GEOTHERMAL ACTIVITY MAPPING USING THERMAL IR LINE SCANNER IMAGERY

D. F. de VRIES

CANSYD Australia Pty Ltd

SUMMARY – Mapping accurately, pixel by pixel, the thermal infrared surface expression of a geothermal field provides the necessary factual document of the extent and condition of the field. Such documentation becomes reference material for future monitoring and geothermal area change detection surveys. The Daedalus airborne multispectral scanner is a spinning mirror line scanner, similar in construction and specification to the LANDSAT TM 4 and 5 satellites, which include the thermal infrared spectral band of 8.5 to 14 um. Pre-dawn thermal IR surveys is a well established mapping routine to locate and identify the ground-surface thermal features associated with structural geology lineaments and faults, ground percolating waters, underground coal fires, buried palaeochannels, geothermal activity and underground pipeline reticulation lines.

1. INTRODUCTION

The thermal infra-red (IR) scanner and imagery is a tried and true form of temperature mapping technology. It was originally developed in analogue form for aerial land surveys flown from aircraft. Later in the 1970's the thermal IR technology was upgraded into digital form in preparation for installation on satellites. The meteorologic and oceanographic science disciplines have enjoyed the most success in thermal IR imagery applications as the world has become familiar with their products, even down to the weather maps on television each evening.

However, the thermal IR bands of the satellite sensors have and remain to have inadequate spatial and thermal resolution to be of any significant value to detect the dynamic change in volcanic geothermal activity. The airborne digital thermal IR imagery has progressed in its technology and service and continues to play a significant roll in accurately measuring the geothermal heat "footprint" pattern critical in factually documenting volcanic zones and their temporal variations.

The airborne digital thermal IR data set has been available in New Zealand and Australia for some years. Capturing the data at night and before dawn (pre-dawn) is now a service that requires good navigation made easier with advent of Global Positioning Systems (GPS) and excellent communication links. It is worth noting that each airborne mission to collect data requires detailed planning in preparation for the "scanner instrument launch". The plans must consider the variables in weather, seasons, atmospheric conditions, terrain, dynamic characteristics of the target, resolution, budgets, airspace, airport curfews and the crew.

This paper will provide evidence that pre-dawn thermal IR imagery captured from an airborne line scanner instrument provides a cost effective solution to quantitatively map known and unknown active geothermal fields in remote or urban locations.

2. AIRBORNE SCANNER IMAGING

The term "imaging" is a term at variance with the more conventional term and methodology of recording pictures of the earths surface by frame format photography. These are considered "frame grabbers". Classic aerial photography cameras and video reorders are in fact frame format photography instruments.

In contrast to "frame grabbers", the thermal IR imaging line scanner generates a digital scene line by line from beneath a moving aircraft. The line scanner accumulates an image by looking at each pixel on the ground, each in turn, as the scanning instrument's mirror rotates and the aircraft flies forward.

Progressively, an image is captured. The image is generated by the forward action of the aircraft and the rapidly spinning mirror visiting each pixel on the ground. The final product image is generated in the post flight processing routine. Intensive mathematical analysis can be directed to the calibrated data. For the crew on the aircraft, a real-time quick-look image is generated during flight facilitates the crew member in confirming data capture success.

3. THE SCIENCE - THERMAL IR

Thermal infra-red light is emitted and reflected. Thermal IR emitted from the earth is energy that has been originally received from the sun and absorbed and stored by the earth. Unlike visible light though, infrared light is emitted by any object that has a temperature above absolute zero Kelvin (minus 273°C). A fire source on the ground such as solid fuel or hydrocarbon fires or from beneath the ground such as from underground coal fires and geothermally active volcanic zones, all emit thermal IR. The hotter the temperature, the brighter the IR light until the object emits visible light.

