# An Empirical Absolute Calibration Model for Optical Sensors Using Pseudo Invariant Calibration Sites (PICS)

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# Outline

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  - ➢ Long term trending of Landsat 7 ETM+ using Libya 4
- Absolute Calibration Model development
  - MODIS Terra as absolute radiometer
  - Hyperion for spectral
  - Development of BRDF model
    - ➢ For Solar Zenith Angle
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- Absolute Calibration Model validation
  - ➢ Validation of the model using Terra & AQUA MODIS, Landsat 7 ETM+, MERIS, UK-2 DMC
- Conclusions

**Acknowledgement:**

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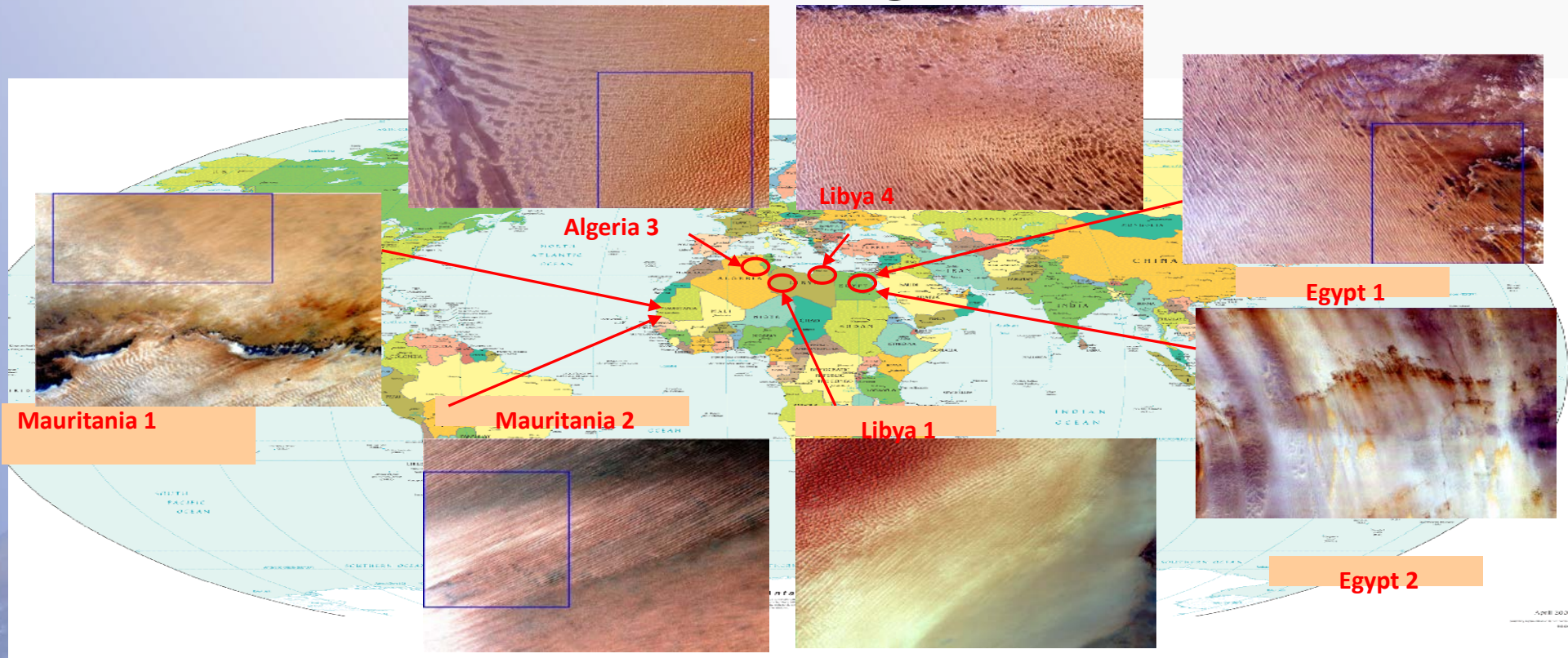
**The MODIS data have been provided by MODIS Characterization Support Team (MCST).**

# 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:
  - Develop a comprehensive and accurate PICS absolute calibration model that can be SI traceable.
    - Empirical approach (*presented today*)
      - Developing surface and atmospheric models based on satellite and meteorological observations.
    - First Principles approach (*presented next year*)
      - Develop surface and atmospheric models based on the inherent physics of the site.

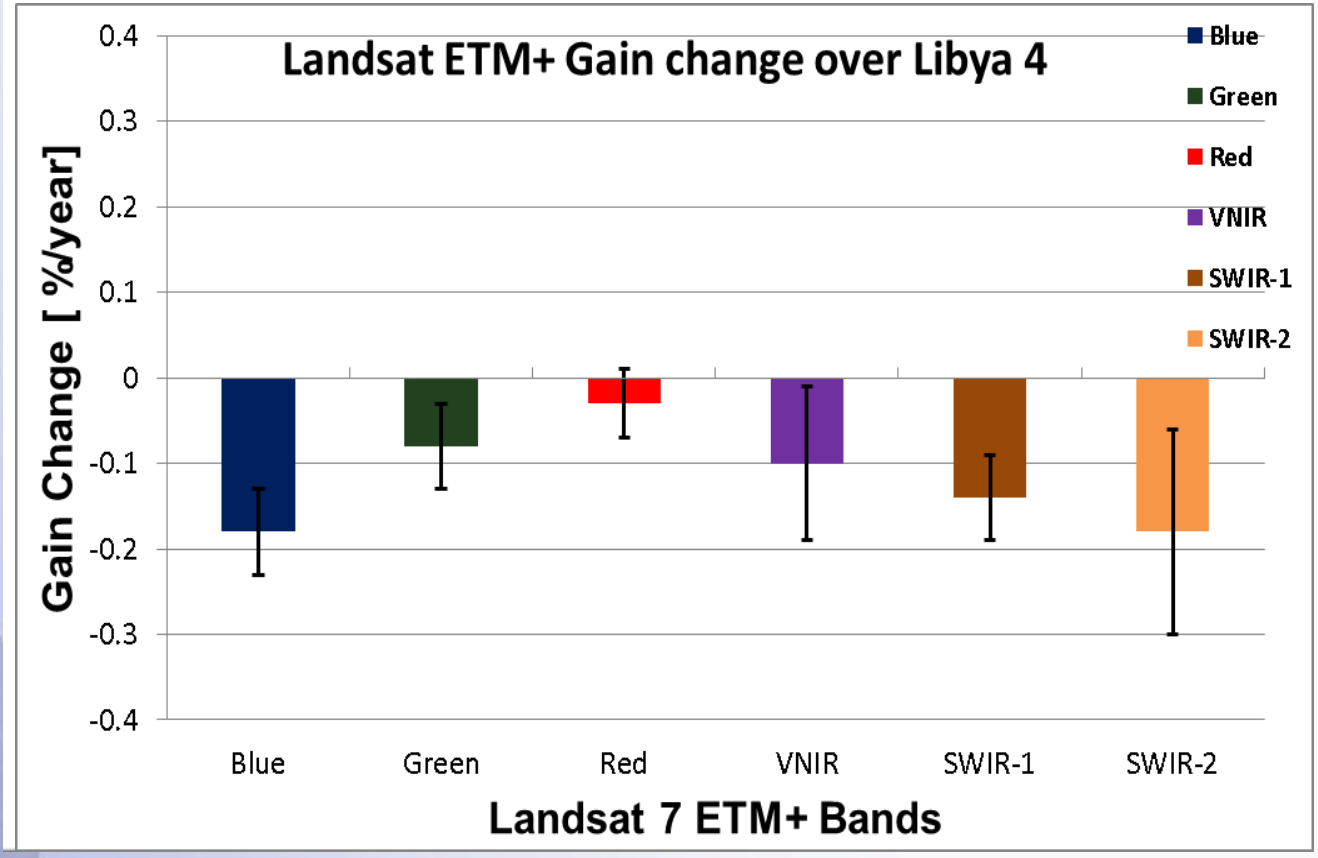
# PICS Background




- 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 (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° 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+ show that Libya 4 is stable to ~ 2% in the VNIR bands and ~3% in the SWIR bands.
- Changes of as little as 0.2 percent per year are measurable with ETM+ over a decade

