Landsat Archive Calibration Issues and Potential Strategy

Landsat Science Team Meeting
January 9, 2007
USGS EROS

Dennis Helder
South Dakota State University

The Team…

- South Dakota State University
  - Jim Dewald, Dave Aaron Larry Leigh
  - Rimy Malla, Cody Anderson, Sirish Uprety, Raj Bhatt, Dan Morstad
- USGS EROS
  - Ron Morfitt, Esad Micijevic, Gyanesh Chander, Obaidul Haque
- NASA GSFC
  - Brian Markham, Julia Barsi, Ed Kaita, Lawrence Ong, Raviv Levy

The Team…

- South Dakota State University
  - Jim Dewald, Dave Aaron Larry Leigh
  - Rimy Malla, Cody Anderson, Sirish Uprety, Raj Bhatt, Dan Morstad
- USGS EROS
  - Ron Morfitt, Esad Micijevic, Gyanesh Chander, Obaidul Haque
- NASA GSFC
  - Brian Markham, Julia Barsi, Ed Kaita, Lawrence Ong, Raviv Levy

The Team…

- South Dakota State University
  - Jim Dewald, Dave Aaron Larry Leigh
  - Rimy Malla, Cody Anderson, Sirish Uprety, Raj Bhatt, Dan Morstad
- USGS EROS
  - Ron Morfitt, Esad Micijevic, Gyanesh Chander, Obaidul Haque
- NASA GSFC
  - Brian Markham, Julia Barsi, Ed Kaita, Lawrence Ong, Raviv Levy

The Team…

- South Dakota State University
  - Jim Dewald, Dave Aaron Larry Leigh
  - Rimy Malla, Cody Anderson, Sirish Uprety, Raj Bhatt, Dan Morstad
- USGS EROS
  - Ron Morfitt, Esad Micijevic, Gyanesh Chander, Obaidul Haque
- NASA GSFC
  - Brian Markham, Julia Barsi, Ed Kaita, Lawrence Ong, Raviv Levy

The Team…

- South Dakota State University
  - Jim Dewald, Dave Aaron Larry Leigh
  - Rimy Malla, Cody Anderson, Sirish Uprety, Raj Bhatt, Dan Morstad
- USGS EROS
  - Ron Morfitt, Esad Micijevic, Gyanesh Chander, Obaidul Haque
- NASA GSFC
  - Brian Markham, Julia Barsi, Ed Kaita, Lawrence Ong, Raviv Levy

The Team…

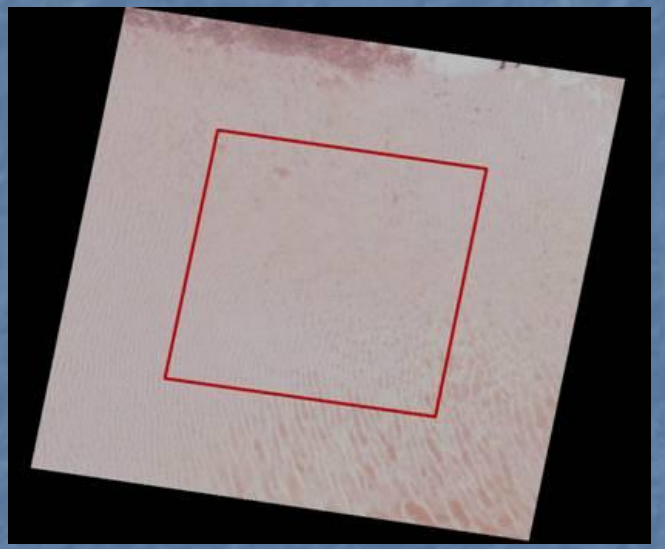
- South Dakota State University
  - Jim Dewald, Dave Aaron Larry Leigh
  - Rimy Malla, Cody Anderson, Sirish Uprety, Raj Bhatt, Dan Morstad
- USGS EROS
  - Ron Morfitt, Esad Micijevic, Gyanesh Chander, Obaidul Haque, Pat Scaramuzza
- NASA GSFC
  - Brian Markham, Julia Barsi, Ed Kaita, Lawrence Ong, Raviv Levy

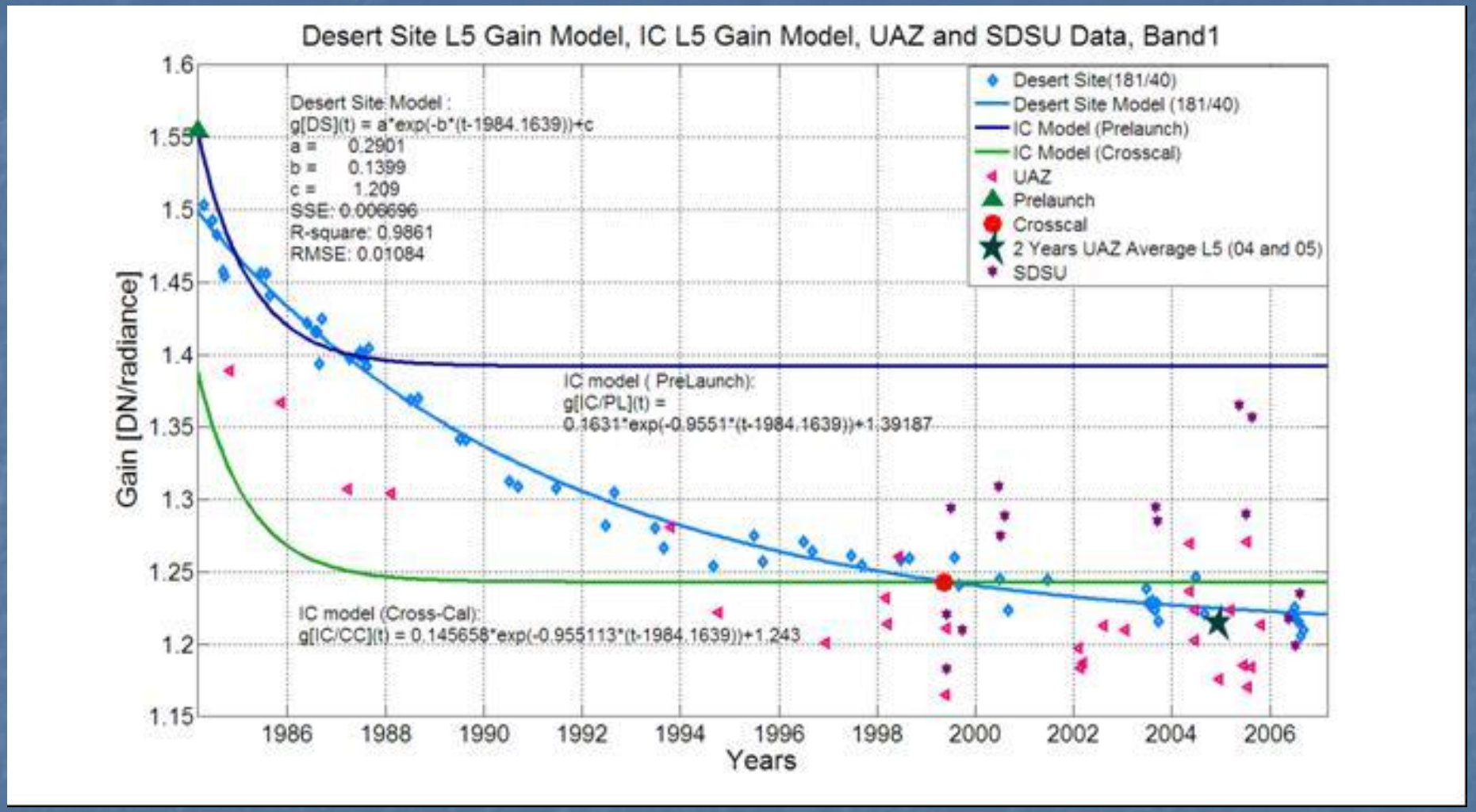
Landsat Archive Calibration Issues and Potential Strategy

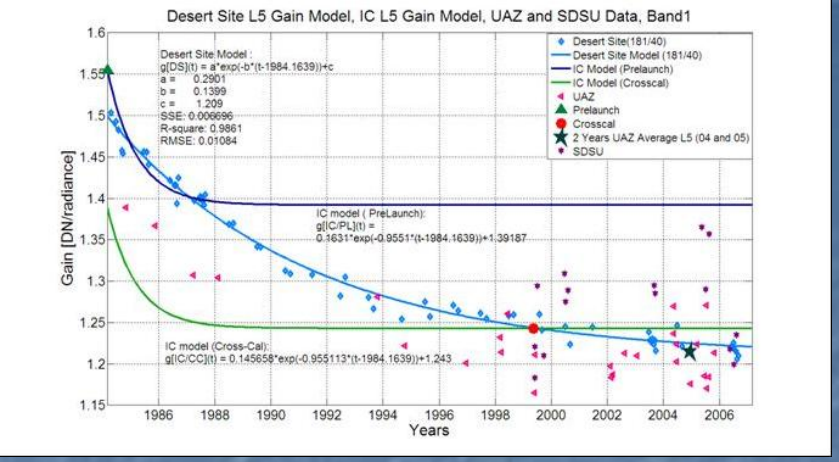
- Outline
  - Thematic Mappers
    - L5 TM to L7 ETM+
    - L4 TM to L5 TM
  - TM to MSS
    - L5 TM to MSS
    - L4 TM to MSS
  - L1 to L5 MSS
    - L4/5 MSS
    - L4 to L3 MSS – the critical step
    - L1 to L3 MSS – capturing the first decade

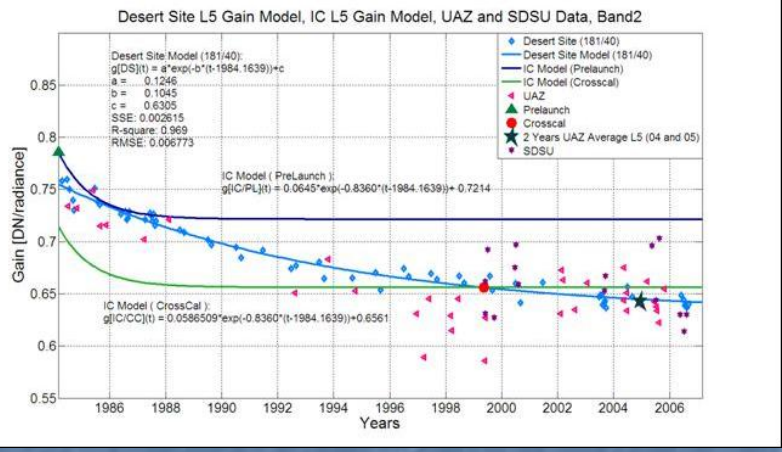
Landsat 5 Radiometric Gain Update Using Multiple Calibration Sources

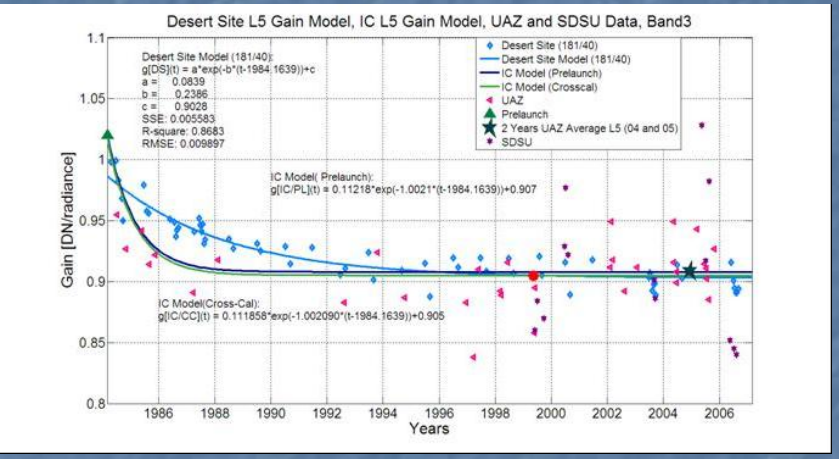
- Desert Sites used in L5 calibration update
  - Saharan location: Path 181 Row 40
  - Collaboration with CNES
  - Processing steps:
    - Center 3000 x 3000 pixels used
    - Level 0R data
    - Check for saturated pixels (Band 5)
    - Sun angle > 48.5^{o}
    - Earth-sun distance and SZA correction
    - Outgassing correction for cold focal bands

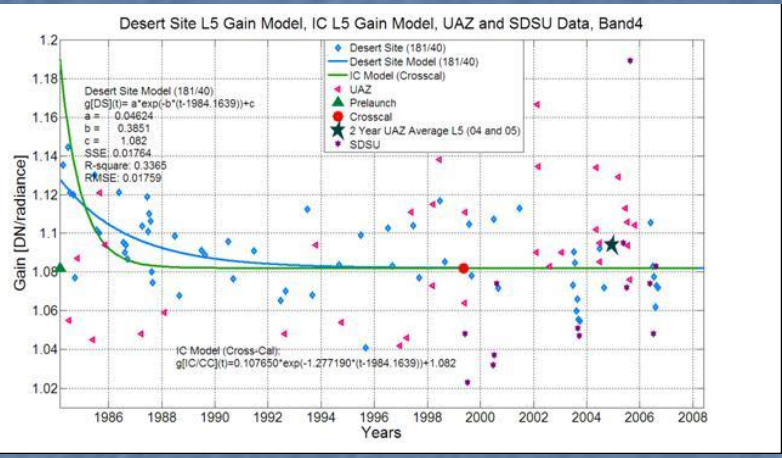


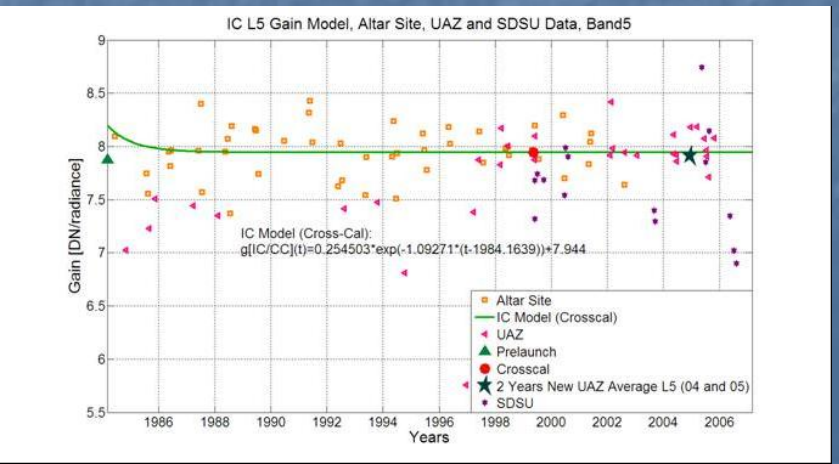

Desert Site L5 Gain Model, IC L5 Gain Model, UAZ and SDSU Data, Band1
Desert Site Model :
g[DS](t) = a*exp(-b*(t-1984.1639))+c
a = 0.2901
b = 0.1399
c = 1.209
SSE: 0.006696
R-square: 0.9861
RMSE: 0.01084
IC model (PreLaunch):
g[IC/PL](t) =
0.1631*exp(-0.9551*(t-1984.1639))+1.39187
IC model (Cross-Cal):
g[IC/CC](t) = 0.145658*exp(-0.955113*(t-1984.1639))+1.243
Desert Site(181/40)
Desert Site Model (181/40)
IC Model (Prelaunch)
IC Model (Crosscal)
UAZ
Prelaunch
Crosscal
2 Years UAZ Average L5 (04 and 05)
SDSU
Gain [DN/radiance]
Years
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006

