Landsat PICS-based Calibration Update

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Outline

- PICS Cloud Mask development for automated trending
- Landsat 8 OLI stability based on PICS analysis
- Landsat 8 cross-calibration using Libya 4

BRIEF OVERVIEW OF AUTOMATIC CLOUD MASK FOR PICS TO SUPPORT LANDSAT CALIBRATION

Cloud and Cloud Shadow Detection Tests

1. Test_1 = Temperature Test

- Is a deterministic and definitive test.
- detects 85% to 95% clouds and cloud shadows from a cloudy scene.
- Distinguishes the clear scenes from cloudy scenes.

2. Test_2 =
$$\frac{TOA_Reflectance(Red_{band}*Green_{band})}{TOA_Reflectance(SWIR1_{band}*SWIR2_{band})}$$

Similar to NDVI, NDSI, Whiteness tests etc.

•
$$NDVI = \frac{Refl_{NIR} - Refl_{RED}}{Refl_{NIR} + Refl_{RED}}$$

• $NDSI = \frac{Refl_{GREEN} - Refl_{SWIR1}}{Refl_{GREEN} + Refl_{SWIR2}}$

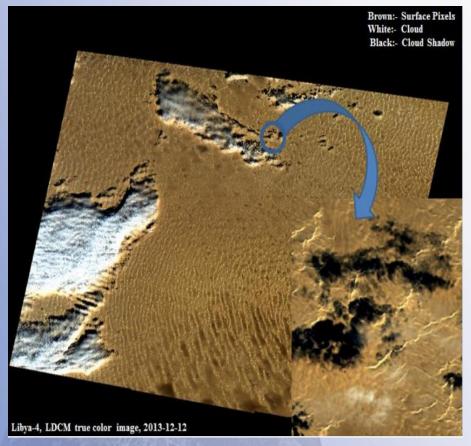
3. Test_3 =
$$\frac{TOA_Reflectance(NIR_{band})}{TOA_Reflectance(SWIR1_{band})}$$

Adds information from NIR channel and detects cloudy pixels.

4. $Test_4$ (Shadow Test) = $TOA_Reflectance$ (SWIR1_{band} * SWIR2_{band})

 SWIR bands give lower reflectance from shadow of clouds than from clear desert pixels.

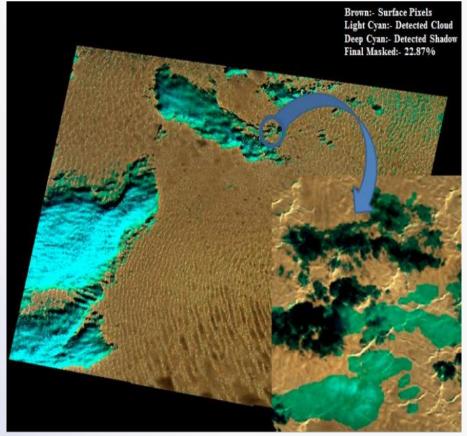
Result (3): Libya-4: Cloudy OLI Image, 2013-12-12



Brown: surface pixels (true color image)

· White : cloud

Black : shadow of cloud



• Brown: surface pixels

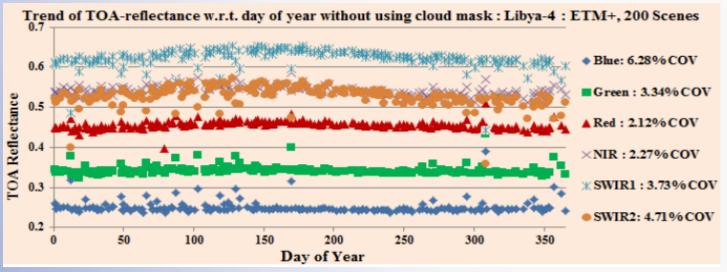
Cyan : detected clouds and shadows

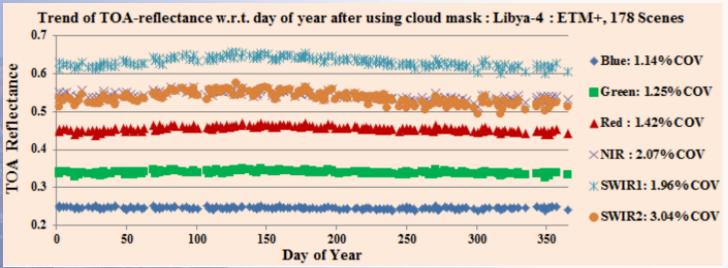
• 22.87 % cloud pixels including false detection

 8,313,776 pixels out of 236,348,746 pixels are detected as cloudy pixels

All clouds and their shadows have been detected, highlighted by cyan color.

