ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

EO-1 Science Validation Team Meeting

Hilo, HA November 18-22

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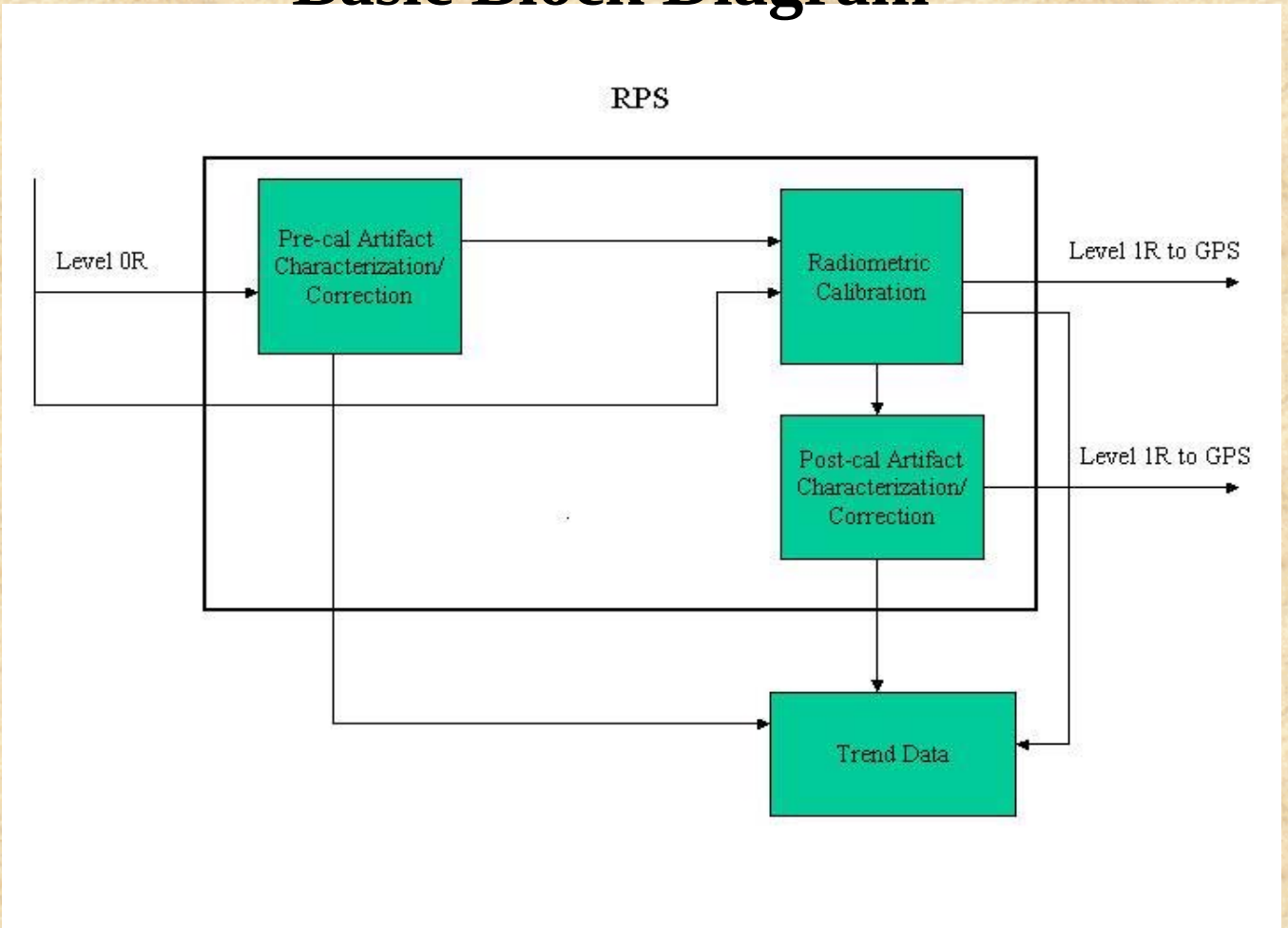
ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

Outline

- Bias Stability
  - ALI vs. Landsat
- Lamp/Detector Stability
  - ALI vs. Landsat
- SNR
  - ALI vs. Landsat
- Cross-calibration
  - ALI vs. ETM+
- Radiometry Summary and Conclusions
- Advanced Land Imager/ Hyperion: Geometric Performance

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

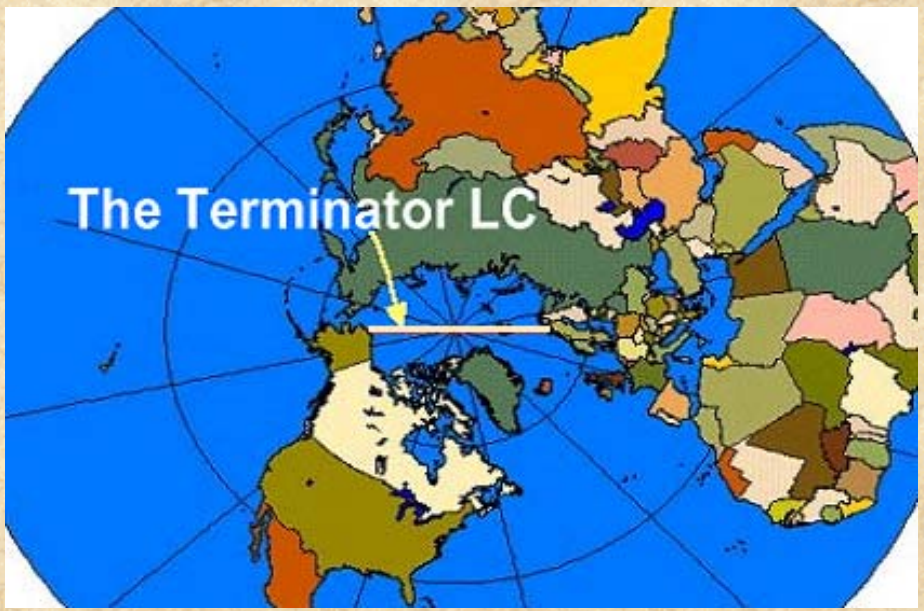
Radiometric Processing Subsystem (RPS) Basic Block Diagram



ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- Bias Stability: ALI

Long Collects
Brookings LC: April 30, 2001, 1392 km, 46,405 frames
Terminator LC: July 4, 2001, 2349 km, 78,331 frames



ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- Bias Stability: ALI

Out of 15,360 detectors…

No detectors in Bands 1, 1p, 2, 3, 4, 4p, 5 drifted

3 detectors in SCA 1, Band 5p drifted

BrookingsLC: Band 5p, SCA 1					
Detector	Pre-cal Mean (DN)	Pre-cal Std. Dev. (DN)	Dark Mean (DN)	Dark Std. Dev. (DN)	Difference (DN)
1	685.4	2.21	692.2	1.38	-6.76
3	544.4	1.24	548.8	1.11	-4.34
221	756.9	10.5	788.1	10.8	-31.2

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- Bias Stability: ALI

Out of 15,360 detectors…

103 detectors in SCA 1, Band 7 drifted

Brookings LC: Band 7, SCA 1					
Detector	Pre-cal Mean (DN)	Pre-cal Std. Dev. (DN)	Dark Mean (DN)	Dark Std. Dev. (DN)	Difference (DN)
1	877.1	4.24	895.8	2.04	-18.6
3	624.5	2.78	636.5	1.93	-12.0
5	529.1	2.21	539.6	1.48	-10.5
9	694.7	2.6	712.0	1.93	-17.3
11	807.8	3.47	824.2	2.85	-16.5
13	1071	6.06	1091	4.64	-20.4
15	815.3	3.63	831.6	2.73	-16.4
19	725.4	3.25	741.3	2.71	-15.9
21	632.8	3.61	643.3	2.42	-10.5
25	558.2	2.54	569.0	2.43	-10.8
309	870.2	4.91	885.9	4.15	-15.7

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

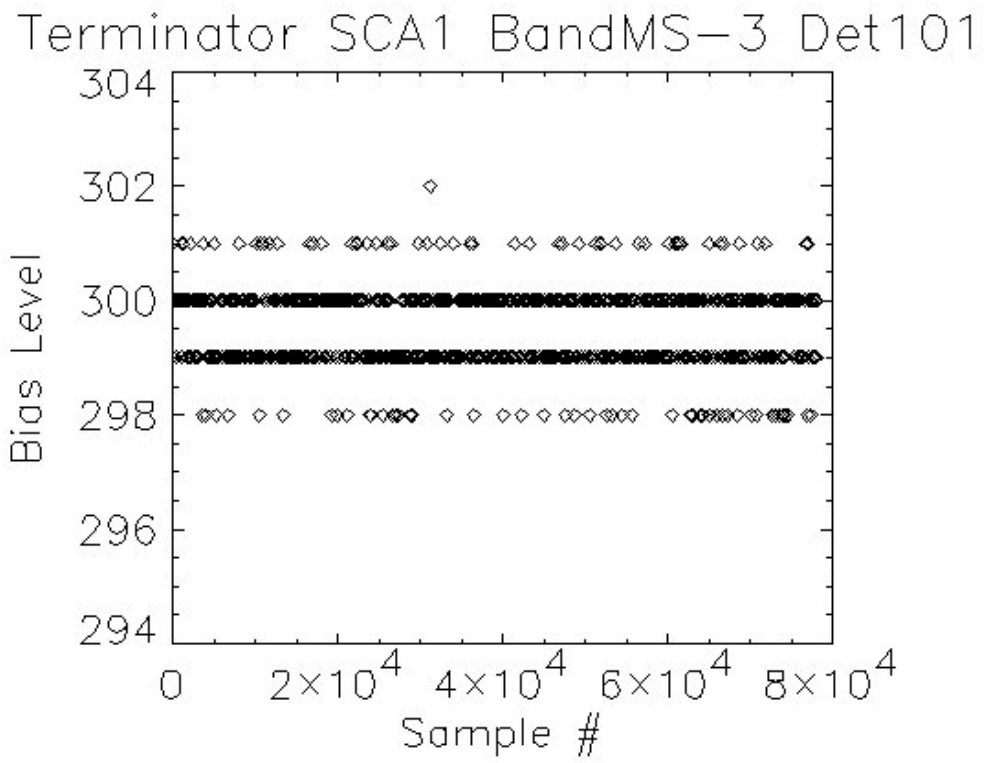
•Bias Stability: ALI

Terminator LC: all ‘night’ data

316 detectors with >3% change in range;

65 detectors with >3.5% change in range;

2 detectors with >7% change in range.



ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

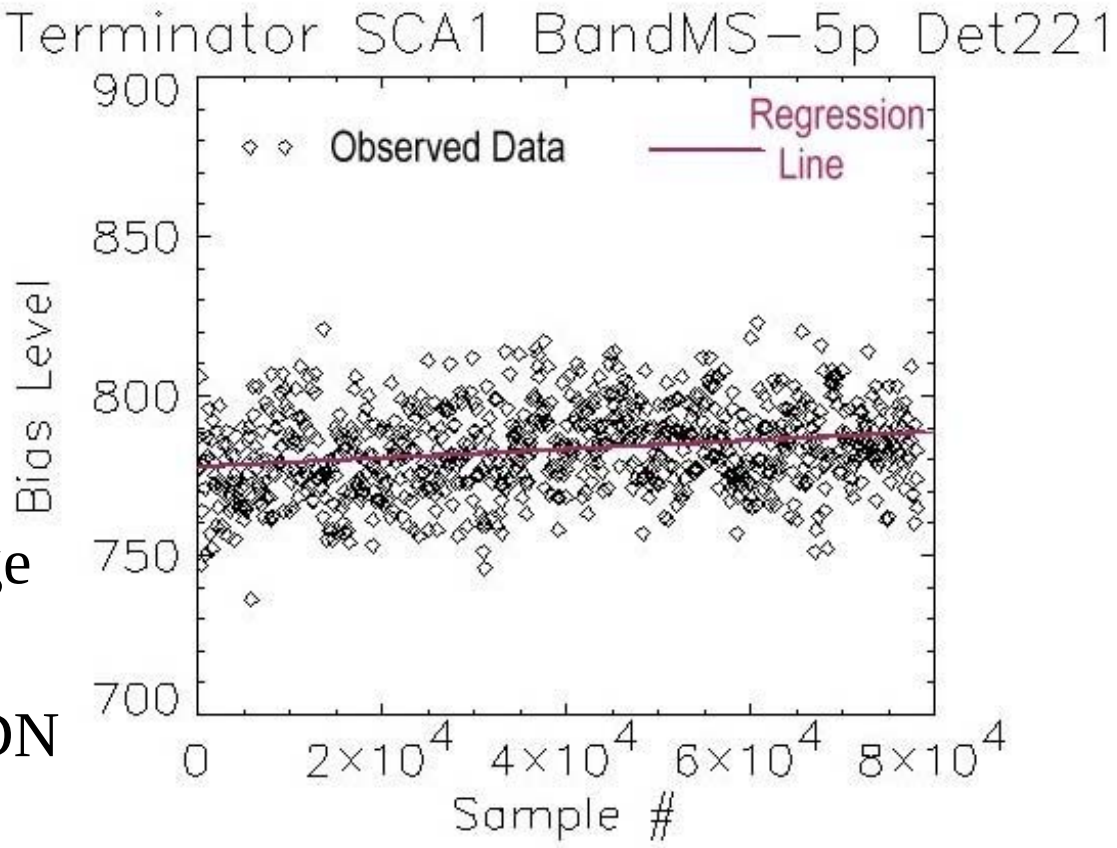
- Bias Stability: ALI

Terminator LC: all 'night' data

2 Worst Case Detectors:

Band 5p, SCA 1, Det. 221

Band 5, SCA 1, Det. 201



12 DN change

_ = 13.8 DN

range ≅ 50 DN

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- Bias Stability: ALI

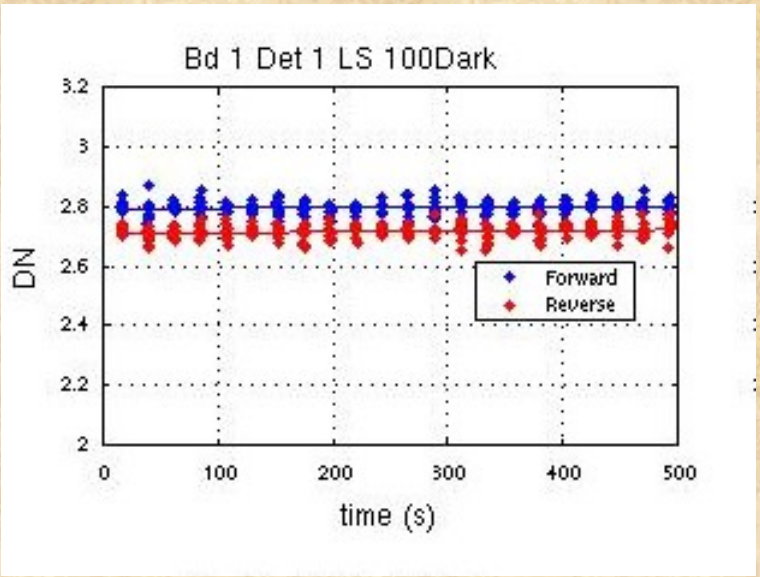
Terminator LC: all 'night' data

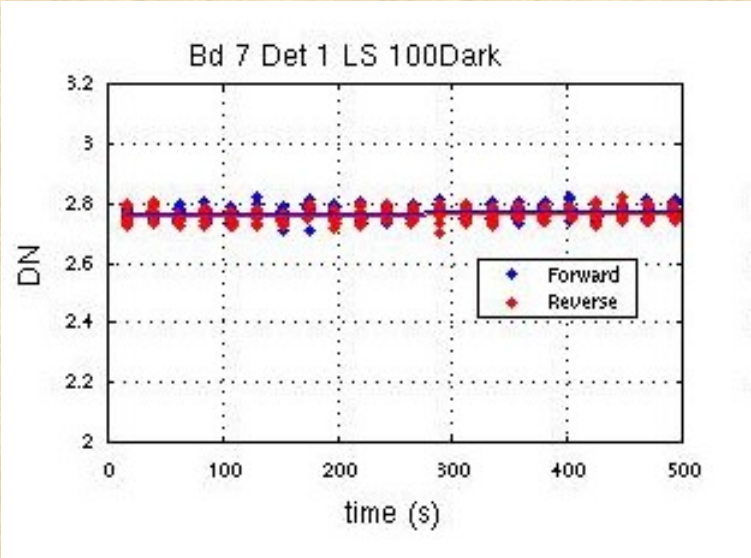
SCA 1: Worst case detectors

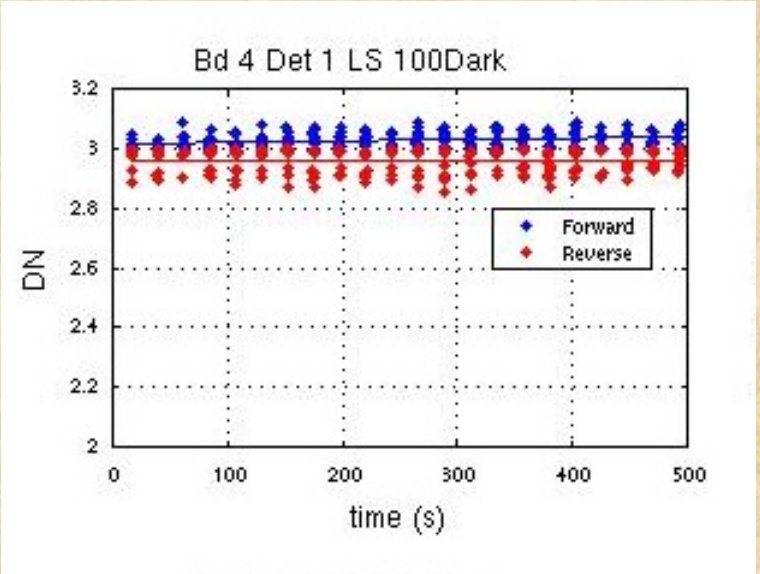
Band	Detector	Est. Slope DN/10,000 frames	Bias Level Change, DN
5p	221	1.6	12.5
5p	318	0.7	5.5
5	201	0.7	4.9
7	19	0.3	2.4
7	309	0.9	6.4
7	302	0.2	1.6

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- Bias Stability: Landsat 5
  - 27 Consecutive night scenes
  - ~5000 km
  - No change in bias level!



