CONTINUUM REMOVAL ANALYSIS OF THE CHLOROPHYLL ABSORPTION FEATURE TO DETECT PLANT STRESS INDUCED BY LIQUID HYDROCARBON CONTAMINATION

Ieda Del'Arco Sanches [a,b], *Carlos Roberto de Souza Filho* [b]

[a] Remote Sensing Division (DSR), National Institute for Space Research (INPE), Brazil

[b] Institute of Geosciences, University of Campinas (UNICAMP), Brazil

This work explores the continuum removal (CR) technique to detect plant stress in visible/near infrared wavelengths. The red edge of the 680 nm chlorophyll absorption is a key feature in plant stress studies (e.g., [1], [8], [7]). The CR transformation consists of estimating the absorptions not due to the band of interest and removing their effects [2]. The CR technique normalises the reflectance spectrum and isolates absorption features to allow comparison between absorption bands on a common basis [4]. The CR method was initially used in geological remote sensing and was first applied to studies of leaf biochemistry by [5]. [6] demonstrated that the distinction between healthy and contaminated plant samples was improved when analysing the continuum-removed reflectance compared to reflectance and first derivative of reflectance data. In that study, they applied the CR using fixed continuum channels (e.g. 550-570 nm). Pre-stipulated wavelengths (i.e. left and right channels) used to determine the continuum line for the CR of a specific absorption feature can be adjusted for each sample to better represent the feature (PRISM software, [3]). In the present study, a time series of close range canopy reflectance data of a grass plant species (*Brachiaria brizantha)* grown in liquid hydrocarbon-contaminated (diesel – DSL; gasoline-GSL) soil was acquired with a portable spectrometer (ASD FieldSpec® 3 Hi-Res). The parameters describing the chlorophyll 680 nm absorption feature (continuum channels, depth, width, and area) were derived using the CR applied to the spectra using fixed (FIX) and adjusted (ADJ) continuum channels. Differences between CR-FIX and CR-ADJ results are observed in Figure 1 for all parameters but the feature centre (Table 1). Left and right channels of the continuum line differs some 16 nm and 8 nm on average, respectively, for the FIX and ADJ methods. In addition, the mean depth, width (FWHM – full width at half maximum) and area of the 680 nm feature yielded with the ADJ technique showed higher values. The analysis of the parameters estimated for the 680 nm absorption feature (CR-ADJ) for each of the contamination treatments, indicates that plants stressed by DSL and GSL display mean values of depth, width and area substantially lower than healthy plants (CTR) (Table 2). The results imply that to better characterize an absorption feature, the application of the CR technique using adjusted channels is superior and should be favoured in the analysis. Plant stress in brachiaria grass induced by the contamination of soil with DSL and GSL can be detected with spectral feature analysis focusing on the depth, width or area of the 680 nm chlorophyll absorption feature.

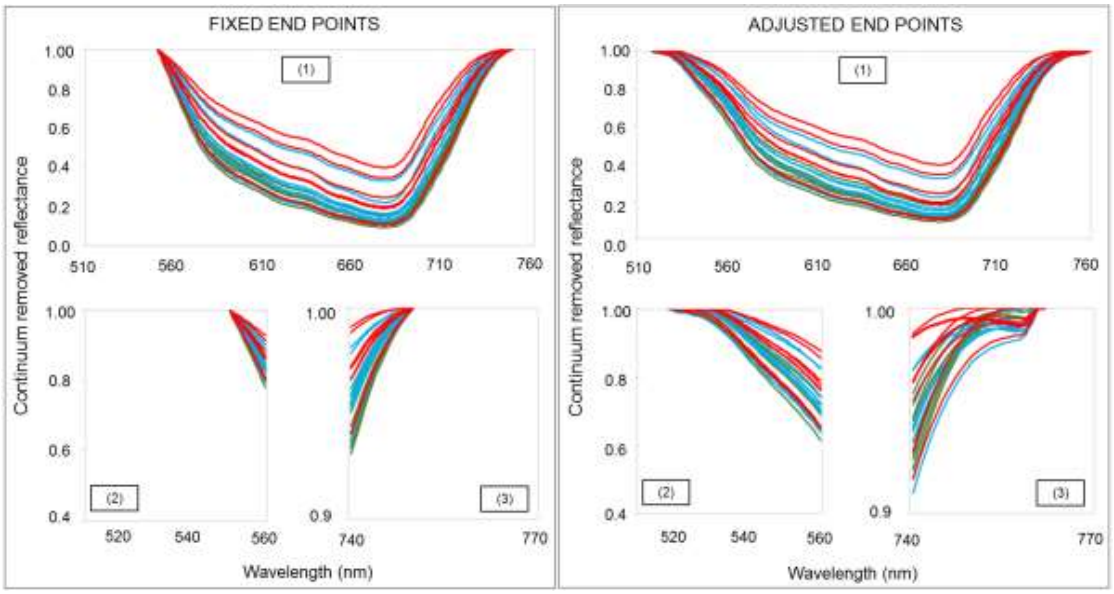

Figure 1. Continuum removed reflectance using fixed (FIX) and adjusted (ADJ) continuum channels for: (1) the 680 nm chlorophyll absorption feature. (2) Zoom in the wavelengths smaller than 560 nm and. (3) Zoom in the wavelengths greater than 740 nm. The curves in green, blue and red correspond to the samples of the control (CTR), contaminated with diesel (DSL) and contaminated with gasoline (GSL), respectively.