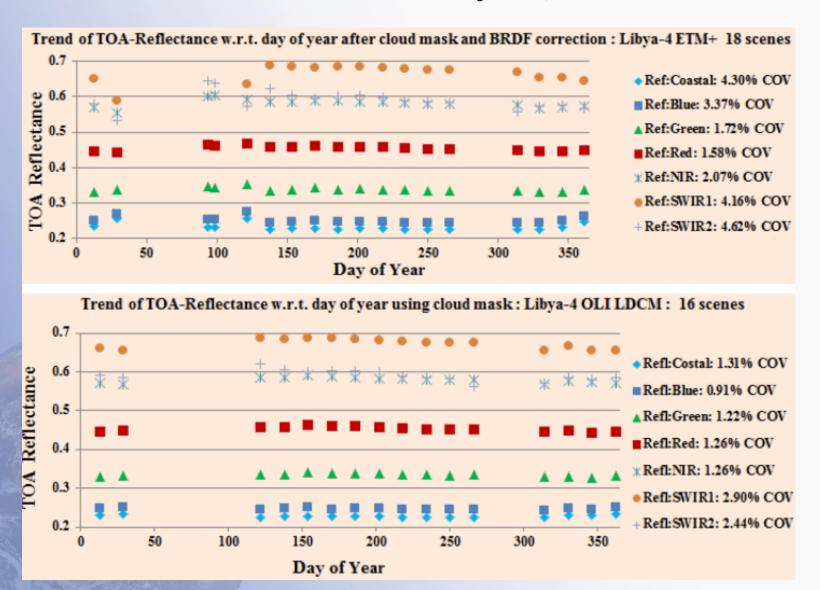
TOA-Reflectance Trend: Libya-4, 200 Scenes: ETM+





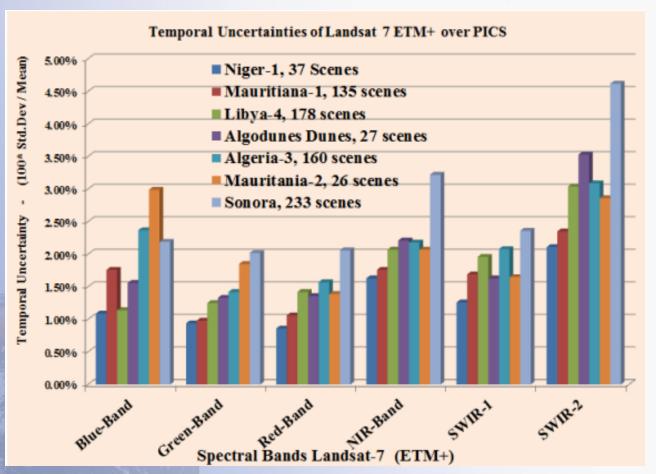
- Uncertainties are largely reduced to less than 3% in all spectral bands.
- Scenes having more than <u>60%</u> clouds or having some <u>artifacts</u> are considered as outlier scenes and removed manually.

TOA-Reflectance Trend: Libya-4,18 Scenes: OLI



• Uncertainties are largely reduced to less than 2.5% in all spectral bands.

Uncertainty Analysis after Cloud Mask (No BRDF Correction)



- Libya-4 and Niger-1 have lowest uncertainties compared to other PICS sites.
- Sonora and Mauritania-2 have highest uncertainties.
- Uncertainties are mostly less than 3% in all spectral bands from all sites, except for Sonora and Algodones Dunes.

Conclusion

- Automated cloud-mask algorithm calculates dynamic threshold value for each test to detect the cloud and cloud shadow pixels accurately, and masks them.
- Test-1 (Temperature test) is definitive and most accurate test, so this is the heart of this cloud-mask algorithm.
- This algorithm works properly with all cloudy scenes available in any PICS location from TM, ETM+ and OLI sensors.
- This algorithm improves the radiometric profiles and their uncertainties, and is used in automated PICS calibration.

