INTER-BAND CALIBRATION FOR HYPERSPECTRAL WATER REMOTE SENSING: DEMONSTRATION FOR CHRIS-PROBA

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ABSTRACT

The retrieval of information on water particles and in particular on phytoplankton composition from hyperspectral remote sensing data requires the accurate quantification of minor spectral variations in reflectance, particularly if second derivative reflectance spectra are calculated. To avoid spurious features in CHRIS-PROBA hyperspectral images over coastal water targets a methodology is presented here for improvement of inter-band calibration. This methodology is based on the selection of "clear water" pixels and the application of a polynomial fit, in order to calculate a single set of calibration coefficients. Results show the presence of a strong coherent signal in inter-band variability between different pixels and different images and confirmed the necessity of an additional inter-band calibration correction. The application of this inter-band calibration correction allowed to reduce inter-band variability by 53%. Although this method has been developed for CHRIS-PROBA, it could easily be transferred to other hyperspectral sensors.

Index Terms— hyperspectral, inter-band calibration, CHRIS-PROBA, water applications

1. INTRODUCTION

There is growing interest in the user of hyperspectral remote sensing for the monitoring and understanding of aquatic ecosystems. In particular, it is expected with hyperspectral data to derive information on the phytoplankton community composition ([1], [2]) or to identify a certain algae species [2]. Algorithms allowing the identification of certain phytoplankton groups or species are generally based on difference in pigment absorption which requires very accurate reflectance data as it is necessary to identify small changes in reflectance within a short spectral range.

However, sensors in orbit are submitted to change in environmental conditions (e.g. temperature) and instrumental drift along their life time. To solve this problem, onboard calibration systems and vicarious calibration algorithms have been developed ([4], [5]). While calibration efforts are generally aimed at providing best possible absolute radiometric calibration, the specific need for good inter-band calibration has received less attention, but is particularly important for hyperspectral algorithms using second derivatives of wavelength.

In this paper, we present a methodology to provide inter-band calibration correction factors for a set of hyperspectral (mode 1) CHRIS-PROBA images acquired between 2018 and 2020 in different coastal and open waters sites. The CHRIS optical sensor was launched in 2001 on the PROBA1 platform and, until the recent launch of PRISMA and DESIS sensors, it was the only available satellite hyperspectral sensor. CHRIS has been extensively used for land applications although its potential for water application has been also demonstrated [6]. The inter-band calibration methodology has been developed within a larger project which aims to produce a set of hyperspectral CHRIS-PROBA images over coastal and inland waters [7] but could also be useful for the new generation of hyperspectral sensors which are currently in development phase or have been recently launched.

2. METHOD

2.1. CHRIS-PROBA data

CHRIS-PROBA images were required with mode 1 and multi-view acquisition option. Mode 1 on CHRIS allows to obtain the highest spectral resolution (62 spectral bands in the 400nm-1000nm range) and multi-view acquisition acquires 5 images of the same target with different geometry [8]. Level 1 (version 4.1; Cutters and Johns 2005) HDF CHRIS files were downloaded from the ESA server (https://tpm-ds.eo.esa.int/smcat/PROBA1-CHRIS/0/0/0/). TOA reflectance spectra were corrected for gas absorption using estimations of water vapor, oxygen and ozone transmittances calculated by ACOLITE software (https://odnature.naturalsciences.be/remsem/software-and-data/acolite). Level 1 images were then processed with the striping correction algorithm developed by [9]. Although this algorithm is also supposed to correct for spectral noise induced by the detector array, observations shown strong and coherent remaining noise in top of atmosphere (TOA) reflectance spectra justifying an additional inter-band calibration step.

During the period 2018-2020, 96 multi-view (i.e. 5 replicates) CHRIS_PROBA images were acquired in 10 different geographic sites over coastal and inland waters and in 2 open water sites.

