Using ATSR-2 data to understand the temporal and spatial dynamics of vegetation in the arid region of Jordan

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Abstract
Vegetation cover in arid regions is typically sparse, showing large spatial and temporal variability due to factors such as the availability of water and the quality and type of soil. This paper describes how these variations can be detected and monitored using ATSR-2 imagery. Using data collected over a two year period for the semi-arid Badia region of Jordan, a geometric optical/empirically based model was used to detect changes in vegetation cover. Results showed that the use of a model considering processes at the sub-pixel scale allows one to model changes in reflectance with changing percentage vegetation cover, and thus predict cover from ATSR-2 imagery. Correlations of 0.85 were found between predicted percentage vegetation covers and actual observations made at 17 field sites in the study area.

Introduction

90 % of the land area of Jordan can be described as land useful for the grazing of livestock (Ibu-Irmaileh, 1994). It is an important resource providing a means of subsistence for the nomadic people of the Bedouin tribes, who move around the desert margins to find food for their sheep, goats and camels. Grazing land in arid regions typically supports vegetation that is sparse in cover, and temporally and spatially variable. This paper describes work carried out in an area of north-east Jordan, investigating the way in which the Along Track Scanning Radiometer (ATSR-2) can be used to study the spatial and temporal dynamics of vegetation in arid regions. Using a geometric optical/empirically based model, percentage vegetation cover values are predicted from ATSR-2 imagery.

ATSR-2

The ATSR-2 was launched on board the European Research Satellite (ERS-2) in April 1995. With a coverage cycle of 6 days, a 500 km swath and a spatial resolution of 1 * 1 km at nadir, it is particularly well suited to the application of land cover mapping and monitoring over large spatial areas. The ATSR-2 has seven wavebands, centred at 0.555 μm, 0.659 μm, 0.865 μm, 1.6 μm, 3.7 μm, 10.8 μm and 12 μm. It was designed specifically for vegetation studies by providing four wavebands in the visible and near-infrared regions of the electromagnetic spectrum. These wavebands are particularly narrow (i.e. 20 nm for the red waveband compared to100 nm of the Advanced Very High Resolution Radiometer), and should aid the detection of the red/near-infrared characteristics of vegetation (Mason and Delderfield, 1990). Another feature of ATSR-2 is that it has a dual view. Every point on the Earth's surface is scan twice, once at nadir and once at a forward look angle of 55°. Discussion of the utility of the dual view in relation to arid land vegetation detection is discussed elsewhere (see Edwards, 1999), and for the purposes of this paper, imagery taken at nadir is considered.

The Study Area

Two regions of Jordan were the study area for this work, the Badia region of Jordan and the Jordan Valley. The Badia region of Jordan lies in the north-east, 'pan-handle' of Jordan. Bordered by Syria in the north, and Saudi Arabia in the South, the region covers an area of approximately 11,210 km^2. The Badia has an arid climate (50 mm yr^{-1}), and vegetation in the area is sparse, showing large temporal and spatial variations. Dry, woody, xerophytic shrubs dominate the area, interspersed with green ephemeral species in the period immediately after winter rainfall.

The Jordan Valley, by contrast, is an area of much higher rainfall (up to 500 mm yr^{-1}), and intense irrigation. Banana plantations, orange groves and olive orchards mean vegetation in the region forms a dense coverage of green, photosynthetically active plants. The area provides higher percentage vegetation coverages (up to 100%) with which to compare with the low coverages in the Badia.

Methodology

The field area was visited on three occasions, in the autumn of 1995, the spring of 1996 and the autumn of 1997. On each occasion, field surveys were carried out at 17 field sites, selected on the basis of being flat, homogeneous, and large enough to cover the equivalent of 3 x 3 ATSR-2 pixels (after the formula of Justice and Townshend, 1981). At each field site, three 30 x 30 m quadrats were randomly located. Within each quadrat, ten 20 m transects were laid out, again positioned using random co-ordinates. Every plant crossing the transect was measured for width, height, and shape, and percentage vegetation cover estimates were calculated from the amount of vegetation crossing the transect divided by the total transect length.

Following a European Space Agency Principle Investigator award (UK.A02.125) to White and Millington, ATSR-2 images were acquired to coincide with periods of field data collection. Unfortunately, due to the temporary breakdown of ATSR-2, imagery could not be collected during the Spring of 1996. It was collected for the following year instead.

Imagery was received as a level 1b gridded brightness temperature (GBT) product. It was radiometrically calibrated and atmospherically corrected using the Simulation of the Satellite Signal in the Solar Spectrum (5S) code (Tanré *et al*., 1990). Using ground control points collected in the field, geometric correction was then carried out.

