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

Initial concepts

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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 <u>**absolute**</u> 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:

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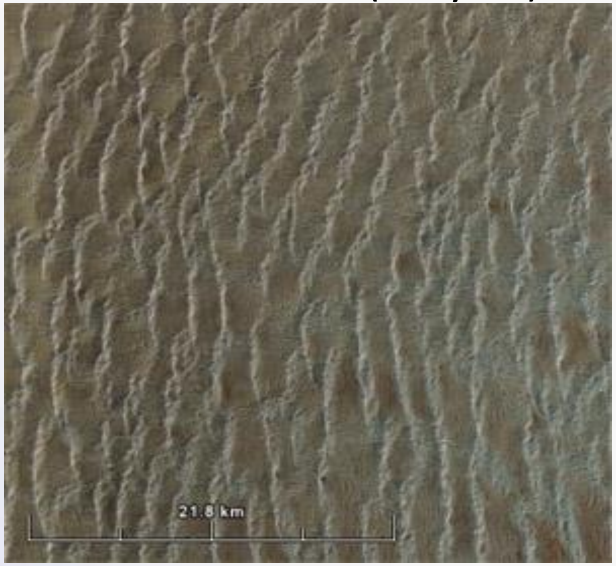
PICS Background

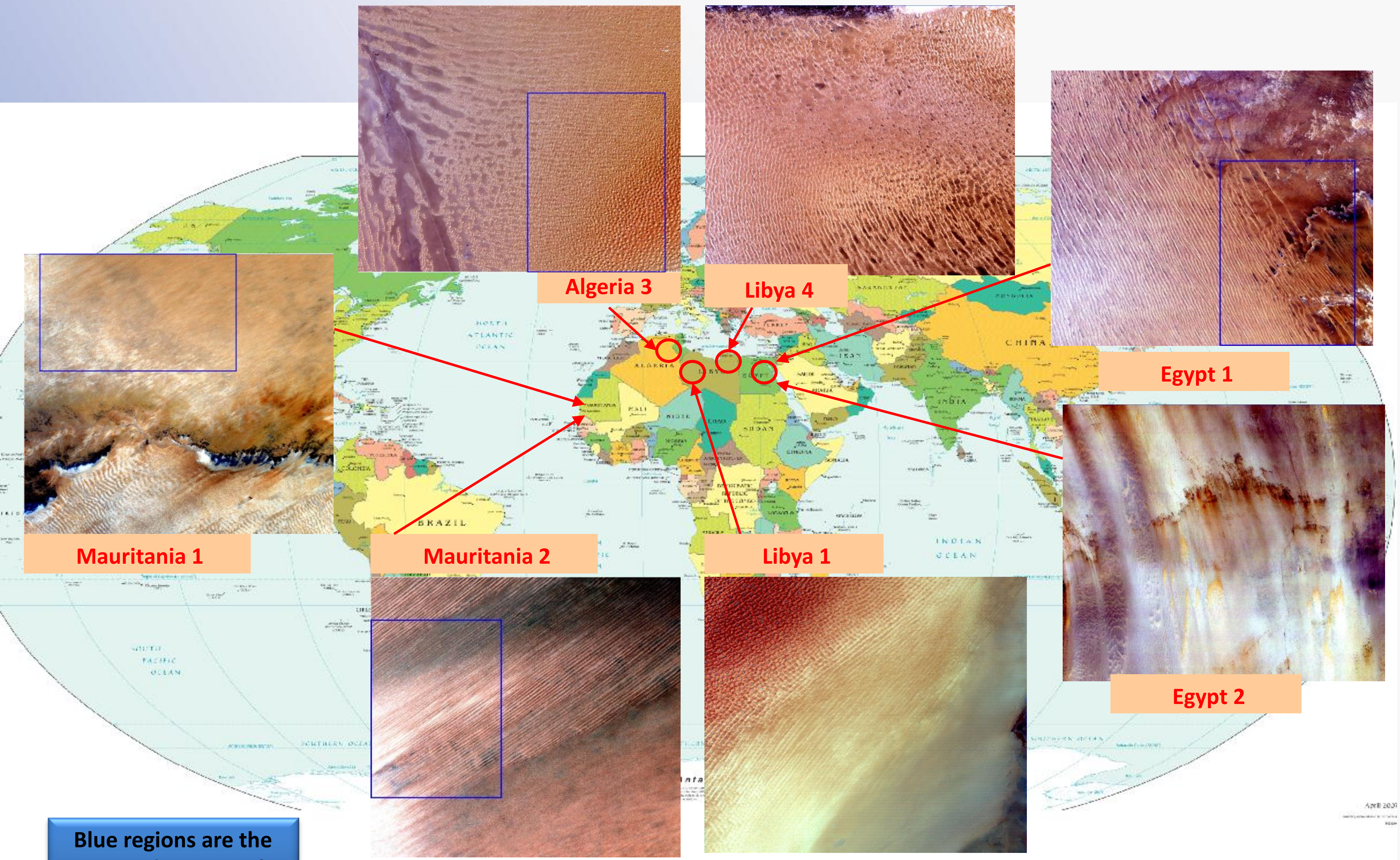
- PICS have been used for on-orbit radiometric trending of optical satellite sensors for at least 15 years.
- The most highly regarded sites used by the calibration community tend to be in the Sahara desert of North Africa.
- A suite of sites has been developed and endorsed by CEOS and currently be viewed 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 (75^{o}06’S, 123^{o}21’E, elevation 3.2 km) to calibrate visible bands.

