Using Hyperion to Develop an Absolute Calibration Model for the Libya 4 Invariant Test Site

- Initial concepts

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Calcon-2012
Objective

• Pseudo Invariant Calibration Sites (PICS) have been used for many years to determine the stability of optical satellite sensors.
• However, the potential exists to use PICS for absolute calibration of optical satellite sensors. As a sensor views a calibration panel in the laboratory during pre-launch testing, in an analogous manner consider the sensor viewing PICS while on orbit.
• Specific goals:
  – Determine the intrinsic stability of PICS.
  – Develop a comprehensive and accurate PICS absolute calibration model that can be SI traceable.
    ➢ Empirical approach
      ▪ Developing surface and atmospheric models based on satellite and meteorological observations.
    ➢ First Principles approach
      ▪ Develop surface and atmospheric models based on the inherent physics of the site.
Outline

• PICS Background
• Libya 4 test site
  ➢ Long term trending of Landsat 7 ETM+ using Libya 4
• Introduction to sensors
  • EO-1 Hyperion - spectral model
  • Introduction Terra MODIS (calibrated radiometer)
• Derivation of hyperspectral profile of the target
• Stability of Libya 4 using Hyperion

Acknowledgement:
This work was supported by the NASA Landsat Project Science Office and USGS EROS.
The MODIS data has been provided by MODIS Characterization Support Team (MCST).
Outline con’t..

• Absolute calibration Development
  - Absolute scaling factor—anchoring spectral model to Terra MODIS
  - Development of BRDF models
    - For Solar Zenith Angle
    - For View Zenith Angle

• Validation of the model using Terra MODIS and Landsat Red bands
  - Validation of the model for all the bands

• Conclusions
PICS Background

- PICS have been used for on-orbit radiometric trending of optical satellite sensors for at least 15 years.
- Highly regarded sites used by the calibration community tend to be in the Sahara desert of North Africa.
- A suite of sites has been developed and endorsed by CEOS (can be viewed at http://calval.cr.usgs.gov/sites_catalog_ceos_sites.php#CEOS)
Long Term Trending of Landsat using Libya 4

- Location: 28.55 lat, 23.39 long, elevation of 118 m above sea level.
- Has been used for an extended period of time by many investigators.
- Possibly the most stable and brightest desert site.
- Long term observations from ETM+ show that Libya 4 is stable to ~2% in the VNIR bands and ~3% in the SWIR bands.
The Earth Observing 1 (EO-1) Hyperion

- Launched on 11/21/2000
- Pushbroom sensor with a single telescope and two grating spectrometers
- 196 calibrated bands from 0.4 to 2.5 µm, 30 m spatial res., 10 nm spectral res. and 7.5 km swath width
- Good coverage over PICS
  - Over 170 cloud free acquisitions over Libya 4
  - Over 130 acquisitions over Egypt 1
  - More than 30 collects over Mauritania 1& 2 and Algeria 3
  - Cloud cover less than 10%

Terra MODIS

- Launched on December 18, 1999.
- Pushbroom sensor with a swath of 2330 km.
- 36 spectral channels
- Diffuser based calibration, radiometric calibration of better than 3%
- Temporal resolution of 1 to 2 days, acquires large number of data over PICS
LIBYA 4 Stability Based On EO-1 Hyperion

- Except for absorption features, uncertainty is within 4%.
- Temporal stability site was studied by selecting spectral channels with very high atmospheric transmittance in the Short Wave Infra-Red Region (SWIR).

Transmittance

\[
\begin{align*}
\text{CH}_4 &= 0.9917 \\
\text{CO}_2 &= 0.9981 \\
\text{AER}+\text{CLD} &= 0.9969 \\
\text{MOLECULAR} &= 0.9917 \\
\text{Combined} &= 0.9846
\end{align*}
\]

1628 nm
Development of a linear BRDF model-illumination

- Viewing geometry was restricted to within +/- 5 nadir degrees to minimize the effects caused by non-nadir viewing.
- Annual cycles visible are primarily due to varying solar illumination angles coupled with the bidirectional reflectance distribution function (BRDF) of the surface.
- Temporal uncertainty is found to be 2.46%.
- Simple linear empirical BRDF model was developed to correct for variations caused by solar zenith angles.
Development of a linear BRDF model-illumination cont’d..

- Linear BRDF model show that temporal stability improved to 0.84 % for this channel.
- Consistent Uncertainties with Ross-Li model
- Sub 1% results were observed for other high transmittance SWIR channels too. (1558 nm, 1568 nm, 1588 nm, 1598 nm, 1618 nm, 1638 nm, 1648 nm, 1659 nm, 1679 nm)
- Without atmospheric effects, site stability is better than 1%

[Graph showing temporal trend of Hyperion over Libya 4-1628 nm with data points and uncertainties]
Absolute scaling factor—anchoring spectral model to Terra MODIS

- Assuming Terra to be the calibration standard, the Hyperion spectrum can be scaled appropriately.
- Scale factor calculated using six available same day (viewing angles < 5°, solar zenith angle of 30°–5°) pairs.
- Statistical analysis indicated mean scaling values could be clustered into three groups: band 7, bands 3, 2 and 6 and bands 1, 4 (α = 0.05).
- Hyperspectral scale model was then developed using the smooth linear interpolation between these three gain points.

