Towards a Worldwide Library of Pseudo-Invariant Radiometric Calibration Sites

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•Acknowledgement:

This work was supported by the NASA Landsat Project Science Office and USGS EROS.

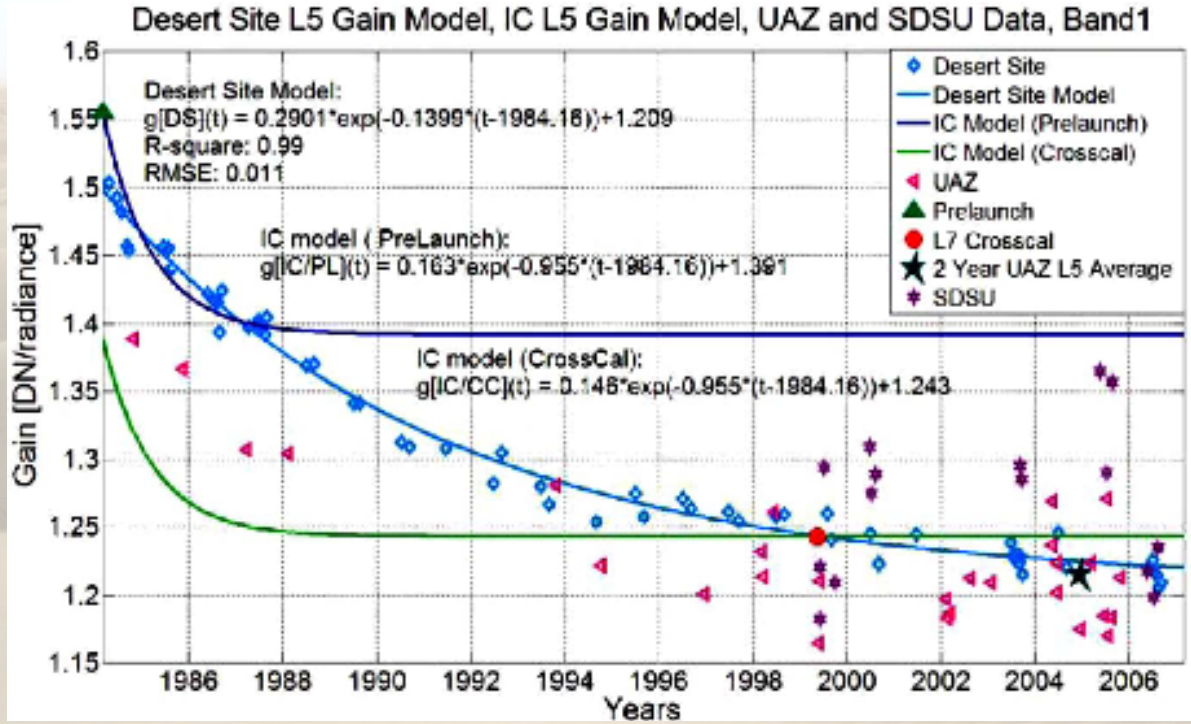
Background

- Playas (dry lakebeds), salt flats, and desert sand sites are prime candidates to be Pseudo-Invariant Calibration Sites (PICS) and numerous sites have previously been proposed.
  - Stable both temporally and spatially over long periods of time
  - Arid regions have lower probability of cloud cover
  - Near-flat surface spectral reflectance
  - Potential problems with PICS
    - BRDF Effects
    - Soil Moisture/Snow Cover
    - Atmospheric Scatter

(Teillet, Barsi, Chander, Thome – "Prime Candidate Earth Targets for the Post-Launch Radiometric Calibration of Space-Based Optical Imaging Instruments" in Proc. SPIE Int. Symp. , San Diego, CA, 2007*)*

Background

- One PICS, Saharan Desert - Libya 4 (P181/R40), has improved the uncertainty in the absolute calibration of Landsat 5 TM to under 5 percent.
  - Characteristic curves developed from this study are currently used for lifetime absolute calibration of L5 TM.
  - Band 5 saturates nearly everywhere within the Saharan Desert.



(Helder et al. – "Updated Radiometric Calibration for Landsat 5 TM Reflective Bands," IEEE Transactions on Geoscience and Remote Sensing, Vol. 42, No. 12, December 2007)

Rationale

- Previous Landsat absolute calibration work has used a rather crude method for ensuring that the same physical area of land was being viewed throughout the study and also only considered large portions of the scene.
  - These shortcomings can be improved through a first order geometric corrections to the scan alignment of each scene as well as a scene to scene correlation.
  - Looking at smaller areas or grids within a scene may also show which portions of each site are most invariant, therefore improving upon the uncertainty of using PICS for calibration.
- Although other sites have been identified as prime candidates for PICS, extending this approach to long term satellite archive calibration has not yet been done.
  - Studying the Landsat 5 TM lifetime trends at these candidate PICS not only validates that Libya 4 is invariant, but also provide alternate PICS around the world that are suitable for calibration work.
  - A network of suitable PICS provides a consistent calibration source that can be used to not only calibrate the Landsat archive but can be used for all satellite sensors.

Experimental Procedures

- Potential PICS were evaluated and chosen for this study based upon their size, location, climate characteristics, and scene availability in the USGS Landsat 5-TM archive.
- Once a site is chosen, L1R Landsat 5-TM scenes from the archive are ordered and geometric corrections are made to ensure that the same ground target area is visible in each scene.
  - Web-enabled (free) L1T products were not available for timeframe of this project.
- A grid approach is used to determine which general areas of each site are the most invariant.
- The grid size was determined based on the desert size.
  - Due to processing time and memory constraints, around 400 ROIs were desired at each site.
  - For the large deserts this resulted in a grid size of 300 x 300 pixels, medium deserts 200 x 200 pixels, and smaller deserts a 40 x 40 pixel grid.
- To determine the most invariant regions, the **PICS Min-Noise Algorithm** was developed.
  - Mean radiance of each grid is calculated for each scene.
  - Grid cells with lowest temporal standard deviation of the mean are chosen as most invariant.

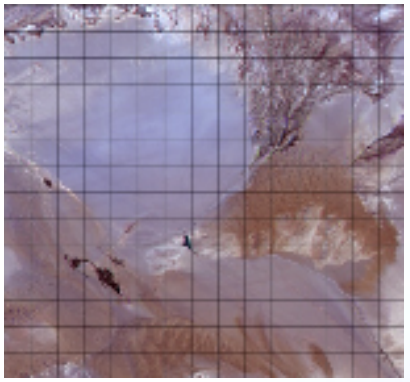
Scene Selection

PICS	L5 TMR Scenes processed with TMIAS	% of cloud free scenes out of total scenes available (Visible Inspection)	Total scenes in USGS Archive
Libya 4, Sahara Desert	48	56.5	85
Libya 1, Sahara Desert	26	63.4	41
Algeria 3, Sahara Desert	26	46.4	56
Mauritania1, Sahara Desert	7	25.9	27
Mauritania 2, Sahara Desert	4	18.2	22
Egypt 1, Sahara Desert	22	53.7	41
Egypt 2, Sahara Desert	25	58.1	43
Sonoran Desert, Mexico	46	60.2	486
Barreal Blanco, Argentina	14	45.2	31
Arabia 2, Middle East	19	57.6	33
Dunhuang, China	6	37.5	16
Simpson Desert 2, Australia	32	48.9	96

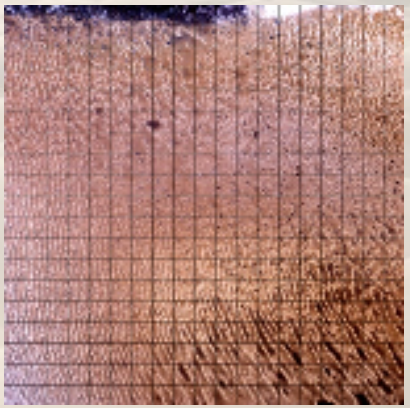
- Certain sites, such as Mauritania and Dunhuang, are more likely to be affected by cloud cover.

