APPLICATION OF SATELLITE IMAGERY TO EXPLORE AND MONITOR GEOTHERMAL SYSTEMS

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ABSTRACT

SPOT and LANDSAT TM satellite imagery have been used to map surface manifestations associated with the Wairakei and Waiotapu geothermal systems in the Taupo Volcanic Zone, New Zealand. These manifestations include fumaroles, steaming and hydrothermally altered ground, and sinter. In both areas there are also distinctive patterns of geothermally stressed vegetation that extend over much larger areas than do most individual surface features. This stressed vegetation has reflectance characteristics different from those of the surrounding non-stressed vegetation that allow it to be distinguished on high spatial resolution SPOT (20 m) and LANDSAT TM (30 m) multispectral imagery. Though conventional SPOT **XS** and LANDSAT TM colour infrared band combinations can distinguish various surface features, they do not clearly separate thermally stressed from adjacent non-stressed vegetation. The fundamental discriminatory information is contained within the mid-infrared TM band 5 (1.55-1.75 pm). TM colour composite images that combine bands 5 and 4 (near-infrared) and a visible wavelength band (1, 2 or 3) allow such discrimination. A SPOT-TM hybrid image, created by combining the higher spatial resolution SPOT **XS** bands 2 and 3 with the TM band *5,* yields better results. This evaluation shows that geothermally stressed vegetation provides a very good target for satellite remote sensing, which will aid exploration and monitoring geothermal systems in highly vegetated areas.

1. INTRODUCTION

Geothermal systems are an important indigenous source of energy for many countries, however, their initial reconnaissance and exploration can be difficult and highly expensive. This is especially true in difficult access areas and in the highly vegetated temperate and tropical regions. We have been investigating the development of satellite remote sensing techniques that may provide rapid and low-cost means for the identification and investigation of these systems and, in some cases, aid with the monitoring of their surface activity (Cochrane, ***et*** *al.,* 1993; Mongillo, *et al.,* 1993).

Most major geothermal systems exhibit surface activity, which can occur in a variety of forms, including hot pools and streams; fumaroles; bare, altered and hot ground; sinter deposits and hydrothermal eruption craters. These features tend to be relatively small, typically less than a few 10's of metres in size, though much larger features (eg. large hot pools, areas of steaming ground, sinter deposits) are not uncommon. Generally, the active surface features exhibit anomalously high temperatures. However, a few active features (e.g. very dilute and soda springs) and the extinct ones (e.g. old sinter deposits and areas of hydrothermally altered ground) do not.

Where geothermal activity occurs in vegetated regions, vegetation anomalies, or stressed vegetation, caused by the presence of elevated ground temperatures, geothcrrnal fluids and anomalous soil composition (due to alteration and deposition products) can exist (Camacho ***et*** *al.,* 1982; Cochranc, ***et al.,*** 1993; Dawson, 1964; del Rio, ***et*** *al.,* 1980; Given, 1980; Miller and Cooper, 1969; Mongillo, ***et*** *al.,* 1993). These anomalies can extend over much larger areas than the surface manifestations.

The remote sensing of geothermal systems relies on detecting radiation reflected andor emitted from surface features and discriminating it from that originating from the surrounding regions. Successful application requires a maximum spatial resolution on the order of the size of the features of interest and the correct spectral information (wavelength and resolution). Of the few known satellite remote sensing geothermal studies that have been published prior to 1987, only two have considered detection of surface features (Camacho, ***et al.,*** 1982; Jinich, ***et*** *al.,* 1981), and all have suffered from insufficient spatial resolution (280 m) which severely restricted applications, and no doubt, led to the hiatus in such investigations.