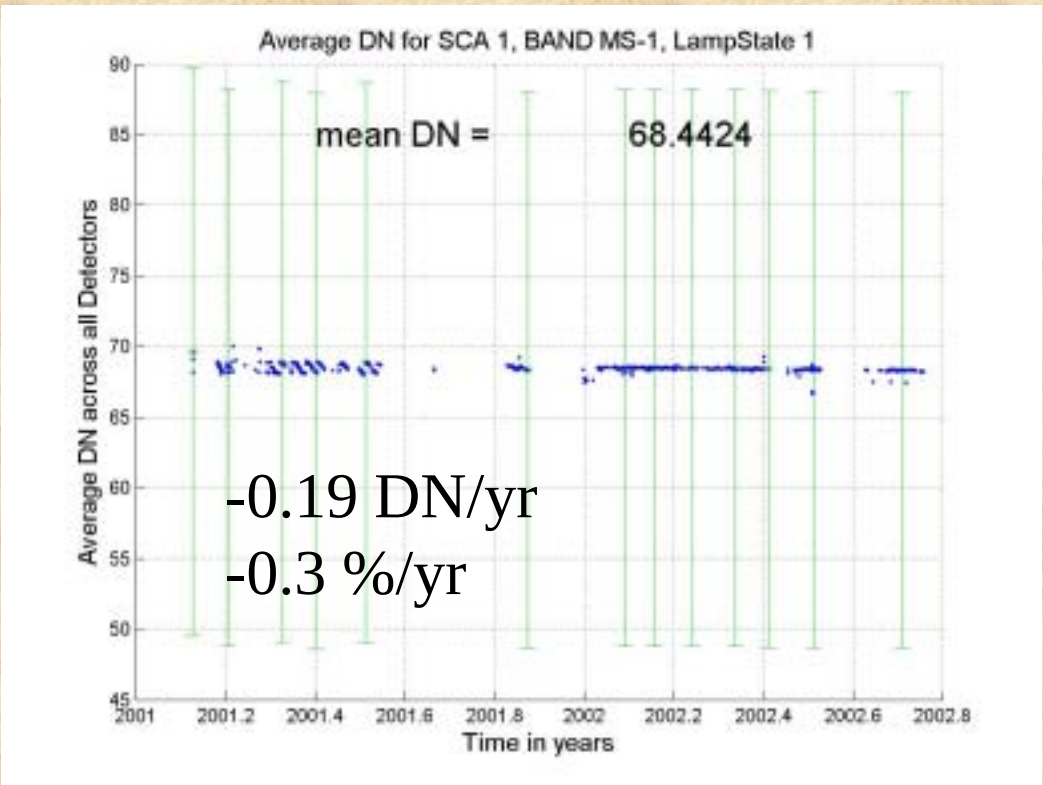




ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- Lamp/Det. Stability: ALI

- 2441 scenes from Feb. 2001 through Oct., 2002.
- All 3 lamp states.
- Mean response of all detectors in each SCA.
- Std. Dev. Plotted as error bar.
- Focal plane contamination not removed.



ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

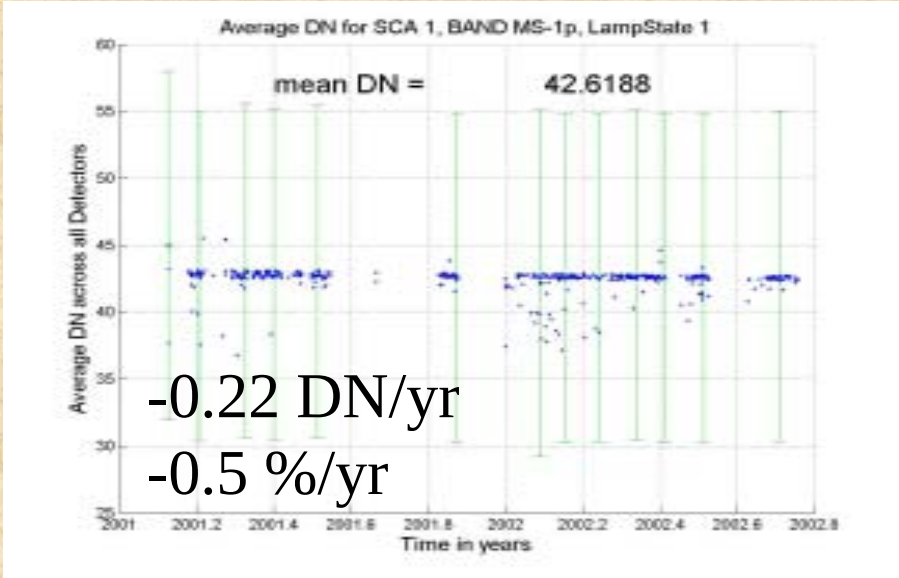
- Lamp/Det. Stability: ALI

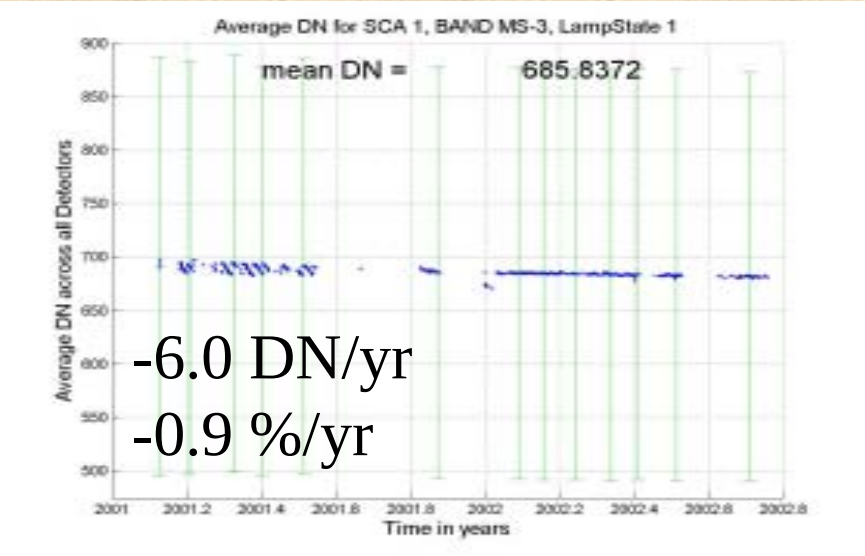
  Bands 1p, 1, 2, 3—

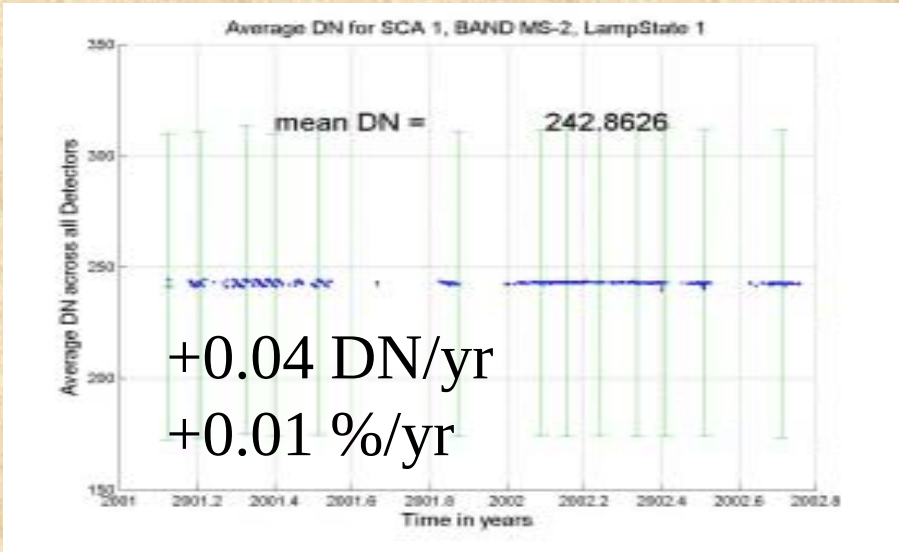
  All ‘fairly’ stable over time;

  All SCA’s;

  DN’s directly related to _.





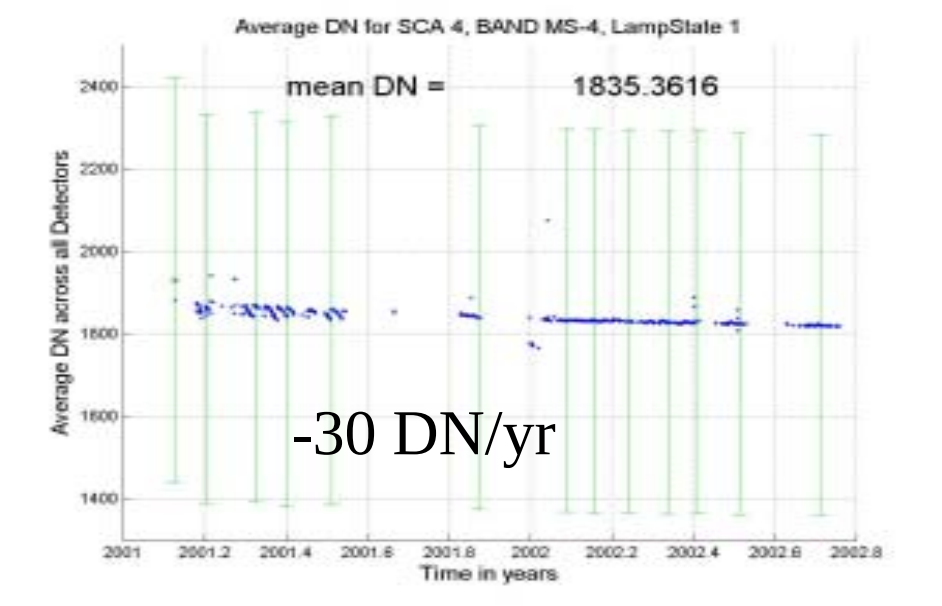


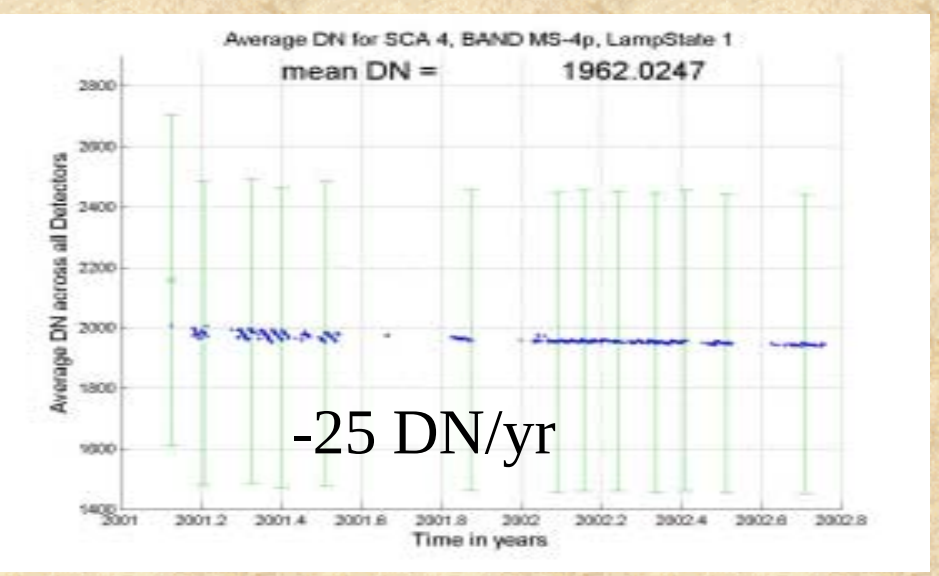
ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- Lamp/Det. Stability: ALI

Bands 4 and 4p:

- Decaying trend—
  - ➢ 1.5% & 1.3% per year;
- Independent of lamp state & SCA.





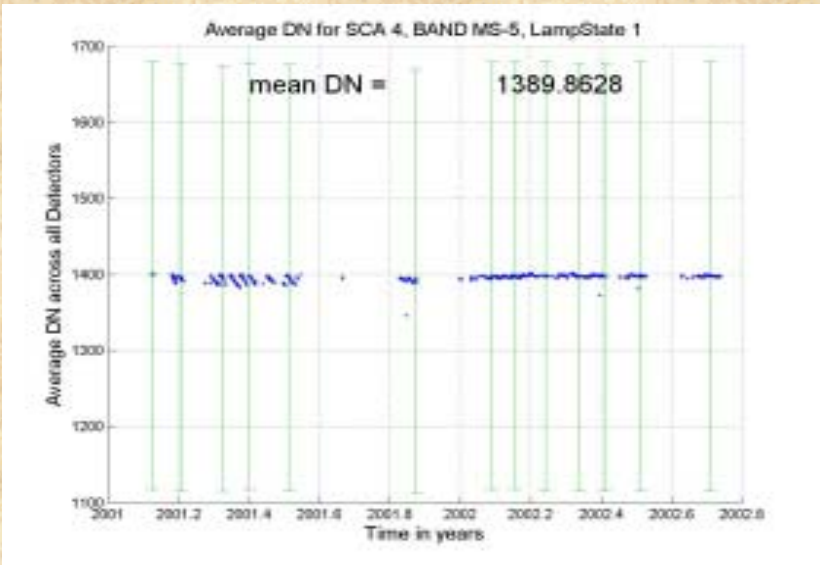
ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

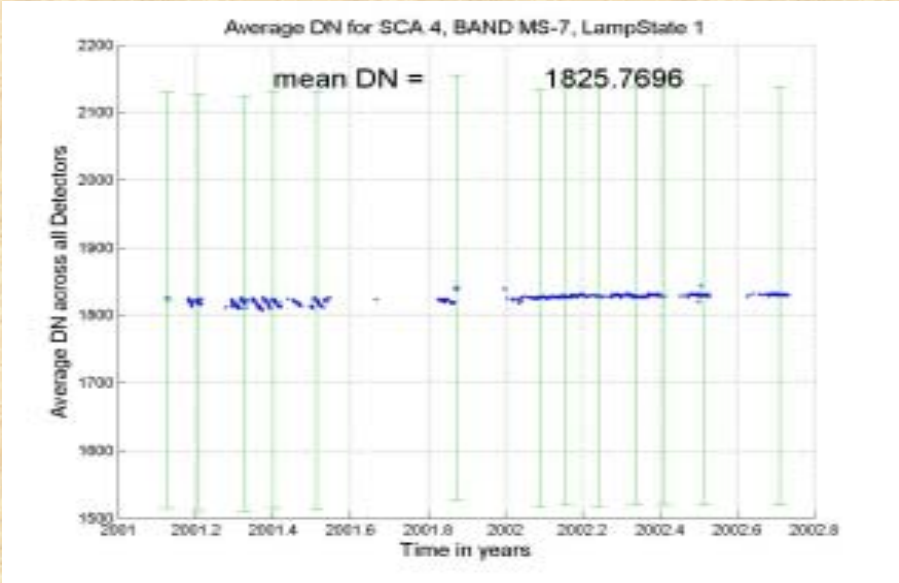
- Lamp/Det. Stability: ALI

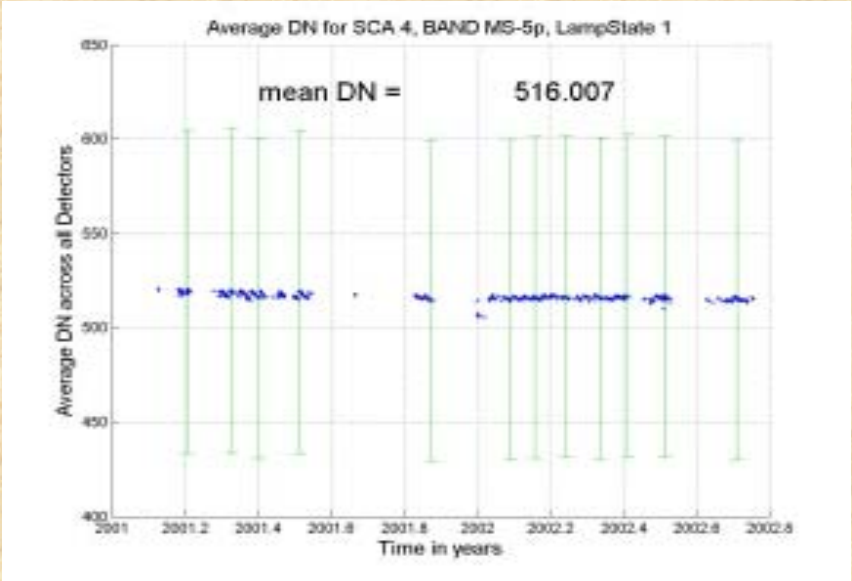
Bands 5, 5p, 7—

Stable or slight upward trend

<0.5%/year.





