NS001 Thematic Mapper Simulator Based Vegetation Indices for Stress Detection in Coniferous Forests

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Abstract

Airborne equivalent Landsat Thematic Mapper data acquired from a metal-stressed Norway spruce stand in the visible to shortwave infrared spectral region performed reasonably well in differentiating stressed from non-stressed trees within the forest canopy. Transformed spectral band data ranked the highest in this ability, with the normalised difference, band difference, and simple band ratio utilising the blue and near-infrared spectral bands providing the best discrimination.

1. INTRODUCTION

The generally mixed or mosaicked forests of Austria, with their commonly broken or patchy canopy cover, present a wide diversity of landscape elements that can unduly influence the spectral response characteristics of forest canopies acquired by rather coarse spatial resolution of the Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) sensor systems, with their respective 80 m and 30 m ground instantaneous fields of view (GIFOV). Airborne sensor systems, such as NASA's NS001 Thematic Mapper Simulator (TMS), provide Landsat TM equivalent spectral band coverage of a scene, but at a spatial resolution between 5 - 10 m. This is more commensurate with the type, distribution, and extent of forests in Austria and elsewhere in central Europe. Table 1 gives the NS001 sensor system characteristics as related to the instrument flown in 1986.

Six of the reflectance channels of the NS001 Thematic Mapper Simulator cover the spectral region from 0.46 - 2.40 microns and are equivalent to the six reflectance bands of Landsat TM in wavelength position and bandwidth, with an additional channel included in the near-infrared spectral region. Table 2 lists the TMS bands and the corresponding plant properties measured. Like their TM counterparts,these channels correspond to plant specural features that are related to important plant properties and therefore can be used to determine the state of health and vitality of a plant canopy.

As part of a NASA multi-sensor campaign in Europe during the summer of 1986, NS001 TMS data were acquired from a metal-stressed Norway spruce forest situated in southeastern Austria and evaluated for their ability to discriminate stressed from healthy trees, using both single, combined, and transformed spectral bands in conjunction with ancillary ground data collected from the test site.

2. TEST SITE DESCRIPTION AND DATA COLLECTION

Stress in conifers, particularly low levels of stress, is often manifested by morphological or structural rather than visible physiological changes to the tree canopy. Such changes are characteristic of a Norway spruce stand growing in soils containing high concentrations of copper, lead, and zinc, where needles of stressed trees are commonly thinner and shorter than those of non-stressed trees and, in some cases, display a perceptible, although weak chlorosis. Leaf area indices (LAI's) for damaged parts of the stand are lower than for healthy parts, which is again indicative of predominately morphological changes to the canopy.

NS001 Thematic Mapper Simulator data acquired from the test site were co-registered to canopy damage maps configured from soil metal and leaf area index isopleth maps derived from point source data obtained from a 50-m sampling grid covering the test site. Soil metal maps were based on samples collected from the base of the B-horizon and analysed for copper, lead, and zinc content, whereas LAI maps were determined from DBH (diameter at breast height level) measurements of trees contained in 5-m radius sample plots. A 100-point dot grid scaled to the dimensions of the 8 x 8 m ground instantaneous field of view (GIFOV) of

TABLE 1

NS001 THEMATIC MAPPER SIMULATOR SENSOR SYSTEM

Number of Channels	8
Spectral Range	0.46 – 2.38 μm (visible–shortwave infrared) 10.90 – 12.30 μm (thermal infrared)
Noise Equivalent Spectral Radiance/Degrees per Count	1.18 – 2.38 (visible–shortwave infrared)/ 0.08 (thermal infrared)
Digitisation	8 bits
Roll Compensation	± 15°
Flying Height (test site)	3300 m (a.g.l.)
Instantaneous Field of View (IFOV)	2.38 mrad
Ground Instantaneous Field of View (GIFOV)	8 m
Field of View (FOV)	100° (66° effective)
Swathwidth (test site)	7.9 km (4.3 km effective)