Grid Size Selection

PICS	Size of each GRID (pixels)	Total number of grids
Libya 4, Sahara desert	300×300	361
Libya 1, Sahara desert	300×300	361
Algeria 3, Sahara desert	300×300	342
Mauritania1,Sahara desert	300×300	361
Mauritania 2,Sahara desert	300×300	361
Egypt 1,Sahara desert	300×300	342
Egypt 2,Sahara desert	300×300	342
Sonoran Desert,Mexico	200×200	361
Barreal Blanco,Argentina	40×40	462
Arabia 2,Middle East	300×300	361
Dunhuang,China	200×200	210
Simpson Desert 2,Australia	300×300	324



•Dunhuang, China



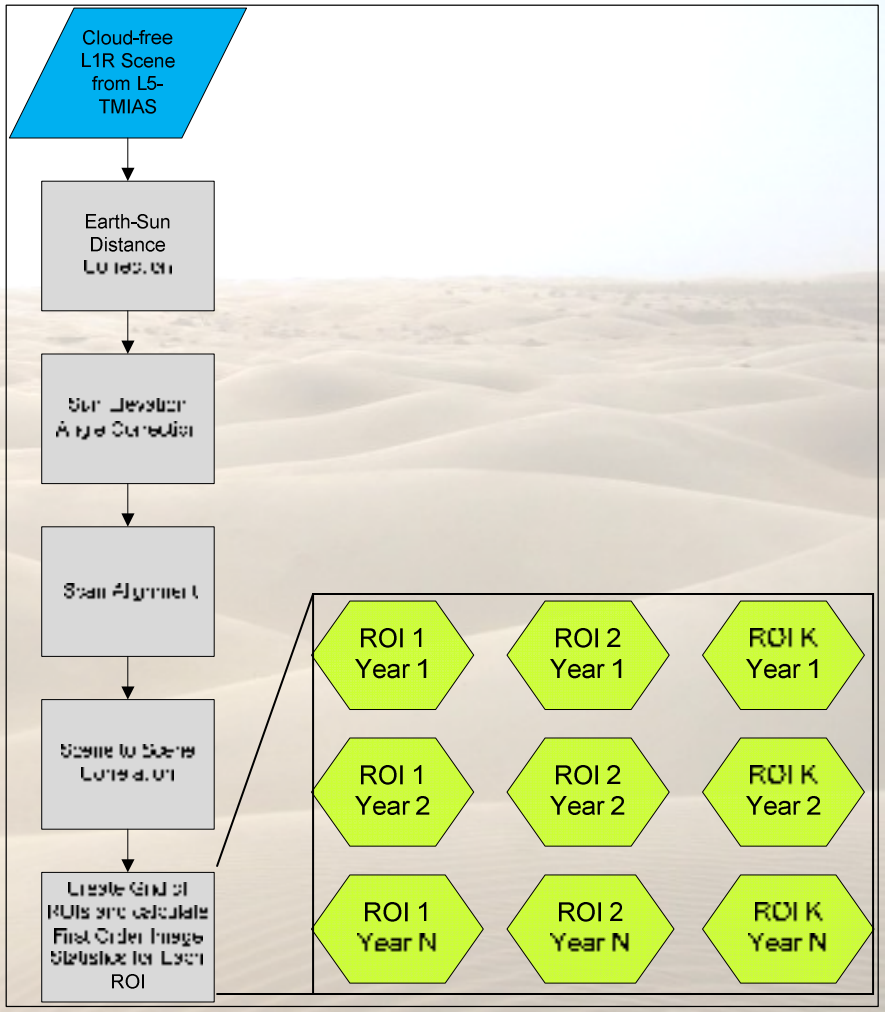
•Libya 4, Sahara

•300 x 300 pixel grids were nominally chosen, however the desert/salt flat (Sonoran Desert and Barreal Blanco Salt Flat) size occasionally required use of a smaller grid.

Detailed Processing Procedure

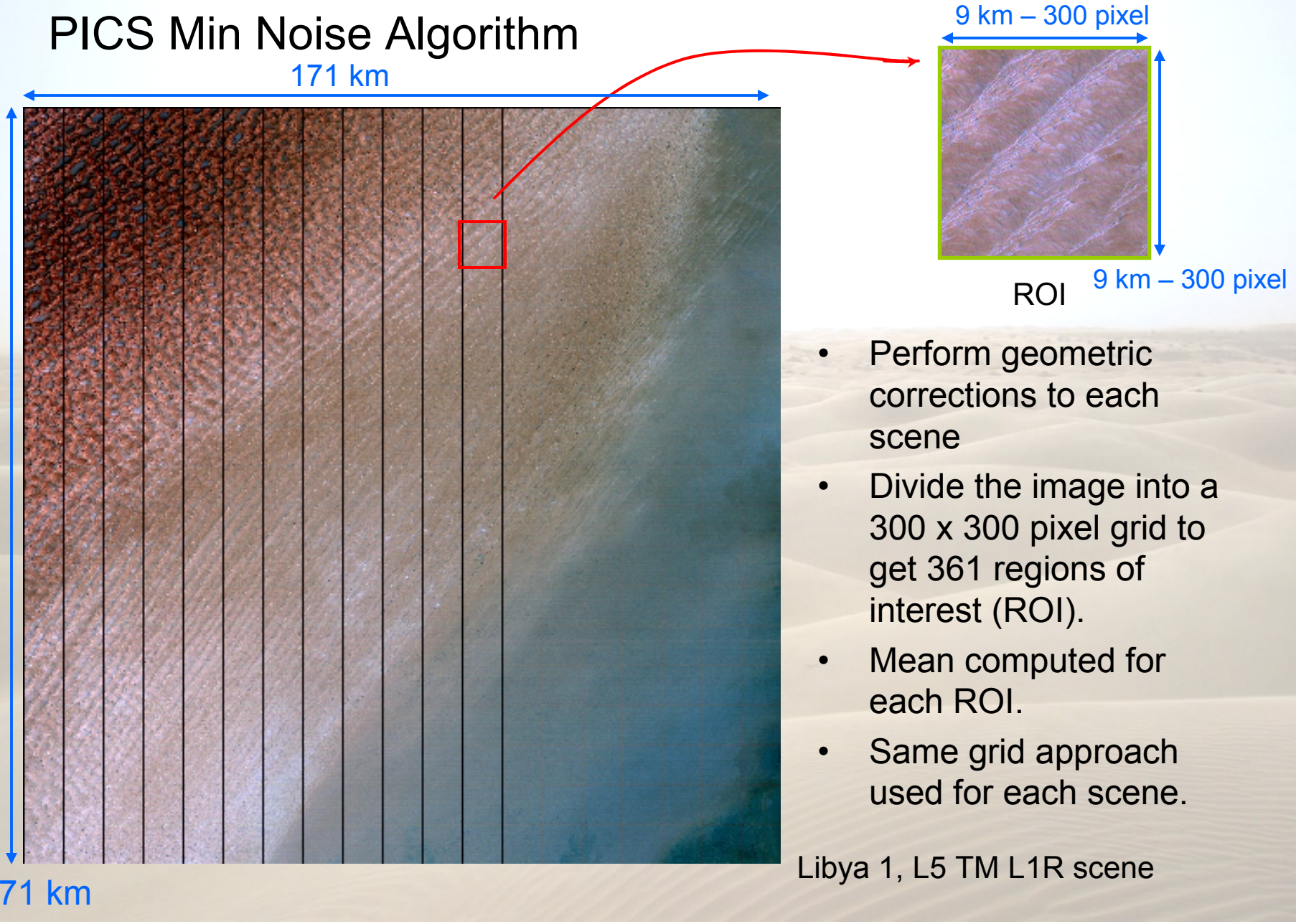
- TMIAS Processing
  - Artifact Correction
    - ME/SCS
    - Relative Gain
  - Bias Subtracted
  - Conversion to Radiance

- SDSU Processing
  - Exclude saturated scenes
  - Earth-Sun Distance correction
  - Sun Elevation correction
  - Scan Alignment correction
  - Scene-to-Scene Correlation
  - First-Order Image Statistics
    - Mean
    - Std. Deviation
    - Min/Max