A modelling approach

Initially reflectance values were compared to percentage vegetation cover estimates using vegetation indices. This is a well known method by which reflectance values in the red and near-infrared wavelengths are ratioed and used to give an indication of the vegetation present on the ground (see Tucker *et al*., 1985, Curran, 1980). The results from the use of vegetation indices were poor. Correlations between percentage vegetation coverages found in the Badia and the Normalised Difference Vegetation Index (NDVI) were low and insignificant. These results confirmed those of other studies which comment that the nature of the vegetation, high soil reflectances and the high degree of shadow mean that vegetation of low coverages is very difficult to detect using a standard vegetation index technique (Choudbury and Tucker, 1987, Kennedy, 1989).

Adopting a modelling approach enables one to consider processes happening at the sub-pixel scale and take factors such as soil background and shadow into account. There are numerous models which have been developed to look at arid land vegetation (for example, Jupp *et al.*, 1986, Franklin and Turner, 1992). In this case, the model by Jasinski (1996) was adopted. This is essentially a hybrid model lying between an exclusively empirically-based model and a very detailed physically-based model requiring a large number of inputs. It is invertible in that it allows direct calculation of percentage vegetation estimates from the remotely sensed data, and is good in that it can be used without the need of extensive field data. Field data is only used for model validation. This is particularly advantageous in regions where many areas are inaccessible, or resources are limited for costly field campaigns.

Jasinski's model was formulated for percentage vegetation cover estimation from Landsat Thematic Mapper imagery. Using an area of forest in France, and sparse shrublands in Wulnut Gulch, Arizona, he found that percentage vegetation cover could be estimated from a single Landsat TM scene. The work done here extends his model to consider its application to ATSR-2 data.

The canopy is modelled as a series of spheres on a flat planar background. In the Badia region, 64 % of plants encountered along transects were grouped into the spherical shape category, so this model was considered appropriate to use. Pixel reflectance is made up of four components, illuminated ground, illuminated canopy, shaded ground and shaded canopy. The reflectance of each component can be defined in terms of canopy transmittance. The equations used are shown in figure 1.

For a given percentage vegetation cover, the proportion of each component is calculated based on the solar zenith angle (taken from the image header), and geometric optics. Reflectance and transmittance values are allocated based on the position of pixels in the red/near-infrared feature space of a satellite image, in this case, an ATSR-2 image.

Using a linear mixture model, the red and near-infrared reflectance of a pixel of a particular percentage vegetation cover is taken as the sum of the proportion of each component multiplied by its reflectance. For a more detailed explanation of the model, see Jasinski 1996, and Edwards, 1999.

Model inversion occurs as, for each pixel reflectance, the percentage vegetation cover to give a specific red/near-infrared reflectance can be calculated. Every red/near-infrared pixel pair within an image can be allocated a percentage vegetation cover in this way.

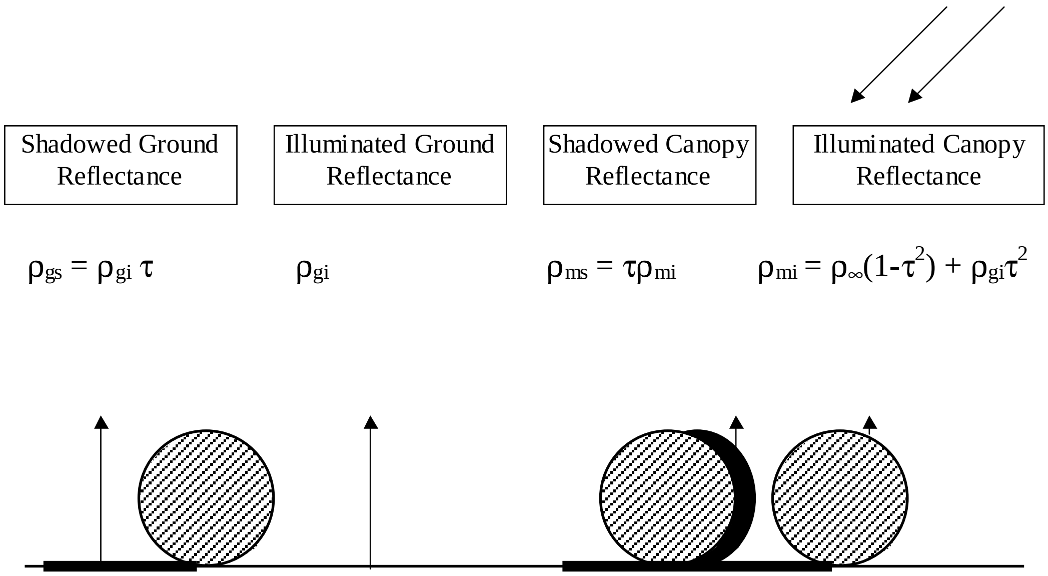

Figure 1: The surface is modelled as a series of spheres on a flat planar background. Each component is defined in terms of component reflectance, reflectance at zero transmittance, ρ_{∞} and canopy transmittance, τ