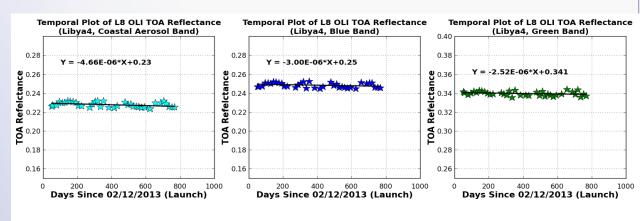
LANDSAT 8 OLI STABILITY BASED ON PICS ANALYSIS

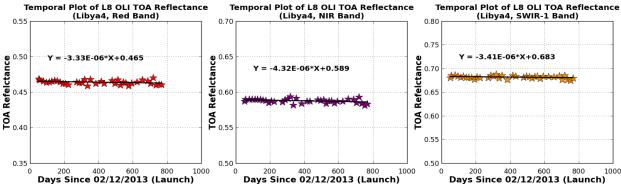
Background

- OLI images over top 4 PICS (Libya 4 &1, Egypt 1 and Sudan 1 were processed to trend TOA reflectance.
 - ➤ More than 30 "cloud free" acquisitions over these PICS
 - > Some of the scenes verified with the PICS cloud mask.
- Temporal stability and gain changes (linear drifts) were estimated for each band using these PICS
- Weighted mean was then calculated to estimate the drift using images acquired since launch
- PICS based estimates were compared with the on-board measurements.

Libya 4 (181/40) trending

- Data in the PICS database trended and corrected for the solar zenith angle trends
- 'Cloud' in some of the data points verified with the PICS cloud mask.
- For cleaner spectral bands, the uncertainty hovers around 0.5%.



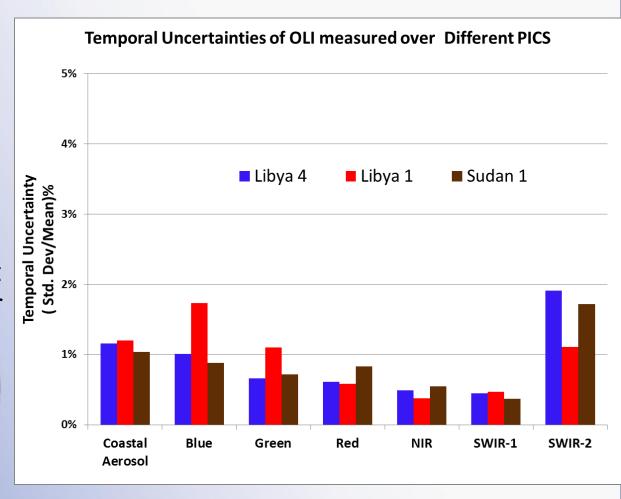


Temporal Plot of L8 OLI TOA Reflectance					
0.75	(Lib	ya4, SW	IR-2 Ba	nd)	
0.75					
0.70					
	Y = -7.0	6E-06*X+	0.606		
0.65					
0.60	****	***	*	Mark	
0.65 0.65 0.65 0.55 0.55	*				
0.50					
0.45					
0.40					
0	Days Sine	400 ce 02/1 2	600 2/ 2013	800 (Launc	1000 h)

Landsat	Temp. Uncertainty		
Bands	(1-Sgma/Mean)		
Coastal	1.16%		
Aerosol	1.10%		
Blue	1.01%		
Green	0.66%		
Red	0.61%		
NIR	0.49%		
SWIR-1	0.45%		
SWIR-2	1.91%		

OLI Temporal Uncertainties across different PICS

- The temporal stability is
 ~1 % for all thee sites
 except for SWIR-2 which
 is ~2%.
- Cleaner spectral bands such as Red, NIR and SWIR-1 generally exhibit uncertainties of ~0.5% or better.