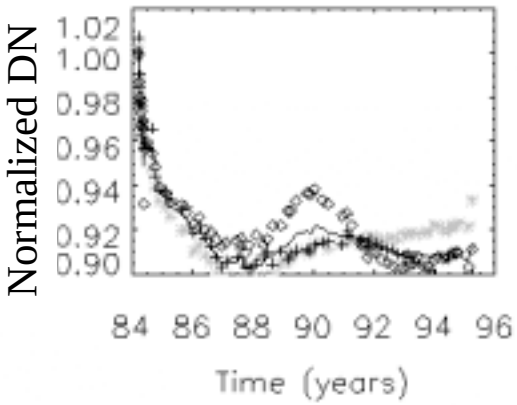


ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

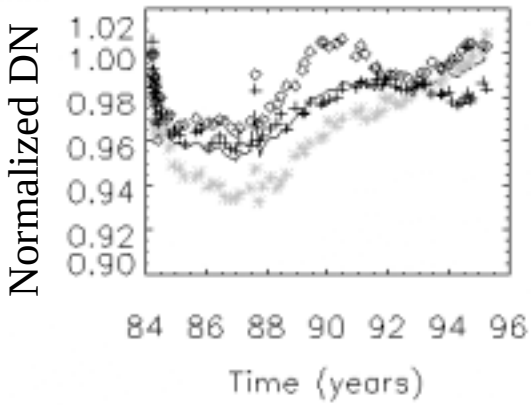
•Lamp Stability: Landsat 5

- 3 Independent lamp states.
- Each lamp response different.
- Initial decay due to detector response.
- Following increase due to lamp radiance.

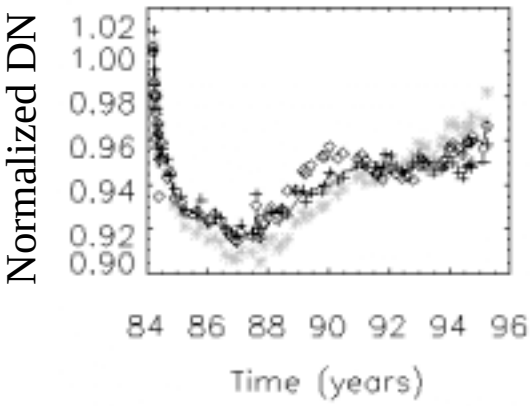
Normalized Lamp Response Band 1



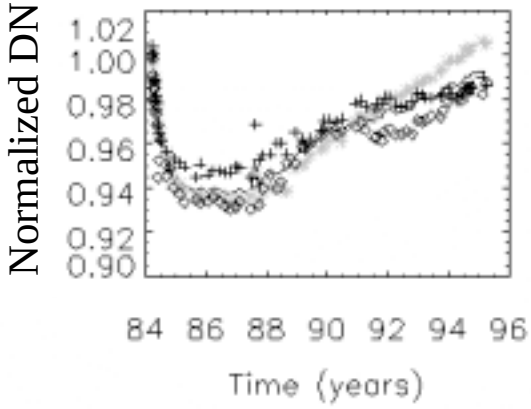
Normalized Lamp Response Band 2



Normalized Lamp Response Band 3

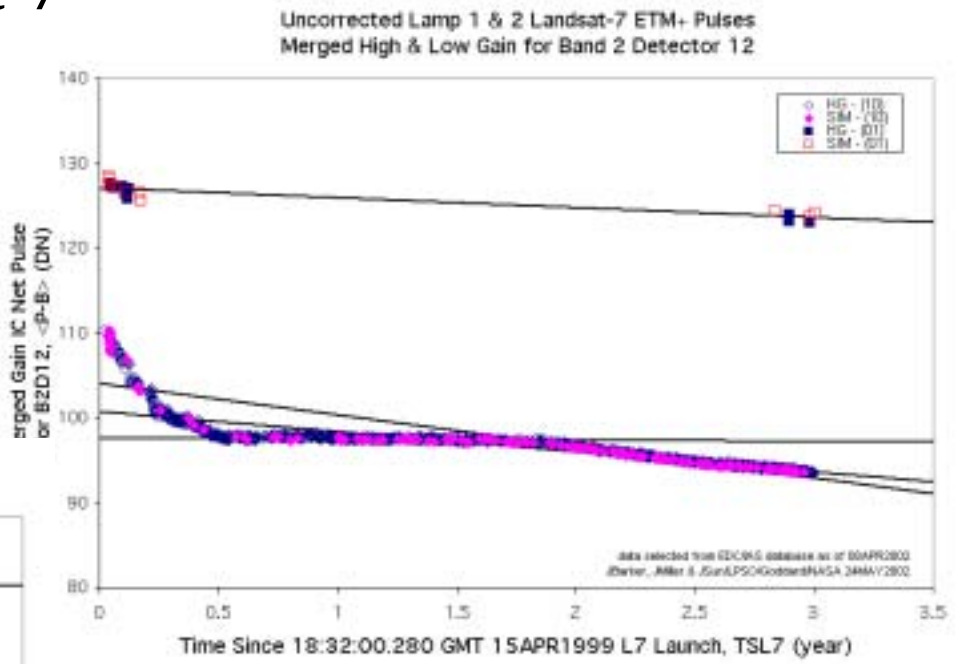


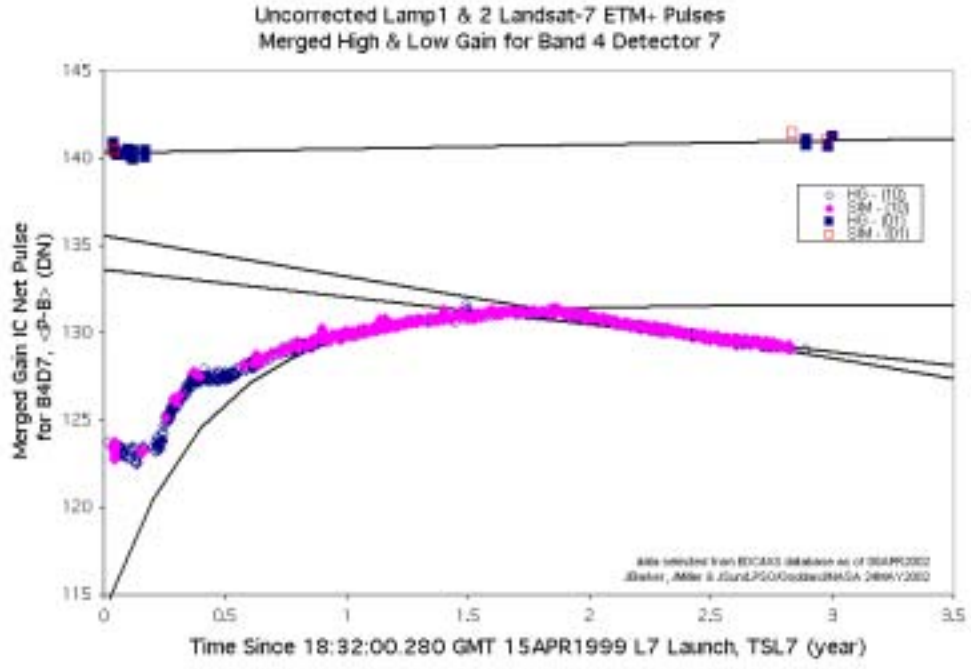
Normalized Lamp Response Band 4



ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- Lamp Stability: Landsat 7





Courtesy Landsat Project Science Office, GSFC.

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- SNR

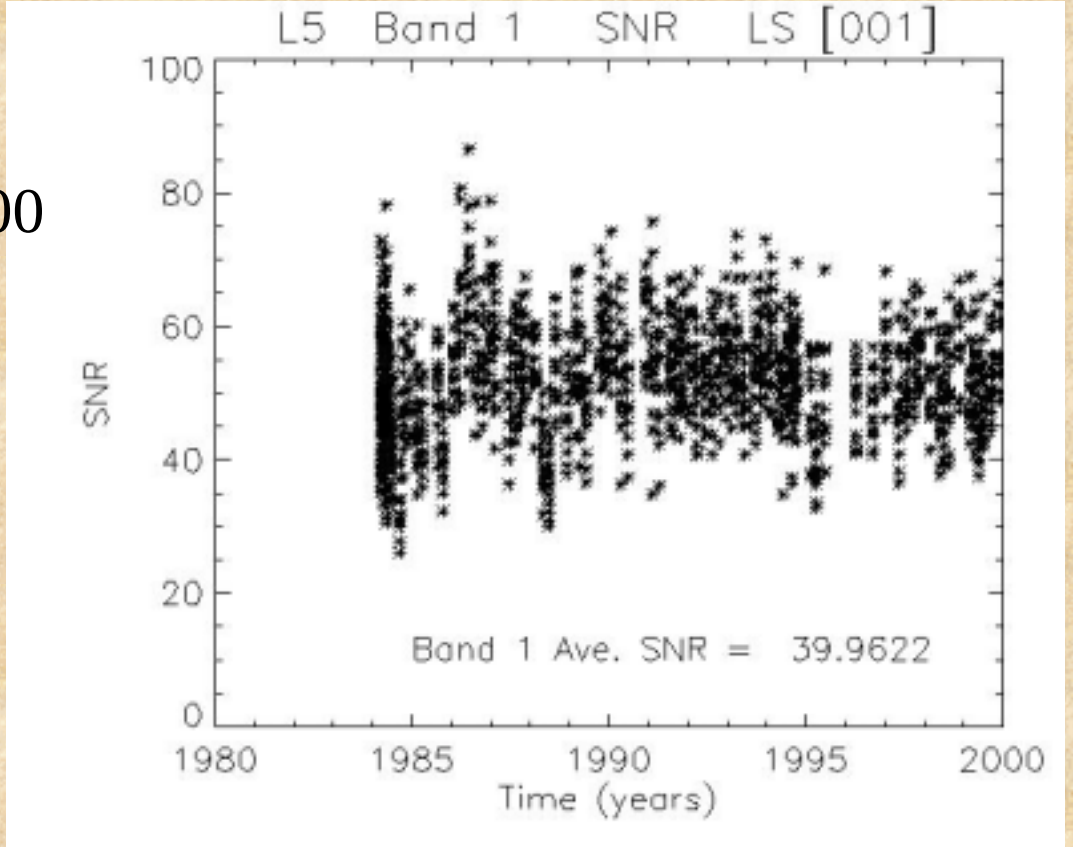
Definition:

$$SNR = \frac{\text{Mean Lamp Response}}{\text{Std. Dev. Of Lamp Response}}$$

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

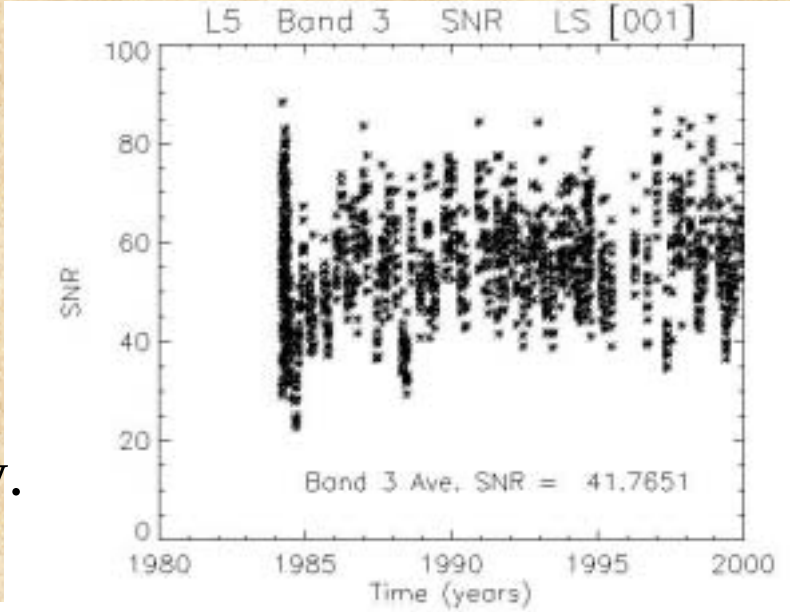
- SNR: Landsat 5

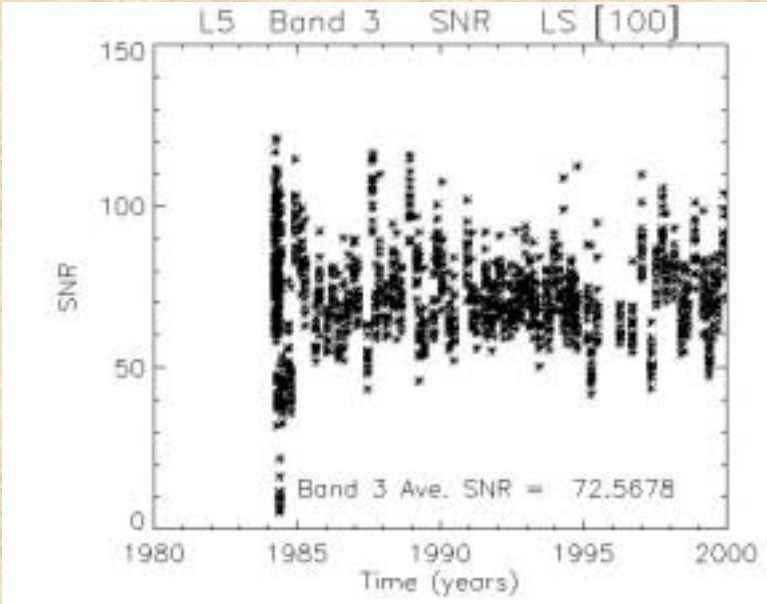
- Plotted from launch to 2000
- 16 detectors per band
- 3 independent lamp states

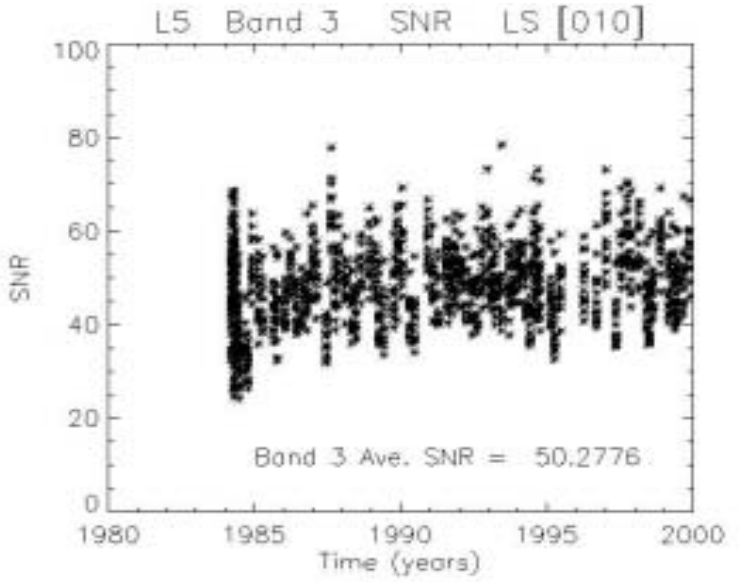


ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- SNR: Landsat 5
- Primary focal plane:
- Stable—no changes in 15 years!
- SNR directly related to lamp intensity.





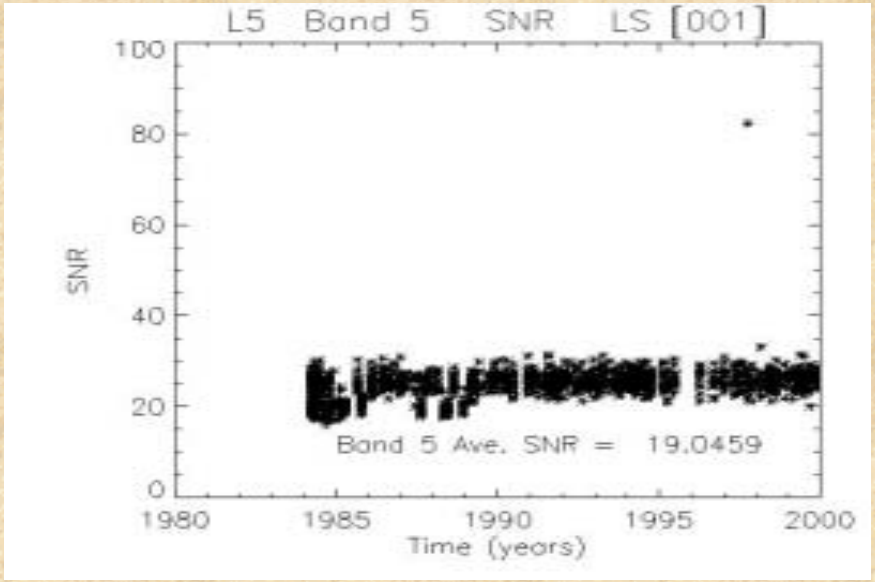


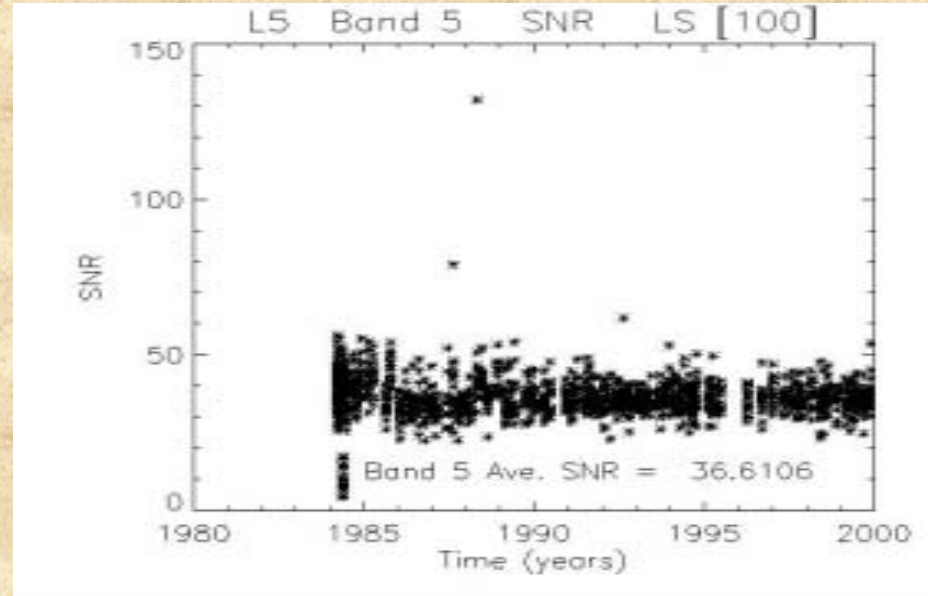
ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

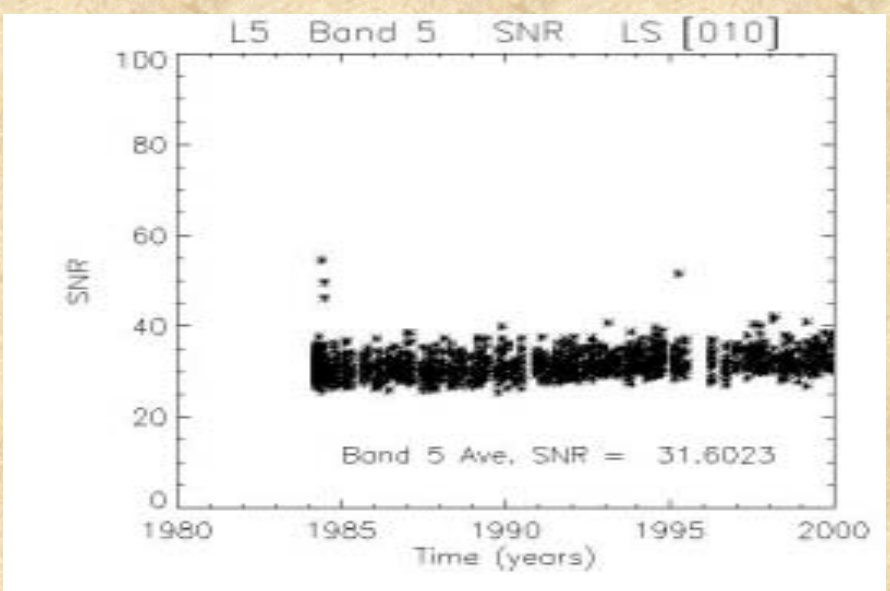
- SNR: Landsat 5

Cold Focal Plane:

- Less variation among detectors.
- Stable—no changes in 15 years!
- SNR also related to lamp intensity.







ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- SNR: Landsat 5

Landsat 5 SNR			
	LS 001	LS 010	LS 100
Band 1	40.0	56.5	90.4
Band 2	39.7	52.0	85.7
Band 3	41.8	50.3	72.6
Band 4	35.2	52.9	71.2
Band 5	19.0	31.6	36.6
Band 7	33.0	44.3	78.6

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

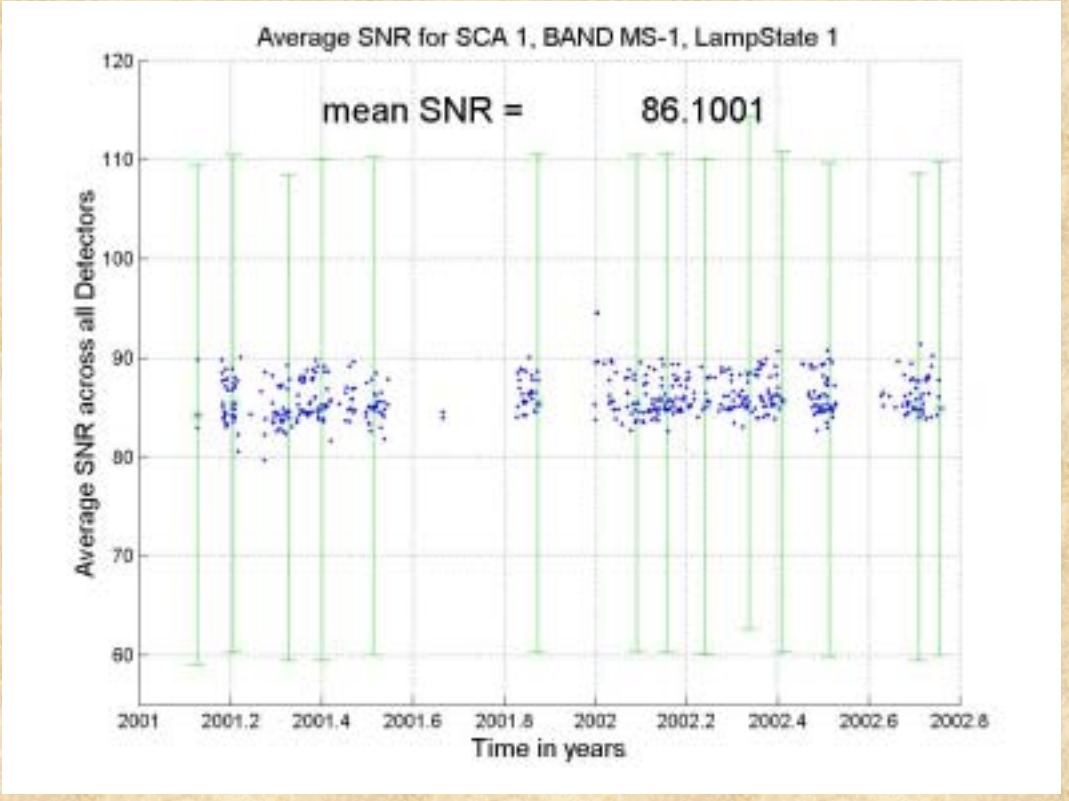
•SNR: ALI

•Plotted from Feb 2001 through August 2002.

•Mean and Std. For 320 detectors.

•4 SCA's

•3 independent lamp states

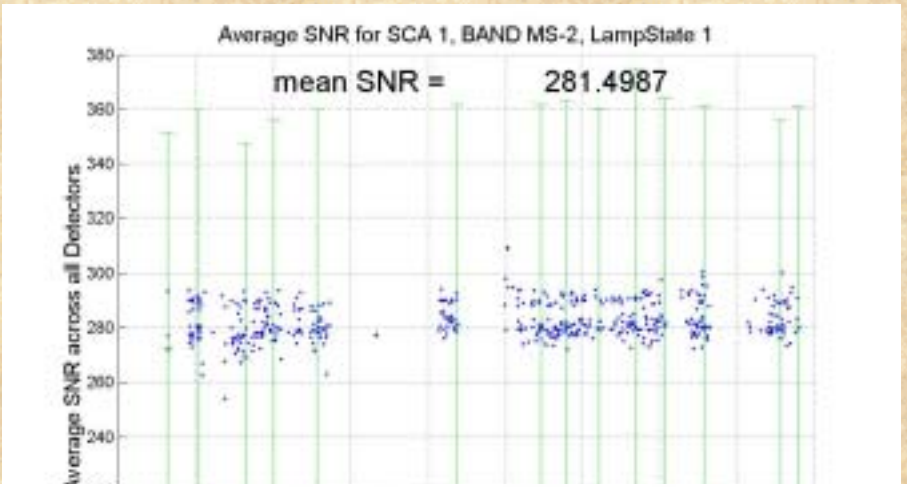


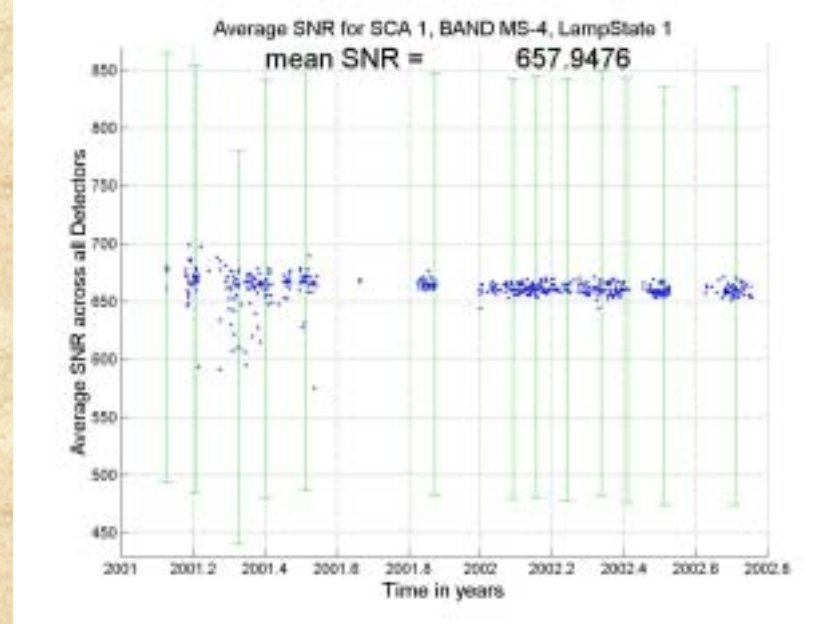
ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

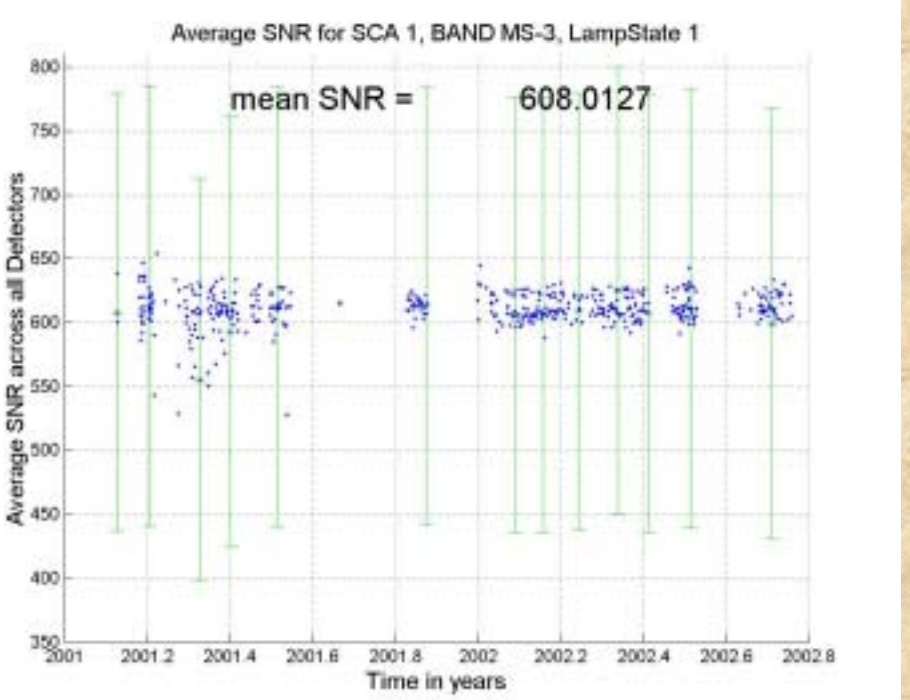
- SNR: ALI

Bands 1, 1p, 2, 3, 4, 4p, 5:

- No trends detectable.
- DN level and noise level increase with lamp state.







ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

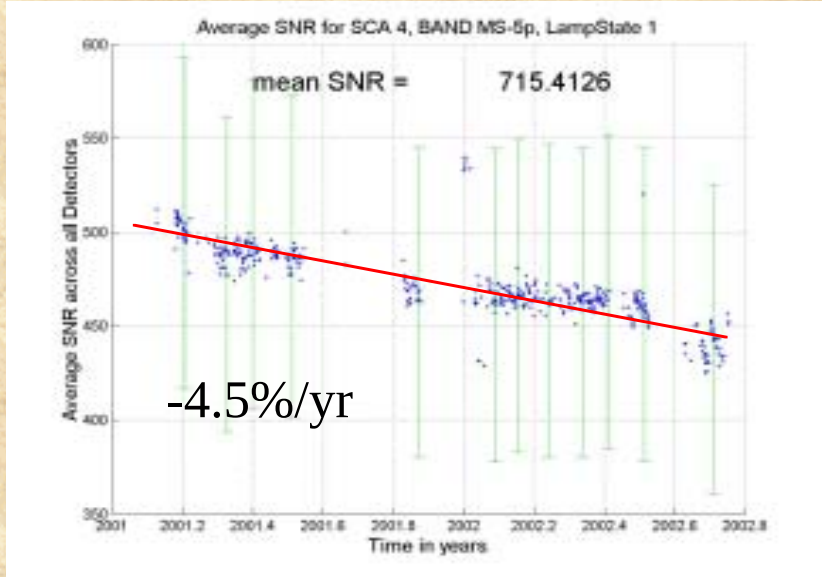
- SNR: ALI

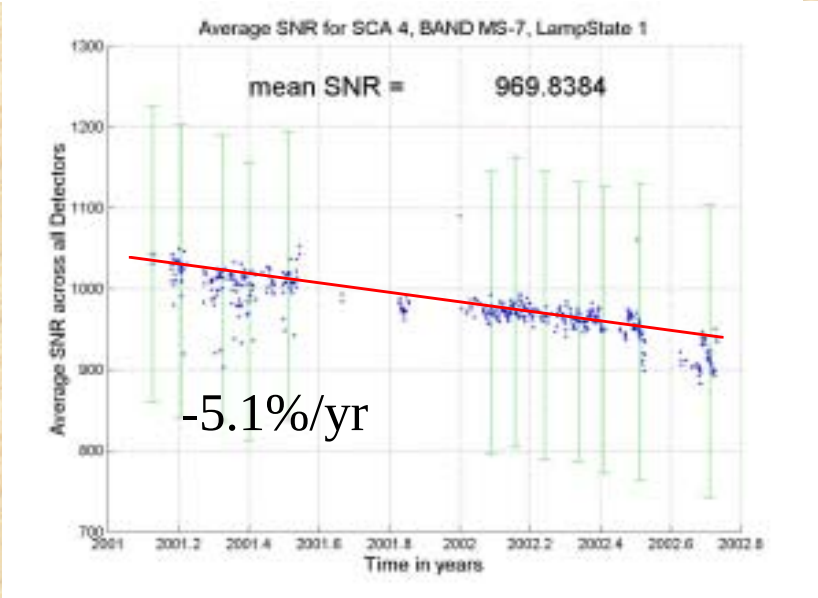
Bands 5p and 7:

Downward trends

4% to 5% per year

Primarily Lamp State 1 for Band 7, SCA 1 & 2





ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- SNR: ALI vs. Landsat 5

Landsat 5/ALI(SCA4) SNR			
	LS 001/LS3	LS 010/LS2	LS 100/LS1
Band 1	40.0/70.7	56.5/131	90.4/186
Band 2	39.7/254	52.0/450	85.7/605
Band 3	41.8/456	50.3/735	72.6/884
Band 4	35.2/420	52.9/645	71.2/812
Band 5	19.0/104	31.6/208	36.6/1262
Band 7	33.0/67.8	44.3/134	78.6/970

