Scientific background material for the “vegspec” package in Python

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The goal of the “vegspec” package in Python is to encapsulate the computations of 1) more than 145 published spectral vegetation indices and 2) several published pretreatment calculations for vegetative spectral reflectance data (ρ). An exhaustive literature search identified more than 145 spectral vegetation indices developed in remote sensing science from 1968 to the present time (Table 1). Given input of a single vegetative reflectance spectrum, the “vegspec” package computes each spectral vegetation index and encapsulates the results for use in further data analysis. A main advancement of the package is its representation of the spectral vegetation indices using the syntax of both the Python programming language and the LaTeX typesetting system, the latter of which rendered each index in mathematical notation as presented in Table 1. For indicies that required “soil line” parameters, the slope (a) was specified as 1.166 and the intercept (b) was specified as 0.042, based on Huete et al. (1984) who reported mean soil line parameters for 20 soils with varying spectral properties. However, users can also specify their own soil line parameters, if desired.

Remote sensing literature over the past decades has also documented several preprocessing treatments to condition spectral reflectance data prior to analysis. Examples include 1) the first and second derivatives of spectral reflectance (ρ' and ρ'', respectively) (Horler et al., 1983), 2) the base-10 logarithm ($\log_{10}$) of the inverse of spectral reflectance and its first and second derivatives ($\log_{10}\rho$, $(\log_{10}\rho)'$, and $(\log_{10}\rho)''$, respectively) (Blackburn, 1998a; Yoder and Pettigrew-Crosby, 1995), and 3) band depth or continuum removal analysis of reflectance spectra (ρ_{CR}) (Curran et al., 2001; Huang et al., 2004; Kokaly and Clark, 1999). Given input of a single vegetative reflectance spectrum, the “vegspec” package computes these six pretreatments and encapsulates the results for use in further data analysis. Spectral derivatives are computed using a Savitsky-Golay filter in Python’s “scipy” package (Virtanen et al., 2020), and continuum removal analysis requires use of a convex hull algorithm also in scipy. Computations of spectral derivatives were required for computation of several spectral vegetation indices.

Table 1: Chronological summary of 148 spectral vegetation indices developed from 1968 to the present time. Indices are defined using formulas based on reflectance (ρ), the first derivative of reflectance (ρ'), and the second derivative of reflectance (ρ'') with wavelengths (λ) identified either specifically in nanometers (i.e., λ_{675}) or generally as blue (λ_{BLU}), green (λ_{GRN}), red (λ_{RED}), red edge (λ_{RDE}), or near-infrared (λ_{NIR}) wavebands.

Year	Code	Description	Formula	Citation
1968	BRSR	Birth simple ratio	$\frac{\rho_{745}}{\rho_{675}}$	Birth and McVey (1968)
1969	JSR	Jordan simple ratio	$\frac{\rho_{800}}{\rho_{675}}$	Jordan (1969)
1973	NDVI	Normalized Difference Vegetation Index (NDVI)	$\frac{\rho_{\mathrm{NIR}}-\rho_{\mathrm{RED}}}{\rho_{\mathrm{NIR}}+\rho_{\mathrm{RED}}}$	Rouse et al. (1973)
1977	PVI	Perpendicular Vegetation Index (PVI)	$\frac{\rho_{\mathrm{NIR}}-a\rho_{\mathrm{RED}}-b}{\sqrt{1+a^2}} : (a=1.166, b=0.024)$	Richardson and Wiegand (1977); Jackson et al. (1980); Huete et al. (1984)
1978	WLREIP	Wavelength of red edge inflection point	$\lambda_{\mathrm{RDE}} = \arg\max_{\lambda}(\rho'(\lambda) : 680 \leq \lambda \leq 750)$	Collins (1978); Horler et al. (1983)
1979	DVI	Difference Vegetation Index (DVI)	$\rho_{\mathrm{NIR}}-\rho_{\mathrm{RED}}$	Tucker (1979)
1979	NDVI2	Normalized Difference Vegetation Index 2 (NDVI2)	$\frac{\rho_{\mathrm{GRN}}-\rho_{\mathrm{RED}}}{\rho_{\mathrm{GRN}}+\rho_{\mathrm{RED}}}$	Tucker (1979)