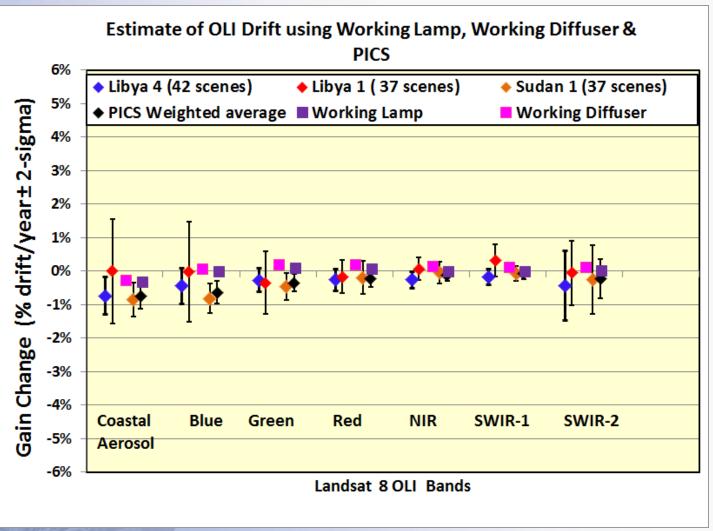


OLI-ETM+ comparison

- On comparison, it can be seen that for all 3 PICS, OLI temporal uncertainty is better than ETM+ for every band. The most noticeable differences can be seen in the NIR and SWIR-1 bands.
 - For NIR bands, the ETM+
 uncertainties are hovering around
 1.7% whereas the OLI uncertainties
 are around 0.5% which is a pleasing
 improvement of more than 1.1%.
 - Similarly, for the SWIR-1 band, the ETM+ uncertainties are around 1.2% whereas OLI uncertainties are around 0.6% or better which shows improvement of more than 0.5%.
 - SWIR-2 also exhibits a similar story where the temporal uncertainties in OLI are less than ETM+ by about 0.5%.

Landsat	OLI Temporal Uncertainty since launch			ETM+ Temporal Uncertainty since Feb 2013		
Bands	Libya 4	Libya 1	Sudan 1	Libya 4	Libya 1	Sudan 1
Coastal Aerosol	1.16%	1.20%	1.04%			
Blue	1.01%	1.76%	0.88%	1.12%	2.50%	1.65%
Green	0.66%	1.08%	0.72%	0.92%	1.35%	1.28%
Red	0.61%	0.65%	0.83%	0.91%	0.89%	0.97%
NIR	0.49%	0.40%	0.55%	1.84%	1.68%	1.72%
SWIR-1	0.45%	0.58%	0.37%	1.22%	1.22%	1.15%
SWIR-2	1.91%	1.14%	1.72%	2.40%	1.94%	2.11%

Drift Estimate using PICS



Black Diamond: PICS data weighted inversely by their uncertainties.

Observations

- The observed drift is higher in the coastal aerosol band using both methods and in the same direction.
 - PICS exhibit drift of around 0.7% per year and the onboard calibrators show a drift of around 0.3% per year but are within the uncertainties of PICS based drifts.
- In the blue band, PICS-based numbers are higher than the on-board measurements and differ by around 0.5% with the disagreement almost within the PICS-based uncertainties.
- For cleaner spectral bands such as green, red, NIR and SWIR-1 bands, the onboard numbers and PICS-based numbers show closer agreement.
 - PICS show a drift of around 0.1 to 0.2% per year whereas diffuser and lamp exhibit a change of around 0.05 to 0.2% per year and are within the uncertainties of PICS measurements.
- For SWIR-2 the uncertainties associated with PICS-based measurements are higher because of the location in the electromagnetic spectrum but the methods agree to within PICS-based uncertainties.

L8 PICS-based Cross Calibration to ETM+ & Aqua MODIS

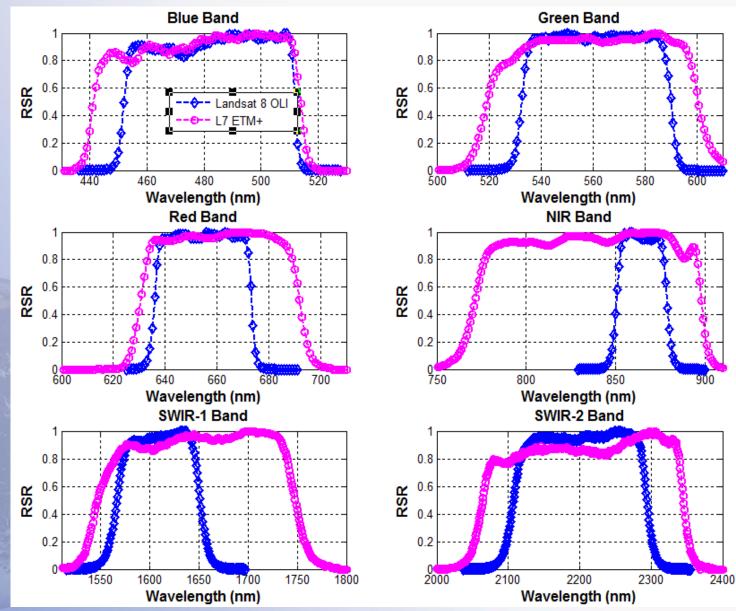
Cross calibration between L7 ETM+ & L8 OLI

