Derivation of Unpolarized Effective Relative Spectral Response for Optical Crosstalk Mitigation in VIIRS

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1. INTRODUCTION

The Visible Infrared Imager Radiometer Suite (VIIRS) instrument is a visible/infrared sensor developed for the nation's next generation weather and climate monitoring system, National Polar-Orbiting Operational Environmental Satellite System (NPOESS), to produce Environmental Data Records (EDR) for both operational and scientific applications [1]. One VIIRS EDR of particular value to both the operational and scientific communities is Ocean Color. The Ocean Color EDR uses the first seven VIIRS bands in the visible and near-infrared portion of the spectrum. Knowledge of each VIIRS band's relative spectral response (RSR) is essential for the algorithms to successfully retrieve the water-leaving radiance component and determine Ocean Color. The thermal vacuum tests for VIIRS Flight 1 sensor for the NPOESS Preparatory Project (NPP) included the RSR and optical crosstalk by viewing a highly polarized light source of a grating Spectral Measurement Assembly (SpMA). Since the visible and near infrared (VisNIR) bands of VIIRS on the Flight 1 are observed to have optical crosstalk that is sensitive to the polarization of incident light, it is possible for the RSR and crosstalk to be mischaracterized due to polarization of the test equipment. An RSR that describes only one polarization state of VIIRS may lead to errors in the Ocean Color EDR product. A polarization-independent "unpolarized RSR" is preferred to minimize such errors.

Supplemental tests were conducted to correct for the polarization in the SpMA source. Results of the supplemental test provided good correlation enabling extrapolation to wavelengths and bands beyond the test range. Analysis of the data has resulted in a prescription for correcting the SpMA polarization that is relatively mild. These observations suggest an effective RSR for the unpolarized light is applicable to mitigate the effects of the optical crosstalk in the VIIRS Flight 1 and the polarization of the Earth scene is likely to only exhibit a minor impact on the Ocean Color EDR. It is noted that the root cause of the optical crosstalk for Flight 1 has been corrected for Flight 2 and beyond.

2. TEST PROCEDURES AND ANALYSIS

The RSR were characterized at a high spectral resolution (~2.2 nm) under FP-15 test for the extended in-band wavelength range and under FP-16 test at a low resolution (~5.5 nm) for the region from ~350 to 1100 nm. We have spectral stitched the the FP-15 and FP-16 test data using an innovative method. The FP-15 data is firstly convolved with the FP-16 spectral slit function and then matched with the FP-16 data using a SNR weighted least square fitting that appears to reduce the uncertainty as compared with some of the current methods.

The polarization sensitivity of the optical crosstalk was measured on M1 (412 nm), M3 (488 nm), M4 (555 nm) and M6 (746 nm) at several strong crosstalk peaks using a slit and a spot illumination under ETP-655 test for polarization sensitivity of VIIRS. A wired grid polarizer was inserted to select a polarization output of the SpMA at 4 polarization angles, 0, 45, 90, and 135 degrees. Degree of polarization and phase angle are derived by a signal-to-noise-ratio weighted best fitting of the test data to a cosine function of the twice of a polarization angle. The point illumination tests also enable us to derive a filter spread function (FSF) of the crosstalk which describes the optical crosstalk for different detectors within the same spectral band.

3. RESULTS

Figure 1 shows an example of the derived crosstalk influence coefficient as functions of the receiver detector when a point source of a specific polarization illuminates a single detector (detector 9) of M1 at 676.2 nm. At left is for the intra-band crosstalk, and at right is the inter-band M1 to M2 crosstalk. The y-axis is the influence coefficient and the x-axis is the detector number. Figure 1 shows a relatively narrow filter spread function for both the intra-band and inter-and crosstalks. The degree of polarization of the optical crosstalk is ~15% for M1 intra-band crosstalk and ~24% for the inter-band M1 to M2 crosstalk The phase angles difference is ~84 degree, closely to 90 degree, between intra band M1 crosstalk and inter-band M1 to M2 (445 nm) crosstalk.

The band-average degree of polarization of the crosstalk are relatively low, ~19%, 23%, 28%, and 18% for M1, M3, M4 and M6 sender bands, respectively, as averaging over the intra-band and inter-band crosstalks and over the out-of-band wavelengths. The phase angles for a majority of the crosstalks appears to be in opposite signs, with a phase shift close to 90 degree between the intra and inter-band crosstalks, as illustrated in Figure 1 for M1 at 676.2 nm and also observed clearly in M6 at 834.5 nm and M4 at 606.5 and 733 nm. Note that the 0 degree phase angle is in general more favorable for the intra-band crosstalk and the 90 degree more favor for the inter-band crosstalk. There is apparently no polarization dependence for the fluorescence peaks as illustrated in M6 at 488 and 640.5 nm.

The polarization parameters are extrapolated to untested wavelengths and bands based on several correlations. For M1, M2, M3, and I1 the crosstalk peaks appear to occur as repeated busts of several sharp spikes. There are about 6 spikes within a burst. There is a strong correlation in the relative intensity of the spikes and their phase angle for each of the peaks in the bursts. This correlation enables us to extrapolate to the untested wavelengths in M1, M2, M3 and I1 (640 nm) based on the measurements in M1 and M3.