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

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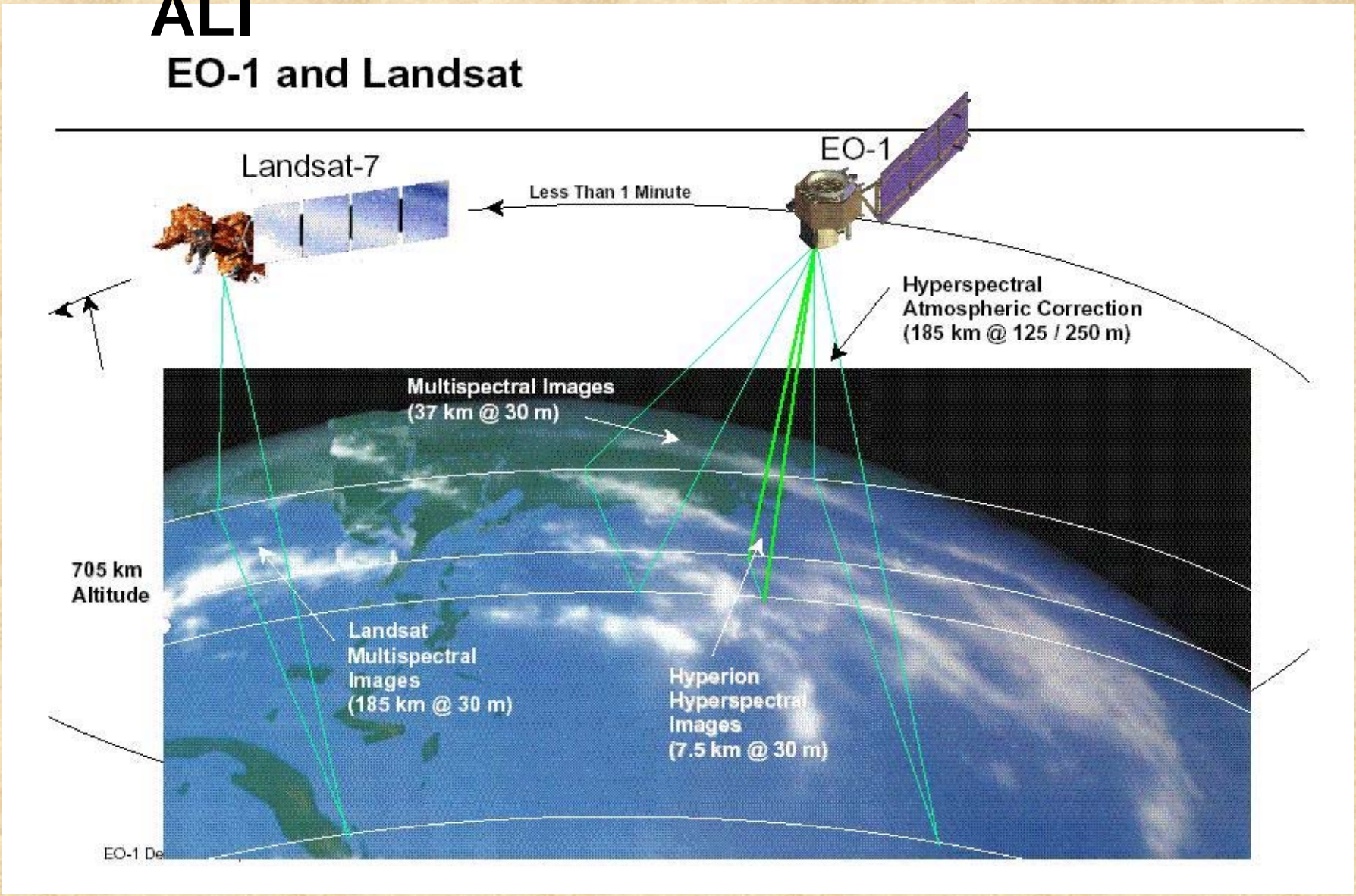
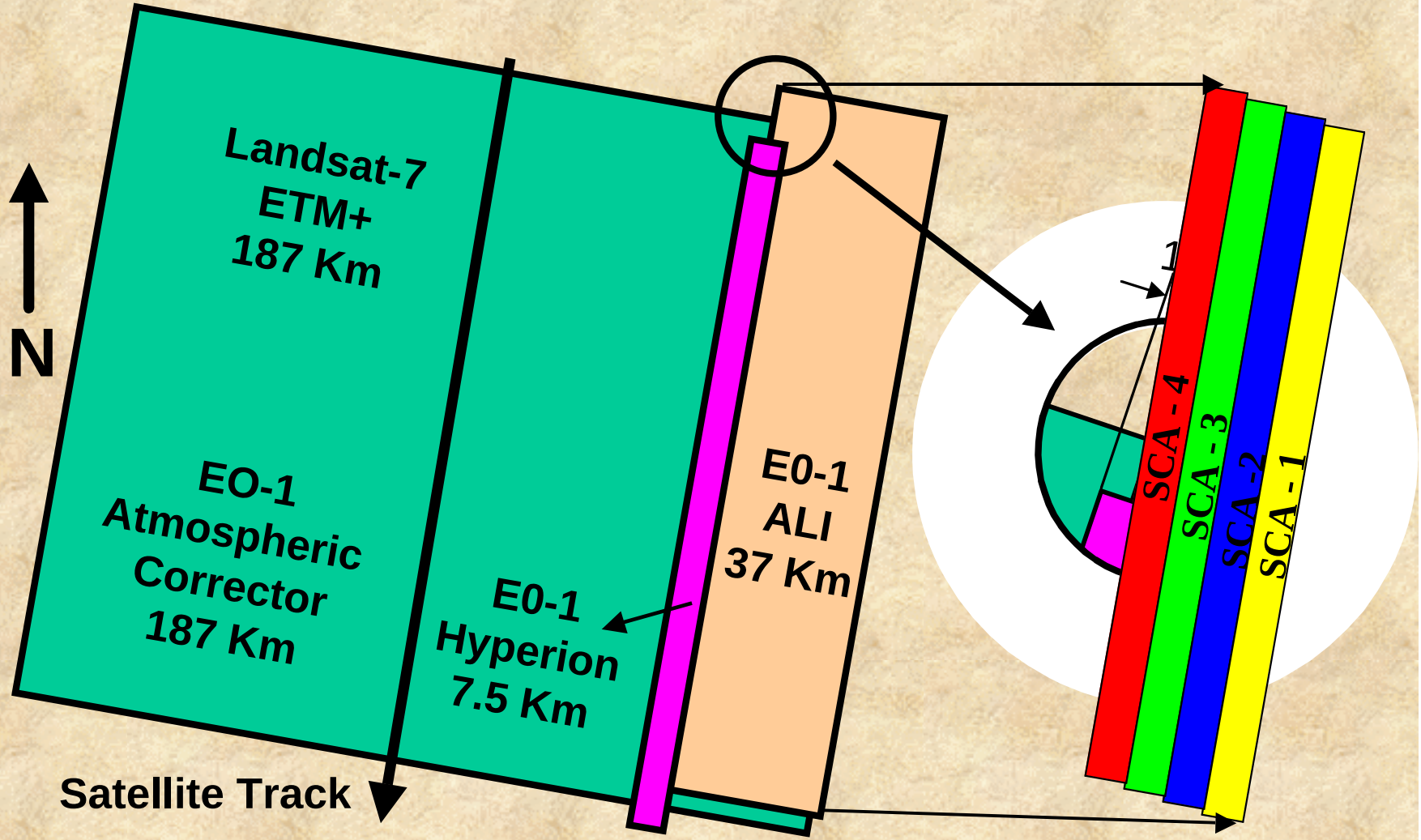
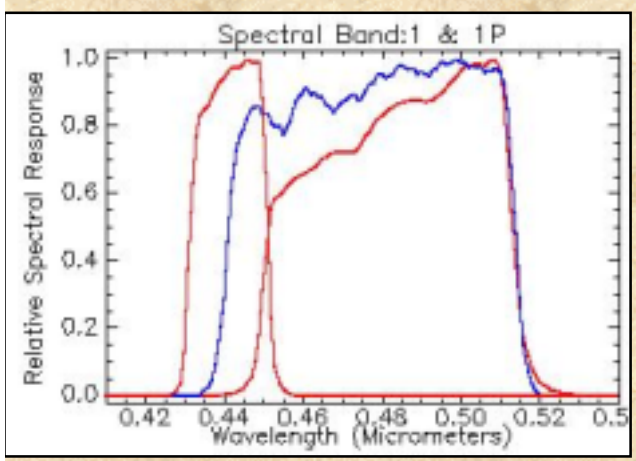
Cross-Calibration of ETM+ and ALI

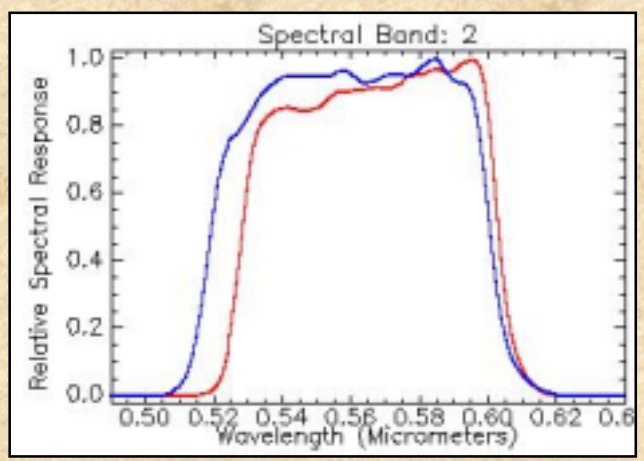


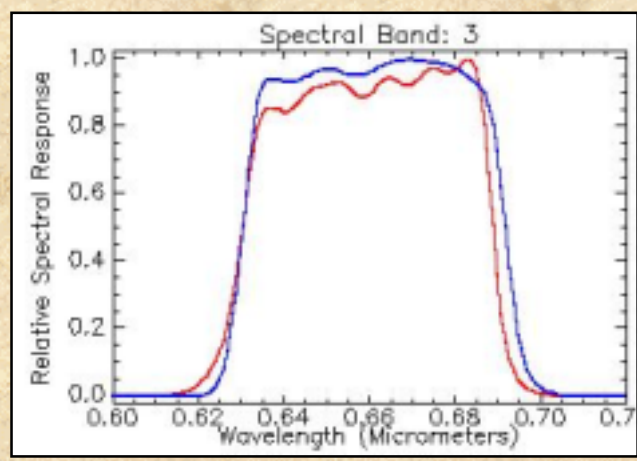
EO-1, L7 Descending Tracks

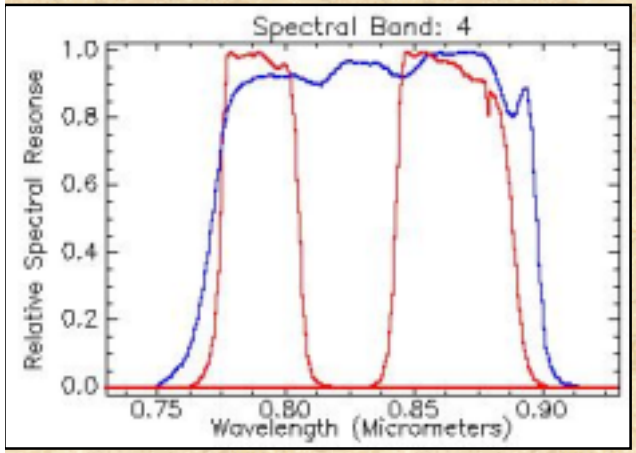


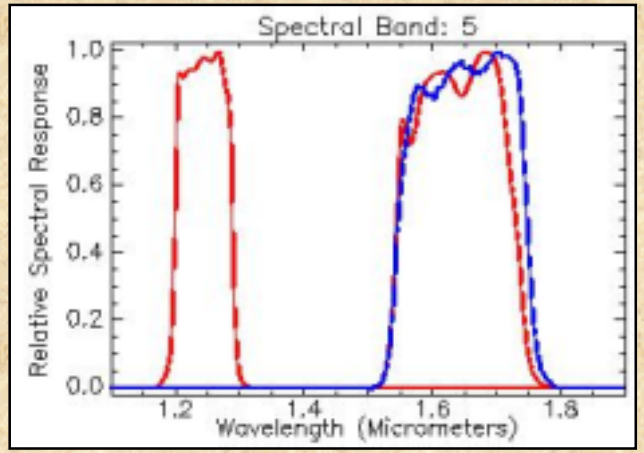
Relative Spectral Response (RSR) Profiles

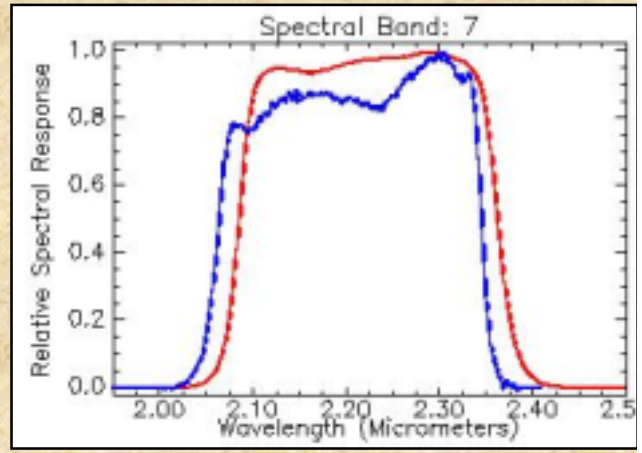












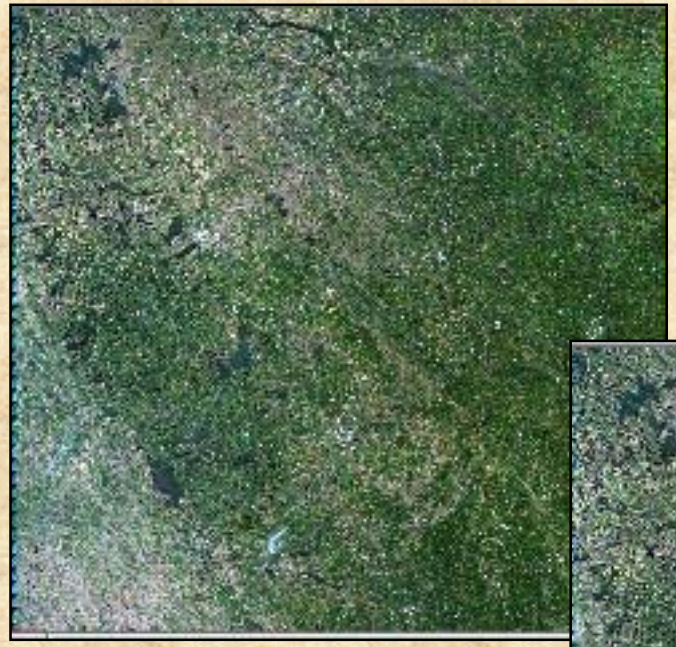
ALI **ETM+**

Cross-Calibration

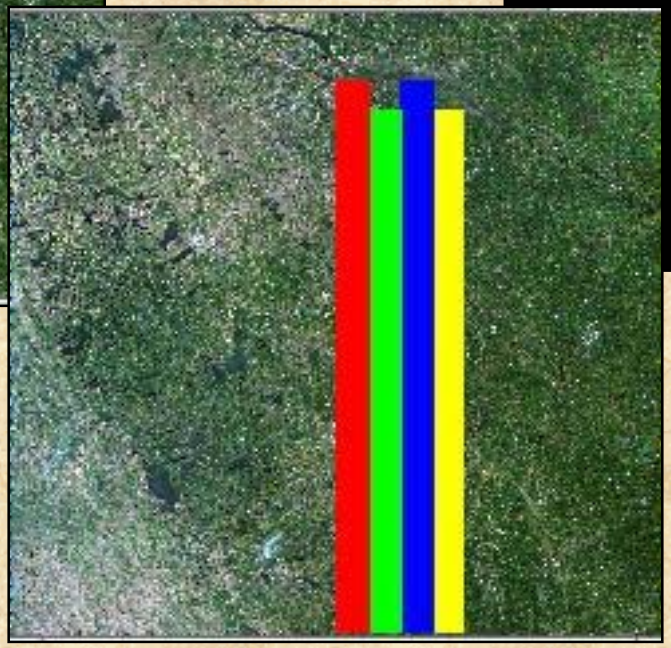
- Image Pairs from ALI and ETM+
  - Image statistics based on large common areas between the image pairs
  - Compared Predicted TOA radiance to measured radiance

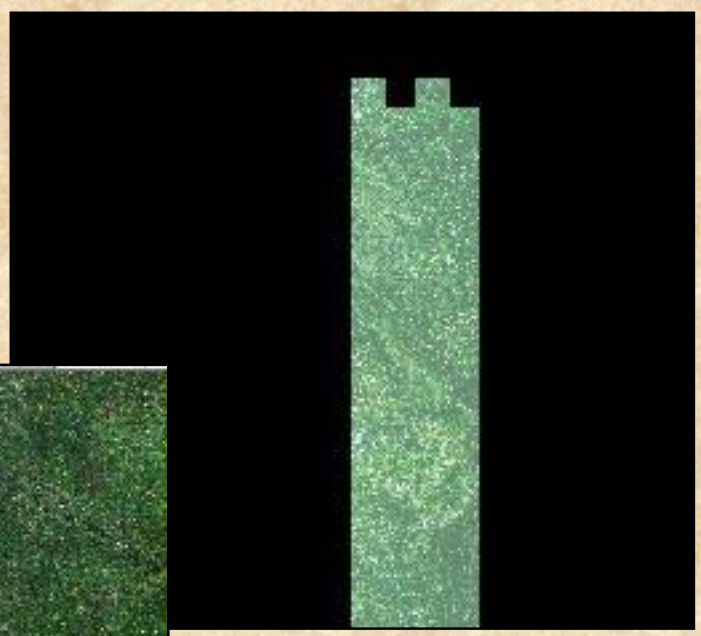
Location	Date	DOY	Path/Row
Brookings	Sept. 05, 2001.	248	029/029
Railroad Valley	June. 30, 2001.	181	040/033
White Sands	Mar. 25, 2001.	84	033/037

ETM+ / ALI Scenes from Brookings (DOY 248)



ETM+ Scene

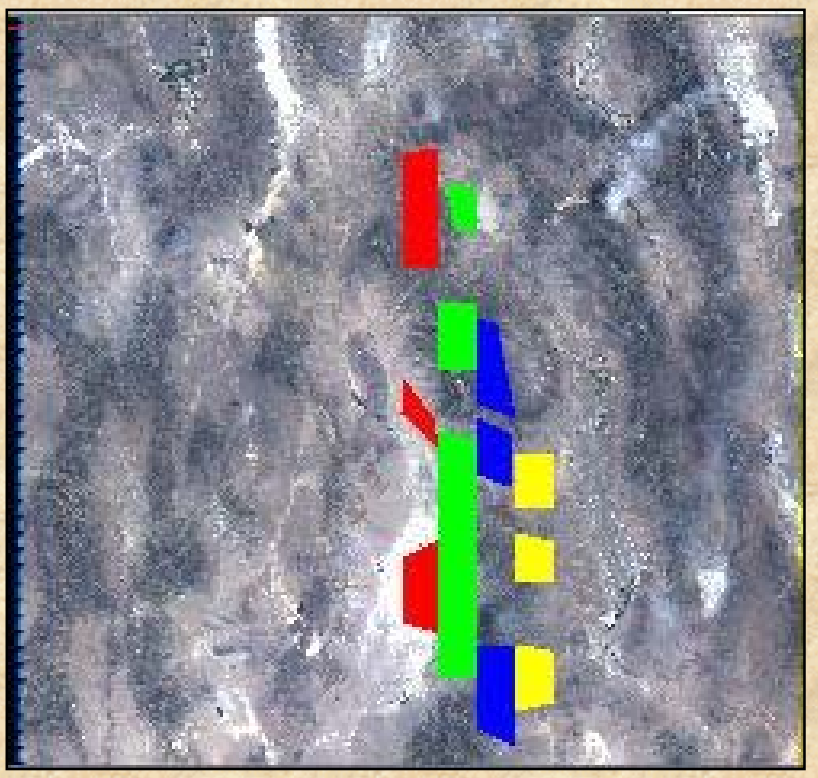




ETM+ region common to ALI scene

Common Ground Regions

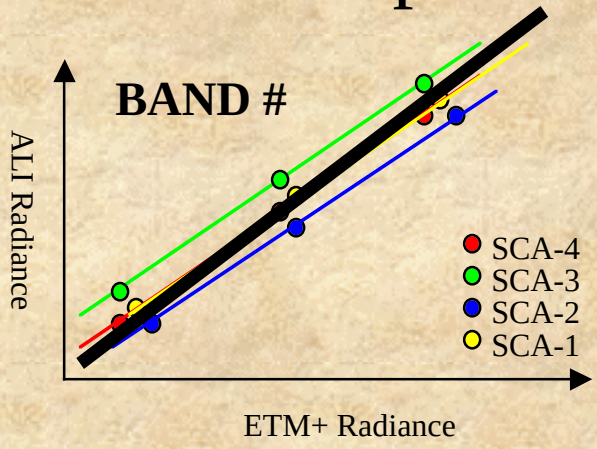
White Sands (084)