Methodology

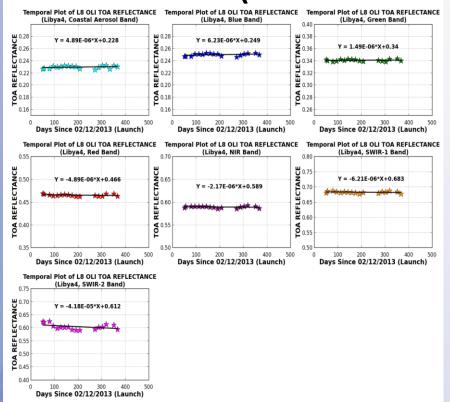
- Cross calibration using ETM+ & OLI using image statistics over Libya 4.
- Analysis done in both At-sensor Radiance and TOA Reflectance Space.
- ChKur Solar model used to derive Esun for L7 ETM+ and EO-1 Hyperion
- EO-1 Hyperion used to derive the SBAF

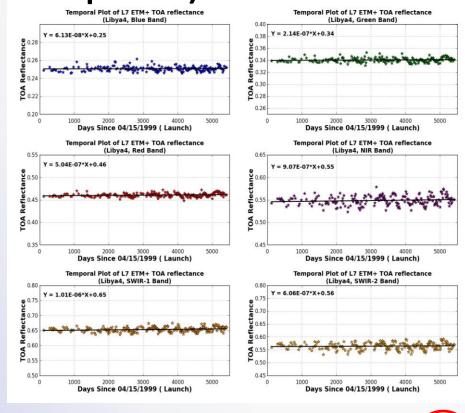
Relative Spectral Response Comparisons

- Bigger
 'spectral
 mismatches'
 in NIR and
 SWIR-1
 bands
 - L8 in blue
 - L7 in 'red'



Libya 4 based X-cal results (Reflectance Space)



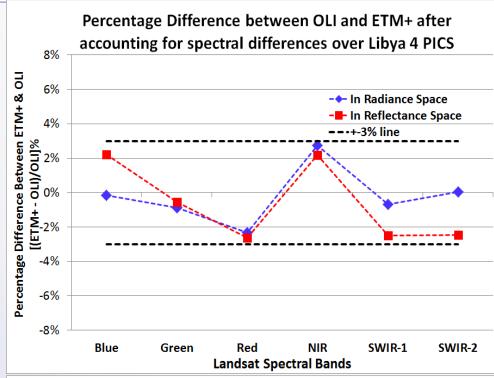


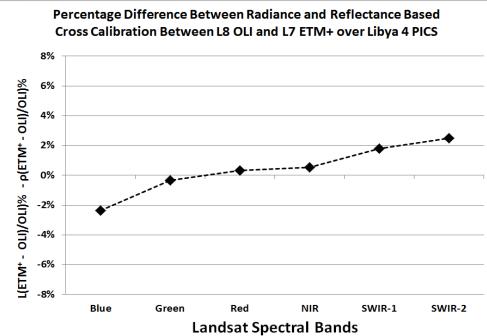
- In general ETM+ & OLI bands agree to within ±2.5% across the spectral channels.
- -ve sign indicates that reflectance reported by OLI is higher than ETM+.

Bands	L8 OLI	L7 ETM+	SBAF (Hyperion Derived)	% Diff Before SBAF	% Diff after SBAF
Blue	0.249	0.250	1.015	0.70%	2.22%
Green	0.340	0.340	0.997	-0.24%	-0.54%
Red	0.466	0.459	0.989	-1.57%	-2.64%
NIR	0.589	0.546	1.104	-7.43%	2.20%
SWIR-1	0.683	0.650	1.026	-4.92%	-2.49%
SWIR-2	0.612	0.562	1.063	-8.23%	-2.45%

Cross calibration comparisons - Radiance & Reflectance Space

- Both radiance and reflectance based cross calibration results show that agreement between ETM+ & OLI is generally within ±2%.
- Radiance and Reflectance based comparisons are within ±2% for all bands
- Note: At-sensor radiance is scaled by sun zenith angle and earth sun distance.
- -ve sign indicates OLI is brighter.