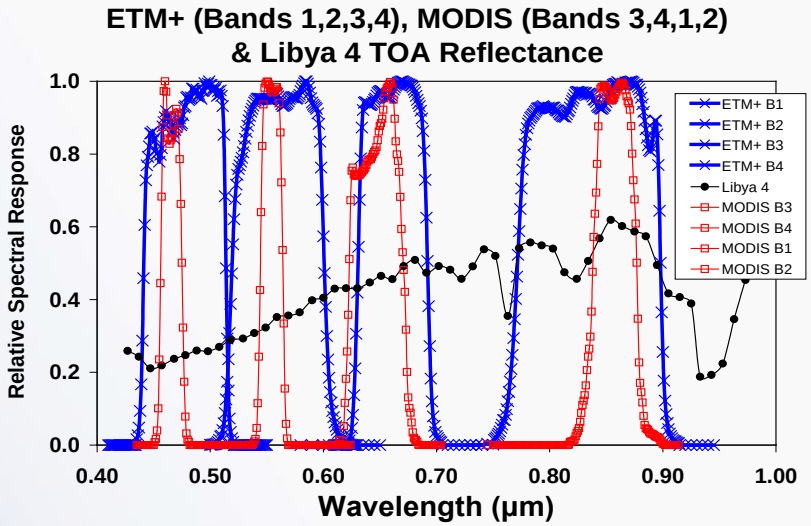


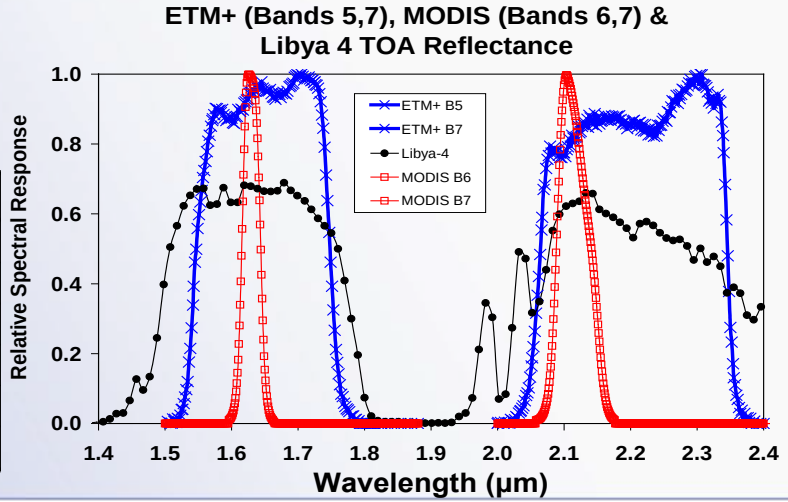
# Libya 4 Abs Cal Model

- An absolute calibration model was developed where the Terra MODIS was the calibrated radiometer and EO-1 Hyperion was used to derive the spectral content of the target.
- Terra MODIS data was used to derived the BRDF due to solar zenith angle.
- Hyperion data was used to derive BRDF due to viewing zenith angle.
- A simple empirical atmospheric model was developed using Hyperion channels
- The model was validated using different suites of sensors such as Terra & Aqua MODIS, ETM+, UK DMC2, MERIS etc.

# Absolute scaling factor- anchoring spectral model to Terra MODIS

- Assuming Terra to be the calibration standard, the Hyperion spectrum can be scaled appropriately so that the model produces the same value as Terra when integrated over the Terra spectral band-pass.
  - 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 ($\alpha = 0.05$).
  - Hyperspectral scale model was then developed using the smooth linear interpolation between these three gain points.

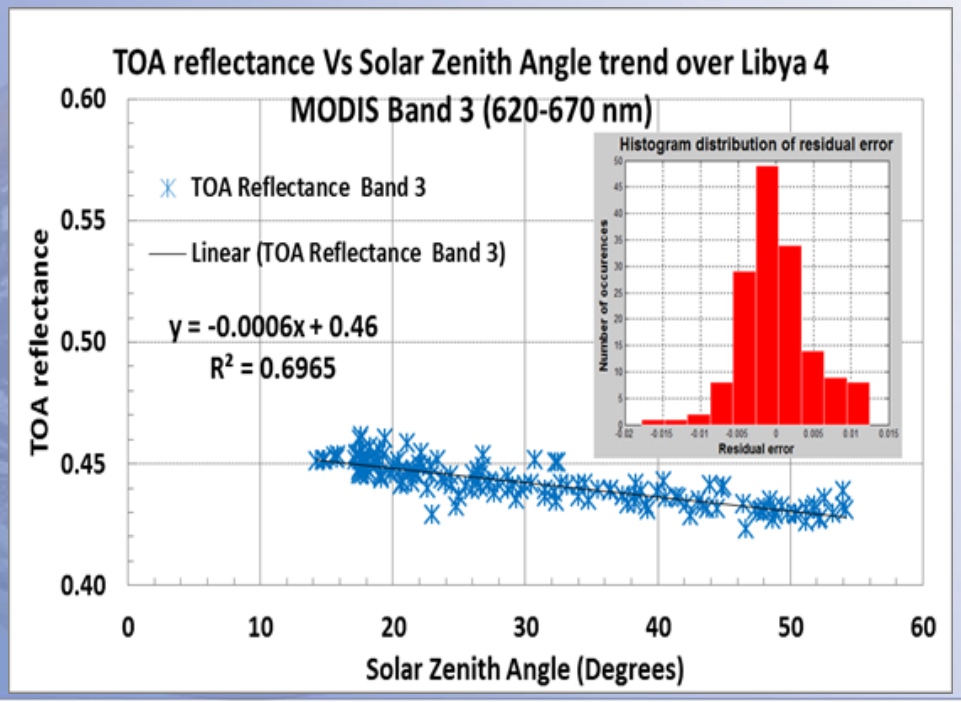


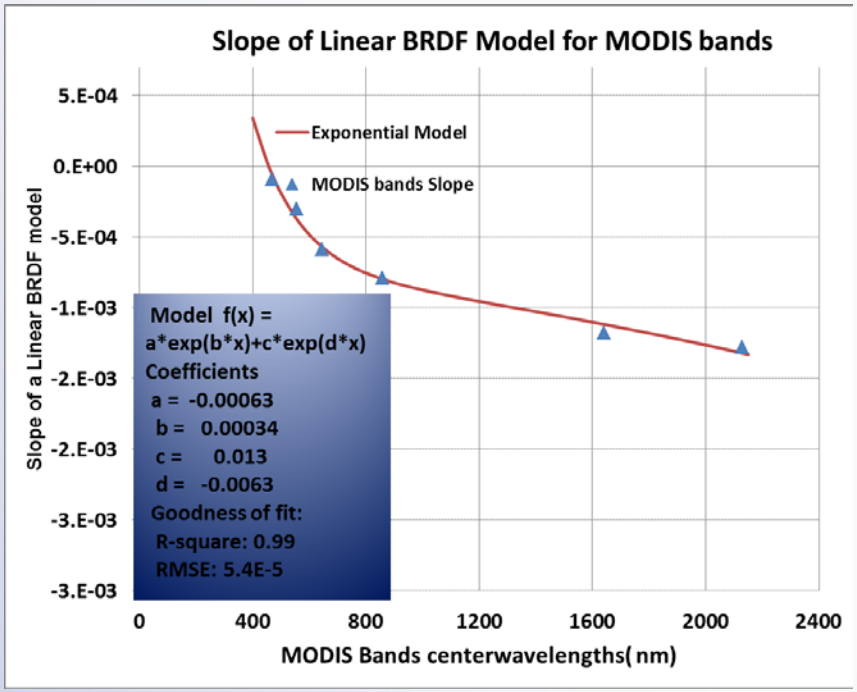




| MODIS Bands | 7/4/2004 | 9/6/2004 | 9/22/2004 | 9/25/2005 | 6/24/2006 | 9/15/2007 | Average | STD |
|---|---|---|---|---|---|---|---|---|
| 3 (459-479 nm) | 1.025 | 0.992 | 1.001 | 0.998 | 0.973 | 0.979 | 0.995 | 1.82% |
| 4( 545-565 nm) | 1.029 | 1.006 | 1.008 | 1.009 | 1.000 | 1.000 | 1.009 | 1.05% |
| 1 (620-670 nm) | 1.024 | 1.010 | 1.007 | 1.013 | 1.003 | 1.001 | 1.010 | 0.83% |
| 2 (841-876 nm) | 0.993 | 0.990 | 0.978 | 0.988 | 0.973 | 0.983 | 0.984 | 0.81% |
| 6 (1628-1652 nm) | 0.996 | 1.001 | 0.991 | 0.999 | 0.977 | 0.984 | 0.992 | 0.95% |
| 7 (2105-2155 nm) | 0.986 | 0.974 | 0.960 | 0.966 | 0.952 | 0.954 | 0.965 | 1.32% |

# BRDF Model Development—Solar Zenith Angle

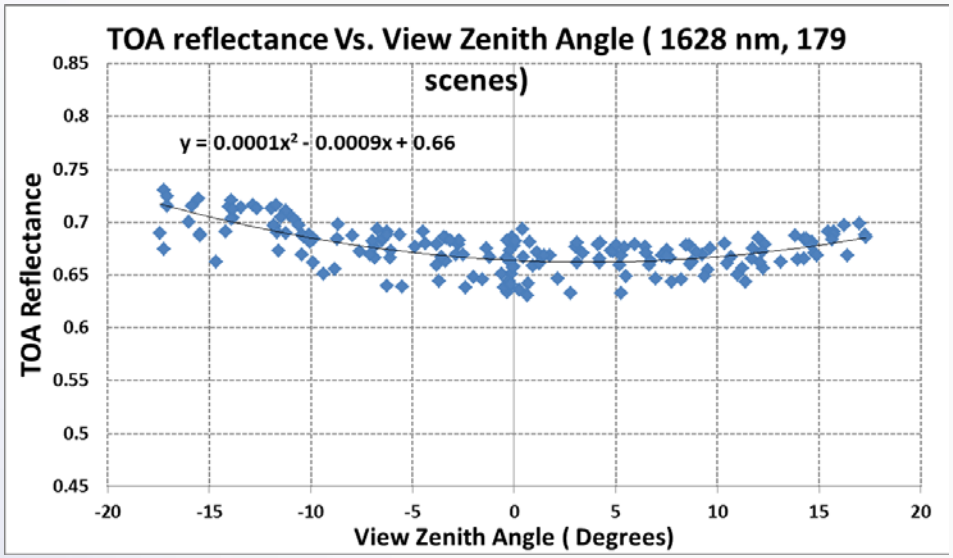
- MODIS observations from 2000 to 2010 were used to develop a linear BRDF model.
- Example is shown in the figure for red band.
- Similar linear model was generated for 6 solar reflective bands.
- The resulting slope value was plotted as a function of center wavelengths.
- BRDF/SZA was modeled using a simple two exponential fit with very high value of $R^2$ and low RMSE.

