Modis Polarization Ray Tracing Using ZEMAX®

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Abstract

On-orbit optical sensors are the primary data source for the remote sensing community.Rigorous pre-flight characterization and calibration is a key to the success of their mission. Indeed, preliminary calibration and correction factors are determined during this process. A series of measurements were performed prior to the launch of NASA's Moderate Resolution Imaging Spectroradiometer (MODIS). In particular, its polarization sensitivity was measured and the data made available.

In this work, our motivation was to simulate the experiment using computer ray tracing software. Our goal was to reproduce the polarization data acquired during the pre-launch measurements. Based on that, we could evaluate the evolution of the different coatings (Mirror, Beam splitters, Anti-reflection and Band pass filters) due to degradation over time. We were able to virtually reproduce the experiment and estimate the polarization sensitivity. The results were compared to the pre-launch measurement and an analysis of the whole MODIS optical system was performed in order to explain for the differences.

A full description of the MODIS polarization ray tracing procedure along with a discussion of the results and their implications on past, present and future work will be given.

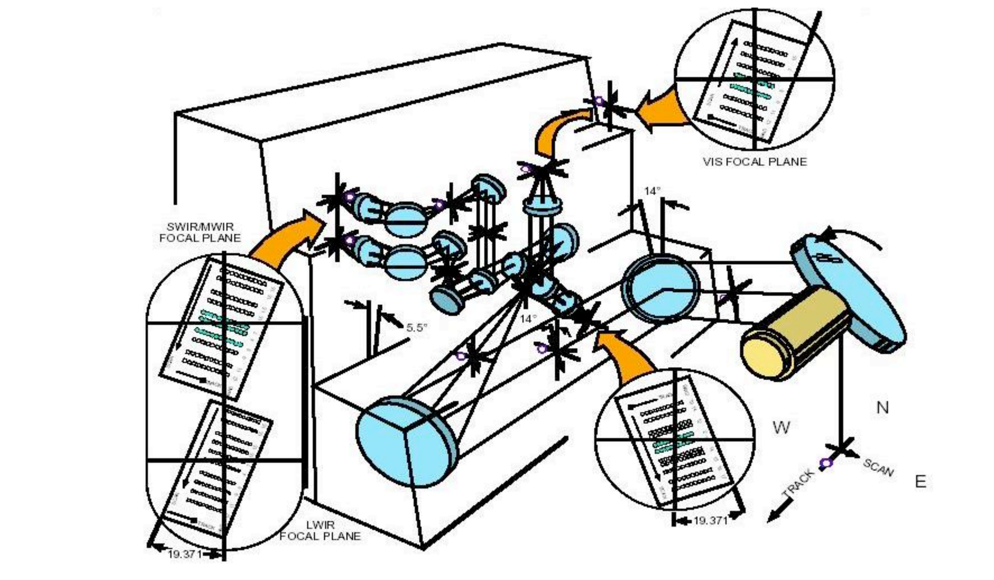
Introduction

In order to reproduce the pre-launch polarization data and do a comparison, we needed to:

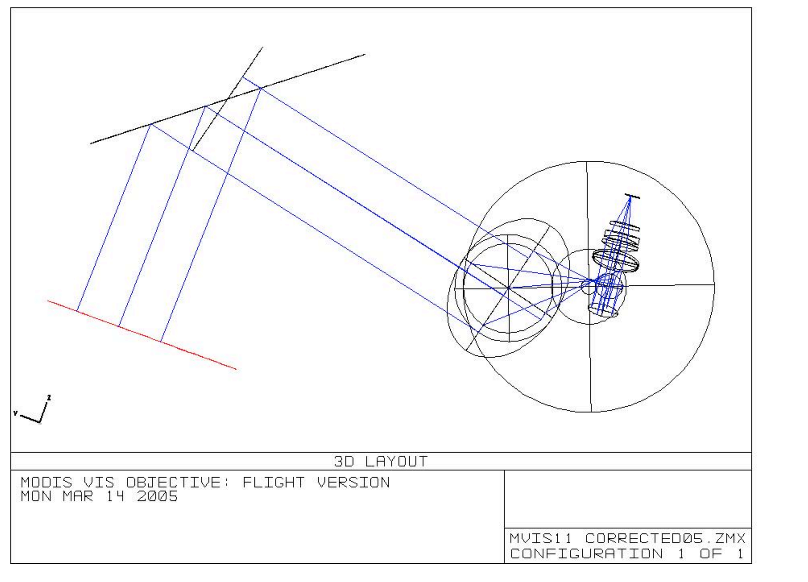
- Get the prescription for the full MODIS optical system and use that as input in Zemax.
  - ⇨ This was provided by NASA.
- Get coating parameters for each element of the MODIS optical system.
  - ⇨ Unfortunately, the manufacturer could not provide us with that information.
  - ⇨ Reverse engineering was used in order to model the coatings on each optical element. This was performed by Sam Pellicori….

  Reproduce the experiment using ZEMAX.
  - ⇨ Macros were created using the ZEMAX programming language (ZPL).
- Obtain the same type of parameters as for the original experiment.
  - ⇨ Polarization amplitude and Phase shift were obtain by fitting the data output from ZEMAX

MODIS optical system

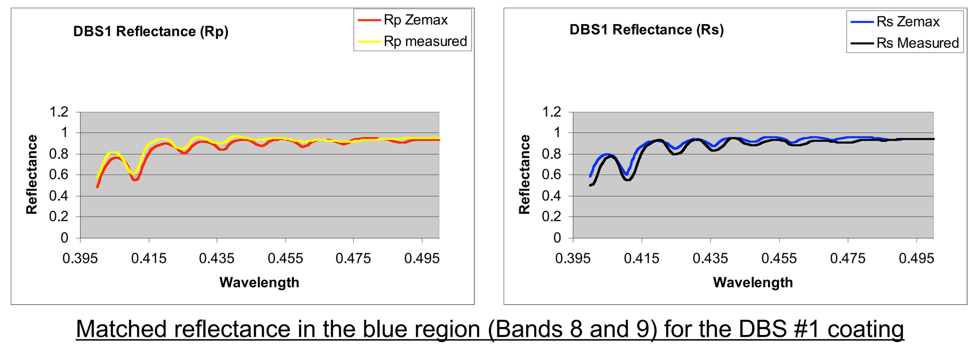


MODIS visible optical system in ZEMAX



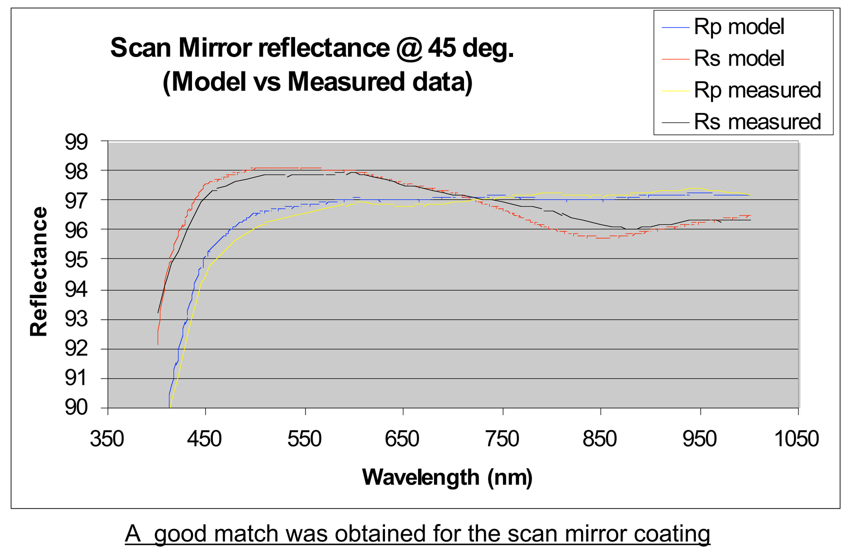
Dichroic beam splitter 1 design (S. Pellicori)

