Absolute Calibration of Optical Sensors
Using Pseudo Invariant Calibration Sites (PICS)
Initial concepts

Dennis Helder
Nischal Mishra
Sandip Shrestha
Image Processing Laboratory
SDSU
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 using Libya 4
• Introduction to Hyperion
  ➢ Stability of Libya 4 using Hyperion
  ➢ BRDF model using Hyperion
• Absolute calibration
  ➢ Anchoring the data
  ➢ Use of Terra MODIS to develop an empirical Libya 4 model
  ➢ Application of the Libya 4 model - Landsat 7 ETM+
• Conclusions
• Discussion - the way forward

Acknowledgement:
This work was supported by the NASA Landsat Project Science Office and USGS EROS.
PICS Background

- PICS have been used for on-orbit radiometric trending of optical satellite sensors for at least 15 years.
- The most 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 and currently be viewed at http://calval.cr.usgs.gov/sites_catalog_ceos_sites.php#CEOS
- The chief advantages of these locations are the relatively high reflectances, extremely limited rainfall that severely curtails any vegetative growth, and the relatively limited human population which limits human-induced changes.
- Growing interest in Dome C, Antarctica (75º06’S, 123º21’E, elevation 3.2 km) to calibrate visible bands.
Blue regions are the optimal regions of interest (ROI)
Long Term Trending of Landsat using Libya 4

- Location: 28.55° latitude and 23.39° longitude at an elevation of 118 m above sea level.
- Has been used for an extended period of time by many investigators, and it is possibly the most stable and brightest desert site.
- The Libya 4 PICS has the advantage of large size (171 km × 171 km).
- Long term observations from ETM+ and TM shows that Libya 4 is stable to ~ 2% in the VNIR bands and ~3% in the SWIR bands.
- Band 5 saturates for TM and hence not shown.
Steps to develop Absolute Calibration Model

• Surface Model
  ➢ To the degree possible, separate atmospheric effects from surface effects.
  ➢ Develop initial Bidirectional Reflectance Distribution Function (BRDF) through empirical observation.
    ➢ Largely a function of viewing and illumination geometry.
  ➢ Develop physical model of surface
    ➢ Dune structure and orientation
    ➢ Basic reflectance properties of sand
  ➢ Ideally empirical and physical models agree within uncertainties.

• Atmospheric Model
  ➢ Analysis of water vapor and aerosol features for development of empirical model.
  ➢ Use of meteorological data as indicator of atmospheric conditions
  ➢ Radiative transfer codes to determine top-of-atmosphere radiances

• Traceability to Absolute Radiometry
  ➢ SI traceability and traceability to national standards must be strictly adhered to so that uncertainties for each step of the process can be accurately developed.
Absolute Calibration: First Steps, Proof of Concept

• Key concept: anchor trending curves with an absolute calibration.
• A wide array of sensors have been observing Libya 4 regularly and provides an opportunity to create a PICS model for absolute calibration.
  – Need a hyperspectral model.
  – Need to anchor the hyperspectral model absolutely.
• Hyperion images over PICS provides a unique opportunity to understand the PICS hyperspectrally
  – Absolute calibration of sensor has been characterized, not updated operationally
  – Relative calibration (spectral dimension) more important for this application
• MODIS Terra provides an ability to anchor the hyperspectral model absolutely.
  – Very well calibrated absolutely
  – In tandem orbit with EO-1 Hyperion for several years
The Earth Observing 1 (EO-1) Hyperion

- Part of NASA’s New Millennium Program to provide high quality calibrated data for hyperspectral application evaluations.
- Launched on 11/21/2000 as a one year mission.
- Pushbroom sensor with a single telescope and two grating spectrometers.
- Capable of resolving 220 spectral bands from 0.4 to 2.5 µm out of which 196 bands are calibrated.
- 30 m spatial resolution, 10 nm spectral resolution and 7.5 km swath width.