According to Wien's Law, the maximum emission of energy from a body occurs at a wavelength inversely proportional to its temperature, so the earth radiates energy at a longer wavelength than the sun. The exact formula is:

Wavelength (pm) = 2898/Temperature (“K)) –

this is the wavelength of the ground surface at 27°C temperature, which equals 300” Kelvin.

Wavelength = 2898/300 = **9.5** pm which is in the Thermal IR spectrum.

The emission of radiation **from** any feature on the earth's surface is due to the vibrational interaction of its constituent molecules. When a body of material is marginally or extremely hot the molecules are vibrating actively. This agitation arises when light of just the right wavelength hits a particular molecule. Once it starts vibrating, the molecule re-radiates the same wavelength of light. This is the process of absorption and emission. IR light wavelengths cause molecular vibrations to occur.

Every molecule has its own characteristic frequency of vibration. So, unlike a blackbody emitter, molecules emit energy that departs from a Planck distribution. This means that the infrared light emitted by vibrating molecules can be used to identify them. They are measured in terms of “radiance: watts of energy per unit of area”. With changes in temperature, come changes in radiance.

The resulting emitted radiation in the thermal IR spectrum provides the source of photons for capture in a scanner instrument.

The limiting factor in counting photons transmitted between the ground surface source and the aircraft is the atmospheric column itself. The atmosphere contains gases, in particular, carbon dioxide and water vapour. These two atmospheric materials absorb the thermal IR radiation spectrum with exception of a window between 8pm and 14µm. Within this atmospheric window‘ some sensor instruments are designed to measure the thermal electromagnetic radiation emission with the least amount of extraneous absorption.

4. THE INSTRUMENT

Thermal IR energy cannot be photographed onto chemically prepared emulsion films. The radiant flux must be electronically captured by a photovoltaic cell.

The Daedalus 1268 line scanner instrument measures the spectra of the 8.5µm to 13.0µm thermal IR spectral window. The electronic detectors in the scanning instrument, similar to solar photovoltaic cells, sense the emitted infrared energy captured by the scanning mirror and converts it to electrons. Each photon captured participates in generating an electron. The scanner instrument captures the one thermal IR data stream on two channels. Channel 11 is the standard data stream and Channel **12** is an adjustable, aircrew operator controlled data stream.

The IR spectrum is calibrated within the scanner head *against* two controllable thermal blackbodies. For reference, a blackbody emitter lies within the instrument. The mercury cadmium telluride (HgCdTe) photodiode detector is cooled by liquid nitrogen to near zero Kelvin. Each scan is referenced against the blackbody.

The digital count of electrons of each pixel becomes the data stream for image processing and mapping the site. The thermal infrared band is unaffected by sun glint, smoke haze or aerosol induced variances as viewed by an airborne platform.

By recording the air temperature and the level of humidity on the ground and the air temperature at aircraft altitude, an atmospherically corrected image of apparent ground and water surface temperatures (radiant surface temperatures) to an accuracy of <0.5°C is generated. The infrared reference source temperature ranges are –15°C to +50°C with respect to the head heat sink temperature. The instrument measures the temperature differences to a precision of <0.1°C in the –15° C to +50°C temperature zone but can also measure to <0.5°C precision in the 50°C to 100 °C temperature range. The Daedalus 1268 multispectral scanner measures ten other spectral bands in the visible, near infra-red and short wave infra-red spectrum. The band edges of the channels of the line scanner are listed in Table 1.

Channel	Band Edges (µm)	Band Edges (µm)	Noise Equivalent	(LANDSAT TM 4 and 5) equivalent)
Ch 1	0.420	0.450	< 1.0%	
Ch 2	0.450	0.520	< 0.2%	(Ch 1)
Ch 3	0.520	0.600	< 0.15%	(Ch 2)
Ch 4	0.605	0.625	< 0.2%	
Ch 5	0.630	0.690	< 0.1%	(Ch 3)
Ch 6	0.695	0.750	< 0.2%	
Ch 7	0.760	0.900	< 0.2%	(Ch 4)
Ch 8	0.910	1.050	< 0.5%	
Ch 9	1.550	1.750	< 0.7%	(Ch 5)
Ch 10	2.080	2.350	< 0.7%	(Ch 7)
Ch 11	8.500	13.000	< 0.08°C	(Ch 6)