Continued on next page

Table 1 – Continued from previous page

Year	Code	Description	Formula	Citation
1988	WLREIP2	Wavelength of red edge inflection point 2	$700 + 40\left(\frac{(\rho_{670} + \rho_{780})/2 - \rho_{700}}{\rho_{740} - \rho_{700}}\right)$	Guyot and Baret (1988); Cho and Skidmore (2006)
1988	SAVI	Soil-Adjusted Vegetation Index (SAVI)	$(1 + L)\left(\frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{RED}}}{\rho_{\mathrm{NIR}} + \rho_{\mathrm{RED}} + L}\right) : (L = 0.5)$	Huete (1988)
1989	TSAVI	Transformed Soil-Adjusted Vegetation Index (TSAVI)	$\frac{a(\rho_{\mathrm{NIR}} - a\rho_{\mathrm{RED}} - b)}{\rho_{\mathrm{RED}} + a\rho_{\mathrm{NIR}} - ab} : (a = 1.166, b = 0.024)$	Baret et al. (1989); Huete et al. (1984)
1989	WDVI	Weighted Difference Vegetation Index (WDVI)	$\rho_{\mathrm{NIR}} - C\rho_{\mathrm{RED}} : (C = 1.166)$	Clevers (1989); Huete et al. (1984)
1989	MSI	Moisture Stress Index	$\frac{\rho_{1600}}{\rho_{820}}$	Hunt and Rock (1989)
1990	BD	Boochs derivative	ρ'_{703}	Boochs et al. (1990)
1990	BDR	Boochs derivative ratio	$\frac{\rho'_{703}}{\max(\rho'(\lambda) : 680 \leq \lambda \leq 750)}$	Boochs et al. (1990)
1990	SAVI2	Soil-Adjusted Vegetation Index 2 (SAVI2)	$\frac{\rho_{\mathrm{NIR}}}{\rho_{\mathrm{RED}} + b/a} : (a = 1.166, b = 0.024)$	Major et al. (1990); Huete et al. (1984)

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Year	Code	Description	Formula	Citation
1990	WLREIPG	Wavelength of red edge inflection point, Gaussian fit	$\lambda_{\text{RDE}} = \lambda_0 + \sigma : \rho(\lambda) = \rho_{\text{s}} - (\rho_{\text{s}} - \rho_0) \exp\left(\frac{-(\lambda_0 - \lambda)^2}{2\sigma^2}\right)$	Miller et al. (1990)
1990	WLCWMRG	Wavelength of chlorophyll-well minimum reflectance, Gaussian fit	$\lambda_0 : \rho(\lambda) = \rho_{\text{s}} - (\rho_{\text{s}} - \rho_0) \exp\left(\frac{-(\lambda_0 - \lambda)^2}{2\sigma^2}\right)$	Miller et al. (1990)
1991	TSAVI2	Transformed Soil-Adjusted Vegetation Index 2 (TSAVI2)	$\frac{a(\rho_{\text{NIR}} - a\rho_{\text{RED}} - b)}{a\rho_{\text{NIR}} + \rho_{\text{RED}} - ab + X(1 + a^2)} : (X = 0.08, a = 1.166, b = 0.024)$	Baret and Guyot (1991); Huete et al. (1984)
1992	CPSR1	Chappelle simple ratio 1	$\frac{\rho_{675}}{\rho_{700}}$	Chappelle et al. (1992)
1992	CPSR2	Chappelle simple ratio 2	$\frac{\rho_{675}}{\rho_{650}\rho_{700}}$	Chappelle et al. (1992)
1992	CPSR3	Chappelle simple ratio 3	$\frac{\rho_{760}}{\rho_{500}}$	Chappelle et al. (1992)
1992	PRI	Photochemical Reflectance Index (PRI)	$\frac{\rho_{550} - \rho_{531}}{\rho_{550} + \rho_{531}}$	Gamon et al. (1992)
1992	GEMI	Global Environment Monitoring Index (GEMI)	$\eta(1 - 0.25\eta) - \frac{\rho_{\text{RED}} - 0.125}{1 - \rho_{\text{RED}}} : (\eta = \frac{2(\rho_{\text{NIR}}^2 - \rho_{\text{RED}}^2) + 1.5\rho_{\text{NIR}} + 0.5\rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}} + 0.5}$	Pinty and Verstraete (1992)

Continued on next page

Table 1 – Continued from previous page

Year	Code	Description	Formula	Citation
1993	BMSR	Buschmann simple ratio	$\frac{\rho_{550}}{\rho_{800}}$	Buschmann and Nagel (1993)
1993	BMLSR	Buschmann log simple ratio	$\log_{10}\left(\frac{\rho_{800}}{\rho_{550}}\right)$	Buschmann and Nagel (1993)
1993	BMDVI	Bushmann difference vegetation index	$\rho_{800} - \rho_{550}$	Buschmann and Nagel (1993)
1993	PSR	Peñuelas simple ratio	$\frac{\rho_{970}}{\rho_{900}}$	Peñuelas et al. (1993)
1993	PD	Peñuelas derivative	$\min(\rho'(\lambda) : 900 \leq \lambda \leq 970)$	Peñuelas et al. (1993)
1993	WLPD	Wavelength of PD	$\arg\min_{\lambda}(\rho'(\lambda) : 900 \leq \lambda \leq 970)$	Peñuelas et al. (1993)
1993	VSR	Vogelmann simple ratio	$\frac{\rho_{740}}{\rho_{720}}$	Vogelmann et al. (1993)
1993	VDR	Vogelmann derivative ratio	$\frac{\rho'_{715}}{\rho'_{705}}$	Vogelmann et al. (1993)
1994	CRSR1	Carter simple ratio 1	$\frac{\rho_{695}}{\rho_{420}}$	Carter (1994)

