Landsat Calibration: Interpolation, Extrapolation, and Reflection

LDCM Science Team Meeting
USGS EROS
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And the IP Lab crew

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Image Processing Lab

Outline

- Interpolation: What has been done to calibrate the Landsat archive?
- Extrapolation: How is calibration going to extend to the LDCM era?
- Reflection: Calibration, the Science Team and…

Interpolation

- Where were we when we started this dance in January 2007?
  - Landsat 7 ETM+ was stable with calibration to 5% uncertainty
  - Landsat 5 TM was unstable but characterized, cross-cal'd to ETM+ with 3-5% precision. Now 27 years old!
- What didn't we know in January 2007?
  - Landsat 4 TM calibration (although nearly done)
  - Landsat MSS calibration
    - 5 sensors x 4 bands x 6 detectors = 120 channels
    - Consistent with each other? Absolute??
  - Use of Pseudo Invariant Cal Sites (PICS)
    - Extend back to 1972?
    - Data available?
    - Enough precision?

Interpolation (2)

- Where are we today in August 2011?
  - Landsat 4 TM calibration done
  - Landsat 1-5 MSS sensors done
    - Consistent with each other
    - Placed on an absolute scale
  - Confident that the PICS approach can provide 3% precision

Interpolation (3)

Table 11. Landsat Sensor Absolute Radiometric Calibration Uncertainties (%)								
	Landsat-7 ETM+	Landsat-5 TM	Landsat-4 TM	Landsat-5 MSS	Landsat-4 MSS	Landsat-3 MSS	Landsat-2 MSS	Landsat-1 MSS
Band 1	5	7	9	8	9	9	10	11
Band 2	5	7	9	8	9	9	10	11
Band 3	5	7	9	9	10	10	11	12
Band 4	5	7	9	14	18	18	22	25
Band 5	5	7	9					
Band 7	5	7	9					
Band 8	5							

- From Forty-Year Calibrated Record of Earth Reflected Radiance from Landsat: A Review
  - By Brian Markham and Dennis Helder, Remote Sensing of the Environment, Vol. Sometime soon…

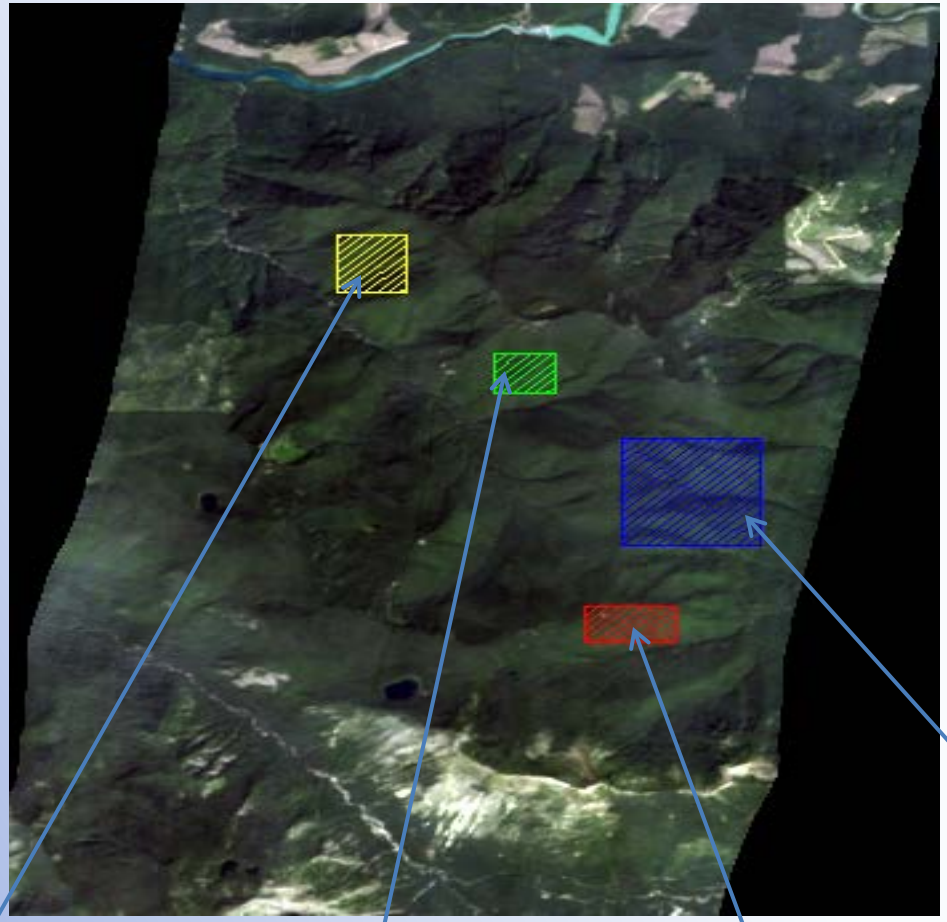
Interpolation (4)