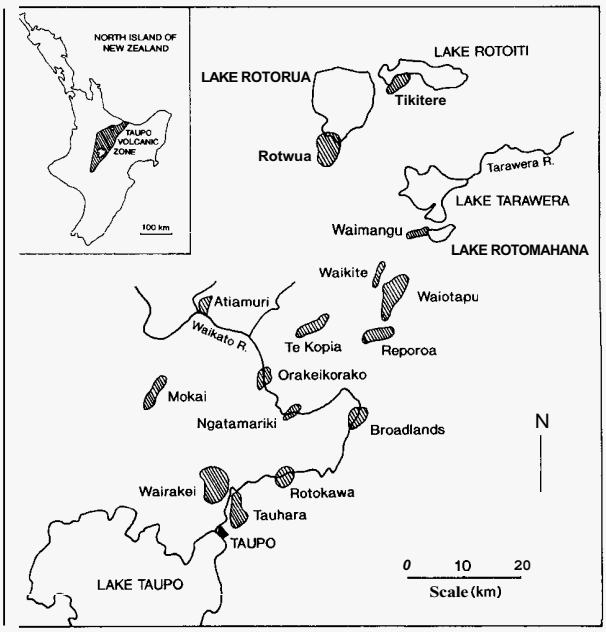


Fig. 1. Sketch map showing the locations of major geothermal fields in the Taupo Volcanic Zone between Rotorua and Lake Taupo.

Recent availability of high spatial resolution SPOT PAN (panchromatic, 10 m) and multispectral (20 m) and LANDSAT TM multispectral (30 m) satellite data for the TVZ, and positive results from a preliminary study (Mongillo and Belliss, 1987). have encouraged us to investigate the role of satellite remote sensing for geothermal studies in the TVZ of the North Island of New Zealand (Fig. 1). This paper reports on research in progress and evaluates the use of SPOT and LANDSAT TM satellite data for detecting and mapping surface features associated with the Wairakei and Waiotapu geothermal fields (Fig. 1). Major consideration is given to the detection of stressed vegetation and its role as an indicator of the

presence of geothermal activity. Examples of colour composite images that combine the necessary spectral reflectance information for detecting stressed vegetation (plant community structure, floristic composition and density), bare and altered geothermal ground and inferring ground temperatures are presented (Fig. 4). The special role of the reflective near mid-infrared TM band 5 (1.55-0.75 pm) as a specific indicator of thermally stressed vegetation is demonstrated.

2. STUDY AREA

The Wairakei and Waiotapu geothermal fields are located in the central TVZ (Fig. 1), a complex volcano-tectonic Quaternary rift with widespread volcanism, which covers an area of about 12 500 km^2, and includes over 20 major geothermal fields (Cole 1986: Simmons *et al.,* 1992).

Detailed descriptions of the Wairakei geothermal field and some of the effects of its exploitation are provided by Grindley (1965) and Allis (1981), respectively. Several arcas of extensive surface thermal activity occur in the Wairakei field (Fig. 2). Craters of the Moon thermal area, a major tourist attraction, was created in its present form as a consequence of reservoir drawdown resulting from the exploitation of Wairakei which began in 1958 (Allis, 1979: 1981). Surface heat flow, in the form of steam-heated activity, rose to a maximum of about 420 MW by 1964, ten times above its pre-exploitation value. By 1979, this had decreased to its present value of about 220 MW (Allis, 1981). The surface activity, mainly through its effects on ground temperatures, has had a major impact on the vegetation development (Dawson, 1964; Given, 1980). Changes in surface activity at the Craters of the Moon still continue (Mongillo and Allis, 1988) and are reflected by variations in its vcgetation.

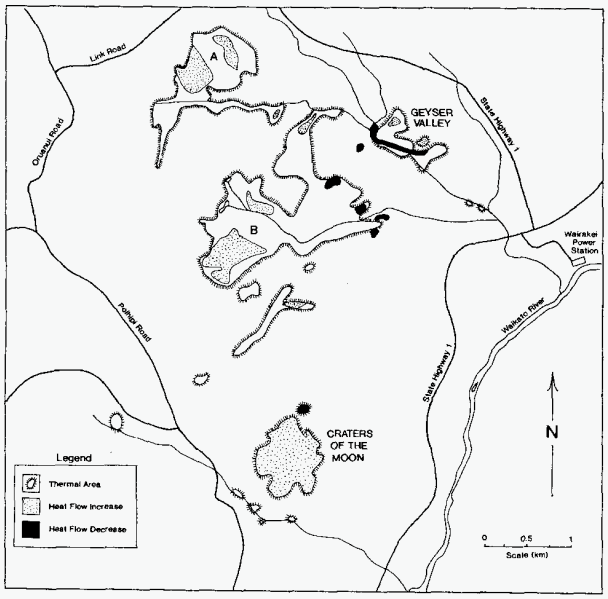


Fig. 2. Areas of major surface thermal activity associated with the Wairakei geothermal field. Craters of the Moon and areas A and B have undergone the greatest increases in heat flow while Geyser Valley has sustained the largest decrease (after Allis, 1981).