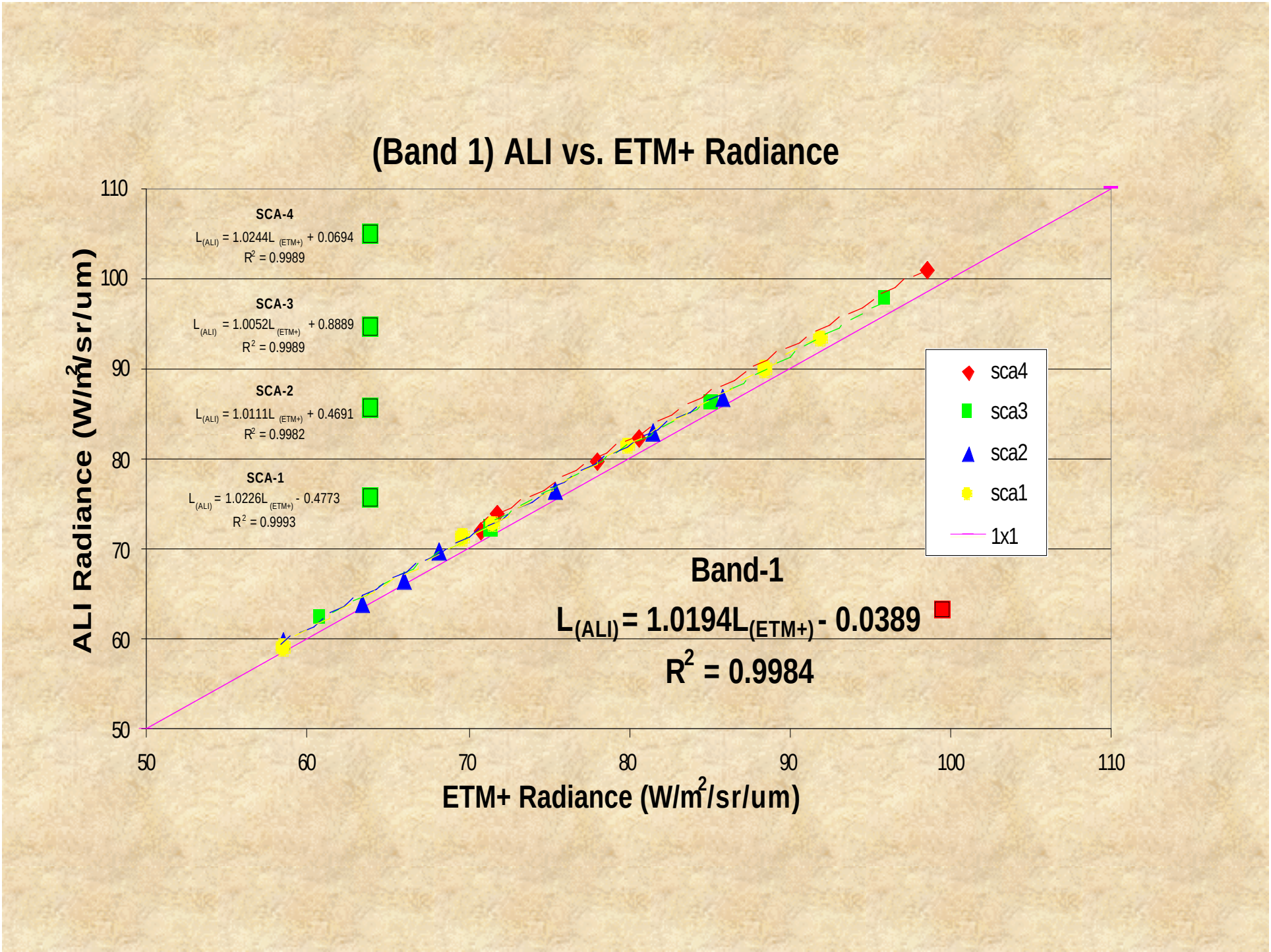
Railroad Valley (181)

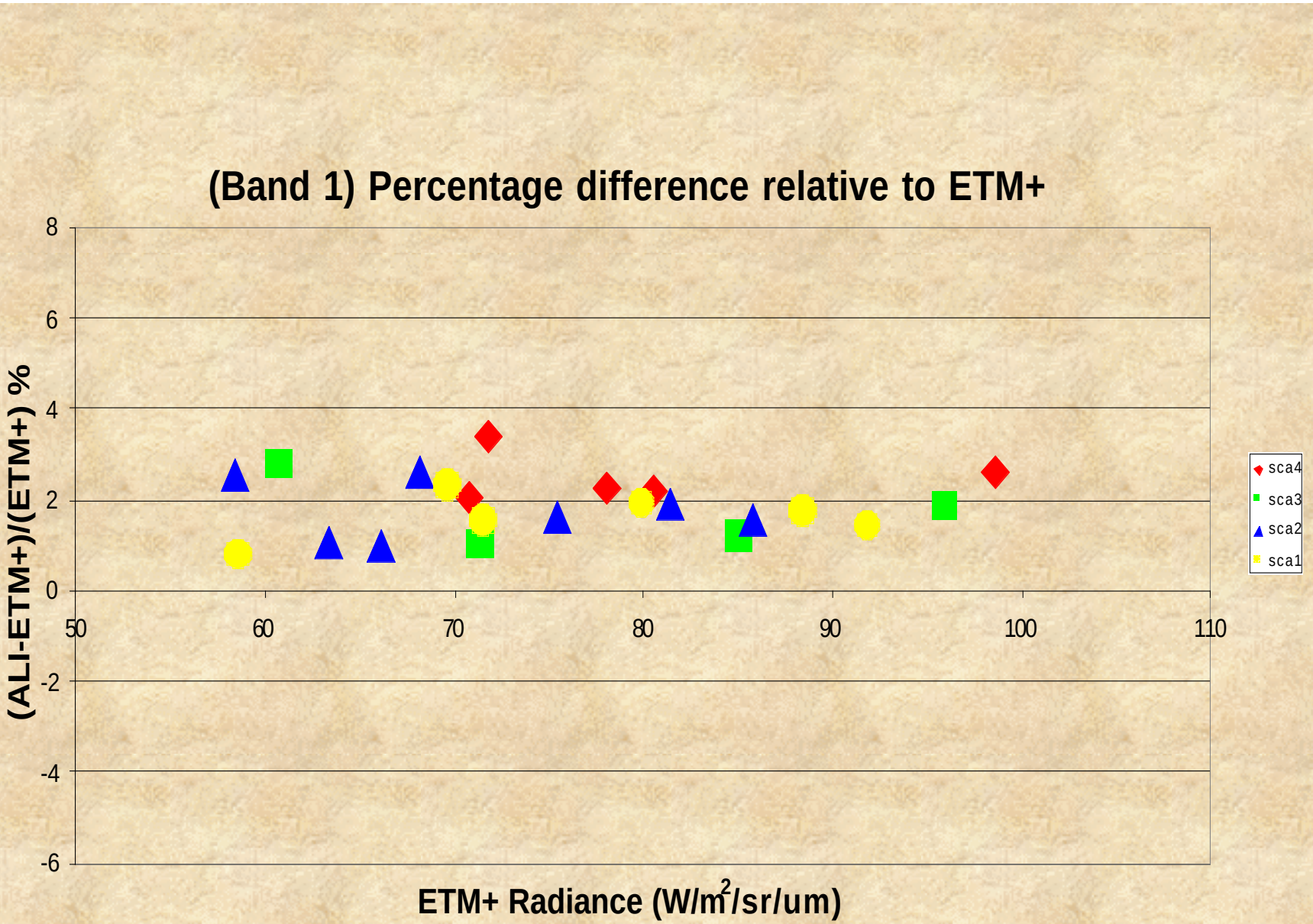
Hypothesis Test

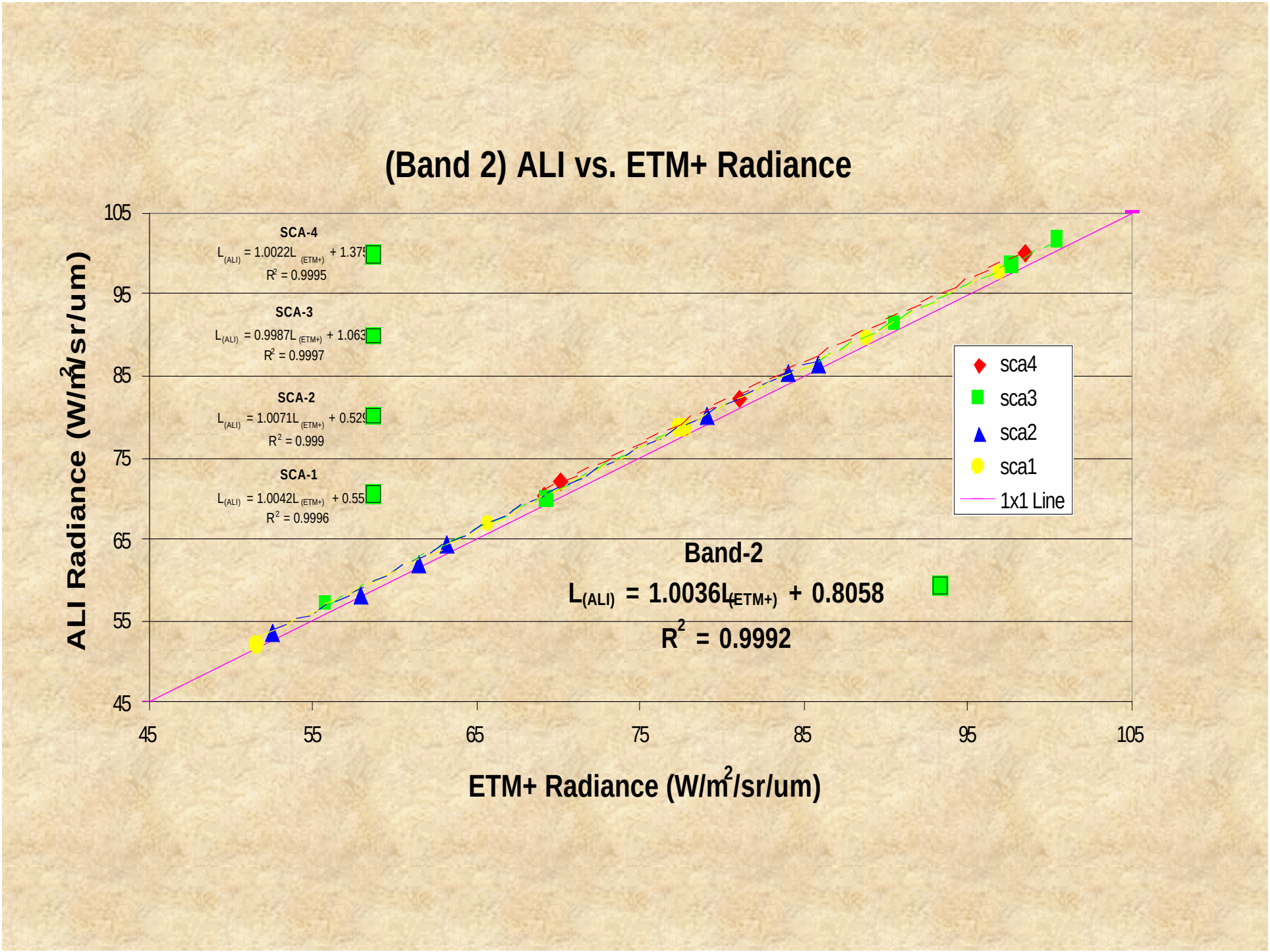
- Cross-Calibration results were tested for slope=1 and intercept=0:
  - Fitting a regression line to each SCA data common to ALI /ETM+
    - $L_{(ALI)} = \beta_1 L_{(ETM+)} + \beta_0$
  - Applying a slope/intercept hypothesis test to the regression lines

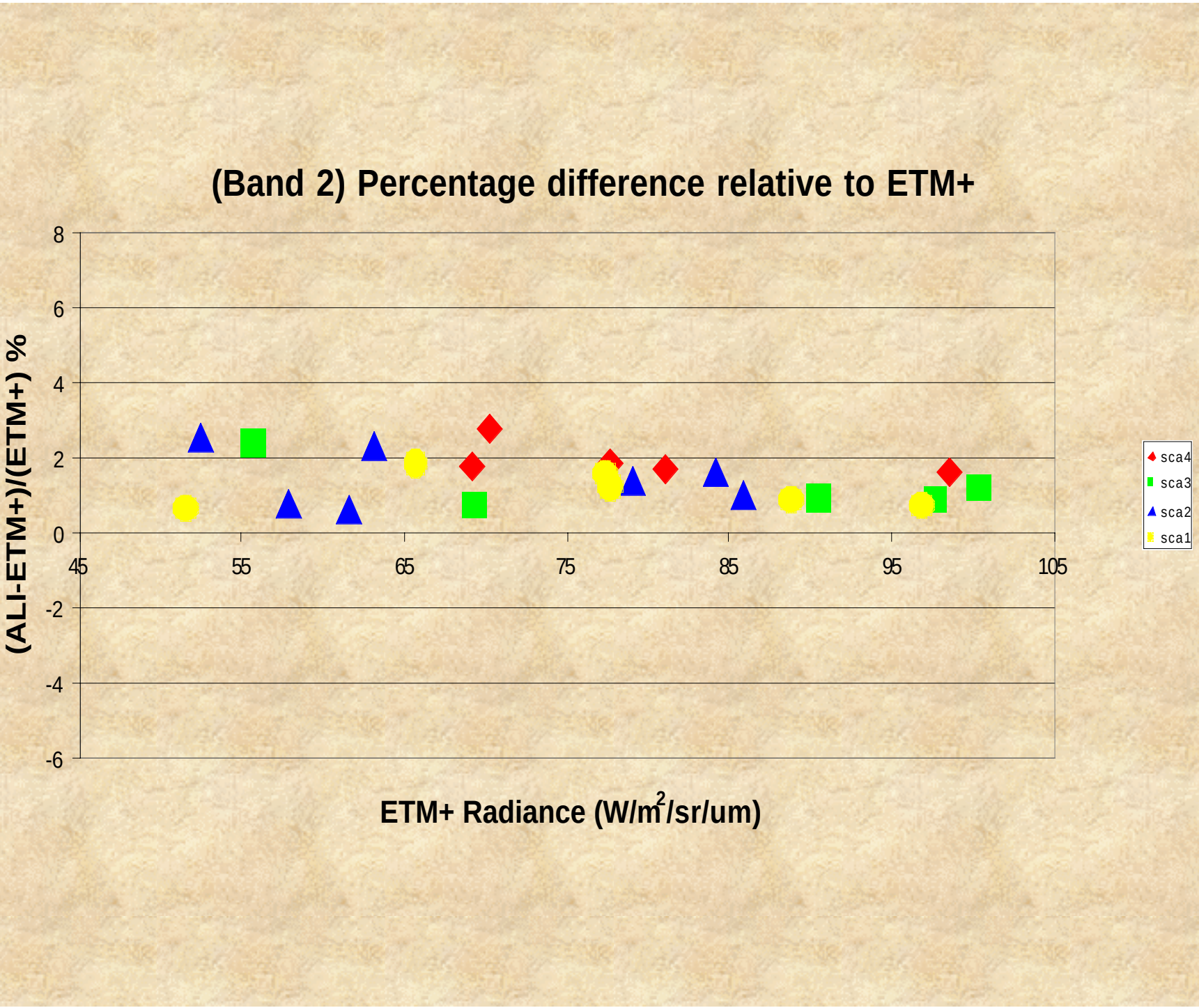


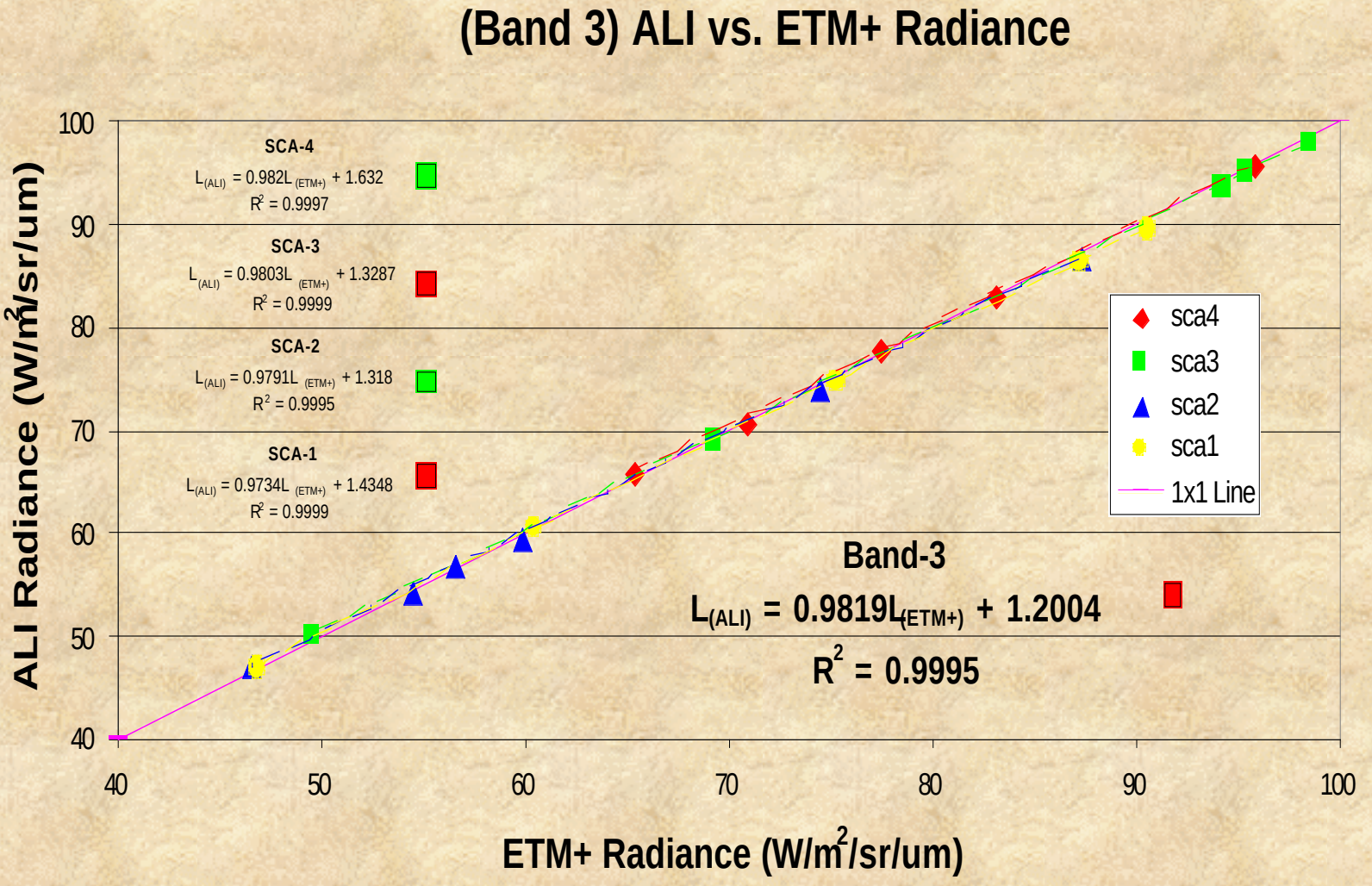
SLOPE	*Intercept*
$H_o: \beta_1 = 1$	$H_o: \beta_0 = 0$
$H_1: \beta_1 \neq 1$	$H_1: \beta_0 \neq 0$