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<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>3 (459-479 nm)</td>
<td>1.025</td>
<td>0.992</td>
<td>1.001</td>
<td>0.998</td>
<td>0.973</td>
<td>0.979</td>
<td>0.995</td>
<td>1.82%</td>
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<tr>
<td>4 (545-565 nm)</td>
<td>1.029</td>
<td>1.006</td>
<td>1.008</td>
<td>1.009</td>
<td>1.000</td>
<td>1.000</td>
<td>1.009</td>
<td>1.05%</td>
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<tr>
<td>1 (620-670 nm)</td>
<td>1.024</td>
<td>1.010</td>
<td>1.007</td>
<td>1.013</td>
<td>1.003</td>
<td>1.001</td>
<td>1.010</td>
<td>0.83%</td>
</tr>
<tr>
<td>2 (841-876 nm)</td>
<td>0.993</td>
<td>0.990</td>
<td>0.978</td>
<td>0.988</td>
<td>0.973</td>
<td>0.983</td>
<td>0.984</td>
<td>0.81%</td>
</tr>
<tr>
<td>6 (1628-1652 nm)</td>
<td>0.996</td>
<td>1.001</td>
<td>0.991</td>
<td>0.999</td>
<td>0.977</td>
<td>0.984</td>
<td>0.992</td>
<td>0.95%</td>
</tr>
<tr>
<td>7 (2105-2155 nm)</td>
<td>0.986</td>
<td>0.974</td>
<td>0.960</td>
<td>0.966</td>
<td>0.952</td>
<td>0.954</td>
<td>0.965</td>
<td>1.32%</td>
</tr>
</tbody>
</table>
Development of Linear BRDF model - Illumination

- MODIS Observations for 10 years was used to develop a linear BRDF model.
- Example shown for red band, similar model was generated for 6 bands.
- The resulting slope value were plotted as a function of their center wavelengths.
- Exponential model developed to predict change in BRDF as a function of wavelength.
Development of a BRDF model-viewing angle

- BRDF as a function of viewing angle is clearly non-linear
- 2nd order polynomial model developed, similar to Ross-Li model; higher order terms were statistically insignificant
- Model reduces variability due to view angle to less than 1% at atmospherically clear wavelengths.

\[
y = 8E-5x^2 - 0.0004x + 0.66
\]

**TOA Reflectance Vs. View Zenith Angle (1628 nm, 179 scenes)**

**Temporal Trend of Hyperion over Libya 4-1628 nm**

- TOA ref @1628 nm
- BRDF corrected

Number of Images: 179
Uncertainty before = 3.05%
Uncertainty after = 0.86%
Off-nadir MODIS data were not available when the work was done.

Hence spectrally cleaner Hyperion channels were used to model the slope.

Two term exponential model developed as a function of wavelength to predict second order term; first order term essentially constant.

Thus the absolute calibration model is of the form:

\[
\text{Slope of quadratic look angle} = a \times \exp(b \times x) + c \times \exp(d \times x)
\]

Coefficients:
- \(a = 0.00014\)
- \(b = -0.00010\)
- \(c = -0.0006\)
- \(d = -0.0039\)

R-square: 0.99
RMSE: 4.4e-6
Validation of the model using Terra MODIS

- Currently the model has been tested only for nadir views.
- Results provided for red bands show the systematic as well as the random error is of the order of 1.4% in this band.
- The fit is very good due to MODIS being used to develop the model.

![Temporal Trend of MODIS over Libya 4 - Band 1](620-670 nm)

![Percent Difference between Libya 4 Model and ETM+ measurements (MODIS Band 1)]

RMSE = 1.39%
STD = 1.33%
Validation of the model using Landsat 7 ETM+

- Comparison is made between the Libya 4 model prediction and at-sensor reflectance derived from ETM+ measurements.
- Percent difference between the two is on the order of 1.2% RMSE and the spread of ~ 1%.
- The uncertainties are similar between MODIS and ETM+ suggesting a good model fit. This may be due to the higher degree of similarity between the ETM+ and MODIS bands at this wavelength.
Validation Summary for all bands

- For both MODIS and ETM+ sensors,
  - STD is better than 2% for all the bands, except SWIR -2 bands which has slightly higher values.
  - Systematic offsets are within 2.5% in VNIR bands
  - Higher offset exists between the two sensors in the SWIR1 and SWIR2 channels (~ 5%).

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<tr>
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<th>ETM+ Bands</th>
<th>Root Mean Squared Error (RMSE)</th>
<th>STD of residues</th>
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Conclusions

- Hyperion measurements in a transparent channel showed that precision better than 1% is possible in Libya 4.
- A simple model was then developed for Libya 4 using Hyperion for the spectral information and Terra MODIS as reference for the absolute calibration.
  - This model was validated through use of observations by the L7 ETM+ sensor.
  - After accounting for the spectral bandpass, it was shown that the simple model was consistent with ETM+ to within 1.5%.
  - This agreement is well within the stated calibration accuracies of these two sensors (2% reflectance-based for Terra, and 5% radiance-based for ETM+).
  - ETM+ bands at longer wavelengths show substantially greater bias—up to 5% in the SWIR.
- Work in progress to expand the model with broader view geometries, and develop more exact surface and atmospheric components.
- Validate the model with multiple suites of sensors.
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**ETM+ Bands**

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<th>Solar Irradiance (W/m²μm)</th>
<th>Percent Diff.</th>
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<tbody>
<tr>
<td>Thuillier</td>
<td>Chkur</td>
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<td>1 (450-515 nm)</td>
<td>1997</td>
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<tr>
<td>2 (525-605 nm)</td>
<td>1812</td>
</tr>
<tr>
<td>3 (630-690 nm)</td>
<td>1533</td>
</tr>
<tr>
<td>4 (750-900 nm)</td>
<td>1039</td>
</tr>
<tr>
<td>5 (1550-1750 nm)</td>
<td>230.8</td>
</tr>
<tr>
<td>7 (2090-2350 nm)</td>
<td>84.9</td>
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