The Waiotapu geothermal field, described in detail by Hedenquist (1986), is a major tourist attraction, having a wide variety of outstanding surface features (Fig. 1). The features present include large areas of steaming ground, fumaroles and collapse and dissolution craters, mud pools, silica deposits (notably a large silica terrace), hot pools, areas of hydrothermal clays and hydrothermal eruption craters. Three large hydrothermal eruption craters in the south of the field contain Lakes Ngakoro, Whangioterangi and Champagne Pool, the largest chloride discharge feature at Waiotapu.

The wider Wairakei and Waiotapu regions exhibit a diversity of vegetation, including plantations of exotic timber trees (Pinus spp.) and cleared forest and scrubland areas which support a range of pastoral farming. Regions of indigenous forest (bush) and structurally and floristically simpler communities of bracken fern, kanuka and manuka scrubland and swampland are also present. Within the thermal areas a close relationship exists between vegetation and ground temperature (Cochrane **er** *al.,* 1993: Dawson, 1964; Dawson and Dickinson, 1970; Given, 1980; Mongillo *et al.,* 1993). The extensive and complex distribution patterns of thermally stressed vegetation can reflect both current and former conditions. There is a vegetation gradient ranging from bare ground (too hot to support plants), through a low prostrate moss community, to a low sparse prostrate dwarfed kanuka shrub community, denser prostrate kanuka, taller erect kanuka, to ambient temperature ground where erect broadleaved shrubs and low trees replace the heat stressed vegetation. Ground that has recently cooled supports a dominantly manuka scrubland. Vegetation present on thermal ground is characterised by its sclerophyllous (tough leafed), microphyllous (small leafed), prostrate, dwarf nature, resulting in its having low spectral reflectance.

3. METHODS

Imagery from SPOT XS (multispectral), SPOT PAN (panchromatic) and LANDSAT TM (multispectral) satellite scanners were assessed by visual interpretation. The spatial resolutions and sensor spectral band configurations for the three scanners are shown in Fig. 3.

SPOT **XS** (acquired 1 September 1989) and LANDSAT TM *(25* December 1990) subscenes covering the Wairakei geothermal area were registered to a corresponding rectified SPOT PAN (31 December 1990) image, making the data sets geometrically compatible. The LANDSAT TM (25 December 1990) subscene of the Waiotapu area was left unrectified, there being little distortion over the small area covered.

Various image processing techniques have been investigated to define the most appropriate for mapping geothermal surface features, with special emphasis on discriminating stressed vegetation (Cochrane, *et al.,* 1993; Deroin, *et al.,* accepted; Mongillo, *et al.,* 1993). Herc, we evaluated LANDSAT TM and SPOT XS data combined in various colour composite combinations. Previous studies (*ibid.*) suggested the importance of the mid-IR information provided by TM band 5 for mapping vegetation, and especially for discriminating geothermally stressed vegetation. Consequently, combinations of the LANDSAT TM visible (bands 1, 2 and 3) and near-IR (band 4) with the mid-IR (band 5) were explored for the Waiotapu area, eg. $TM3_b4_g5_r$ (where 1, 2 and 3 indicate the band numbers and b, g, r subscripts indicate blue, green and red colour contributions) (Fig. 4a). A SPOT colour IR (CIR) combination, $SPOT1_b2_g3_r$, of the larger Wairakei area and a magnified segment of it covering Craters of the Moon were also examined (Figs. 4b and 4c). To incorporate the higher SPOT XS spatial resolution and the important TM mid-IR wavelength information, a hybrid colour composite using SPOT XS bands 2 and 3 with LANDSAT TM band 5, $SPOT1_b2_gTM5_r$, was employed (Fig. 4d).

Aerial photographs were used and field visits conducted to aid with the interpretation and evaluation of the satellite imagery.