- A preliminary study was performed in order to find which elements of the MODIS optical system determined the polarization sensitivity of the instrument.
- It was found that the 1st dichroic beamsplitter was the most important optical element. Getting a good coating model for this element was a priority.
- The second element was the scan mirror. Again, efforts were made to get a good match with the pre-launch measurements (characterization of MODIS optical system).



Matched reflectance in the blue region (Bands 8 and 9) for the DBS #1 coating

Scan mirror coating design (S. Pellicori)

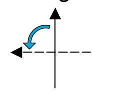


A good match was obtained for the scan mirror coating

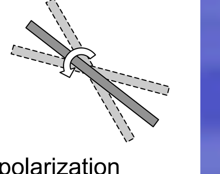
Pre-launch measurements protocol

Pre-launch polarization measurements procedure:

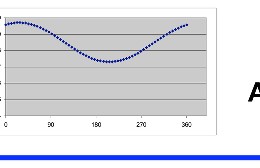
- A linearly polarized source was used as input.
- This source was rotated from 0 to 360 degrees in front of the MODIS entry port.



- Repeated for several scan mirror angles ranging between 15 to 60 degrees.



- The data was recorded for every band and detector (10 per band).
- Ideally the transmission at each scan mirror angle would be plotted versus the polarization angle and fit to the following equation. The reality was complicated by a 4 cycle interference.



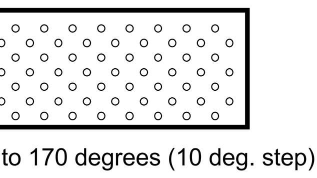
$$T = A \cdot (1 + a\cos(2\theta + \varphi)) \quad \text{Eq. 1}$$

A = Amplitude ; a = Pol. Amplitude ; φ = Phase shift

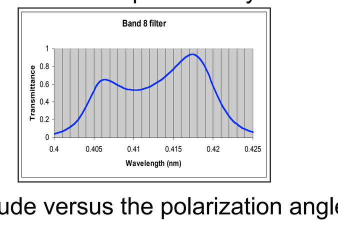
Reproducing the pre-launch measurements in ZEMAX

Architecture of the Macro created in ZEMAX to reproduce the pre-launch experiment:

- A linearly polarized bundle of rays was sent through the entrance pupil of the MODIS system.



- Polarization angle was varied from 0 to 170 degrees (10 deg. step).
- Scan mirror angle was varied from 15 to 61 degrees (2 deg. step).
- For each channel, the transmittance was computed every 1 nm within the In-band.



- This allowed us to plot the amplitude versus the polarization angle for each scan mirror angle.

Polarization in ZEMAX

- **Basic polarization formula for a simple surface.**

$$R_p = \left(\frac{\tan(\theta_i - \theta_t)}{\tan(\theta_i + \theta_t)}\right)^2 = \left(\frac{n_2\cos(\theta_i) - n_1\cos(\theta_t)}{n_2\cos(\theta_i) + n_1\cos(\theta_t)}\right)^2 \qquad Tp = 1 - Rp$$

$$R_s = \left(\frac{\sin(\theta_i - \theta_t)}{\sin(\theta_i + \theta_t)}\right)^2 = \left(\frac{n_1\cos(\theta_i) - n_2\cos(\theta_t)}{n_1\cos(\theta_i) + n_2\cos(\theta_t)}\right)^2 \qquad Ts = 1 - Rs$$

- **POLDEFINE Ex, Ey, PhaX, PhaY**

Ex, Ey: Electric field magnitudes **PhaX, PhaY: Phase angles**

Used to define the polarization state of the chief ray.