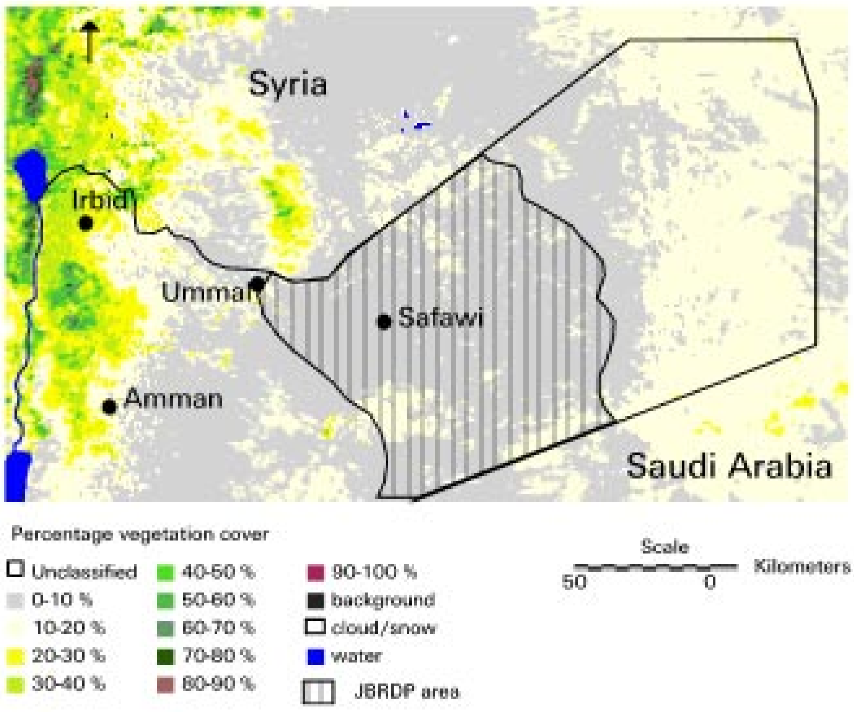

Figure 2: Percentage vegetation cover map derived from the 06/09/95 ATSR-2 image using model inversion. Using the model, every pixel in the image has been assigned a percentage vegetation class based on the position of the pixel in the red/near infrared feature space. The map shows high vegetation coverages in the Jordan Valley, and low coverages in the Badia

The model was run with a number of ATSR-2 images. Figure 2 shows a percentage vegetation cover map produced as a result of model inversion for the 06-09-95 image. This image represents a dry season image. Rainfall occurs in the winter months, and vegetation responds in the early spring. By September, vegetation in the Badia region is dry and of low coverages. In Figure 2, vegetation shows coverages in the Badia of 0-20 %. Irrigation in the Jordan Valley takes place all year round. Vegetation coverages are much higher (50-100%) as a result.

In order to validate the model, theoretical percentage vegetation cover values as derived from the model were compared with vegetation cover estimates taken in the field. Figure 3 shows the relationship between predicted versus actual percentage vegetation cover values for the 06/09/95 image.

Figure 3 indicates that the model predicts percentage vegetation cover well, with an R^2 of 0.85. From the equation of the best fit line (y = 0.6298x + 0.0591), it can be seen that the model under predicts the coverage on the ground. This could be due to the fact that cover in the Jordan Valley is not always spherical in shape, and a high degree of overlap occurs.