Libya 1 Example

PICS Min Noise Algorithm



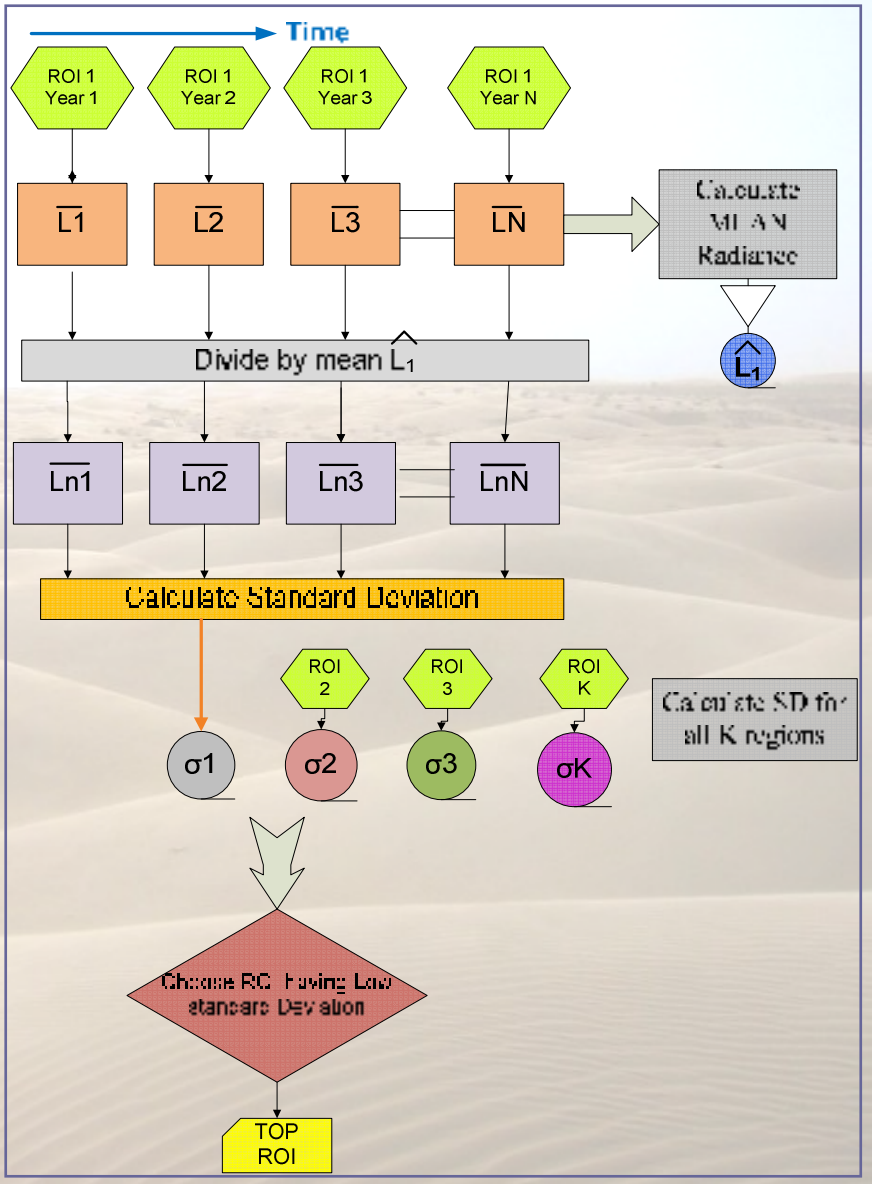
- Perform geometric corrections to each scene
- Divide the image into a 300 x 300 pixel grid to get 361 regions of interest (ROI).
- Mean computed for each ROI.
- Same grid approach used for each scene.

Libya 1, L5 TM L1R scene

Libya 1 Example

PICS Min-Noise Algorithm: ROI Selection

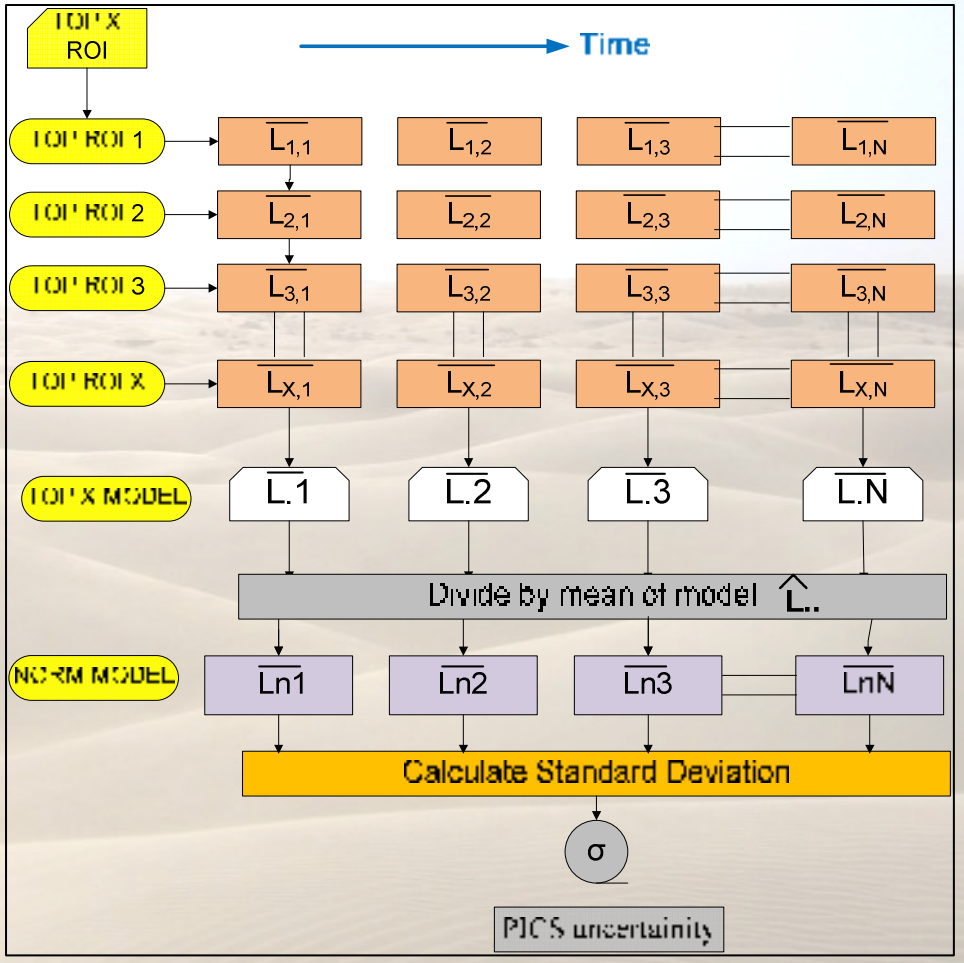
- Given N scenes in the study and K region of interest grids:
  - Each ROI has a time series of N radiance values ($\overline{L_i}$) with an overall mean radiance ($\hat{L}_K$).
  - Each ROI was normalized by that region's overall mean radiance ($\hat{L}_K$) to obtain ($\overline{Ln_i}$) (now overall mean radiance for each normalized ROI is 1).
  - A temporal standard deviation of each ROI's normalized radiance (σ) was calculated to determine the best ROI.
  - Lowest temporal standard deviation corresponds to best ROI.



Libya 1 Example

PICS Min-Noise Algorithm: Uncertainty Calculation

- The radiance of the top X regions ($L_{X,N}$) are averaged at each date to obtain the top X model (L.N).
- The model was then normalized by its mean ($\hat{L}_{..}$) so that the normalized model would have an overall mean of 1.
- A two-month moving average filter was used on the normalized radiance model to attempt to account for any small temporal changes due to atmosphere and bidirectional reflectance at the site.
- The temporal standard deviation of the normalized model is then calculated as the 1-sigma uncertainty for this site.



Libya 1 Example

Testing equality of variance for site size optimization

- Comparing the uncertainty of smaller portions of a site with the uncertainty of the site as a whole can give an idea of whether it would be beneficial to use a smaller region of the site for calibration work rather than the whole site.
- A common test for equality of variance is Levene's Test.
  - H0: $\sigma^2_1 = \sigma^2_2 = \ldots = \sigma^2_k$
  - Ha: $\sigma^2_i \neq \sigma^2_j$ for at least one pair (i,j)
  - The Levene test statistic is defined as:

$$W = \frac{(N-k)}{(k-1)} \frac{\sum_{i=1}^{k} N_i (\bar{Z}_{i.} - \bar{Z}_{..})^2}{\sum_{i=1}^{k} \sum_{j=1}^{Ni} (Z_{ij} - \bar{Z}_{i.})^2}, \quad where \;\; Z_{ij} = \left| Y_{ij} - \bar{Y}_{i.} \right| \;\; and \;\; \bar{Y}_{i.} = mean \; of \; ith \; subgroup$$

  - Given a variable Y with sample size of N divided into k subgroups, where Ni is the sample size of the ith subgroup. $\bar{Z}_{i.}$ are the group means of Z_{ij} and $\bar{Z}_{..}$ is the overall mean of Z_{ij}.
  - The Levene Test rejects the null hypothesis that variances are equal if $W > F_{(\alpha,k-1,N-k)}$

- This test can be applied at PICS locations, such as Libya 1, to compare the uncertainty when the top X regions varies from 1 to the total number of regions.
  - For the first attempt at using this method, let X be equal to 10, 50, 100, and the total number of regions for the site.
  - Running the Levene Test provides statistical evidence to whether there is a benefit to refining the size of the area used in calibration studies

Reference: *Levene, H. (1960). In Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling, I. Olkin et al. eds., Stanford University Press, pp. 278-292*