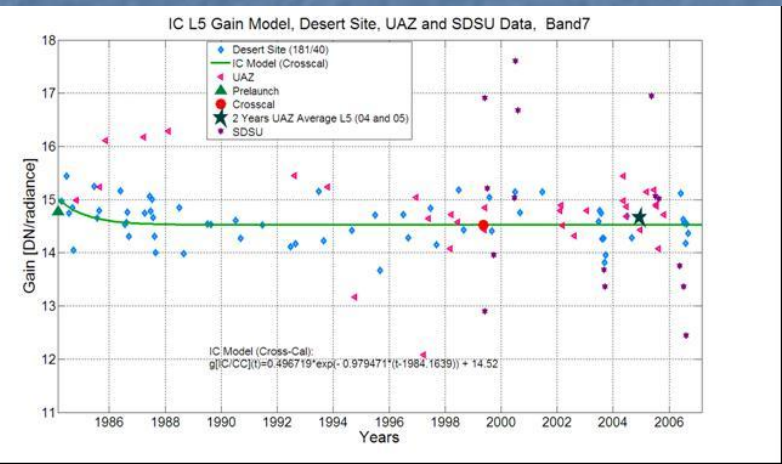

Desert Site L5 Gain Model, IC L5 Gain Model, UAZ and SDSU Data, Band1
Desert Site Model :
g[DS](t) = a*exp(-b*(t-1984.1639))+c
a = 0.2901
b = 0.1399
c = 1.209
SSE: 0.006696
R-square: 0.9861
RMSE: 0.01084
IC model (PreLaunch):
g[IC/PL](t) =
0.3631*exp(-0.9551*(t-1984.1639))+1.39187
IC model (Cross-Cal):
g[IC/CC](t) = 0.145658*exp(-0.955113*(t-1984.1639))+1.243
Desert Site(181/40)
Desert Site Model (181/40)
IC Model (Prelaunch)
IC Model (Crosscal)
UAZ
Prelaunch
Crosscal
2 Years UAZ Average L5 (04 and 05)
SDSU
Gain [DN/radiance]
Years


Desert Site L5 Gain Model, IC L5 Gain Model, UAZ and SDSU Data, Band2
Desert Site Model (181/40):
g[DS](t) = a*exp(-b*(t-1984.1639))+c
a = 0.1246
b = 0.1045
c = 0.6305
SSE: 0.002615
R-square: 0.969
RMSE: 0.006773
IC Model (PreLaunch):
g[IC/PL](t) = 0.0645*exp(-0.8360*(t-1984.1639))+ 0.7214
IC Model (CrossCal):
g[IC/CC](t) =0.0586509*exp(-0.8360*(t-1984.1639))+0.6561
Desert Site (181/40)
Desert Site Model (181/40)
IC Model (Prelaunch)
IC Model (Crosscal)
UAZ
Prelaunch
Crosscal
2 Years UAZ Average L5 (04 and 05)
SDSU
Gain [DN/radiance]
Years


Desert Site L5 Gain Model, IC L5 Gain Model, UAZ and SDSU Data, Band3
Desert Site Model (181/40):
g[DS](t) = a*exp(-b*(t-1984.1639))+c
a = 0.0839
b = 0.2386
c = 0.9028
SSE: 0.005583
R-square: 0.8683
RMSE: 0.009897
IC Model(Prelaunch):
g[IC/PL](t) = 0.11218*exp(-1.0021*(t-1984.1639))+0.907
IC Model(Cross-Cal):
g[IC/CC](t) = 0.111858*exp(-1.002090*(t-1984.1639))+0.905
Desert Site (181/40)
Desert Site Model (181/40)
IC Model (Prelaunch)
IC Model (Crosscal)
UAZ
Prelaunch
2 Years UAZ Average L5 (04 and 05)
SDSU
Gain [DN/radiance]
Years


Desert Site L5 Gain Model, IC L5 Gain Model, UAZ and SDSU Data, Band4
Desert Site Model (181/40):
g[DS](t)= a*exp(-b*(t-1984.1639))+c
a = 0.04624
b = 0.3851
c = 1.082
SSE: 0.01764
R-square: 0.3365
RMSE: 0.01759
IC Model (Cross-Cal):
g[IC/CC](t)=0.107650*exp(-1.277190*(t-1984.1639))+1.082
Desert Site (181/40)
Desert Site Model (181/40)
IC Model (Crosscal)
UAZ
Prelaunch
Crosscal
2 Year UAZ Average L5 (04 and 05)
SDSU
Gain [DN/radiance]
Years


IC L5 Gain Model, Altar Site, UAZ and SDSU Data, Band5
IC Model (Cross-Cal):
g[IC/CC](t)=0.254503*exp(-1.09271*(t-1984.1639))+7.944
Altar Site
IC Model (Crosscal)
UAZ
Prelaunch
Crosscal
2 Years New UAZ Average L5 (04 and 05)
SDSU
Gain [DN/radiance]
Years


IC L5 Gain Model, Desert Site, UAZ and SDSU Data, Band7
IC Model (Cross-Cal):
g[IC/CC](t)=0.496719*exp(-0.979471*(t-1984.1639)) + 14.52
Desert Site (181/40)
IC Model (Crosscal)
UAZ
Prelaunch
Crosscal
2 Years UAZ Average L5 (04 and 05)
SDSU
Gain [DN/radiance]
Years

L5 TM Radiometric Gain Model

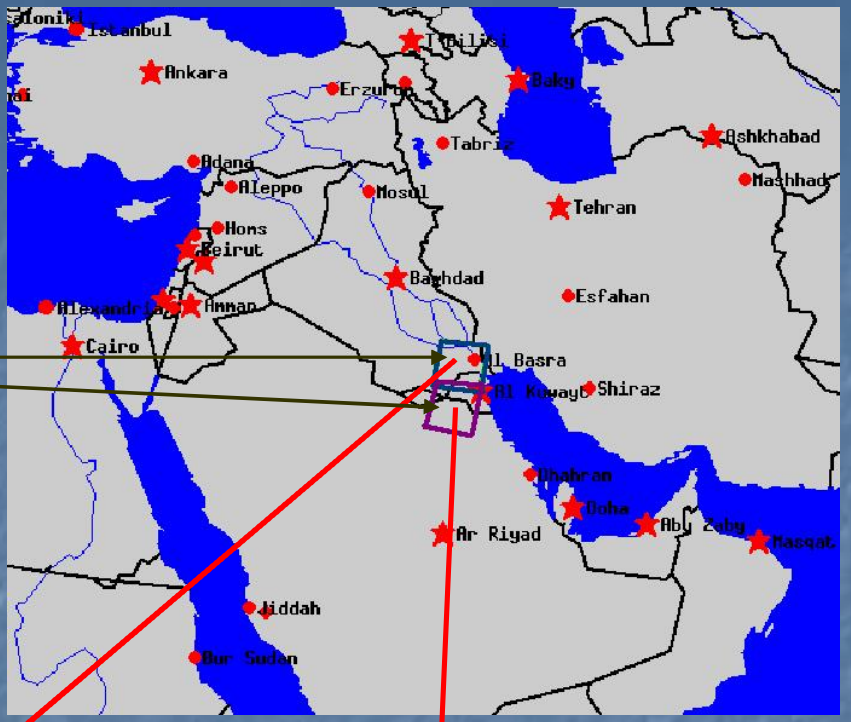
- Radiometric gain of L5 TM based on cross-calibration with L7 ETM+.
- 3 independent calibration sources in excellent agreement (<2%): L7 cross-calibration, U. of Arizona vicarious calibration, pseudo-invariant site trending.
- Accuracy better than 5% early in life and improving to 2% after the first three years.
- Results reported in "**Updated Radiometric Calibration for the Landsat 5 Thematic Mapper Reflective Bands**" accepted for publication in IEEE-TGRS.

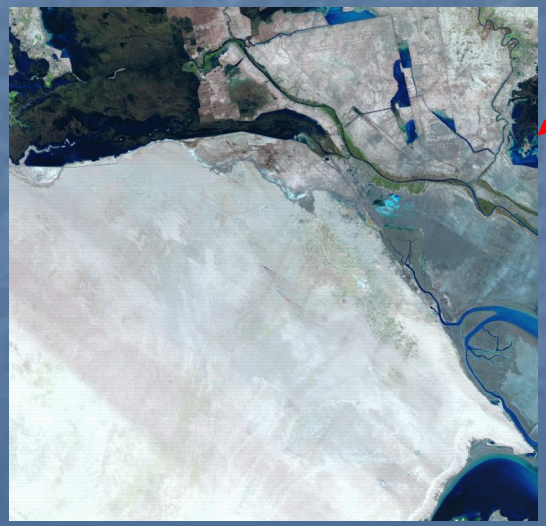
$$G(t) = \alpha_0 e^{-\alpha_1 (t - t_0)} + \alpha_2$$

Landsat 5 Radiometric Gain Model Parameters			
Band	α_0	α_1	α_2
1	0.2901	0.1399	1.209
2	0.1246	0.1045	0.63
3	0.0839	0.2386	0.903
4	0	0	1.082
5	0	0	7.944
7	0	0	14.52

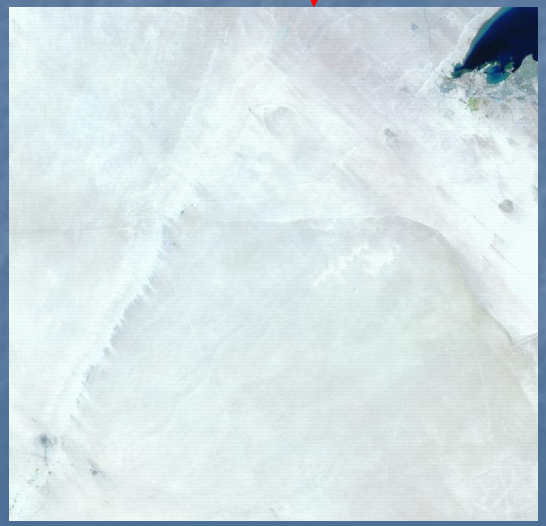
Proposed L4 TM Radiometric Calibration

- Overview of Procedure
  - Current calibration based solely on IC lamp regression and pre-launch gain estimates
  - Proposed model based on cross-calibration with Landsat 5 TM via near-coincident collects
    - Several test sites used in middle-east, Sahara, and North America.
    - Results from this analysis provided absolute calibration estimates on several individual dates.
    - Spectral filters on L4 TM and L5 TM nearly identical.
  - IC lamps used as a trending tool
    - Lamps appear much better behaved than L5, and used less often.
    - No lamp discontinuities as in L5, all three lamps trended quite smiliarly unlike L5, two lamps virtually identical in response.
  - Pseudo-invariant sites used to provide an independent measure of gain trending
    - Much less data available due to limited usage of L4
    - Best time series was situated in Middle-East: Iraq and Saudi Arabia
      - Conflicts in the gulf region added extra difficulty to the analyses!
  - Resulting model integrates preceding three methodologies into an overall recommendation for L4 TM calibration





P166R39



P166R40

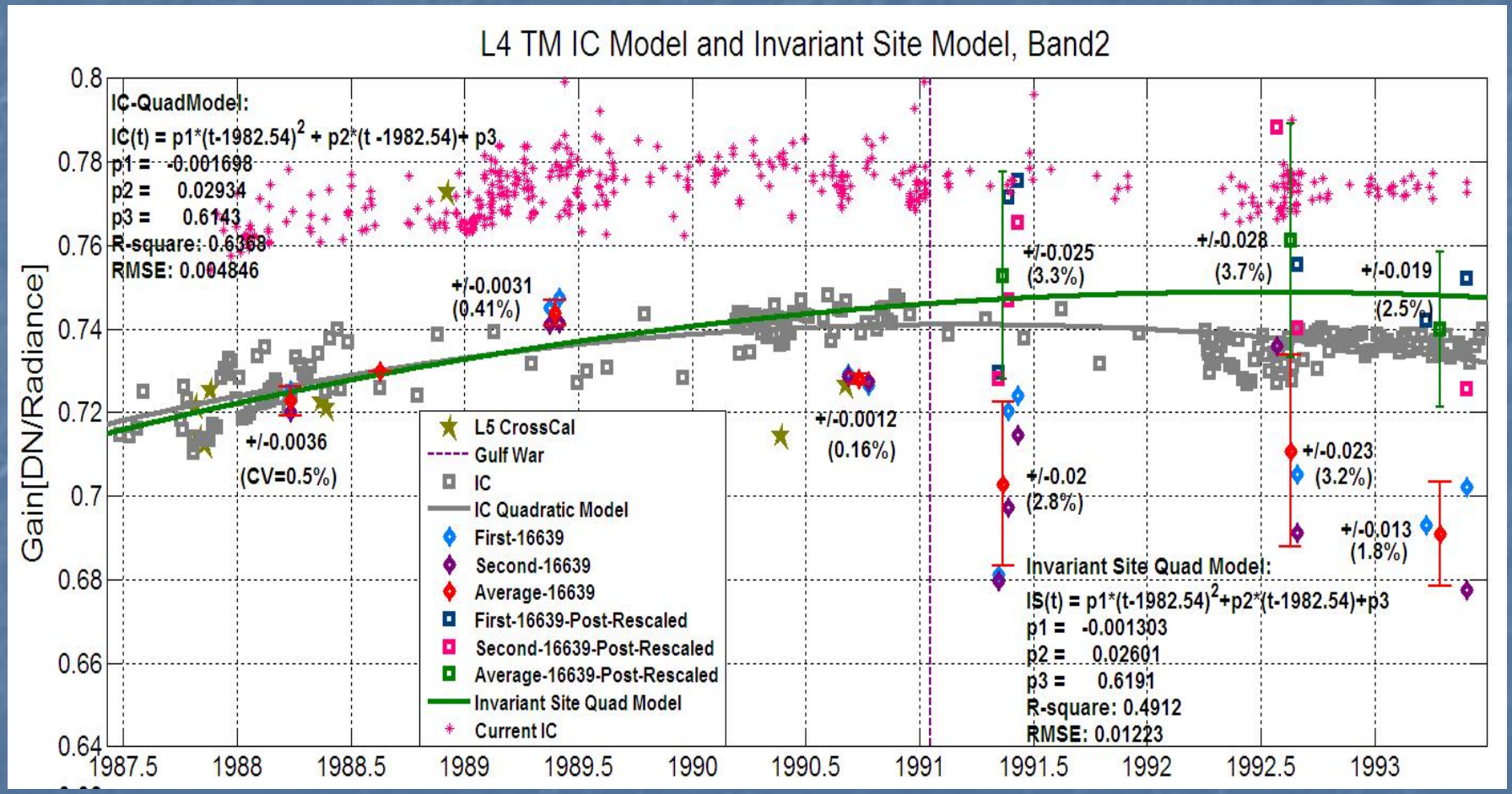
Acquisition Dates for P166R39

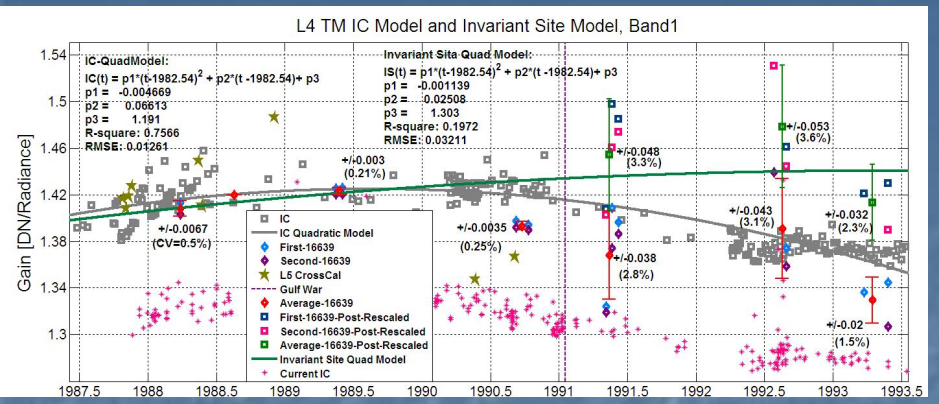
1988	1989	1990	1991	1992	1993
2/6/1988	4/13/1989	9/7/1990	2/14/1991	6/24/1992	2/19/1993
2/22/1988	5/15/1989	10/9/1990	3/2/1991	7/26/1992	3/23/1993
3/9/1988	5/31/1989	12/28/1990	5/5/1991	8/27/1992	5/26/1993
3/25/1988	7/2/1989		5/21/1991	9/28/1992	
8/16/1988	8/3/1989		6/6/1991		
10/19/1988	8/19/1989		7/8/1991		
11/20/1988			7/24/1991		
			8/9/1991		
7 scenes	**6 scenes**	**3 scenes**	**8 scenes**	**4 scenes**	**3 scenes**