4. RESULTS

The images in Fig. 4 illustrate the image processing methods examined and indicate the relative merits of each procedure for geothermal surface feature detection and mapping. Note that the black and white reproductions presented here are of much lower quality than the original colour images from which they were produced.

A LANDSAT TM colour composite image of the Waiotapu geothermal area is shown in Fig. 4a. This image combines 30 m spatial resolution visible, near-IR and mid-IR wavelength data,

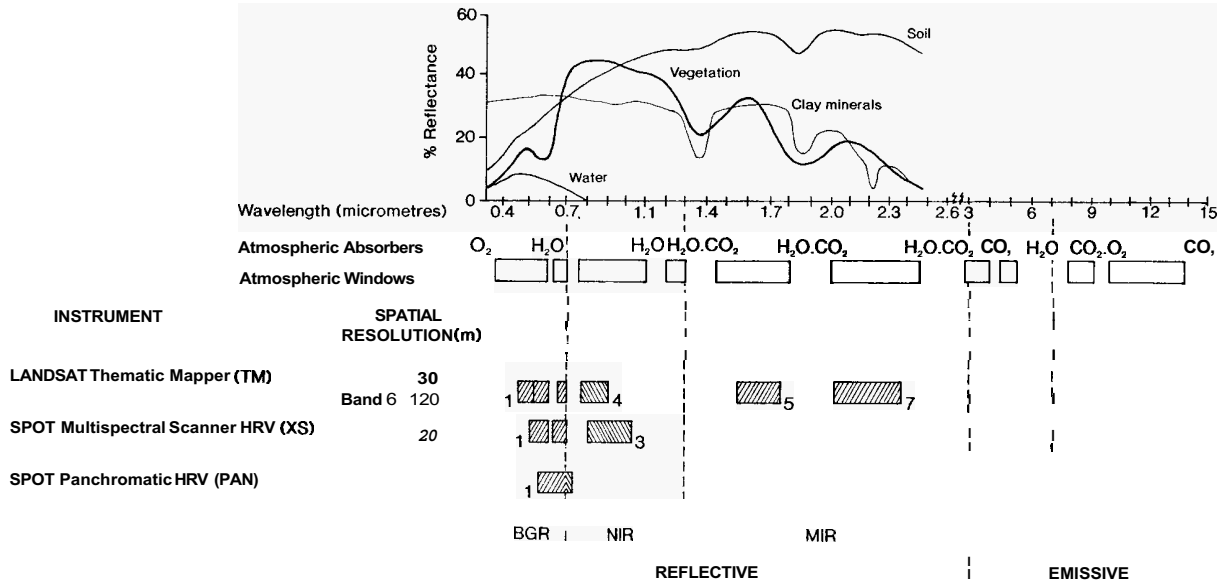


Fig. 3. Chart illustrating typical vegetation, soil, water and alteration mineral reflectance spectra: atmospheric absorption constituents and wavelength locations; and SPOT and LANDSAT TM satellite spatial resolutions and spectral band configurations.

$TM3_b4_g5_r$, hence embraces a wider wavelength range than can be obtained with the SPOT XS data. The two dark blue features (N,11 and J,16) in the image are lakes and the yellow linear features (P,15 to F,12 to B,17) are unpaved (pumice) roads. The dark green-black colour (areas around O,9; D,15 and 0.21) is due to healthy mature pine trees, the yellow (A-P,1-7) to pasture, the yellow-green (A-E,21-22; H-K,21-22) to very young pines and the pink (A-I,13-22) to recently logged areas with some regenerating vegetation present. The brown, pink, white and yellow-green zone extending vertically through the centre of the image (A-P.7-15) includes the central Waiotapu thermal arca. The tonal variations in this zone are mainly caused by stressed vegetation effects. Comparison with the vegetation map (Fig. 5) of the area demonstrates the detail afforded by this imagery. The white patches (H-I,10-11; L,I 1-12; and M-O,16-18) correspond to arcas of bare and altered geothermal ground. The large light blue arca (I-J,12) corresponds to a large silica sinter terrace which is often covered by chloride watcr discharging from Champagne Pool (I,11). Two smaller blue spots (L.11 and L.12) correspond to two watcr filled hydrothermal eruption craters in the Alum Cliffs and Frying Pan Flat areas.