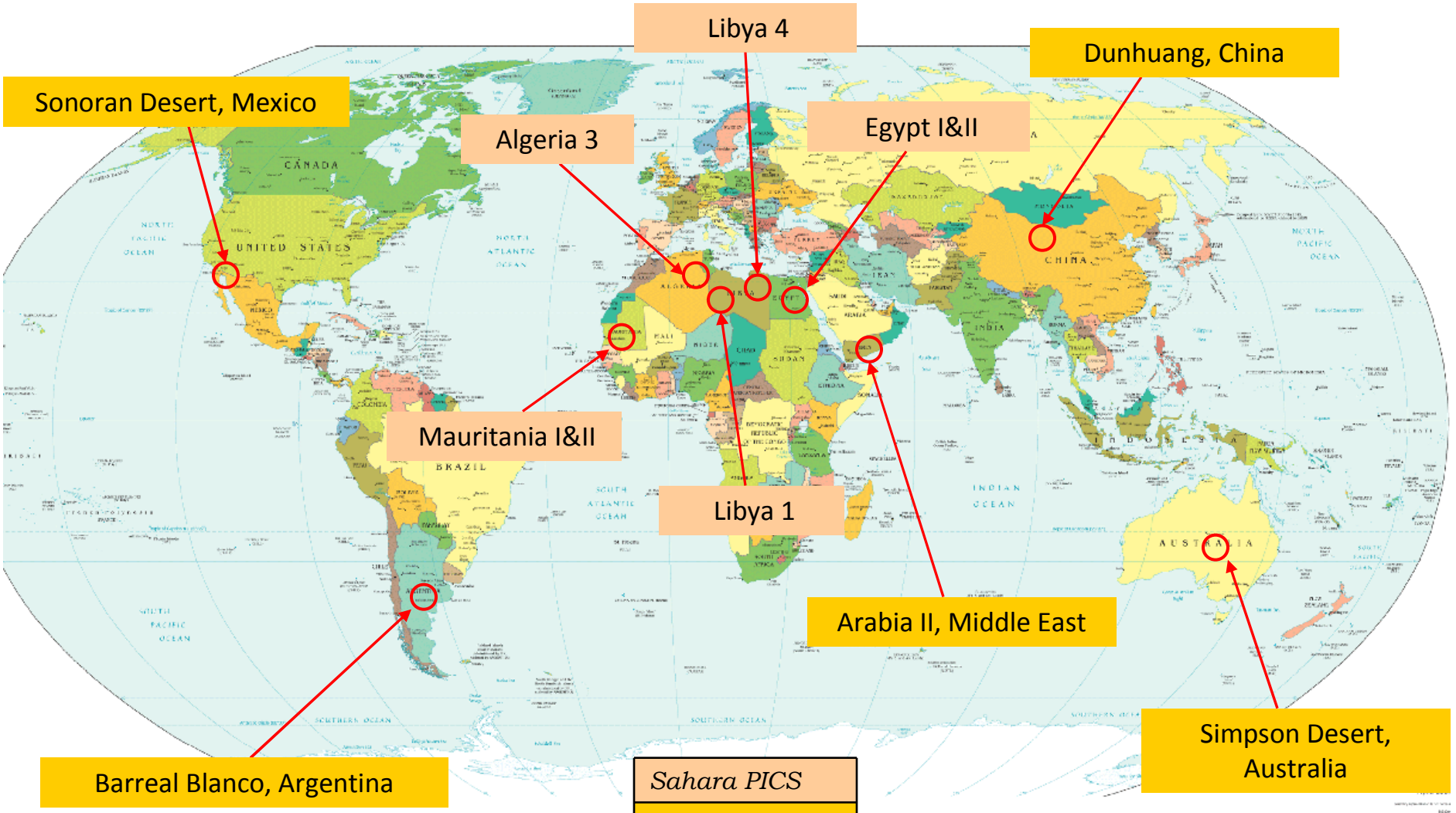
Libya 1 Example

Testing equality of variance for site size optimization

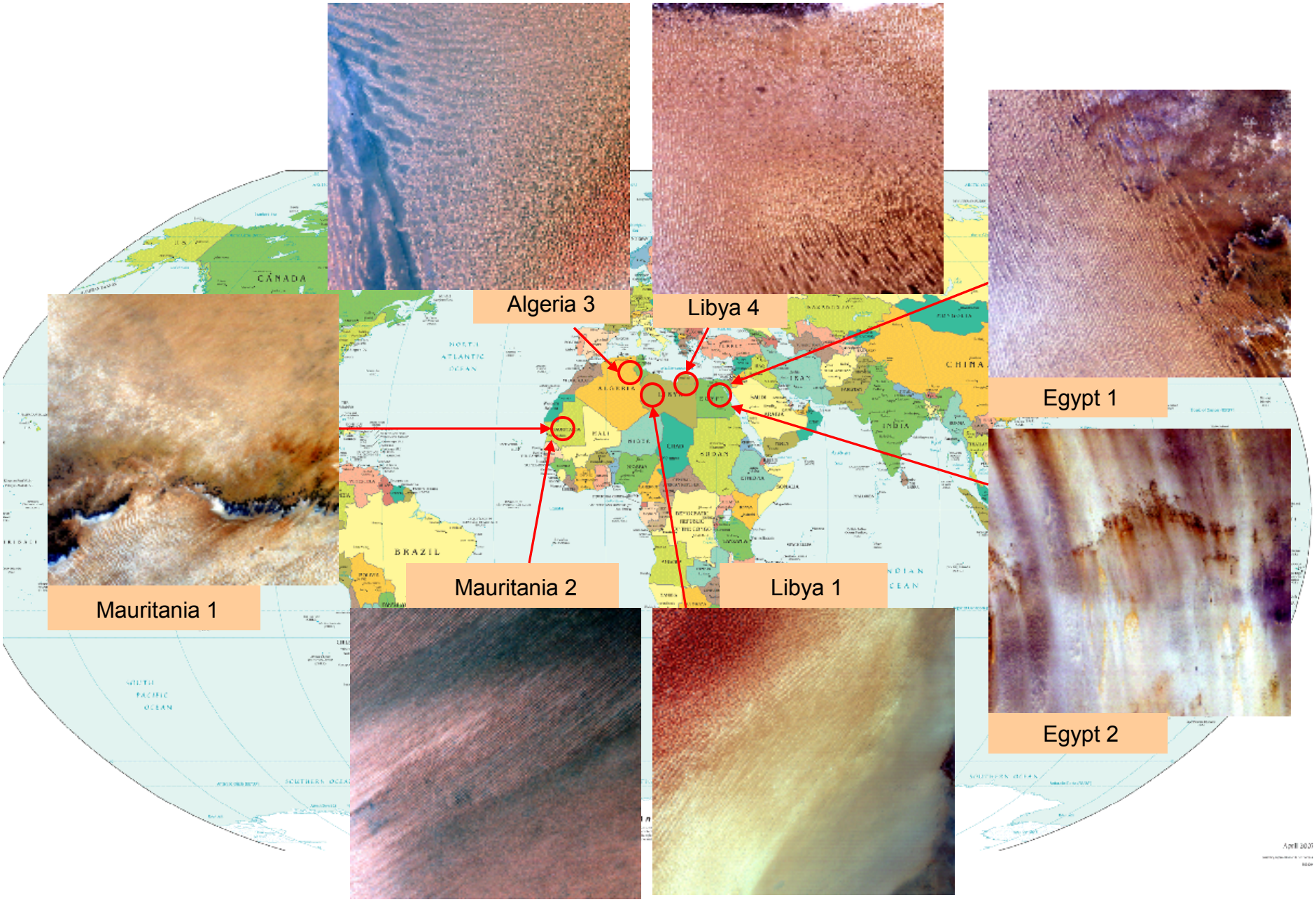
Libya 1: Levene Test of Equality of Variances				
L5 TM bands		Variance	p-value	Ho:σ1=σ2=σ3=σ4
Band 1	Top 10	0.000161	0.6285	Accept
	Top 50	0.000133		
	Top 100	0.000142		
	All region	0.000227		
Band 2	Top 10	0.000061	0.5185	Accept
	Top 50	0.000077		
	Top 100	0.000096		
	All region	0.000157		
Band 3	Top 10	0.000035	0.1836	Accept
	Top 50	0.000044		
	Top 100	0.000055		
	All region	0.000083		
Band 4	Top 10	0.000229	0.8628	Accept
	Top 50	0.000255		
	Top 100	0.000268		
	All region	0.000341		
Band 7	Top 10	0.000283	0.4552	Accept
	Top 50	0.000285		
	Top 100	0.000297		
	All region	0.000423		

- The Levene Test table shows p-values that are calculated for each band of Libya 1 and whether to accept or reject the null hypothesis of equal variances.
- If the p-value was less than 0.05 then H0 would be rejected and equality of variances for all region sizes would not be true.
- Libya 1 shows that the variances are statistically equal no matter the size of the site used. Therefore the recommended region for use in calibration would be the entire Libya 1 site.