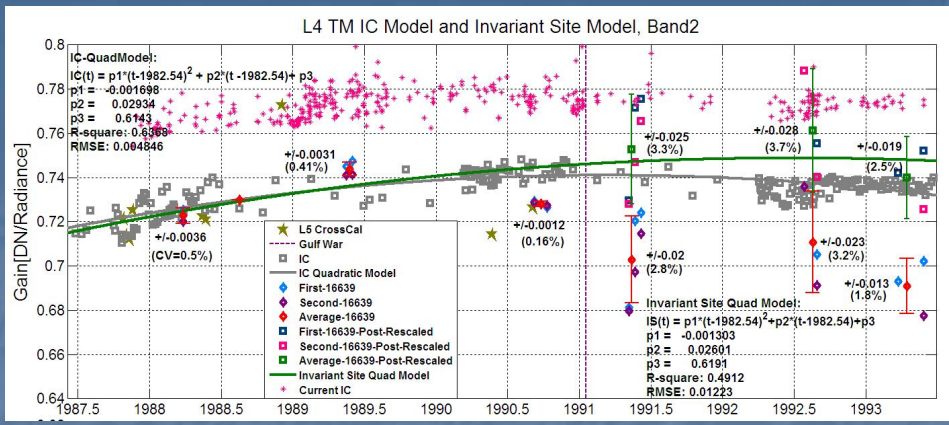
Total: 31 scenes
Selected: 13 scenes (highlighted in light blue)

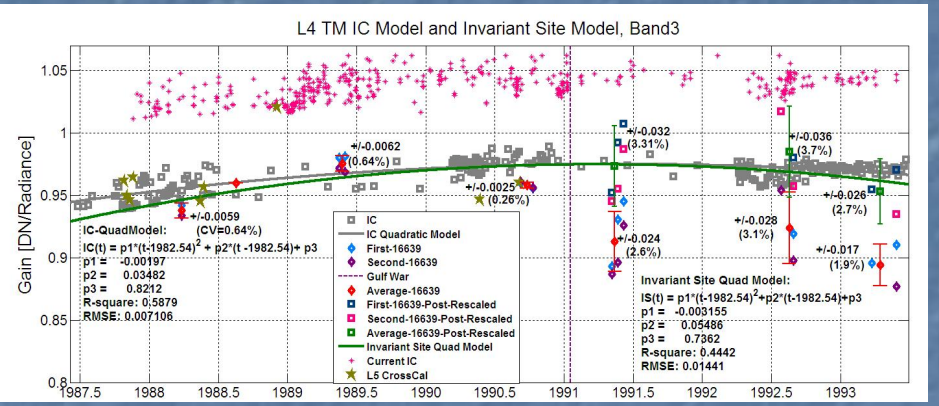
Data Analysis (Comparison of Invariant Site Data with IC data and L5 CrossCal)

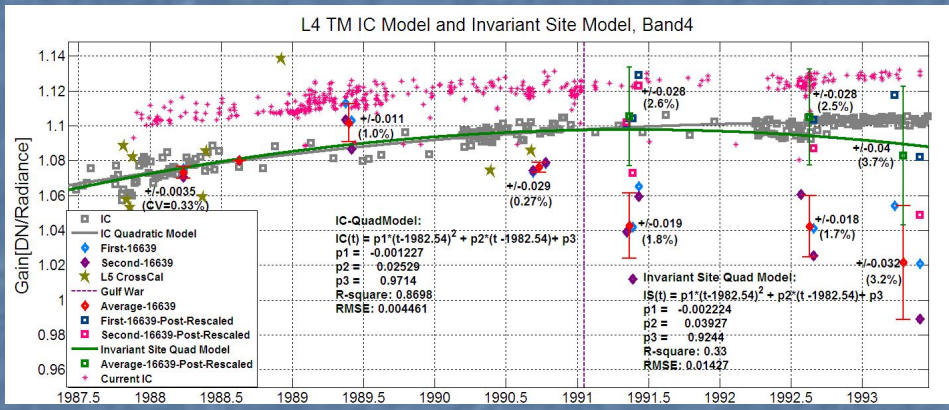
- **Landsat 5 cross calibration**
  - L4/L5 cross calibration ratios (L4/L5) scaled by L5 Gain Model (LUT07) give Landsat 5 cross calibration points.
- **IC**
  - Fit a simple model to the Landsat 4 post-gap IC data.
  - Scale the Landsat 4 post-gap IC model to Landsat 5 cross calibration points using least square method.
- **Invariant Site**
  - Two subregions from P166R39 (First-16639 and Second-16640) and one subregion from P166R40 (First-16640) were used.
  - Calculate the normalization factor at Year =1988.63 (Year 1988/DOY 229). The year 1988.63 was selected as this year was common to both the invariant sites P166R39 and P166R40.
  - Scale data using the same factor that has been used to scale Landsat 4 post-gap IC Model.
  - Averages of the invariant sites data from the 3 subregions of the two sites falling within short period of time are determined.

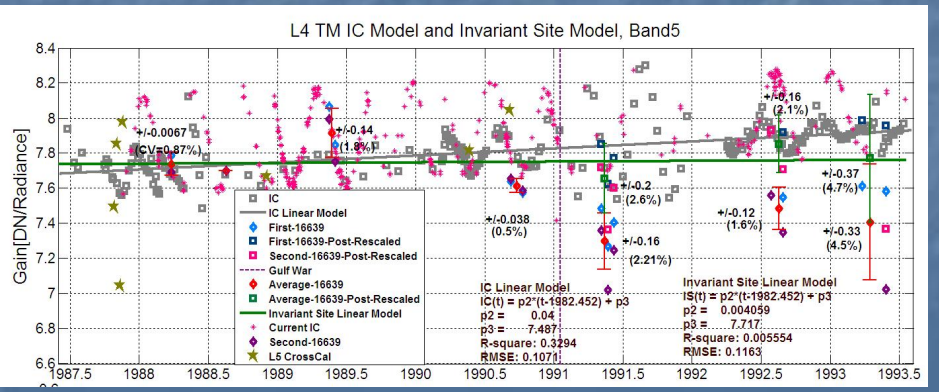

L4 TM IC Model and Invariant Site Model, Band2
IC-QuadModel:
IC(t) = p1*(t-1982.54)^2 + p2*(t -1982.54)+ p3
p1 = -0.001698
p2 = 0.02934
p3 = 0.6143
R-square: 0.6368
RMSE: 0.004846
+/-0.0036
(CV=0.5%)
+/-0.0031
(0.41%)
+/-0.0012
(0.16%)
+/-0.025
(3.3%)
+/-0.028
(3.7%)
+/-0.019
(2.5%)
+/-0.02
(2.8%)
+/-0.023
(3.2%)
+/-0.013
(1.8%)
L5 CrossCal
Gulf War
IC
IC Quadratic Model
First-16639
Second-16639
Average-16639
First-16639-Post-Rescaled
Second-16639-Post-Rescaled
Average-16639-Post-Rescaled
Invariant Site Quad Model
Current IC
Invariant Site Quad Model:
IS(t) = p1*(t-1982.54)^2+p2*(t-1982.54)+p3
p1 = -0.001303
p2 = 0.02601
p3 = 0.6191
R-square: 0.4912
RMSE: 0.01223
Gain[DN/Radiance]
0.8
0.78
0.76
0.74
0.72
0.7
0.68
0.66
0.64
1987.5
1988
1988.5
1989
1989.5
1990
1990.5
1991
1991.5
1992
1992.5
1993

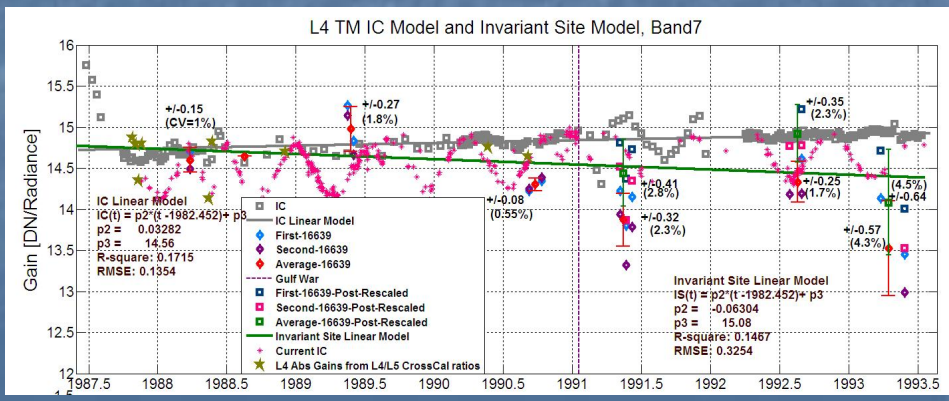

L4 TM IC Model and Invariant Site Model, Band1
Gain [DN/Radiance]
IC-QuadModel:
IC(t) = p1*(t-1982.54)^2 + p2*(t -1982.54)+ p3
p1 = -0.004669
p2 = 0.06613
p3 = 1.191
R-square: 0.7566
RMSE: 0.01261
Invariant Sita Quad Model:
IS(t) = p1*(t-1982.54)^2 + p2*(t -1982.54)+ p3
p1 = -0.001139
p2 = -0.02508
p3 = 1.303
R-square: 0.1972
RMSE: 0.03211
+/-0.0067 (CV=0.5%)
+/-0.003 (0.21%)
+/-0.0035 (0.25%)
+/-0.048 (3.3%)
+/-0.038 (2.8%)
+/-0.053 (3.6%)
+/-0.043 (3.1%)
+/-0.032 (2.3%)
+/-0.02 (1.5%)
IC
IC Quadratic Model
First-16639
Second-16639
L5 CrossCal
Gulf War
Average-16639
First-16639-Post-Rescaled
Second-16639-Post-Rescaled
Average-16639-Post-Rescaled
Invariant Site Quad Model
Current IC


L4 TM IC Model and Invariant Site Model, Band2
Gain[DN/Radiance]
IC-QuadModel:
IC(t) = p1*(t-1982.54)^2 + p2*(t -1982.54)+ p3
p1 = -0.001698
p2 = 0.02934
p3 = 0.6143
R-square: 0.6368
RMSE: 0.004846
+/-0.0036 (CV=0.5%)
+/-0.0031 (0.41%)
+/-0.0012 (0.16%)
+/-0.025 (3.3%)
+/-0.02 (2.8%)
+/-0.028 (3.7%)
+/-0.023 (3.2%)
+/-0.019 (2.5%)
+/-0.013 (1.8%)
Invariant Site Quad Model:
IS(t) = p1*(t-1982.54)^2+p2*(t-1982.54)+p3
p1 = -0.001303
p2 = 0.02601
p3 = 0.6191
R-square: 0.4912
RMSE: 0.01223
L5 CrossCal
Gulf War
IC
IC Quadratic Model
First-16639
Second-16639
Average-16639
First-16639-Post-Rescaled
Second-16639-Post-Rescaled
Average-16639-Post-Rescaled
Invariant Site Quad Model
Current IC


L4 TM IC Model and Invariant Site Model, Band3
Gain [DN/Radiance]
IC-QuadModel: (CV=0.64%)
IC(t) = p1*(t-1982.54)^2 + p2*(t -1982.54)+ p3
p1 = -0.00197
p2 = 0.03482
p3 = 0.8212
R-square: 0.5879
RMSE: 0.007106
+/-0.0059
+/-0.0062 (0.64%)
+/-0.0025 (0.26%)
+/-0.032 (3.31%)
+/-0.024 (2.6%)
+/-0.036 (3.7%)
+/-0.028 (3.1%)
+/-0.026 (2.7%)
+/-0.017 (1.9%)
Invariant Site Quad Model:
IS(t) = p1*(t-1982.54)^2+p2*(t-1982.54)+p3
p1 = -0.003155
p2 = 0.05486
p3 = 0.7362
R-square: 0.4442
RMSE: 0.01441
IC
IC Quadratic Model
First-16639
Second-16639
Gulf War
Average-16639
First-16639-Post-Rescaled
Second-16639-Post-Rescaled
Average-16639-Post-Rescaled
Invariant Site Quad Model
Current IC
L5 CrossCal


L4 TM IC Model and Invariant Site Model, Band4
Gain[DN/Radiance]
+/-0.0035 (CV=0.33%)
+/-0.011 (1.0%)
+/-0.029 (0.27%)
+/-0.028 (2.6%)
+/-0.019 (1.8%)
+/-0.028 (2.5%)
+/-0.04 (3.7%)
+/-0.018 (1.7%)
+/-0.032 (3.2%)
IC-QuadModel:
IC(t) = p1*(t-1982.54)^2 + p2*(t -1982.54)+ p3
p1 = -0.001227
p2 = 0.02529
p3 = 0.9714
R-square: 0.8698
RMSE: 0.004461
Invariant Site Quad Model:
IS(t) = p1*(t-1982.54)^2 + p2*(t -1982.54)+ p3
p1 = -0.002224
p2 = 0.03927
p3 = 0.9244
R-square: 0.33
RMSE: 0.01427
IC
IC Quadratic Model
First-16639
Second-16639
L5 CrossCal
Gulf War
Average-16639
First-16639-Post-Rescaled
Second-16639-Post-Rescaled
Invariant Site Quad Model
Average-16639-Post-Rescaled
Current IC


L4 TM IC Model and Invariant Site Model, Band5
Gain[DN/Radiance]
+/-0.0067 (CV=0.87%)
+/-0.44 (1.8%)
+/-0.038 (0.5%)
+/-0.2 (2.6%)
+/-0.16 (2.21%)
+/-0.16 (2.1%)
+/-0.12 (1.6%)
+/-0.37 (4.7%)
+/-0.33 (4.5%)
IC Linear Model
IC(t) = p2*(t-1982.452) + p3
p2 = 0.04
p3 = 7.487
R-square: 0.3294
RMSE: 0.1071
Invariant Site Linear Model
IS(t) = p2*(t-1982.452) + p3
p2 = 0.004059
p3 = 7.717
R-square: 0.005554
RMSE: 0.1163
IC
IC Linear Model
First-16639
First-16639-Post-Rescaled
Second-16639-Post-Rescaled
Gulf War
Average-16639
Average-16639-Post-Rescaled
Invariant Site Linear Model
Current IC
Second-16639
L5 CrossCal


L4 TM IC Model and Invariant Site Model, Band7
Gain [DN/Radiance]
+/-0.15 (CV=1%)
+/-0.27 (1.8%)
+/-0.08 (0.55%)
+/-0.41 (2.8%)
+/-0.32 (2.3%)
+/-0.35 (2.3%)
+/-0.25 (1.7%)
(4.5%)
+/-0.64
+/-0.57 (4.3%)
IC Linear Model
IC(t) = p2*(t -1982.452)+ p3
p2 = 0.03282
p3 = 14.56
R-square: 0.1715
RMSE: 0.1354
Invariant Site Linear Model
IS(t) = p2*(t -1982.452)+ p3
p2 = -0.06304
p3 = 15.08
R-square: 0.1467
RMSE: 0.3254
IC
IC Linear Model
First-16639
Second-16639
Average-16639
Gulf War
First-16639-Post-Rescaled
Second-16639-Post-Rescaled
Average-16639-Post-Rescaled
Invariant Site Linear Model
Current IC
L4 Abs Gains from L4/L5 CrossCal ratios

L4 TM Recommendations

- Recommend the adoption of a LUT approach for the L4 TM post-gap period based on the invariant site trend tied to the L5 cross-cal points.

