

## Relation between spectral reflectance and vegetation index

S.M.Singh

NERC Unit for Thematic Information Systems, Department of Geography, University of Reading, UK

**ABSTRACT:** Atmospheric corrections are applied to the Advanced Very High Resolution Radiometer (AVHRR) channel-1 and channel-2 data. Both raw and atmospherically corrected Normalized Difference Vegetation Indices (NDVIs) are calculated. A comparison between them shows a contrast enhancement by a factor of at least two when atmospheric corrections are applied. Spectral reflectances and atmospherically corrected NDVI are partially correlated indicating a possibility of improving surface cover classification using NDVI and spectral reflectances instead of NDVI values alone. Raw NDVI and atmospherically corrected NDVI do not have a unique relationship but are highly correlated. This indicates that atmospheric corrections be applied to each scene of interest.

### 1 INTRODUCTION

The visible channel (0.58-0.68  $\mu\text{m}$ ; hereafter referred to as channel-1) and near infrared channel (0.725-1.1  $\mu\text{m}$ ; hereafter referred to as channel-2) data from the Advanced Very High Resolution Radiometer (AVHRR) instrument flown on the Tiros-N/NOAA meteorological satellites have been found to be useful for monitoring health and vigour of photosynthetically active vegetation canopy. These data have been used for mapping and monitoring vegetation cover on local and continental scale (for example, see Tucker et al., 1983, 1984 and Hayes and Cracknell, 1984) as well as on a global scale (Justice et al., 1985). There is a daily coverage at higher latitudes but around the equator complete coverage requires three days. This means that the global coverage data could be obtained in three days if there were no cloud covers. There is an absorption band of chlorophyll within channel-1 wavelength range whereas wavelengths within channel-2 spectral band width are strongly reflected by green pigments. In principle, the data from these two spectral channels should be correlated to the abundance of vegetation. Many relations exist in the literature for calculating vegetation index, for example, see Hayes (1985). Most popular of all relations is the so-called Normalized Difference Vegetation Index (NDVI) which is defined as

$$\text{NDVI} = \frac{\text{DN2} - \text{DN1}}{\text{DN2} + \text{DN1}} \quad (1)$$

where DN1 and DN2 are channel-1 and channel-2 pixel values, respectively. There are several advantages of using equation (1) rather than channel-2 data only; because of optical properties of photosynthetically active chlorophyll as noted above, equation (1) results in enhanced values of NDVI, which could be useful particularly for low vegetation; the relation (1) partially compensates for atmospheric interference, solar elevation, changing solar irradiance on the surface and topographic effects (see, Justice et al., 1985).

Ideally, one would have liked to remove atmospheric effects from these data first and then calculated vegetation indices because band ratioing does not remove atmospheric effects completely (Holben and Justice, 1981). The reason is that

atmospheric contaminations in channel-1 and channel-2 are not proportional to each other. The larger the view angle of the sensor the larger the atmospheric contribution is expected to be. Therefore, even if there were no topographic effects and if surfaces were Lambertian in nature, the NDVI values calculated from equation (1) have strong view angle dependence (Duggin et al., 1982), a significant fraction of which is expected to be due to atmospheric effects. Within the framework of vegetation mapping and monitoring, the same surface area is viewed from various viewing angles (from different orbits) and it is evident from the work of Duggin et al. (1982) and many others that the NDVI values do depend on the view angle. However, it has not yet been possible to come up with a perfect atmospheric correction algorithm because of the difficulties in estimating atmospheric contamination due to aerosols. Nevertheless, an approximate estimate of atmospheric contribution to remotely sensed data can be made.

One finds the same NDVI value for several surface cover types (Townshend and Tucker, 1985) and, therefore, vegetation type classification using NDVI values alone has limited success. Ideally, one would like to have several spectral band data which are partially or poorly correlated among themselves so that each spectral channel data carries information about the nature of surface cover which supplements information carried in other spectral channels. Using Landsat Thematic Mapper (TM) data Toll (1985) demonstrates that the land cover classification accuracy does not improve by adding spectral channel data which are highly correlated to other channel(s) data which are already used for classification. Also, when photosynthetically active chlorophyll amount increases (say, in dense forests) the NDVI values calculated from equation (1) tend to saturate thereby limiting the range of applicability of equation (1). Under such circumstances it would be interesting to see how channel-1 reflectivity changes and whether or not this reflectivity is still a sensitive function of vegetation abundance. It is in this spirit that a brief summary of atmospheric correction technique will be presented, channel-1 and channel-2 reflectivities will be calculated, raw and atmospherically corrected NDVI will be calculated and relationship between reflectivities and NDVI values will be examined in order to find some uncorrelated or partially correlated parameters which may prove to be valuable for land cover classification.