Table 1 - *Daedalus 1268 Instrument*

5. PRE-DAWN SURVEYS

Day-time captured thermal IR imagery tends to present a more uniform ground surface response, as the sun's thermal irradiance emissions are still active upon the ground surface materials. It is important to note that the thermal infrared response, as viewed by an airborne platform, is unaffected by sun glint and aerosol induced variances

Night-time captured thermal IR imagery, preferably captured just before dawn, provides a higher level of contrast between materials viewed on the ground surface, as viewed by an airborne platform. At night, when the ground surface is cooling, temperature variations caused by the direct influence of sunlight become much more subdued and the patterns due to the conduction of heat from the subsurface are more clearly seen in thermal images.

For this reason night-time sorties, or pre-dawn thermal surveys are preferred for detecting subtle temperature differences. Each pixel temperature variation is more readily apparent, influenced by contrasting variations in soil moisture and porosity of rocks. Further, night-time thermal IR imaging is free of solar shadowing of high topographic relief and high clouds, and more often than not takes advantage of the calm evening air conditions.

6. THEMISSION

Each project and therefore flight mission requires the aircraft to be located over a pre-determined site at a pre-determined time, altitude, heading and airspeed. Table 2 shows the relationship between aircraft altitude above ground, pixel resolution and swath width of the ground track. Undulating terrain will generate varying pixel resolution and swath width.

Unstable atmospheric conditions will cause some aircraft attitude variations, roll, yaw, pitch and speed. Clouds, wind, wind shears and fog, do hamper good data collection operations. The scanner instrument requires as a minimum an aircraft roll correction mechanism. A gyroscope mechanism maintains a one directional correction on the instrument. Newly developed full attitude data recording mechanisms, including GPS (Global Positioning System) data, provides a critical parallel data stream to georectifying the image flight path at the time of image processing and image analysis. GPS data assists in accurately locating the flight track on the ground with sub-metre precision. Airborne captured images have higher resolution and better signal to noise qualities than satellite imagery.

Another georectification method is to merge airborne data with satellite georectified data.

Timing of the mission is important. The dry summer conditions will more readily capture the contrasting soil and rock temperature features.

Pixel size (metres)	Aircraft AGL (m)	Image Swath (km)
30 x 30	12,000	19.5
20 x 15	8,000	12.7
15 x 15	6,000	9.6
10 x 10	4,000	6.4
5.0 x 5.0	2,000	3.2
3.0 x 3.0	1,200	1.9
2.0 x 2.0	800	1.3

Resolution is dependant on the application. Regional surveys should be flown at high altitudes to acquire imagery cheaply over a large area. The more detailed mapping programs will require low-level overflights. Low-level flights generate more data and require for some applications more intense georectification.

7. INTERPRETING TIR IMAGERY

The monochrome thermal IR images of a site flown before dawn are essentially of ground surface temperature. Ground temperature differences are due to complex interactions of the physical properties in the rock, the soil and man-made structural materials. The most important property of a ground cover material is its moisture content. This influences surface temperature. The simplistic result of all this is that moist soils are always cooler than dry soils.

The interpretation of thermal images is entirely photogeological provided that the thermal properties of rocks and soils are taken into account. Faults, fracture zones and lineaments are inferred from alignments of cool, moist soils and weathered rock zones, in the same way that an experienced field geologist would interpret spring and seep line fiom linear thermal contrasts due to dry and moist soils.

Urban features such as bitumen pavement roads, concrete pavements, compacted dirt roads and tracks, are all distinguishable in TIR imagery. For example compacted earth is cooler compared with concrete and asphalt surfaces.