Continued on next page

Table 1 – Continued from previous page

Year	Code	Description	Formula	Citation
1994	CRSR2	Carter simple ratio 2	$\frac{\rho_{605}}{\rho_{760}}$	Carter (1994)
1994	CRSR3	Carter simple ratio 3	$\frac{\rho_{695}}{\rho_{760}}$	Carter (1994)
1994	CRSR4	Carter simple ratio 4	$\frac{\rho_{710}}{\rho_{760}}$	Carter (1994)
1994	CRSR5	Carter simple ratio 5	$\frac{\rho_{695}}{\rho_{670}}$	Carter (1994)
1994	FSUM	Area of the first derivative red edge peak from 680 nm to 780 nm	$\sum_{\lambda=680}^{780} \rho'(\lambda) d\lambda$	Filella and Peñuelas (1994); Filella et al. (1995)
1994	DREIP	Amplitude of the first derivative at red edge inflection point	$\max(\rho'(\lambda) : 680 \leq \lambda \leq 780)$	Filella and Peñuelas (1994); Filella et al. (1995)
1994	NDVI3	Normalized Difference Vegetation Index 3 (NDVI3)	$\frac{\rho_{750} - \rho_{705}}{\rho_{750} + \rho_{705}}$	Gitelson and Merzlyak (1994)
1994	GSUM1	Sum of reflectance from 705 nm to 750 nm, normalized by reflectance at 705 nm	$\sum_{\lambda=705}^{750} \left(\frac{\rho(\lambda)}{\rho_{705}} - 1 \right) d\lambda$	Gitelson and Merzlyak (1994)

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Year	Code	Description	Formula	Citation
1994	GSUM2	Sum of reflectance from 705 nm to 750 nm, normalized by reflectance at 555 nm	$\sum_{\lambda=705}^{750} \left(\frac{\rho(\lambda)}{\rho_{555}} - 1 \right) d\lambda$	Gitelson and Merzlyak (1994)
1994	NLI	Nonlinear Index (NLI)	$\frac{\rho_{\mathrm{NIR}}^2 - \rho_{\mathrm{RED}}}{\rho_{\mathrm{NIR}}^2 + \rho_{\mathrm{RED}}}$	Goel and Qin (1994)
1994	CAR	Chlorophyll Absorption in Reflectance (CAR)	$\sqrt{\frac{(b^T b)(a^T a) - (a^T b)^2}{(a^T a)}} : \left(a = \begin{bmatrix} \lambda_{700} - \lambda_{550} \\ \rho_{700} - \rho_{550} \end{bmatrix}, b = \begin{bmatrix} \lambda_{670} - \lambda_{550} \\ \rho_{670} - \rho_{550} \end{bmatrix} \right)$	Kim et al. (1994)
1994	CARI	Chlorophyll Absorption Ratio Index (CARI)	$\mathrm{CAR} \times \left(\frac{\rho_{700}}{\rho_{670}} \right)$	Kim et al. (1994)
1994	NPCI	Normalized Pigments Chlorophyll ratio Index (NPCI)	$\frac{\rho_{680} - \rho_{430}}{\rho_{680} + \rho_{430}}$	Peñuelas et al. (1994)
1994	EGFN	Edge-Green First-derivative Normalised difference index (EGFN)	$\frac{\max(\rho'(\lambda_{\mathrm{RDE}})) - \max(\rho'(\lambda_{\mathrm{GRN}}))}{\max(\rho'(\lambda_{\mathrm{RDE}})) + \max(\rho'(\lambda_{\mathrm{GRN}}))} : (500 \leq \lambda_{\mathrm{GRN}} \leq 600, 680 \leq \lambda_{\mathrm{RDE}} \leq 750)$	Peñuelas et al. (1994)

