CHRIS/PROBA-1 RADIOMETRIC CALIBRATION ASSESSMENT

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ABSTRACT

The radiometric calibration assessment assessed the spectral response changes over time for the Compact High Resolution Imaging Spectrometer (CHRIS)/Proba-1 mission. As Barrax was the test site for the 2003/2004 SPARC campaign and has been acquired since, it was chosen.

The results presented have shown a comparison of in-situ spectra measured during the ESA SPARC, SEN2FLEX and SEN3EXP campaigns with CHRIS/Proba-1 imagery acquired between 2003 and 2019 at the Barrax site in Spain. The CHRIS imagery were processed using the CHRIS-Box, and results indicate that the measurements in the first band in Mode 1 are significantly underestimated and in the Near-InfraRed (NIR) are slightly overestimated. The low value at the blue end is expected from the previously calculated CHRIS calibration coefficients, while previous results suggested the near-infrared was also underestimated.

Further analysis will focus on using the atmospheric campaign data to see if the potential errors and uncertainties in the CHRIS atmospheric correction can be reduced. Also, the campaign airborne and satellite data can be compared to the CHRIS and in-situ spectra.

***Index Terms*—** Hyperspectral, calibration, CHRIS, Proba-1

1. INTRODUCTION

Originally designed as a two-year mission, and launched in October 2001, the Project for OnBoard Autonomy-1 (Proba-1) continues to support ESA's Earthnet Programme. With orbital drift, the mission has captured both ascending and descending mode data, and the Local Time of Descending Node is currently 02:59. CHRIS can provide up to 62 channels over the 400-1050 nm spectral range, with reduced specification in the 400-450nm region, operating in five different acquisition modes [RD.1]. The data is acquired for specific sites using a chosen acquisition mode, which may focus on a maximum number of channels or highest spatial resolution; 17 m nadir ground sampling distance.

During the years of operation, the programmability of CHRIS has given rise to many investigations and findings, aiding the definition of future hyperspectral imaging missions for both scientific and service-oriented operational applications; including, potentially, the Copernicus Expansion Sentinel candidate 'CHIME'.

The radiometric calibration assessment aimed to assess spectral response changes in the radiometric response since the 2003/2004 SPARC Campaign. As Barrax was the location of the SPARC Campaign, and has been regularly acquired since, it was chosen for the assessment.

2. BARRAX TEST SITE

The Barrax test site is situated within La Mancha, Spain, a plateau 700 m above sea level, with differences in elevation of up to only 2 m and the regional water table being approximately 20-30 m below the land surface [RD.2]. It is 20 km away from the capital town of the province, Albacete (30°3' N, 2° 6'W). The site is complex but with clearly delineated fields growing different crops, see Figure 1.

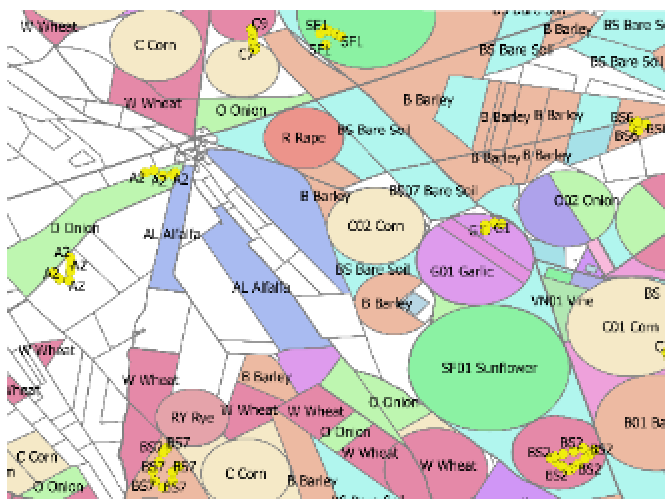

Figure 1. Barrax land use classification from SEN3EXP overlaid with spectral measurements (yellow dots) from the SPARC 2004 campaign.

For the 2003/2004 SPARC campaigns, CHRIS data was acquired on the 12, 13 & 14 July 2003 plus 15 & 16 July 2004. CHRIS was collected in Mode 1, which is 62 spectral bands across the full swath width. Concerning atmospheric measurements, two radiosonde balloons were launched daily; one in the early morning (to get stable atmospheric condition) and the other just at the time of satellite/aircraft overpass. There were also airborne Lidar flights, for vertical aerosol profiles, ground-based sunphotometers and high spectral resolution sky radiance measurements.