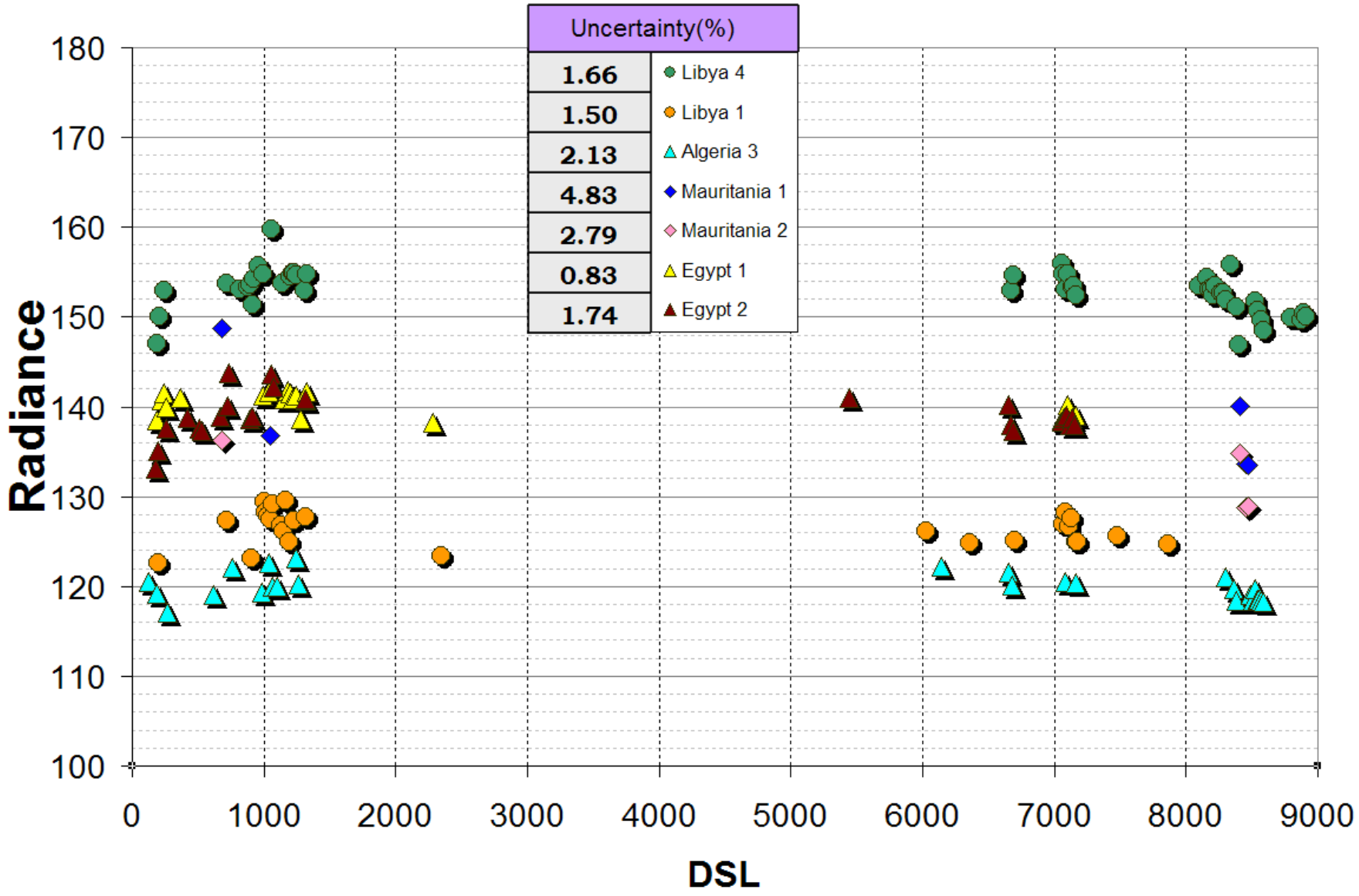
Using These Procedures on PICS Around the World…



Sahara PICS


Algeria 3
Libya 4
Egypt 1
Mauritania 1
Mauritania 2
Libya 1
Egypt 2

Sahara PICS, L5 TM band 1: Radiance vs DSL



All Saharan sites in all bands show the desired flat response that is expected from an invariant site viewed from the well calibrated Landsat 5 TM sensor.

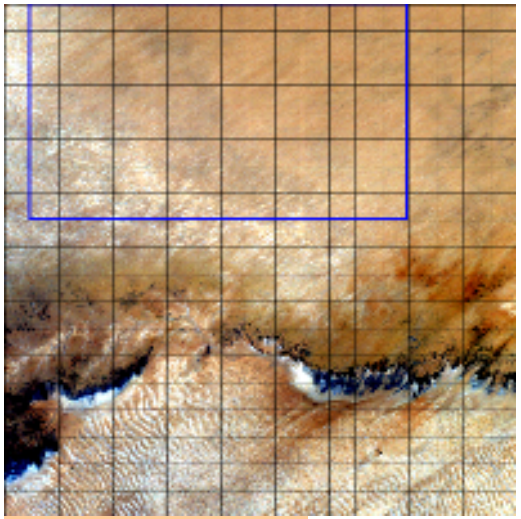
Summary, Sahara PICS Uncertainties

Site	# of Scenes	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Libya 4	48	1.66	1.07	1.23	1.62	Sat	2.30
Libya 1	26	1.50	1.25	0.92	1.86	Sat	2.04
Algeria 3	26	2.13	0.99	1.42	2.20	Sat	3.23
Mauritania 1	7	4.83	1.28	0.45	0.80	Sat	1.63
Mauritania 2	4	2.79	0.29	0.69	0.69	Sat	2.15
Egypt 1	22	0.83	0.59	0.89	1.56	Sat	1.75
Egypt 2	25	1.74	1.16	0.95	1.78	Sat	2.26

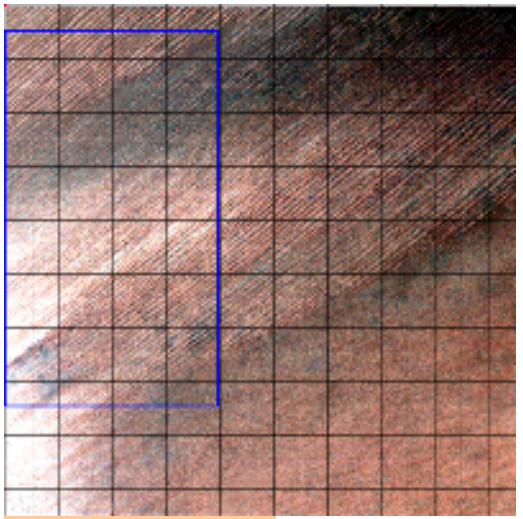
- Saharan sites show to have uncertainties of around 2 percent or less across every site with exception to Algeria 3- Band 7 and Mauritania 1- Band 1.
- Cold Focal Plane (CFP) uncertainties are higher than Primary Focal Plane (PFP) uncertainties across all sites
- Band 5 saturates at every Saharan site.
- The Mauritania 1 site failed to reject the equal variances hypothesis due to the small sample size of scenes used for the study. Both Mauritania site uncertainties can be considered suspect as the number of scenes used was inadequate for a statistical study.
- **Bottom Line: All Saharan PICS are invariant**

Best Regions for Saharan PICS Determined via Levene's Test

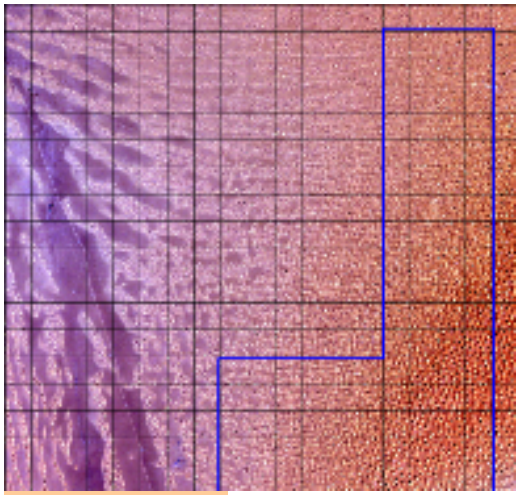
PICS	*Recommended region for Calibration*
Libya 4	*Entire Site*
Libya 1	*Entire Site*
Algeria 3	*Top 100 ROI*
Mauritania 1	*Top 100 ROI*
Mauritania 2	*Top 100 ROI*
Egypt 1	*Top 100 ROI*
Egypt 2	*Entire Site*