The $TM1_b4_g5_r$ and $TM2_b4_g5_r$ band combinations of the Waiotapu area wcrc also examined. These also showed good discrimination of thermally stressed vegetation due to the spectral contribution of band 5, with minor variations resulting from the use of the differcnt visible bands.

The SPOT **XS** colour composite imagc ($SPOT1_b2_g3_r$; simulated CIR format) in Fig. 4b covers most of the Wairakei geothermal area, hence is reproduced here at small scale (image magnification of 1). The imagc shows good detail in the characteristic tones of a simulated CIR colour composite. The red-brown coloured regions (A-I,3-19 and J-P,1-12) are pine plantations. The linear light-blue-grey features (P,15-E,16; E,17-C,22; etc.) are roads. The circular pattern of light blue and white coloured spots (B-E,4-8) includes the Alum Lake thermal area. The white features in the north and to the east of this area (B,7-E,9-C,11) are caused by steam plumes discharging from silencers and separator plants. The blue feature (A,5) just northwest of the circular pattern is Alum Lake and the distribution of cyan coloured spots in the western and southern portions of the circular pattern (B,4-E,6) are due to bare, steaming and altered ground and hot pools. The dark greenish to grey arcas (A-E.4-6) include zones of stressed vegetation.

The circular cyan coloured area in the southern red-brown pine region (N-P.5-9) is the Craters of the Moon thermal area. The main active areas appear as the small, white-cyan spots (0.6; O,7-8; P,7; P,8) with the whitest features due to the presence of steam issuing from fumaroles and areas of steaming ground. The flanking thermally stressed scrubby vegetation shows as a distinct dark greenish grey tone (O-P,6-8). It is starkly contrasted against the dark red to red-brown tones of the healthy plantation pines (J-P,1-12). There is also no confusion between the grey-green scrub tones (J-K,3-6) and the rangc of whitish pinks and pinks to brighter light reds of pasture areas (E-1.1-10: H-P,17,22).

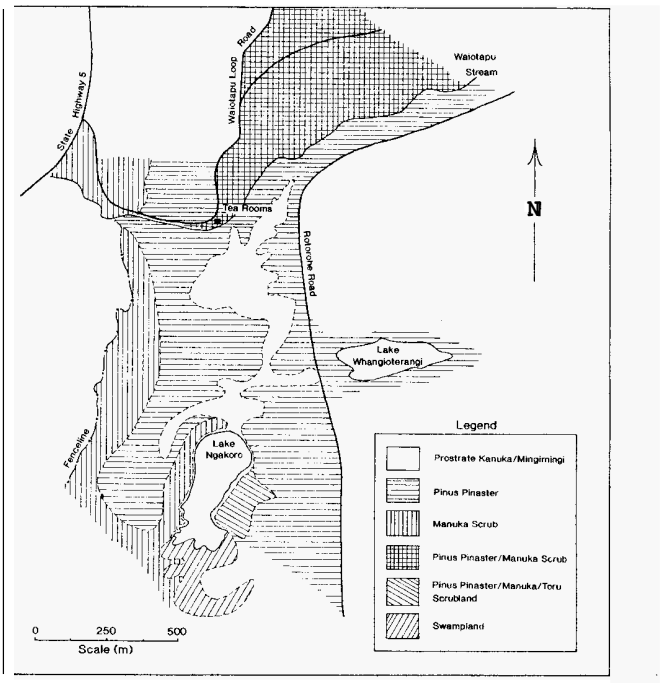


Fig. 5. Map of the major vegetation types covering the main Waiotapu thermal arca (after Clarkson. 1982).



Fig. 4a.

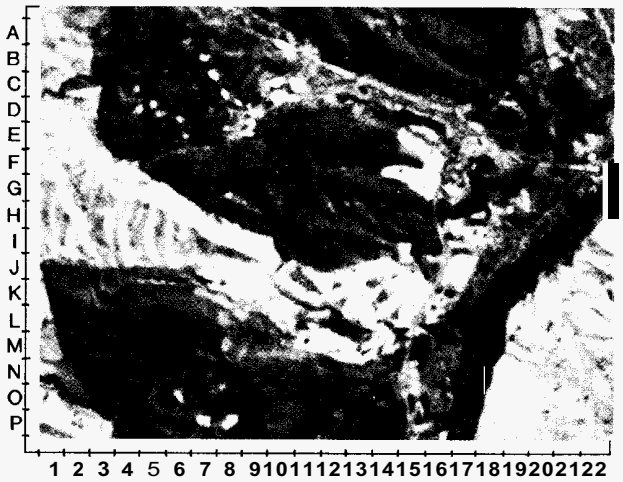


Fig. 4b. (© CNES).