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Year	Code	Description	Formula	Citation
1994	MSAVI1	Modified Soil-Adjusted Vegetation Index 1 (MSAVI1)	$(1+L)\left(\frac{\rho_{\mathrm{NIR}}-\rho_{\mathrm{RED}}}{\rho_{\mathrm{NIR}}+\rho_{\mathrm{RED}}+L}\right):(L=1-2a\times\mathrm{NDVI}\times\mathrm{WDVI},a=1.166)$	Qi et al. (1994); Huete et al. (1984)
1994	MSAVI2	Modified Soil-Adjusted Vegetation Index 2 (MSAVI2)	$\frac{2\rho_{\mathrm{NIR}}+1-\sqrt{(2\rho_{\mathrm{NIR}}+1)^2-8(\rho_{\mathrm{NIR}}-\rho_{\mathrm{RED}})}}{2}$	Qi et al. (1994)
1995	ESUM1	Area of the first derivative red edge peak from 626 nm to 795 nm	$\sum_{\lambda=626}^{795}\lvert\rho'(\lambda)\rvert d\lambda$	Elvidge and Chen (1995)
1995	ESUM2	Area of the second derivative red edge peaks from 626 nm to 795 nm	$\sum_{\lambda=626}^{795}\lvert\rho''(\lambda)\rvert d\lambda$	Elvidge and Chen (1995)
1995	NDPI	Normalized Difference Pigment Index (NDPI)	$\frac{\rho_{670}-\rho_{420}}{\rho_{670}+\rho_{420}}$	Peñuelas et al. (1995a)
1995	SIPI	Structure Independent Pigment Index (SIPI)	$\frac{\rho_{800}-\rho_{445}}{\rho_{800}-\rho_{680}}$	Peñuelas et al. (1995a)
1995	SRPI	Simple Ratio Pigment Index (SRPI)	$\frac{\rho_{430}}{\rho_{680}}$	Peñuelas et al. (1995b)
1995	NPQI	Normalized Phaeophytinization Index (NPQI)	$\frac{\rho_{415}-\rho_{435}}{\rho_{415}+\rho_{435}}$	Peñuelas et al. (1995b)

Continued on next page

Table 1 – Continued from previous page

Year	Code	Description	Formula	Citation
1995	RDVI	Renormalized Difference Vegetation Index (RDVI)	$\frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{RED}}}{\sqrt{\rho_{\mathrm{NIR}} + \rho_{\mathrm{RED}}}}$	Roujean and Breon (1995)
1996	MSR	Modified Simple Ratio (MSR)	$\frac{\rho_{\mathrm{NIR}}/\rho_{\mathrm{RED}} - 1}{\sqrt{\rho_{\mathrm{NIR}}/\rho_{\mathrm{RED}} + 1}}$	Chen (1996); Roujean and Breon (1995)
1996	PRI2	Photochemical Reflectance Index 2 (PRI2)	$\frac{\rho_{539} - \rho_{570}}{\rho_{539} + \rho_{570}}$	Filella et al. (1996)
1996	NDWI	Normalized Difference Water Index (NDWI)	$\frac{\rho_{860} - \rho_{1240}}{\rho_{860} + \rho_{1240}}$	Gao (1996)
1996	GTSR1	Gitelson simple ratio 1	$\frac{\rho_{750}}{\rho_{550}}$	Gitelson and Merzlyak (1996, 1997); Lichtenthaler et al. (1996)
1996	GTSR2	Gitelson simple ratio 2	$\frac{\rho_{750}}{\rho_{700}}$	Gitelson and Merzlyak (1996, 1997); Lichtenthaler et al. (1996)
1996	GNDVI	Green Normalized Difference Vegetation Index (GNDVI)	$\frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{GRN}}}{\rho_{\mathrm{NIR}} + \rho_{\mathrm{GRN}}}$	Gitelson et al. (1996)

Continued on next page

Year	Code	Description	Formula	Citation
1996	OSAVI	Optimized Soil-Adjusted Vegetation Index (OSAVI)	$(1+L)\left(\dfrac{\rho_{\mathrm{NIR}}-\rho_{\mathrm{RED}}}{\rho_{\mathrm{NIR}}+\rho_{\mathrm{RED}}+L}\right):(L=0.16)$	Rondeaux et al. (1996)
1997	WI	Water Index (WI)	$\dfrac{\rho_{900}}{\rho_{970}}$	Peñuelas et al. (1997)
1998	PSSRA	Pigment Specific Simple Ratio for chlorophyll a (PSSRa)	$\dfrac{\rho_{800}}{\rho_{680}}$	Blackburn (1998a,b)
1998	PSSRB	Pigment Specific Simple Ratio for chlorophyll b (PSSRb)	$\dfrac{\rho_{800}}{\rho_{635}}$	Blackburn (1998a,b)
1998	PSSRC	Pigment Specific Simple Ratio for carotenoid (PSSRc)	$\dfrac{\rho_{800}}{\rho_{470}}$	Blackburn (1998a,b)
1998	PSNDA	Pigment Specific Normalized Difference for chlorophyll a (PSNDa)	$\dfrac{\rho_{800}-\rho_{680}}{\rho_{800}+\rho_{680}}$	Blackburn (1998a,b)
1998	PSNDB	Pigment Specific Normalized Difference for chlorophyll b (PSNDb)	$\dfrac{\rho_{800}-\rho_{635}}{\rho_{800}+\rho_{635}}$	Blackburn (1998a,b)
1998	PSNDC	Pigment Specific Normalized Difference for carotenoid (PSNDc)	$\dfrac{\rho_{800}-\rho_{470}}{\rho_{800}+\rho_{470}}$	Blackburn (1998a,b)

