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THERMAL INFRARED VIDEO IMAGERY OVER THE ROTORUA GEOTHERMAL FIELD

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ABSTRACT

Delineation and monitoring of surface thermal activity at geothermal development sites and in tourist and urban areas is important for both planning and safety reasons. Because the standard groundbased methods for such work are time consuming, and often impractical, we have been developing helicopter-borne video thermal infrared scanner techniques. In a single 2-hour survey, a total area of 15-20 km^2 can be covered at a ground resolution of 1-2 m^2.

The results obtained at Rotorua demonstrate the value and power of the video data capture method, which provides real-time monitoring and the ability to store large quantities of readily accessible continuous imagery. We have also established an image processing facility which allows the imagery to be digitized for analysis by powerful image processing techniques. We have been able to accurately map thermal features in relatively inaccessible areas, detect thermal water flowing through open and covered drains and thermal inflows to streams and lakes, detect hot spots in sealed roads and carparks constructed over thermal areas, and establish baseline data to compare with future infrared surveys for monitoring changes in surface activity.

INTRODUCTION

The Rotorua Geothermal Field represents an extremely important resource for its cultural value, as a tourist attraction, and as a source of energy for domestic and commercial use. Though there have been many scientific studies conducted at the Rotorua Geothermal Field, (DSIR et al, 1985), several of the fundamental attributes of the geothermal system, including its size, structure, and dismbution of associated surface thennal activity, remain to be accurately defined. Consequently, the DSIR mounted an intensive investigation of the Rotorua geothermal system during the 1989-90 financial year. As a part of this study, a Comprehensive helicopter-borne thermal IR scanner survey was conducted over the Rotorua Geothermal Field to obtain a baseline map of surface thermal activity. A discussion of this infrared survey and the results obtained are presented in this paper.

BACKGROUND

The Rotorua Geothermal Field has an approximate surface area in excess of 10 km^2, much of which extends beneath the city itself. The major surface thermal activity associated with the field is concentrated in several widely distributed locations, including: Whakarewarewa, Arikikapakapa, Ngapuna, Sulphur Flats, Government Gardens, Kuirau Park and Ohinemutu (Figure 1). It is known that changes in both the character and location of such surface thermal activity occur naturally, and that these changes can be accelerated by exploitation (Allis, 1981; Simpson, 1985). Changes in exploitation rate may also influence thermal features.

During the 1970's and early 1980's, there was extreme concern expressed that *over-exploitation* was adversely affecting the important natural features at Whakarewarewa Thermal Reserve, an important Maori cultural and tourist site. As a result, an intensive 4-year monitoring study was conducted (1982-1985) which culminated in the political decision to close those exploiting geothermal bores located within a 15 km radius of the area It was hoped that such a decrease in exploitation would help restore some of Whakarewarewa's natural features as well as prevent further degradation of those remaining. This decrease in exploitation might also induce change in the thermal activity at other localities.

Since much of the surface activity in Rotorua is located close to urban areas, recreational reserves and tourist developments, it is clearly very important to accurately characterise and monitor it for feature preservation and safety reasons, as well as for planning purposes (Dickinson, 1973; Mongillo, 1988; 1989). Changes in surface activity can also signal changes in the underlying geothermal system, hence, knowledge of them is of scientific importance as well as of use for field management purposes.

The measurement of individual feature temperatures and shallow ground temperature surveys have commonly been used to characterise geothermal activity and monitor for any change. Unfortunately, these methods are generally incomplete, often impractical, and extremely time consuming and expensive. Thus, important monitoring is often neglected. To overcome these problems, a helicopter-borne video thermal infrared scanner technique was developed for use in New Zealand by DSIR Geophysics Division (now DSIR Geology and Geophysics). The method is founded upon the principle that all objects having kinetic temperatures (T) above absolute zero (0 K) emit thermal infrared (IR) radiation which has a total energy content proportional to T^4. This thermal IR radiation emitted by the scenes of interest is detected by the scanner and recorded on a video tape as imagery in shades of grey. In general, the hotter the surface feature, the brighter (whiter) it appears on the imagery. The video imagery can be viewed on a standard TV-VCR system as a quick assessment method. However, the real power of the method results from digitizing the imagery and applying computer processing techniques which allow image correction and enhancement, hence providing much greater detail and more quantitative information.

