A METHODOLOGY TO ASSESS THE IMPACT OF OPTICAL AND ELECTRONIC CROSSTALK IN A NEW GENERATION OF SENSORS USING HERITAGE SENSORS

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Abstract

Electronic and optical crosstalk are radiometric challenges that often exist in the focal plane design in many sensors such as MODIS. A methodology is described to assess the impact due to optical and electronic crosstalk on the measured radiance, and thereafter, the retrieval of geophysical products using MODIS Level 1 data sets. Based on a postulated set of electronic and optical crosstalk coefficients, and a set of MODIS scenes, we have simulated a system signal contamination on any detector on a focal plane when another detector on that focal plane is stimulated with a geophysical signal. The original MODIS scenes and the crosstalk impacted scenes can be used with validated geophysical algorithms to derive the final data products. Products contaminated with crosstalk are then compared to those without contamination to assess the impact magnitude and location, and will allow us to separate Out-Of-Band (OOB) leaks from band-to-band optical crosstalk, and identify potential failures to meet climate research requirements.

***Index Terms**: crosstalk, characterization, performance, sensor, MODIS, environmental products*

1. INTRODUCTION

New generations of satellites are being designed for Earth observation, and are planned to launch in the next decade. These new sensors will build upon experiences and lessons acquired from previous missions, and must satisfy stringent data quality requirements, such as crosstalk and Out-of-Band (OOB) requirements, necessary for long term climate change research [1, 2, 3].

The new generation of environmental satellites will be required to develop a comprehensive specification definition for both optical and electronic crosstalk, as well as reliable test procedures to collect appropriate data in the pre-launch phase. Crosstalk Influence Coefficients (ICs) derived from pre-launch spectral measurements will be the foundation of this methodology to assess crosstalk impact on MODIS-like sensor radiance, and associated geophysical algorithm. Analysis of crosstalk contaminated products will indicate potential problems, and help to determine if a hardware fix and/or on-orbit mitigation plan is necessary.

This paper describes a methodology for assessing crosstalk radiance contamination in the newly designed sensors for bands similar to those from heritage sensors. This method can be applied for both optical crosstalk and electronic crosstalk performance assessment, it uses crosstalk characterization data sets from newly designed sensors in conjunction with heritage space based data to assess the crosstalk impact on the data measurement, and the higher level products. In addition, this method will allow separation of band-to-band optical crosstalk from Out-of-Band (OOB) contamination, and inclusion of crosstalk polarization and measurement uncertainties.

The new sensor electronic and optical crosstalk characterization was performed for 7 MODIS-like bands (Table I), from which associated crosstalk coefficients of influence were generated during sensor level testing. These coefficients were then applied to 2 MODIS granules representing Ocean and Aerosol disciplines (Figure 1) to generate the crosstalk affected radiance.

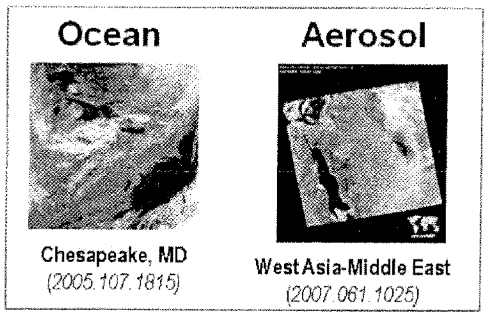

Figure 1. MODIS granules used in the crosstalk impact assessment, for Ocean and Aerosol disciplines.

The comparison of the radiance with and without crosstalk was performed, and an assessment of the new sensor crosstalk magnitude was determined. This analysis has identified sensor bands most affected by crosstalk, and also provided valuable information concerning design issues, and hence, initiating mitigation processes to improve FPA performance.