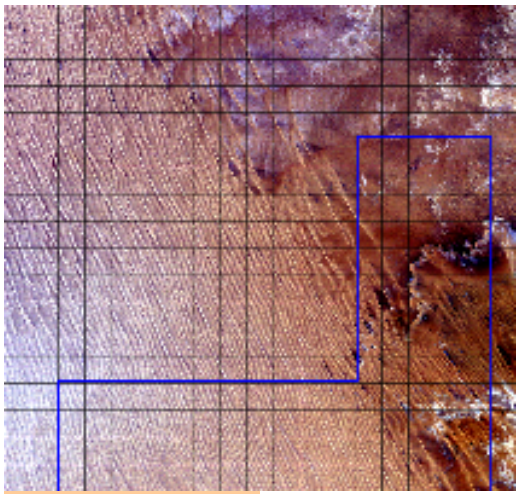
Mauritania 1



Mauritania 2



Algeria 3

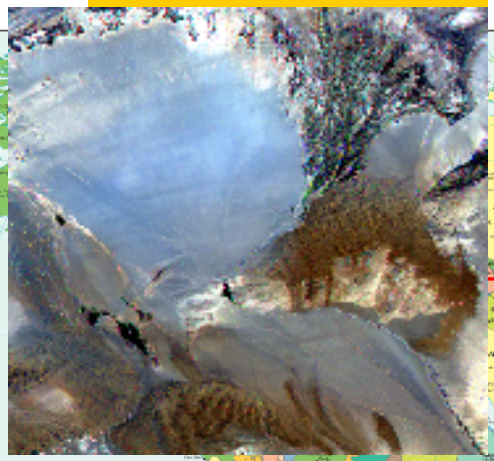


Egypt 1

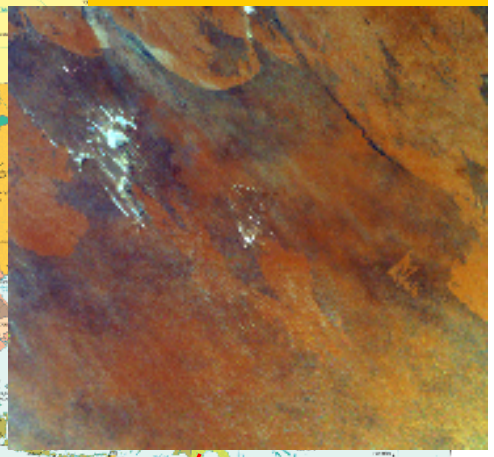
Global PICS

Sonoran Desert, Mexico

Dunhuang, China



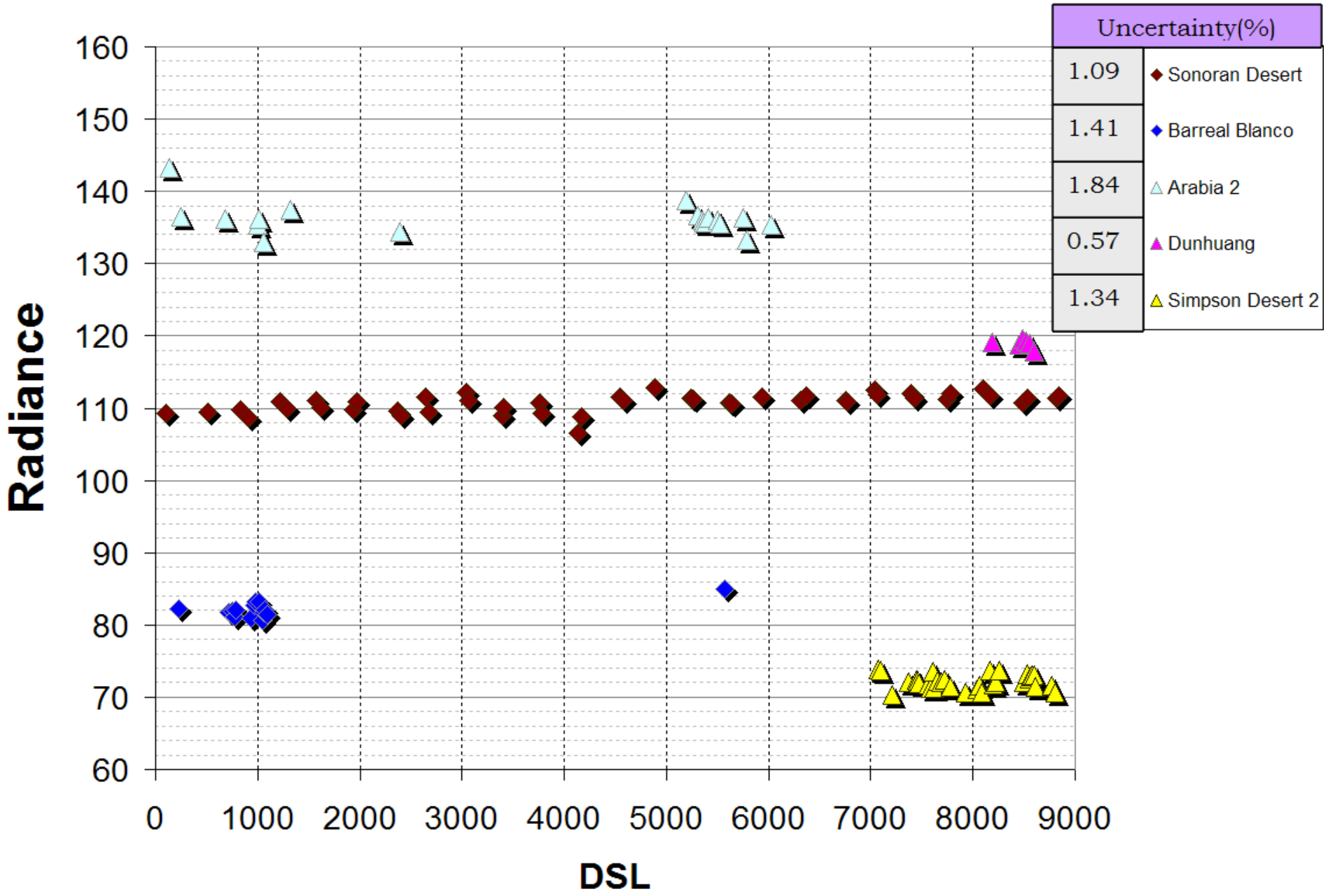
