

## THE ANGULAR VEGETATION INDEX: AN ATMOSPHERICALLY RESISTANT INDEX FOR THE SECOND ALONG TRACK SCANNING RADIOMETER (ATSR-2)

S. E. PLUMMER, P. R. NORTH AND S. A. BRIGGS

British National Space Centre,  
Remote Sensing Applications Development Unit,  
Monks Wood, Abbots Ripton,  
Cambridgeshire, PE17 2LS  
UK

Tel: 44 487 3381

Fax: 44 487 3277

### ABSTRACT:

A vegetation index which is resistant to atmospheric scattering, the Angular Vegetation Index (AVI), is defined. This index has been developed for the three optical channels which will be provided by the second Along Track Scanning Radiometer (ATSR-2) although it is similarly applicable to any sensor with green, red and near infrared wavebands. A sensitivity analysis is performed using a coupled soil-vegetation-atmosphere model which combines a soil model, the PROSPECT leaf model, SAIL canopy model with hot-spot and the Lowtran-7 atmospheric package. Preliminary results for a canopy with a spherical leaf angle distribution, for one solar position and at the nadir view indicate that the AVI is resistant to the effects of variation in atmospheric optical depth and aerosol size distribution. Based on example light and dark soils AVI is also unaffected by soil brightness. Variation in leaf chlorophyll concentration does, however, affect AVI but only beyond an LAI of 2.

**KEY WORDS:** Atmospheric resistance, ATSR-2, vegetation index, simulation

### 1. INTRODUCTION

This paper presents preliminary work on the development and testing of a new vegetation index for use with data from the second Along Track Scanning Radiometer (ATSR-2). The ATSR-2 instrument will be launched on ERS-2 in 1995 as a follow-on to the ATSR sensor on ERS-1. It will match the characteristics of ATSR but will also carry three experimental optical channels centred at 555, 659 and 865 nm with a bandwidth of 20 nm. Additionally the ATSR-2 provides a dual look capability along track using a conical scan mechanism with a spatial resolution of 1 km at nadir and 2x3 km for the 55° forward view. The three channels are positioned to maximise the difference between vegetation and background but also to avoid major atmospheric absorptions. These optical data will offer an alternative to the current Advanced Very High Resolution Radiometer (AVHRR), for regional and global vegetation monitoring.

The Normalised Difference Vegetation Index (NDVI), which is a combination of the of measurements in the near-infrared and red wavelengths, provides a measure of changes in vegetation. However, when calculated from top-of-the-atmosphere (TOA) radiances NDVI is highly sensitive to variation in optical thickness and when calculated from measurements made with the AVHRR sensitive to absorption by columnar water vapour. The dominant atmospheric effect, however, is due to atmospheric scattering by atmospheric aerosols and gases. Further advances in quantitative remote sensing of vegetation, therefore, require the development of either accurate atmospheric correction or redefinition of NDVI such that it is insensitive to atmospheric effects.

Recently a number of authors (Kaufman and Tanré 1992, Pinty and Verstraete 1992, Philpot 1991) have suggested indices to either redefine the NDVI to make it less sensitive to atmospheric effects or provide alternatives to NDVI. The proposal by Philpot (1991) requires sufficient wavebands to generate a second derivative for each waveband used to develop the ratio algorithm. The examples given use high spectral resolution data rather than that available from ATSR-2. The Pinty and



Verstraete algorithm, the Global Environment Monitoring Index (GEMI), is a non-linear index which attempts to combine the sensitivity of the Simple Ratio (SR) for low vegetation cover and the NDVI for deep vegetation while being resistant to atmospheric effects. Simulations with this index, however, have shown it to have a small dynamic range and be highly sensitive to soil colour. The Atmospherically Resistant Vegetation Index (ARVI) (Kaufman and Tanré 1992) takes advantage of information provided by the blue waveband of the MODIS sensor to make NDVI less variable with atmospheric perturbation. Unfortunately, this approach cannot be applied to ATSR-2 data, since the assumptions behind the method cannot be translated to use a green waveband.

The focus of this preliminary work was to consider how the information from the three optical channels of ATSR-2 could be used to provide a vegetation index that was resistant to atmospheric scattering whilst at the same time being sensitive to variation in vegetation amount.