Fig. 4c. (© CNES).



Fig. 4d. (© CNES).

Fig. 4a. presents a LANDSAT $TM3_b4_g5_r$ image covering the main thermal areas of the Waiotapu geothermal field. Fig. 4b. shows a rectified SPOT XS colour composite image ($SPOT1_b2_g3_r$) which covers the major areas of surface thermal activity associated with the Wairakei geothermal field. Fig. 4c. displays the Craters of the Moon portion of the image in Fig. 4b. magnified by a factor of 4. Fig. 4d. presents the hybrid $SPOT2_b3_gTM5_r$ image corresponding to Fig. 4c. All images have been contrast enhanced. North is toward the top on all the images.

In this colour composite image (Fig. 4b) it is difficult, however, to differentiate between stressed vegetation and non-stressed, narrowleaved scrub communities. Areas of broadleaved regenerating shrubs and low trees to the northeast of the rim of the Craters of the Moon show as a darkish red tone (P,10) slightly different from the darker more brown-red of the pines. The large steam mains (B,11-F,22) and the buildings associated with the Wairakei Geothermal Power Station complex (F,22) and buildings and parking areas in Wairakei Village (A-C.21-22) show as bluer than the cyan tones of bare ground. This composite is useful, especially for known areas, but as noted, has limitations for mapping vegetation covering heated ground. Interpretation in this example is also hampered by the small scale of the image.

The Craters of the Moon thermal area, which appears in the lower portion of Fig. 4b, is enlarged in Fig. 4c. In this magnified (x 4) image more subtleties in tonal patterns are obvious. The steam features, which appear white, are clearly depicted, with even their shadows (black areas to their left) identifiable. Areas of bare ground appear as light bluish to white in colour. Vegetation is present almost everywhere between the bare, strongly steaming areas. Healthy vegetation is evident on the image by its reddish-brown colour. The thermally stressed vegetation, mainly stunted kanuka and moss, is discernable by its greyish-red to yellow tones, with differences in it clearly distinguishable by the tone variations. However, it is not possible to consistently separate the thermally stressed vegetation from that present on normal ground. This $SPOT1_b2_g3_r$ image proved better than the corresponding LANDSAT TM visible-near IR combinations, $TM1_b2_g4_r$, $TM2_b3_g4_r$ or $TM1_b3_g4_r$), probably because of its higher spatial resolution (vis. 20 m vs. 30 m).

A hybrid colour composite image, $SPOT2_b3_gTM5_r$, of the Craters of the Moon thermal area is shown in Fig. 4d. It incorporates the 20 m spatial resolution SPOT XS bands 2 and 3 plus the mid-IR TM band 5. Comparison with the corresponding SPOT XS image (Fig. 4b) shows that a larger tonal range is present in this hybrid image. As with the SPOT image the white features correspond to bare thermal ground areas and large steam plumes. The healthy pine trees appear as dark green and are mainly concentrated around the circumference of the area, with younger pines along the right side of the image appearing lighter green. The tones of the stressed vegetation zones range from yellow, light brown, darker brown, green-brown, to green, representing the vegetation successional stages (from hot to ambient ground): moss; prostrate, sparse coverage kanuka: denser kanuka; taller prostrate kanuka to taller kanuka; finally, erect kanuka, kanuka/manuka and mixed broadleaved shrubs and low trees (and some stunted pines) which mark the thermal/ambient ground boundary.

5. DISCUSSION

The results presented here show that it is possible to use the multispectral data available from the current high spatial resolution SPOT and LANDSAT TM instruments to detect the presence of geothermal fields in highly vegetated areas, and in some eases, to map directly the larger surface features and, indirectly, the existence of hot ground by using stressed vegetation as a surrogate.