THE SURVEY

A comprehensive aerial thermal IR survey of the Rotorua Geothermal Field was conducted on 1 March 1990. Three simultaneous sets of imagery were obtained using two different video thermal IR scanners and a visible video camera mounted on a helicopter platform.

INSTRUMENTATION

The thermal infrared imagery was obtained using two different video thermal IR scanners; a FLIR Systems 1000A (owned by the Philips Search and Rescue Trust, Taupo) and an Inframetrics 525 (owned and operated by ASEA-Brown-Boveri, Hamilton), both mounted on a Squirrel helicopter (operated by Helicopter Services, Taupo, Ltd). The use of both instruments afforded the opportunity to compare them under exactly the same operating conditions and provided a redundancy which proved to be of the greatest value when the FLIR detector cooling system failed about mid-way through the survey.

FLIR 1000A: The FLIR system has the complete scanner mechanism, infrared detectors, compressed argon gas cylinder and cryostat, all contained within a 32 cm diameter sphere mounted beneath the helicopter. The thermal IR radiation from the scene passes into the sphere through a germanium window, where it enters the optical-mechanical scanning system which focuses and sweeps it across two rows of single mercury-cadmium-telluride detectors which are cooled to about 87 K by a compressed gas (argon) cryostat. The detector system is sensitive in the 8-12 μm wavelength band, with peak sensitivity at about 10.6 μm. An external controller, located inside the helicopter, controls the instrument and processes the electrical signals from the detectors to produce black and white imagery of the scene temperature pattern. The imagery thus produced can be observed on a portable TV-monitor and simultaneously recorded on a standard VHS-PAL portable video cassette recorder.

The FLIR instrument has a total frame field of view (i.e. image size) of 28° (horizontal) x 17° (vertical) with an instantaneous field of view of 1.87 milliradians. The nominal survey altitude was 610 m (2000 ft) above ground level, providing a nadir ground resolution element of about 1.1 m and a total image size of about 300 m x 180 m, or 5.4×10^2 m^2. Each black and white image consists of about 400 lines with about 260 pixels (picture elements) per line. An uncalibrated grey scale is superimposed along the top of the imagery. The instrument's pointing azimuth and elevation, controlled by a joystick from within the helicopter, are indicated by cursor positions relative to fiducial marks (short, bright lines) located along the top and righthand si& of the imagery.

Inframetrics 525: Details of the Inframemcs 525 instrumentation can be found in Mongillo (1988). Relative to the FLIR, it has a similar nadir ground resolution of 1.2 m, but a smaller image size of 192 m x 150 m (2.9×10^4 m^2) at 610 m altitude. The imagery consists of 240 lines with 157 elements per line and has a temperature range scale located along the left edge and an intensity wedge superimposed along the bottom.

To assist with location and interpretation, simultaneous visible video imagery was also obtained using a portable video camera.

SURVEY DETAILS

The first comprehensive baseline video thermal IR survey of the Rotorua Geothermal Field was conducted between 6.30 pm and 9.15 pm on 1 March 1990. Vertical imagery was obtained over an 18 km^2 area, which included all known thermally active areas and extended well beyond the boundary of the field as it is *presently* defined (DSIR et al, 1985).

A total distance in excess of 150 km was flown, covering 32 flight lines plus set-up and calibration runs, at a nominal altitude of 610 m (Figure 1). The typical helicopter airspeed was about 60 knots (110 km/hr). The weather conditions during the 5-day period prior to the survey had been very stable, warm and dry. During the survey, the sky was clear and a light west to southwest wind was present, which caused minor deviations from the planned flight lines.

