EXTREME CASE OF SPECTRAL BAND DIFFERENCE CORRECTION BETWEEN THE OSIRIS-REX-NAVCAM2 AND DSCOVR-EPIC IMAGERS

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ABSTRACT

Earth-viewed images acquired during a recent asteroid-intercept mission present a unique opportunity for radiometric calibration of visible imagers onboard a space exploration probe. Measurements from the CERES-consistent DSCOVR-EPIC imager act as a reference in providing spatially, temporally, and angularly matched radiance values for deriving OSIRIS-REx-NavCam sensor calibration gains. The calibration is accomplished using an optimized all-sky tropical ocean ray-matching technique, which employs complex pixel remapping, navigation correction, and angular geometry consideration. Of critical consideration in this specific inter-calibration event is the extreme difference in spectral response function (SRF) width between the NavCam and EPIC imagers, which could cause a rather large bias. The NASA-LaRC SCIAMACHY-based online spectral band adjustment factor (SBAF) calculation tool provides an empirical solution to such potential spectral-difference-induced biases through a high-spectral-resolution hyperspectral convolution approach. The adjustments produced from this tool can effectively reduce the calibration gain bias of NavCam2 by nearly 6%, thereby adjusting the NavCam2 sensor to within 3.2% of its pre-launch calibration. These results highlight the capability of the SBAF tool to account for exceptionally disparate SRFs.

Index Terms— Calibration, Ray-matching, SBAF, SRF, OSIRIS-REx-NavCam, DSCOVR-EPIC

1. INTRODUCTION

The OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer) is a NASA mission designed to characterize the geology, texture, morphology, geochemistry, and spectral properties of near-Earth asteroid RQ36, or 101955 Bennu [1]. The probe was launched on 8 September 2016 and arrived at the asteroid on 3 December 2018 [2]. Onboard the OSIRIS-Rex spacecraft, the Touch And Go CAMera System (TAGCAMS) enables asteroid navigation and confirmation of sample retrieval, and is driven by three cameras: NavCam1, NavCam2, and StowCam. NavCam1 will primarily acquire images of the asteroid, whereas NavCam2 is a copy of NavCam1 with the primary function of supporting the spacecraft's natural feature tracking systems. To verify the camera pre-launch radiometric calibration, the spacecraft was able to capture twenty-three NavCam1 and three NavCam2 images of the Earth during an Earth-gravity-assist flyby maneuver on 22 September 2017.

A recent study was conducted to calibrate the sequence of NavCam (both NavCam1 and NavCam2) images by utilizing coincident ray-matched Deep Space Climate Observatory Earth Polychromatic Camera (DSCOVR-EPIC) imager data, which is at Lagrange point L1 [3][4][5][6]. These proceedings highlight results from one of the NavCam2 ray-matched comparisons. The EPIC imager was first radiometrically scaled the Aqua-MODIS Collection 6.1 band 1 (0.65 μm) reference calibration using the NASA Clouds and the Earth's Radiant Energy System (CERES) project all-sky tropical ocean ray-matching (ATO-RM) calibration approach [4]. One matter of important consideration in this calibration study is the rather large disparity between the exceptionally narrow EPIC and comparatively broad NavCam2 spectral response functions (SRFs) – for which accurate adjustment is necessary. Inadequate spectral difference correction could significantly bias the NavCam2 calibration results.

2. METHODOLOGY

Empirically calculated spectral band adjustment factors (SBAFs) are used to account for radiance difference caused

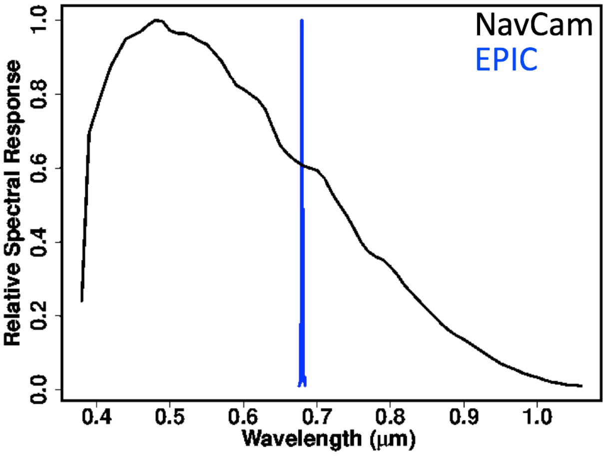

Fig. 1. Spectral response functions of the NavCam2 and EPIC instruments. The NavCam2 visible spectral width is more than 700 nm (0.70 μm), whereas the EPIC reference is only 20 nm (0.02 μm), thus highlighting the importance of consideration for spectral disparity.

by the disparate NavCam2 and EPIC sensor SRFs, which illustrate the potential for varied spectral energy captured for comparable bands (Fig. 1) [7]. The adjustment is especially sensitive in this inter-calibration event because the EPIC SRF, at only 20-nm width, is exceptionally narrow relative to the more than 700-nm SRF width of NavCam2 (see Fig. 1). Because Earth-reflected spectra are dependent on the incoming solar spectral radiance determined by the scene condition (i.e., the surface reflectance, atmospheric composition, and cloud state), the ATO-RM methodology removes some uncertainty by excluding land and its complex spectral signatures. Nevertheless, the Earth-reflected ATO spectra is not uniform across the broad NavCam2 SRF, and because EPIC and the NavCam2 SRFs are exceptionally different, an accurate SBAF for predicting the difference in radiance owed to the SRF disparity is of critical importance when attempting to inter-calibrated these two sensors.

