SPATIAL AND SPECTRAL RESOLUTION NECESSARY FOR REMOTELY SENSED VEGETATION STUDIES

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The following is an outline of the required spatial and spectral resolution needed for accurate vegetation discrimination and mapping studies as well as for determination of state of health (i.e. detection of stress symptoms) of actively growing vegetation.

A. Spatial Resolution

The spatial resolution required for accurate vegetation discrimination and mapping is directly related to the complexity of the canopy being studied. A relatively homogeneous canopy (crop plantings, conifer forests consisting of one or two species, etc.) requires less spatial resolution for accurate mapping than does a more heterogeneous canopy (conifer/hardwood mixes, multiple species of hardwoods, etc.) which contains greater scene variation. The Lost River NASA/Geosat test site in eastern West Virginia (ridge and valley province of the Appalachians) represents one of the most complex areas for vegetation discrimination and mapping available in the United States.

The Lost River test site is heavily forested (approximately 80%), representing a typical eastern mixed deciduous/evergreen (Oak-Hickory-Pine) cover type. The non-forested areas of the sites are generally under cultivation (lawns, pastures and field crops such as corn or hay) and thus surface reflectance data are totally dominated by vegetation. The vegetation cover occurring at Lost River is typical of the entire ridge and valley portion of West Virginia.

As a product of the recently completed NASA/Geosat study, highly accurate supervised vegetation classifications for the Lost River area have been produced. A total of seven forest tree classes (species or species associations) are recognized with approximately 90% accuracy of class assignment. Data used to produce these images are from Johnson Space Center's NS-001 airborne scanner (Thematic Mapper Simulator), acquired with an instantaneous field of view (IFOV) of 15 m (11 m resolution over center of the field). A recent overflight (October, 1981) has provided NSTL Thematic Mapper Simulator data for the same area acquired with an IFOV of 30 m. In terms of accuracy of vegetation discrimination, these data provide a background for assessing the degree of spatial resolution required for a given level of accuracy.

Degradation of NS-001 Lost River data (15 m IFOV), using a low-pass, 3 x 3 filtering produced data corresponding to that acquired with approximately 45 m resolution. A vegetation classification, produced using these degraded data and the same training areas used for the 15 m data, proved less than optimal. Although the produced image was never field checked, considerable loss of usable information resulted in less precise (i.e. detailed) vegetation discrimination and mapping than is possible with the 15 m data. Clearly, 15 m spatial resolution represents an upper limit necessary for accurate analysis of a heterogeneous vegetation canopy.

In study of crop type and maturation as well as stress symptoms in plants growing over mineralized soils (containing heavy metals such as copper, lead and zinc), good success (Collins, 1978; Collins et al., 1981) has been achieved using a 500 channel spectroradiometer with an 18 m IFOV. This spatial resolution allows for detection of the so-called red-shift of .007 to .010 µm in the chlorophyll absorption band in homogeneous crop canopies (this red shift has been related to metal-induced stress).

Based on these results and the degree of accuracy possible in vegetation mapping at the Lost River test site, using 15 m resolution, it is my opinion that an instrument delivering spatial resolution ranging from 10 to 15 m is required for accurate geobotanical study in the future. While improved spatial resolution may be possible, I am of the opinion that the increased amount of data made available is likely unnecessary and may in fact create additional problems related to excessive amounts of data (varying reflectance data from separate portions of a single tree crown, for example) leading to amplification of scene "noise."

B. Spectral Resolution

Broad-band spectral data (NS-001) for the Lost River test site are available for two phenologic periods; September (near the end of the growing season for woody species) and October (period for fall foliage display, selected to afford maximum species discrimination data). NS-001 bands 3 (0.63 - 0.69 µm), 4 (0.76 - 0.90 µm), 5 (1.00 - 1.30 µm), 6 (1.55 - 1.75 µm) and 7 (2.08 - 2.35 µm) are the most useful in providing accurate vegetation discrimination and classification of forest species and species associations using October foliage display data.

The analysis of NS-001 spectral data acquired over the Lost River test site provides insight into the utility of these broad-band data in mapping densely vegetated terrain. The work of Harold Lang (at JPL - Final Geosat Report) shows that based on an evaluation of interband correlation matrices, principal components analyses, and stepwise discriminant analyses for the supervised vegetation classifications produced for the Lost River study, in order of decreasing utility for vegetation discrimination, the four most important NS-001 VNIR bands may be ranked in the following order: band 6 (1.55 - 1.75 µm), band 3 (0.63 - 0.69 µm), band 5 (1.00 - 1.30 µm), band 4 (0.76 - 0.90 µm). The somewhat surprising absence of the bands at 0.45 - 0.52 µm (band 1) and 0.52 - 0.60 µm (band 2) is attributed to their high positive correlation with the 0.63 - 0.69 µm band. The high ranking of the 1.00 - 1.30 µm band is significant, since data will not be acquired in that wavelength range by the Landsat-D TM. NS-001 bands at 0.52 - 0.60 µm (band 2), 0.63 - 0.69 µm (band 3) and 0.76 - 0.90 µm (band 4) were of considerable value in the process of vegetation discrimination and mapping since they may be used to produce images which mimic aerial CIR photography, an image format with which field botanists and photointerpreters are familiar.