2.2. Calculation of inter-band calibration coefficients

Assuming that for clear waters the TOA reflectance spectra corrected for gas absorption should be smooth without sharp changes in concavity [5], it is possible to model TOA spectra by fitting a smoothing function. The term “clear water” refers in this paper to water with low algae and suspended sediment concentration so that the water reflectance spectra is smooth, without significant bumps and depressions induced by pigment absorption or particulate scattering. Then, inter-band calibration coefficients could be derived from the difference between the smooth spectra and the TOA reflectance spectra on a pixel-by-pixel basis. This test has been performed on a selection of 28 CHRIS-PROBA images where clear water pixels were expected. This dataset includes two target sites for oligotrophic waters (MOBY and BOUSSOLE) and five coastal waters sites where clear water pixels are expected (Table1).

Table 1: List of selected sites to calculate inter-band calibration coefficients. The site names and code are referring to the CHRIS-PROBA referencing.

Site name	code	latitude	longitude
Nice	N9	43.65°N	7.20°E
Le-Verdon	J4	45.55°N	-1.04°E
Port-St-Louis	P5	43.32°N	4.88°E
Thornton-Bank	T6	51.53°N	2.95°E
MOBY	U6	20.81°N	-157.20°E
Zhoushan	Z6	29.80°N	122.70°E
BOUSSOLE	Q6	43.37°N	7.90°E

On each selected image and each pixel, the TOA reflectance spectrum was corrected for gas absorption and an order 8 polynomial fit was performed. Polynomial function was fitted on the spectral range 400 nm to 730 nm only because (1) NIR values (730 to 900 nm) presents a lower interest for phytoplankton studies and (2) in the NIR region, errors in gas absorption correction have a strong impact on reflectance spectra. The order 8 polynomial has been selected as it best adapts to TOA reflectance spectral shape without over fitting small-scale variability (Figure 1). For each pixel, the quality of the polynomial fit on the TOA reflectance spectra was measured by the variable named D according to the following equation:

$$D = \frac{\sum_{i=1}^{36} |\rho_i - \rho_{smooth\ i}|}{\sum_{i=1}^{36} \rho_i}$$

Where ρ_i refers to gas corrected TOA reflectance for the spectral band number i and $\rho_{smooth\ i}$ to the fitted value on the polynomial curve for the same band. Hence, D can be seen as the average percent difference between the fit and the reflectance spectra. Low D values indicate that the reflectance spectrum is very close to the polynomial fit and that the pixel can be used in the computation of calibration coefficients. On the contrary, higher D values means that the polynomial curve doesn’t fit properly the reflectance spectra and should not be used as a reference for calculating calibration coefficients. After the visual analysis of a large number of spectra, the upper limit for selecting a pixel for calculating intercalibration coefficients was set to 0.03.

3. RESULTS AND DISCUSSION

3.1. Image based coefficients

Calibration coefficients computed on a pixel basis were averaged to obtain a calibration coefficient per image and per spectral band. Figure 2 shows inter-band calibration coefficients computed for each spectral band (column) and for each image (row). Figure 2 displays blue, red or white vertical strips which confirm the coherent structure of small-scale (inter-band) spectral variability. This pattern is retrieved between images from different dates and locations. In particular, a good consistency is observed between coastal water images and images from open oligotrophic waters (region codes Z6 and Q6).

