Comparison of Vegetation Index Compositing Scenarios: BRDF Versus Maximum VI Approaches

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Abstract -- Satellite sensors, such as the AVHRR, SPOT and soon to be launched MODIS, MISR, VEGETATION and GLI acquire bidirectional reflectance data under different solar illumination angles. These systems will capture the strong anisotropic properties that vary with relative amounts and types of vegetation and soil within each pixel. Therefore, some knowledge of the bidirectional reflectance distribution function (BRDF) is a requirement for successful interpretation of directional reflectance data and vegetation indices, and derivation of land-cover-specific biophysical parameters. The objectives of this research were: a) to parameterize empirical and semi-empirical BRDF models for different land cover types and MODIS spectral bands, b) utilize the BRDF models to correct off-nadir measurements to nadir-equivalent values for vegetation index (VI) compositing and biophysical interpretation and c) compare different vegetation index compositing scenarios.

High spectral (10-12 nm), and spatial (3 m at nadir), resolution bidirectional reflectance factor (BRF) measurements from the Advanced Solid State Array Spectroradiometer (ASAS) flown on the NASA C-130B aircraft were used for the analysis. Leaf area index (LAI) measurements were made concurrently at most of the study sites which included deciduous and coniferous forest, grassland and shrub savanna land covers. The normalized difference vegetation index (NDVI) and modified VI (MVI) were selected as classifiers in five different vegetation index composite scenarios:

- a maximum VI based on apparent reflectance data,
- a maximum VI based on at-surface reflectance data,
- a BRDF standardized VI, based on at-surface reflectances at nadir view angle (using a representative sun angle),
- a BRDF normalized VI, based on at-surface reflectances at nadir view and nadir sun angles,
- a normalized bidirectional VI distribution function (BVIF).

Nadir-equivalent VI accuracy and predictability were evaluated for all compositing scenarios using the measured nadir observations as a reference. Extrapolation of the BRDF models to nadir sun angles was found to be inaccurate. VI composite scenarios based on the standardization of reflectances to nadir view angles was more accurate than the maximum VI approach. The results of the analysis emphasize the importance of standardizing BRF for vegetation index compositing schemes and retrieval of biophysical parameters.

INTRODUCTION

The interpretation and utilization of vegetation index data on a global scale is affected by a combination of factors such as the surface soil and vegetation properties, atmospheric conditions and the solar illumination and sensor characteristics. There is a wide range of variability among these factors, affecting each vegetation index and therefore their biophysical interpretation in a specific way. This will be a major issue when dealing with forthcoming data from the Moderate Resolution Imaging Spectroradiometer (MODIS) [1].

The Advanced Very High Resolution Radiometer (AVHRR) normalized difference vegetation index (NDVI) compositing scenario is based on a maximum NDVI approach and includes additional cloud screening and data quality checks [2]. Although the maximum NDVI approach was designed to select pixels without clouds and closest to nadir within a 10-day period, research has shown that these assumptions cannot be sustained. Selected pixels often have large view angles and are not always cloud-free [3,4]. Since residual clouds and the view angle alter the surface reflectances and thus the VIs, comparisons of global vegetation types will not be consistent throughout the year.

The objective of this research was to compare different vegetation index compositing scenarios utilizing bidirectional reflectance data for a range of vegetation types.

DATA AND METHODS

Major land cover types included in this study are deciduous and coniferous forest (Oregon Transect Ecosystem Research Project - OTTER, Boreal Ecosystem Atmosphere study-BOREAS), grassland (First ISLSCP Field Experiment - FIFE) and shrub savanna sites (Hydrologic, Atmospheric pilot Experiment in the Sahel - HAPEX-Sahel). High spectral resolution bidirectional reflectance factor (BRF) measurements were made with the Advanced Solid State Array Spectroradiometer (ASAS) instrument flown at ~5000m altitude. The ASAS reflectance data were convolved into the first three MODIS bands (ρ_{red}, ρ_{nir}, ρ_{blue}; 620-670 nm, 841-876 nm, 459-479 nm) and corrected for atmosphere effects with "6S". Aerosol optical depth data from the airplane and field sunphotometers and variable aerosol distributions and atmosphere profiles were used to correct for atmospheric effects and calculate reflectance factors. For each target all scenes were co-registered after which average apparent and surface reflectances were extracted for each MODIS band for an area of about 1-2 km^2. The view zenith angles ranged between 0° and 60° in both the forward scatter and backscatter direction. The NDVI and modified vegetation index (MVI) were used as classifiers in the five composite scenarios:

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$$NDVI = (\rho_{nir} - \rho_{red})/(\rho_{nir} + \rho_{red}), \quad (1)$$

$$MVI = 2.5\,(\rho_{nir} - \rho_{red})/(1 + \rho_{nir} + 6\rho_{red} - 7.5\rho_{blue}). \quad (2)$$

In this study two BRDF models were used to model the BRF and VI data. The empirical Walthall BRDF model [5]:

$$\rho(\theta_v, \phi_s, \phi_v) = a\theta_v^2 + b\theta_v \cos(\phi_v - \phi_s) + c, \quad (3)$$

where the reflectance ρ is a function of the view zenith angle θ_v, and the sun and view azimuth angles ϕ_s, ϕ_v ; a, b and c are coefficients obtained using a least square fitting procedure. c is equal to the nadir reflectance. The semi-empirical Roujean model:

$$\rho(\theta_s, \phi_s, \theta_v, \phi_v) = k_{iso} + k_{geo} f_{geo} + k_{vol} f_{vol}, \quad (4)$$

where f_{geo} and f_{vol} are functions related to geometric and volume scattering components; k_{iso} represents the isotropic bidirectional reflectance (for $\theta_s = \theta_v = 0$), k_{geo} and k_{vol} are parameters related to several canopy geometric and optical properties [6]. Roujean's BRDF model was inverted to compute the reflectances at the mean and nadir solar zenith angles and nadir view zenith angle. Both models were parameterized for both MODIS band reflectance data and vegetation index data.

RESULTS AND DISCUSSION

An example of ASAS BRF (apparent and at-surface reflectances for three MODIS bands) are given in Fig. 1 for "tigerbush", collected during HAPEX (1992). Graphical presentations of the different vegetation types will appear in a future communication. The difference between TOA and at-surface reflectance factors are minimal for all data sets because they were collected under fairly clear sky conditions (all aerosol optical depths @ 550 nm were below 0.27). For most vegetation types, the backscatter direction had the highest reflectance response. Although the hot spot effect (increase in reflectance when view and solar zenith and azimuth angles are the same) was barely noticeable (around -45° in Fig. 1), hot spot effects can be seen in some of the peak MVI responses in Fig. 2.

The vegetation index response about nadir showed significant variability and was different for each vegetation type (Fig. 2). Both the NDVI and MVI were affected by the view angle, but the MVI showed larger deviations about nadir.

The results of the five composite scenarios are presented for the MVI and partly for the NDVI (Table 1). Percentages of absolute difference, between the measured nadir VIs and the VIs resulting from the different composite scenarios, were computed for each vegetation type. The mean difference and standard deviation for all vegetation types were computed per composite scenario to show the differences in performance (Table 1). The larger the mean difference, the larger the "error" with respect to nadir-equivalent estimation of the VI. The maximum VI scenarios generally showed a preference for off-nadir view

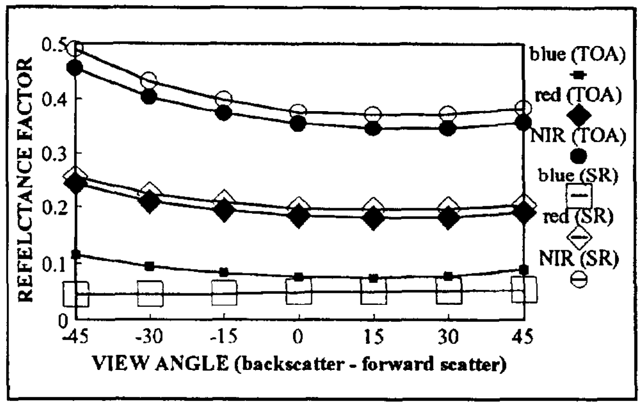

Fig. 1: BRF for HAPEX Tigerbush site (Sept 3, 1992, solar zenith angle 45°; data in solar principal plane) MODIS bands blue, red and near infrared, (TOA - top of atmosphere reflectance; SR - surface reflectance).