Table 1. Statistics of the 680 nm chlorophyll absorption feature parameters of all samples analysed using continuum removal with fixed (FIX) and adjusted (ADJ) continuum channels. The mean differences between fixed and adjusted parameters are highlighted in grey.

		Left channel	Right channel	Center	Depth	FWHM	Area
FIX	Minimum	550	750	678	699	129	84
	Maximum	550	750	679	899	149	124
	Mean	550	750	678	827	140	107
	SD	0	0	0	67	7	14
ADJ	Minimum	518	756	678	702	131	87
	Maximum	529	761	679	901	152	129
	Mean	525	760	678	830	143	111
	SD	5	2	0	66	8	15
ADJ - FIX	Minimum	-23	4	0	3	2	3
	Maximum	-12	9	0	2	4	5
	Mean	-16	8	0	2	3	4
	SD	5	2	0	0	0	1

FWHM – full width half maximum; SD – standard deviation.

Table 2. Statistics of the 680 nm chlorophyll absorption feature parameters obtained with the continuum removal using adjusted continuum channels. Data are presented for each of the treatments: control (CTR), plants contaminated with diesel (DSL) and plants contaminated with gasoline (GSL).

		Left channel	Right channel	Center	Depth	FWHM	Area
CTR	Minimum	518	757	678	823	141	108
	Maximum	528	761	679	909	154	132
	Mean	523	760	679	876	148	122
	Range	10	4	1	86	13	24
	SD	4	2	0	23	4	7
DSL	Minimum	518	761	678	680	129	83
	Maximum	530	762	679	898	152	129
	Mean	525	761	678	835	142	112
	Range	12	1	1	218	24	46
	SD	5	0	0	73	9	16
GSL	Minimum	518	750	678	605	122	69
	Maximum	530	761	678	896	151	127
	Mean	526	758	678	779	137	101
	Range	12	11	0	291	28	58
	SD	5	4	0	103	10	21

FWHM – full width half maximum; SD – standard deviation.

ACKNOWLEDGEMENTS

I. D. Sanches is grateful to FAPESP for her post-doctorate scholarship. The authors are thankful to Wilson Oliveira (Petrobras) and Marcos Nopper Alves (CPQBA-UNICAMP) for their innovative ideas and contributions during the field experiments. We are greatly indebted to Luciola Magalhaes and Giuliana Quiterio for their involvement with all phases and aspects of the spectral measurements in the field. We also acknowledge the researchers of the Technology Program for Transport (PROTRAN) of the Research Center of Petrobras (CENPES), especially to Pedro Altoe Ferreira, Lis Maria Leoni Rabaco and Renato Seixas da Rocha, for the financial and logistic support dedicated to the Biomarkers Project developed in partnership with UNICAMP.

REFERENCES

[1] Carter, G.A., & Miller, R.L. (1994). Early detection of plant stress by digital imaging within narrow stress-sensitive wavebands. *Remote Sensing of Environment*, 50, 295-302.

[2] Clark, R.N. & Roush, T.L. (1984). Reflectance spectroscopy: Quantitative analysis techniques for remote sensing applications. *Journal of Geophysical Research*, 89, 6329-6340.

[3] Kokaly, R.F. (2001). Investigating a physical basis for spectroscopic estimates of leaf nitrogen concentration. *Remote Sensing of Environment*, 75, 153-161.

[4] Kokaly, R.F. (2011). PRISM: Processing routines in IDL for spectroscopic measurements (installation manual and user´s guied, version 1.0). U.S. Geological Survey Open-File Report 2011–1155, 432 p., available at http://pubs.usgs.gov/of/2011/1155/.

[5] Kokaly, R.F. & Clark, R.N. (1999). Spectroscopy determination of leaf biochemistry using band-depth analysis of absorption features and stepwise multiple linear regression. *Remote Sensing of Environment*, 67, 267-287.

[6] Sanches, I.D., Souza Filho, C.R., Magalhães, L.A., Quitério, G.C.M., Alves, M.N. & Oliveira, W.J. (2013). Assessing the impact of hydrocarbon leakages on vegetation using reflectance spectroscopy. *ISPRS Journal of Photogrammetry and Remote Sensing*, 78, 85-101.

[7] Sanches, I.D., Souza Filho, C.R., Magalhães, L.A., Quitério, G.C.M., Alves, M.N. & Oliveira, W.J. (2013). Unravelling remote sensing signatures of plants contaminated with gasoline and diesel: An approach using the red edge spectral feature. *Environmental Pollution*, 174, 16-27.

[8] Zarco-Tejada, P.J., Pushnik, J.C., Dobrowski, S. & Ustin, S.L. (2003). Steady-state chlorophyll a fluorescence detection from canopy derivative reflectance and double-peak red edge effects. *Remote Sensing of Environment*, 84, 283-294.