Certain spectral regions, when studied with high resolution, are seen to contain a great many fine spectral features that may well provide useful data for improved vegetation discrimination studies. Based on laboratory studies (reflectance data from the Beckman 5240 spectrophotometer) the 0.80 to 1.30 µm region contains the greatest amount of fine spectral structure (both reflectance and absorbance features; note Table 1), data which relate to leaf structure. The 1.50 to 1.75 μm and 2.00 to 2.40 μm regions also contain fine spectral structure, in this case relating to leaf moisture content (Gausman et al., 1978; Tucker, 1980) and thus, state of health (senescence vs. active growth). Table 1 lists areas of fine spectral structure in the VNIR, SWIR, and TIR, which will be of use in both vegetation discrimination and stress detection.

According to the work of Collins et al. (1981) and others, the spectral region most affected by mineral-induced stress lies between .550 μm and .750 μm, with the symptomatic red-shift occurring on the far wing of the red chlorophyll absorption band centered at approximately .680 μm (principal absorption peak for chlorophyll-a molecules associated with the photosynthetic light trap). As stated previously, the red-shift consists of a .007 to .010 μm shift of the chlorophyll shoulder to slightly longer wavelengths (.690 to .700 μm).

In the study of phenologic changes (ontogenetic or maturation stages), crop plants such as corn, wheat, and sorghum demonstrate a similar red-shift in the chlorophyll-a absorption band (Collins, 1978). The red-shift (again .007 to .010 μm) occurs along the entire length of the absorption wing, but is most pronounced on the chlorophyll shoulder centered at about .740 μm (ranging from .700 to .750 μm). In both cases (mineral-induced stress and progressive maturation) the red-shift may be related to a decrease in chlorophyll production.

The instrumentation used by Collins (1978) in his study of crop canopies was an airborne 500 channel spectroradiometer with .0014 μm spectral resolution, collecting data in the .400 to 1.100 μm spectral region. Collins noted that the red-shift can be measured with .010 μm-wide spectral bands centered at .745 μm and .785 μm. These two bands plus one centered at .670 μm provide enough information to identify a variety of crop plants as well as detect the symptomatic red-shift. Tucker and Maxwell (1976) have demonstrated that wide spectral bands of .050 μm or more do not provide adequate information in the 700 to 750 μm range for detection of the chlorophyll absorption edge.

C. Summary

Good success has been achieved in vegetation discrimination and mapping of a heterogeneous forest cover in the ridge and valley portion of the Appalachians using multispectral data acquired with a spatial resolution of 15 m (IFOV). A sensor system delivering 10 to 15 m spatial resolution is needed for both vegetation mapping and detection of stress symptoms.

Based on the vegetation discrimination and mapping exercises conducted at the Lost River site, accurate products (vegetation maps) are produced using broad-band spectral data ranging from the .500 to 2.500 μm portion of the spectrum. In order of decreasing utility for vegetation discrimination, the four most valuable NS-001 VNIR bands are: 6 (1.55-1.75 μm), 3 (0.63-0.69 μm), 5 (1.00-1.30 μm) and 4 (0.76-0.90 μm). Spectral data acquired in the 1.00-1.30 μm range is essential. Finer spectral detail from certain wavelength regions (0.80-1.30 μm, 1.50-1.75 μm, and 2.00-2.40 μm) will supply additional useful information for vegetation mapping and monitoring, provided that 10-15 m spatial resolution is possible.

References

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TABLE 1. FINE STRUCTURE OF PLANT SPECTRA IN THE VNIR, SWIR AND TIR

Wavelength (μm)	Type of Feature	Value
.440-.500	Absorbance	Detection of changes in chlorophyll/carotenoid ratios (related to stress).
.650-.700	Absorbance	Detection of chlorophyll states as well as tannin and anthocyanin content. Initial stress detection.
.700-.750	Reflectance	Senescence detection. Dead or dormant vegetation.
.800-.840	Absorbance	Possibly related to leaf anatomy and/or state of hydration.
.865	Reflectance	Height of feature may be useful in species discrimination.
.940-.980	Absorption	Shifts in this minor water absorption band may be useful in species discrimination and determination of hydration state.
1.060-1.100	Reflectance	Shifts in peaks may be related to leaf anatomy and/or morphology. May be useful for species discrimination.
1.140-1.220	Absorbance	Shifts in this minor water absorption band may be useful in species discrimination and determination of hydration state.
1.250-1.290	Reflectance	Height of this feature very useful for species discrimination of senescent forest species. A ratio of this feature with the one at 1.645 μm offers a good indication of moisture content and thus stress.
1.630-1.660	Reflectance	An indication of moisture content of leaf. May also be an indicator of variation in leaf anatomy. May be useful for species discrimination. An indicator of leaf moisture content when used as a ratio with the 1.270 μm data above.
2.190-2.300	Reflectance	An indicator of moisture content. May also be of value in species discrimination.
3.000-5.000; 8.000-14.000	Reflectance	Little is known concerning the value of thermal IR data in the study of vegetation. This is an area that needs further study.