Band	%Change in Gain from NLAPS
1	+6
2	-5
3	-7
4	-2
5	-3
7	~0

- Further investigations required to consider how to handle the pre-gap time period.
- Further consideration of Band 1 calibration may also be warranted.

MSS Calibration Plan Outline

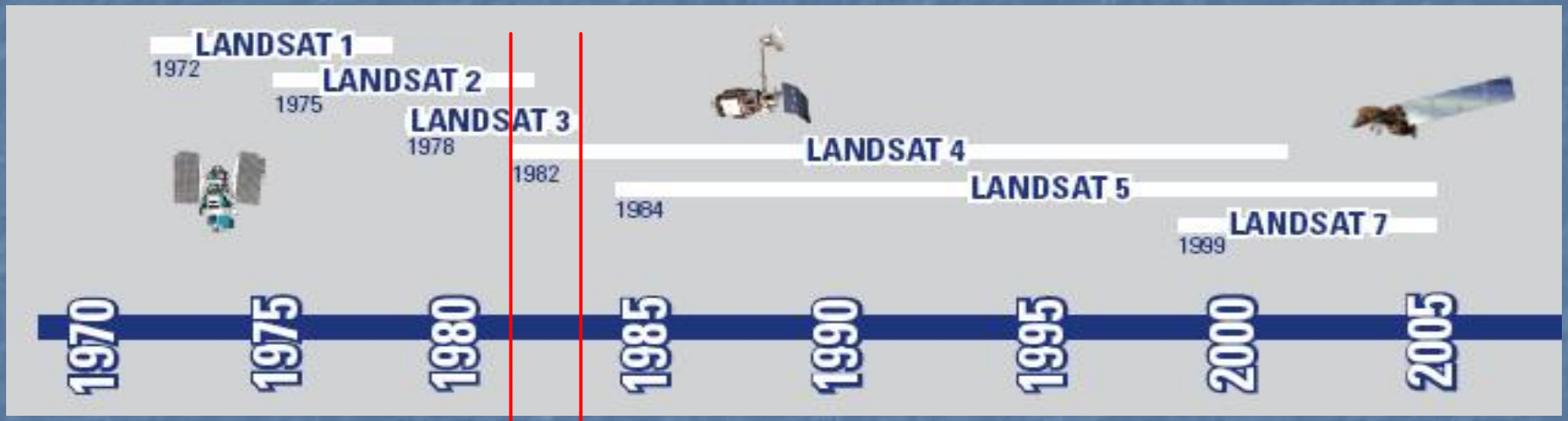
Goals:

- Ultimately to consistently radiometrically calibrate the entire Landsat archive. This segment looks backwards in time to Landsat 1 and 1972. The complete story also looks forward in time to the OLI instrument and beyond.
- To determine the limits on the calibration accuracy of the Landsat archive back to Landsat 1.
- To build upon the calibration knowledge obtained from the TM instruments to optimally calibrate the MSS instruments.
- If calibration improvements are impossible, then at least determine the probable error bounds in current calibration approaches to the MSS archive.

MSS Calibration Plan Outline

- **L5 MSS Calibration**
  - Calibrate to L5 TM through coincident scenes
  - Develop trend through use of invariant sites
  - Develop trend through use of internal cal wedge data
- **L4 MSS Calibration**
  - Calibrate to L4 TM through coincident scenes
  - Calibrate to L5 MSS through coincident or near-coincident scenes
  - Develop trend through use of invariant sites
  - Develop trend through use of cal wedge data
- **L3 MSS Calibration**
  - Calibrate to L4 MSS through coincident or near coincident scenes
    - Note: this is likely the highest risk point in the process!
  - Potential cross-calibration to L4 TM through coincident or near coincident scenes
  - Develop trend through use of invariant sites
  - Develop trend through use of cal wedge data
- **Landsat 2 MSS Calibration**
  - Calibrate to L3 MSS through coincident or near coincident scenes
  - Develop trend through use of invariant sites
  - Develop trend through use of cal wedge data
- **Landsat 1 MSS Calibration**
  - Calibrate to L2 MSS through coincident or near coincident scenes
  - Develop trend through use of invariant sites
  - Develop trend through use of cal wedge data

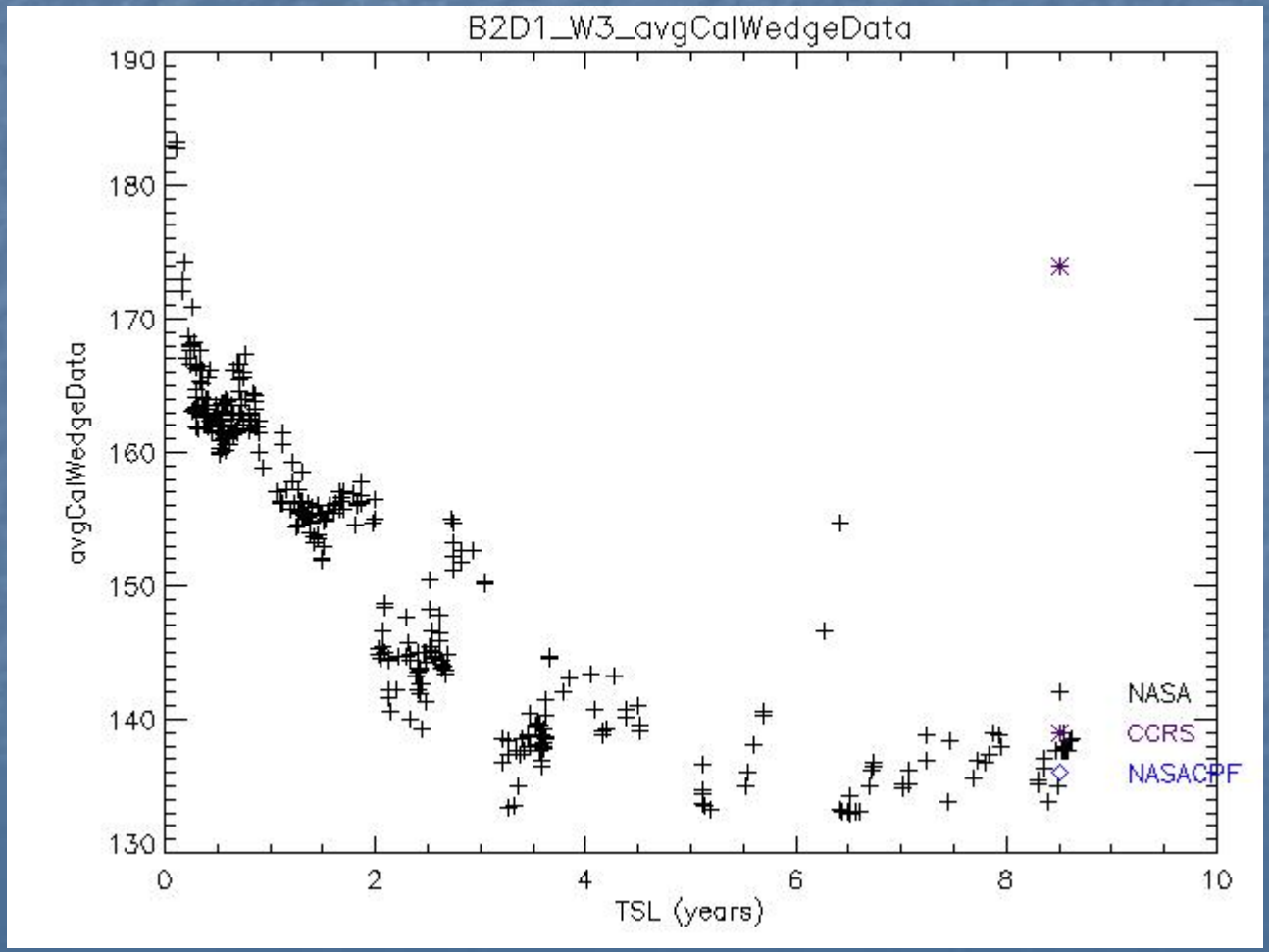
MSS Calibration Plan Outline



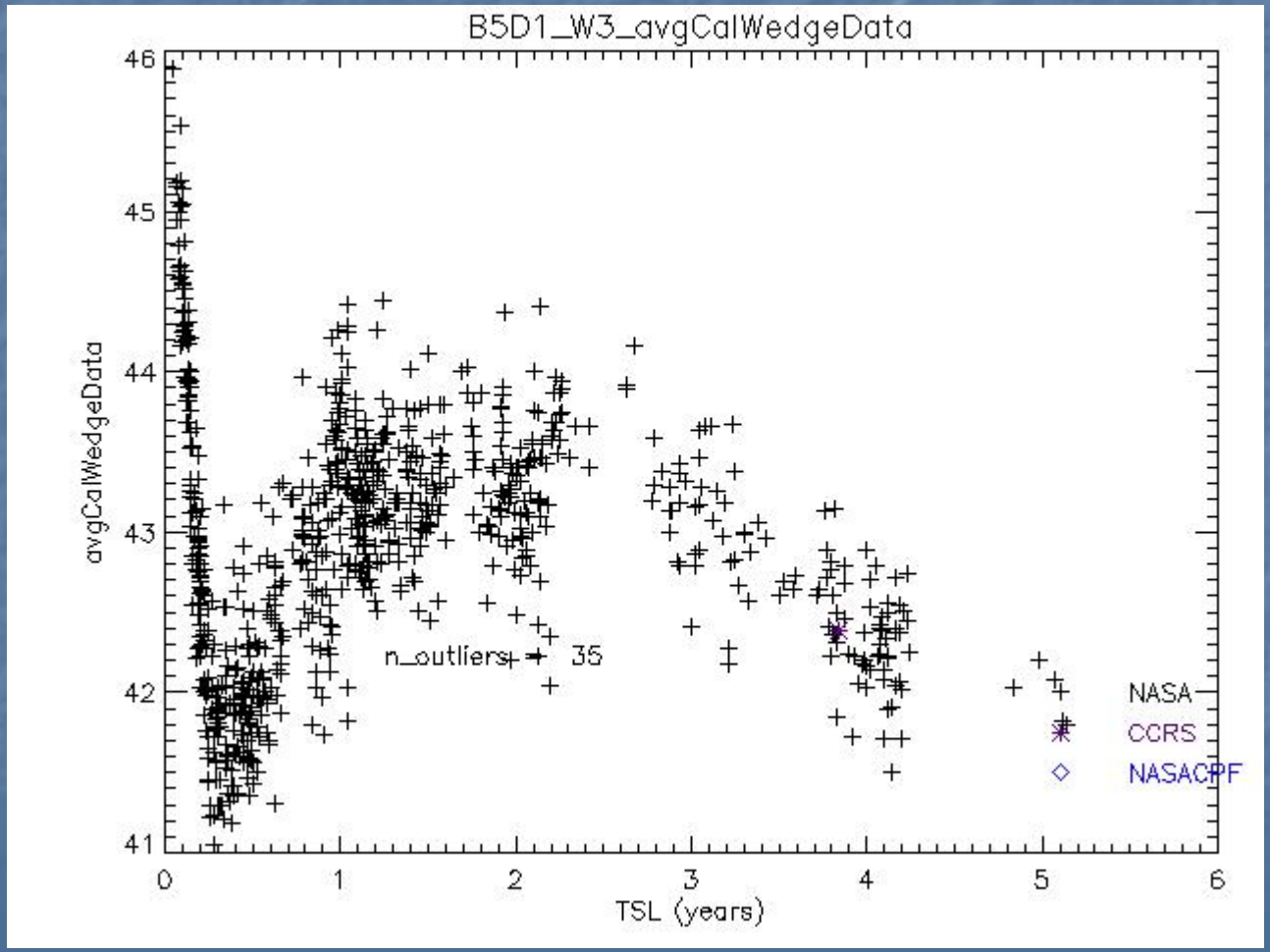
July 16, 1982 March 31, 1983

Critical overlap period to extend calibration to the first decade of Landsat!

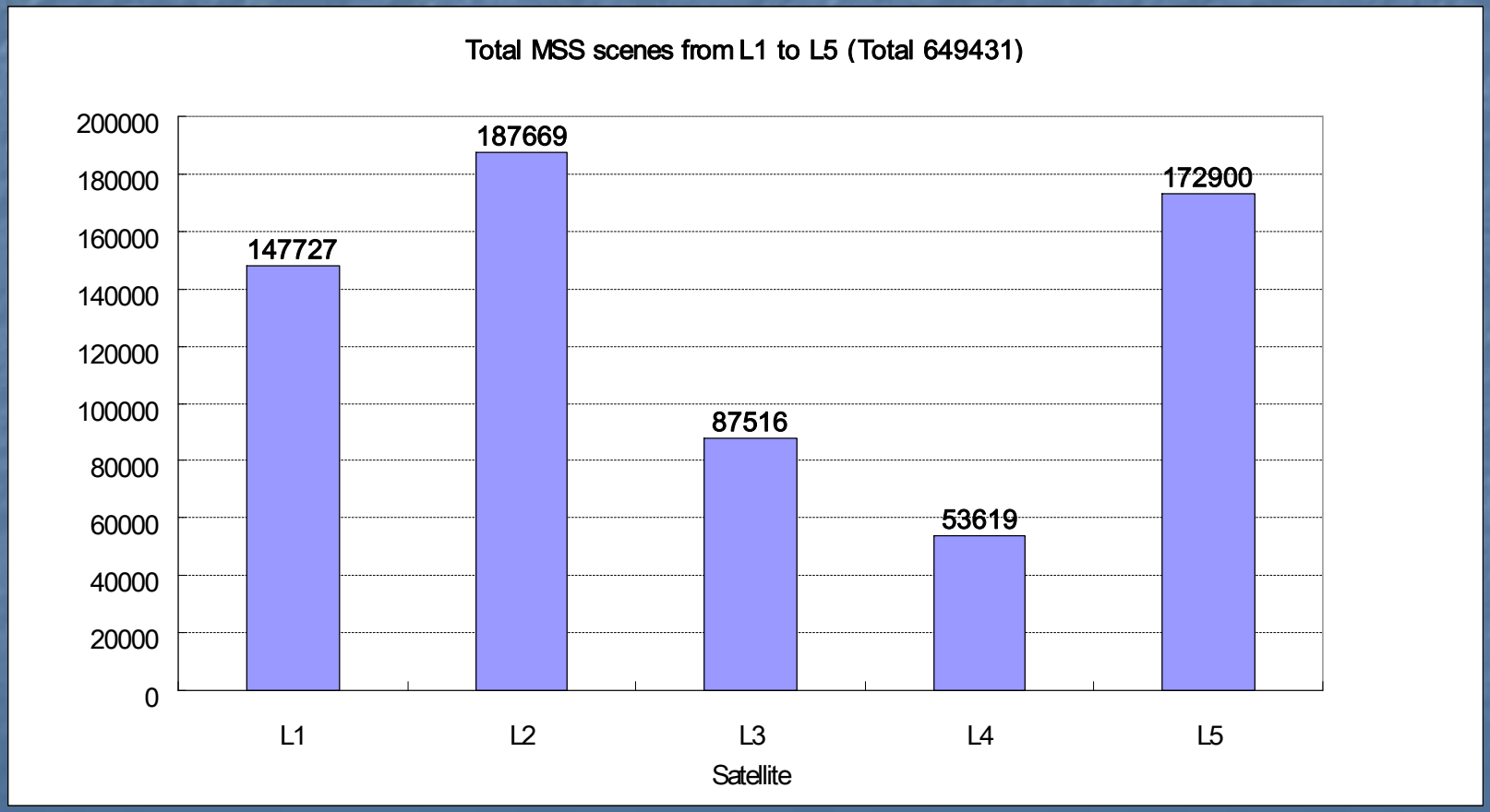
Example of L5 MSS Lifetime Cal Wedge Data