ETM+ Bands 3 2 1 (Libya 4)



Google Earth Ground Picture

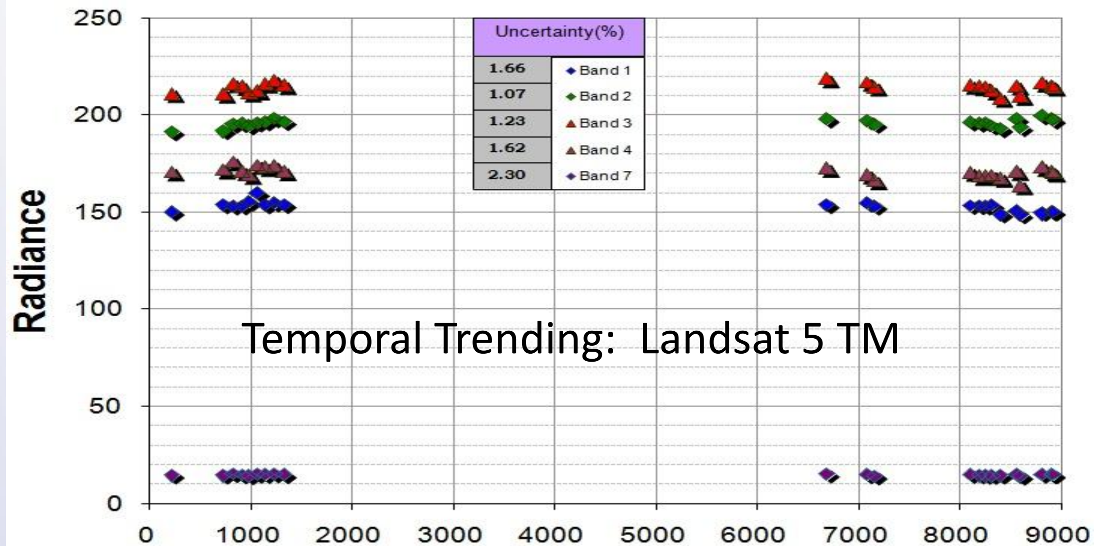
OPTIMIZED SAHARAN PICS

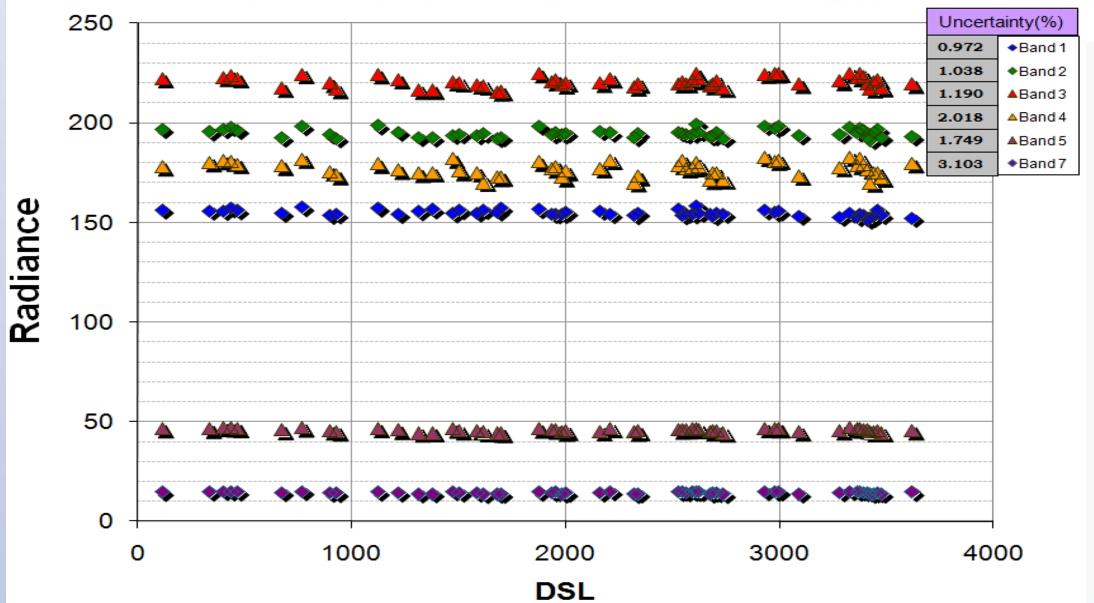


Blue regions are the optimal regions of interest (ROI)