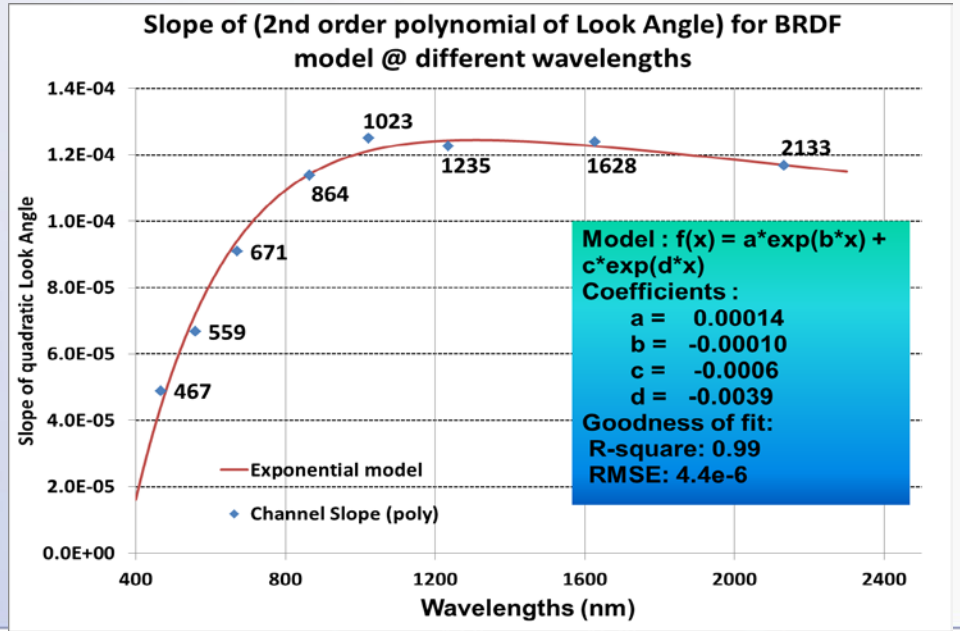


# BRDF Model Development —Viewing Angle

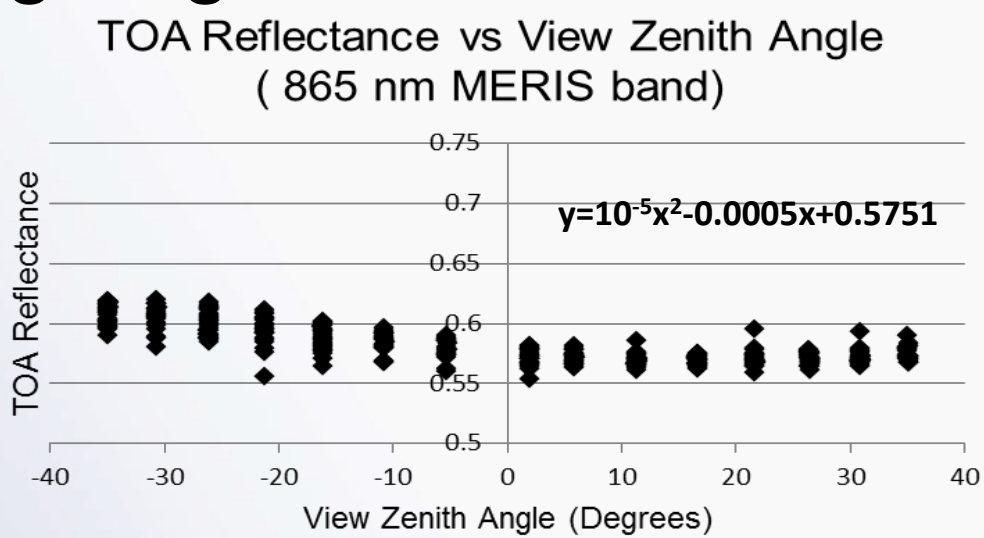
- Hyperion Observations from 2004 to 2011 were used to develop BRDF models due to view zenith angle
- View zenith angle vs. TOA reflectance was modeled using 2nd order polynomial
- Results: sub 1% achievable in 'clean' channels.
- Lower plot shows the slope of second order terms for 9 spectrally cleaner Hyperion channels as a function of their center wavelengths.
- As seen in the figure, exponential models were fitted to these slopes with high $R^2$ and low RMSE

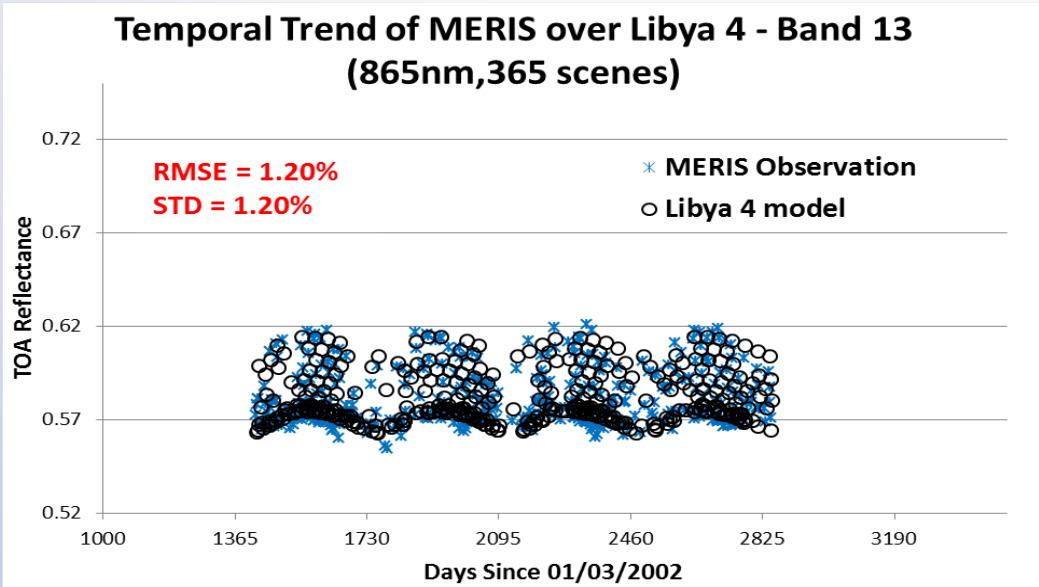


# Development of a BRDF model—larger viewing angles

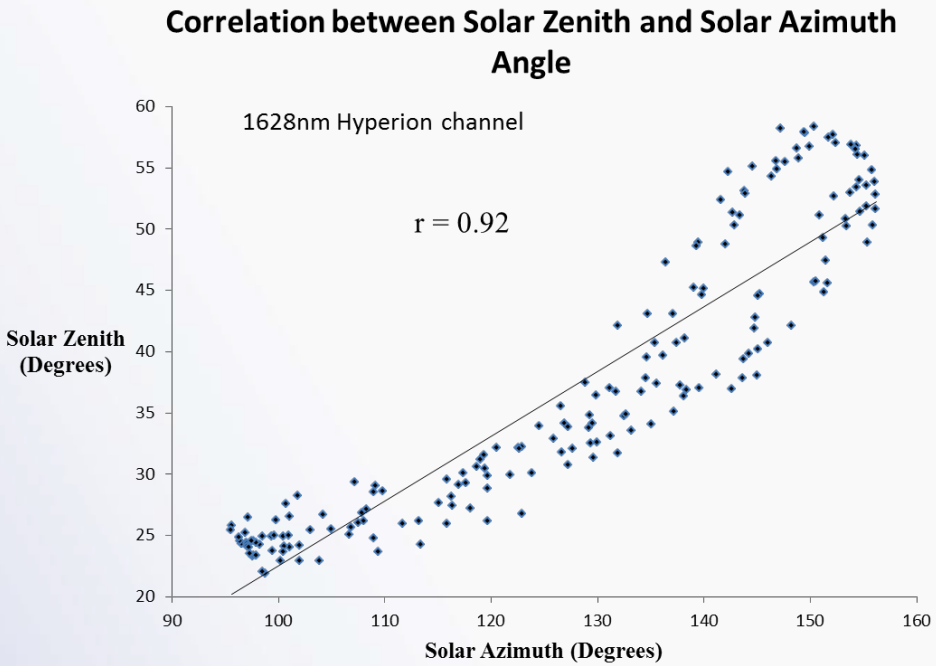
- Hyperion has limited view angles.
- The second order model fit was then performed with the MERIS data ( ± 40 degrees).
- Results shown for 865 nm MERIS bands show that 1.2% is possible with the empirical BRDF model.
  - DIMITRI database, 2006-2009



# Solar Zenith vs. Solar Azimuth: Test of Multi Collinearity

- A strong positive correlation exists between Solar Zenith and Solar Azimuth variables.
  - Examine Variance Inflation Factor (VIF)
  - If VIF > 5, Multicollinearity Exists.
  - VIF measures the inflation in the variances of the parameter estimates due to collinearity that exists among the regressors or (dependent) variables.
  - Hence it is sufficient to include only one of them in the model.

