gain: Forced Zero Intercept
SDSU 2004-2006 data
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
100
200
300
400
DN
y =0.2609x
0.2101
SDSU Average gain is 24% higher than 'standard' gain
band 3
B3 Factory
Linear (band 3)


OrbView Band 4 Gain: Forced Zero Intercept
SDSU 2004-2006 data
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
100
200
300
400
500
DN
y =0.1681x
0.1417
SDSU Average gain is 19% higher than 'standard' gain
band 4
B4 Factory
Linear (band 4)

IKONOS

VICARIOUS CALIBRATION RESULTS

SDSU

2006

2006 IKONOS Results:

Three attempts were made, only one potentially useable: July 27

- Site was ‘shot between the clouds’ with significant overlapping haze.

- Attempted a ‘light trapping’ model but results to date show too large an uncertainty to be reportable.

Unfortunately same was true for last year.

Medium Res: AWiFS

VICARIOUS CALIBRATION

RESULTS

SDSU

2006

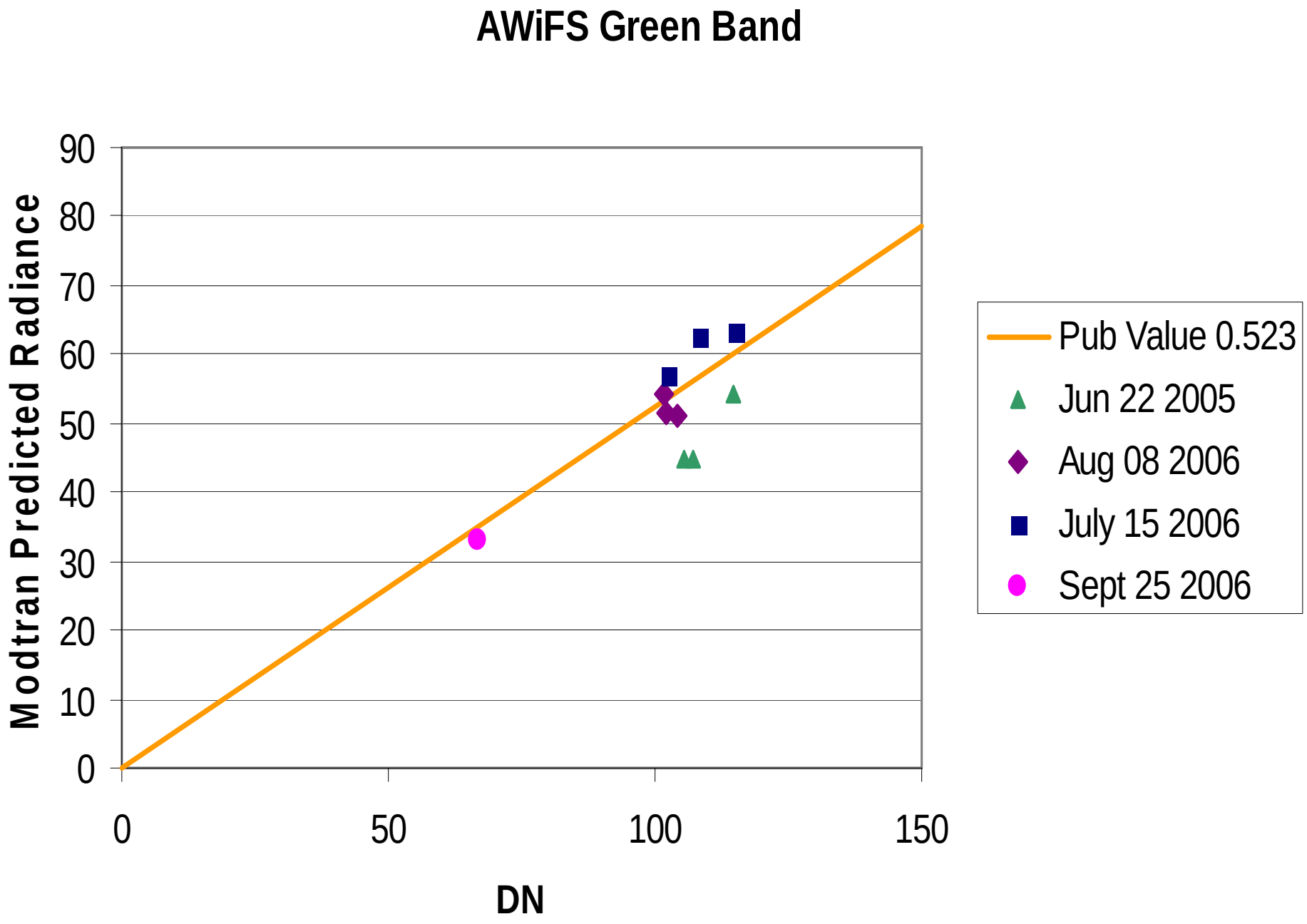
AWiFS

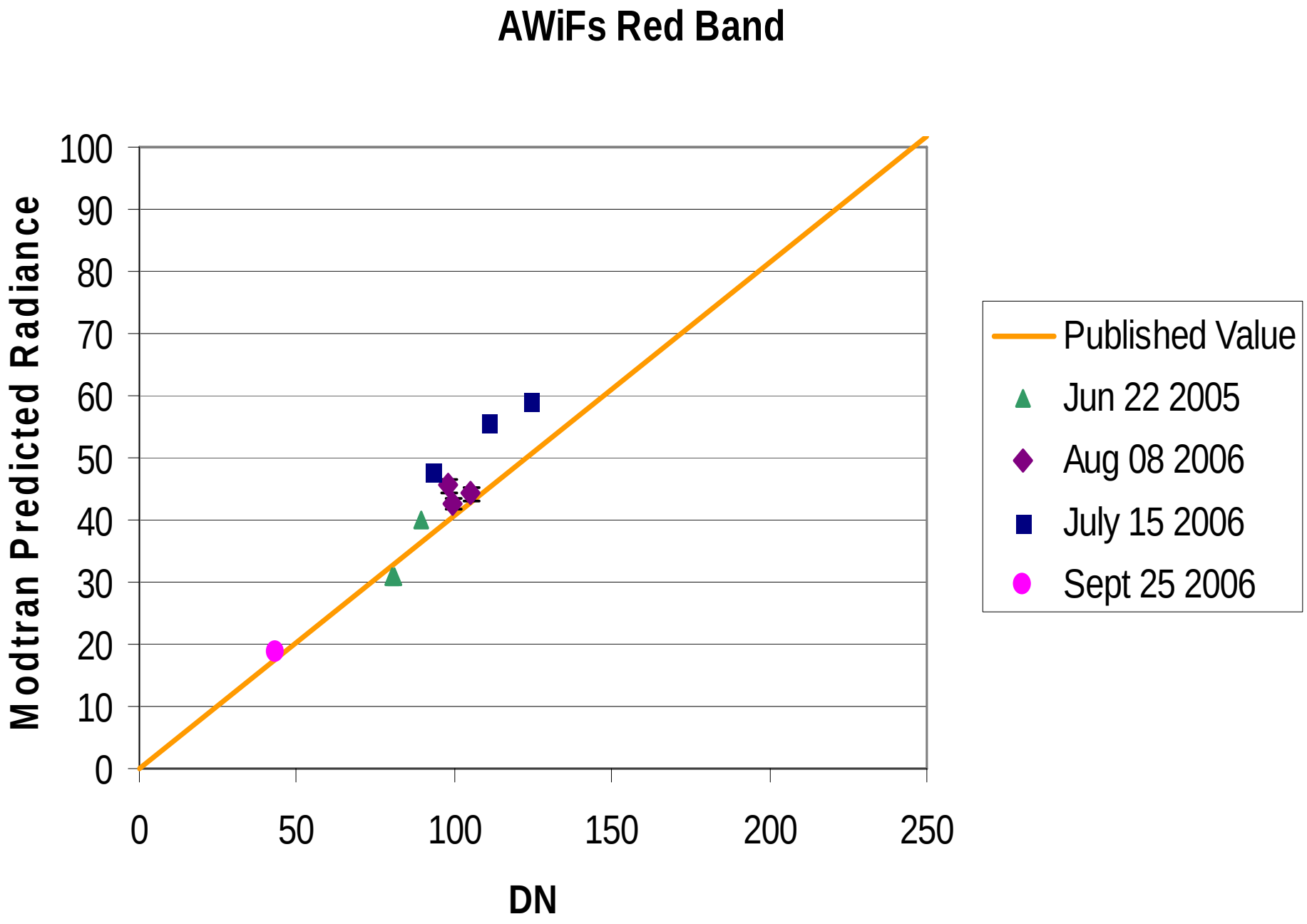
As part of the DCWG efforts, worked with SSC in 2005 to do an initial analysis of AWiFS Calibration