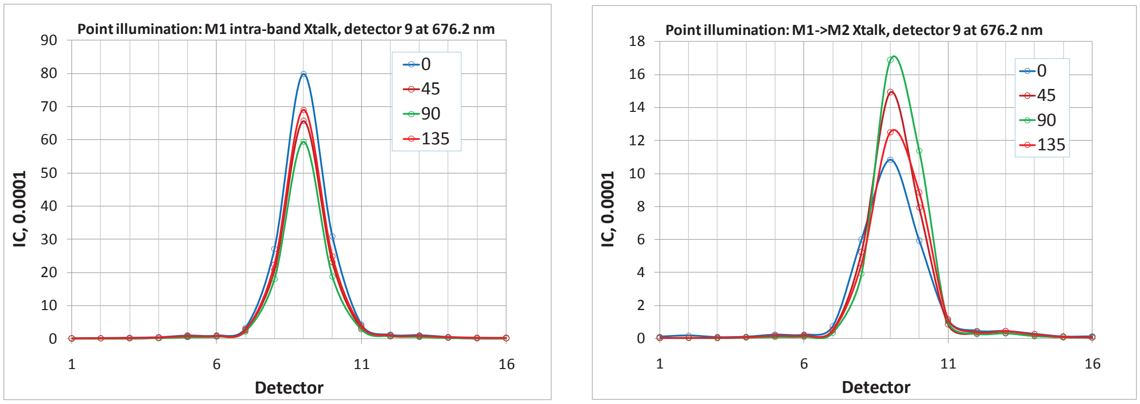

Figure 1: At left, measuring band M1 intra-band crosstalk, the 0° orientation has the highest influence coefficient. At right, measuring the inter-band M1-to-M2 crosstalk, the 0° orientation has the lowest influence coefficient. There is a phase shift of almost 90° between the intra-band and inter-band crosstalk.

We have also found a strong correlation among the filter spread function (FSF), the polarization parameters and the filter orientation. FSF are derived from the point-source illumination under ETP-655 test for polarization sensitivity of optical crosstalk and a horizontal-slit illumination over the integrated filter assembly (IFA) under STR-355a, a special test request to characterize optical crosstalk). The filters with a broad-band blocking coating facing the incident light, such as moderate resolution bands M4 (555 nm) to M7 (865 nm) and image band I2 (865 nm), appear to exhibit much wider FSF than those with an opposite orientation, such as moderate resolution bands M1 (412 nm) to M3 (488 nm). Hence the crosstalk measurements in M4 and M6 can reasonably be used to extrapolate to M4 to M7 and I2.

The fluorescence peaks at 488 and 640.5 nm in M6 show no significant dependence on polarization. This is expected since fluorescence is not an elastic scattering. The observation enables us to assign zero degree of linear polarization for all the fluorescence peaks on the blue side of the in-bands for M4, M5, M6, M7, I1 and I2, which are made of various color glass substrates.

In addition, the peaks at 560 and 580 nm in M5 can be attributed to the direct transmission (or leaks) of the color glass. This is based on the facts that the peaks as a very narrow spread, and are presence in either filter orientations. The glass leak is expected to have no polarization dependence since it is not a scattering process.

4. CORRECTION ALGORITHM

Our Northrop Grumman-led team has proposed the use of an effective RSR to mitigate the optical crosstalk for Ocean Color EDR. This is based the concept that the spectral response from the inter-band crosstalk can also be corrected as the intra-band crosstalk in a true RSR, especially under nearly uniform scenes often observed for Ocean Color EDRs. The effective RSRs are derived by summing over a stitched RSR of FP-15 and FP-16 and the crosstalk from all sender bands for a given wavelength per a receiver detector. The effective RSR for unpolarized light is derived by correcting the RSR as measured with the polarization parameters of SpMA outputs and the polarization parameters of the crosstalk by using the following equation,

$$IC_{FP16} = IC_{unpolarized}(1 + DoLP_{SpMA} \bullet DoLP_{Xtalk} \bullet \cos 2(\alpha - \phi_{Xtalk} - \chi_{SpMA}))$$

Here IC $_{\text{FP-16}}$ is influence coefficient as measured in FP-16; IC $_{\text{unpolarized}}$ is the influence coefficient for unpolarized light; χ_{SpMA} is phase angle of SpMA outputs as derived from ETP-654; χ_{SpMA} is phase angle of SpMA outputs as derived from ETP-654; DoLP$_{\text{Xtalk}}$ is the degree of linear polarization of crosstalk as derived from ETP-655; and φ_{Xtalk} is phase angle of crosstalk as derived from ETP-655.

5. CONCLUSIONS

Analysis of the test data has resulted in a prescription for correcting the SpMA polarization that is relatively mild. The difference between the effective RSR as measured and the one corrected for the SpMA polarization is about 2 to 5%, as calculated based on the area under the out-of-band. These small differences are attributed to the relatively low degree of polarization of the crosstalk, ranging from ~18 to 28%, and to the opposite phase angles between the intra-band and inter-band crosstalks that result in the cancellation of polarization effects. These observations suggest the derived effective RSR for the unpolarized light is applicable to mitigate the effects of optical crosstalk in the VIIRS Flight 1 instrument and the polarization of the Earth scene is likely to only exhibit a minor impact on the Ocean Color EDR.

Reference [1]: Raytheon Corporation, “VIIRS Radiometric Calibration Algorithm Theoretical Basis Document”, Version 5 revision 5 (2005)