TABLE I. DESCRIPTION OF MODIS BANDS INVOLVED IN THE CROSSTALK ASSESSMENT

New Sensor Bands			MODIS Equivalent Bands		
Band	Range (um)	HSR (m)	Band	Range	HSR
M1	0.402 - 0.422	750	B8	0.405 - 0.420	1000
M2	0.436 - 0.454	750	B9	0.438 - 0.448	1000
M3	0.478 - 0.498	750	B3	0.459 - 0.479	500
			B10	0.483 - 0.493	1000
M4	0.545 - 0.565	750	B4	0.545 - 0.565	500
			B12	0.546 - 0.556	1000
M5	0.662 - 0.682	750	B13	0.662 - 0.672	1000
			B1	0.673 - 0.683	250
M6	0.739 - 0.754	750	B15	0.743 - 0.753	1000
M7	0.846 - 0.885	750	B16	0.862 - 0.877	1000
			B2	0.841 - 0.876	250

2. TESTING

The crosstalk performance assessment was tested for a MODIS-like new sensor, where the Vis/NIR FPA has 7 bands, and each band has 16 detectors. The crosstalk signal measured in the pre-launch phase was processed to derive associated crosstalk radiance. The test design used to measure crosstalk is described in Figure 2, and consists of a monochromatic illumination source and a vertical slit to stimulate each band of the FPA separately, to measure the crosstalk signal at the detector level for all non-illuminated bands and detectors. Illumination spanned the entire visible and near infrared spectrum [350-1100 nm], then binned into 16 spectral ranges to reflect the sensor bandwidths. These crosstalk measurements allowed us to identify detectors with significant band-to-band optical crosstalk and out-of-band contribution separately. These measurements led to a sender-receiver matrix of 7x16x16 coefficients.

Simulation of what the sensor would see from space during the pre-launch testing phase is a very complex process. Therefore, mixed situations of bright surfaces, such as clouds or snow, and dark surfaces, such as ocean, might not be properly described in this process. The illumination levels used in the crosstalk characterization measurements were close to the maximum radiance level for each band, and crosstalk was scaled linearly with the sender radiance. This might be a good approximation for optical crosstalk contamination but not necessarily true for data product impact, since a heterogeneous scene from space might produce different patterns or different crosstalk magnitude not characterized at the sensor testing level. A quality check of the crosstalk measurements was performed, and associated sender-receiver coefficients of influence were processed.

In addition, optical crosstalk was shown to be dependent not only on the source wavelength, but also its polarization and spatial characteristics (e.g. angular scatter). Sensitivity to polarization was derived using a wire-grid polarizer at 4 angles (0, 45, 90, and 135 degrees), for a few bands and detectors, and allowed to generate a Filter Spread Function (FSF) of the new sensor. In this paper, a simplified FSF (polarization independent) was used to characterize optical crosstalk scatter in the track direction.

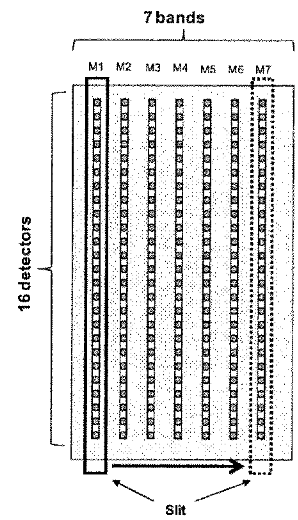

Figure 2. Test design for crosstalk measurements at the sensor level. Illumination band-by-band through a vertical slit, using a monochromatic source spanning the visible and near infrared spectrum.

3. APPLICATION TO MODIS SCENES

Bands from MODIS Level 1B files are extracted then pre-processed to simulate the new sensor radiance contaminated data:

- Crosstalk originating from spectra not covered in the MODIS bands were estimated using a band weighted empirical method.
- Pixels where the radiance is saturated were estimated using adjacent bands.

The process of generating the new sensor data with crosstalk is achieved through convolutions of the sender-receiver coefficients of influence and MODIS bands. This approach can be adapted to bands with a different number of detectors and different spatial resolution than MODIS.

In addition, the bands positions on the focal plane can also be adjusted in this approach to reflect the new sensor design. Positions between different bands on the new focal plan are characterized using offset values, needed in the computation of the crosstalk radiance when using the MODIS proxy data. Crosstalk contribution to the radiance on-board calibration is also included in the algorithm described below:

$$L^*_{ev}(b_r,d_r)=\frac{1}{1+\gamma(b_r,d_r)}\cdot\left[L_{EV}(b_r,d_r)+\sum_{\lambda_s=1}^{N_{\lambda_s}}\sum_{b_s=1}^{N_{b_s}}x(b_s,b_r,\lambda_s)\sum_{j=1}^{N_{d_s}}FSF(d_s)L_{EV}(b_s,d_s,\lambda_s)\right]$$