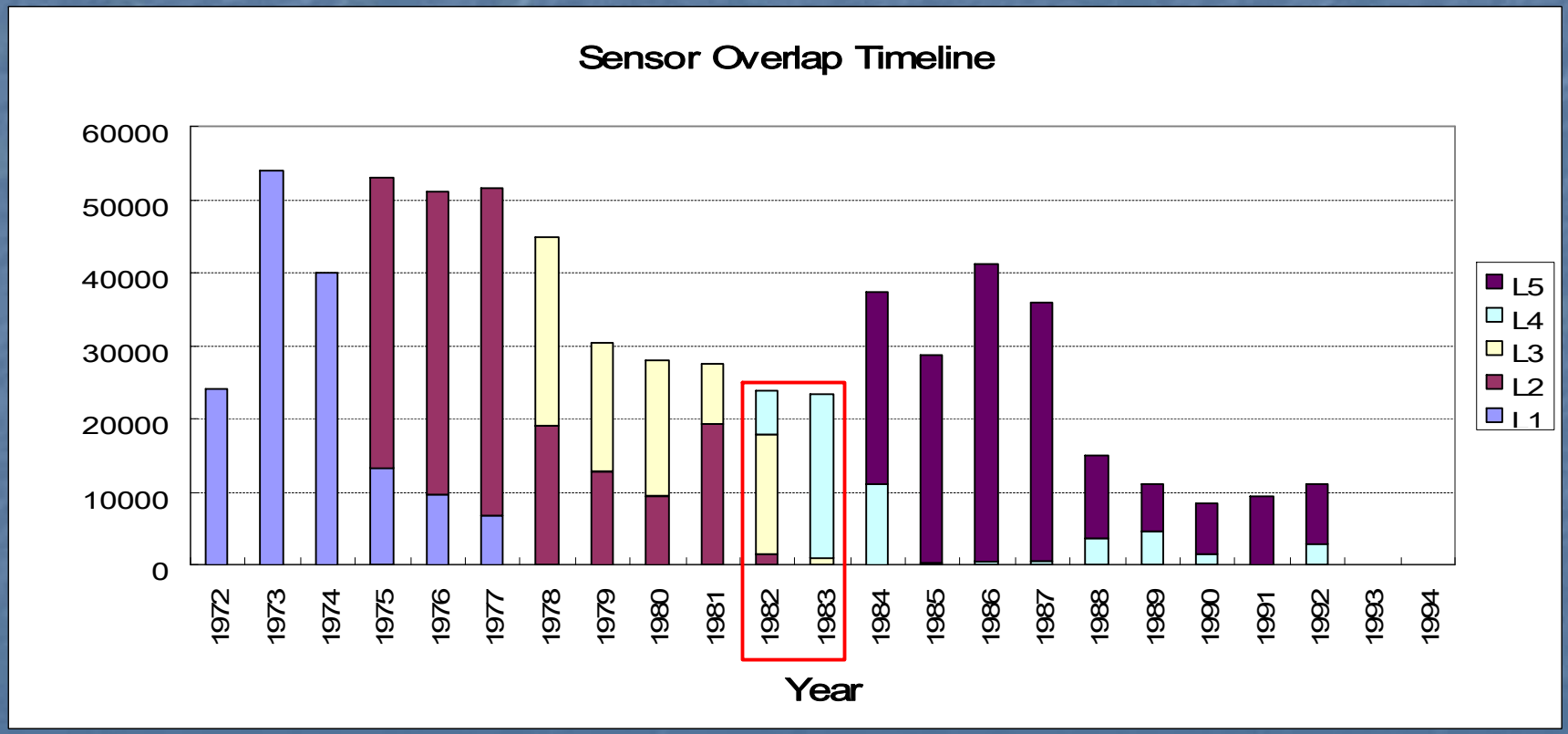
Example of L1 MSS Lifetime Cal Wedge Data



Satellite specific breakdown



Overlap Timeline



Overlap Timeline

Year	L1	L2	L3	L4	L5
1972	24100				
1973	53884				
1974	40047				
1975	13138	39784			
1976	9633	41424			
1977	6824	44774			
1978	101	18868	25858		
1979		12801	17572		
1980		9280	18724		
1981		19257	8142	1	
1982		1481	16348	6058	
1983			872	22460	
1984				11141	26204
1985				348	28447
1986				423	40780
1987				464	35469
1988				3612	11217
1989				4687	6506
1990				1377	7059
1991				116	9174
1992				2932	8043
1993					0
1994					1
Total Scenes	147727	187669	87516	53619	172900

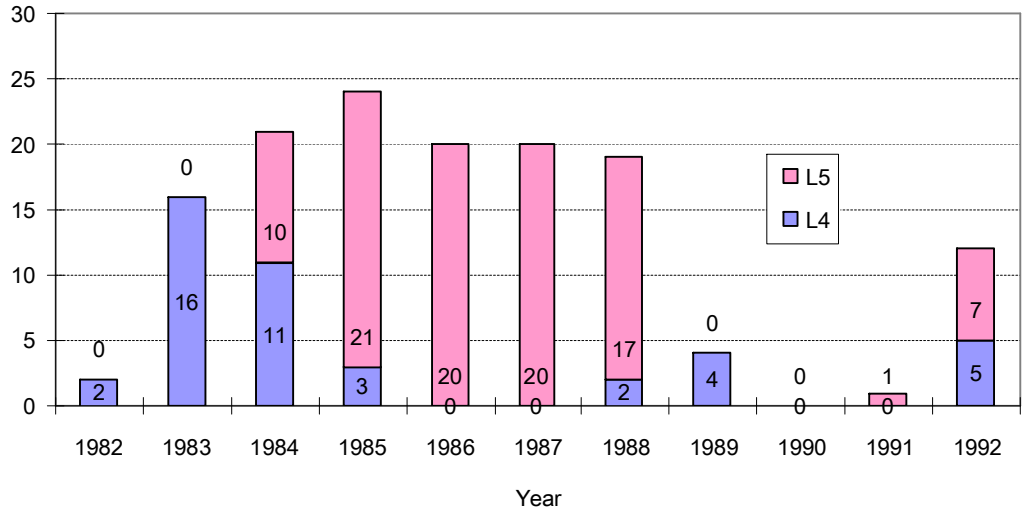
Available L4/L5 MSS scenes for known Calibration Sites

SN	Cal Site	Path	Row	Total L4 MSS scenes	Total L5 MSS scenes
1	Algeria 3	192	39	0	14
2	Algeria 5	195	39	0	19
3	Amburla	102	76	1	0
4	Arabia 1	164	47	0	15
5	Arabia 2	162	46	1	10
6	Barreal Blanco	232	82	0	21
7	Bonneville Salt Flats	39	32	35	99
8	Dunhuang	137	32	0	0
9	Dunrobin	94	76	18	0
10	Egypt 1	179	41	0	22
11	Egypt 2	177	44	2	15
12	Ivanpah Playa	39	35	38	99
13	La Crau	196	30	0	21
14	Lake frome	97	81	0	0
15	Libya 1	187	43	0	20
16	Libya 2	182	43	0	21
17	Libya 4	181	40	0	29
18	Lunar Lake Playa	40	33	38	87

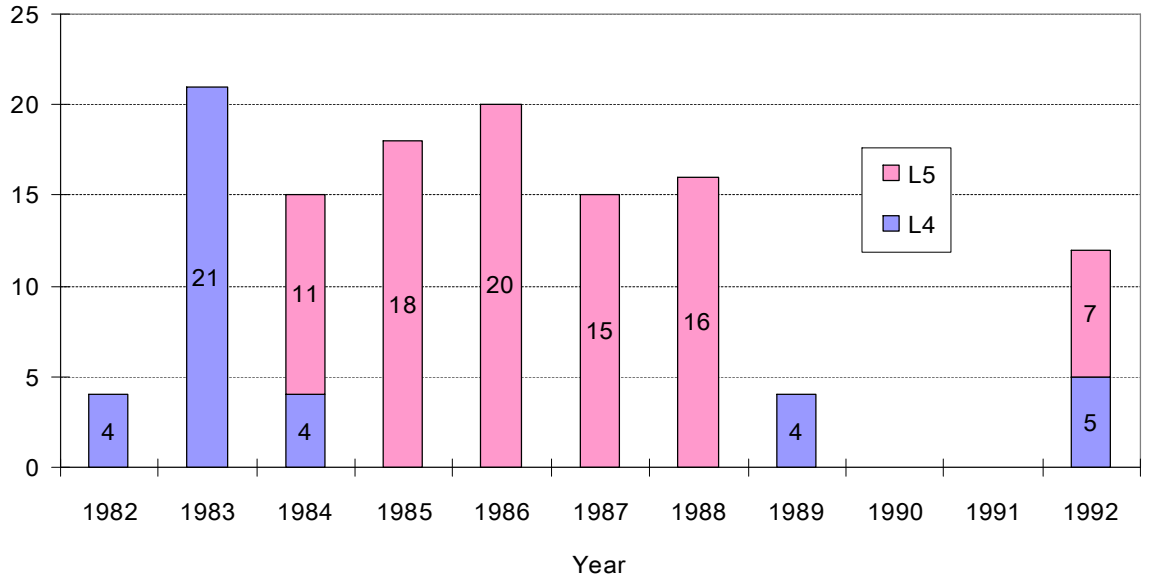
Available L4/L5 MSS scenes for known Calibration Sites

19	Mali 1	198	47	0	16
20	Mauritania 1	201	47	0	8
21	Namib Desert 1	179	77	0	7
22	Namib Desert 2	182	72	0	6
23	Niger 1	188	46	1	24
24	Niger 2	188	45	1	23
25	RRV	40	33	38	87
26	Rogers Dry Lake	41	36	32	87
27	Sechura Desert	10	64	0	25
28	Sonoran Desert	38	38	20	88
29	Sudan 1	177	45	0	17
30	Taklamakan Desert	146	32	0	0
31	Tinga Tingana	97	80	0	0
32	Uyuni Salt Flats	233	74	1	27
33	Warrabin	95	78	19	0
34	White Sands	33	37	43	96
35	Winton	96	76	1	0
36	Yemen Desert 1	164	48	0	16
37	Brookings	29	29	45	174

L4/L5 MSS Scenes from White Sands (P33R37)



L4/L5 MSS Scenes from RRV (P40R33)



Examples of L3/L4 MSS/(TM) Coincident/Near Coincident Scenes

Sonoran Desert

L3 MSS

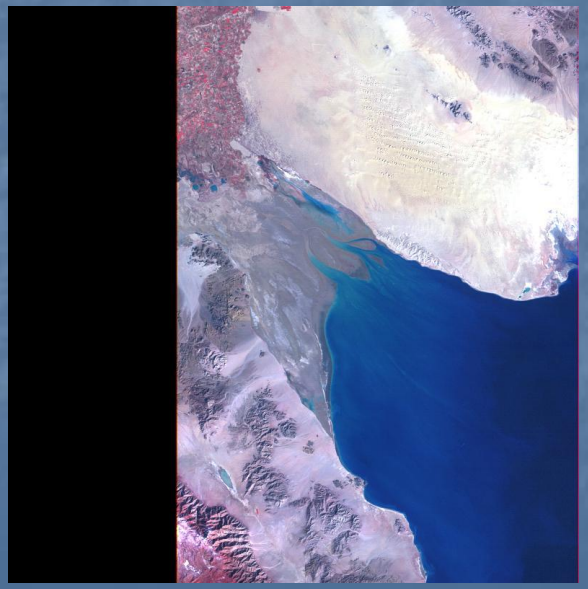
- **ID: LM30410381982365AAA03**
- **Cloud Cover: 90%** Qlty: 9
- Date: 1982/12/31
- Sun Elevation 27
- Sun Azimuth 147

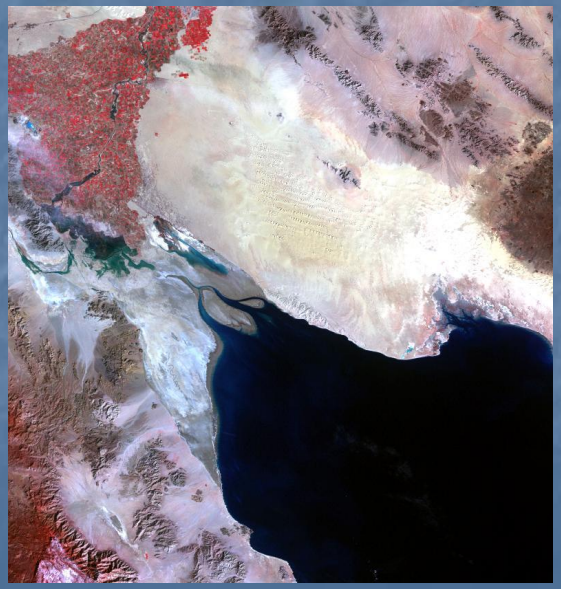
L4 MSS

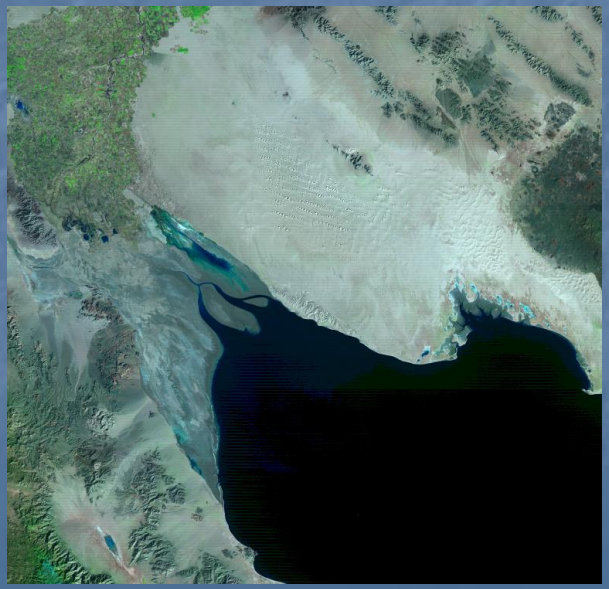
- **ID: LM40380381983022AAA03**
- Cloud Cover: 10% Qlty: 9
- Date: 1983/1/22
- Sun Elevation 29
- Sun Azimuth 144

L4 TM

- **ID: LT40380381983006XXX03**
- Cloud Cover: 10% Qlty: 9
- Date: 1983/1/6
- Sun Elevation 28.11
- Sun Azimuth 147.24