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%

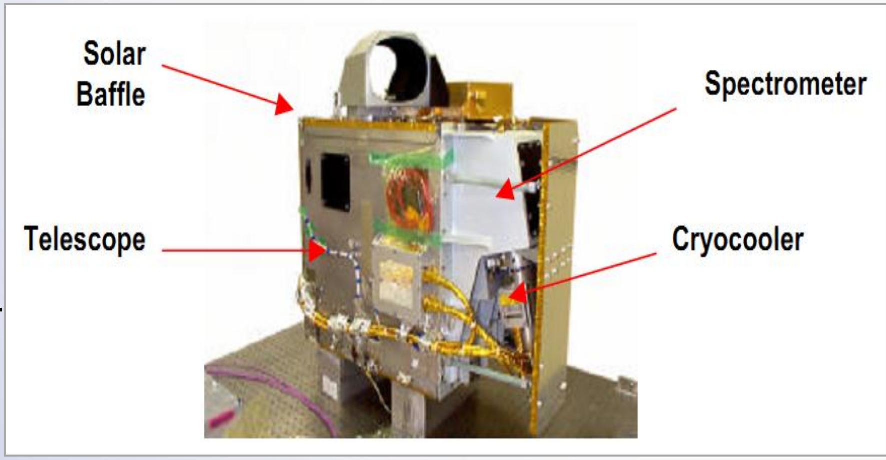
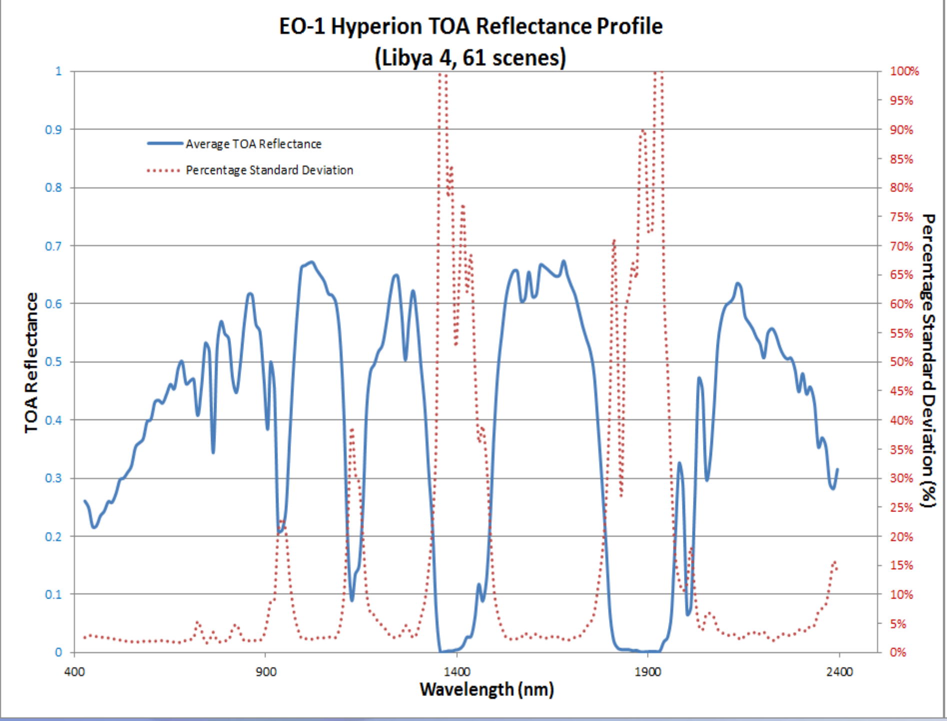
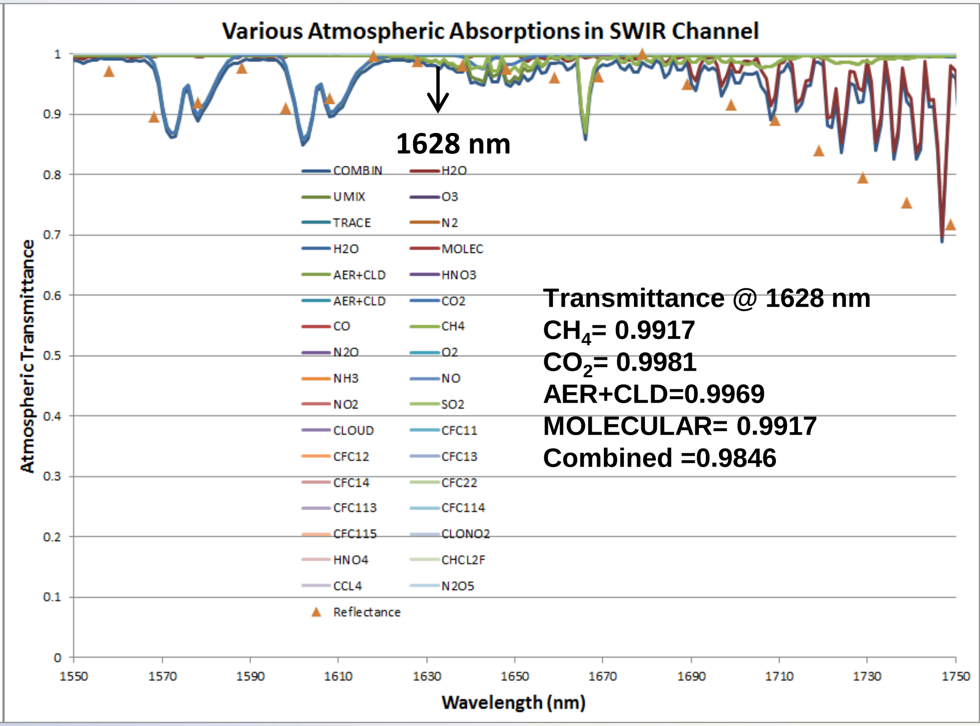