- Does all this calibration effort, mostly in the desert, actually improve things?
  - A quick study in the forests of Washington state…
  - Landsat 5: 20 MSS and 16 TM scenes from 1984 – 1992. 7 same day scenes.
  - Nine Hyperion scenes for target spectra

Site Selection

- Selection of vegetated site for cross cal is dependent on
  - Nature of vegetation: not changing frequently
  - Homogeneity of Vegetation
  - Availability of hyperspectral signature of target area
  - Available cloud-free TM and MSS scenes
- Coniferous forest site
  - located at WRS Path/Row-46/28
  - In Washington State

ROI Selection



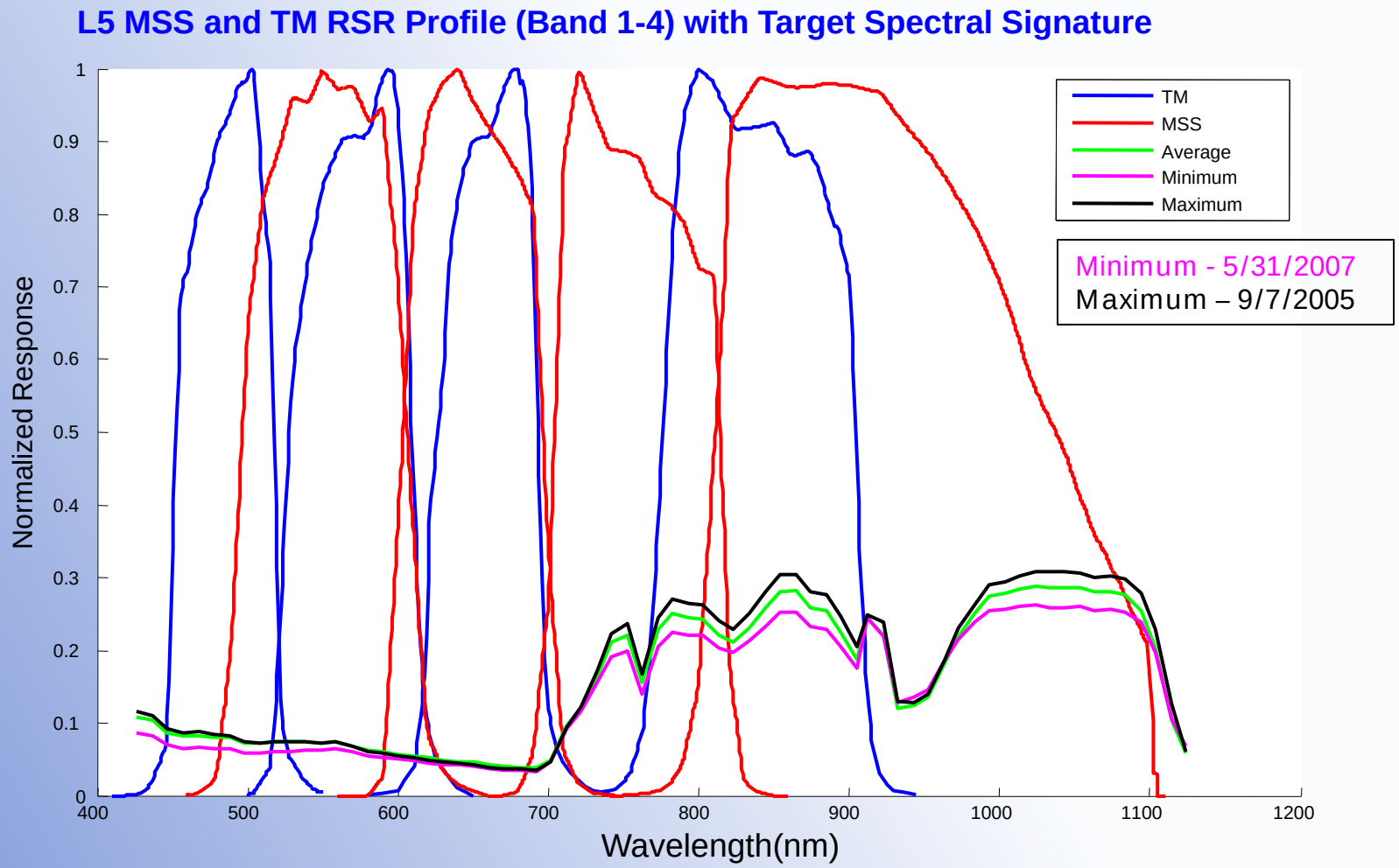
ROI 4: 0.678 km^2
26X 29 Pixels

ROI 2: 0.414 km^2
22 X 21 Pixels

ROI 1: 0.550 km^2
34 X 18 Pixels

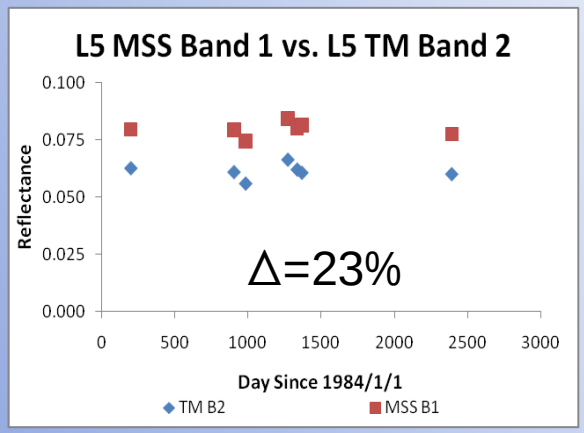
ROI 3: 2.527 km^2
52 X 54 Pixels

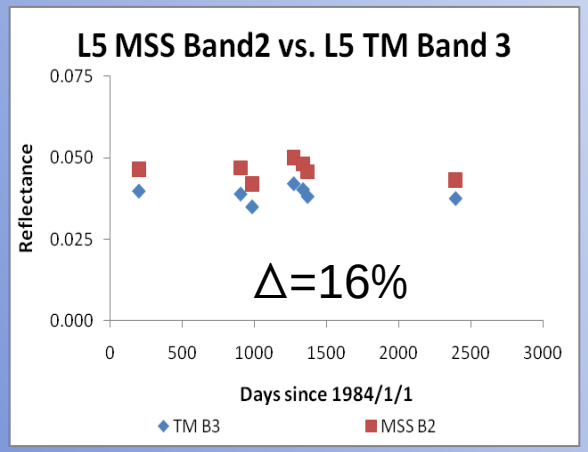
Spectral Signature of Target overlapped with TM and MSS RSR



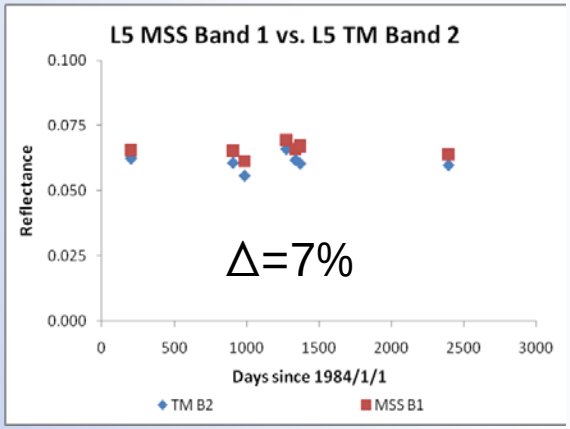
MSS to TM Consistency: Forests

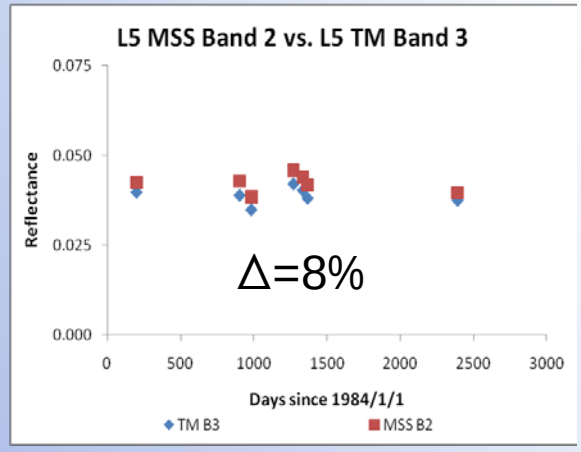
No Calibration
No SBAF Correction





With Calibration
No SBAF





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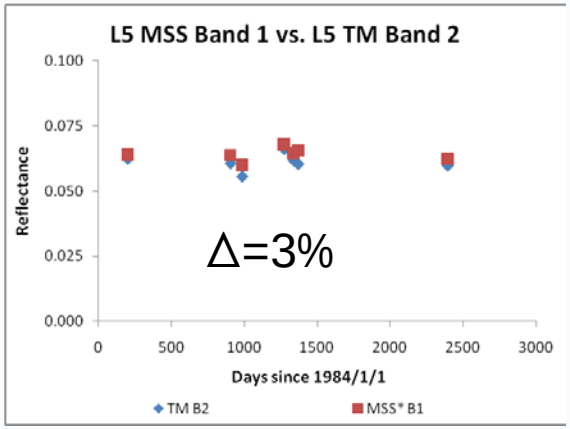