TABLE 2

NS001 THEMATIC MAPPER SIMULATOR BANDS

AND CORRESPONDING PLANT CANOPY PROPERTIES

Channel	Bandwidth (μm)	Plant Property
1	0.46 – 0.52	Foliar Chlorophyll/Carotenoid Content
2	0.53 – 0.60	Green Reflectance Peak
3	0.63 – 0.70	Foliar Chlorophyll Content
4	0.77 – 0.91	Canopy Biomass
5	1.13 – 1.35	Canopy Biomass
6	1.57 – 1.71	Foliar Water Content
7	2.08 – 2.38	Foliar Water Content
8	10.90 – 12.30	Leaf Temperature

the TMS sensor was used to calculate the point-weighted average of the metal and LAI values for each pixel representing the test site canopy.

3. DATA ANALYSIS AND RESULTS

Statistical relationships between canopy damage data (TMS pixel metal and LAI values) and spruce canopy reflectance data (TMS pixel radiance values) derived using linear regression analysis and an analysis of variance established the collaterality of the two data sets. In addition to the seven single reflectance bands, simple band differences and ratios, normalized differences, and principal component analysis were also employed in the data analysis to accentuate changes in the plant canopy-solar radiation relationships as measured by the NS001 TMS. Table 3 lists the NS001

TABLE 3
NS001 THEMATIC MAPPER SIMULATOR BANDS
AND TRANSFORMATIONS USED IN THE ANALYSIS

Band 1	TMS Band
Band 2	
Band 3	
Band 4	
Band 5	
Band 6	
Band 7	
Band 4 − Band 1	Band Difference
Band 4 − Band 2	
Band 4 − Band 3	
Band 4 − Band 6	
Band 4 − Band 7	
Band 4 / Band 1	Single Band Ratio
Band 4 / Band 2	
Band 4 / Band 3	
Band 4 / Band 6	
Band 4 / Band 7	
(Band 4 − Band 1) / (Band 4 + Band 1)	Normalised Difference
(Band 4 − Band 2) / (Band 4 + Band 2)	
(Band 4 − Band 3) / (Band 4 + Band 3)	
(Band 4 − Band 6) / (Band 4 + Band 6)	
(Band 4 − Band 7) / (Band 4 + Band 7)	
First Principal Component	
Second Principal Component	
Third Principal Component	

Thematic Mapper Simulator bands and transformations used in the analysis. Bands 4 and 5 contain similar canopy information and therefore only band 4 was employed in the informations.

For the data sets examined, the normalised difference, band difference, and simple band ratio incorporating TMS bands 1 and 4 provided the best discrimination between stressed and non-stressed trees. These are followed, in descending order of usefulness, by band difference between TMS bands 3 and 4, first principal component, band difference between TMS bands 2 and 4, TMS single bands 4 and 5, and the band difference between TMS 4 and 6. Correlation coefficients for the highest ranked transformations range between -0.71 and - 0.77 and are significant at greater than 99 per cent probability level.

4. CONCLUSIONS

The negative statistical relationships exhibited by the highly ranked TMS single bands and transformations are in agreement with the expected decrease in canopy reflectance in the near-infrared wavelength region (TMS band 4) and corresponding increase in the visible (TMS bands 1, 2 and 3) and shortwave infrared (TMS bands 6 and 7) wavelength regions. The ranking of five of the TMS transformations above the highest ranked TMS single band in ability to discriminate stress in the spruce tree stand demonstrates the capacity of such transformations to enhance weakly discernible differences in a canopy's spectral response to stress conditions as recorded by the individual TMS bands.

Although the higher spatial resolution of NS001 TMS data allows for a more detailed assessment of the spatial distribution of canopy damage within a forest compared to lower resolution equivalent spaceborne data acquired by Landsat TM, the spectral data acquired from the forest canopy are, except for one additional and highly autocorrelated band, identical and therefore provide comparable canopy information. Differences in canopy information content between NS001 TMS and Landsat TM data sets are primarily due to the difference in platform altitude and field of view of the two sensor systems.

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