## 2. CONCEPT

Atmospheric scattering can be separated into molecular or Rayleigh scattering and aerosol or Mie scattering. The former is characterised by an optical thickness which decreases as a function of wavelength approximately equal to  $\lambda^{-4}$  although the exact form is contingent on atmospheric pressure. The effect of atmospheric aerosols on remote sensing is dependent on the chemical and physical characteristics of the aerosol (Kaufman 1989), although if the aerosol is assumed to be spherical it can be approximated by Mie Theory which also exhibits a decrease with wavelength. A further difficulty is the spatial and temporal inhomogeneity of the aerosol loading. With reference to remote sensing of vegetation the effect of atmospheric scattering declines with wavelength resulting in increased TOA reflectance in visible wavelengths and when allied with continuum absorption a decline in TOA reflectance in near-infrared wavelengths. Thus increased optical thickness can be equated to a rotational movement with a large positive component in the green waveband, a smaller one in the red and a negative component in the near-infrared. An index which is invariant with this rotational movement should exhibit resistance to atmospheric effects.

The emergence of vegetation over a dark soil will result in an increase in reflectance in green wavelengths, although as chlorophyll density increases this may decline again; a decrease in red wavelengths associated with vegetation reflectance and a strong increase in near-infrared wavelengths. Thus an index which represents the dynamic range of reflectance in each of these bands will provide a good indication of vegetation presence. An index, the Angular Vegetation Index (AVI), which is intended to incorporate the sensitivity to vegetation presence whilst being insensitive to the rotational movement was defined using the three ATSR-2 channels to calculate the angle subtended in the red chlorophyll absorption well (Figure 1):

$$AVI = \tan^{-1} \left\{ \frac{\lambda_3 - \lambda_2}{\lambda_2} [\rho(\lambda_3) - \rho(\lambda_2)]^{-1} \right\} + \tan^{-1} \left\{ \frac{\lambda_2 - \lambda_1}{\lambda_2} [\rho(\lambda_1) - \rho(\lambda_2)]^{-1} \right\} \quad (1)$$

where  $\rho(\lambda_i)$  is the radiance in band  $i$  normalised by the exo-atmospheric incident flux and  $\lambda_i$  is the centre wavelength of band  $i$ . The dependence on wavelength position is removed by normalising to the centre wavelength,  $\lambda_2$ . The value of AVI is scaled to 0-1 range by subtraction from 180 and division by 90.

## 3. MATERIALS AND METHODS

The sensitivity of AVI to the presence of vegetation, atmospheric perturbation and soil colour was tested using a forward model developed for simulating the at-sensor radiance for ATSR-2. The simulator comprises scattering models for soil, leaves, vegetation canopy and atmosphere. Nadir reflectance data obtained from the Purdue Soils database (Stoner *et al.* 1980) were used to represent the soil. Off-nadir effects were generated by inversion of Hapke's functions to derive the average particle single scattering albedo,  $\omega$ . The remaining coefficients were represented by typical values obtained from other experiments.



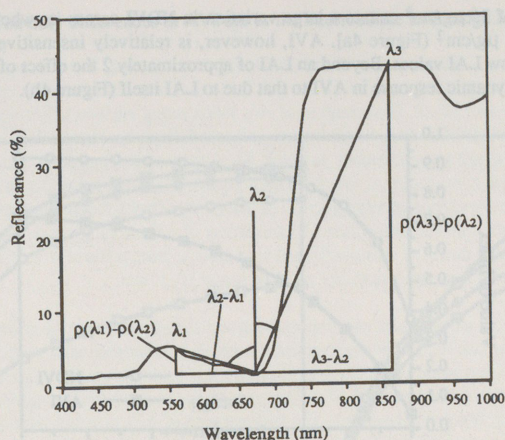


Figure 1: Parameters used in calculation of the Angular Vegetation Index (AVI)

The vegetation canopy reflectance was derived from a combination of the PROSPECT (Jacquemoud and Baret 1990) leaf reflectance model and the SAIL canopy reflectance model (Verhoef 1984) with a 'bolt-on' hotspot (Jupp and Strahler 1991). The at-sensor radiance distribution function was generated from the SAIL-generated bi-directional reflectance distribution function (BRDF) using the LOWTRAN-7 atmospheric model (Kneizys *et al.* 1988). Finally this was convolved with the sensor model to generate the at-sensor radiance received for the three channels of ATSR-2.

The relative sensitivity of the AVI was tested against the equivalent NDVI. In examination of the sensitivity to the atmosphere the input parameters for PROSPECT were set for a healthy grass leaf ( $C_{ab} = 35 \mu\text{g}/\text{cm}^2$ ,  $C_w = 0.01 \text{ cm}$  and  $N = 1.5$ ). Similarly the SAIL model was constrained to a dark soil, spherical leaf angle distribution, and the leaf area index (LAI) varied from 0 to 6. View zenith and azimuth were both  $0^\circ$  and solar zenith and azimuth set at  $30^\circ$  and  $30^\circ$  relative to North respectively. The effect of atmosphere was tested by varying ground visibility from 10 to 50 km and the aerosol size distribution using rural and maritime aerosol models provided in LOWTRAN-7. The effect of soil colour was examined using typical 'light' (Caribou) and 'dark' (Berkshire) soils extracted from the Purdue Soils Database, while the effect of leaf colour was tested by varying chlorophyll concentration from 5 to  $35 \mu\text{g}/\text{cm}^2$ .