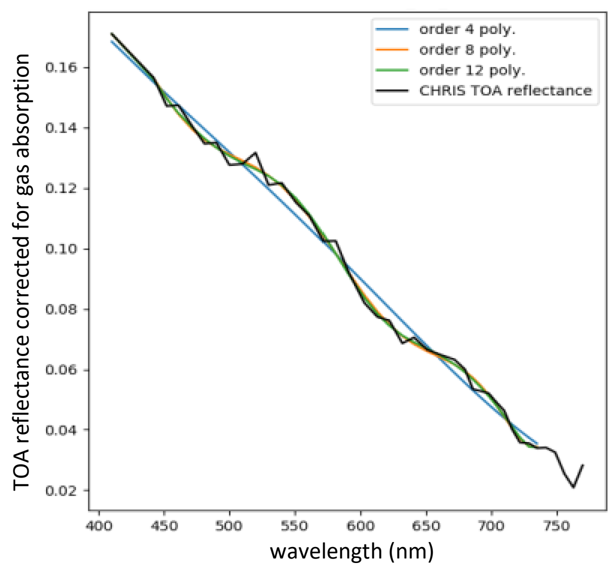

Figure 1. TOA reflectance spectra corrected for gas absorption extracted from the CHRIS-PROBA image from Port-St-Louis on 2019-03-16 (FZA=-36°). Color lines show three different polynomial fits of order 4, 8 and 12.

Calibration correction coefficients range between 0.95 and 1.05 for bands 1 to 26 (i.e. 400 nm to 680 nm). From band 27 (690 nm) calibration coefficients show more extreme values (from -0.85 to 1.15). As these last bands match with absorption peak of oxygen and water vapor, it is suspected that inter-band calibration coefficients also tend to correct for errors in the correction of gas absorption. These errors could be due to wrong estimation in absorbing gas content or, more probably, to errors in the spectral calibration of the CHRIS sensor [9].

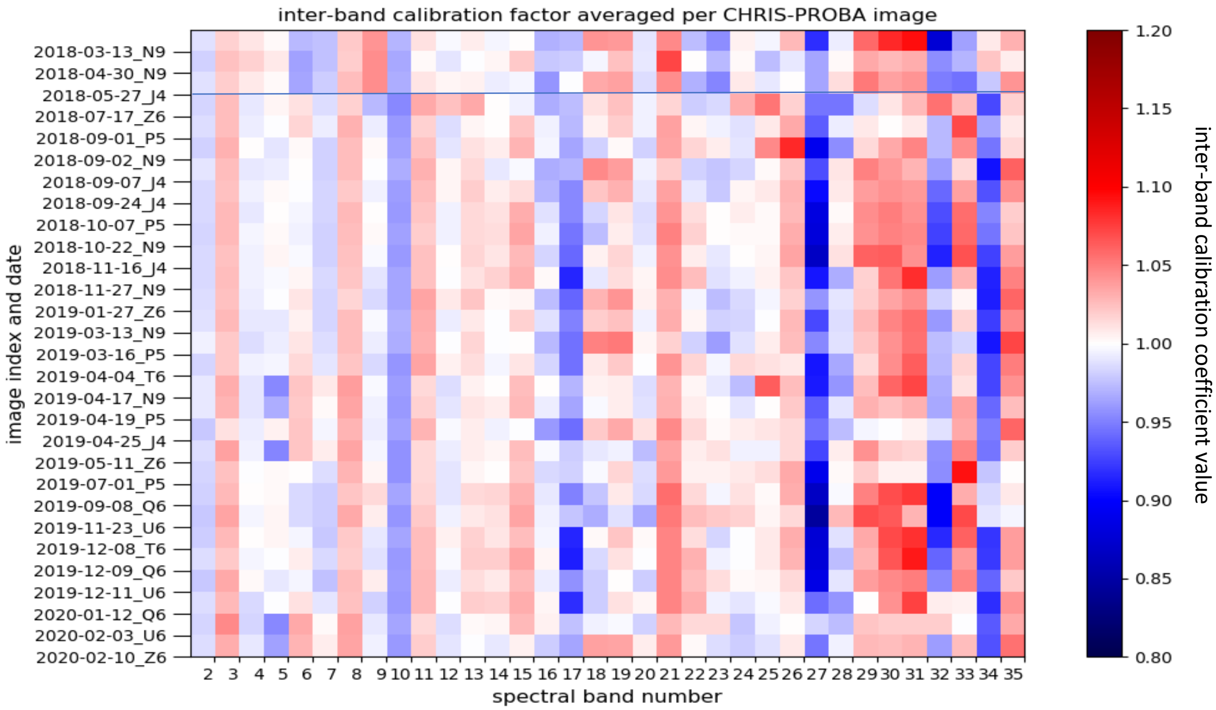

Figure 2. Color map indicating for each image (row) and spectral band (column) the median inter-band calibration coefficient. Images are ordered by date and their location is indicating with region code (see Table 1). The blue horizontal line separates the period March-May 2018 to July 2018 – February 2020 where a shift was observed.