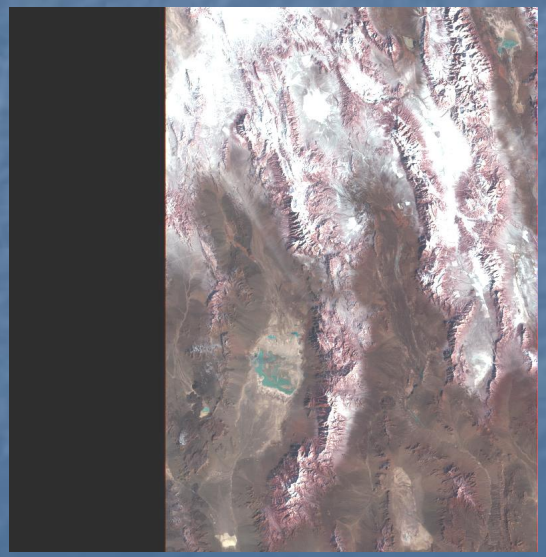




Railroad Valley

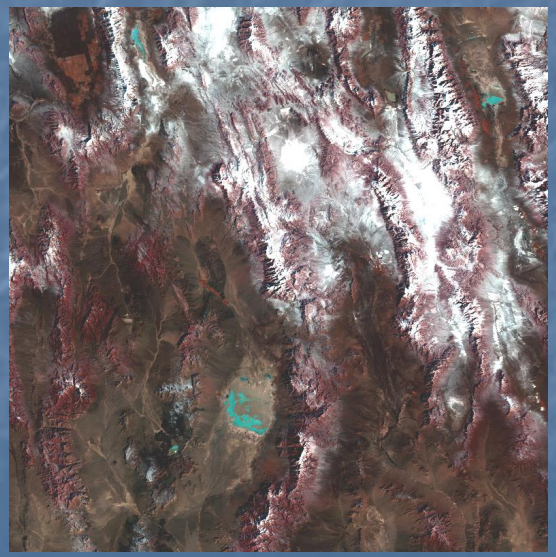
L3 MSS

- **ID: LM30430331983002AAA03**
- Cloud Cover: 0% Qlty: 9
- Date: 1983/1/2
- Sun Elevation 22
- Sun Azimuth 150



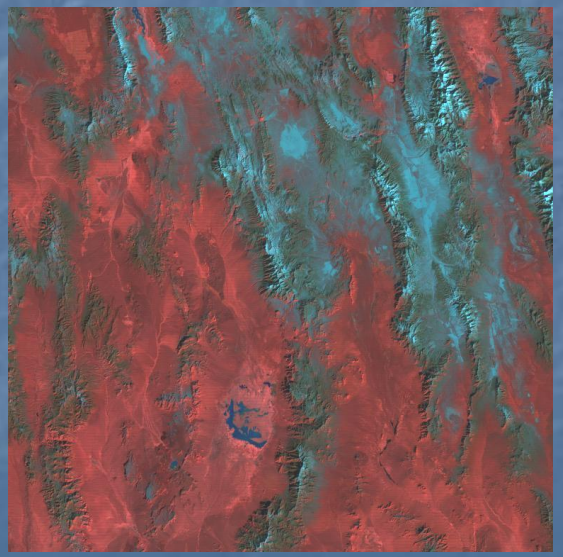
L4 MSS

- **ID: LM40400331982353AAA03**
- Cloud Cover: 10% Qlty: 9
- Date: 1982/12/19
- Sun Elevation 22
- Sun Azimuth 152



L4 TM

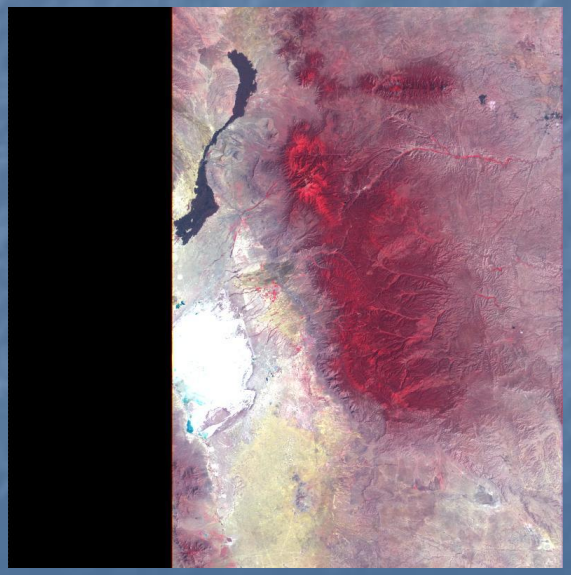
- **ID: LT40400331982353XXX04**
- Cloud Cover: 10% Qlty: 9
- Date: 1982/12/19
- Sun Elevation 22.56
- Sun Azimuth 152.66



White Sands

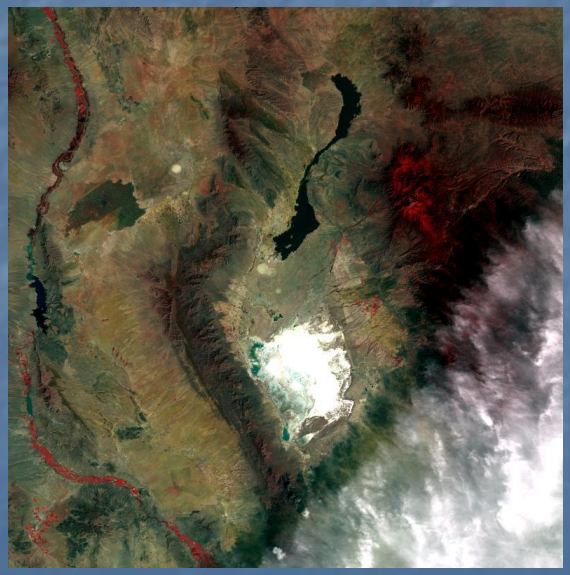
L3 MSS

- **ID: LM30350371982269AAA05**
- Cloud Cover: 0% Qlty: 9
- Date: 1982/9/26
- Sun Elevation 46
- Sun Azimuth 136



L4 MSS

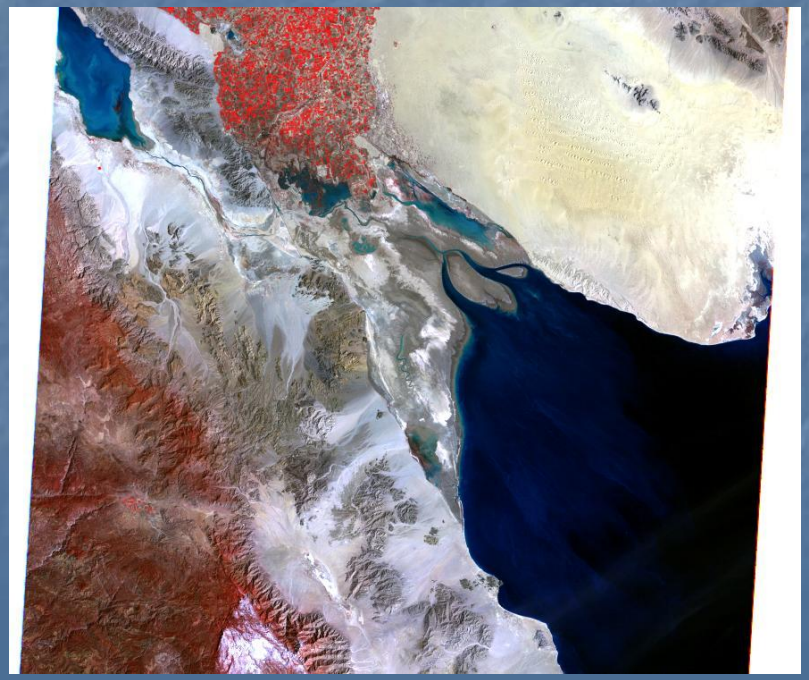
- **ID: LM40330371982272AAA03**
- Cloud Cover: 30% Qlty: 9
- Date: 1982/9/29
- Sun Elevation 46
- Sun Azimuth 138



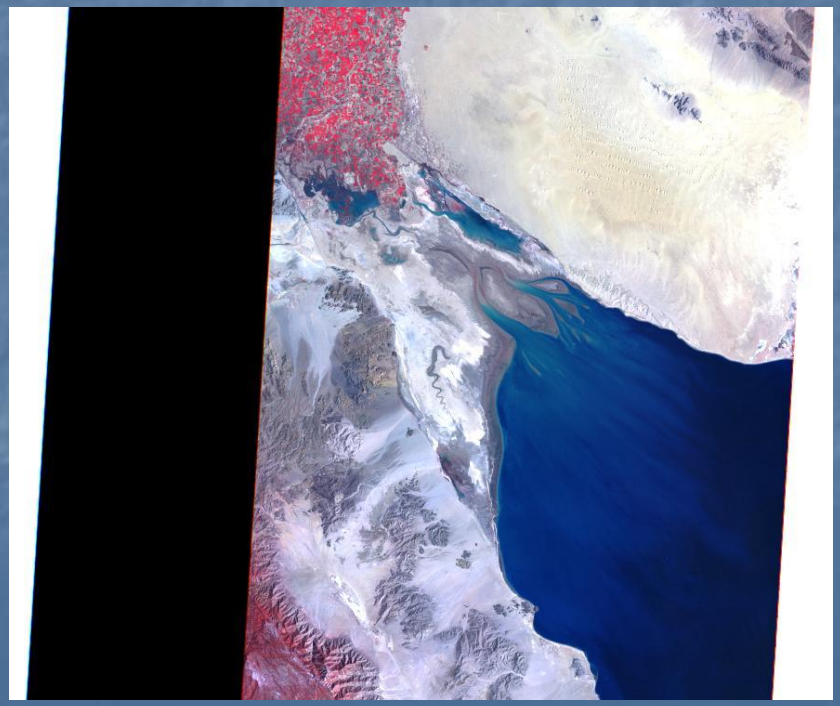
L2/L3 MSS Near Coincident Scenes

Sonoran Desert (WRS1 P41R38)

- ID: LM20410381981073AAA03
- Cloud Cover: 10% Qlty: 9
- Date: 1981/3/14
- Sun Elevation 42
- Sun Azimuth 129

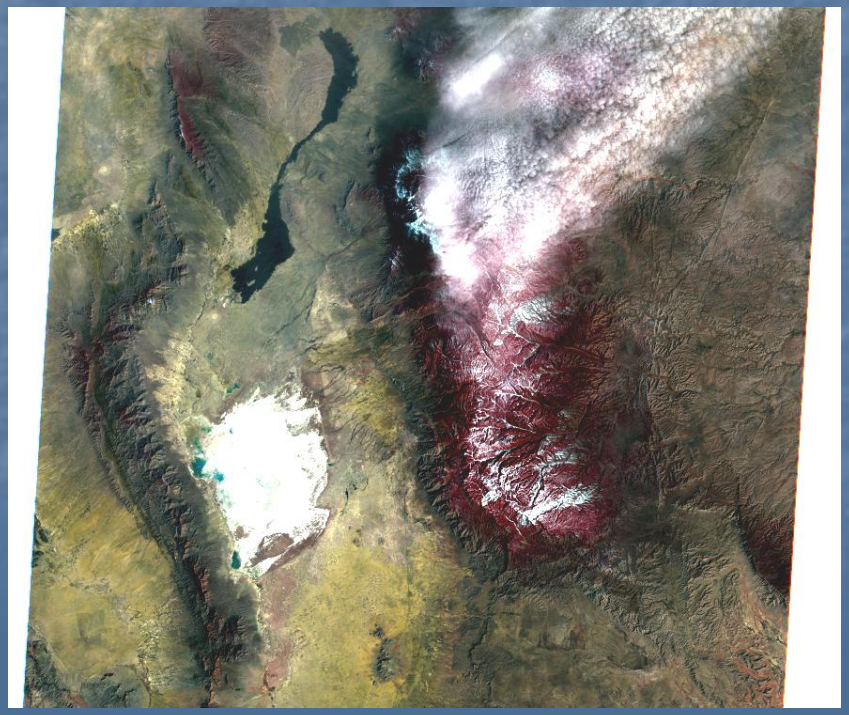


- ID: LM30410381981082AAA04
- Cloud Cover: 0% Qlty: 7
- Date: 1981/3/23
- Sun Elevation 45
- Sun Azimuth 125

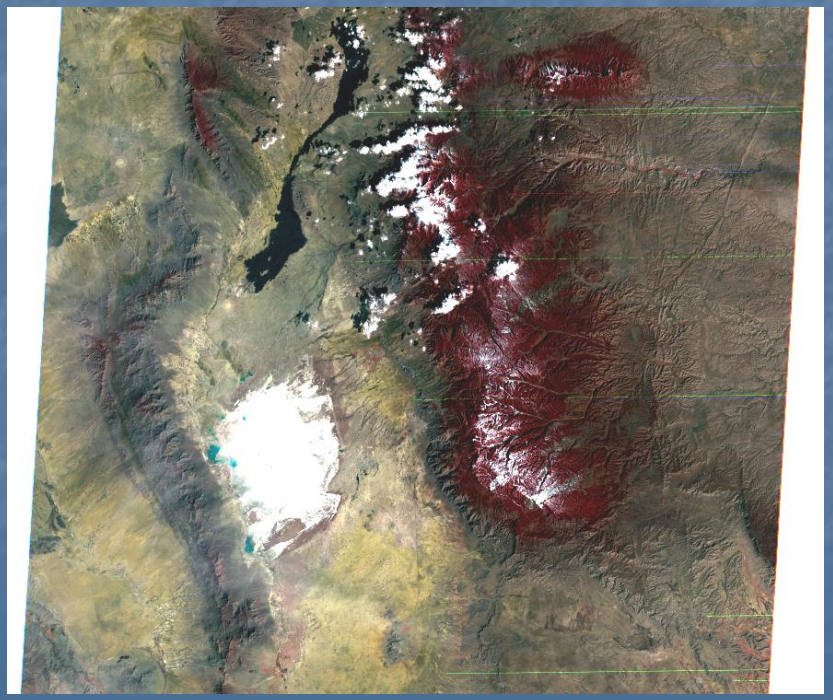


White Sands (WRS1 P35R37)

- ID: LM20350371979042AAA03
- Cloud Cover: 10% Qlty: 7
- Date: 1979/2/11
- Sun Elevation 30
- Sun Azimuth 136



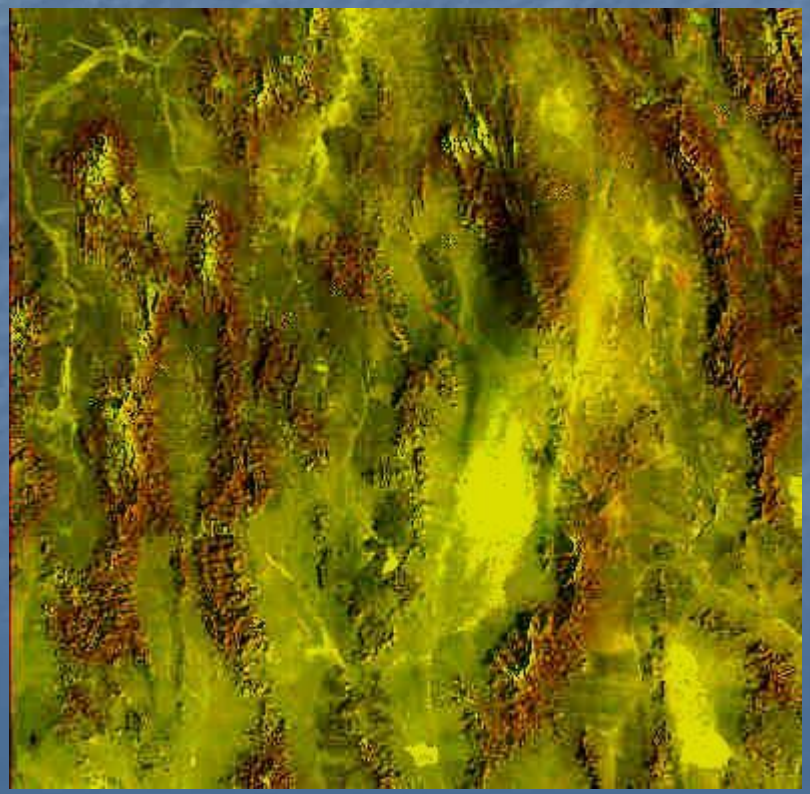
- ID: LM30350371979051AAA05
- Cloud Cover: 10% Qlty: 9
- Date: 1979/2/20
- Sun Elevation 35
- Sun Azimuth 137