Simpson Desert, Australia



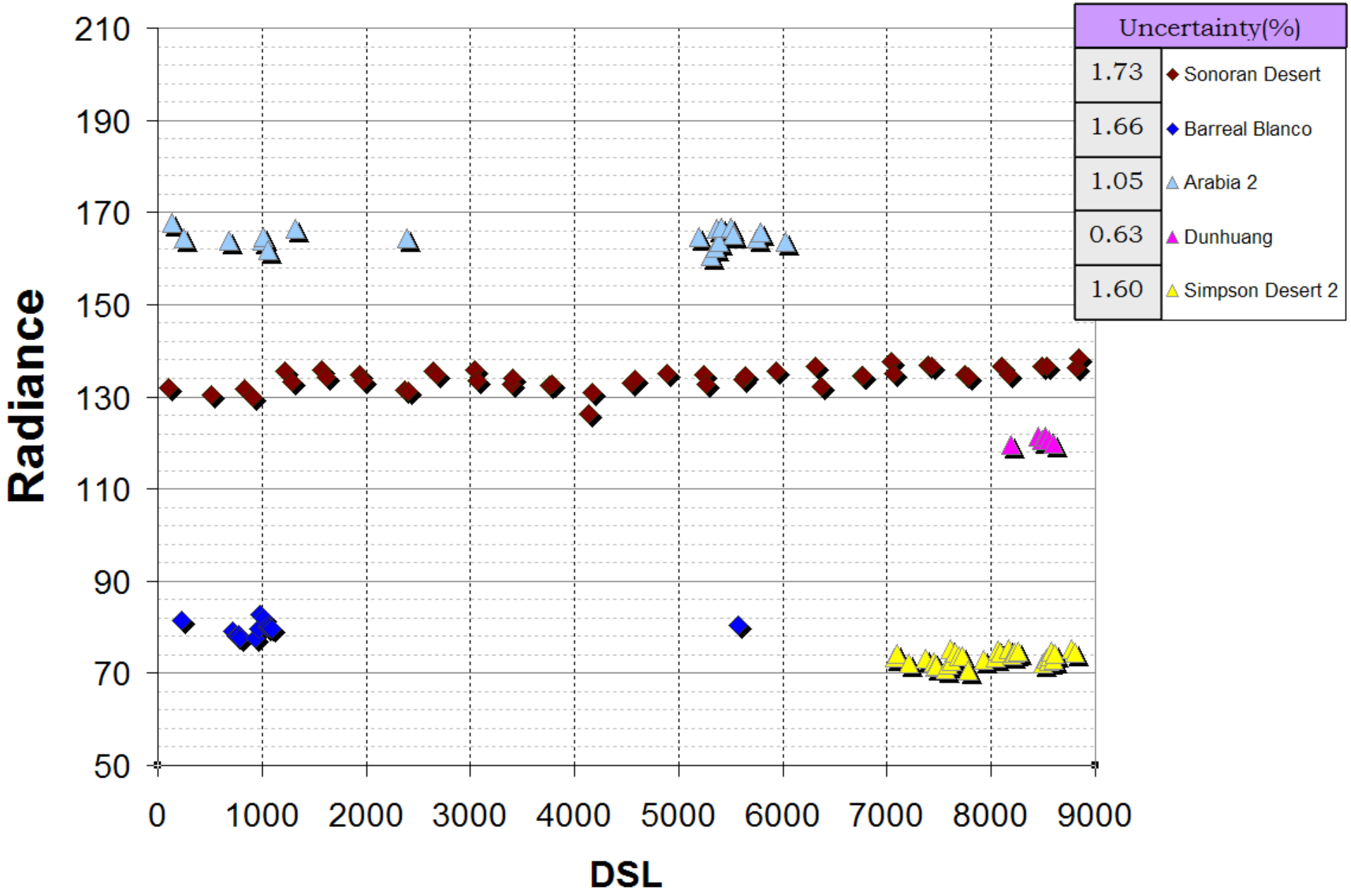
Barreal Blanco, Argentina

Arabia II, Middle East

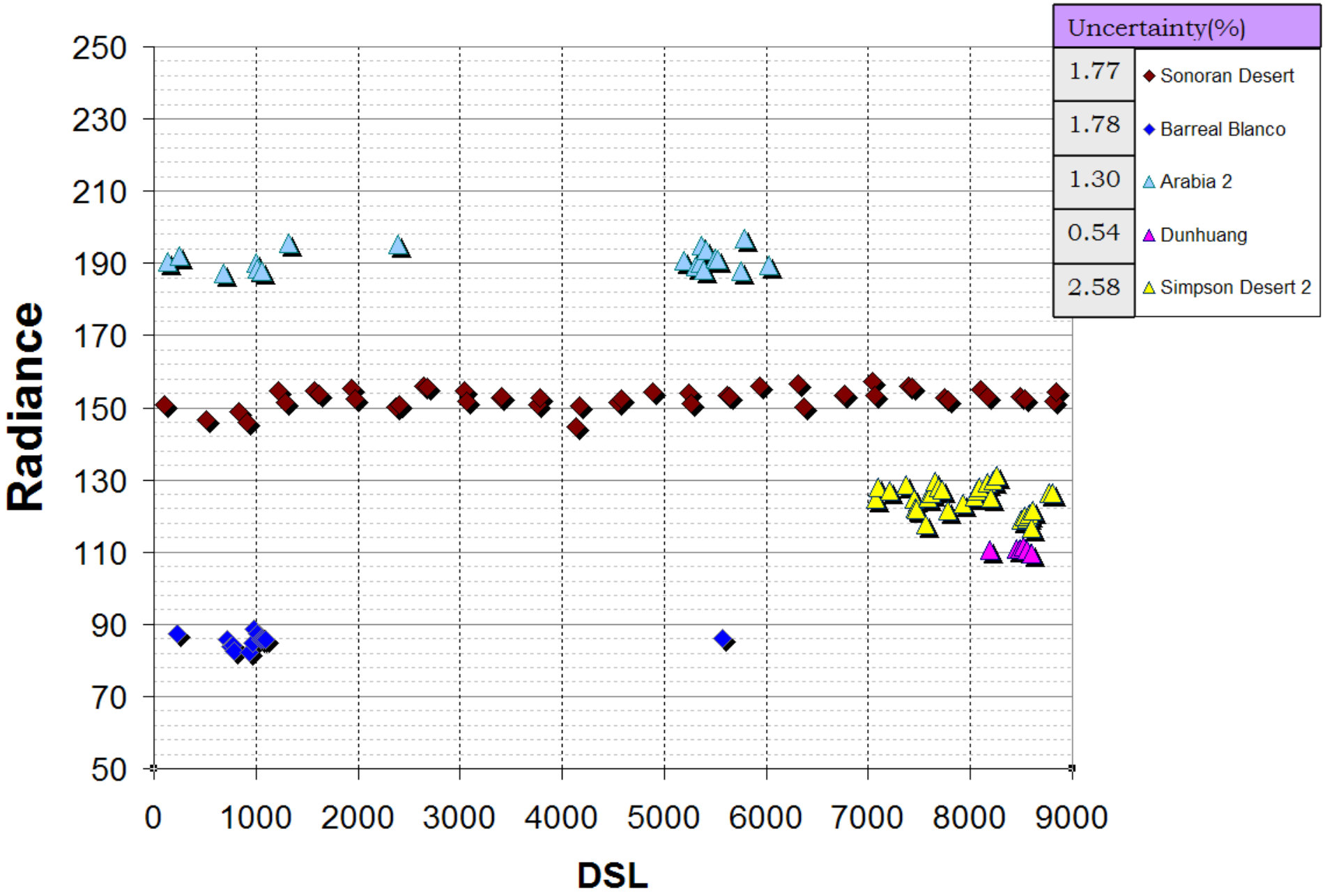
Global PICS, L5 TM band 1: Radiance vs DSL



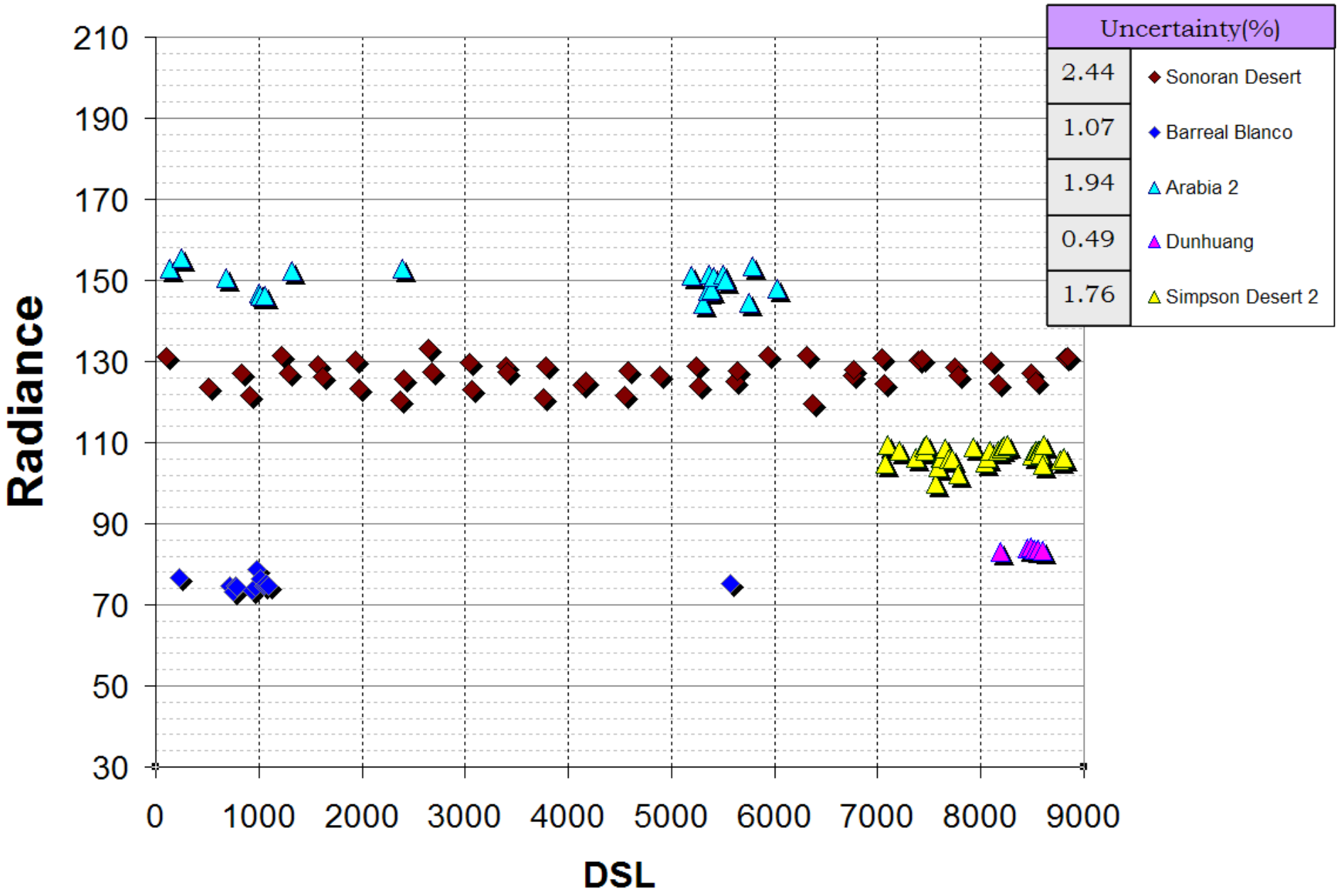
Global PICS, L5 TM band 2: Radiance vs DSL