Continued on next page

Table 1 – Continued from previous page

Year	Code	Description	Formula	Citation
1998	DSR1	Datt simple ratio 1	$\frac{\rho_{672}}{\rho_{550}\rho_{708}}$	Datt (1998)
1998	DSR2	Datt simple ratio 2	$\frac{\rho_{672}}{\rho_{550}}$	Datt (1998)
1999	DNDR	Datt normalized difference ratio	$\frac{\rho_{850}-\rho_{710}}{\rho_{850}-\rho_{680}}$	Datt (1999a,b)
1999	DDR1	Datt first derivative ratio	$\frac{\rho'_{754}}{\rho'_{704}}$	Datt (1999b)
1999	DDR2	Datt second derivative ratio	$\frac{\rho''_{712}}{\rho''_{688}}$	Datt (1999b)
1999	GMSR	Gamon simple ratio	$\frac{\rho_{\mathrm{RED}}}{\rho_{\mathrm{GRN}}}$	Gamon and Surfus (1999)
1999	PSRI	Plant Senescence Reflectance Index (PSRI)	$\frac{\rho_{678}-\rho_{500}}{\rho_{750}}$	Merzlyak et al. (1999)
2000	TVI	Triangular Vegetation Index (TVI)	$0.5[120(\rho_{750}-\rho_{550})-200(\rho_{670}-\rho_{550})]$	Broge and Leblanc (2000)
2000	MCARI	Modified Chlorophyll Absorption in Reflectance Index (MCARI)	$[(\rho_{700}-\rho_{670})-0.2(\rho_{700}-\rho_{550})]\left(\frac{\rho_{700}}{\rho_{670}}\right)$	Daughtry et al. (2000)

Continued on next page

Table 1 – Continued from previous page

Year	Code	Description	Formula	Citation
2000	MOR	MCARI OSAVI ratio	$\frac{\text{MCARI}}{\text{OSAVI}}$	Daughtry et al. (2000)
2000	ZTSR1	Zarco-Tejada simple ratio 1	$\frac{\rho_{685}}{\rho_{655}}$	Zarco-Tejada et al. (2000a,b)
2000	CI	Curvature Index (CI)	$\frac{\rho_{683}^2}{\rho_{675}\rho_{691}}$	Zarco-Tejada et al. (2000a,b)
2000	ZTDR1	Zarco-Tejada derivative ratio 1	$\frac{\rho'_{730}}{\rho'_{706}}$	Zarco-Tejada et al. (2000b)
2000	ZTSR2	Zarco-Tejada simple ratio 2	$\frac{\rho_{750}}{\rho_{710}}$	Zarco-Tejada et al. (2000b)
2001	CAI	Cellulose Absorption Index (CAI)	$0.5(\rho_{2019} + \rho_{2206}) - \rho_{2109}$	Daughtry (2001)
2001	ARI	Anthocyanin Reflectance Index (ARI)	$(\rho_{550})^{-1} - (\rho_{700})^{-1}$	Gitelson et al. (2001)
2001	MND1	Maccioni normalized difference 1	$\frac{\rho_{780} - \rho_{710}}{\rho_{780} - \rho_{680}}$	Maccioni et al. (2001); Datt (1999b)

Continued on next page

Table 1 – Continued from previous page

Year	Code	Description	Formula	Citation
2001	MND2	Maccioni normalized difference 2	$\frac{\rho_{542} - \min(\rho(\lambda_{\text{RED}}))}{\rho_{750} - \min(\rho(\lambda_{\text{RED}}))} : 660 \leq \lambda_{\text{RED}} \leq 680$	Maccioni et al. (2001)
2001	MND3	Maccioni normalized difference 3	$\frac{\rho_{706} - \min(\rho(\lambda_{\text{RED}}))}{\rho_{750} - \min(\rho(\lambda_{\text{RED}}))} : 660 \leq \lambda_{\text{RED}} \leq 680$	Maccioni et al. (2001)
2001	MND4	Maccioni normalized difference 4	$\frac{\rho_{556} - \min(\rho(\lambda_{\text{RED}}))}{\rho_{750} - \min(\rho(\lambda_{\text{RED}}))} : 660 \leq \lambda_{\text{RED}} \leq 680$	Maccioni et al. (2001)
2001	CAINT	Chlorophyll Absorption INTegral (CAINT)	$\sum_{\lambda=600}^{735} \left(\frac{\rho(\lambda)}{y(\lambda)}\right) d\lambda : y(\lambda) = \frac{\rho_{735} - \rho_{600}}{\lambda_{735} - \lambda_{600}}(\lambda - 600) + \rho_{600}$	Oppelt and Mauser (2001, 2004)
2001	ZTSUM	Area of the first derivative peak from 680 nm to 760 nm	$\sum_{\lambda=680}^{760} \rho'(\lambda) d\lambda$	Zarco-Tejada et al. (2001b)
2001	PRI3	Photochemical Reflectance Index 3 (PRI3)	$\frac{\rho_{531} - \rho_{570}}{\rho_{531} + \rho_{570}}$	Zarco-Tejada et al. (2001b)
2001	ZTDPR1	Zarco-Tejada derivative peak ratio 1	$\frac{\rho'_{\lambda_{RDE}}}{\rho'_{\lambda_{RDE}+12}} : \lambda_{RDE}$ from WLREIPG	Zarco-Tejada et al. (2001b); Miller et al. (1990)