Fig: Schematic of the EO-1 Hyperion Sensor

LIBYA 4 Stability Based On EO-1 Hyperion

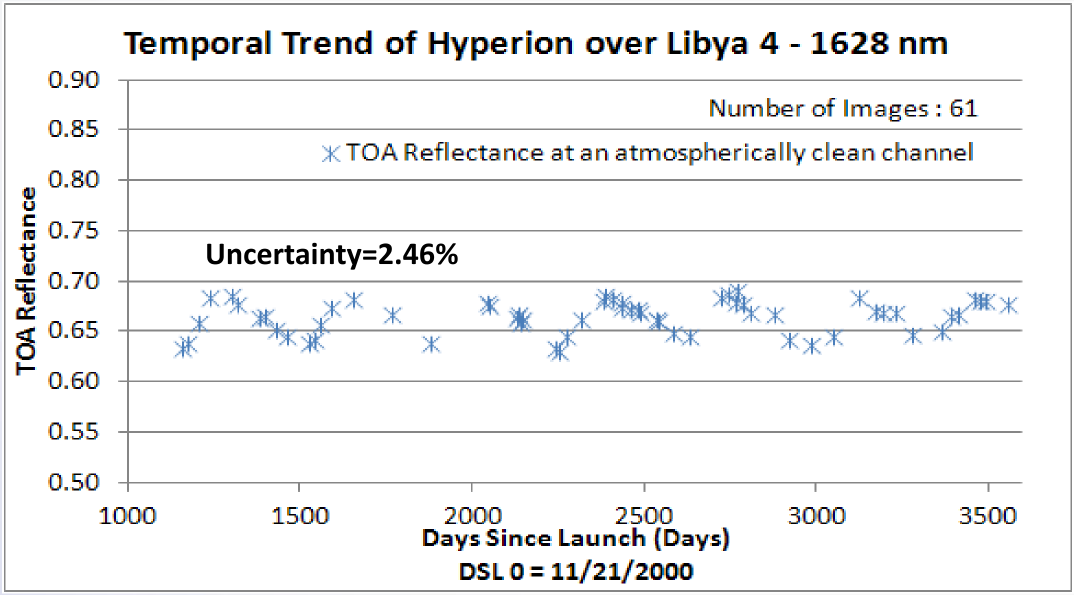
- The temporal stability of the Libya 4 site was studied by selecting Hyperion spectral channels with very high atmospheric transmittance in the Short Wave Infra-Red Region (SWIR).
- The viewing geometry of the sensor was restricted to within +/- 5 degrees to minimize the effects caused by non-nadir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