- Good coverage over PICS
  - Over 195 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%
LIBYA 4 Stability Based On EO-1 Hyperion

- The temporal stability of the Libya 4 site was studied by selecting Hyperion spectral channels with very high atmospheric transmittance in the Short Wave Infra-Red Region (SWIR).
- The viewing geometry of the sensor was restricted to within +/- 5 degrees to minimize the effects caused by non-nadir viewing.
- Except for the absorption features, the uncertainty is within 4%.

**Transmittance @ 1628 nm**

- CH₄ = 0.9917
- CO₂ = 0.9981
- AER+CLD = 0.9969
- MOLECULAR = 0.9917
- Combined = 0.9846
The annual cycles visible in this plot (blue asterisks) are primarily due to varying solar illumination angles coupled with the bidirectional reflectance distribution function (BRDF) of the surface.

Top figure shows the temporal uncertainty (standard deviation divided by the mean) was found to be 2.46%.

Bottom figure shows how TOA reflectance varies with solar zenith angle.

A simple linear empirical BRDF model was developed to correct for variations caused by solar zenith angles at different acquisition dates.
Results of linear BRDF model correction

- Figure shows the trending after applying the BRDF model (black circles).
- The variation caused by annual cycle oscillation is reduced significantly and the temporal stability improved to 0.84 % for this channel.
- 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)
- These data suggest that with the implementation of BRDF model in a transparent atmosphere, a sensor can be calibrated to better than 1% accuracy.
- Atmospheric models are needed to extend this work to wavelengths where atmosphere is not transparent.
Empirical Absolute Cal model for Libya 4 using Terra MODIS

- The analogous spectral bandpasses for TERRA MODIS and ETM+, along with the corresponding spectral response of Hyperion over Libya 4 are shown.
- Assuming Terra to be the calibration standard, Hyperion spectrum can be scaled appropriately so that the model produces the same value as Terra when integrated over the Terra spectral bandpass.
- The scale factor was derived by averaging multiple Hyperion and MODIS images.
- When considering multiple dates, it is necessary to also consider solar zenith angle (SZA) effects which dominate the BRDF of the Libyan surface.
- Only BRDF changes due to SZA have been addressed for simplicity.
Empirical Absolute Cal model for Libya 4 using Terra MODIS (cont’d.)

- All other factors, such as azimuthal effects, higher order surface reflectance changes, and all atmospheric effects have not been considered.
- The resulting simple model is

\[ \rho_{\text{Libya4}}(\lambda, \text{SZA}) = K \rho_h(\lambda)[a(\lambda)(\text{SZA}) + 1] \]

- The percent difference between the model predictions and the MODIS measurements shows the RMSE of the difference within 1%.
- The difference is random as the model is based on MODIS as reference sensor.
A comparison is made between the Libya 4 model prediction and at-sensor reflectance derived from ETM+ measurements as shown where the black circles show the absolute calibration model prediction and the blue x’s show ETM+ measurements. The percent difference between the two is on the order of 1% RMSE. A little bias is observed between the model and measurements probably due to absorption features in wider ETM+ band.
Conclusions

• Hyperion measurements in a transparent channel showed that precision better than 1% is possible in Libya 4.
• A simple nadir-looking model was then developed for Libya 4 in the ‘red’ band 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%.
• This agreement is well within the stated calibration accuracies of these two sensors (2% reflectance-based for Terra, and 5% radiance-based for ETM+).
• Work in progress to expand the model to all wavelengths, view geometries, and develop more exact surface and atmospheric components.
Discussion-the way forward

• Extend the developed model by
  ▪ Developing a more comprehensive model for BRDF. Only BRDF changes due to SZA have been addressed for simplicity.
  ▪ Development of atmospheric models to account for non-unity transmittance and scattering.
  ▪ Expand the spectral range (example was shown only for red band)
  ▪ Develop physical models
  ▪ Extend to other PICS
  ▪ Develop SI traceability

▪ A proposal:
  ▪ Consider the advantages that would occur if all optical sensors imaged Libya 4 (and other Saharan PICS) regularly. What would the impact be for cross-calibration of sensors and development of the PICS absolute calibration methodology?!