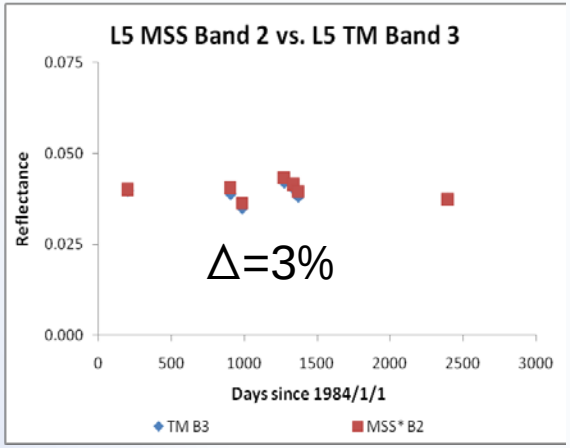

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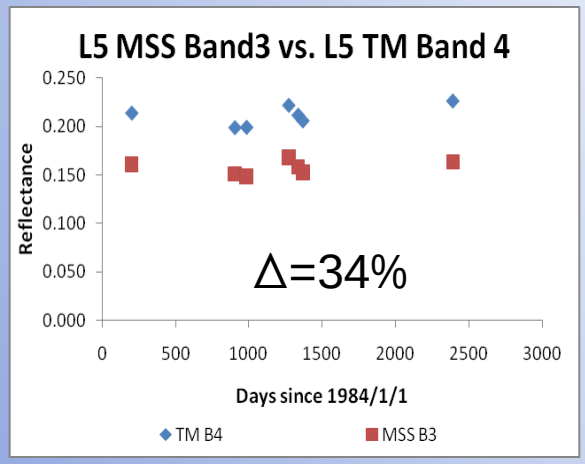
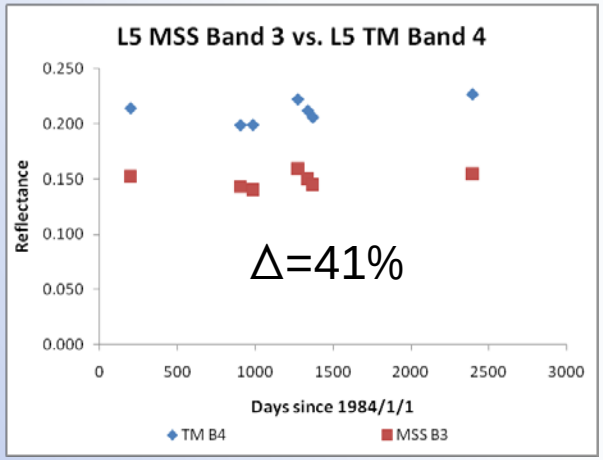
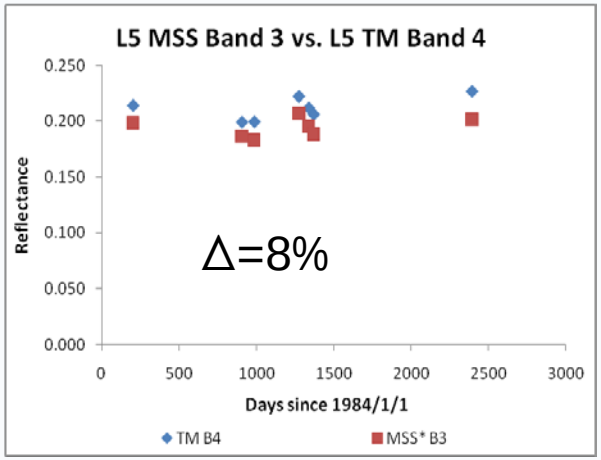
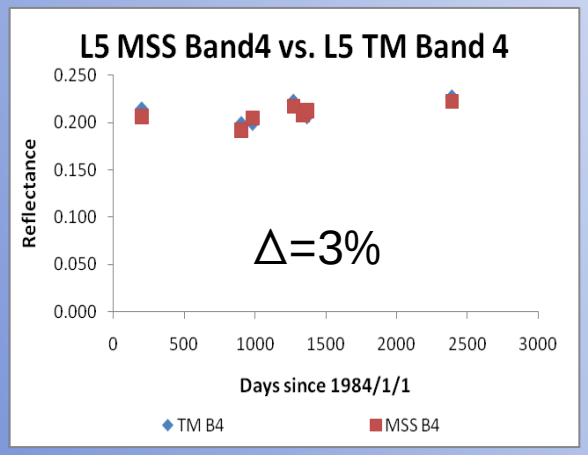
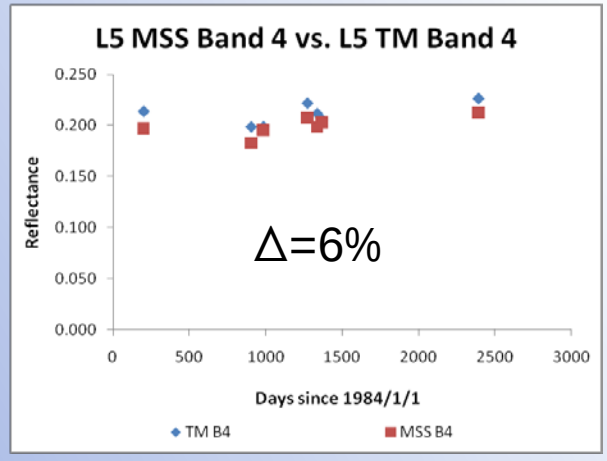
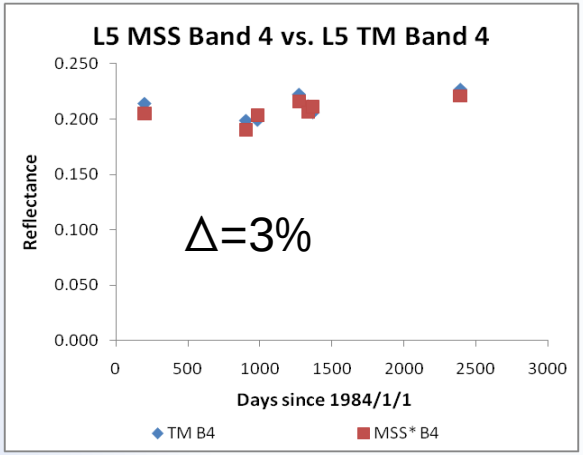