## 2 ATMOSPHERIC CORRECTION SCHEME

The satellite-sensor recorded radiance,  $L(\lambda)$  in  $\text{mW}/(\text{cm}^2 \text{sr } \mu\text{m})$  is calculated from (Hughes and Henderson-Sellers, 1982)

$$L(\lambda) = 0.01 \cos \theta_s K e(\lambda) [G \text{ DN} + I]/\pi \quad (2)$$

where  $\theta_s$  is the solar zenith angle,  $K$  is the correction factor for Sun-Earth distance variation,  $\text{DN}$  is the digital count,  $G$  is the percentage spectral albedo per count,  $I$  is the percentage intercept albedo (Lauritson et al., 1979) and  $e(\lambda)$  is given by

$$e(\lambda) = \int_0^\infty \bar{E}(\lambda^1) \hat{\phi}(\lambda^1) d\lambda^1 \quad (3)$$

where  $\lambda^1$  is a dummy integration variable,  $\bar{E}(\lambda)$  is the solar irradiance on the top of atmosphere for mean Sun-Earth distance per unit projected area (Thekaekara et al., 1969) and  $\hat{\phi}(\lambda)$  is the sensor response function which is normalized to unity, i.e.

$$\int_0^\infty \hat{\phi}(\lambda) d\lambda = 1 \quad (4)$$

so that

$$\hat{\phi}(\lambda) = \phi(\lambda) / \int_0^\infty \phi(\lambda^1) d\lambda^1 \quad (5)$$

where the values of  $\phi(\lambda)$  can be estimated from Lauritson et al. (1979). On the other hand the satellite-sensor recorded radiance may be expressed as

$$L(\lambda) = L_{\text{PR}}(\lambda) + L_{\text{pa}}(\lambda) + L_s(\lambda)t(\lambda, \theta) \quad (6)$$

where  $L_{\text{PR}}(\lambda)$  is the Rayleigh path radiance,  $L_s(\lambda)$  is the aerosol path radiance,  $L_{\text{pa}}(\lambda)$  is the diffuse surface radiance,  $t(\lambda, \theta)$  is the diffuse transmittance from surface being viewed to the sensor and  $\theta$  is the zenith angle of a ray from surface being viewed to the sensor. In writing equation (6), separability of the Rayleigh and aerosol atmospheres has been assumed (Gordon, 1978). Within the single scattering approximation an expression for path radiance may be written as

$$L_{\text{px}}(\lambda) = \bar{E}(\lambda) K T_{\text{oz}}(\lambda, \theta_s) \tau_x(\lambda) \times$$

$$[P_x(\psi_-) + \rho(\lambda, \theta_s) P_x(\psi_+)] \quad (7)$$

where  $T_{\text{oz}}$  is the two way transmittance through the ozone layer,  $\tau$  is the optical thickness,  $P$  is the phase function,  $\psi$  is the scattering angle,  $\rho$  is the surface reflectivity and  $x = R$  for Rayleigh scattering processes and  $x = a$  for aerosol scattering processes. Further details can be found in Singh and Cracknell (1986). For a Lambertian surface the diffuse reflectance is defined by

$$\rho(\lambda) = \pi L_s(\lambda) / E_g(\lambda) \quad (8)$$

where  $E_g(\lambda)$  is the global solar irradiance on the surface. Note that the global solar irradiance is not known without experimentation and it changes with solar elevation, wavelength and optical thickness. In this work global solar irradiance was

estimated using an expression given by Singh et al. (1985). To calculate surface reflectances from the AVHRR data an iterative method was adopted which is summarized below.

To start with  $\rho$  was set equal to zero. An average continental type aerosol was assumed (Janza, 1975) and path radiances were estimated from equation (7). Clearly path radiances estimated in this manner would be underestimated, the diffuse surface radiance,  $L_{\text{S}}(\lambda)$ , calculated from equations (2), (6) and (7) would be overestimated. When this value of  $L_{\text{S}}(\lambda)$  is substituted in equation (8) then the resulting diffuse reflectance would be larger than the actual value. In the next step of iteration this value of reflectance is used in equation (7) and the above procedure is repeated. Using reasoning parallel to the above it is apparent that the reflectivity obtained from the second iteration step would be smaller than the actual value. This procedure is continued until a desired convergence is reached, i.e. until the absolute difference in reflectivities from  $n$ th and  $(n+1)$ th iteration steps is found to be smaller or equal to a prefixed threshold value. The threshold is determined from equation (8) with radiance which is equivalent to half a digital number. This iterative procedure has been tested using ten AVHRR scenes and for most cases only three or four iterations were required and there was only one case for which about seven iterations were required for the desired convergence. The atmospherically corrected NDVI was then evaluated from

$$\text{NDVI} = \frac{\rho(\lambda_2) - \rho(\lambda_1)}{\rho(\lambda_2) + \rho(\lambda_1)} \quad (9)$$