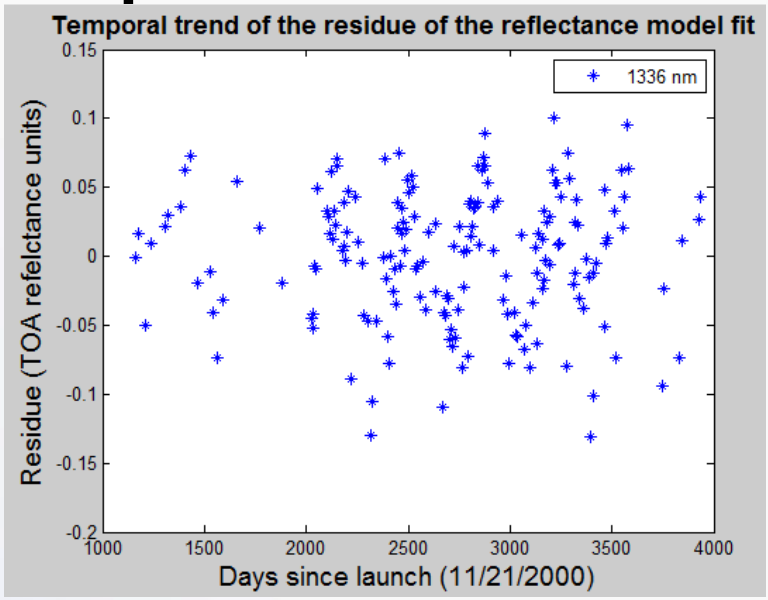


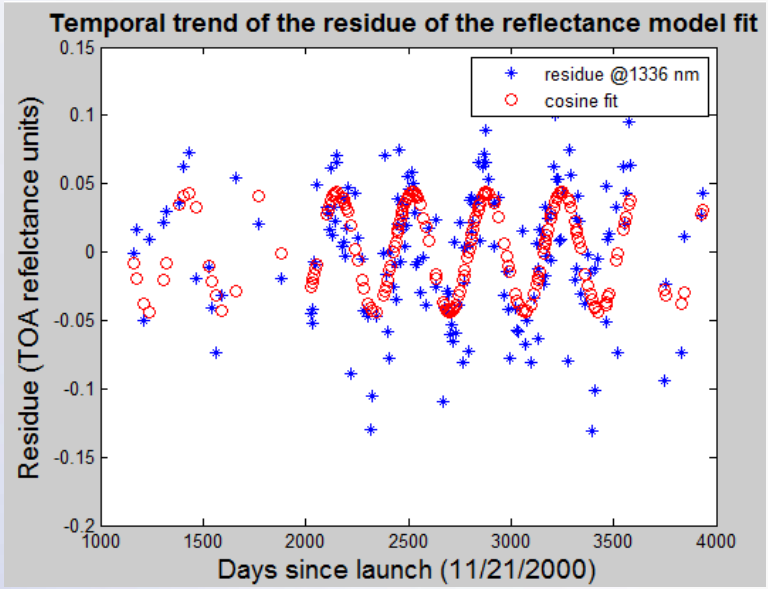

| | Solar Zenith | Look Angle | Look Angle (2nd order) | Solar Azimuth |
|---|---|---|---|---|
| **VIF** | 7.450018 | 1.212867 | 1.001935 | 7.866710 |
| Decision | TRUE | FALSE | FALSE | TRUE |

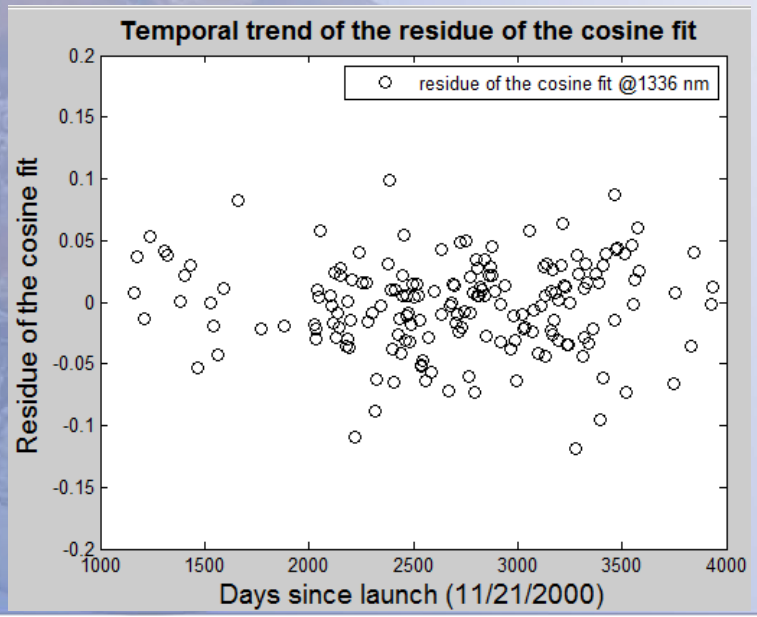
# Development of atmospheric model

## Procedure

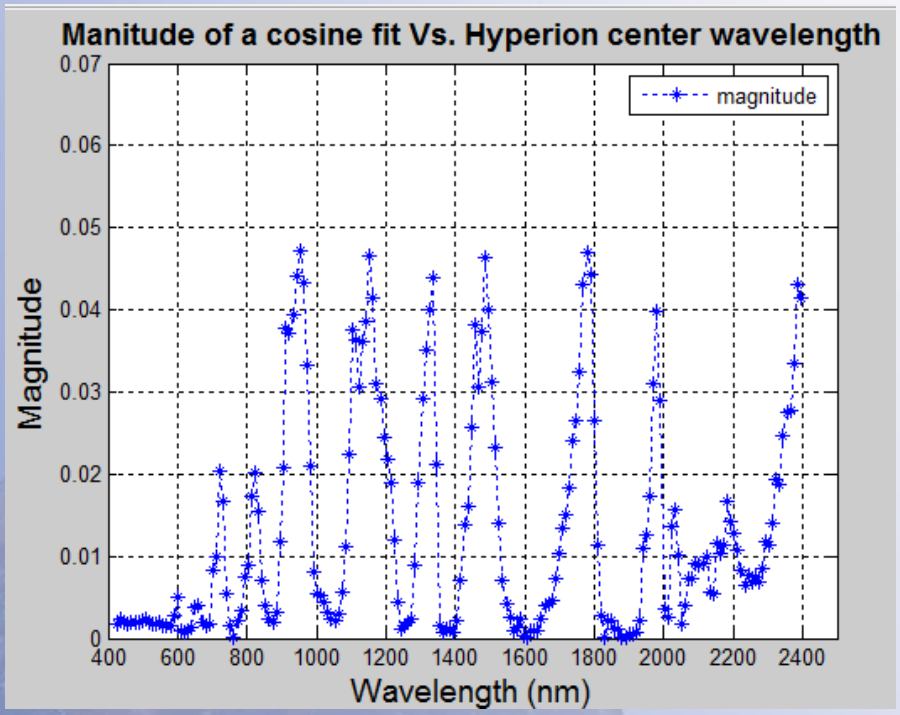
- Each Hyperion channel was modeled using
  $\rho(\theta_{SZ}, \theta_{VZ}, \lambda) = a_\lambda + b_\lambda * \theta_{SZ} + c_\lambda * \theta_{VZ} + d_\lambda * \theta_{VZ}^2$
- Residuals of the fit were then calculated for each Hyperion channels center-wavelength.
- A fit of the form
  $f(t) = a_0 + \sum_{n=1}^{\infty}\left(a_n \cos\frac{n\pi t}{T} + b_n \sin\frac{n\pi t}{T}\right)$ was applied to the residuals to model the periodic atmospheric cycle in Hyperion channels (T=365.2).
- For simplicity, the first order form with n=1 was considered.
- Plot shows the model fit performed to Hyperion channel at 1336 nm as it has a pronounced water vapor absorption feature.