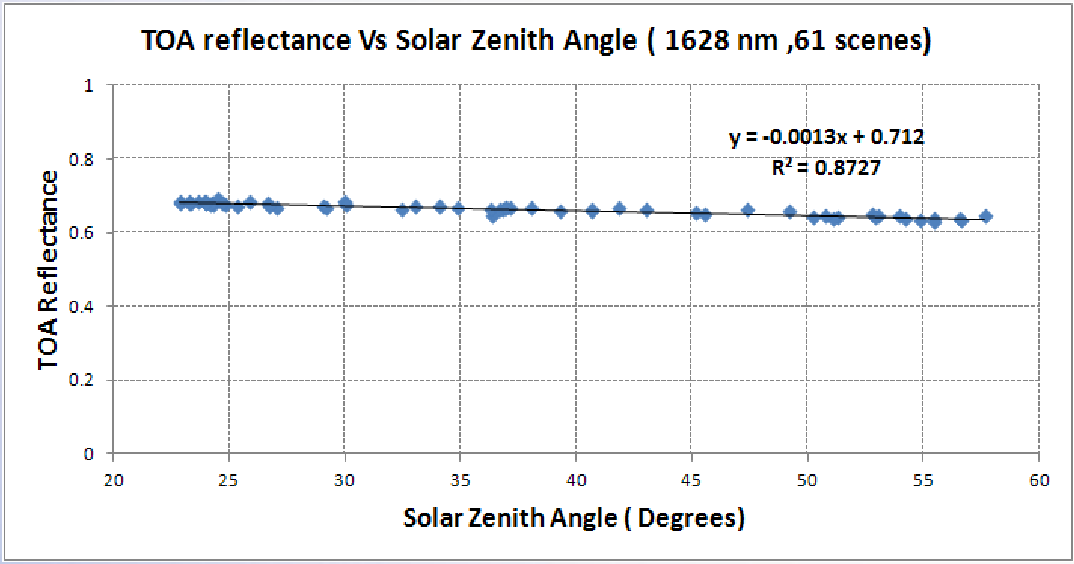




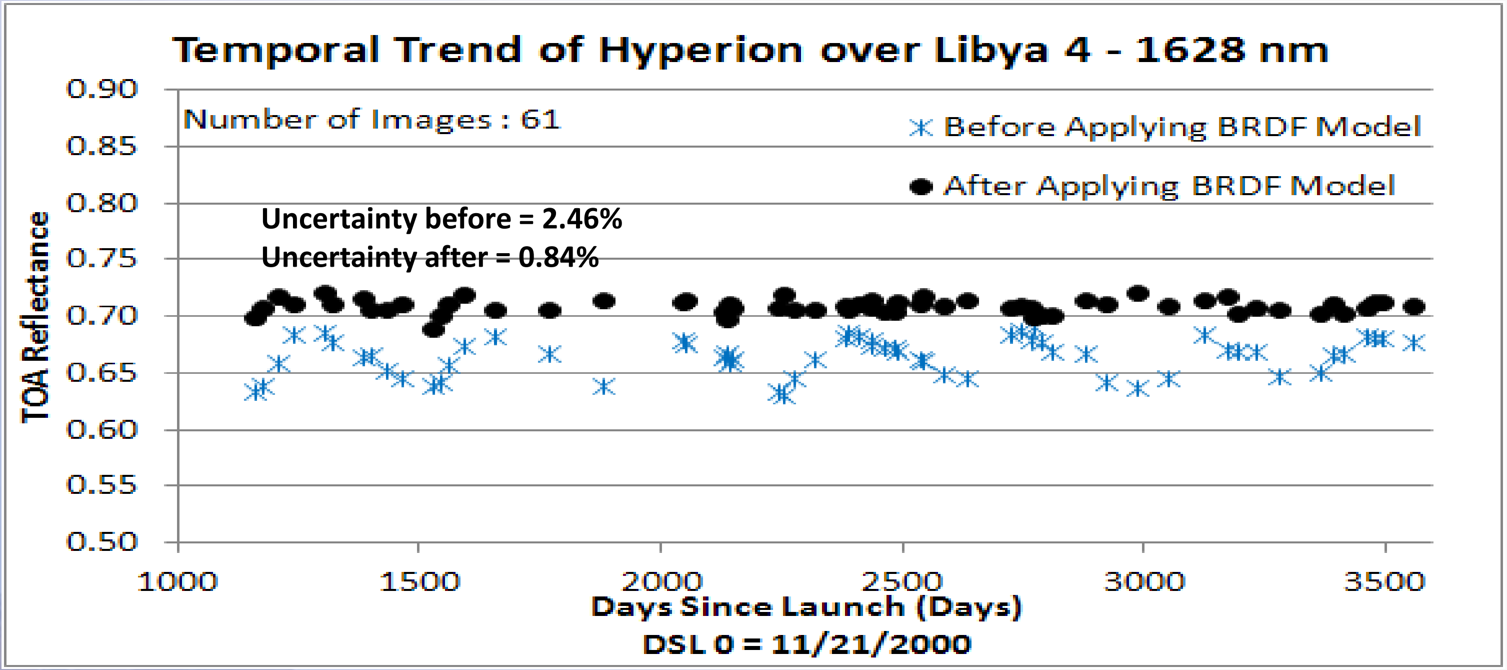
Development of a linear BRDF model

- 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.





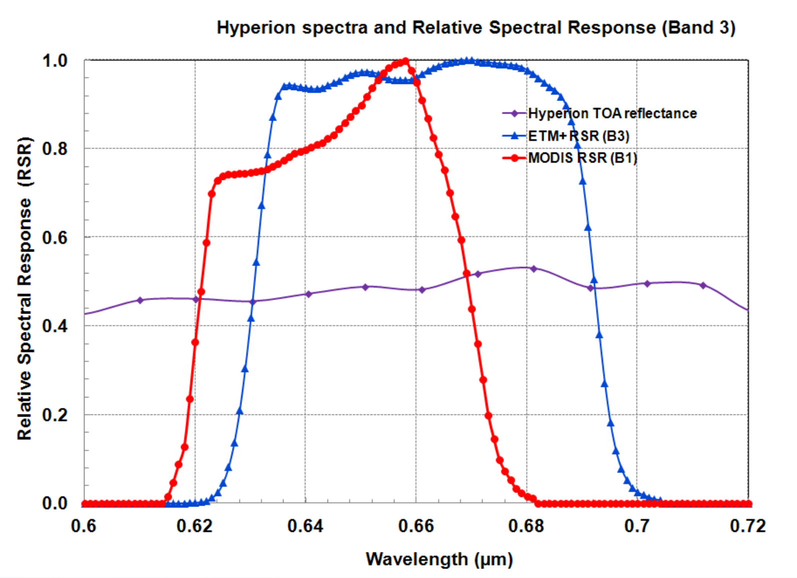
Results of linear BRDF model correction

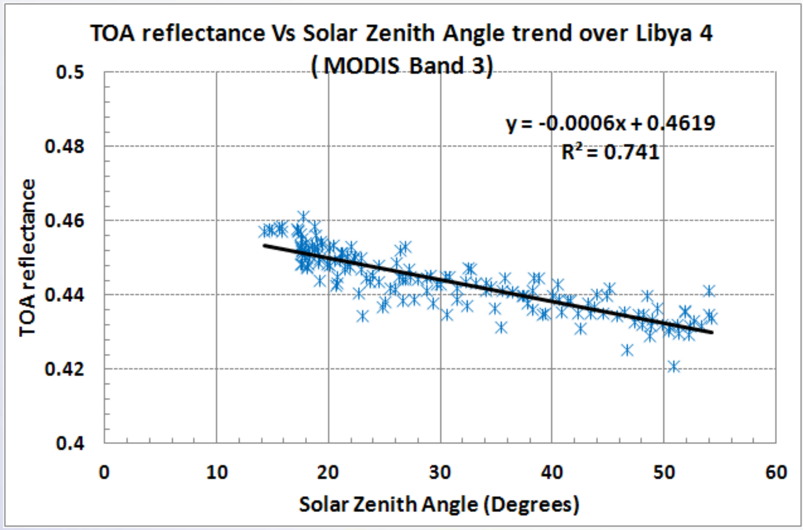


- Figure shows the trending after applying the BRDF model (black circles).
- The variation caused by annual cycle oscillation is reduced significantly and the temporal stability improved to 0.84 % for this channel.
- Sub 1% results were observed for other high transmittance SWIR channels too. (1558 nm, 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.