Continued on next page

Table 1 – Continued from previous page

Year	Code	Description	Formula	Citation
2001	ZTDPR2	Zarco-Tejada derivative peak ratio 2	$\frac{\rho'_{\lambda_{RDE}}}{\rho'_{\lambda_{RDE}+22}} : \lambda_{RDE}$ from WLREIPG	Zarco-Tejada et al. (2001b); Miller et al. (1990)
2001	ZTDP21	Zarco-Tejada derivative peak ratio 21	$\frac{\rho'_{\lambda_{RDE}}}{\rho'_{703}} : \lambda_{RDE}$ from WLREIPG	Zarco-Tejada et al. (2001b); Miller et al. (1990)
2001	ZTDP22	Zarco-Tejada derivative peak ratio 22	$\frac{\rho'_{\lambda_{RDE}}}{\rho'_{720}} : \lambda_{RDE}$ from WLREIPG	Zarco-Tejada et al. (2001b); Miller et al. (1990)
2001	GI	Greenness Index	$\frac{\rho_{554}}{\rho_{677}}$	Zarco-Tejada et al. (2001b)
2001	ZTSR3	Zarco-Tejada simple ratio 3	$\frac{\rho_{680}}{\rho_{630}}$	Zarco-Tejada et al. (2001a)
2001	ZTSR4	Zarco-Tejada simple ratio 4	$\frac{\rho_{685}}{\rho_{630}}$	Zarco-Tejada et al. (2001a)
2001	ZTSR5	Zarco-Tejada simple ratio 5	$\frac{\rho_{687}}{\rho_{630}}$	Zarco-Tejada et al. (2001a)

Continued on next page

Table 1 – Continued from previous page

Year	Code	Description	Formula	Citation
2001	ZTSR6	Zarco-Tejada simple ratio 6	$\frac{\rho_{690}}{\rho_{630}}$	Zarco-Tejada et al. (2001a)
2002	VARI	Visible Atmospherically Resistant Index (VARI)	$\frac{\rho_{\mathrm{GRN}} - \rho_{\mathrm{RED}}}{\rho_{\mathrm{GRN}} + \rho_{\mathrm{RED}} - \rho_{\mathrm{BLU}}}$	Gitelson et al. (2002a)
2002	CRI500	Carotenoid Reflectance Index (CRI550)	$(\rho_{510})^{-1} - (\rho_{550})^{-1}$	Gitelson et al. (2002b)
2002	CRI700	Carotenoid Reflectance Index (CRI700)	$(\rho_{510})^{-1} - (\rho_{700})^{-1}$	Gitelson et al. (2002b)
2002	TCARI	Transformed Chlorophyll Absorption Ratio Index (TCARI)	$3\left[(\rho_{700} - \rho_{670}) - 0.2(\rho_{700} - \rho_{550})\left(\frac{\rho_{700}}{\rho_{670}}\right)\right]$	Haboudane et al. (2002)
2002	TOR	TCARI OSAVI ratio	$\frac{\mathrm{TCARI}}{\mathrm{OSAVI}}$	Haboudane et al. (2002)
2002	EVI	Enhanced Vegetation Index (EVI)	$2.5\left(\frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{RED}}}{\rho_{\mathrm{NIR}} + 6\rho_{\mathrm{RED}} - 7.5\rho_{\mathrm{BLU}} + 1}\right)$	Huete et al. (2002)
2002	NDNI	Normalized Difference Nitrogen Index (NDNI)	$\frac{\log_{10}(\rho_{1510}^{-1}) - \log_{10}(\rho_{1680}^{-1})}{\log_{10}(\rho_{1510}^{-1}) + \log_{10}(\rho_{1680}^{-1})}$	Serrano et al. (2002)
2002	NDLI	Normalized Difference Lignin Index (NDLI)	$\frac{\log_{10}(\rho_{1754}^{-1}) - \log_{10}(\rho_{1680}^{-1})}{\log_{10}(\rho_{1754}^{-1}) + \log_{10}(\rho_{1680}^{-1})}$	Serrano et al. (2002)