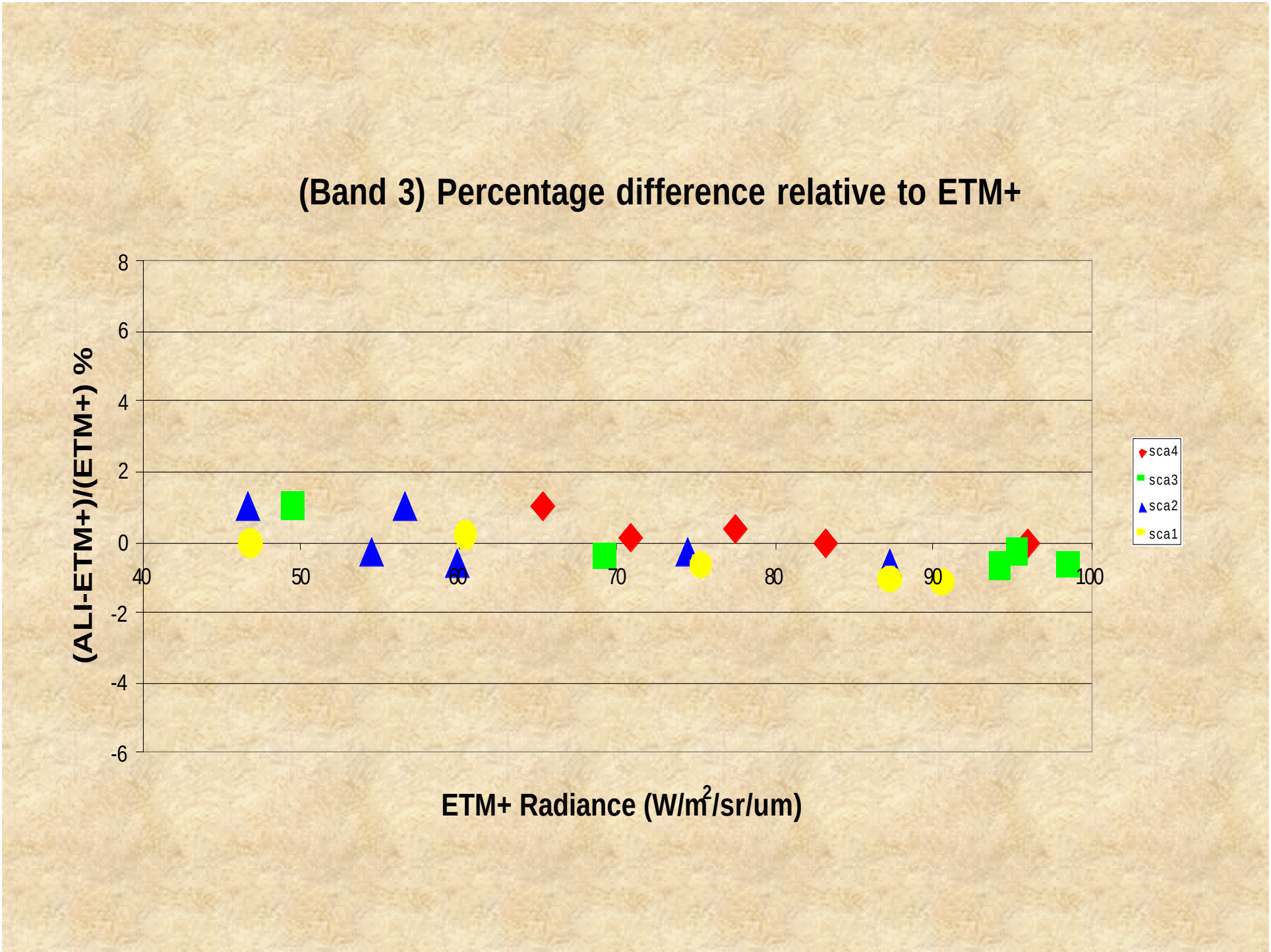

(Band 1) ALI vs. ETM+ Radiance
SCA-4
L(ALI) = 1.0244L (ETM+) + 0.0694
R2 = 0.9989
SCA-3
L(ALI) = 1.0052L (ETM+) + 0.8889
R2 = 0.9989
SCA-2
L(ALI) = 1.0111L (ETM+) + 0.4691
R2 = 0.9982
SCA-1
L(ALI) = 1.0226L (ETM+) - 0.4773
R2 = 0.9993
sca4
sca3
sca2
sca1
1x1
Band-1
L(ALI) = 1.0194L(ETM+) - 0.0389
R2 = 0.9984
ALI Radiance (W/m2/sr/um)
ETM+ Radiance (W/m2/sr/um)
110
100
90
80
70
60
50
50
60
70
80
90
100
110

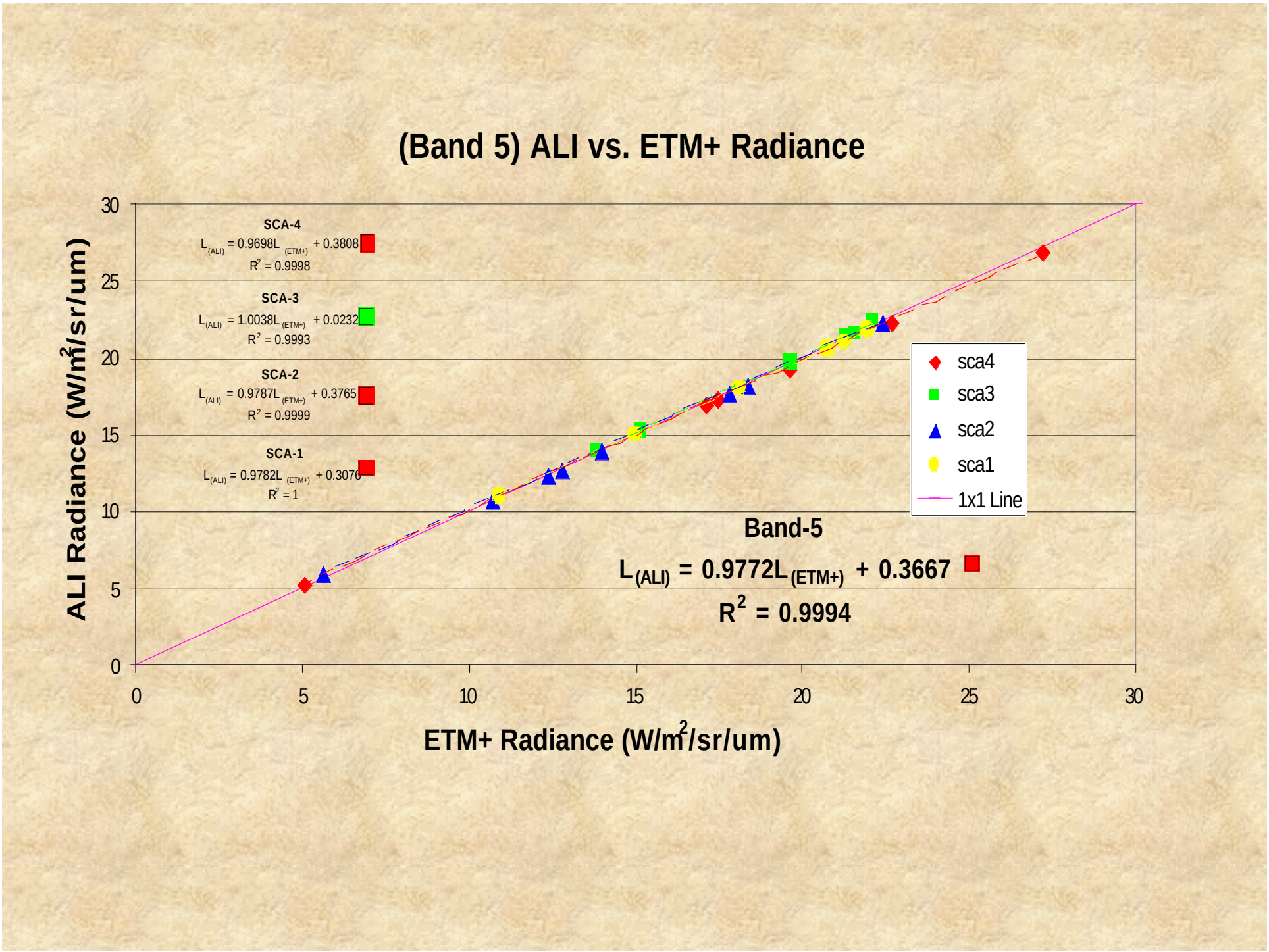

(Band 1) Percentage difference relative to ETM+
(ALI-ETM+)/(ETM+) %
8
6
4
2
0
-2
-4
-6
50
60
70
80
90
100
110
ETM+ Radiance (W/m2/sr/um)
sca4
sca3
sca2
sca1

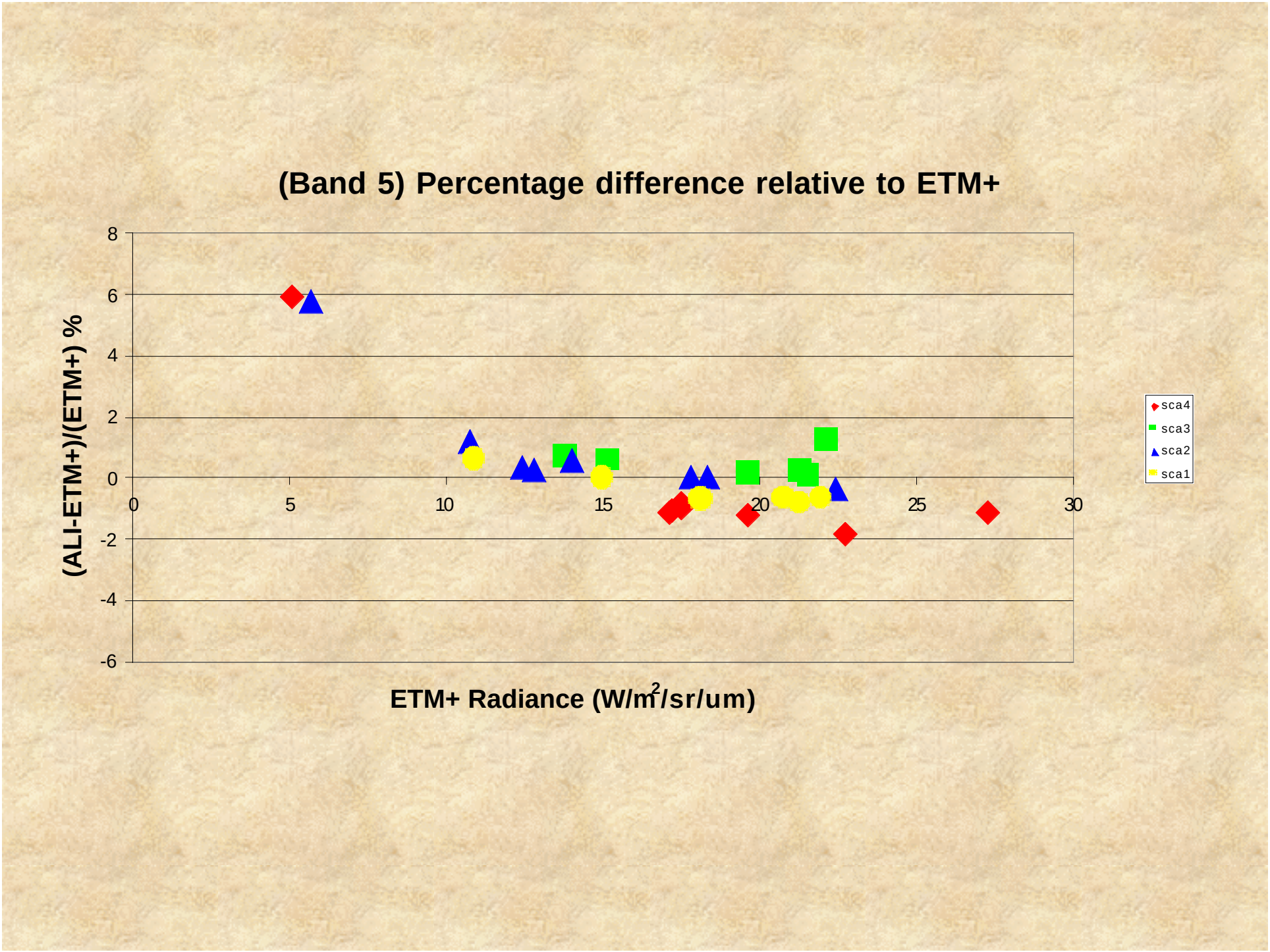

(Band 2) ALI vs. ETM+ Radiance
ALI Radiance (W/m2/sr/um)
ETM+ Radiance (W/m2/sr/um)
105
95
85
75
65
55
45
45
55
65
75
85
95
105
SCA-4
L(ALI) = 1.0022L (ETM+) + 1.37
R2 = 0.9995
SCA-3
L(ALI) = 0.9987L (ETM+) + 1.063
R2 = 0.9997
SCA-2
L(ALI) = 1.0071L (ETM+) + 0.529
R2 = 0.999
SCA-1
L(ALI) = 1.0042L (ETM+) + 0.55
R2 = 0.9996
Band-2
L(ALI) = 1.0036L(ETM+) + 0.8058
R2 = 0.9992
sca4
sca3
sca2
sca1
1x1 Line


(Band 2) Percentage difference relative to ETM+
(ALI-ETM+)/(ETM+) %
8
6
4
2
0
-2
-4
-6
45
55
65
75
85
95
105
ETM+ Radiance (W/m2/sr/um)
sca4
sca3
sca2
sca1


(Band 3) ALI vs. ETM+ Radiance
ALI Radiance (W/m2/sr/um)
ETM+ Radiance (W/m2/sr/um)
100
90
80
70
60
50
40
40
50
60
70
80
90
100
SCA-4
L(ALI) = 0.982L(ETM+) + 1.632
R2 = 0.9997
SCA-3
L(ALI) = 0.9803L(ETM+) + 1.3287
R2 = 0.9999
SCA-2
L(ALI) = 0.9791L(ETM+) + 1.318
R2 = 0.9995
SCA-1
L(ALI) = 0.9734L(ETM+) + 1.4348
R2 = 0.9999
sca4
sca3
sca2
sca1
1x1 Line
Band-3
L(ALI) = 0.9819L(ETM+) + 1.2004
R2 = 0.9995

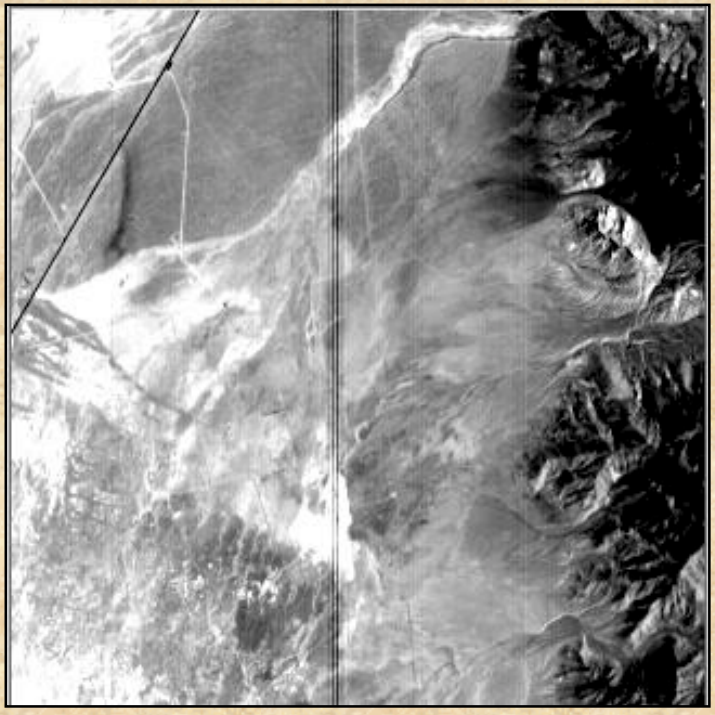

(Band 3) Percentage difference relative to ETM+
(ALI-ETM+)/(ETM+) %
8
6
4
2
0
-2
-4
-6
40
50
60
70
80
90
100
ETM+ Radiance (W/m2/sr/um)
sca4
sca3
sca2
sca1