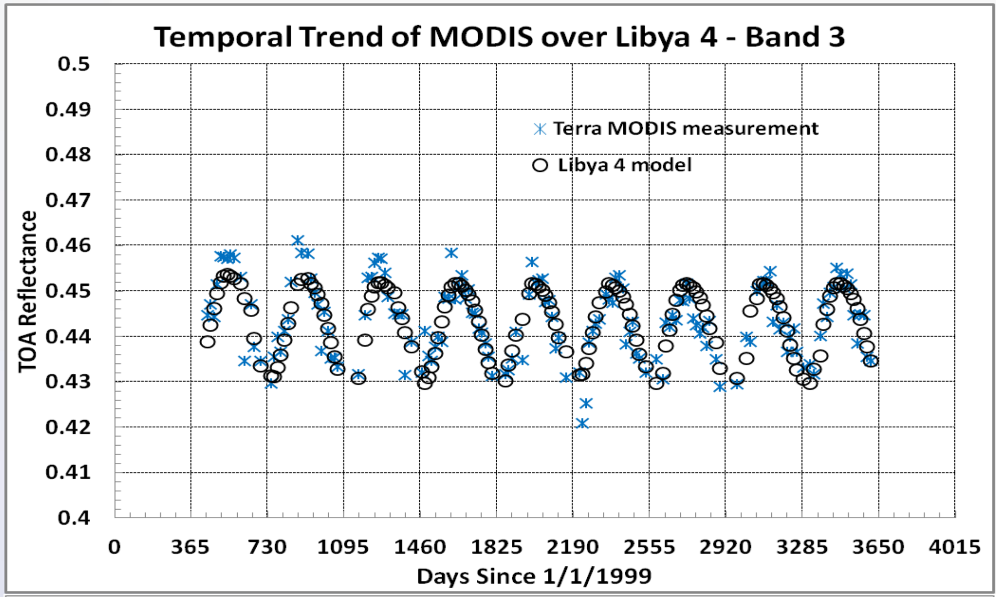


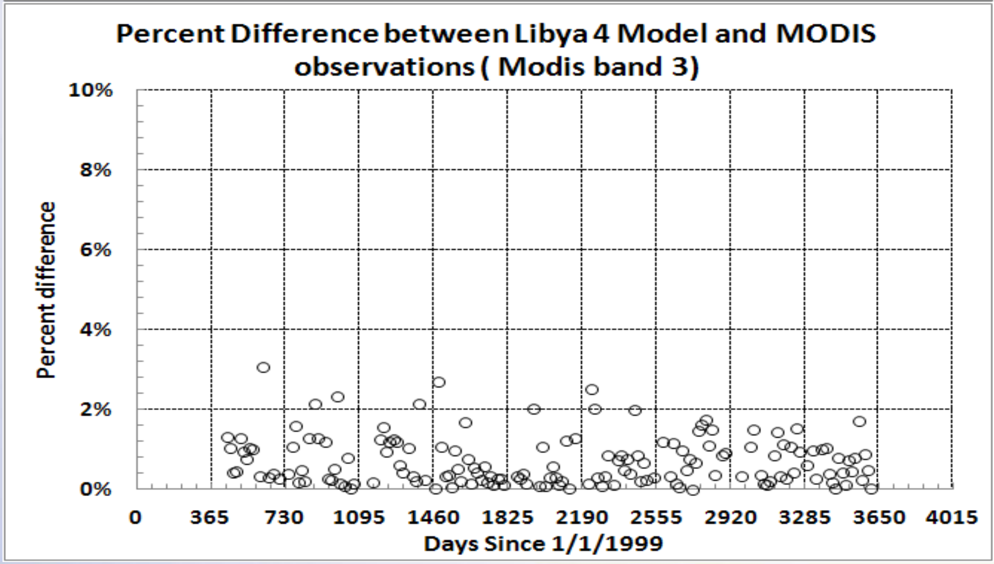
Empirical Absolute Cal model forLibya 4 using Terra MODIS (cont'd.)