In the Wairakci and Waiotapu geothermal fields the geothermally stressed Vegetation extends over areas much larger in size than most individual surface features, creating targets many times larger than the LANDSAT TM and SPOT XS spatial resolution elements. This is the case for other TVZ geothermal fields examined (Cochrane *et al.,* 1993) and is believed to be the general situation for all geothermal fields occurring in highly vegetated regions. The stressed vegetation is characterised by its similar spectral reflectances in the visible (V) and near-IR (NIR) and higher reflectance in the mid-IR (MIR) when compared to surrounding non-stressed vegetation. Hence, it can be detected and discriminated using visual interpretation of contrast enhanced TM colour composite images incorporating V, NIR and the MIR bands (eg. $TM3_b4_g5_r$) as illustrated in Fig. 4a. Neither the TM CIR, nor the SPOT CIR composite, which is of higher spatial resolution, provide this discrimination (Fig. 4b) in the TVZ geothermal areas, probably because much of the common non-stressed vegetation present (kanuka and manuka scrub) also has small dark, fibrous leaves and exhibits similar V and NIR reflectances. This explains the importance, in the New Zealand situation, of the information provided by the MIR TM band 5 (1.55-1.75 pm).

It is also possible to detect and, with some a *priori* knowledge, discern the larger geothermal surface features at Wairakei and Waiotapu by the wide range of tones on both the large and small scale SPOT CIR and TM CIR and $TM3_b4_g5_r$ images. For example, large areas of bare hydrothermally altered ground at both Craters of the Moon and Waiotapu, the steam plumes from steaming ground and larger fumaroles at Craters of the Moon, the large hot pools and large sinter deposits at Waiotapu clearly differ from the surrounding vegetation (Figs. 4a, 4b and 4c).

With the stressed vegetation identified on the small scale TM imagery (Fig. 4a) providing a guide to the geothermal areas, both the small and large scale (higher magnification) images can be generated, allowing more detailed feature mapping to be conducted (Fig. 4c). On the Waiotapu $TM3_b4_g5_r$ image (Fig. 4a), a wide range of tones are discerned in the known thermal areas corresponding to the presence of various larger surface features, eg. Champagne Pool, the sinter terrace, and expanses of bare and hydrothermally altered ground. Though the SPOT CIR image does not uniquely separate geothermally stressed from non-stressed vegetation, it does show a variety of detailed structure within defined geothermal areas (Fig. 4c) indicating the presence of different surface features, including steam plumes, bare ground and stressed vegetation. The higher spatial resolution of the SPOT data (20 m) also helps here and makes it more useful than the corresponding TM CIR images.

The clear delineation of the stressed vegetation by the $TM3_b4_g5_r$ band combination and the spatial detail afforded by the SPOT CIR image suggested that it would be appropriate to investigate creation of a hybrid colour composite, $SPOT2_b3_gTM5_r$. Such an image could provide the optimum characteristics of high spatial resolution and the important MIR spectral information, allowing more detailed mapping of the vegetation, especially the successional stages of geothermally stressed vegetation, which reflect the ground temperature conditions known to exist in New Zealand geothermal fields. As illustrated in Fig. 4d, this image does provide a larger tonal range than either the SPOT CIR or $TM3_b4_g5_r$ image with very good spatial detail (cf. Mongillo *et* al., 1993 and Fig. 4c here).

It is necessary to comment on the influences of the 16 month difference between the acquisition times of the SPOT XS (spring: 1 September 1989) and the LANDSAT TM (summer: 25 December 1990). A few minor changes occurred in the natural and man-made surface features during this time: eg. the red spots occur in places where there is high TM band 5 reflectance due to the reduced steam emission from the large feature in the lower left of centre (compare with the steam plume shadow in the SPOT CIR image in Fig.4c) and the clearing of vegetation for track and road construction along the left and right periphery of the area. The New Zealand indigenous vegetation is mainly evergreen so exhibits minimal seasonal phenological changes and shows a prevailing uniformity in the spectral characteristics throughout the year. At Craters of the Moon, the major seasonal differences in spectral reflectance are manifest in the prostrate mat moss community which is present on the hottest vegetated areas and mixed with the sparse prostrate kanuka ecotone community on the adjacent cooler ground. In the spring this moss is green in appearance, while in the summer it becomes light-brown. This results in the pinkish coloured patches on the SPOT CIR image (Fig. 4c) and the yellowish coloured areas on the hybrid image (Fig. 4d), which add much of the tonal variation. The other predominant communities (eg. kanuka, manuka and *Pinus spp.*) exhibit no major changes, thus appearing red on the SPOT CIR image and green on the hybrid image. Simultaneous high spatial resolution (18 m) satellite VNIR and MIR JERS-1 imagery of several geothermal areas in the TVZ now exists. Examination of this data should allow a more definitive evaluation of the MIR contribution for large scale geothermal surface feature mapping.