Observing carefully Figure 2, one can notice a shift between images taken in the period January to May 2018 (first 3 dates) and images from the period July 2018 to February 2020. It is particularly visible in bands 6, 9, 11 and 33 where color changes from red to blue or blue to red. This shift suggests something happens for the sensor around June 2018 and although we were not able to identify what could cause such a sensor discontinuity, two final sets of calibration coefficients have been considered for processing the January to May 2018 period and the period starting from July 2018. Final inter-band calibration coefficients were computed by averaging the image-based calibration coefficients displayed in Figure 2 for each period of interest (data available here: (ftp://ftp.rbins.be/heloise/IGARSS2021_DATA_SUP/INTERBAND_CALIBRATION_COEFFS_CHRIS_PROBA.csv). The analysis of standard deviation associated to each coefficient (results not shown) shows relatively small values (about 0.015) from band 1 to band 24. From band 25 inter-image variability increases with a standard deviation around 0.04. However, as calibration factors also increase, inter-band calibration remains relevant.

3.2. Calibration performances

To measure how inter-band variability changes after the application of inter-band calibration coefficients, inter-band calibration was applied to all TOA reflectance spectra that could be modelled by a polynomial function (i.e. pixels with D < 0.03). Then, the D metric was re-estimated after application of the calibration. Results shows that D was reduced in all images. Before inter-band calibration, inter-quartiles interval for D values was 0.0179-0.020 with a median value of 0.0186, after inter-band calibration, this

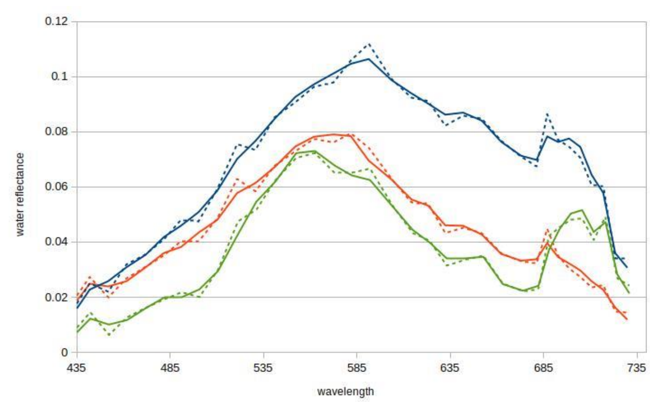

Figure 3. CHRIS-PROBA water reflectance spectra processed with (solid lines) and without (dashed lines) inter-band calibration. Blue spectra was extracted from Buenos-Aires image on 2020-11-13 (-34.56°N, -58.40°E), green spectra was extracted from Etang de Berre image on 2019-09-11 (43.44°N, 5.10°E) and orange spectra was extracted from Ostend image on 2020-05-05 (51.24°N, 2.92°E).

interval is 0.0081-0.011 and the median value is reduced to 0.0092, indicating a decreasing of about 50% of the inter-band variability. Remaining variability could be due to natural variability, radiometric noise or other sources of coherent noise impacting images individually.
Figure 3 illustrates the impact of the inter-band calibration on water reflectance spectra extracted from three CHRIS-PROBA images which were not selected for calculated inter-bands calibration coefficients because of the presence of turbid or eutrophic waters. Water reflectance was obtained from a dedicated atmospheric correction algorithm adapted to coastal waters ([11], [7]) with (solid lines) and without (dotted lines) application of inter-band calibration on TOA reflectance. Results confirm that the inter-band calibration tends to reduce inter-band variability especially in the range 435 nm - 680 nm. As many algal pigments absorbs light in this range, we think that the present inter-band calibration method could help for the application of hyperspectral phytoplankton retrieval algorithms to remote sensing data.