- 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

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

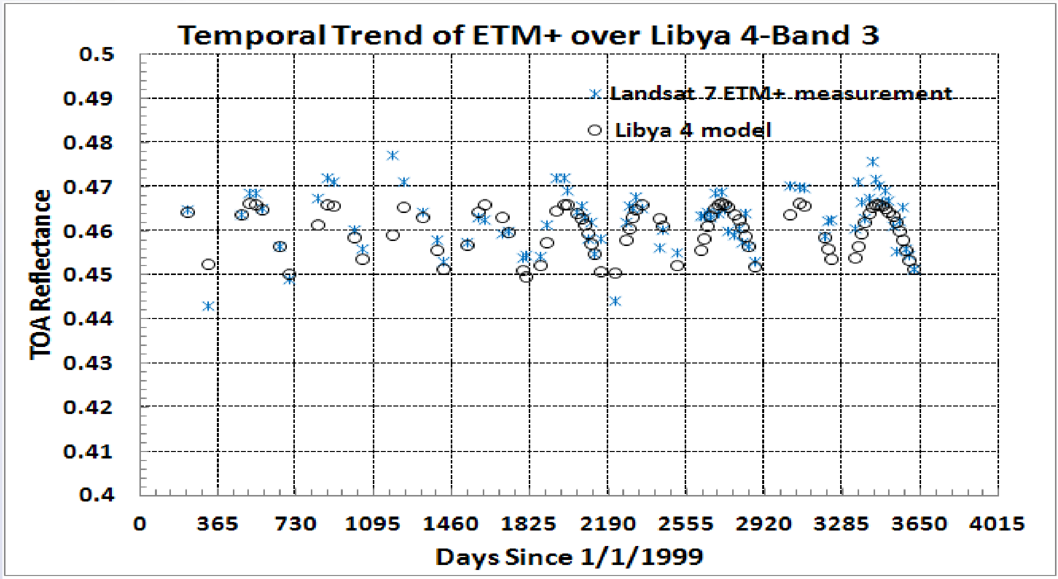
- The percent difference between the model predictions and the MODIS measurements shows the RMSE of the difference within 1%.
- The difference is random as the model is based on MODIS as reference sensor.

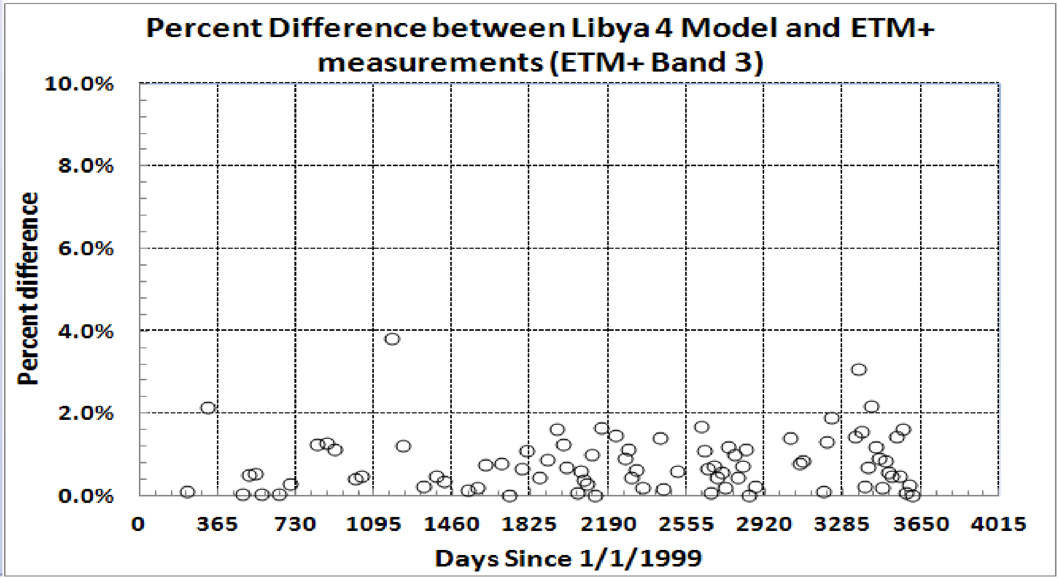




Validation of the model using ETM+ measurements

- 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?!