The results obtained in this study have direct application to monitoring large scale changes in geothermal surface conditions which occur both naturally and as a consequence of exploitation. Natural migration and growth of hot ground in parts of Yellowstone National Park (USA) caused major die-back and visually apparent stress of pine trees over large areas, on time scales of a few years (Miller and Cooper, 1969). Experience at Wairakei shows that exploitation can also create large changes in surface activity and influence sizeable areas of vegetation, eg. Craters of the Moon, on time scales of a few years. The changes at Wairakei have continued for the entire production period (Allis, 1979; 1981; Mongillo and Allis, 1989). These changes in surface activity and associated vegetation are known to cover areas large enough to be easily detectable and measurable by current satellites, eg. LANDSAT TM (30 m), SPOT XS (20 m) and JERS-1 (18 m). Hence, the methods demonstrated here should provide a means for monitoring this change by the comparison of multi-temporal satellite imagery.

6. CONCLUSIONS

A range of multi-band combinations of SPOT (CIR) and LANDSAT (CIR; V,NIR,MIR) data and a hybrid SPOT-TM combination ($SPOT2_b3_gTM5_r$) show varying degrees of usefulness for detecting and mapping surface features in the geothermal areas of the TVZ. The TM V,NIR,MIR combination provides excellent images for detecting geothermal areas in highly vegetated areas because it detects and discriminates their stressed vegetation. Hence, this combination could be very valuable for initial regional (and even more local) reconnaissance and exploration to locate geothermal areas. The $TM3_b4_g5_r$ image appears to be the best of the three combinations for the conditions examined. It is concluded that this discriminatory capability results from the incorporation of MIR (1.55-1.75 pm) information, i.e. TM band 5.

The SPOT CIR composite, though of high spatial resolution, is not able to conclusively discriminate stressed from non-stressed vegetation in TVZ geothermal areas (Fig. 4b and 4c), because much of the common non-stressed vegetation present (kanuka and manuka scrub) also exhibits low spectral reflectance characteristic of the stressed vegetation. However, this may not be the case in non-New Zealand areas, so this conclusion requires further investigation.

Once a geothermal area has been identified, the SPOT XS CIR colour composite image can be very useful for mapping steaming, bare hot and hydrothermal altered ground, large fumaroles, large hot pools, sinter and possibly stressed vegetation. The corresponding

LANDSAT TM CIR composite is less useful because of its poorer spatial resolution (30 m versus 20 m for SPOT). This suggests that a spatial resolution ≤ 20 m provides the critical detail required to map *typical sized* geothermal features.

A hybrid SPOT-TM image, $SPOT1_b2_gTM5_r$, was created to combine the higher SPOT XS spatial resolution and the discriminatory power of TM band 5. The hybrid product had great tonal range and very good spatial detail, and was apparently more valuable than either of the individual satellite products for mapping geothermally stressed Vegetation in the Craters of the Moon area. However, possible seasonal phenological effects caused by the presence of a mat moss require further investigation.

Future satellite studies are being continued at a more detailed level for the Waiotapu geothermal area and extended to include examination of quantitative methods for discerning various geothermal features using classification techniques. The TM and SPOT imagery of the Waiotapu geothermal area will be given detailed feature analysis and compared to high spatial resolution (3 m) GEOSCAN aircraft scanner imagery. JERS-1 satellite imagery of the TVZ acquired 30 August 1992 exists and covers several fields at 18 m spatial resolution. This imagery includes the MIR band (1.55-1.75 μm), so will allow investigation of the hybrid image results presented here.

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