where:

$$\gamma(b_r,d_r)=\sum_{\lambda_s=1}^{N_{\lambda_s}}\sum_{b_s=1}^{N_{b_s}}x(b_s,\lambda_s,b_r)\cdot\sum_{d_s=1}^{N_{d_s}}FSF(d_s)\cdot\frac{L_{SD}(b_s,d_s,\lambda_s)}{L_{SD}(b_r,d_r)}$$

where L_{ev} is the MODIS earth view radiance without crosstalk, L^*_{ev} is the MODIS earth view sensor radiance with crosstalk contamination, b_r is the receiving band, b_s is the sending band, d_r is the receiving detector, d_s is the sending detector, λ_s is the wavelength used to illuminate the sending band, x is the crosstalk coefficient, FSF is the Filter Spread Function, and SD is the on-board Solar Diffuser used for on-orbit calibration. N_{b_s} is the number of bands, N_{d_s} is the number of detectors, and N_{λ_s} is the number of wavelength bins used to illuminate the sender band.

For each band i and each detector j, the crosstalk error relative to MODIS measured radiance is used to assess crosstalk performance. This relative error (%) is computed for the MODIS scene, and is defined as:

$$\Delta_{xtalk}=(L^*_{ij}-L_{ij})/L_{ij}*100$$

4. RESULTS

This approach was tested for a new sensor with 7 reflective bands (M1-M7), assuming 1 km nadir spatial resolution, and 16 detectors in each band. For simplification, this study has excluded the crosstalk coefficients associated with electronic crosstalk.

Ocean and Aerosol product algorithms, which are highly sensitive to crosstalk contaminations, are desirable candidates for quantifying contributions from OOB and band-to-band optical crosstalk. The main reason is that these science algorithms can use an effective Relative Spectral Response (RSR) that can mitigate the OOB contamination, and slightly reduce the spectral optical crosstalk in the final products.

Two (2) crosstalk coefficients maps derived from sensor pre-launch testing were used with the 2 MODIS data granules (Ocean and Aerosol scenes):

1- A crosstalk map for both band-to-band optical crosstalk and Out-of-Band (OOB) contamination
2- A crosstalk map for only band-to-band optical crosstalk.

The 2 MODIS granules representing Ocean and Aerosol products are used in this crosstalk impact assessment, and both are processed using the crosstalk algorithm described above with 2 separate crosstalk coefficient maps (one at a time).

Figure 3 shows (a) the crosstalk radiance error and (b) Standard Deviation (STD) derived using all pixels in the MODIS Ocean scene, for all 7 bands, with and without OOB.

(a)

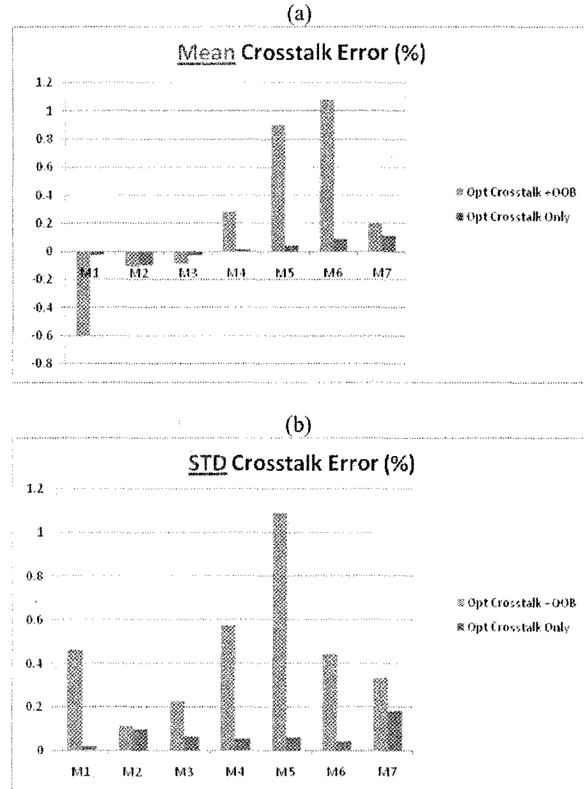

Figure 3. Mean crosstalk relative error (a) and its Standard Deviation (b) derived using MODIS Ocean scene.