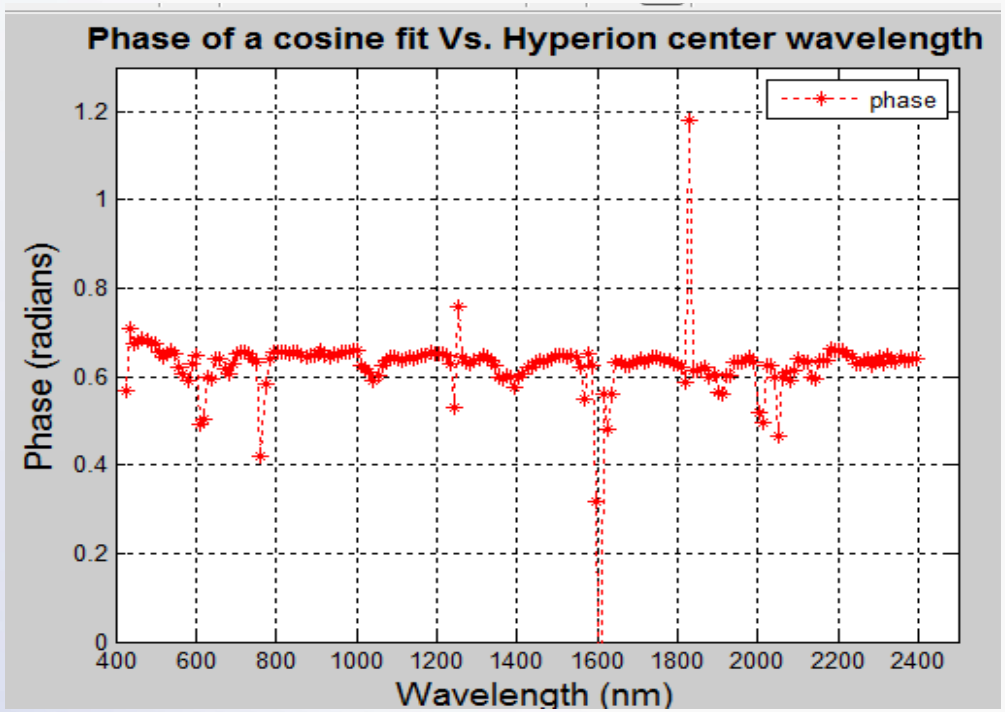


# Magnitude and phase spectra of the cosine fit



# The Model and its Validation

- The resulting absolute calibration model was of the form

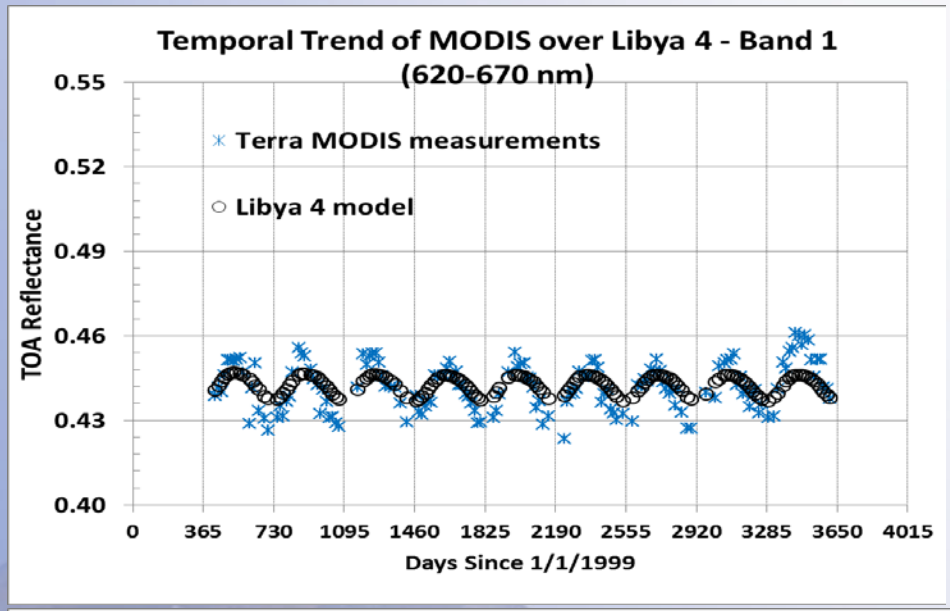
$$\boldsymbol{\rho_{Libya\ 4}}(\lambda, \boldsymbol{SZA}, \boldsymbol{VZA}) = \frac{\boldsymbol{K}(\lambda) * \boldsymbol{\rho_h}(\lambda) * \boldsymbol{f_A}(\boldsymbol{t})}{[\mathbf{1} - (\boldsymbol{SZA} - \mathbf{30}°) * \boldsymbol{m_1}(\lambda) - \boldsymbol{VZA}(\lambda) * \boldsymbol{m_2}(\lambda) - (\boldsymbol{VZA})^{\mathbf{2}} * \boldsymbol{m_3}(\lambda)]}$$

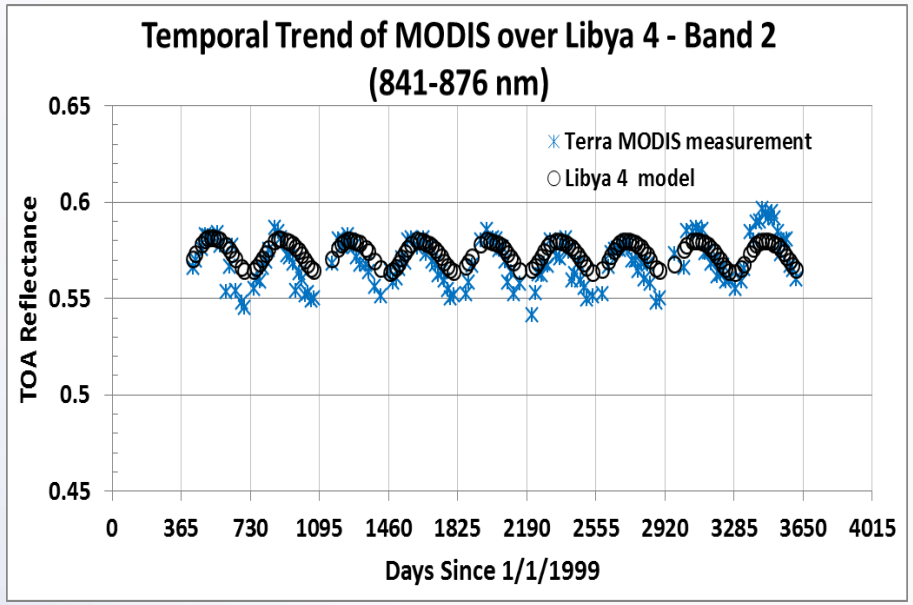
Where,

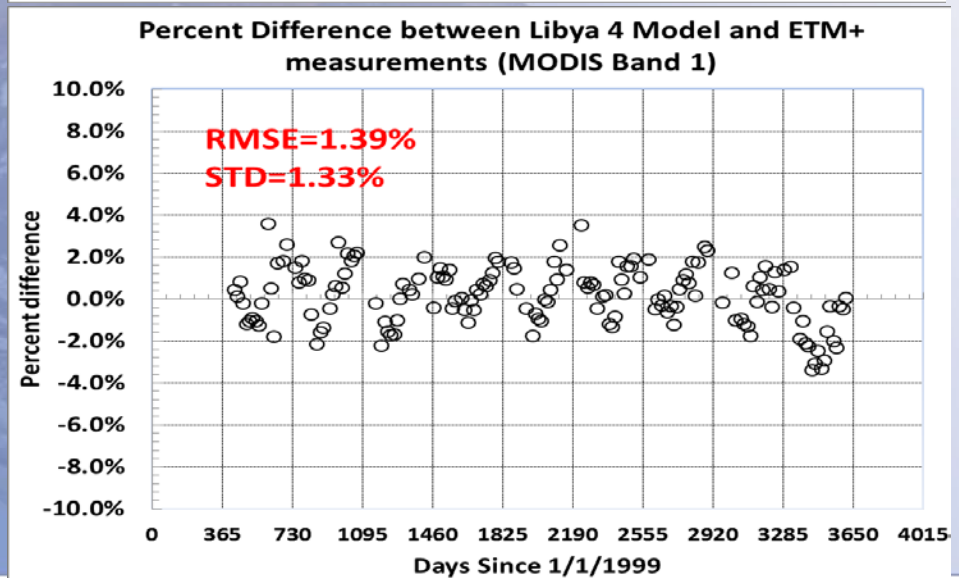
- K = scaling factor,
- $\rho_h$= spectral content of the scene
- $\boldsymbol{f_A}(\boldsymbol{t})$ = atmospheric model
- The BRDF was scaled to 30 degrees solar zenith angle
- The BRDF coefficients for view zenith angle were derived using Hyperion measurements (± 18 deg)

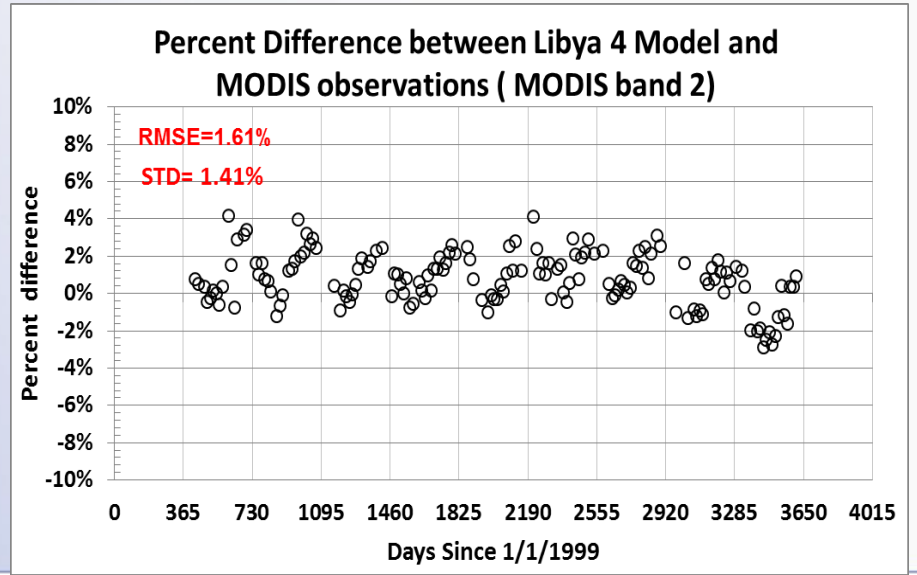
- The model was then validated using different suites of sensors such as Terra, Aqua, ETM+, UK-2DMC, MERIS, etc.