Continued on next page

Table 1 – Continued from previous page

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2002	MSR2	Modified Simple Ratio 2	$\frac{\rho_{750} - \rho_{445}}{\rho_{705} - \rho_{445}}$	Sims and Gamon (2002)
2002	SMNDVI	Sims Modified Normalized Difference Vegetation Index	$\frac{\rho_{750} - \rho_{705}}{\rho_{750} + \rho_{705} - 2\rho_{445}}$	Sims and Gamon (2002)
2003	GRRGM	Gitelson Reciprocal Reflectance Green Model	$\left(\frac{\rho_{\mathrm{NIR}}}{\rho_{\mathrm{GRN}}}\right) - 1$	Gitelson et al. (2003, 2005)
2003	GRRREM	Gitelson Reciprocal Reflectance Red Edge Model	$\left(\frac{\rho_{\mathrm{NIR}}}{\rho_{\mathrm{RDE}}}\right) - 1$	Gitelson et al. (2003, 2005)
2003	DPI	Double-Peak Index (DPI)	$\frac{\rho'_{688}\rho'_{710}}{\rho'^{2}_{697}}$	Zarco-Tejada et al. (2003a)
2003	SRWI	Simple Ratio Water Index (SRWI)	$\frac{\rho_{860}}{\rho_{1240}}$	Zarco-Tejada et al. (2003b)
2004	MTCI	MERIS Terrestrial Chlorophyll Index (MTCI)	$\frac{\rho_{754} - \rho_{709}}{\rho_{709} - \rho_{681}}$	Dash and Curran (2004)
2004	WDRVI	Wide Dynamic Range Vegetation Index (WDRVI)	$\frac{a\rho_{\mathrm{NIR}} - \rho_{\mathrm{RED}}}{a\rho_{\mathrm{NIR}} + \rho_{\mathrm{RED}}} : (a = 0.15)$	Gitelson (2004)

Continued on next page

Table 1 – Continued from previous page

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2004	MCARI1	Modified Chlorophyll Absorption in Reflectance Index 1 (MCARI1)	$1.2[2.5(\rho_{800}-\rho_{670})-1.3(\rho_{800}-\rho_{550})]$	Haboudane et al. (2004)
2004	MCARI2	Modified Chlorophyll Absorption in Reflectance Index 2 (MCARI2)	$\frac{1.5[2.5(\rho_{800}-\rho_{670})-1.3(\rho_{800}-\rho_{550})]}{\sqrt{(2\rho_{800}+1)^2-(6\rho_{800}-5\sqrt{\rho_{670}})-0.5}}$	Haboudane et al. (2004)
2004	MTVI1	Modified Triangular Vegetation Index 1 (MTVI1)	$1.2[1.2(\rho_{800}-\rho_{550})-2.5(\rho_{670}-\rho_{550})]$	Haboudane et al. (2004)
2004	MTVI2	Modified Triangular Vegetation Index 2 (MTVI2)	$\frac{1.5[1.2(\rho_{800}-\rho_{550})-2.5(\rho_{670}-\rho_{550})]}{\sqrt{(2\rho_{800}+1)^2-(6\rho_{800}-5\sqrt{\rho_{670}})-0.5}}$	Haboudane et al. (2004)
2004	DD	Double Difference index (DD)	$(\rho_{749}-\rho_{720})-(\rho_{701}-\rho_{672})$	Le Maire et al. (2004)
2005	LCA	Lignin Cellulose Absorption Index (LCA)	$100[(\rho_{2205}-\rho_{2165})+(\rho_{2205}-\rho_{2330})]$	Daughtry et al. (2005)
2005	RGI	Red Green Pigment Index (RGI)	$\frac{\rho_{690}}{\rho_{550}}$	Zarco-Tejada et al. (2005)
2005	BGI1	Blue Green Pigment Index 1 (BGI1)	$\frac{\rho_{400}}{\rho_{550}}$	Zarco-Tejada et al. (2005)

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Year	Code	Description	Formula	Citation
2005	BGI2	Blue Green Pigment Index 2 (BGI2)	$\frac{\rho_{450}}{\rho_{550}}$	Zarco-Tejada et al. (2005)
2005	BRI1	Blue Red Pigment Index 1 (BRI1)	$\frac{\rho_{400}}{\rho_{690}}$	Zarco-Tejada et al. (2005)
2005	BRI2	Blue Red Pigment Index 2 (BRI2)	$\frac{\rho_{450}}{\rho_{690}}$	Zarco-Tejada et al. (2005)
2006	WLREIPE	Wavelength of red edge inflection point, extrapolation method	$\lambda_{\mathrm{RDE}} = \frac{-(c_1 - c_2)}{m_1 - m_2} : \rho'_1(\lambda) = m_1\lambda + c_1, \rho'_2(\lambda) = m_2\lambda + c_2, m_1 = \frac{\rho'_{700} - \rho'_{680}}{\lambda_{700} - \lambda_{680}}, m_2 = \frac{\rho'_{760} - \rho'_{725}}{\lambda_{760} - \lambda_{725}}$	Cho and Skidmore (2006)
2006	RVIOPT	Reyniers VIopt	$(1 + 0.45)\frac{\rho^2_{\mathrm{NIR}} + 1}{\rho_{\mathrm{RED}} + 0.45}$	Reyniers et al. (2006)
2006	SPVI	Spectral Polygon Vegetation Index (SPVI)	$0.4[3.7(\rho_{800} - \rho_{670}) - 1.2\|\rho_{550} - \rho_{670}\|]$	Vincini et al. (2006)
2007	MMR	MCARI MTVI2 ratio	$\frac{\mathrm{MCARI}}{\mathrm{MTVI2}}$	Eitel et al. (2007)
2008	TCI	Triangular Chlorophyll Index (TCI)	$1.2(\rho_{700} - \rho_{550}) - 1.5(\rho_{670} - \rho_{550})\sqrt{\frac{\rho_{700}}{\rho_{670}}}$	Haboudane et al. (2008)