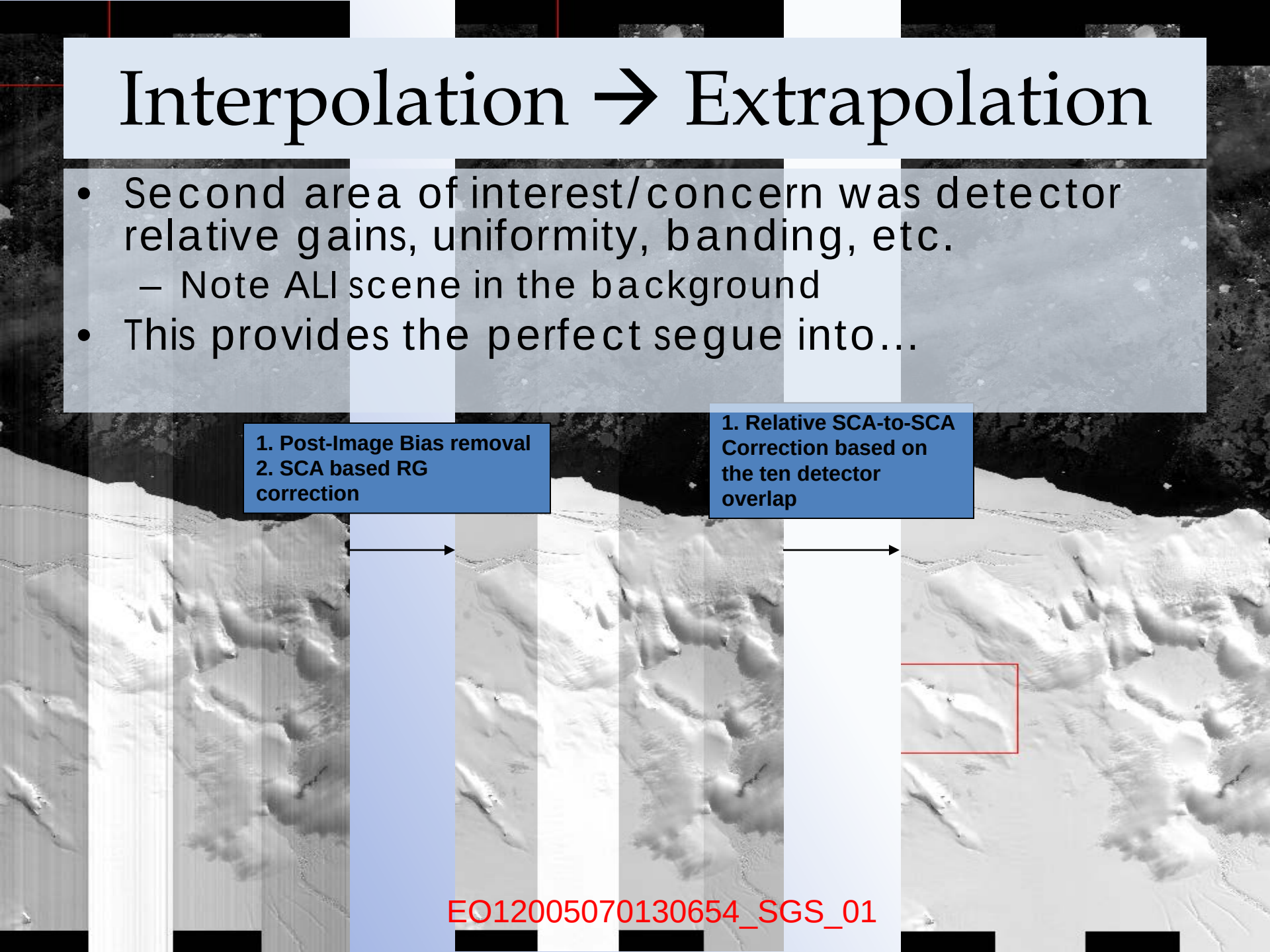






Interpolation → Extrapolation

- Second area of interest/concern was detector relative gains, uniformity, banding, etc.
  - Note ALI scene in the background
- This provides the perfect segue into…



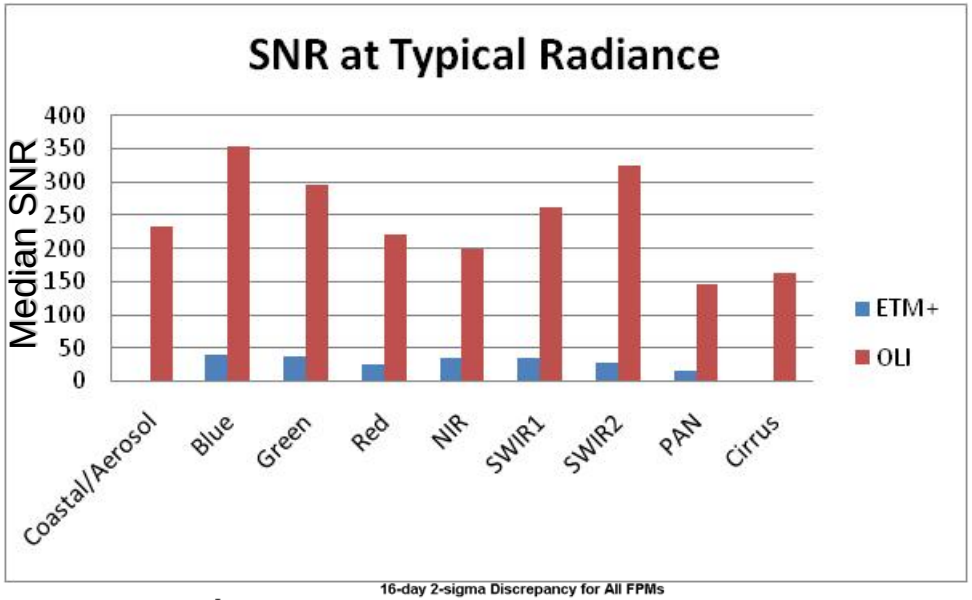