Conclusion

Estimates of percentage vegetation cover for arid land vegetation can be retrieved from ATSR-2 imagery using a modelling approach. Although a good agreement is reached between predicted and actual vegetation cover, the ability to distinguish between very low levels of cover (i.e within the Badia) is still difficult with a modelling approach. Factors which affect the utiility of vegetation indices such as shadow and soil, can be taken into account, they do still affect the

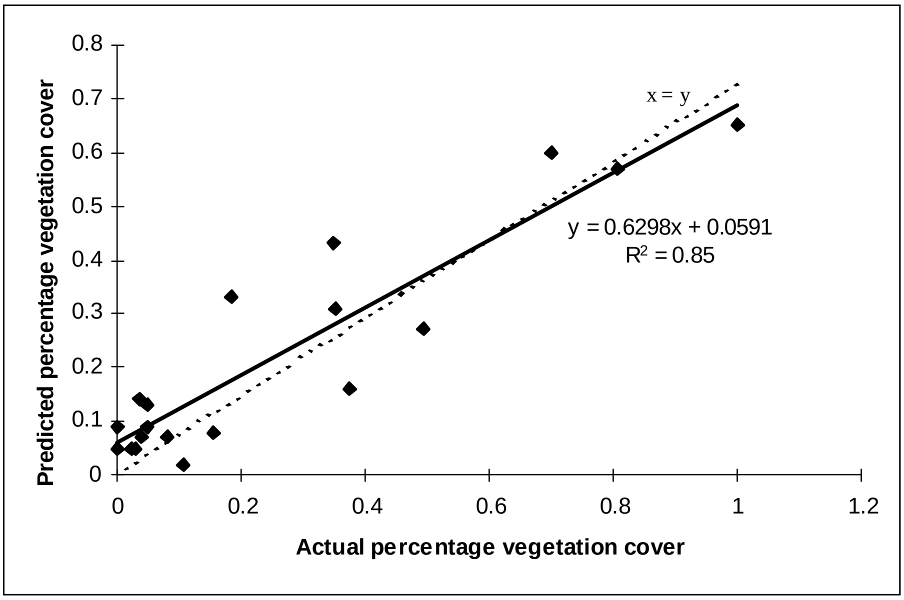

Figure 3: Actual versus predicted percentage vegetation cover, for the 06/09/95 ATSR-2 image. There is a good agreement, with an R^2 of 0.85. The line of best fit, and the x =y (perfect model fit) line have been superimposed.

ability of large spatial resolution sensors such as ATSR-2 to detect very low levels of vegetation cover. Future work should combine the application of the model to imagery with smaller spatial resolutions, and look at ways in which narrow bandwidths can be used to detect and monitor arid land vegetation with very small red/near-infrared differences.

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References
Abu-Irmaileh, B.E., 1994: Al-Mowaqqar, a model for arid rangelands in Jordan: botanical composition and productivity. Journal of Arid Environments 28, pp. 155-162.

Choudbury, B.J., and Tucker, C.J., 1987: Satellite observed seasonal and inter annual variation of vegetation over the Kalahari, The Great Victoria Desert and the Great Sandy Desert 1979-1984. Remote Sensing of Environment 23, pp. 233-241.

Curran, P.J., 1980: Multispectral photographic remote sensing of vegetation amount and productivity. Proceedings of the 14th International Symposium on Remote Sensing of the Environment, Ann Arbor, Michagan, pp. 623-637.

Edwards, M.C., 1999: Detection and monitoring of arid grazing land vegetation using ATSR-2 and geometric optical modelling. Unpublished PhD thesis. University of Leicester.

Franklin, J., and Turner, D.L, 1992: The application of a geometric optical canopy reflectance model to semiarid shrub vegetation. IEEE Transactions on Geoscience and Remote Sensing 30, No. 2, pp. 293-301.

Jasinski, M.F, 1996: Estimation of subpixel vegetation density of natural regions using satellite multispectral imagery. IEEE Transactions on Geoscience and Remote Sensing 34, No. 3, pp. 804-813.

Jupp, D.L.B., Walker, J., and Penridge, L.K, 1986: Interpretation of a vegetation structure in Landsat MSS imagery: a case study in disturbed semi-arid eucalypt woodlands. Part 2. Model based analysis. Journal of Environmental Management 23, pp. 35-57.

Kennedy, P.J., 1989: Monitoring the phenology of Tunisian grazing lands. International Journal of Remote Sensing 10, No. 4, pp. 835-845.

Tanré, D., Deroo, C., Duhaut, P., Herman, M., Morecette, J.J., and Deschamps, P.Y., 1990: Description of a computer code to simulate the satellite signal in the solar spectrum. the 5S code. International Journal of Remote Sensing 11, pp. 659-668.

Tucker, C.J., Vanpraet, C.L., Sharman, M.J., and Van Ittersum, G. 1985: Satellite remote sensing of total herbaceous biomass production in the Senegalese Sahel: 1980-1984. Remote Sensing of Environment 17, pp. 233-249.