L1/L2 MSS Near Coincident Scenes

Railroad Valley (WRS1 P43R33)

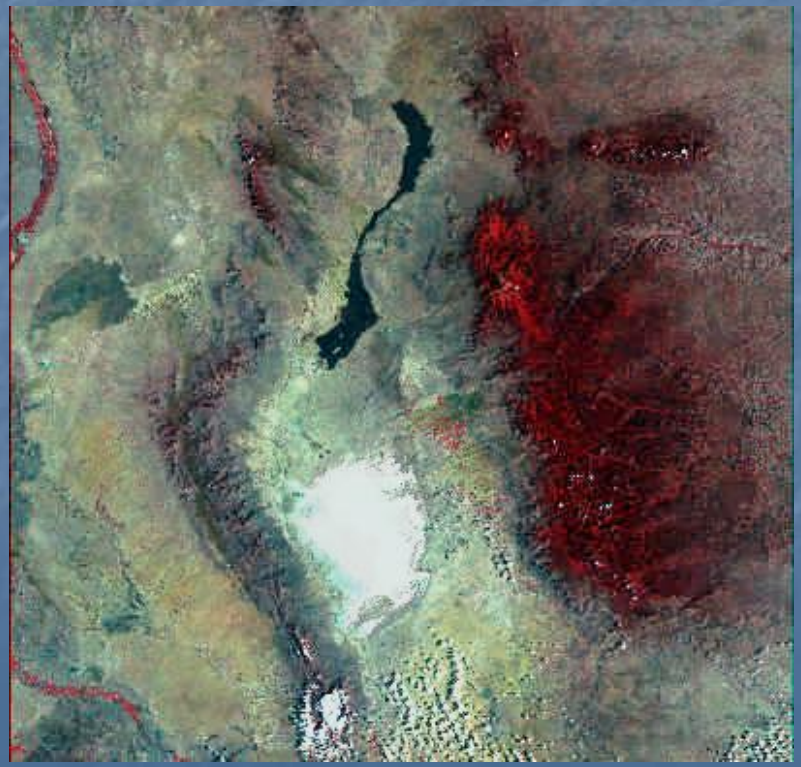
- ID: LM10430331977318AAA01
- Cloud Cover: 0% Qlty: 4
- Date: 1977/11/14
- Sun Elevation 18 ?
- Sun Azimuth 133



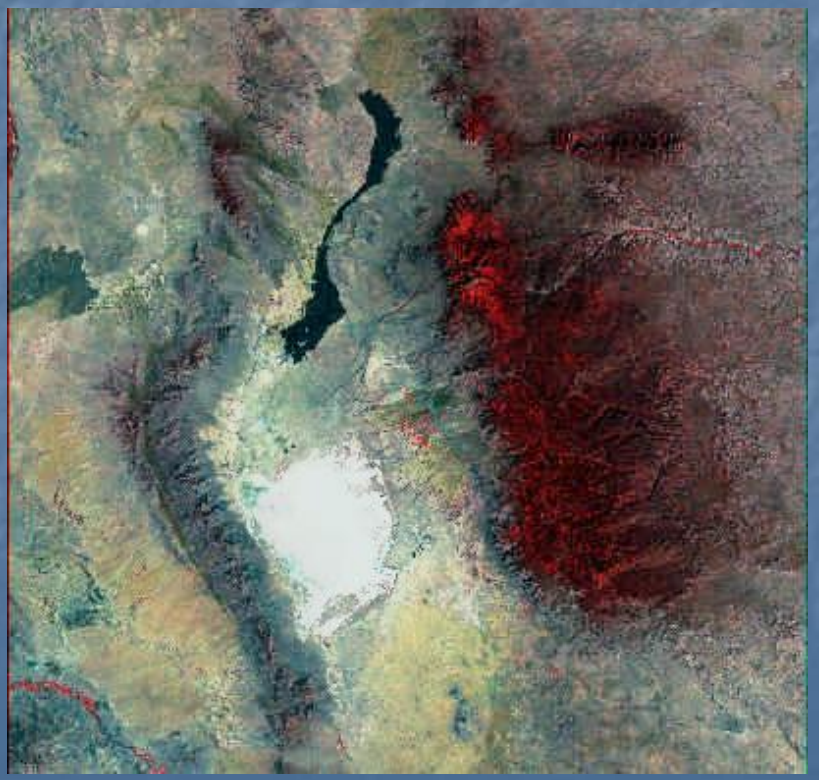
- ID: LM20430331977312AAA03
- Cloud Cover: 0% Qlty: 5
- Date: 1977/11/8
- Sun Elevation 26 ?
- Sun Azimuth 144

White Sands (WRS1 P35R37)

- ID: LM10350371976265AAA04
- Cloud Cover: 10% Qlty: 5
- Date: 1976/9/21
- Sun Elevation 40
- Sun Azimuth 122

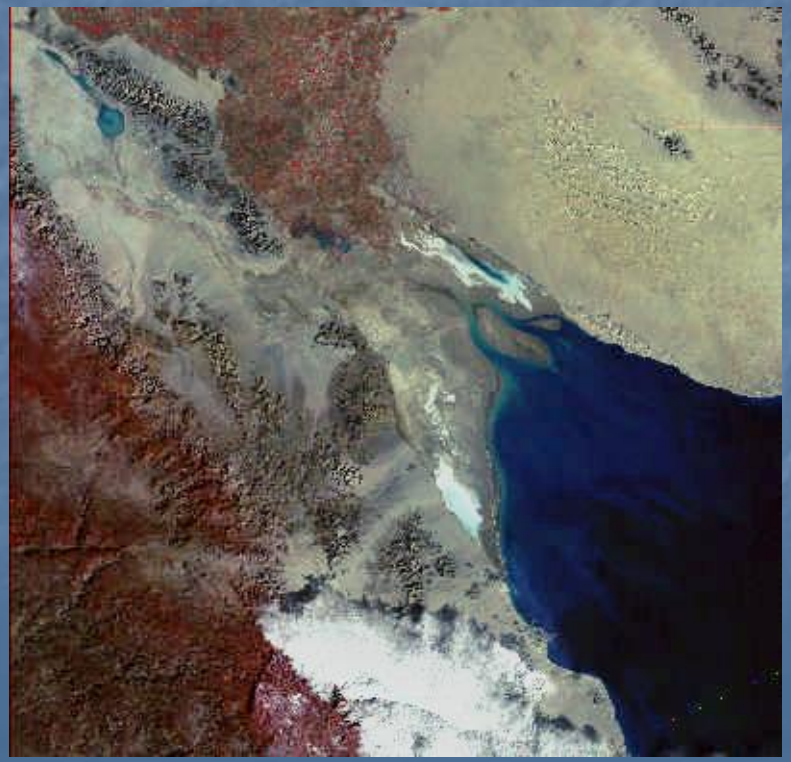


- ID: LM20350371976274AAA03
- Cloud Cover: 0% Qlty: 5
- Date: 1976/9/30
- Sun Elevation 43
- Sun Azimuth 134



Sonoran Desert (WRS1 P41R38)

- ID: LM10410381975348AAA01
- Cloud Cover: 10% Qlty: 4
- Date: 1975/12/14
- Sun Elevation 25
- Sun Azimuth 143



- ID: LM20410381975357AAA01
- Cloud Cover: 10% Qlty: 4
- Date: 1975/12/23
- Sun Elevation 26
- Sun Azimuth 147