Extrapolation (1)

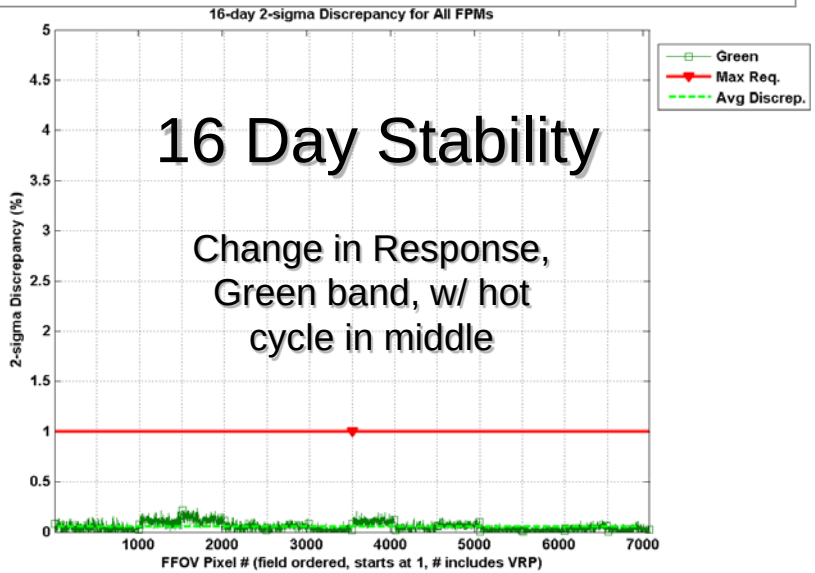
- What are we getting with the OLI sensor?
  - Comments also generally apply to TIRS
  - Better dynamic range
  - Better signal-to-noise ratio
  - Better radiometric resolution
  - Better absolute calibration
  - Better stability(?)