If the atmospheric correction algorithm were perfect then it would suffice to define vegetation index (VI) as  $\text{VI} = \rho(\lambda_2) / \rho(\lambda_1)$ . The reason for retaining the form of equation (9) similar to the form of equation (1) is to further compensate for residual atmospheric contributions and to compensate (partially) for changing solar zenith angle, varying global irradiance and topographic effects.

Topographic effects on remotely sensed data are difficult to correct for. From the work of Duggin et al. (1982) and Singh and Cracknell (1985, 1986) it seems that there are at least three factors which contribute to the satellite data as view angle changes: (a) the larger the view angle the larger is the atmospheric path length and hence the larger will be atmospheric contribution; (b) natural surfaces are non-Lambertian whereas remotely sensed radiances are assumed to be from Lambertian surfaces and (c) solar irradiation on the surface as seen by a remote sensor along a scan line is not necessarily uniform and this is because of shadows cast by vertical relief (natural as well as man made). An approximate atmospheric correction scheme which has been outlined above and which has been applied to a number of images by Singh and Cracknell (1985, 1986) indicates that a significant amount of view angle dependence of atmospheric effects caused by (a) above can be removed. However, it is not yet possible to correct remotely sensed data due to causes (b) and (c) above.

## 3 DATA USED

The AVHRR/2 data from NOAA-7 satellite which have been used in this preliminary investigation were collected at 14:37 GMT on 20 August, 1984 at the Dundee University satellite-data receiving station. The selected area is the United Kingdom from about 50 to 55 degrees latitude. The western part including Ireland were cloudy. Only those pixels were selected for which raw NDVI values were positive. This constraint eliminates water pixels, and to some

extent identifies cloudy pixels over the land. Since the data acquisition time was local afternoon and since there were clouds on the western side of the selected scene, there might have been some pixels which were contaminated by cloud shadows and identification of such pixels is not yet possible.

#### 4 RESULTS AND DISCUSSION

Raw NDVI were calculated using equation (1). The atmospheric correction procedure was implemented and spectral reflectances  $\rho(\lambda_1)$  and  $\rho(\lambda_2)$  were calculated. Equation (9) then yields atmospherically corrected NDVI values. A relation of the form of equation (10) was sought between raw and atmospherically corrected NDVI values.

$$Y = mX + c \quad (10)$$

where Y is atmospherically corrected NDVI and X stands for raw NDVI. Line by line regression analysis was performed on a 512 x 512 scene but because of cloud cover and surrounding waters only about 80 to 200 pixels per scanline corresponded to cloud-free land area. For each scanline raw NDVIs were highly correlated to atmospherically corrected NDVI values. In fact the squared correlation coefficient ranged from 85% to 98%. The parameter c in equation (10) varied from about -0.1 to about -0.03 whereas the slope (or enhancement or magnification) m ranged from about 2.2 to 3.5. These results indicate that the relation (10) is not a unique one. Had it been a unique relation then it would have been of great value. Therefore, it suggests that one has to apply atmospheric correction to each scene of interest. It is also clear from the values of m found above that the atmospherically corrected NDVI imagery should have high contrast compared to the contrast present in raw NDVI maps. Next a relation similar to equation (10) was sought between  $\rho(\lambda_1)$  and atmospherically corrected NDVI. There was a large variability in the value of m (2 to 30) but an important outcome was that the squared correlation coefficient ranged from about 30% to about 90%. This shows that  $\rho(\lambda_1)$  carries some extra information to which NDVI is not sensitive. A similar analysis between  $\rho(\lambda_2)$  and atmospherically corrected NDVI showed a poor correlation between these two parameters. Therefore,  $\rho(\lambda_1)$ ,  $\rho(\lambda_2)$  and atmospherically corrected NDVI values may be useful in improving surface cover type classification and further investigations are underway.