#### 4. RESULTS

##### 4.1 Sensitivity of AVI to Vegetation Fraction, Soil Brightness and Leaf Chlorophyll Concentration

The AVI, calculated from canopy reflectance data, was tested for sensitivity to vegetation fraction represented by LAI, which is used as the base variable for all the tests, soil brightness and leaf chlorophyll concentration. In these tests and those involving the atmosphere the performance of AVI was judged with respect to NDVI. The variation of AVI and NDVI with vegetation amount is shown in Figure 2. Over a range of LAI of 0-6 both the indices are non-linear with NDVI in particular exhibiting a steep increase in value from 0 to an asymptote at an LAI of 3. By contrast AVI continues to increase to an LAI of 6. The effect of soil brightness on NDVI and AVI is revealed in Figure 3. The NDVI exhibits a large decrease in value with increasing soil brightness in line with the observations of Huete (1988) (Figure 3a). The AVI, however, is relatively insensitive to the effect of soil brightness when computed for canopy reflectance data (Figure 3b). A difference in leaf chlorophyll concentration from



5  $\mu\text{g}/\text{cm}^2$  to one of 35  $\mu\text{g}/\text{cm}^2$  causes a large variation in NDVI across its whole range particularly between 5 and 15  $\mu\text{g}/\text{cm}^2$  (Figure 4a). AVI, however, is relatively insensitive to leaf chlorophyll concentration for low LAI values. Beyond an LAI of approximately 2 the effect of chlorophyll starts to produce a similar dynamic response in AVI to that due to LAI itself (Figure 4b).

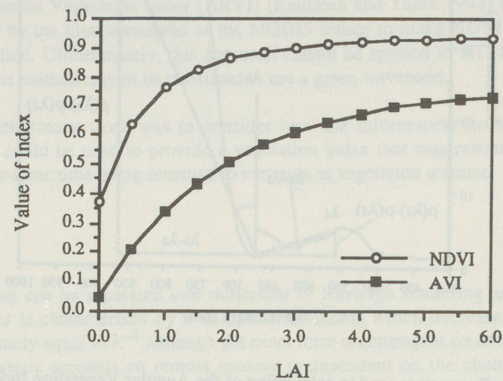


Figure 2: Variation of NDVI and AVI with leaf area index (LAI)

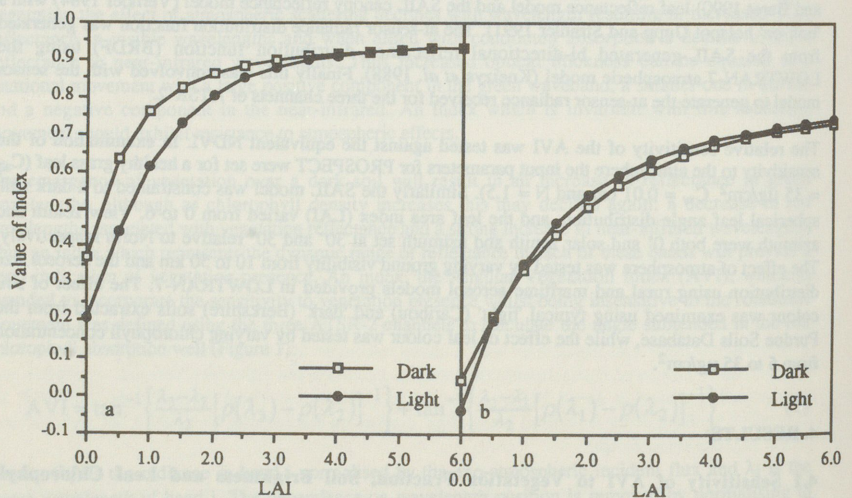


Figure 3: Variation of a) NDVI and b) AVI as a function of LAI and soil brightness

#### 4.2 Effect of Ground Visibility and Aerosol Size Distribution on AVI

The comparison of the sensitivity of AVI and NDVI with decreasing ground visibility for a mid-latitude summer atmosphere and the rural aerosol model is shown in Figure 5. NDVI clearly exhibits large variation with optical thickness. At the maximum LAI this equates to a difference in NDVI of 0.2 and for such an error in ground visibility the estimated LAI occupies a range from 1.7-6.0 (Figure 5a). By contrast the AVI shows little variation with ground visibility particularly over the range 20-50 km (Figure 5b). The effect of error in aerosol size distribution was small for both NDVI and AVI. For 10 km visibility the NDVI exhibited a decrease in value at low LAI as the aerosol size distribution was altered from Maritime to Rural. At 50 km, however, the principal effect was at high LAI with an



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increase in NDVI. The only differences in AVI are in the intermediate LAI range for both a 10 km and a 50 km atmosphere.