OLI Radiometric Performance

(Slide courtesy Brian Markham)

- SNR
  - SNR significantly exceeds requirements and heritage
- Calibration
  - Absolute uncertainty ~4%
    - Extensive round robin for validation
    - Transfer-to-Orbit uncertainties included
  - Stability over 60 seconds (2 standard scenes)
    - <0.02% 2σ
  - Stability over 16 days (time between Solar Diffuser Cals)
    - <0.54% 2σ for all but Cirrus Band which is <1.19%





Extrapolation

	ETM+ High Gain		OLI		ETM+/OLI
Band	**Min Sat Level**	**Rad./DN**	**Min Sat Level**	**Rad./DN**	**Res. Ratio**
Blue	190	0.742	581	0.142	**5.2**
Green	194	0.758	544	0.133	**5.7**
Red	150	0.586	462	0.113	**5.2**
NIR	150	0.586	281	0.069	**8.5**
SWIR 1	31.5	0.123	71	0.017	**7.1**
SWIR 2	11.1	0.043	24	0.006	**7.4**
PAN	156	0.609	515	0.126	**4.8**

- Comparison of radiometric resolution of ETM+ and OLI
  - ETM+ = 8 bits
  - OLI = 12 bits
- Based on published documents
  - Landsat 7 Science Data Users Handbook
  - LDCM OLI Requirements Document
- 5—8 times improved radiometric resolution *with* the SNR to support it!

Excerpts from OLI Requirements

5.6.2.3 Pixel-to-Pixel <u>Uniformity</u>

- ***5.6.2.3.1 Full Field of View***
  - The standard deviation of all pixel column average radiances across the FOV within a band shall not exceed 0.5% of the average radiance.

$$\sqrt{\frac{\sum_{i=1}^{N}(\bar{L}_i - \bar{L}')^2}{N-1}} \leq 0.005 \cdot \bar{L}'$$

- ***5.6.2.3.2 Banding***
  - The root mean square of the deviation from the average radiance across the full FOV for any 100 contiguous pixel column averages of radiometrically corrected OLI image data within a band shall not exceed 1.0% of that average radiance.

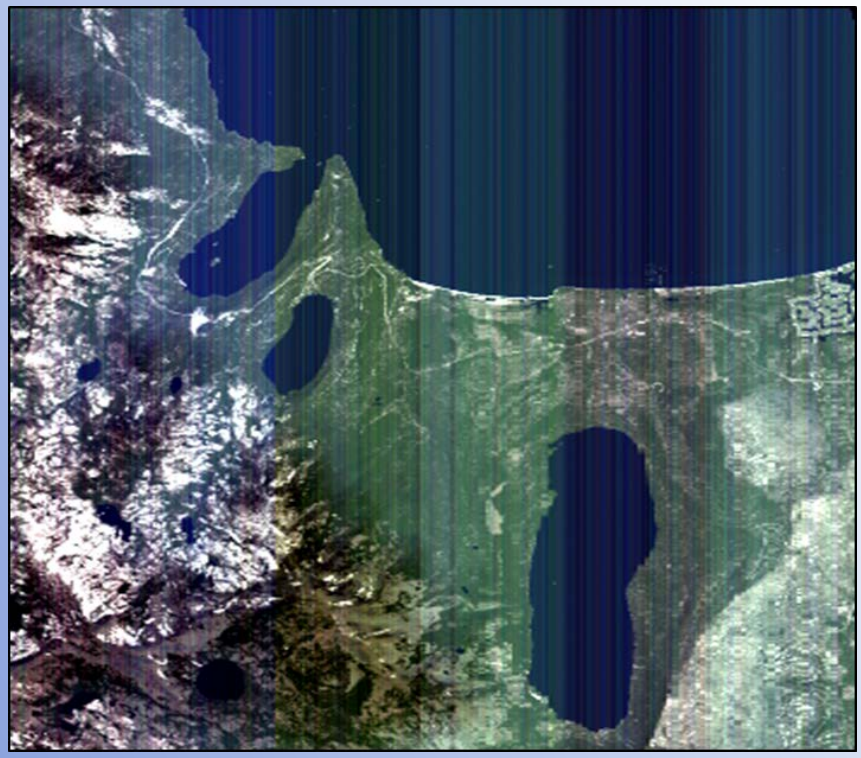
$$\sqrt{\sum_{i=n}^{n+99}(\bar{L}_i - \bar{L}')^2 / 100} \leq 0.01 \cdot \bar{L}'$$