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Year	Code	Description	Formula	Citation
2008	EVI2	Enhanced Vegetation Index 2 (EVI2)	$\frac{2.5(\rho_{\mathrm{NIR}} - \rho_{\mathrm{RED}})}{\rho_{\mathrm{NIR}} + 2.4\rho_{\mathrm{RED}} + 1}$	Jiang et al. (2008)
2008	DDN	New Double Difference index (DDN)	$2\rho_{710} - \rho_{660} - \rho_{760}$	Le Maire et al. (2008)
2008	CVI	Chlorophyll Vegetation Index (CVI)	$\frac{\rho_{\mathrm{NIR}}\rho_{\mathrm{RED}}}{\rho_{\mathrm{GRN}}^2}$	Vincini et al. (2008)
2008	WUTCARI	Transformed Chlorophyll Absorption Ratio Index [705, 750]	$3\left[(\rho_{750} - \rho_{705}) - 0.2(\rho_{750} - \rho_{550})\left(\frac{\rho_{750}}{\rho_{705}}\right)\right]$	Wu et al. (2008)
2008	WUOSAVI	Optimized Soil-Adjusted Vegetation Index [705, 750]	$(1 + L)\left(\frac{\rho_{750} - \rho_{705}}{\rho_{750} + \rho_{705} + L}\right) : (L = 0.16)$	Wu et al. (2008)
2008	WUMCARI	Modified Chlorophyll Absorption in Reflectance Index [705, 750]	$[(\rho_{750} - \rho_{705}) - 0.2(\rho_{750} - \rho_{550})]\left(\frac{\rho_{750}}{\rho_{705}}\right)$	Wu et al. (2008)
2008	WUMSR	Modified Simple Ratio [705, 750]	$\frac{\rho_{750}/\rho_{705} - 1}{\sqrt{\rho_{750}/\rho_{705} + 1}}$	Wu et al. (2008)
2008	WUTOR	TCARI OSAVI ratio [705, 750]	$\frac{\mathrm{WUTCARI}}{\mathrm{WUOSAVI}}$	Wu et al. (2008)
2008	WUMOR	MCARI OSAVI ratio [705, 750]	$\frac{\mathrm{WUMCARI}}{\mathrm{WUOSAVI}}$	Wu et al. (2008)

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Year	Code	Description	Formula	Citation
2010	DCNI	Double-peak Canopy Nitrogen Index (DCNI)	$\dfrac{\left(\dfrac{\rho_{720}-\rho_{700}}{\rho_{700}-\rho_{670}}\right)}{\rho_{720}-\rho_{670}+0.03}$	Chen et al. (2010)
2011	TGI	Triangular Greenness Index (TGI)	$-0.5[(\lambda_{\mathrm{RED}}-\lambda_{\mathrm{BLU}})(\rho_{\mathrm{RED}}-\rho_{\mathrm{GRN}})-(\lambda_{\mathrm{RED}}-\lambda_{\mathrm{GRN}})(\rho_{\mathrm{RED}}-\rho_{\mathrm{BLU}})]$	Hunt et al. (2011)
2011	WDRVI2	Wide Dynamic Range Vegetation Index 2 (WDRVI2)	$\dfrac{\alpha\rho_{\mathrm{NIR}}-\rho_{\mathrm{RED}}}{\alpha\rho_{\mathrm{NIR}}+\rho_{\mathrm{RED}}}+\dfrac{1-\alpha}{1+\alpha}:(\alpha=0.2)$	Peng and Gitelson (2011)
2016	AIVI	Angular Insensitivity Vegetation Index (AIVI)	$\dfrac{\rho_{445}(\rho_{720}+\rho_{735})-\rho_{573}(\rho_{720}-\rho_{735})}{\rho_{720}(\rho_{573}+\rho_{445})}$	He et al. (2016)
2017	DND	Derivative Normalized Difference	$\dfrac{\rho'_{522}-\rho'_{728}}{\rho'_{522}+\rho'_{728}}$	Sonobe and Wang (2017)
2024	GRSUM	Area of the green reflectance peak from 500 nm to 600 nm	$\sum_{\lambda=500}^{600}\rho(\lambda)d\lambda$	Thorp and Thompson

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