# Validation using Terra MODIS - Red and VNIR bands

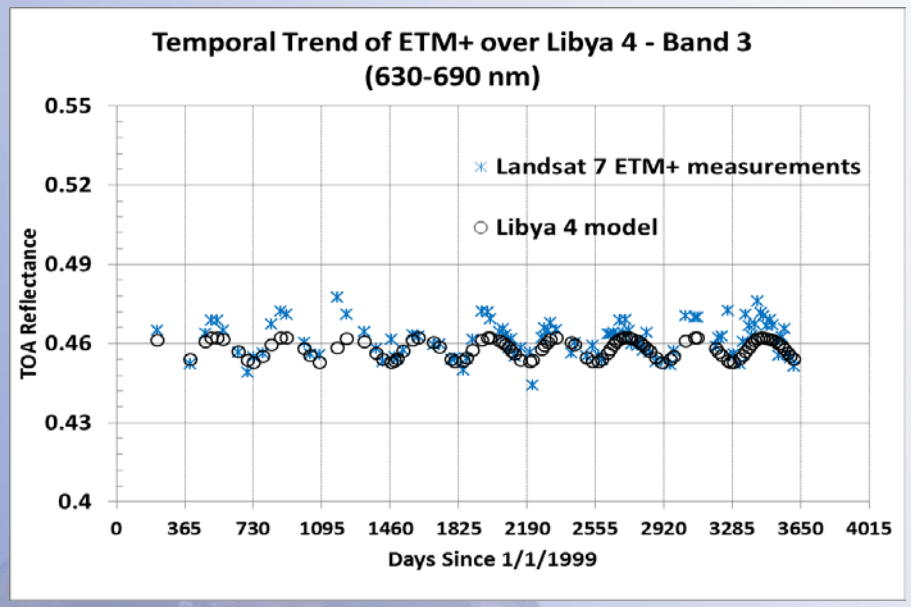


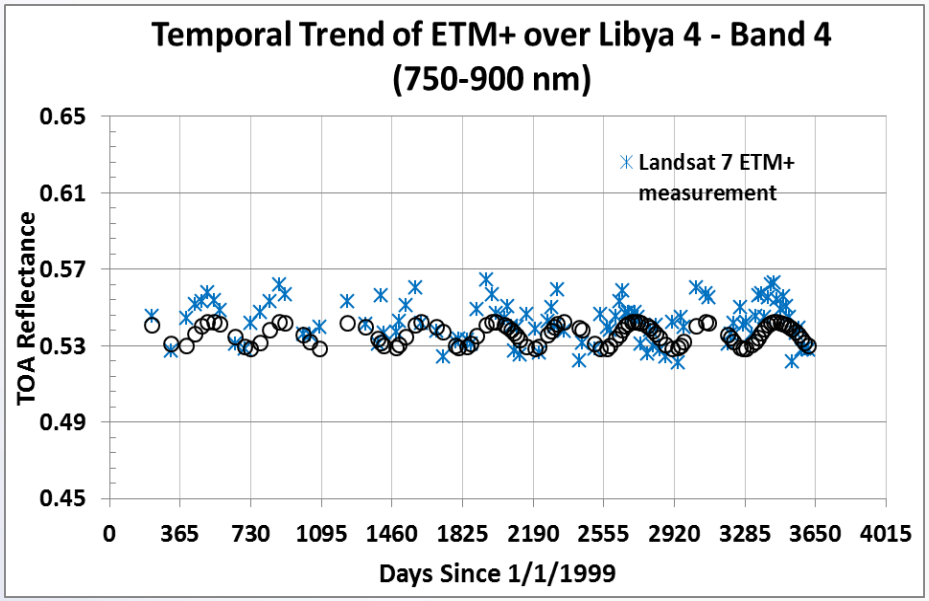



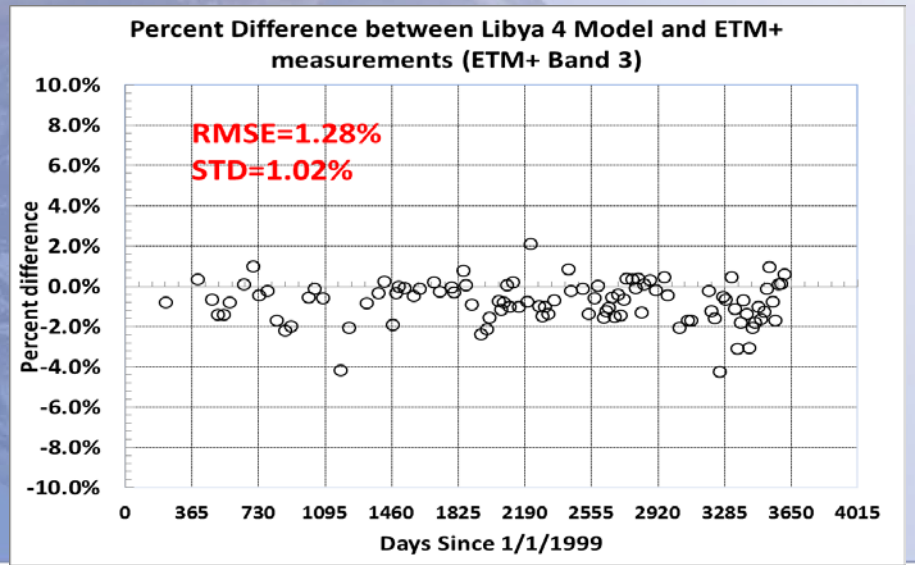



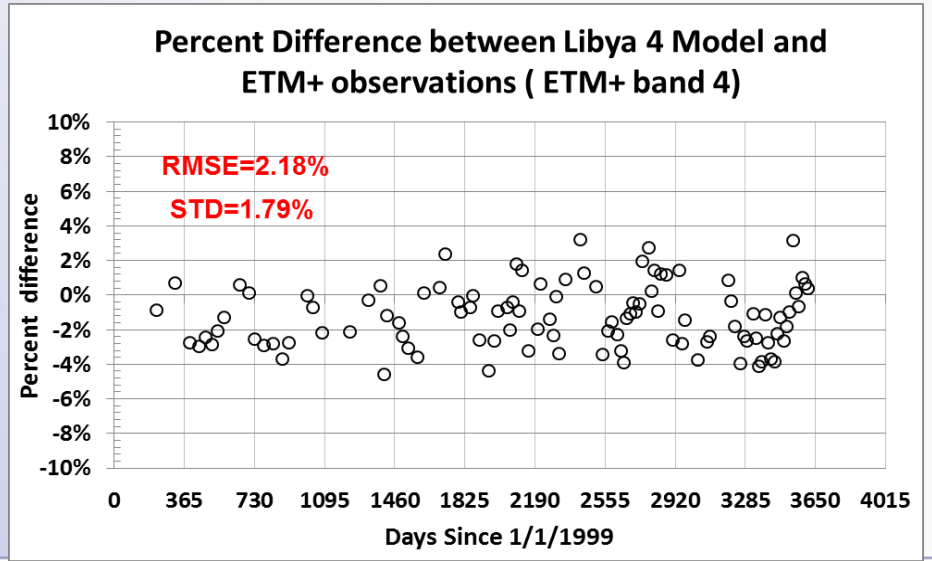



# Validation using Landsat 7ETM+ - Red and VNIR bands

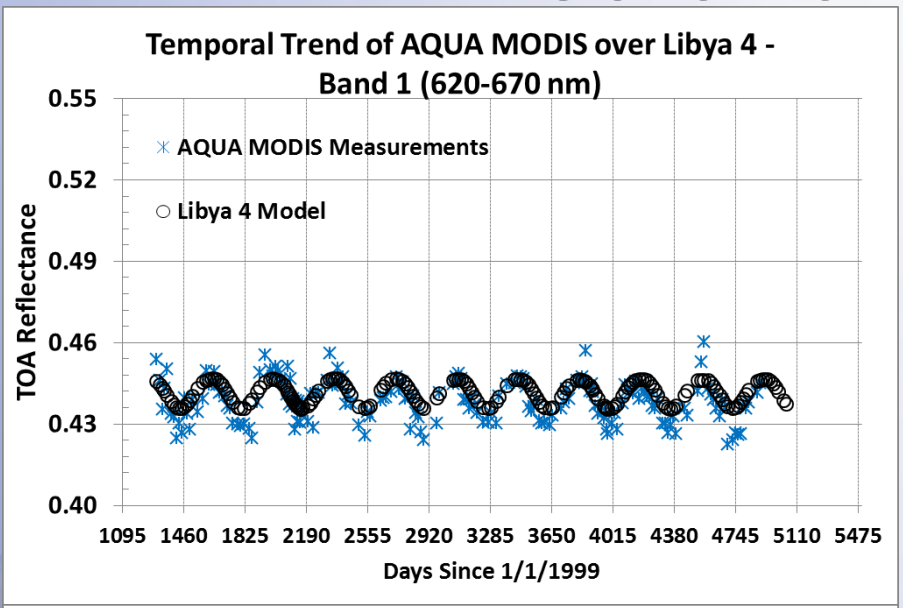


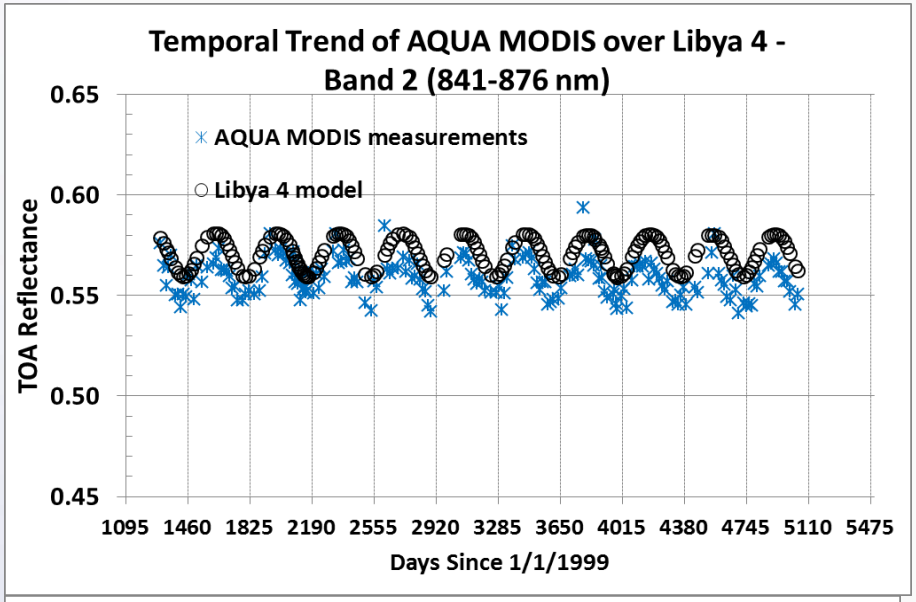



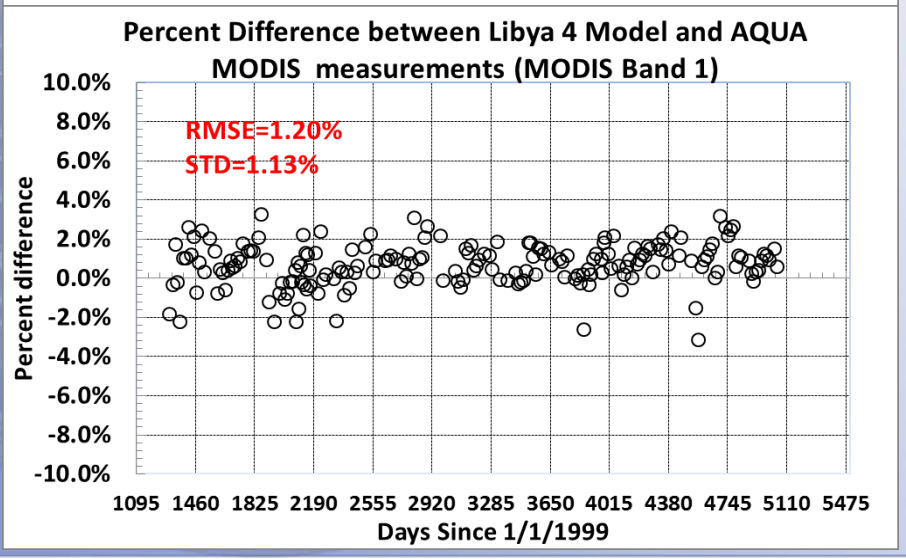



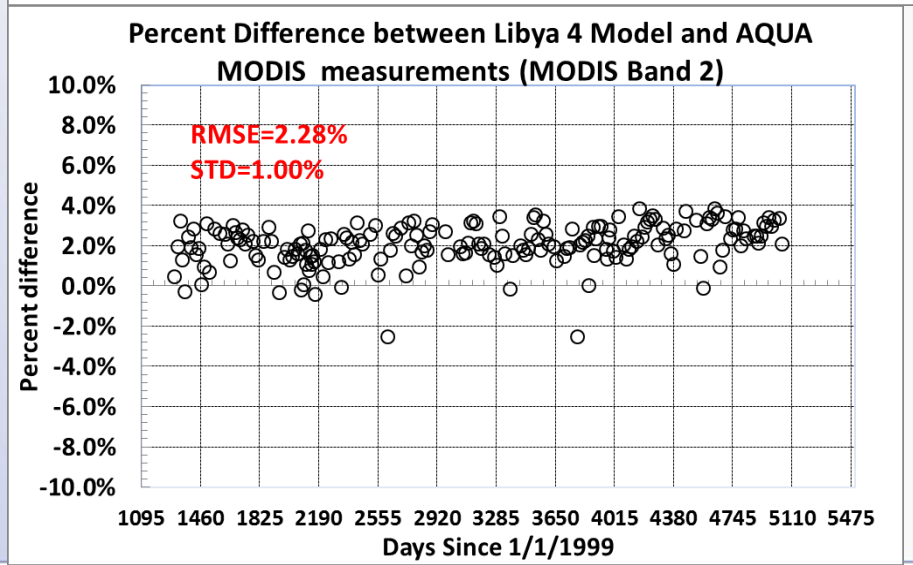



# Validation using Aqua MODIS - Red and VNIR bands

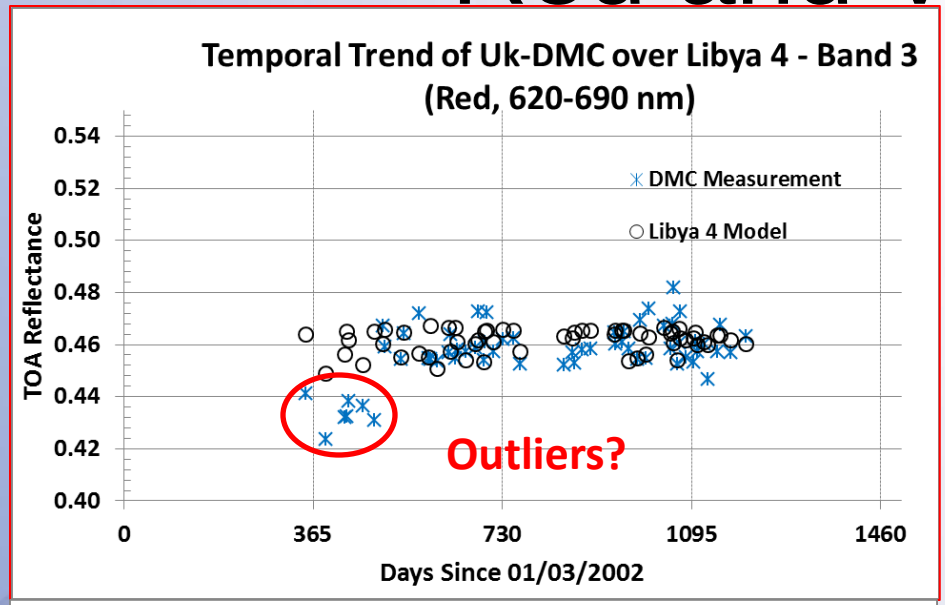


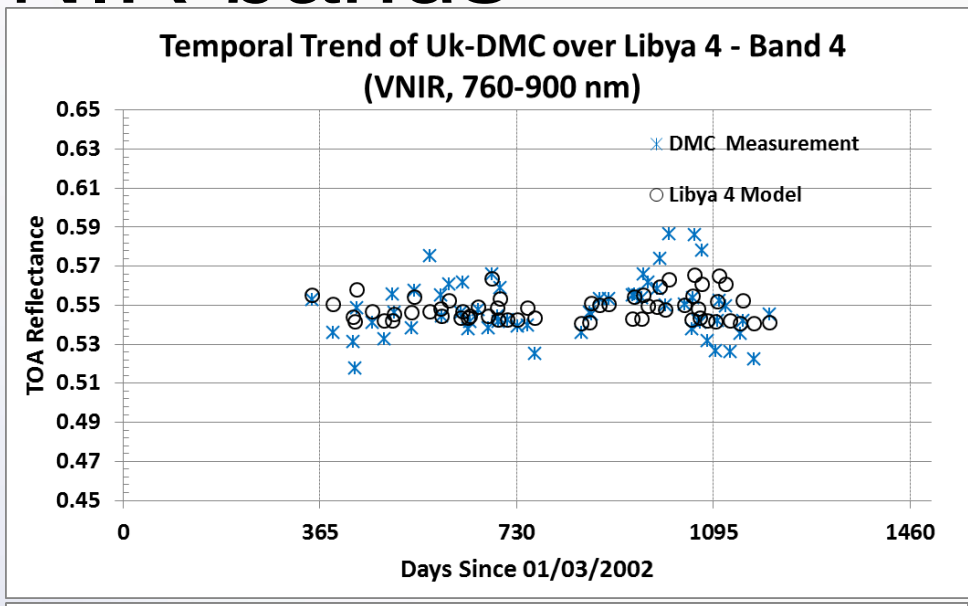



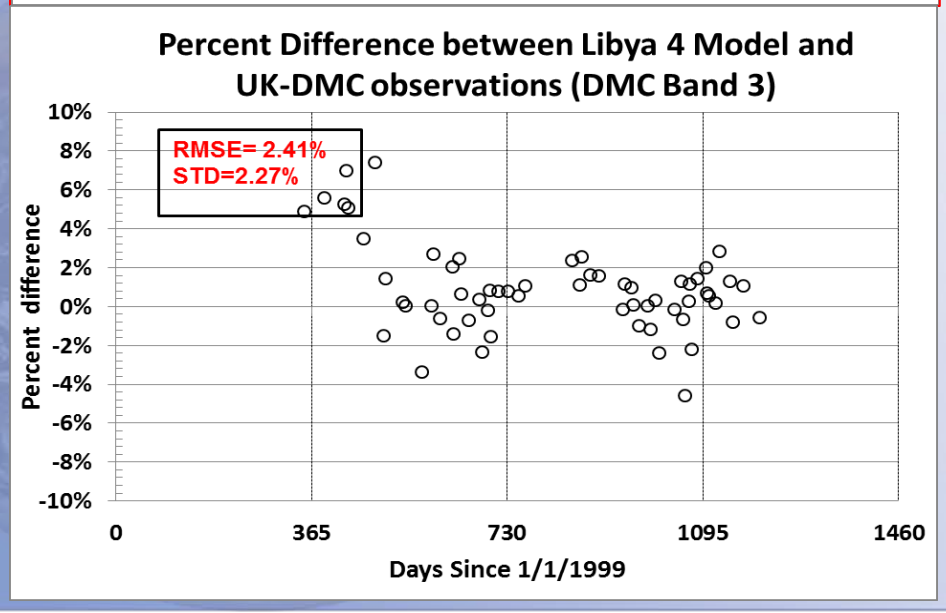



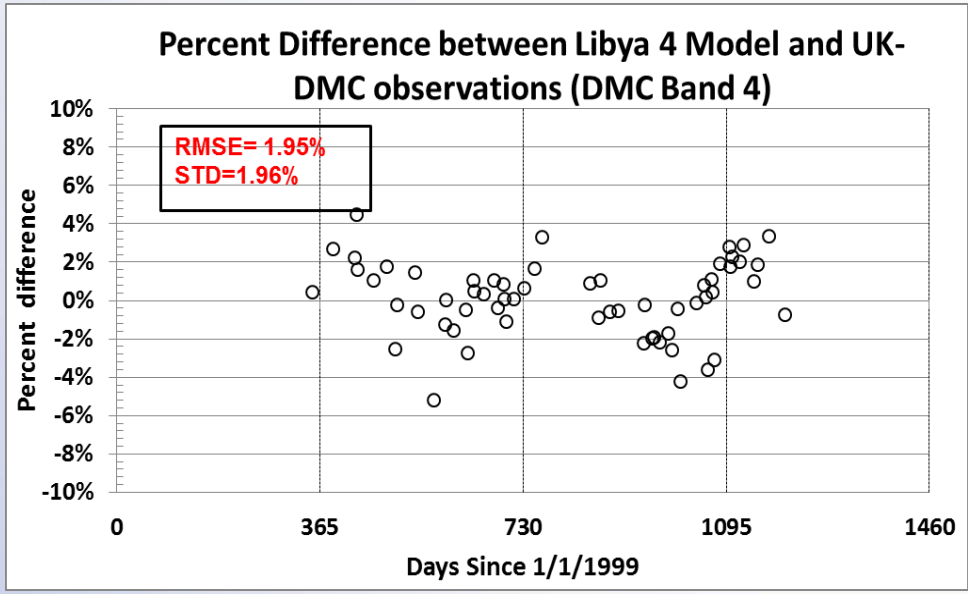



# Validation using Uk-2 DMC - Red and VNIR bands



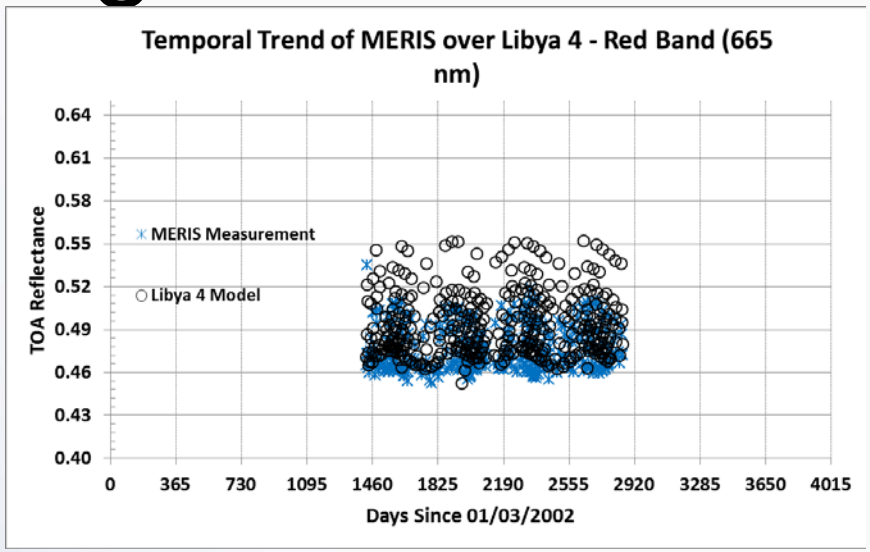



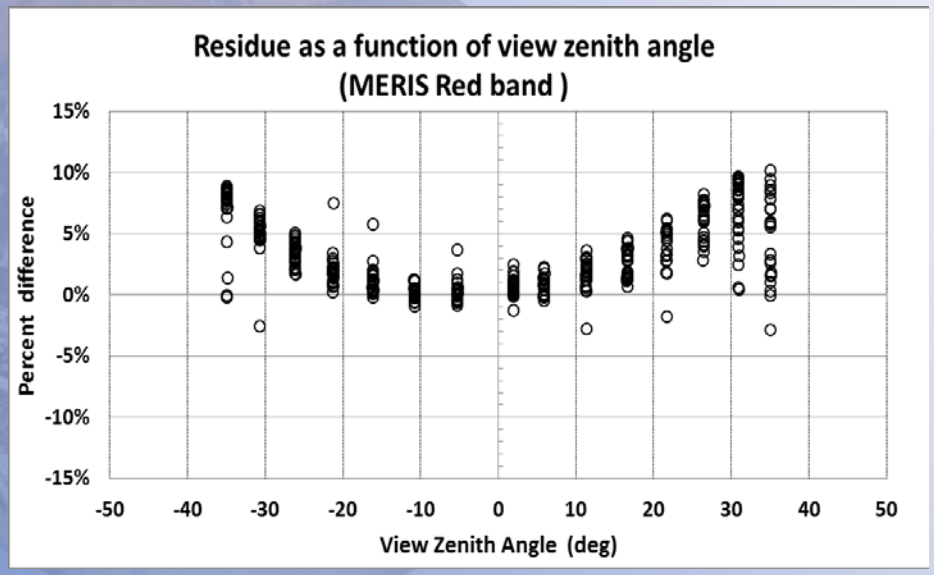