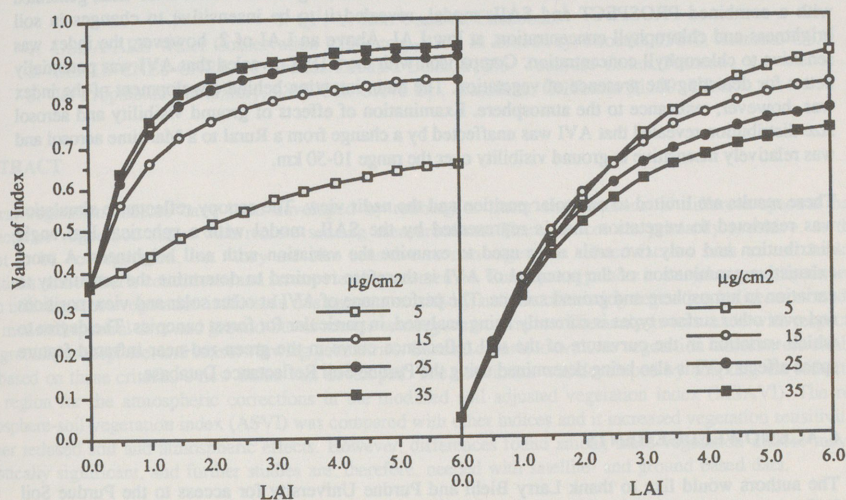


Figure 4: Variation of a) NDVI and b) AVI as a function of LAI and leaf chlorophyll concentration

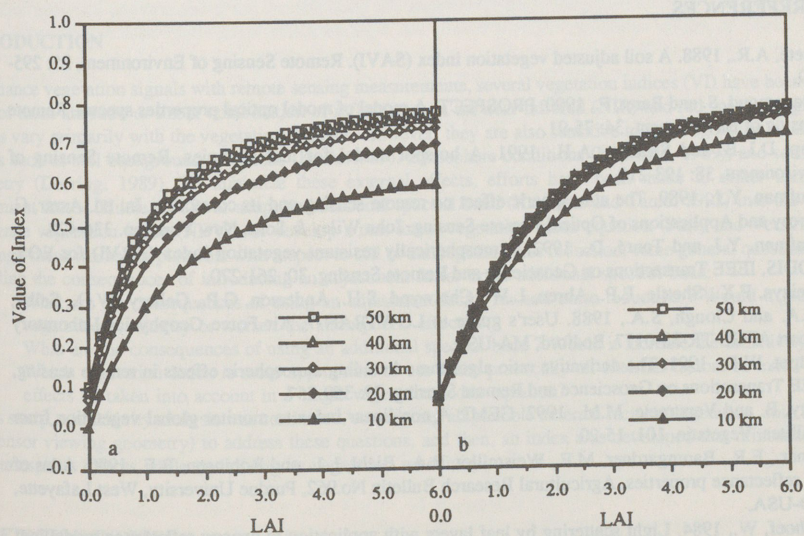


Figure 5: Variation of a) NDVI and b) AVI with ground visibility



## 5. DISCUSSION AND CONCLUSIONS

This paper presents observations on the definition and testing of an atmospherically resistant vegetation index, the Angular Vegetation Index (AVI) for use with data from the second Along Track Scanning Radiometer (ATSR-2). Examination of this index using surface reflectance data, generated with a combined PROSPECT and SAIL model, revealed it to be insensitive to changes in soil brightness and chlorophyll concentration, at low LAI. Above an LAI of 2, however, the index was sensitive to chlorophyll concentration. Comparison with the NDVI revealed that AVI was potentially better for detecting the presence of vegetation. The main intention behind development of the index was, however, resistance to the atmosphere. Examination of effects of ground visibility and aerosol size distribution revealed that AVI was unaffected by a change from a Rural to a Maritime aerosol and was relatively insensitive to ground visibility over the range 10-50 km.

These results are limited to one solar position and the nadir view. The canopy reflectance simulation was restricted to vegetation that is represented by the SAIL model with a spherical leaf angle distribution and only two soils were used to examine the variation with soil brightness. A more exhaustive examination of the potential of AVI is therefore required to determine the sensitivity to variation in atmosphere and ground surface. The performance of AVI at other solar and view positions and over other surface types is currently being analysed, in particular for forest canopies. The degree to which variation in the curvature of the soil reflectance curve in the green-red-near infrared feature space affects AVI is also being determined using the Purdue Soil Reflectance Database.

## 6. ACKNOWLEDGEMENTS

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