SEN2FLEX, in 2005, combined activities in support of solar-induced fluorescence experiments (AIRFLEX) and a Sentinel-2 initiative to prototype the mission's requirements. The SEN2FLEX Data Acquisition Report [RD.3] lists CHRIS/Proba-1 data as having been acquired. However, these files were not available to download from the ESA Third Party Missions Dissemination Service.

SEN3EXP [RD.4], in 2009, supported Sentinel-3 preparations. CHRIS was acquired on the 19, 20 & 29 June plus 7 July 2009. Solar and global irradiance measurements were taken on the 20 June corresponding with airborne acquisitions, and on the 25 June corresponding with MERIS and AATSR overpasses. There were also radiosonde measurements alongside aerosol optical thickness, plus total atmospheric ozone and water.

3. CHRIS/PROBA-1 DATASET AND PROCESSING

The investigation has primarily focused on processing the nadir view image, which will reduce the influence of the Bidirectional Reflectance Distribution Function that is not accounted for in the CHRIS-Box atmospheric correction that assumes a Lambertian surface [RD.6]; see Table 1. However, for the 14 July 2003, the nadir view image was not available.

Table 1. CHRIS Imagery Barrax Acquisitions

Date	Time	Observation Zenith Angle (Image Tag)	Solar Zenith Angle
12/05/2003	11:20	7.76 (3526)	23.00
14/07/2003	11:32	39.42 (35A4)*	20.00
23/03/2004	11:16	10.71 (3F20) & 36.87(3F22)	40.00
16/07/2004	11:25	8.80 (436C)	21.00
07/07/2009	10:10	5.67 (B7A2) & 32.67 (B7A4)	31.00
02/06/2011	08:48	17.77 (DB24) & 40.55 (DB26)	45.00
23/03/2014	17:26	Unknown** (032E)	79.83
04/08/2018	14:29	9.89 (4C85)	36.65
22/03/2019	14:21	2.40 (5775) & 32.21 (5777)	48.04

**Nadir view not available as there were image acquisition issues.*
***Not used because the observation angles are 'unknown'.*

The processing used the BEAM CHRIS-Box [RD.7]:

- **Noise Reduction:** to correct and remove coherent noise, including dropouts and vertical striping.
- **Atmospheric Correction:** The following steps are carried out, based on [RD.13]: derive columnar water vapour; smile correction (correction for small variations in the detector's wavelength across the field-of-view); spectral calibration; spectral polishing (optional, not applied, which removes noisy pixels); calculation of surface reflectances; adjacency correction (optional, not applied). Elevation and topographic effects, which would be calculated from a geolocated digital elevation model, are not considered.
- **Geometric Correction:** Uses telemetry data to account for the satellite's position, velocity and pointing at the moment acquisition, projecting the line of sight onto the Earth's surface to calculate the geographical coordinates.

A comparison of CHRIS spectra before (Top of Atmosphere, TOA) and after atmospheric correction (Bottom of Atmosphere, BOA) is shown in Figure 2. The spectra were extracted for a specific site, Bare Soil (BS) 2, see Figure 1.

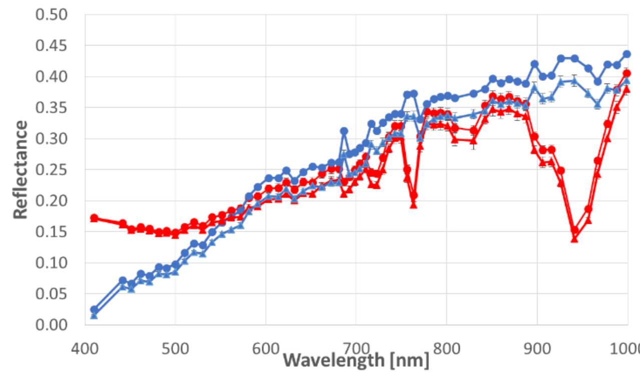

Figure 2. Comparison of CHRIS spectra before (red) and after (blue) atmospheric correction for a bare soil location.

Average field spectra were captured from CHRIS/Proba-1 by extracting a spatially distributed set of points covering the whole field using pins, shown in blue in Figure 3, and then the average and standard deviation were calculated.