#### 5 CONCLUSIONS

The primary motivation was to search for more than one parameter for land-cover classification. Application of atmospheric correction results in an increased contrast between too dissimilar surfaces. It is shown that the atmospherically corrected NDVIs are partially correlated to either channel reflectivity. This means that these three parameters may prove to be of importance in improving land cover classification. Although atmospherically corrected NDVIs and raw NDVIs are highly correlated to each other, these preliminary results indicate that there is no unique relation between these two quantities. Thus, one has to apply atmospheric correction to each scene of interest.

#### ACKNOWLEDGEMENT

This work was carried out under the NERC contract No. F60/G6/12.

#### REFERENCES

- Duggin, M.J., Piwinski, D., Whitehead, V. and Ryland, G., 1982, The scan angle dependence of radiance recorded by the NOAA-AVHRR. Proceedings of the AIAA/SPIE technical meeting, San Diego, California, 23-27 Aug., SPIE Vol. 363, p.98.
- Gordon, H.R., 1978, Removal of atmospheric effects from satellite imagery of the oceans, Appl. Opt., Vol. 13, p.1361.
- Hayes, L., 1985, The current use of Tiros-N series of meteorological satellites for land-cover studies, Int. J. Rem. Sens., Vol. 6, p.35.
- Hayes, L. and Cracknell, A.P., 1984, A comparison of Tiros-N series satellite data and Landsat data over Scotland. Proc. of Integrated Approaches in Remote Sensing, ESA SP-214, p.63.
- Holben, B.N. and Justice, C.O., 1981, An examination of spectral band ratioing to reduce the topographic effect on remotely sensed data, Int. J. Rem. Sens., Vol. 2, p.115.
- Hughes, N.A. and Henderson-Sellers, A., 1982, System albedo as sensed by satellites: its definition on variability. Int. J. Rem. Sens., Vol. 3, p.1.
- Janza, F.J. (editor), 1975, Manual of Remote Sensing, Vol. I, American society of photogrammetry, Falls Church, Virginia.
- Justice, C.O., Townshend, J.R.G., Holben, B.N. and Tucker, C.J., 1985, Analysis of the phenology of global vegetation using meteorological satellite data, Int. J. Rem. Sens., Vol. 6, p.1271.
- Lauritson, L., Nelson, G.J. and Porto, F.W., 1979, Data extraction and calibration of Tiros-N/NOAA radiometers. NOAA technical memorandum NESS-107, NOAA/NESS, Washington D.C.
- Manual of Remote Sensing, 1983, (editor in chief), Data interpretation and applications. American society of photogrammetry, Falls Church, Va.
- Otterman, J., 1983, Absorption of insolation by land surface with sparse vertical protrusions, Tellus, Vol. 35B, p.309.
- Singh, S.M., 1986, Vegetation index and possibility of complementary parameters from AVHRR/2. Int. J. Rem. Sens., Vol. 7, p.295.
- Singh, S.M. and Cracknell, A.P., 1985, Effect of shadows cast by vertical protrusions on AVHRR data. Int. J. Rem. Sens., Vol. 6, p.1767.
- Singh, S.M. and Cracknell, A.P., 1986, The estimation of atmospheric effects for SPOT using AVHRR channel-1 data. Int. J. Rem. Sens., Vol. 7, p.
- Singh, S.M., Cracknell, A.P. and Spitzer, D., 1985, Evaluation of sensitivity decay of Coastal Zone Scanner (CZCS) detectors by comparison with in-situ near surface radiance measurements. Int. J. Rem. Sens., Vol. 6, p.749.
- Thekaekara, M.P., Kruger, R. and Duncan, C.H., 1969, Solar irradiance measurements from research aircraft, Appl. Opt., Vol. 8, p.1713.
- Toll, D.L., 1985, Landsat-4 Thematic Mapper scene characteristics of a suburban and rural area, Photogram. Eng. and Rem. Sens., Vol. LI, p.1471.
- Townshend, J.R.G. and Tucker, C.J., 1985, Continental land cover classification using satellite data. Proc. of the 36th Congress of the International Astronomical Federation, Stockholm, Sweden, Oct. 1985, Peaceful Space and Global Problems of Mankind, Pergamon Press: Oxford, New York, Toronto, Sydney, Frankfurt.
- Tucker, C.J., Gatlin, A. and Schneider, S.R., 1984, Monitoring vegetation in the Nile Delta with NOAA-6 and NOAA-7 AVHRR. Photogramm. Eng. and Remote Sensing, Vol. 50, p.53.
- Tucker, C.J., Holben, B.N. and Goff, T.E., 1984, Intensive forest clearing in Rondonia, Brazil as detected by satellite remote sensing. Remote Sensing Environ., Vol. 15, p.255.