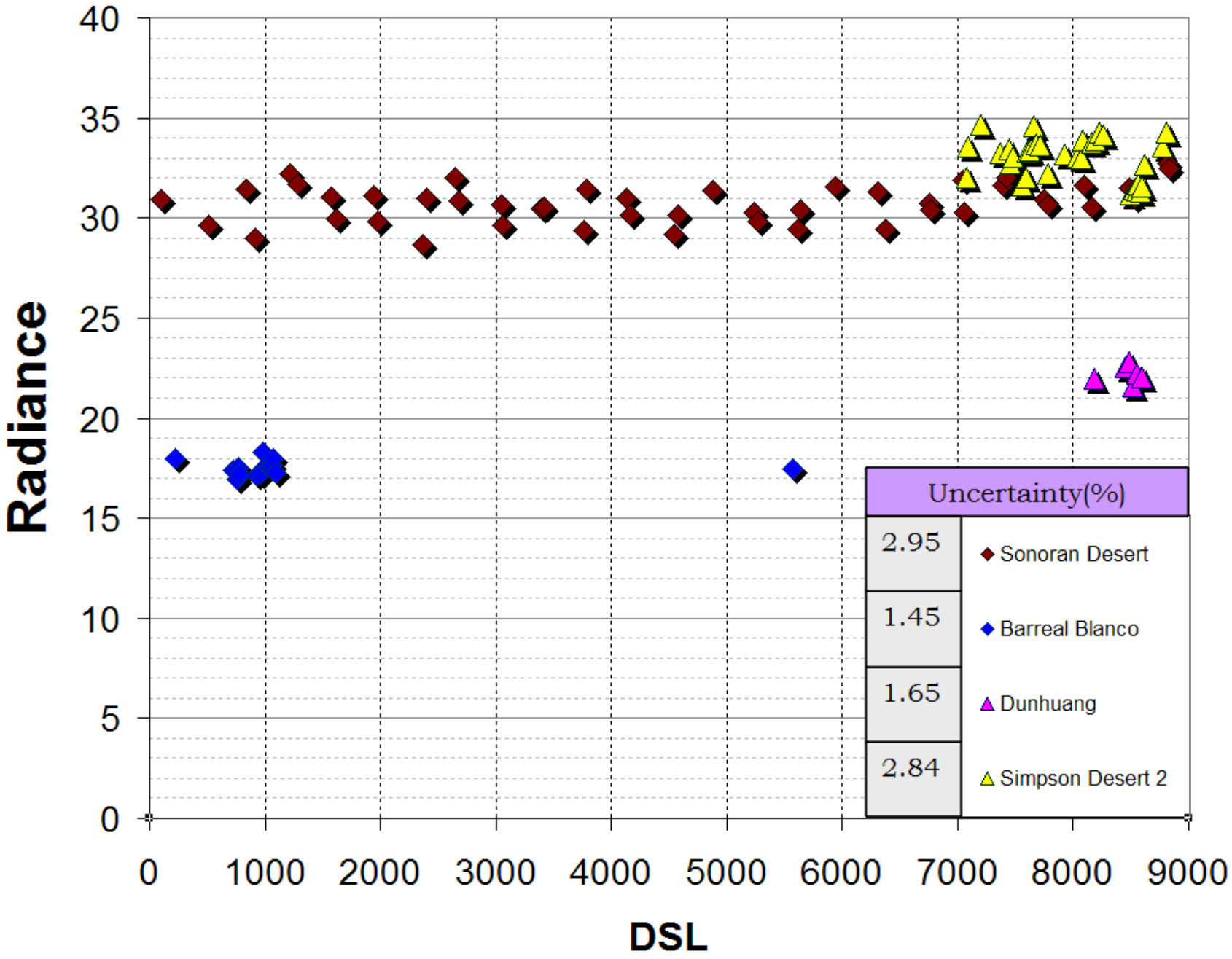
Global PICS, L5 TM band 3: Radiance vs DSL



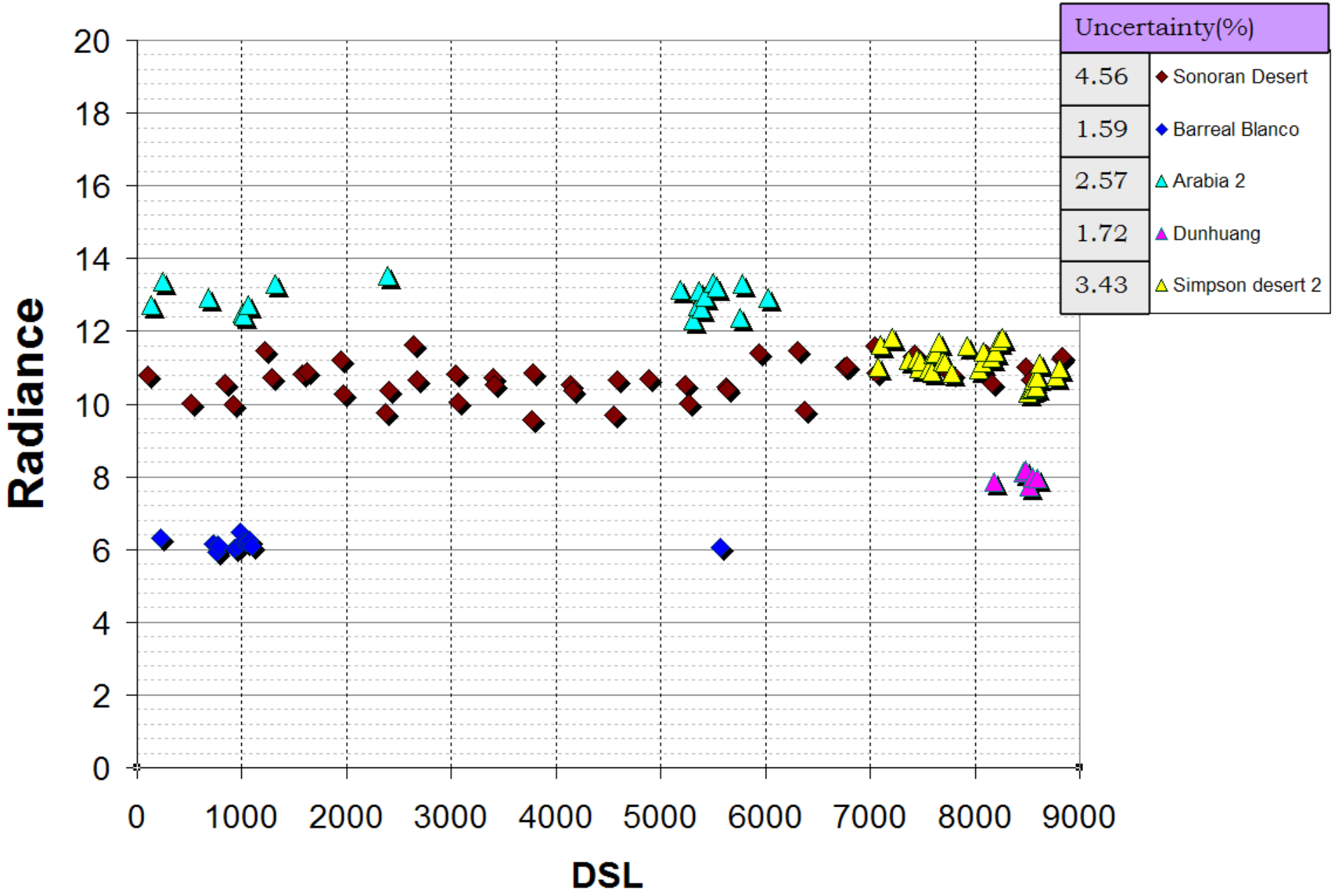
Global PICS, L5 TM band 4: Radiance vs DSL



Global PICS, L5 TM band 5: Radiance vs DSL



Global PICS, L5 TM band 7: Radiance vs DSL



Summary, Global PICS Uncertainties

Site	# of Scenes	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Sonoran desert	46	1.09	1.73	1.77	2.44	2.95	4.56
Barreal Blanco	14	1.41	1.66	1.78	1.07	1.45	1.59
Arabia 2	19	1.84	1.05	1.52	1.94	SAT	2.57
Dunhuang	6	0.57	0.63	0.54	0.49	1.65	1.72
Simpson Desert	32	1.34	1.60	2.58	1.76	2.84	3.43

- The global PICS have uncertainties slightly higher than the Saharan PICS.
- Most PFP Bands have uncertainties between 1-2 percent with the only exception being Simpson Desert- Band 3.
- The CFP uncertainties are higher than the PFP uncertainties for all sites.
- Sonoran Desert, Simpson Desert, and Arabia have CFP uncertainties greater than 2 percent.
- Band 5 only saturates in Arabia and has uncertainty less than 3 percent in all other sites.
- Due to the smaller nature and various non-PICS-like features (Crops/Urban Areas/Water Bodies) found in many of the global sites, the top ten best ROIs were used to find the uncertainties.

Conclusions

- Saharan Desert shows lowest uncertainties values of all PICS tested.
  - 1-2 percent uncertainty across all bands at all sites
  - However, Band 5 saturates at all sites
- The best PICS sites other than the Sahara were found to be Sonoran Desert in North America, Barreal Blanco in South America, Arabia 2 in the Middle East, Dunhuang in Asia, and Simpson Desert in Australia.
  - 1-2 percent uncertainty in most PFP bands for most sites
  - 1.5-3.5 percent uncertainty in CFP bands
  - All sites except Arabia provide suitable Band 5 calibration opportunity
- Uncertainty from certain Saharan sites can be reduced through careful selection of a specified region within each site.
  - Mauritania 1, Mauritania 2, Algeria 3, and Egypt 1
- **Site presented in this work represent an excellent worldwide baseline set for long term monitoring of satellite-based optical imaging systems**

Future Work

- Validate process using L1T data to further ensure that the same ground targets are being viewed in each scene.
- Possible expansion of worldwide PICS
- Utilize Landsat 7 ETM+ archive of PICS scenes
- Continue acquiring Landsat 5/7 data over the specified PICS and immediately image these sites once the OLI mission begins.