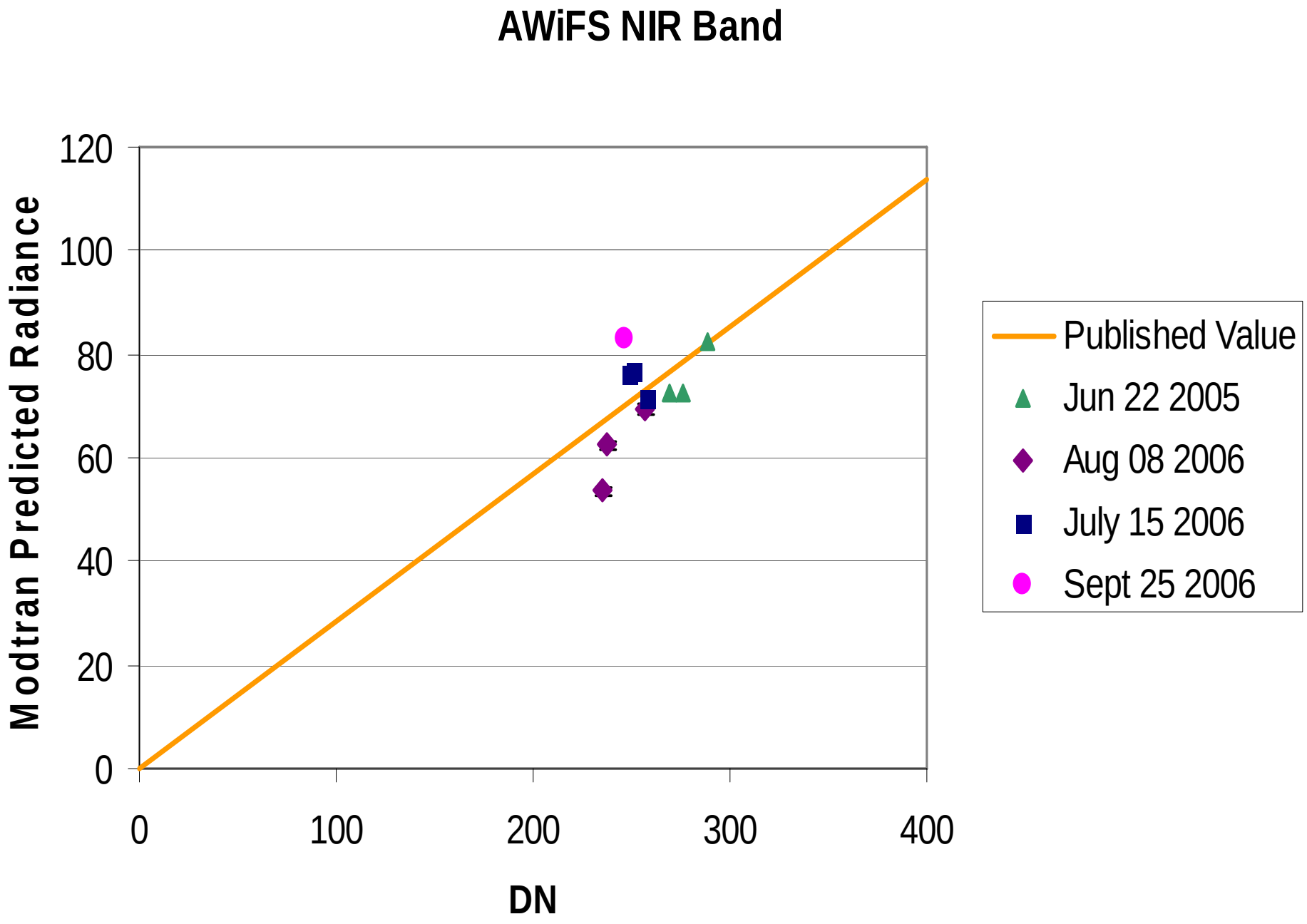
- 2 moderately successful dates
- Wanted to try and extend this analysis
- Applied a ‘data synthesis’ technique
  - Based on SBDE (Spectral Band Difference Effect)
  - Used sites with hyperspectrally characterized reflectance to monitor multiple radiance values via coincident high resolution data collections