- **POLTRACE (Hx), (Hy), (Px), (Py), (Wavelength), (Vec), (Surf)**

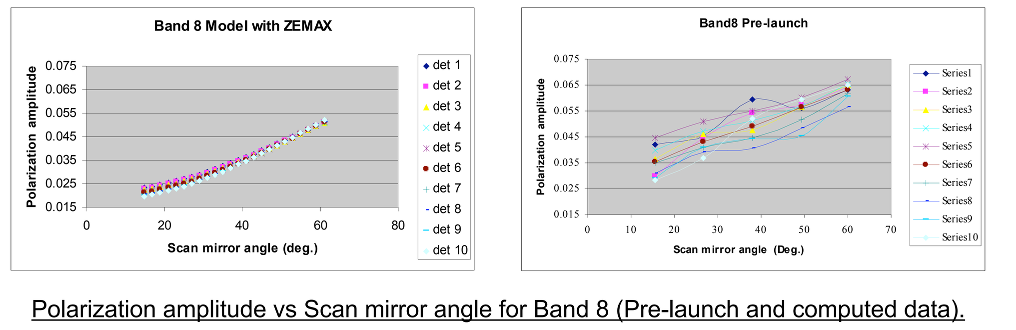
Hx, Hy: Object or Image coordinates **Px, Py: Pupil coordinates**

Wavelength: Chief ray wavelength **Vec: Output parameter**

Surf: Computed surface

Used to get the transmission of a chief ray through the system.

Results for the visible bands



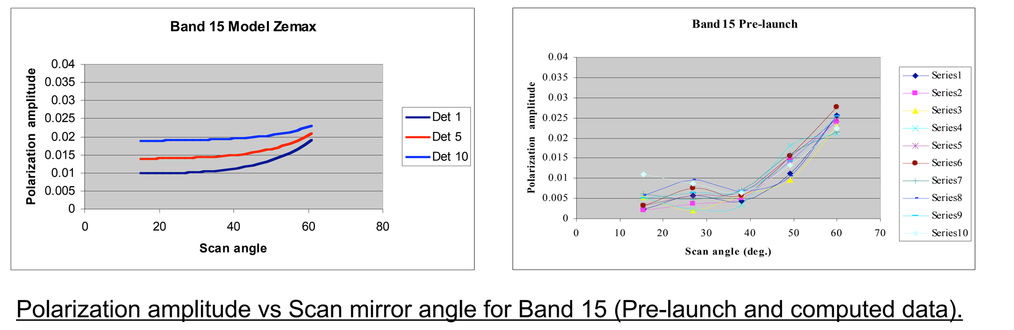
Polarization amplitude vs Scan mirror angle for Band 8 (Pre-launch and computed data).

Because Band 8 (412 nm) is the most polarization sensitive channel, we concentrated our efforts in the blue region of the spectrum (400 – 490 nm).

The overall aspect of the computed data is correct. We see, though, that the modeled polarization amplitude is lower than for the pre-launch data set.

This can be explained by uncertainties from the coating models. We tried to get as close as we could from the real coatings characteristics.

Results for the Near IR bands



Polarization amplitude vs Scan mirror angle for Band 15 (Pre-launch and computed data).

Coating models were optimized for the visible but could be used to compute the polarization amplitude for the near IR.

In the near IR, the most sensitive channel is Band 15 (748 nm). The agreement between the model and the measured data is qualitatively correct but could be better.

The match for the dichroic beam splitter coating was not perfect in this region. This translates into a larger uncertainty for the polarization amplitude.

Conclusion

Several conclusions can be made out of the MODIS Polarization Ray Tracing work:

- **It is possible to model the polarization sensitivity of MODIS and get reasonable agreement with the pre-launch measurements.**
- **Results would probably be better if we had the coatings prescriptions from the manufacturer. Less uncertainty due to reverse engineering. This should be a goal for future sensors.**
- **An accurate model could be used to simulate the effects of aging and contamination on the optical elements of the system.**

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