4. CONCLUSION

A simple methodology allowing to perform post-launch inter-band calibration correction has been presented based on the assumption that reflectance for clear water targets has rather smooth spectral variability. This methodology has been developed for the processing of CHRIS-PROBA hyperspectral images (mode 1), since the normal absolute calibration provided for this sensor is not good enough for application of second derivative reflectance algorithms. The analysis shows strong and coherent inter-band variability. Contrary to simple pixel-based or image-based spectral filtering, here a single set of coefficients for a large period has been calculated which allows to keep natural variability in reflectance spectra. The present methodology allowed to reduce inter-band variability by 50%. Results showed that the determination of calibration coefficients was limited by the impact of gas absorption and would require a better calibration of the spectral response function. Finally, by removing a significant part of the spurious small scale spectral variability of reflectance spectra, this methodology for inter-band calibration should facilitate the application of hyperspectral remote sensing algorithms to retrieve additional information on water particles and especially on phytoplankton composition.

5. AKNOWLEDGEMENTS

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6. REFERENCES

[1] H. Xi, M. Hieronymi, R. Röttgers, H. Krasemann, and Z. Qiu, Z. “Hyperspectral differentiation of phytoplankton taxonomic groups: a comparison between using remote sensing reflectance and absorption spectra.” *Remote Sensing*, 7(11), 14781-14805, 2015.

[2] H. Dierssen, A. Bracher, V. Brando, H. Loisel and K. Ruddick. “Data needs for hyperspectral detection of algal diversity across the globe” *Oceanography*, vol 33 (1), 2020.

[3] B. Lubac, H. Loisel, N. Guiselin, R. Astoreca, L. Felipe Artigas, and X. Mériaux. “Hyperspectral and multispectral ocean color inversions to detect Phaeocystis globosa blooms in coastal waters.” *Journal of Geophysical Research: Oceans*, 113(C6), 2008.

[4] B. Sohn, S. Ham, and P. Yang, P. “Possibility of the visible-channel calibration using deep convective clouds overshooting the TTL.” *Journal of applied meteorology and climatology*, 48(11), 2271-2283, 2009.

[5] N. Martiny, R. Santer, and I. Smolskaia. “Vicarious calibration of MERIS over dark waters in the near infrared”. *Remote Sensing of Environment*, 94(4), 475-490, 2005.

[6] G. Casal, T. Kutser, J. Domínguez-Gómez, N. Sánchez-Carnero, and J. Freire, J. “Mapping benthic macroalgal communities in the coastal zone using CHRIS-PROBA mode 2 images.” *Estuarine, Coastal and Shelf Science*, 94(3), 281-290, 2011.

[7] H. Lavigne, Q. Vanhellemont, K. Ruddick and A. Dogliotti. “New processor and reference dataset for hyperspectral CHRIS-PROBA images over coastal and inland waters”. *In proceedings of the IGARSS 2021 meeting*, submitted.

[8] L. Alonso, and J. Moreno. “Quasi-automatic geometric correction and related geometric issues in the exploitation of CHRIS/PROBA data”. *In Proceedings* of the second CHRIS/Proba Workshop (pp. 28-30), April 2004.

[9] L. Gómez-Chova, L. Alonso, L. Guanter, G. Camps-Valls, J. Calpe, and J. Moreno. “Correction of systematic spatial noise in push-broom hyperspectral sensors: application to CHRIS/PROBA images”. *Applied Optics*, 47(28), F46-F60, 2008.

[10] L. Guanter, R. Richter, and J. Moreno, J. “Spectral calibration of hyperspectral imagery using atmospheric absorption features”. *Applied optics*, 45(10), 2360-2370, 2006.

[11] Q. Vanhellemont, Q. “Adaptation of the dark spectrum fitting atmospheric correction for aquatic applications of the Landsat and Sentinel-2 archives”. *Remote Sensing of Environment*, 225, 175-192, 2019.