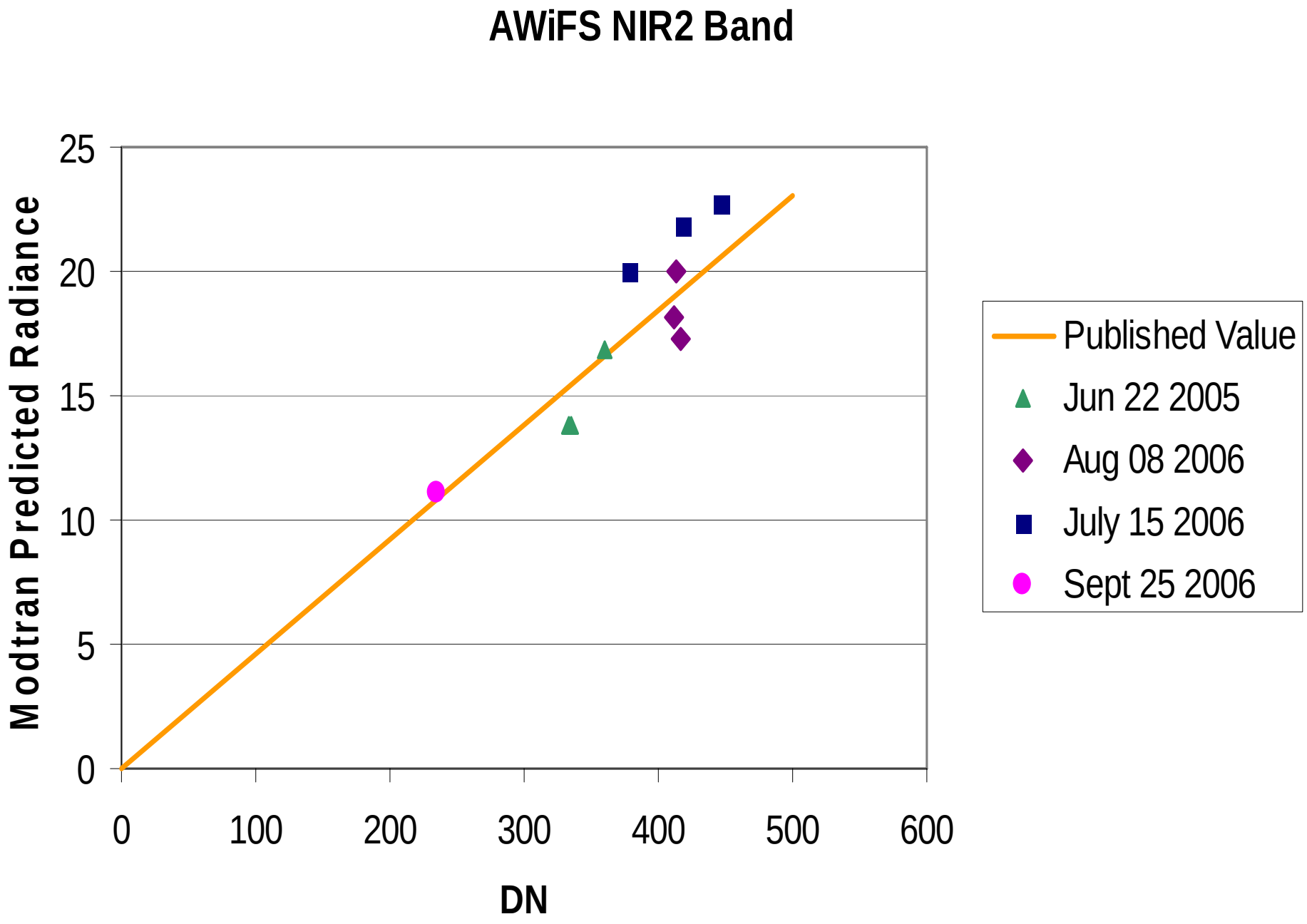
AWiFS

- Utilized planned Landsat data collections and follow-up high resolution collections with coincident imagery from USDA SIA to provide a means for additional data collection.
- Applied a ‘data synthesis’ technique (described JACIE 2006) to extend the effective area and radiance range.


AWiFS Green Band
Modtran Predicted Radiance
90
80
70
60
50
40
30
20
10
0
0
50
100
150
DN
Pub Value 0.523
Jun 22 2005
Aug 08 2006
July 15 2006
Sept 25 2006


AWiFs Red Band
Modtran Predicted Radiance
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
DN
Published Value
Jun 22 2005
Aug 08 2006
July 15 2006
Sept 25 2006


AWiFS NIR Band
Modtran Predicted Radiance
120
100
80
60
40
20
0
0
100
200
300
400
DN
Published Value
Jun 22 2005
Aug 08 2006
July 15 2006
Sept 25 2006


AWiFS NIR2 Band
Modtran Predicted Radiance
25
20
15
10
5
0
0
100
200
300
400
500
600
DN
Published Value
Jun 22 2005
Aug 08 2006
July 15 2006
Sept 25 2006