It is clear that all bands are affected by crosstalk contamination, and some are more affected than others. These bands are used in many products, such as ocean color, and such errors will significantly degrade these products rendering them unacceptable for long term climate research. We can also see clearly that for all bands the OOB contribution is significantly larger than the band-to-band optical crosstalk. Bands M1, M4, M5 and M6 show large mean and STD when the OOB contamination is included. All 7 bands exhibit much smaller mean and STD errors when the OOB is excluded from the crosstalk map, less than 0.1% and 0.2% for the means and STD respectively. Therefore, it is expected that a good effective RSR characterization will help mitigate the level of crosstalk error in the Ocean products derived from this sensor once on-orbit.

The same processing was performed for the MODIS Aerosol scene. Derived mean and STD crosstalk error are described on Figure 4, for all bands and for both crosstalk coefficient maps.

The Aerosol scene is also showing high OOB contribution compared to band-to-band optical crosstalk. Bands M1 and M6 have large mean crosstalk errors when the OOB contamination is included, larger than 0.7, while M1 and M5 have STD values larger than 0.5%. All 7 bands exhibit much smaller mean and STD errors when the OOB is excluded from the crosstalk map, less than 0.2% for both the means and STDs. These results are consistent with the Ocean results, and a good effective RSR characterization is expected to lead to crosstalk mitigation on-obit for Aerosol products.

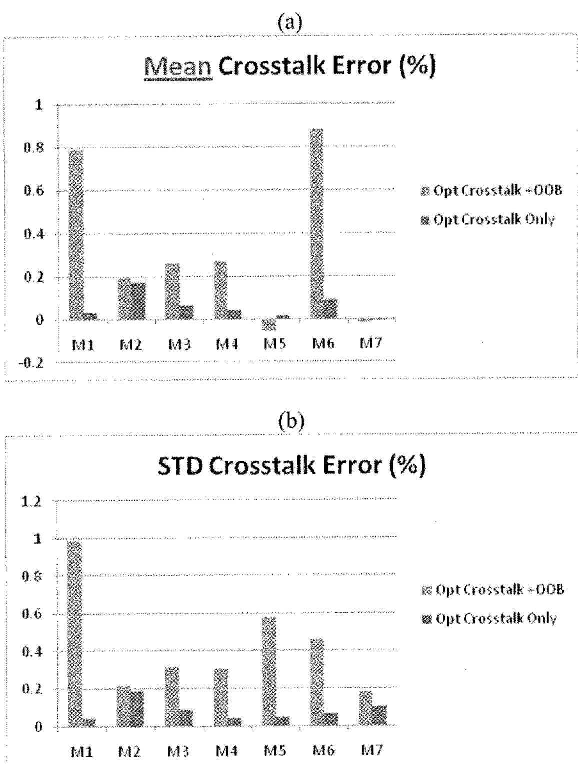

Figure 4. Mean crosstalk relative error (a) and Standard Deviation (b) derived using MODIS Aerosol scene.

We need to emphasize that in this study we have attempted to exclude the electronic crosstalk contamination. However we determined that some crosstalk coefficients are showing negative values, which support the presence of some electronic crosstalk contamination.

These generated crosstalk radiances will be used in a test bed structure to determine if MODIS-like sensor products will have performances within acceptable range, or if the hardware and/or electronic improvements are necessary.

5. SUMMARY

The paper describes an approach for electronic and optical crosstalk assessment, using data from a heritage sensor. Based on these preliminary results, we have shown that all bands of the new sensor will be affected by optical crosstalk and OOB contaminations when using the radiance range considered in 2 MODIS scenes.

This study also shows that OOB contamination is significantly larger than the band-to-band optical crosstalk for all bands, and the mean and STD crosstalk errors are as high as 1.2% and 1.1% respectively when OOB is included. These errors are reduced significantly when the OOB is excluded, and for all bands, the crosstalk means and STD are less than 0.2%.

These results, and results from additional MODIS granules will support further impact assessment of the crosstalk radiance on the biophysical products, generated using bands from the new sensor. These assessments and associated uncertainties are valuable during the pre-launch phase, and will allow important decisions to be made early enough in the program, such as addition or improvement of testing procedures to characterize or correct the crosstalk, or if additional hardware and/or electronic improvements must be considered to meet products performance requirements.

6. REFERENCES

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