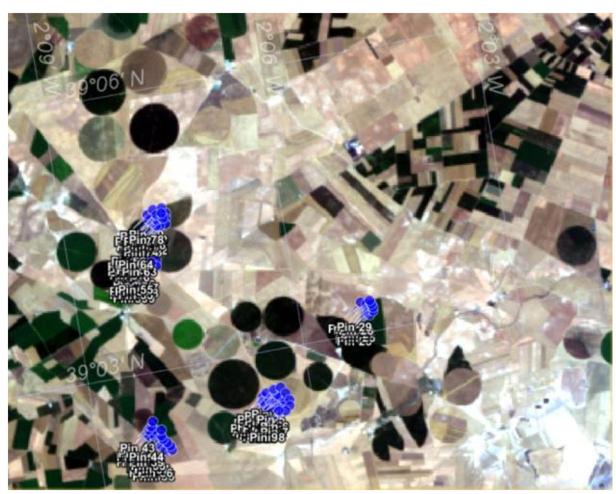

Figure 3. CHRIS/Proba-1 spectra extraction; Extraction pins overlaid on a processed CHRIS image from 16/07/2004.

4. IN-SITU SPECTRA EXTRACTION

For the SPARC campaigns, in-situ spectra were stored as ASCII text files containing radiance spectra for both the ground targets and Spectralon plaques, measured using Analytical Spectral Devices spectroradiometers. Within each field, the team walked around trying to pass over areas representative of the natural variability. They stopped at several locations, taking three ground and a GPS measurement. White reference measurements were taken at the start and end of the transect [RD.6]. For SPARC 2004, target fields had bare soils plus several crops. For this activity, the results focus on the bare soil spectra as these should have a relatively stable response over time.

For the spectrometer measurements, the reflectance was calculated by averaging all the Spectralon measured white reference spectra for a set of field measurements. The standard deviation was checked to ensure the solar illumination had remained constant. Then, each in-field spectrum was divided by this average white reference spectra to calculate individual field reflectance spectra. Then, all the field reflectance spectra were averaged to obtain the average and standard deviation of the spectra for each site.

There was less of a focus on collecting in-situ radiometry within the SEN2FLEX and SEN3EXP campaigns. From reviewing the data, the following BS reflectance spectra were measured: SEN2FLEX 13 July 2005; SEN3EXP 20, 22 and 24 June 2005.

Figure 4 shows the BS spectra from across the campaigns, shown as the mean and standard deviation of each field.

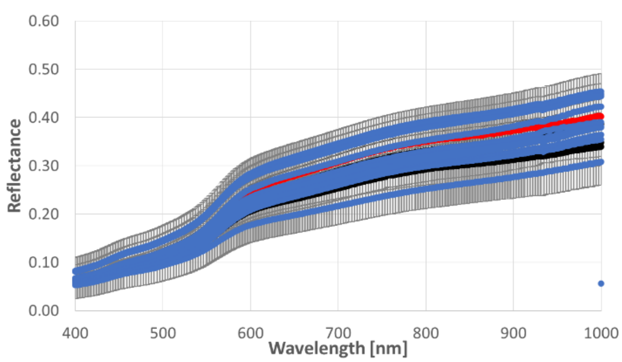

Figure 4. In-situ Bare Soil reflectance spectra, with standard deviation, collected during the SPARC (black), SEN2FLEX (red) and SEN3EXP (red) campaigns.

5. RESULTS

5.1. Previous CHRIS Calibration Coefficients

The 2003/4 SPARC campaign CHRIS acquisitions were used to calculate the CHRIS/Proba-1 calibration; see Figure 5 top. From [RD.10], the largest deviations were found in the wavelengths cantered around 940 nm, which might have been due to water vapour. However, overall, the results confirmed the a–priori expectations, because the focal plane array is designed to have the best radiometric quality in the central wavelengths, getting worse as the wavelength approaches both edges of the spectral domain. Both the general shape and the absolute values of the recalibration curve were in good agreement with the one provided by Sira Technology Ltd calculated from engineering arguments [RD.8]; see Figure 5 bottom.