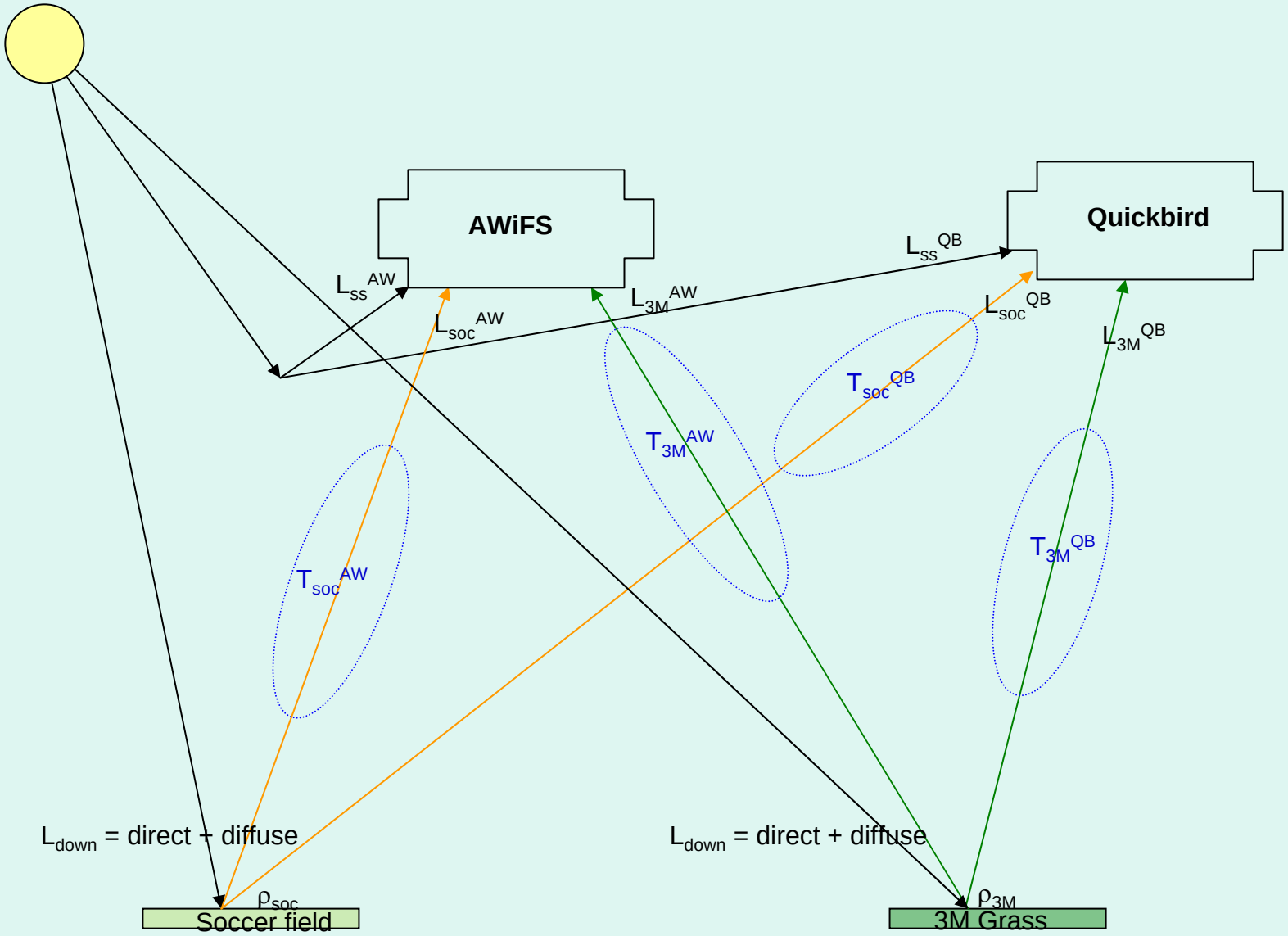
SBDE Based Data Synthesis Technique

Basic Tenent: Use a satellite image with known gain coefficients to estimate TOA radiance as seen by satellite with ‘unknown’ gain coefficients.

- Tried by many groups
  - Gives a reasonable zeroeth order calibration
  - Can improve by correcting for different look angles
  - Can improve by correcting for different filter band response

Common approaches rely solely on spectrally banded satellite data

- very difficult to correctly compensate for atmospheric effects (through different look angles), BRDF, spectral band filter functions, solar scatter, etc.


AWiFS
Quickbird
L_{ss}^{AW}
L_{ss}^{QB}
L_{soc}^{AW}
L_{3M}^{AW}
L_{soc}^{QB}
L_{3M}^{QB}
T_{soc}^{QB}
T_{3M}^{AW}
T_{soc}^{AW}
T_{3M}^{QB}
L_{down} = direct + diffuse
L_{down} = direct + diffuse
ρ_{soc}
ρ_{3M}
Soccer field
3M Grass

Key Concepts for Methodology

- Process radiance and atmospheric data hyperspectrally (MODTRAN)
- Different satellite ‘look angles’ are incorporated into the hyperspectral atmosphere model (via MODTRAN)
- All hyperspectral radiances banding is accomplished using the appropriate hyperspectral filter set for each satellite
- Solar scatter (which is unrelated to ground reflectance) is processed separately so will not be affected by ground scaling.

Methodology (cont)

- The unknown ground level reflectance is synthesized using a combination of in-band radiance ratios
  - brought down to Top of Canopy (TOC) by the atmospheric model
  - within each band's range, scaling factors are calculated
  - these scaling factors then synthesize a set of hyperspectral reflectances for the 'unknown' canopy which are each valid over a specific wavelength range

- New hyperspectral TOC radiances are calculated and propagated to satellite (instrument being calibrated) using MODTRAN

- upwelling radiances are recombined with solar scatter and banded

- These TOA values are compared with satellite DN values to determine gain equation.

Results

Coincident collection opportunities

- June 22, 2005 AWiFS + QB
- Oct 18, 2005 Landsat 7 + QB
- July 15, 2006 AWiFS + OV

June 22 reported JACIE 2006

TBD when resources available to process other two dates

Pack it up for another season

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