Extraneous hot spots generated by their own heat source, image in stark contrast to the surrounding residual thermal materials. As shown in Figure 3 high intensity heat zones are particularly noticeable and measurable.

Imaging features of the non-geological nature, are imaged wind streaks and wind smears which are recognisable but merely artefacts of the atmospheric conditions.

8. GEOTHERMAL ZONE DETECTION

Geothermal active zones are clearly identifiable in night–time captured thermal IR images. The line scanner images locate and quantify the intensity of heat to an accuracy of 0.1°C. The imagery is conducive to digital change detection mapping of two or more data sets captured over a period of time.

Thermal IR imaging essentially images the radiation emitted from the ground surface and the overlying vegetation. There is no direct "penetration" of the earth's surface. All subsurface features are inferred.

A feature that may partially mask a subtle geothermal feature is vegetation. A dense plant or tree canopy may mask low intensity thermal features. However, a geothermal hot spot, depending on its intensity, will thermally condition the overlying vegetation and possibly continue to influence thermal IR signature of the vegetation as a whole.

If, at the time of data capture during night-time imagery operations, there is a cool ground surface wind effective in chilling the vegetation, there is a risk of partially or complete masking of the presence of a geothermal active zone. Wide leaf area vegetation is generally warmer at night because the leaves contain moisture. Leaf temperature contrasts are less extreme for the nettles found on conifer type tree species.

9. CONCLUSIONS

Undefined and remote areas of geothermal activity are conducive to the routine monitoring by thermal IR line scanner. This is a "tried and true" technology. Ground temperature in the Thermal IR spectrum cannot be photographed with convention "film frame grabbers". An airborne digital line scanner will accurately capture and quantifiably record the temperature of each pixel. Such imagery lends itself to multiple surveys over a site on the same flight path therefore compiling data sets for change detection mapping.

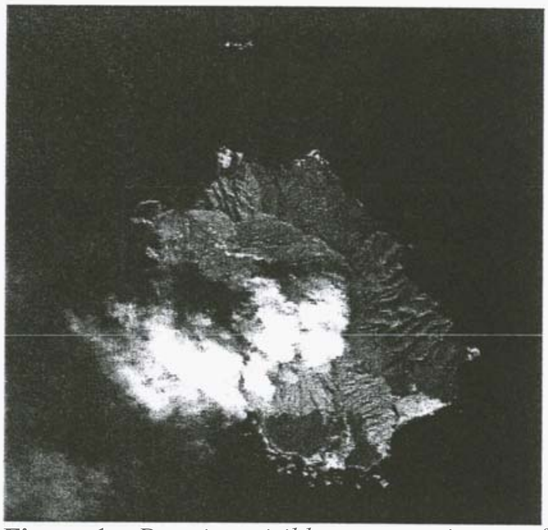

Figure 1 – *Day-time visible spectrum image of White Island, Bay of Plenty, New Zealand.*

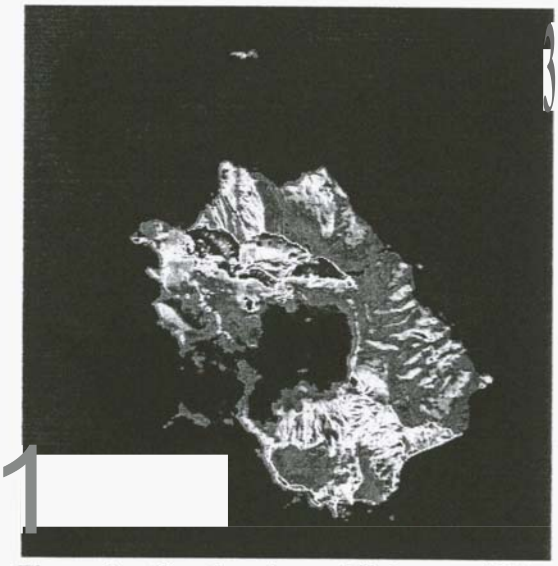

Figure 2 – *Day-time thermal IR image of White Island, Bay of Plenty, New Zealand.*