The Signal to Noise Ratio (SNR) drops off at both the end of the spectrum, with the FWHM response of the CCD detector spectral response being approximately 450-950 nm. Below 450nm, the multilayer coatings on the optics lose their wideband transmission due to limited options for thin films materials, in addition to the scene radiances being low. The multilayer layer interference effects can be seen in the rapid perturbations in Figure 5 bottom. For the longer wavelengths, above 950 nm, much broader bands are used to boost the SNR. For instance, the band at 1019 nm in mode 3 is approximately five times those at 700 nm [RD.9].

Also, from [RD.10], the temporal stability of the CHRIS gain factors was seen as good proof of the instrument reliability, even though the CHRIS/Proba-1 system was launched only for technology demonstration purposes.

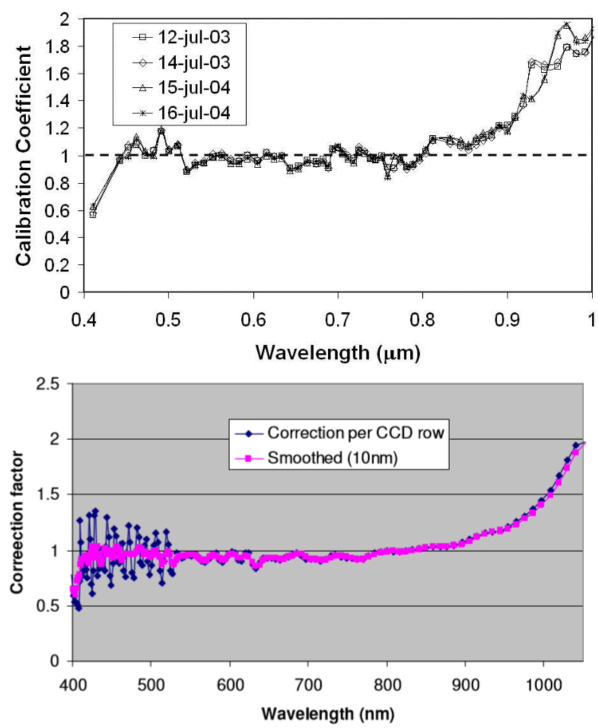

Figure 5. CHRIS calibration coefficients calculated (top) from the SPARC 2004 campaign [RD.10] and (bottom) provided by Sira Technology Ltd [RD.8].

5.2. Comparison of In-situ Spectra from SPARC 2003/2004 Campaigns and CHRIS

To confirm that the in-situ hyperspectral measurements were processed correctly, the plots from this activity were compared to previous results ([RD.10] and [RD.11]); see Figure 6. For the SPARC 2004 CHRIS calibration activity, the radiometric analysis identified an underestimation in the NIR measurements that were corrected using the coefficients shown in Figure 5.

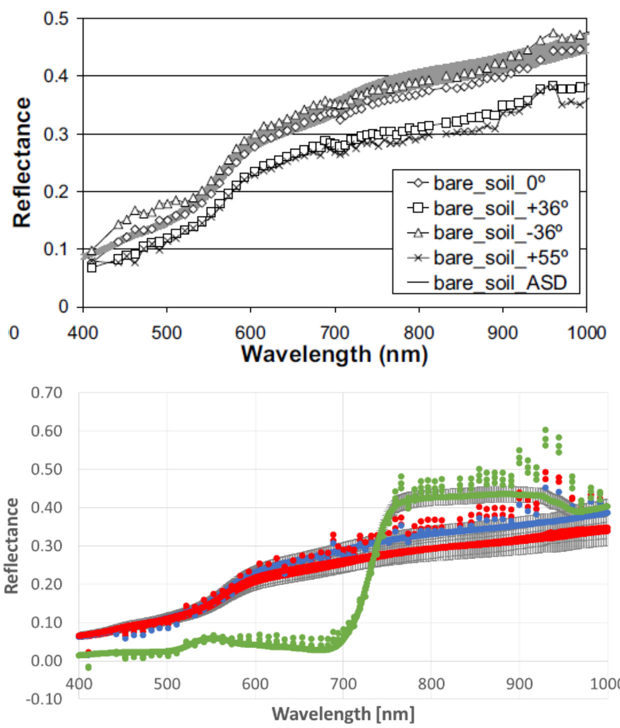

Figure 6. Comparison of the (top) previous SPARC 2004 analysis ([RD.10] Figure 4 and [RD.11] Figure 2) and (bottom) this analysis showing the Bare Soil (red), Bare Soil with sparse vegetation (blue) and corn (green) spectra with solid lines for the spectrometer and circles for CHRIS.