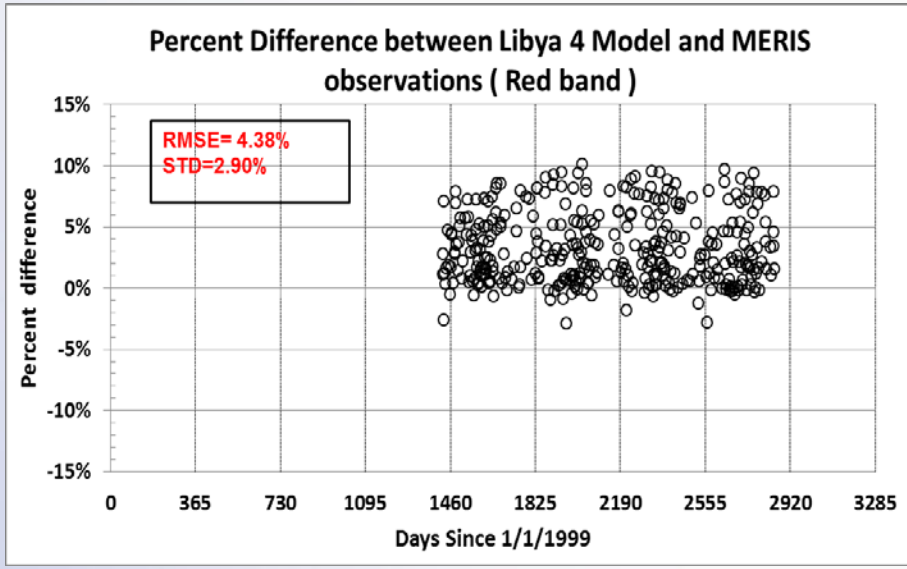



# Validation using MERIS

- MERIS has large sample of off-nadir collects ( up to ± 40 degrees) compared to Hyperion (up to ± 18 degrees).
  - DIMITRI database, 2006-2009
- Provided an opportunity to cross check our model to large viewing zenith angle.
- The error increases as a function of viewing zenith angle—limitation of current SDSU model.

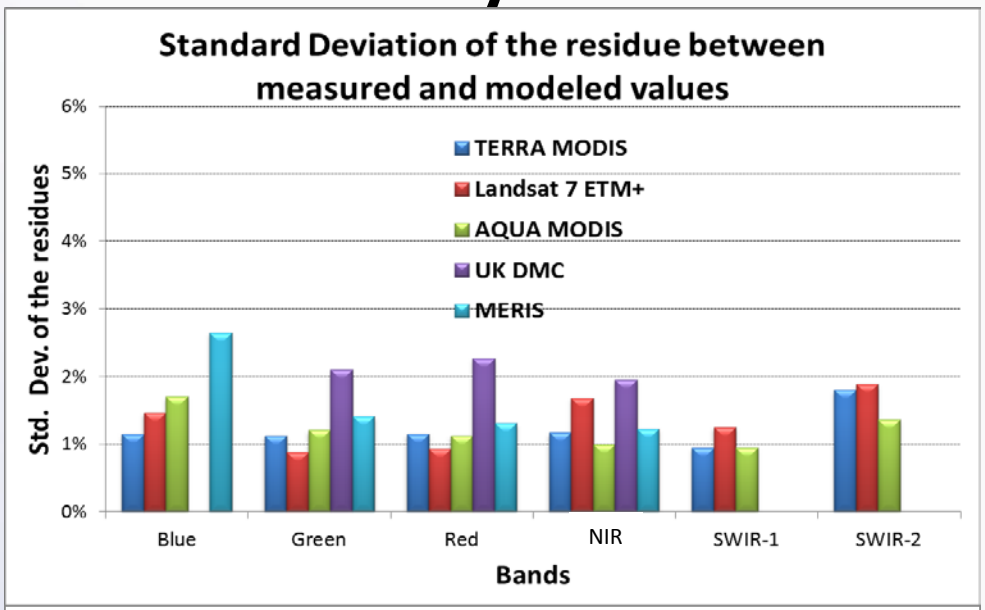


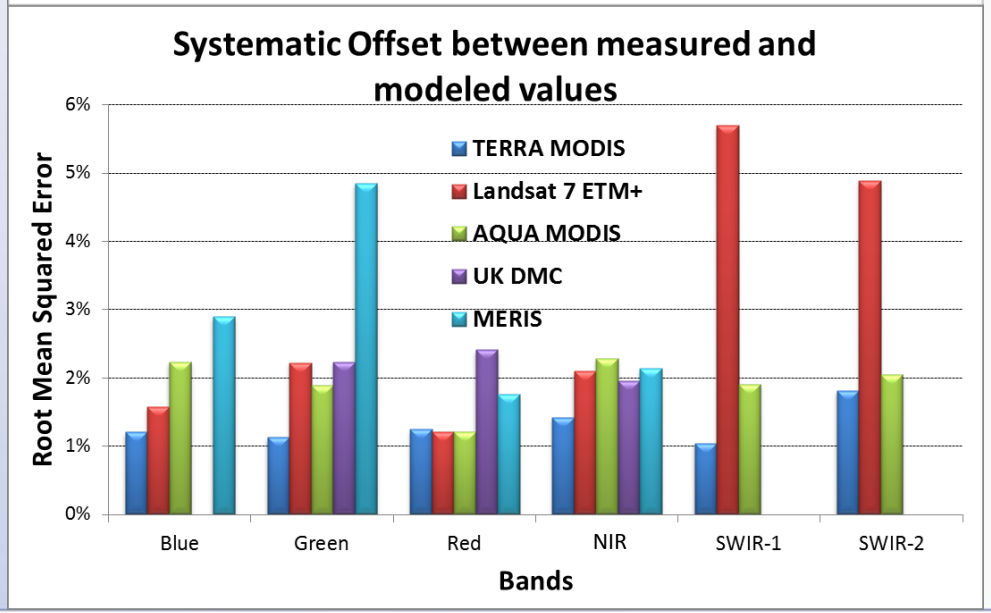



# Validation Summary

- The results have been summarized for different spectral channels of different sensors.
- Besides Landsat and MODIS, all the other sensors are confined to within the visible and near-infrared (VNIR) bands.
- The random uncertainty is within 2% for most cases.
- Systematic uncertainty is within 2.5% for most cases except at the longer wavelengths for Landsat.



# Conclusions

- Empirical absolute calibration model was 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+, AQUA MODIS, DMC, MERIS sensors.
  - With few exceptions, all sensors showed agreement within 3% random (Type A) and systematic (Type B) errors.
    - Systematic (Type B) exceptions were Meris green band and ETM+ SWIR-1 and SWIR-2 bands.
  - Model constraints at this time include limited viewing zenith angle, and coarse to moderate spatial resolution sensors.
- **Current model is an extremely quick and inexpensive approach to absolute radiometric calibration with 3% accuracy and precision.**
- 1st principles model: solar model done; SDSU atmospheric model nearly completed; BRDF surface model begun. Stay tuned next year!

# Thank you!

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