(Band 5) ALI vs. ETM+ Radiance
ALI Radiance (W/m2/sr/um)
ETM+ Radiance (W/m2/sr/um)
0
5
10
15
20
25
30
SCA-4
L(ALI) = 0.9698L (ETM+) + 0.3808
R2 = 0.9998
SCA-3
L(ALI) = 1.0038L (ETM+) + 0.0232
R2 = 0.9993
SCA-2
L(ALI) = 0.9787L (ETM+) + 0.3765
R2 = 0.9999
SCA-1
L(ALI) = 0.9782L (ETM+) + 0.3076
R2 = 1
sca4
sca3
sca2
sca1
1x1 Line
Band-5
L(ALI) = 0.9772L(ETM+) + 0.3667
R2 = 0.9994


(Band 5) Percentage difference relative to ETM+
(ALI-ETM+)/(ETM+) %
8
6
4
2
0
-2
-4
-6
0
5
10
15
20
25
30
ETM+ Radiance (W/m2/sr/um)
sca4
sca3
sca2
sca1

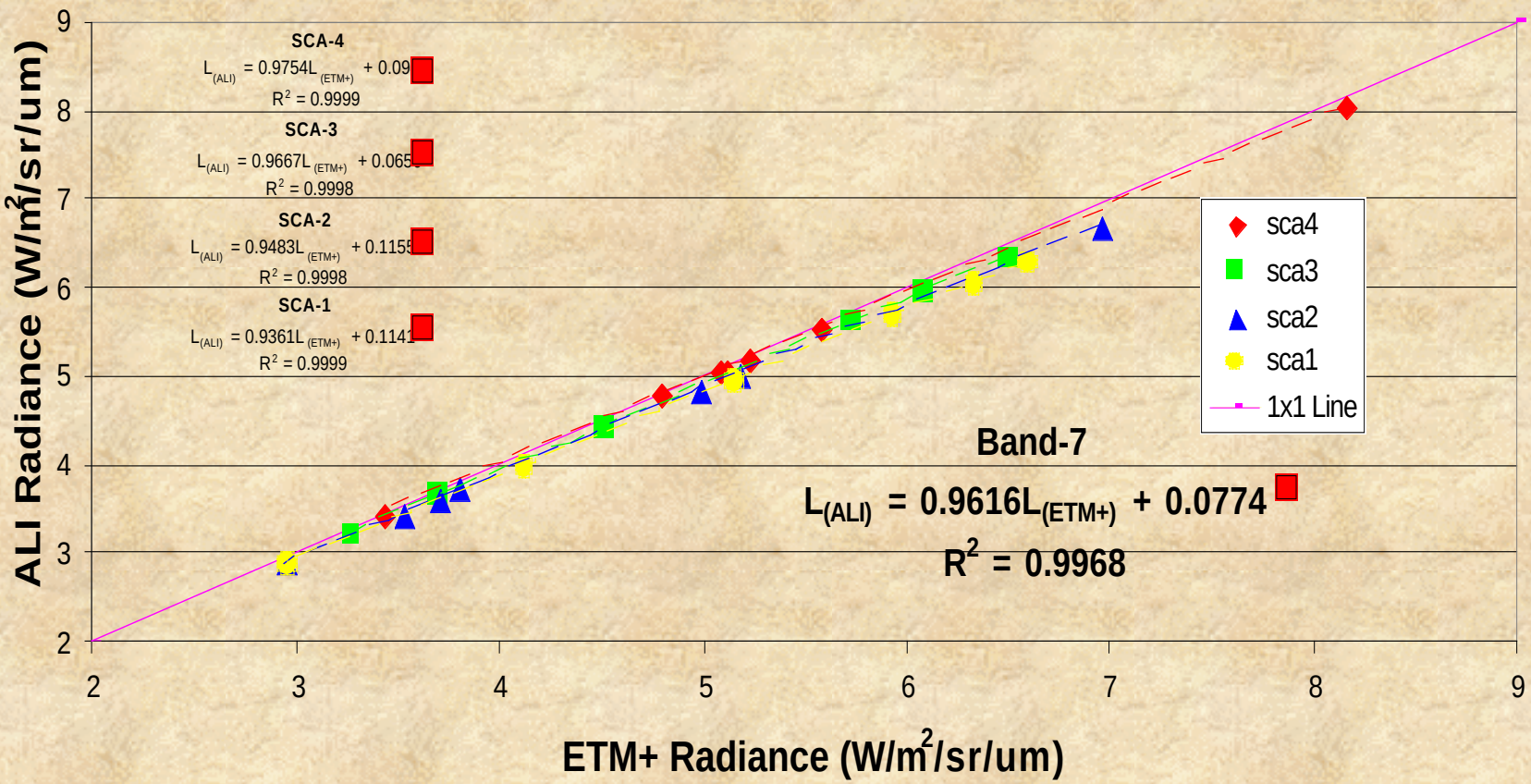
Anomalous detectors in Band-5

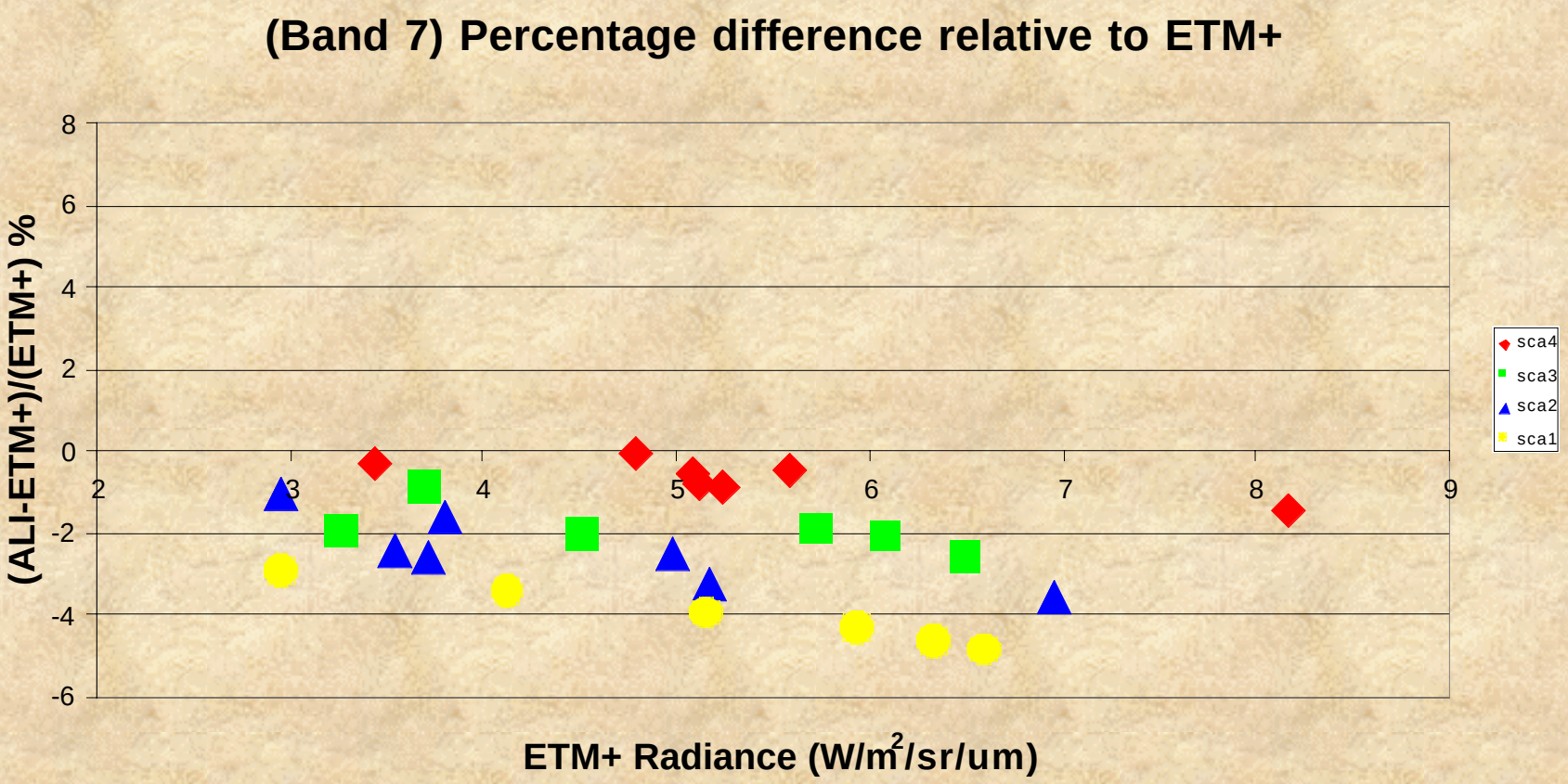
Band:5 (SCA-4)

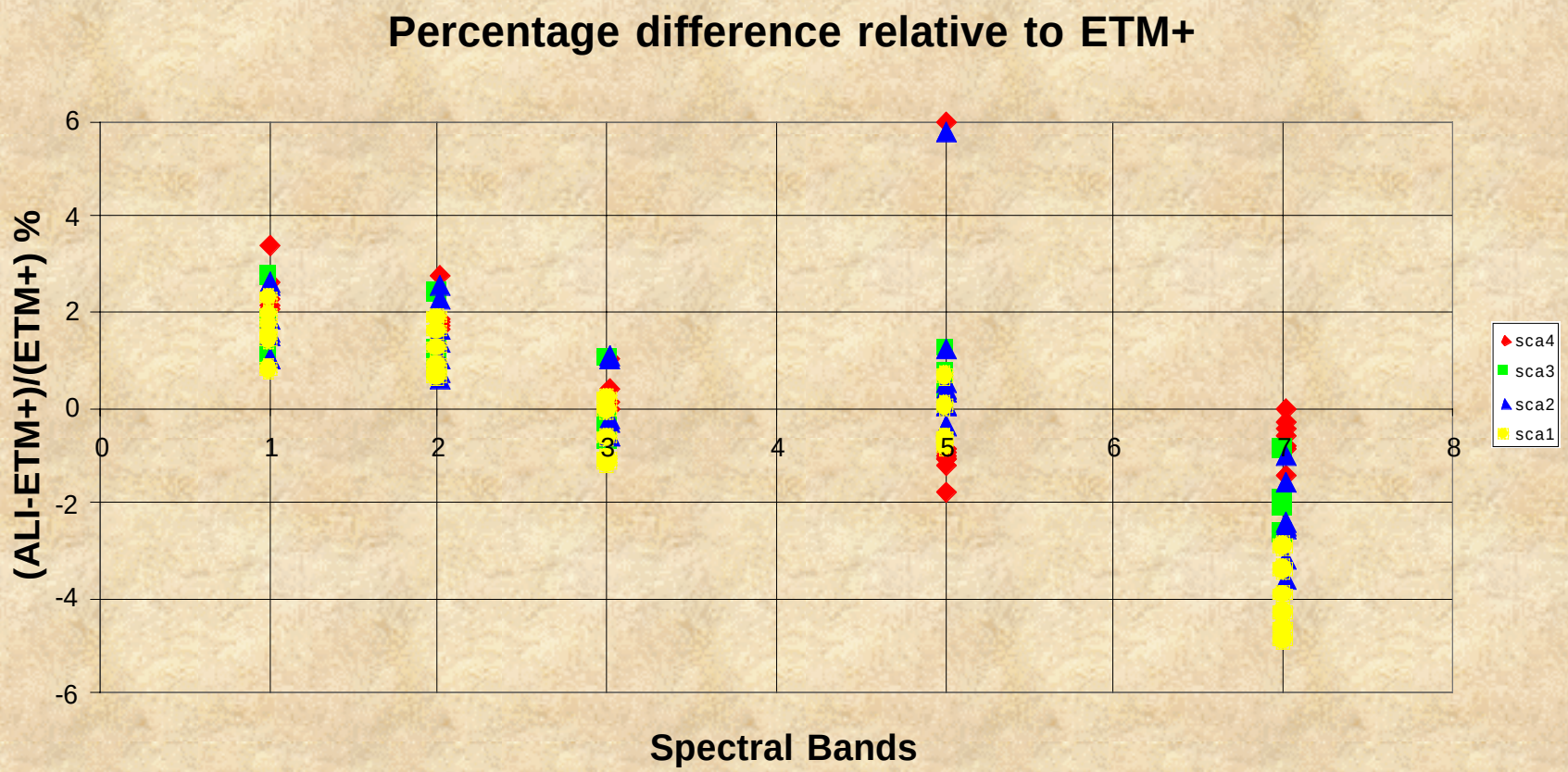


Band:5 (SCA-3)

(Band 7) ALI vs. ETM+ Radiance




(Band 7) Percentage difference relative to ETM+
(ALI-ETM+)/(ETM+) %
8
6
4
2
0
-2
-4
-6
2
3
4
5
6
7
8
9
ETM+ Radiance (W/m2/sr/um)
sca4
sca3
sca2
sca1


Percentage difference relative to ETM+
(ALI-ETM+)/(ETM+) %
6
4
2
0
-2
-4
-6
0
1
2
3
4
5
6
7
8
Spectral Bands
sca4
sca3
sca2
sca1

Results

- The hypothesis was tested at a significance level of α=0.05

Hypothesis Testing (H0: Slope=1)					
	Fail to reject the Null Hypothesis (Slope=1)				
	Reject the Null Hypothesis				
	SCA4	**SCA3**	**SCA2**	**SCA1**	**ALL**
Band1	1.0244	1.0052	1.0111	1.0226	1.0194
Band2	1.0022	0.9987	1.0071	1.0042	1.0036
Band3	0.982	0.9803	0.9791	0.9734	0.9819
Band5	0.9698	1.0038	0.9787	0.9782	0.9772
Band7	0.9754	0.9667	0.9483	0.9361	0.9616

- Results when hypothesis was tested at α=0.001

Hypothesis Testing (H0: Slope=1)					
	Fail to reject the Null Hypothesis (Slope=1)				
	Reject the Null Hypothesis				
	SCA4	**SCA3**	**SCA2**	**SCA1**	**ALL**
Band1	1.0244	1.0052	1.0111	1.0226	1.0194
Band2	1.0022	0.9987	1.0071	1.0042	1.0036
Band3	0.982	0.9803	0.9791	0.9734	0.9819
Band5	0.9698	1.0038	0.9787	0.9782	0.9772
Band7	0.9754	0.9667	0.9483	0.9361	0.9616

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- Summary and Conclusions
  - Bias Stability
    - All detectors stable within a collect with exception of SCA 1, Bands 5p and 7.
    - May want to consider averaging pre-cal and dark regions for these detectors for ‘long collects’.
    - 2 ‘noisy’ detectors, frame-by-frame differences of 50 DN.
    - Landsat bias stable during long collects.
  - Lamp/Detector System Stability
    - ALI Bands 1p-3 changing < -1%/yr.
    - ALI Bands 4, 4p changing ~ -1.5%/yr.
    - ALI Bands 5, 5p, 7 essentially stable.
    - Landsat 10% changes in first 2-3 years.

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- Summary and Conclusions
  - SNR
    - Large SNR, up to 1200, compared to <100 for Landsat 5.
    - ALI essentially constant, exception is Bands 5p,7 with ~5%/yr decrease.
    - Landsat 5 SNR constant, all bands, for 15 years!
  - ALI and ETM+ Cross-calibration
    - Differences tend to be 2% or less, except Band 7 (4%)
    - Linear model can substantially reduce difference.

ADVANCED LAND IMAGER: RADIOMETRIC PERFORMANCE AND COMPARISON TO LANDSAT

- Acknowledgements

  •Thanks to Steve Ungar, Lawrence Ong and the boys at GSFC for the opportunity and support!

  •Thanks to Jeff Mendenhall and Don Lencioni for ALI technical support!

ADVANCED LAND IMAGER HYPERION: GEOMETRIC PERFORMANCE

EO-1 Science Validation Team Meeting

Hilo, HA November 18-22

From EROS Data Center:

Jim Storey

Mike Choate (Presenter)

USGS science for a changing world

SDSU

ADVANCE LAND IMAGER: GEOMETRIC ANALYSIS OF FRAME RATE

3 data sets (Maricopa) with different frame rates used

- 228.365095 frames per second (nominal)
- 212.121180 frames per second
- 182.377713 frames per second

EDC EO1 ALI Geometric Software changed

- Relate all bands to common reference time
- Apply target range specific “detector offset”

Conclusion

Exact sample timing relationships needed between bands.
Especially when bands are sampled at different rates

HYPERION: GEOMETRIC CHARACTERIZATION AND CALIBRATION

Same approaches as used for ALI

Band alignment

- Correlation used to calculate offsets between band pairs
- Offsets used to calculate new line-of-sight equations

Sensor alignment

- Individual offsets measured using DOQ reference
- Time series of offsets used with Kalman Filter to determine new alignment matrices

Conclusions

Band alignment showed improvement

Sensor alignment proved more difficult. Possibly due to narrow field of view or timing uncertainty.