For this analysis, it appears that the NIR is slightly overestimated, and the first Mode 1 blue band (centred at 410 nm) is significantly underestimated. There is a difference in the atmospheric correction applied as this analysis used the CHRIS-Box while the SPARC analysis used the original implementation of the radiative transfer approach based on Modtran Look-Up Tables [RD.13], which was subsequently implemented in CHRIS-Box.

5.2. Time-Series Comparison for the SPARC Bare Soil sites

From the analysis of the land cover map produced during the SEN3EXP campaign, Figure 1, and curvature in the spectra spectral shape there is an indication of some vegetation; it was deduced that only the site BS8 had been BS throughout the time-series.

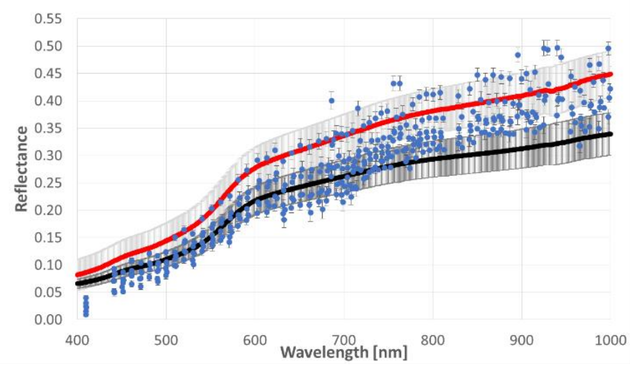

Figure 7. Time-series comparison for the Bare Soil (BS8) CHRIS spectra (blue) with two in-situ spectra plotted for comparison (SEN3EXP BS11, red, and SPARC BS8, black).

No significant change in the CHRIS/Proba-1 calibration is easily discernible from the time-series. Variations can be attributed to changes in both the ground target, e.g. changes in soil moisture, texture and low-level vegetation as the bare soil is unlikely to be completely barren. To investigate this, Figure 8 shows the calculated Normalized Difference Vegetation Index (NDVI) and satellite (zenith) observation angles against the average reflectance (between 540 and 613) for the spectra shown in Figure 7. The changes in observation angle are linked to the Proba-1 orbit that changed significantly during the lifetime of the mission, which resulted in some of the nadir observations being substantially different from zero degrees.

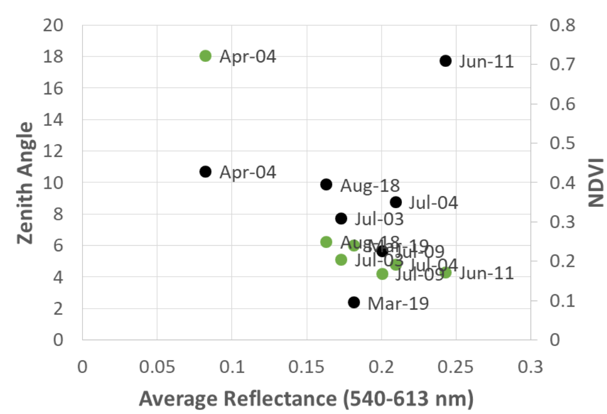

Figure 8. Plot of the calculated NDVI (green) and satellite zenith angle (black) against the average reflectance.

The CHRIS measurements have a reflectance as high as 0.45, with June being higher than July and the lowest values are in March and August; suggesting vegetation phenology is having an impact. The calculated NDVI is low, less than or equal to 0.25 for all those analysed; the April 2004 spectra had a high calculated value of just over 0.7 (see Figure 8) and so was not included in the Figure 7 comparison.

5. CONCLUSIONS AND FUTURE PLANS

The results indicated that the first band in Mode 1 (blue band centred at 410 nm) was significantly underestimated, and the NIR was slightly overestimated. The low value at the blue end is expected from the previous CHRIS Calibration Coefficients while the earlier results suggested the NIR was also underestimated. However, comparison to the CHRIS-Box results from the Atmospheric Correction ATBD (not shown) show similar results, except the first band is much lower in these results.

However, the CHRIS Calibration Coefficients were applied, and the data reprocessed, so the artefacts should have been corrected. From Mike Cutter (pers. comms.):

"The data processed on 14 December 2004 was processed to HDF version 4.1 in "real-time". Data collected and processed immediately before that was processed to HDF version 4.1 in January 2005. This information suggests that HDF version 4.1 went live on 14 December, with the back catalogue being gradually reprocessed after this date."