- ***5.6.2.3.3 Streaking***
  - The maximum value of the streaking parameter within a line of radiometrically corrected OLI image data shall not exceed 0.005 for bands 1-7 and 9, and 0.01 for the panchromatic band.

$$S_i = \left| \bar{L}_i - \frac{1}{2}\left(\bar{L}_{i-1} + \bar{L}_{i+1}\right) \right| / \bar{L}_i$$

These requirements allow the presence of striping and banding…

OLI Scene Simulation



- Lake Tahoe simulated OLI image before gain/bias correction
- ***Courtesy John Schott/RIT via DIRSIG***
  - Fully synthetic scene
- OLI Simulation
  - 14 arrays
  - 60 detectors each; actual values
  - 12 bit quantization
  - Actual OLI noise levels
  - Actual spectral response
  - Actual detector gains/biases
  - Sampled observed non-linearity function
  - No radiometric corrections applied—raw data
  - Perfect geometry

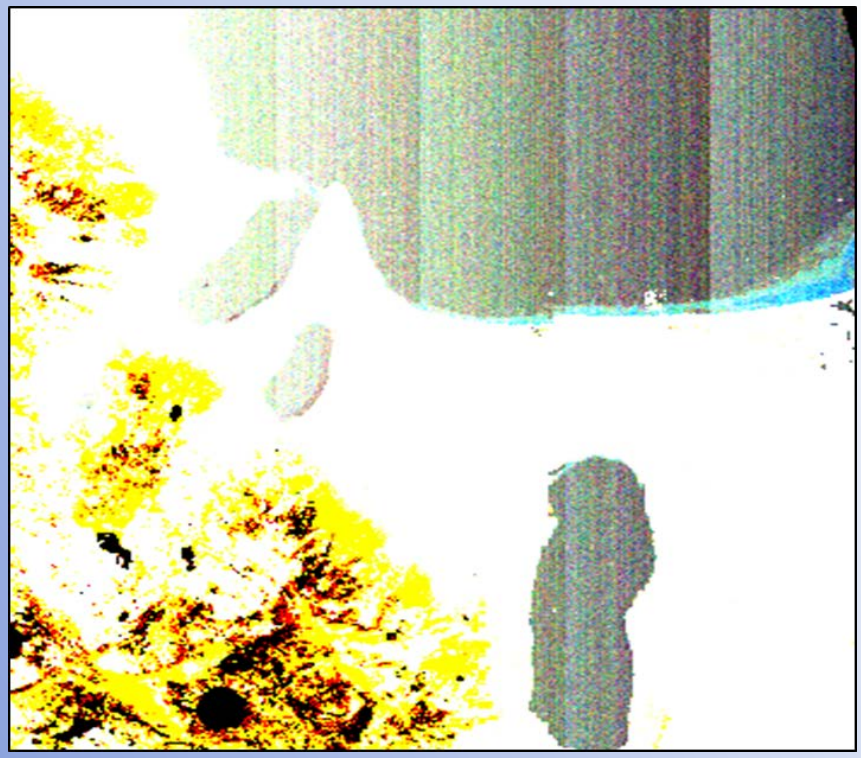
OLI Scene Simulation (2)

- Lake Tahoe Image after gain and bias correction
  - No non-linearity correction applied
- Beautiful!

OLI Scene Simulation (3)

- Gain/bias corrected image with land stretch
  - Square root stretch
- Beautiful!

OLI Scene Simulation (4)



- Water stretch on Lake Tahoe Simulated Image
  - Linear 2%
- Striping
- Banding
- Noise
- **OLI (and TIRS) will be better than anything you've seen**, but they will have 'additional features'

Extrapolation

- OLI and TIRS will be substantially better than any previous Landsat sensor with respect to radiometric performance
- Substantial increase in radiometric resolution and SNR will allow users to detect the signature of the instrument in homogeneous regions with severe stretches
- Strongly suggest users accept this as an additional benefit of using high performance sensors rather than viewing it as a drawback

Reflections

- What a great job!
  - Nice to work with some really smart people for a change!
- Push the calibration in your applications
  - What are the limits?
  - Where does it exceed your needs?
  - Where does the cal fall short?
- What's the value proposition?
- How do you sell a 40 year program to a 2 year government?