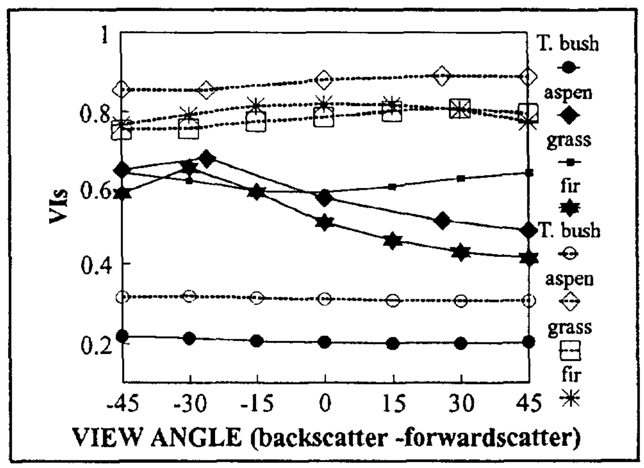

Fig. 2: Effect of surface anisotropy on MVI and NDVI for Tigerbush (HAPEX), Aspen (BOREAS), Douglas fir (OTTER), and Grassland (FIFE) (— MVI, ----- NDVI).

angles for both the NDVI and MVI and both the principal solar plane and the plane orthogonal to this. The hot spot affected the NDVI, but forward scatter view angles were preferentially selected for the maximum NDVI composite scenario. The maximum MVI scenario preferentially selected the backscatter direction. Maximum VI composite scenarios for at-surface reflectances and apparent reflectances had larger errors than the BRDF based scenarios, except for the BRDF scenarios with extrapolation to nadir sun and nadir view zenith angles. The latter scenario (scenario 4, Table 1) resulted in unrealistic estimates of reflectances and VIs. This was likely due to lack of variable solar zenith angles in the data sets. The bidirectional vegetation index function (BVIF) composite scenario was successful with only slightly higher errors than the BRDF composite scenario. The main disadvantage of the BVIF will be the loss of the actual surface reflectances needed to compute other VIs for instance.

The BRDF models (Walthall and Roujean) performed equally well for most vegetation types. A simple BRDF model seemed adequate to model the BRDF for a range of global vegetation types and produced nadir-equivalent VIs with a mean absolute error of about 0.62% for the MVI and 0.18 % for the NDVI, (respective standard deviations were 0.7% and 0.46 %).

CONCLUSIONS

Although limited measurements were available to model the BRDF for all combinations of view/sun azimuth and zenith angles, the parameterization of the BRDF models and the response of NDVI and MVI were different for most land cover types. A BRF correction of off-nadir reflectance factors to nadir equivalent values seems very much needed for both vegetation indices (NDVI and MVI), especially for higher vegetation covers. Maximum VI compositing scenarios introduced larger errors than the BRF composite scenarios (extrapolation to nadir view angle, at a representative sun angle), except when a BRDF model was used to extrapolate to surface reflectances with both nadir view and nadir sun angles. The results emphasize the importance of standardizing BRFs for vegetation index compositing schemes and retrieval of biophysical parameters.

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Table 1: Overview of the at-nadir NDVI and MVI from ASAS data for a range of vegetation types with estimates of measured leaf area index (LAI). Five composite scenarios were compared with reference to the nadir NDVI and MVI; 1) the maximum VI for apparent reflectances (TOA-top of atmosphere), 2) maximum VI for at-surface reflectances (SR), 3) VIs based on nadir-view-equivalent reflectances obtained with the Walthall BRDF model and the Roujean BRDF model, 4) VIs based on nadir view/sun equivalent reflectances obtained with the Walthall BRDF model and the Roujean BRDF model, and 5) nadir equivalent VIs based on substitution of the reflectances by VI values in Walthall's and Roujean's model. Future communications will include the presentation of all BRDF results for the NDVI. (where: (B) = BOREAS, (O)=OTTER, (F)=FIFE, (H)=HAPEX, pp - principal plane; op - orthogonal plane).