The SBAFs are computed using the NASA-LaRC SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY) -based online spectral difference correction calculator, which relies on the statistical regression of SRF-convolved hyperspectral measurements, i.e., imager-equivalent radiance or pseudo-radiance pairs [8]. SCIAMACHY is suitable for this empirical approach because of its fine-scale 0.5-nm spectral resolution, which can adequately resolve the narrow NavCam2 SRF. A 2nd-order regression of the NavCam2 and EPIC pseudo radiance pairs was found to provide an accurate SBAF as a function of radiance across the varied scene conditions observed over ATO (see Fig. 2). The non-linear function does well to capture the SBAF dependence on radiance magnitude without a need for energy stratification [9]. With a reasonably confident SBAF, the significance and accuracy of the ATO-RM inter-calibration results can be better assured.

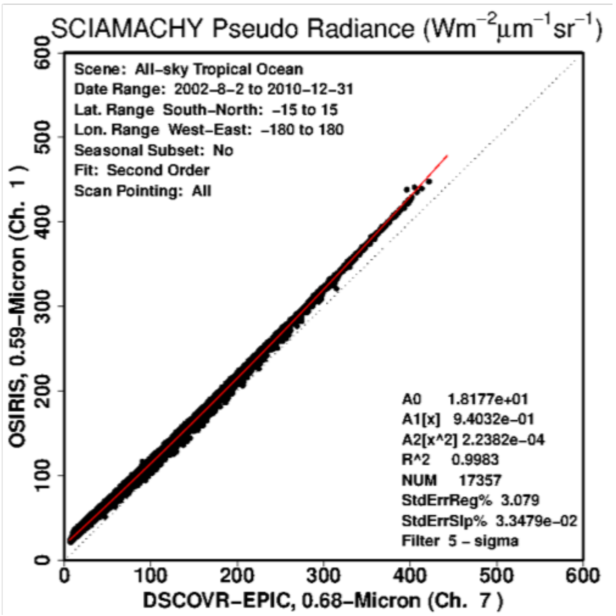

Fig. 2. The SBAF regression of SCIAMACHY-based pseudo-radiances ($Wm^{-2}\mu m^{-1}sr^{-1}$) for EPIC and NavCam2 sensors over all-sky tropical ocean. The 2nd-order adjustment function captures the nonlinear dependency between radiance and scene composition over ATO.

Prior to ray-matching, the EPIC pixel-level radiances were remapped to the NavCam2 field of view to allow effective pixel-to-pixel comparison [3]. Pixels are then matched in areas where the viewing zenith angle (VZA) and relative azimuth angle differences between NavCam2 and EPIC are within 10º and 20º, respectively. Pixels with VZA greater than 40º and regions of sun glint are avoided. Furthermore, a spatial standard deviation (σ_{2D}), determined from the standard deviation divided by the mean of the 8 surrounding and center pixel, is computed for each pixel. Eliminating pixels with σ_{2D} greater than 0.2 removes outliers and reduces the impact of navigation errors, cloud shifts, and complex scene types. Finally, a graduated angle matching method is applied such that matched radiances are more evenly spread across the complete dynamic range [10].

3. RESULTS

Figure 3b highlights results for the 22:38:27 UTC NavCam2 and 22:41:14 UTC EPIC 22 September 2017 image comparison. Two linear regressions are shown. The blue line is the orthogonal linear regression with the associated slope and x-axis offset displayed in the lower right corner. The red line is the linear regression forced through the NavCam2 space count of 160 and signifies the calibration gain. Under perfect ATO-RM conditions, the forced and orthogonal regression slopes should be equal, and the orthogonal regression offset should pass through the NavCam2 space count, which also ensures that the regressions adequately characterizes the full radiance dynamic range by intersecting the cluster or clear-sky matches at the low end. With the SBAF (Fig. 3b), the forced and orthogonal regression slopes are 1.4% different, while