Figure 3 – *Night-time thermal IR image of underground coal fires in the Hunter Valley, Australia.*

Figure 4 – *Night-time thermal IR image identifying hot spots (caused by bush fires) in remote vegetated areas, NSW, Australia. White areas are very hot areas.*

Figure 5 – *Processed night-time thermal IR image of the fire induced hot spots (caused by bush fires) in remote vegetated areas, NSW, Australia. Red zones indicate fire activity – temperature calibrated to 0.5°C.*

Thermal IR imagery of geothermal areas quantifiably measure the dynamics of a field and factually map the area for base line studies and industry development.

The acquisition of airborne thermal IR data can be acquired of any site globally, no matter how remote, and provides a surface expression map of a resource and commodity.

10. ACKNOWLEDGEMENTS

We acknowledge the capture of sample images by Air Target Services Pty Ltd,
PO Box 511, Nowra NSW 2541 Australia
Tel: +61 2 4423 6799,
Fax: +61 2 4422 1772
Email: <ats@airtargets.com.au>
Web: www.airtargets.com.au

11. REFERENCES

de Vries, D.H., Norman, R. **(1994).** Airborne Multispectral Scanner: Daedalus ATM (AADS **1268)** Commercial Operations in Australia. ***Proceedings of the 7th Australasian Remote Sensing Conference.*** pp **128-135** Melb., Australia..

de Vries, D., **(1995).** Airborne Multispectral Data including Thermal IR (Daedalus **1268)** from **a** Learjet Platform. ***Proceedings of 16th Asian Conference on Remote Sensing.*** Thailand.

de Vries, D., **(1996).** Pre-Dawn Thermal Infra-red Imagery - Regolith Mapping Tool. **13th** Australian Geological Convention. Canberra, Australia

de Vries, D., **(1996).** Pre-Dawn Thermal Infrared - A Successful Airborne Data Set. ***Proceedings of the 8th Australasian Remote Sensing Conference.*** Canberra, Australia.

Exploration, Research & Development Unit, **(1977)** Better mapping through Remote Sensing. ***Coal & Base Minerals of South Africa, Vol.25 No.9 Sept 1977.*** South Africa

Jupp, D.L.B., Held, A., Burne, G., Hutton, P., McDonald, E., and Parkin, D. **(1993).** ***The Potential Use of Airborne Scanning for Monitoring Algal Dynamics in Australian Waters.*** CSIRO- COSSA Report No. **30,** Canberra, Australia

Longshaw, T.G., **(1984).** Thermal Infra-red Mapping in Search of Underground Water. ***Proc. of the International Conference on Ground Water Technologies,*** Johannesburg, SA.

Loughlin, W.P., **(1990).** Geological exploration in the western United States by use of airborne scanner imagery. ***Proc. of the IMM Conference - Remote Sensing, An Operational Technology for the Mining*** and ***Petroleum Industries.*** London, UK.

Mongillo, M.A., Bromley C. **(1991).** Ma-red Video Survey of Tokaanu-Waihi Geothermal Field. ***Proc. 13th Nay Zealand Geothermal Workshop,*** Univ. of Auckland.

Mongillo, M.A., Graham D.J. **(1999).** Quantitative Evaluation **of** Airborne Video TIR Survey Imagery. ***Proc. 21st Nay Zealand Geothermal Workshop,*** Univ. of Auckland.

Mukherjee, T. K., Bandyopadhyay, T. K. and Pande S. K. **(1991).** Detection and delineation of depth of subsurface coalmine fires based on airborne multispectral scanner survey in part of Jharia coalfield, India. ***Proceedings of the Eighth Thematic Conference on Geological Remote Sensing.*** Denver, USA. 427-437

Staff of Spectral Africa (Pty) Ltd. **(1978).** Some Practical Applications of Thermal Infra-red Linescanning *Mining Magazine Oct. 1978*