Vegetation type		LAI	sun zenith (°)	reference		Absolute difference (%) between the measured nadir MVI and NDVI and the composited MVI and NDVI													
				SR nadir MVI	SR nadir NDVI	TOA 1) max MVI	view angle (°)	TOA 1) max NDVI	view angle (°)	SR 2) max MVI	view angle (°)	SR 2) max NDVI	view angle (°)	MVI 3) Walt. BRDF	MVI 3) Rouj. BRDF	MVI 4) nadir Rouj.	MVI 5) Walt. BVIF	MVI 5) Rouj. BVIF	MVI 4,5) nadir BVIF
Old Black Spruce (B)	pp	3.5	33.7	0.280	0.744	-14.31	-45	5.81	30	-7.05	-45	0.00	45	-0.55	-0.30	12.00	-0.80	-0.60	20.25
Old Black Spruce (B)	op	3.5	33.5	0.285	0.730	-3.42	0	5.31	0	0.00	0	-0.19	26	1.09	0.97	16.77	1.06	0.97	22.93
Old Aspen (B)	pp	2.4	34.7	0.574	0.882	-21.01	-60	3.09	26	-10.5	-26	-1.67	55	-2.18	-1.44	4.39	-2.70	-1.96	5.64
Old Aspen (B)	op	2.4	36.1	0.540	0.890	-7.07	-26	4.08	0	-0.38	-26	0.00	0	0.17	-0.16	22.69	0.15	-0.17	38.15
Alder tree forest (O)	pp	4.3	34.6	0.461	0.913	-26.76	-45	7.00	30	-14.4	-45	-2.21	45	-1.13	-1.15	32.42	-1.34	-1.42	96.74
Old Forest (O)	pp	6.4	32.3	0.422	0.920	-26.41	-45	7.24	30	-15.7	-45	-1.96	45	-1.17	-1.18	45.41	-1.49	-1.56	143.29
Waring Woods (O)	pp	5.3	30.7	0.354	0.623	-14.85	-30	2.46	30	-8.15	-30	-1.79	-15	-1.17	-1.16	20.61	-1.35	-1.36	36.70
Douglas Fir (O)	pp	8.6	31.5	0.509	0.820	-21.23	-30	4.54	15	-14.6	-30	0.00	0	-2.11	-2.09	29.16	-2.55	-2.51	88.52
green grass (F)	pp	1.3	48.3	0.589	0.785	-23.03	-45	4.14	15	-5.30	45	-2.34	30	-0.53	-0.75	21.20	-0.40	-0.68	221.86
green grass (F)	op	1.3	42.4	0.598	0.784	-15.28	-45	3.98	30	-5.01	-45	-2.02	30	-0.62	-0.55	-28.33	-0.61	-0.54	138.45
senescent grass (F)	pp	0.2	54.3	0.296	0.482	-10.78	45	-1.30	30	-5.64	45	-2.48	30	-0.66	-0.64	13.92	-0.71	-0.67	19.99
senescent grass (F)	op	0.2	60.8	0.304	0.482	-11.52	45	-0.16	-30	-3.72	45	-0.96	-45	-0.02	-0.11	22.55	0.00	-0.10	30.19
Fallow savanna (H)	pp	0.5	36.0	0.219	0.302	-7.35	-45	-2.57	-45	-3.26	-45	-2.74	-45	-0.20	-0.17	2.98	-0.20	-0.18	3.84
Tigerbush (H)	pp	0.5	43.0	0.203	0.309	-5.66	-45	-0.62	0	-1.50	-45	-0.79	-30	0.01	-0.02	3.55	0.02	0.00	10.00
mean absolute difference for all vegetation types						**-14.91**		**3.07**		**-6.81**		**-1.37**		**-0.65**	**-0.62**	**15.66**	**-0.78**	**-0.77**	**63.00**
Standard deviation						**7.22**		**2.90**		**4.90**		**0.94**		**0.82**	**0.70**	**16.10**	**0.97**	**0.85**	**61.33**