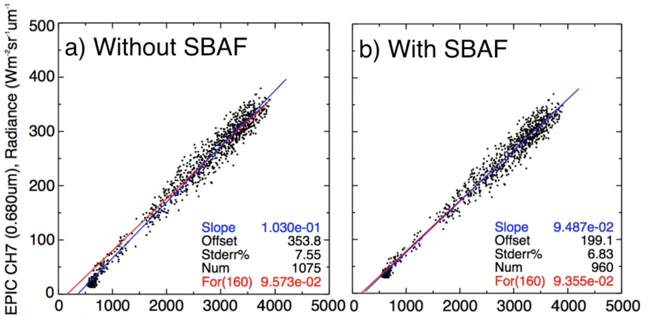

Fig. 3. The 22:38:27 UTC NavCam2 and 22:41:14 UTC EPIC 22 September 2017 a) ATO-RM inter-calibration results. The slope of the linear regression between NavCam2 12-bit counts and EPIC radiance values forced (For) through the NavCam2 space count of 160 signifies the calibration gain. b) Same as a) except with the application of the SBAF.

the offset and space count differ by 39 counts. Without use of an SBAF (Fig. 3a), however, the regression slopes differ by 7.3% with offset and space count difference in excess of 150 counts. Also, without an SBAF it is clearly evident that the force regression misses the cluster of clear-sky radiances completely. The fact that the SBAF corrects these issues and so effectively reduces the forced and regression slope differences validates its computation and application. Also, the SBAF-corrected NavCam2 gain is within 3.2% of the pre-launch calibration, which is within the estimated ATO-RM gain uncertainty [3].

4. CONCLUSIONS

This study has demonstrated the effectiveness of empirical SBAF calculation and application for a visible channel in a case where the spectral widths of the compared instruments are exceptionally different. The non-linear dependence of the SBAF on radiance magnitude was adequately characterized by the 2nd-order regression of the NavCam2 and EPIC pseudo radiance pairs, which served well in aligning the forced and orthogonal ATO-RM inter-calibration regressions, as well as in shifting the gain through the cluster of clear-sky radiances. The better alignment of the two regressions (difference reduced from 7.3% to 1.4%) and closer slope offset and space count values (difference reduced from 150 to 39 counts) signifies high confidence in this empirical SBAF approach.

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] "OSIRIS-REx Factsheet," NASA/Explorers and Heliophysics Projects Division. Available online: https://ehpd.gsfc.nasa.gov/documents/552572main_OSIRIS_REx_Factsheet.pdf (accessed on 31 October 2018).

[2] "OSIRIS-REx Asteroid Sample Return Mission," NASA/Explorers and Heliophysics Projects Division. Available online: https://www.asteroidmission.org/mission/ (accessed on 27 November 2018).

[3] D. Doelling, K. Khlopenkov, C. Haney, R. Bhatt, B. Scarino, and A. Gopalan, "Inter-calibration of the OSIRIS-REx NavCam with Earth viewing imagers," *Remote Sens.* [IN REVIEW], November 2018.

[4] D. Doelling, C. Haney, R. Bhatt, B. Scarino, and A. Gopalan, "Geostationary visible imager calibration for the CERES SYN1deg Edition 4 Product," *Remote Sens.*, *10*, 288, 208.

[5] J. F. Meirink, R. A. Roebeling, and P. Stammes, "Inter-calibration of polar imager solar channels using SEVIRI," *Atmos. Meas. Tech.*, 6, 2495-2508, 2013.

[6] A. Marshak, J. Herman, S. Adam, B. Karin, S. Carn, A. Cede, I. Geogdzhayev, D. Huang, L. Huang, Y. Knyazikhin, M. Kowalewski, N. Krotkov, A. Lyapustin, R. McPeters, K.G. Meyer, O. Torres, and Y. Yang, "Earth observations from DSCOVR EPIC instrument," *Bull. Amer. Meteor. Soc.,* 99, 1829–1850, 2018.

[7] G. N. Chander, N. Mishra, D. Helder, D. Aaron, A. Angal, T. Choi, X. Xiong, and D. Doelling, "Applications of spectral band adjustment factors (SBAF) for cross-calibration," *IEEE Trans. Geosci. Remote Sens.*, 51, 3, 1267-1281, 2013.

[8] B. R. Scarino, D. R. Doelling, P. Minnis, A. Gopalan, T. Chee, R. Bhatt, C. Lukashin, and C. O. Haney, "A web-based tool for calculating spectral band difference adjustment factors derived from SCIAMACHY hyperspectral data," *IEEE Trans. Geosci. Remote Sens*, 54, 5, 2529-2542, 2016.

[9] B. Scarino, D. R. Doelling, A. Gopalan, T. Chee, R. Bhatt, C. Haney, "Enhancements to the open access spectral band adjustment factor online calculation tool for visible channels," *Proc. SPIE 10764, Earth Observing Systems XXIII*, 1076418, 2018.

[10] D. R. Doelling, C. O. Haney, B. R. Scarino, A. Gopalan, and R. Bhatt, "Improvements to the geostationary visible imager ray-matching calibration algorithm for CERES Edition 4," *JTECH*, 33, 2679-2698, 2016.