L1—L5 MSS Data Example

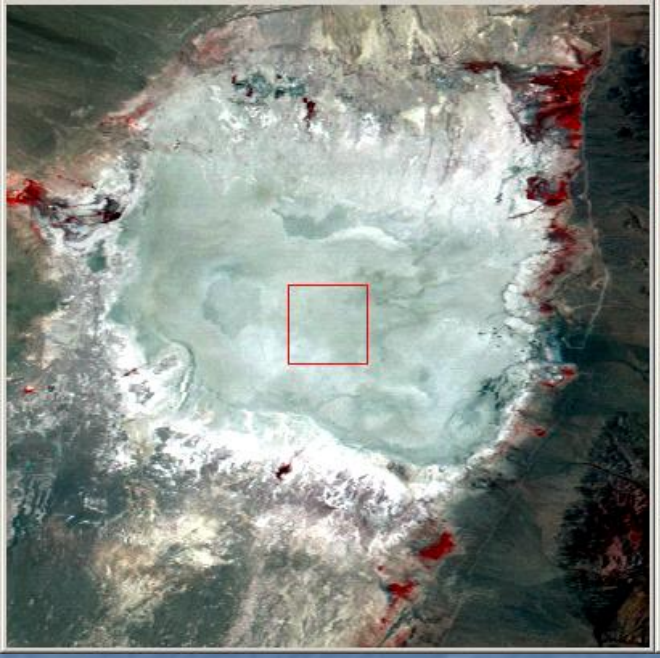
Landsat 5 MSS:
Railroad Valley

Path 40 Row 33

August 1, 1999

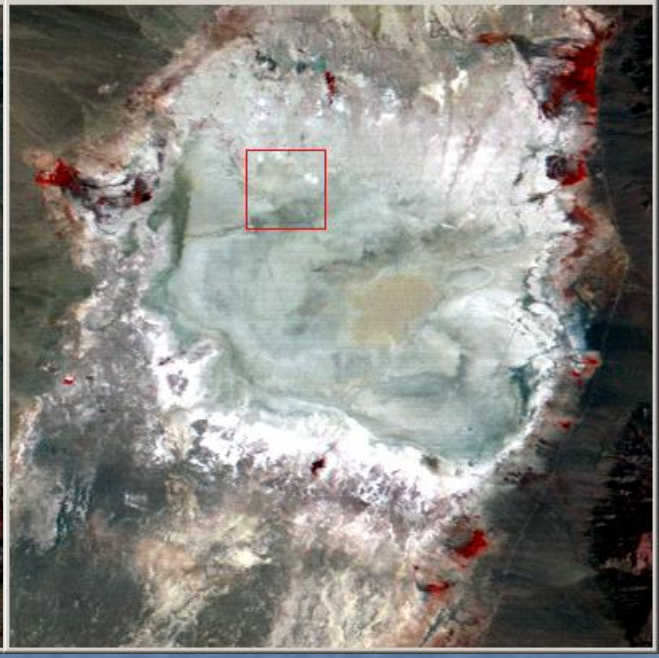
Bands 4/2/1

Two Regions of Interest:
Agricultural and RRV Playa



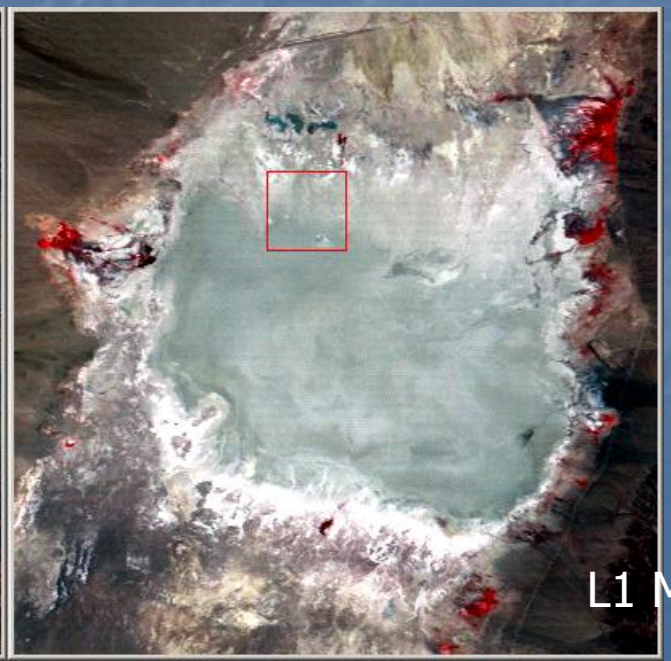
L5 MSS 8/1/99

L4 MSS 7/24/92

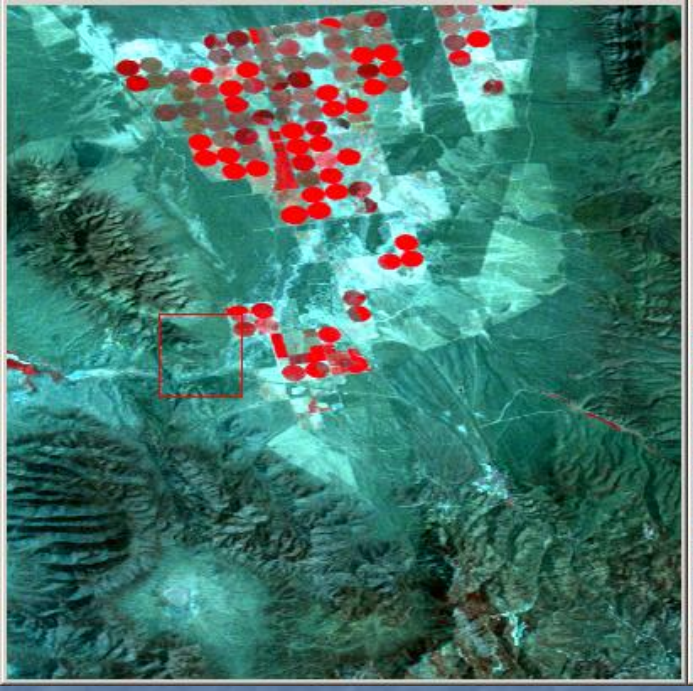


L3 MSS 9/21/81

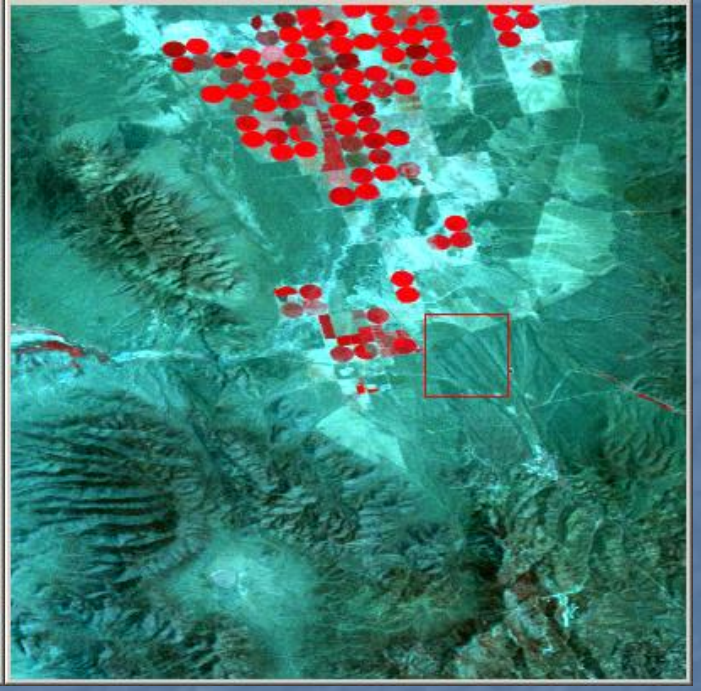
L2 MSS 9/30/81



L1 MSS 7/01/76

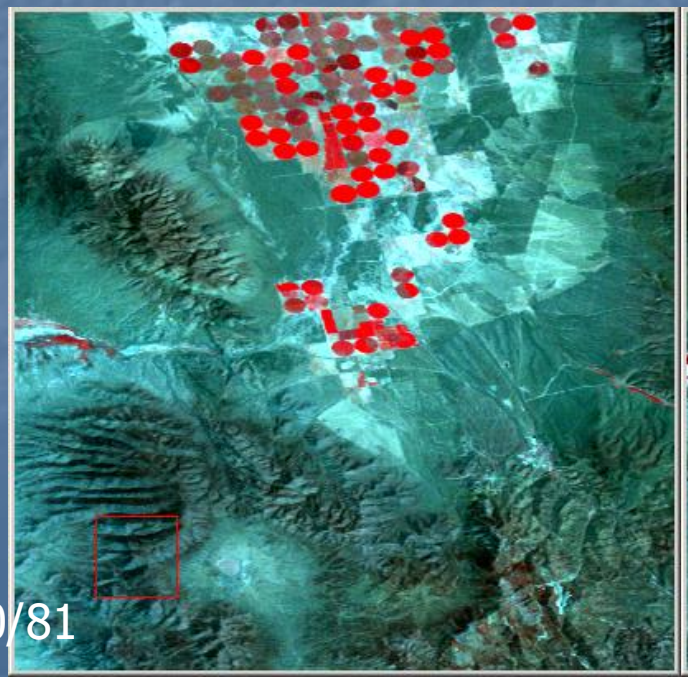


L5 MSS 8/1/99

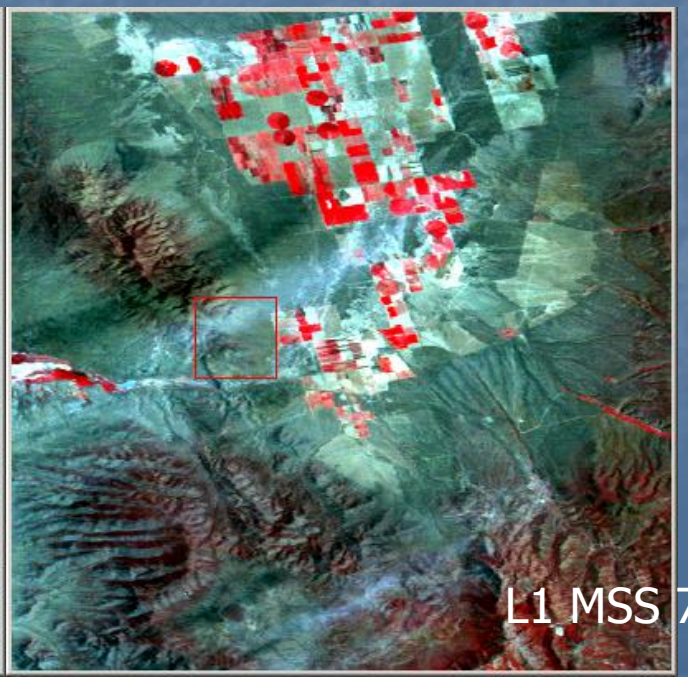


L4 MSS 7/24/92

Region not present in L3 image…!

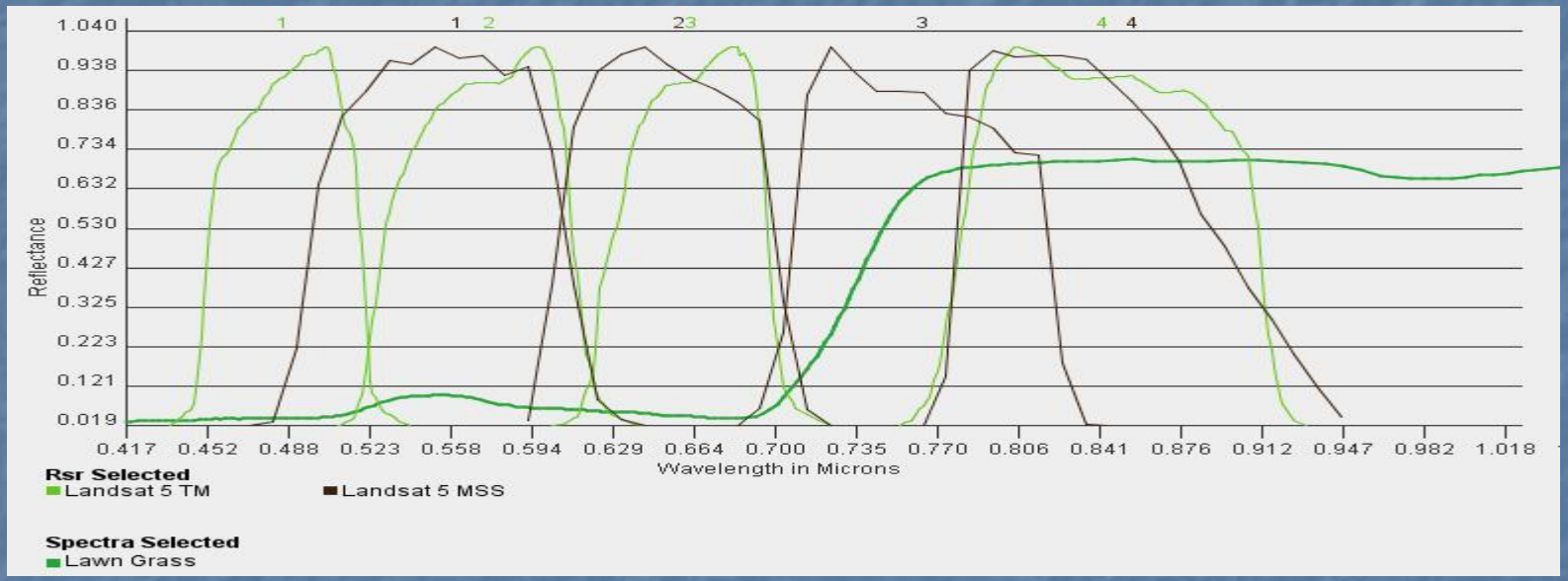


L2 MSS 9/30/81



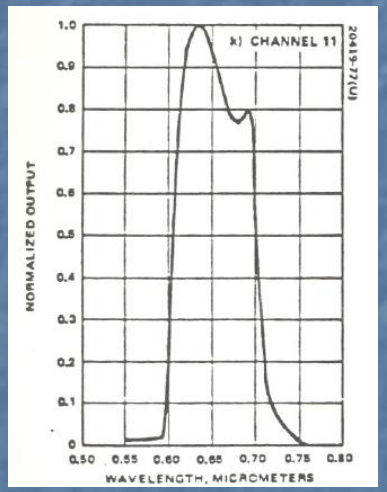
L1 MSS 7/01/76

Spectral Response Issues: TM vs. MSS

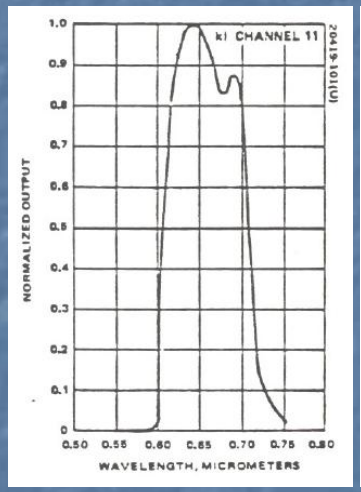


- Substantial differences exist between the spectral responses of TM and MSS
  - MSS bandwidths, in general, are larger than TM bandwidths
  - Spectral overlap between sensors varies widely across bands
    - MSS 4 RSR ≈ TM 4 RSR
    - MSS Band 3 RSR has no TM equivalent
    - MSS Band 2 RSR 'related' to TM Band 3 RSR
    - MSS Band 1 RSR 'related' to TM Band 2 RSR
  - MSS Band 3 straddles the 'red edge'
  - Fundamental limitation on cross-calibration from TM to MSS

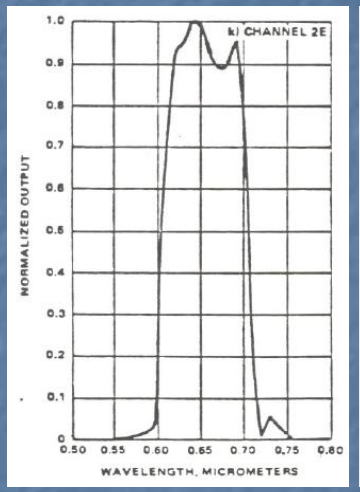
L1-L5 MSS Spectral Filter Responses, Band 2



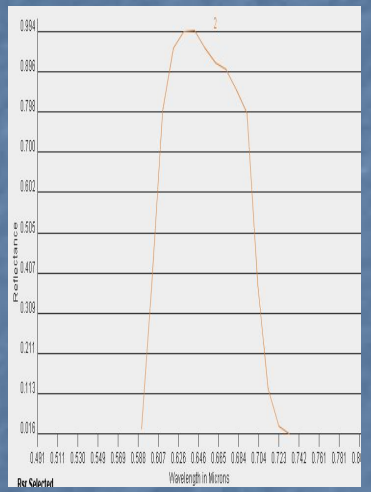
Landsat 1



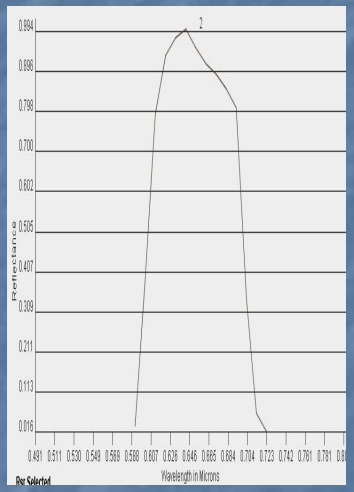
Landsat 2



Landsat 3



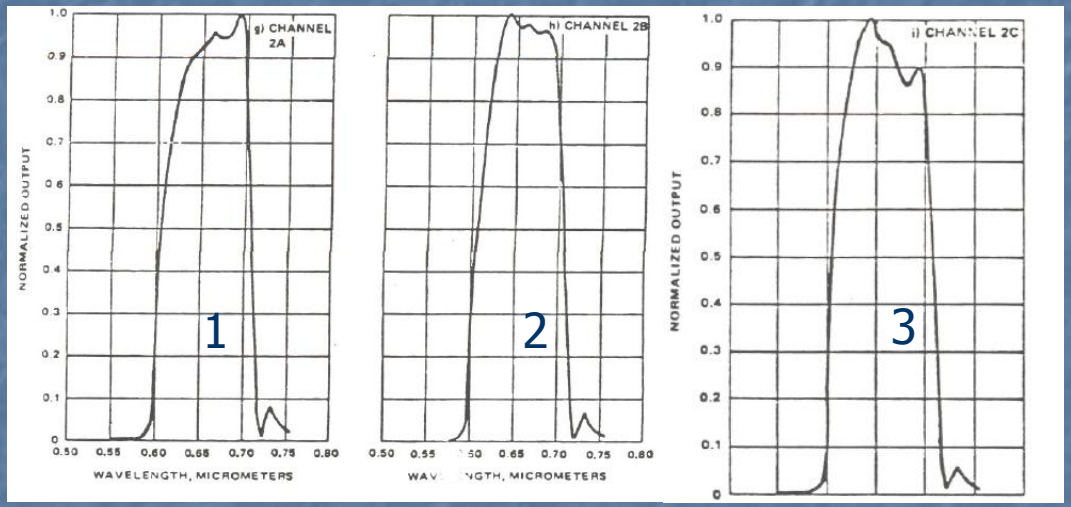
Landsat 4

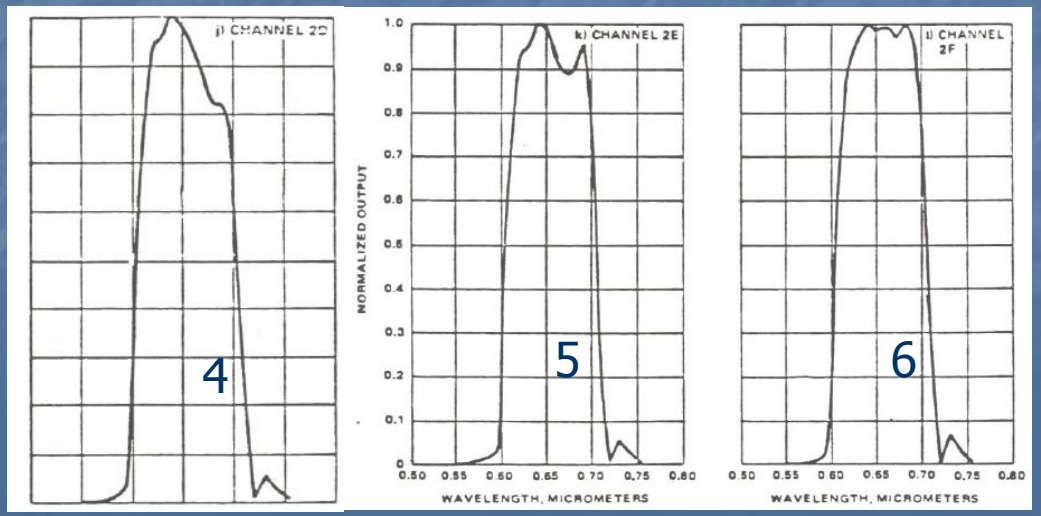


Landsat 5

- Substantial differences in RSR exist across the 5 sensors
- L1—L3 MSS RSR's have never been digitized
- Fundamental limitation to the cross-calibration accuracy
- L4—5 MSS RSR's notably more consistent than predecessor spectral filters

Landsat 3 MSS Spectral Filter Response, Band2, Detectors 1-6





Individual spectral filters used for each detector in MSS.

Substantially differing RSR's within a single band!

Summary

- Landsat 5 TM
  - Lifetime calibration essentially finished
  - Tightly cross-calibrated to L7 ETM+
  - Accuracy from 5% early in life to 2% late in life
  - Usefulness of Pseudo-invariant site approach validated
- Landsat 4 TM
  - Cross-calibration to Landsat 5 TM established through near coincident collects on multiple dates using multiple sites worldwide
  - Lifetime trend established through consistent response of IC lamps and pseudo-invariant sites
    - Band 1 is a possible exception
  - Accuracy predicted to be 10% or better
  - Work continues on 'pre-gap' timeframe
- Landsat 4/5 MSS
  - Data sets exist from which to establish this cross-calibration
  - Fundamental limitation will be in spectral response differences
  - Usefulness of these data for the science community limited
    - Why not just use TM data?
  - Critically important, though, for establishing consistent calibration to L1-L3 MSS
- Landsat 3 MSS
  - Critical link for obtaining consistent calibration for the first decade of Landsat observations
  - Very limited number of overlapping scenes available for pseudo-invariant site approach for linking L3 to L4 MSS
  - Usefulness of on-board calibration information ('cal wedge') unknown at this time for instrument trending
- Landsat 1/2 MSS
  - Substantial numbers of scenes exist for pseudo-invariant site calibration approach
  - Fundamentally limited to near-coincident collects due to orbital mechanics
  - Fundamental limitations exist in RSR differences
  - Usefulness of on-board calibration information also still TBD

Summary (2)

- Current Activities
  - SDSU Image Processing Lab project with EROS to address MSS calibration
    - Initial feasibility study nearing completion
  - EROS committed to building an MSS Image Assessment System (MSIAS)
    - **MSIAS** will join **TMIAS** which has joined the **IAS** to form a comprehensive Landsat image assessment system
    - **ALIAS** also exists for the EO-1 Advanced Land Imager
- Issues
  - Timeframe needed to complete this activity is limited
    - Soon all eyes will be upon OLI!
    - TM calibration took us nearly a decade; can we do 5 MSS instruments in two years???
  - Importance of the Landsat historical archive of the Earth needs to be emphasized at every opportunity