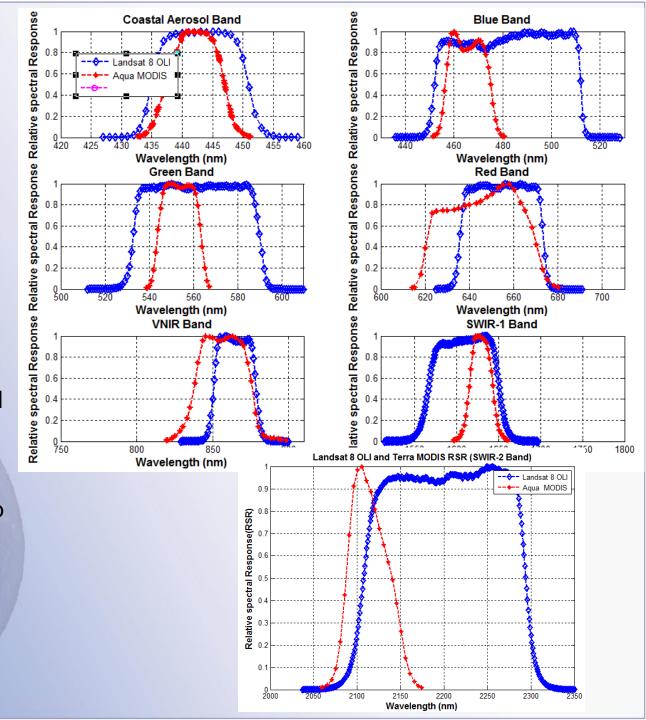




Cross calibration between L8 OLI & Aqua MODIS

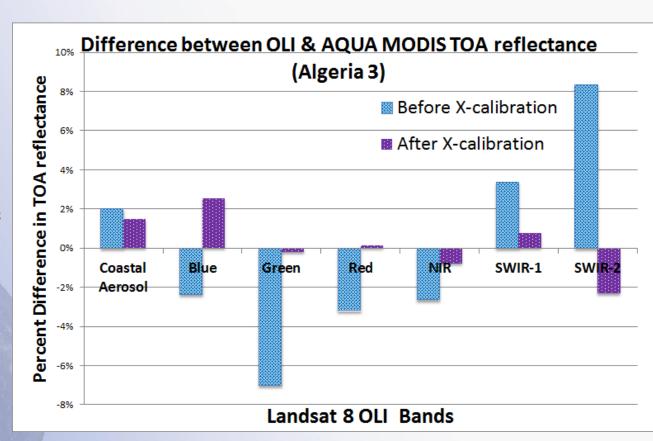
- Global Space-based Inter-Calibration System (GSICS)
 has recommended Aqua MODIS be used as the current
 reference for inter-calibration of reflective solar bands.
- Preliminary investigation based on 7 image pairs over Algeria 3 & 5 sites. (2014)
- Libya 4 nadir image pairs not available at the time the work was done
- 2 and half hour overpass difference
 - BRDF and 'atmospheric' effects due to overpass differences not accounted for
- SBAF using Hyperion images.

- With the refinements to OLI spectral bandpasses, its resemblance to Aqua is better as compared to ETM+.
 - Hence easier to account for spectral band differences.
- Analogous Coastal Aerosol band
- Minimal spectral overlap in the SWIR-2 bands
- Landsat 8 in blue
- MODIS Aqua in red



Results using Algeria 3 sites

- Before SBAF, bigger differences can be seen in Green and SWIR-2 bands
 - SWIR-2 band has 'minimal' spectral overlap.
- After SBAF, all bands agree to within ±2% of each other.
 - Cleaner spectral channels such as Green, Red, NIR and SWIR-1 agree to within ±1%
- OLI agrees to Aqua MODIS much better than ETM+ to Terra.



Summary

- OLI Cross calibration to L7 ETM+ and Aqua MODIS show differences to be within ±2.5%.
- The radiance and reflectance cross comparisons between ETM+ & OLI is within ±2% when using ChKur Solar Model to derive Esun numbers.
- Per yesterday's discussions on a PICS objective:
 - Spectral model is important
 - BRDF model is important
 - Climatology/atmospheric model is important
 - Spatial resolution is important
 - Multiple sites is important