Therefore, questions remain as to why the blue band remains significantly underestimated, even for the early imagery when the calibration coefficients were calculated. There was a difference in the atmospheric correction applied as this analysis has used the CHRIS-Box, while the SPARC analysis used the original radiative transfer approach described in [RD.11]. Both are based on the same research/approach, but there are slight differences in the implementation, and the settings could have varied.

Further analysis of the ESA campaign data will focus on using the atmospheric data, on investigating if the potential errors and uncertainties in the atmospheric correction can be reduced. Also, the airborne and additional satellite data (such as Landsat) data can be compared to the CHRIS and in-situ spectra. Also, during 2018, acquisitions of CEOS LandNet sites started. Therefore, as the number of acquisitions increases, these sites can be included in a future analysis. Some are also RadCalNet sites [RD.14], where in-situ radiometry is measured continually. Further work will also analyse contemporaneous acquisitions with other satellite missions, e.g. PRISMA.

11. ACKNOWLEDGEMENTS

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12. REFERENCES

[RD.1] M. J. Barnsley, J. J. Settle, M. A. Cutter, D. R. Lobb, and F. Teston, "The PROBA/CHRIS Mission: A Low-Cost Smallsat for Hyperspectral Multiangle Observations of Earth Surface and Atmosphere," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 42, no. 7, pp. 1512-1520, 2004.

[RD.2] SPARC 2004 Data Acquisition Report, Contract No. 18307/04/NL/FF (supplied with SPARC campaign data).

[RD.3] SEN2FLEX Data Acquisition Report, Contract No. 19187/05/I-EC (supplied with SEN2FLEX campaign data).

[RD.4] ESA TPM dissemination service: https://tpm-ds.eo.esa.int/oads/access/

[RD.5] SEN3EXP Data Acquisition Report, v1.1 05/03/2010 (supplied with SEN3EXP campaign data).

[RD.6] L. Guanter, L. Alonso, L. Gomez-Chova and J. Moreno, "CHRIS/PROBA Atmospheric Correction Module - Algorithm Theoretical Basis Document," Version 2.0, 20 May 2008 https://www.brockmann-consult.de/beam-wiki/display/CBOX/Algorithm+Theoretical+Basis+Documents

[RD.7] CHRIS-Box BEAM webpage: http://www.brockmann-consult.de/cms/web/beam/project/chris-box

[RD.8] M. Cutter, "Review of aspects associated with the CHRIS calibration," in ESA/ESRIN, editor, Proceedings of 2nd CHRIS/PROBA Workshop, Frascati, Italy, April 2004.

[RD.9] M. Cutter, "CHRIS Proba-1 Dark Current Analysis v1.1," ESA EDAP Technical Note: EDAP.REP.012., 2019.

[RD.10] L. Guanter, R. Richter, L. Alonso, V. Estelles and J. Moreno, "Atmospheric Correction Algorithm for Remote Sensing Data Over Land. I. Application to ESA SPARC Campaigns: Spaceborne Sensors," SPARC Proceedings (supplied with SPARC campaign data), 2005.

[RD.11] L. Guanter, L. Alonso and J. Moreno, "First Results from the PROBA/CHRIS Hyperspectral/Multiangular Satellite System Over Land and Water Targets," *IEEE Geoscience and Remote Sensing Letters*, vol. 2, no. 3., pp. 250-254, July 2005.

[RD.12] CEOS LandNet sites: http://calvalportal.ceos.org/ceos-landnet-sites

[RD.13] L. Guanter, L. Alonso and J. Moreno, "A Method for the Surface Reflectance Retrieval from PROBA/CHRIS Data over Land: Application to ESA SPARC Campaigns," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 43, no. 12, pp. 2908-2917, December 2005.

[RD.14] M. Bouvet K. Thome, B. Berthelot, A. Bialek, J. Czapla-Myers, N. P. Fox, P. Goryl, P. Henry, L. Ma, S. Marcq, A. Meygret, B. N. Wenny and E. R. Woolliams, "RadCalNet: A Radiometric Calibration Network for Earth Observing Imagers Operating in the Visible to Shortwave Infrared Spectral Range," *Remote Sens.*, 2019, https://doi.org/10.3390/rs11202401