The survey progressed westwards from the eastern edge of the field, after performing the initial instrument alignment and set-up over the Rotorua Airport and conducting a calibration run over the general vicinity of the Polynesian Pools. The FLIR instrument began exhibiting problems during flight line 15, and was shut-down after line 17. Thermal IR imagery was obtained for the remaining 50% of the survey using only the Inframetrics instrument. The visible video camera provided good imagery to the end of flight line 17 (about 8.20 pm), after which it was too dark for useful imagery to be obtained.

The ground support necessary for conducting this survey was provided by one navigation crew (to assist the helicopter navigator) and three calibration groups. The calibration groups made ground truth measurements of water surface temperatures at pre-determined sites which included both natural (thermal springs, lakes, streams) and manmade (ambient and heated pools) features. These measurements were made within 0.5 hr of the imagery being collected over the area.

IMAGE ANALYSIS

The image processing facility, recently established at Wairakei, consists of a PC286 computer with an 84 Mbyte hard disk, maths co-processor, and high resolution colour monitor. PC-Epic software developed by DSIR Division of Information and Technology is used to interactively grab selected images, as the video tapes are played back through a standard VCR. These images can be digitally enhanced using a wide variety of processing options. The Inframemcs imagery is initially corrected by performing a relative shift (typically 2 pixels) between the odd and even fields. This eliminates the "saw tooth" banding effect.

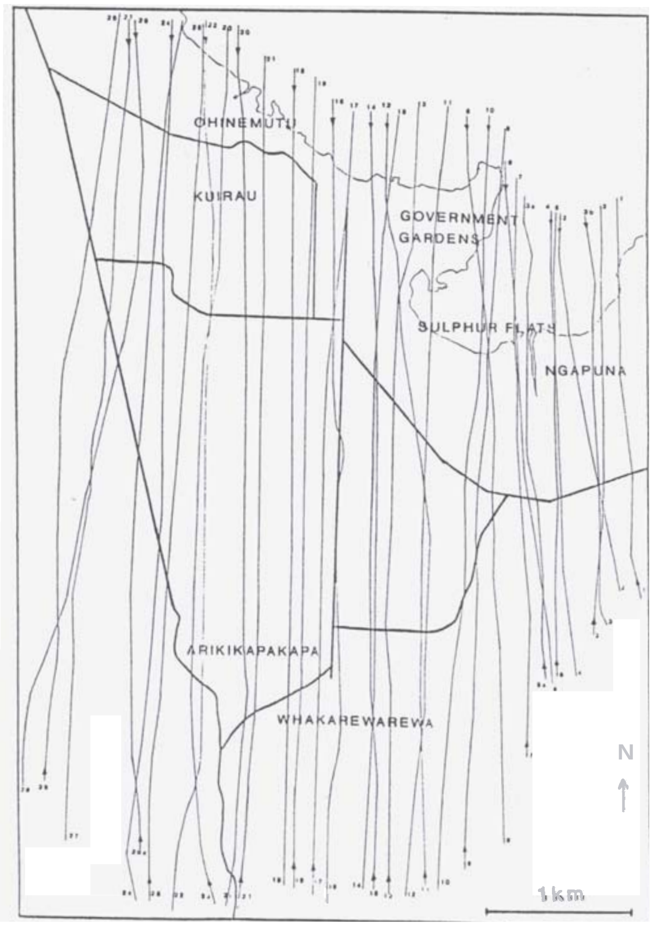

Figure 1. Sketch map of the Rotorua area showing principal streets, the lake edge and the locations of the flight lines used during the 1 March 1990 thermal IR survey.

(The FLIR imagery does not need this correction). The images are then usually filtered with a uniformly weighted 3x3 spatial filter. They may be level-sliced at suitable temperature increments (e.g. 1°C) or pseudo-coloured to highlight certain anomalies. The image can be enhanced by stretching a subset of the full range of pixel values (0 to 255) so that it ranges from black to white. This has the effect of enhancing subtle temperature variations in areas of particular interest. Other enhancement options allow contouring of the pixel values at suitable temperature increments and histogram-equalization. Up to three separately enhanced images can be superimposed.

RESULTS AND CONCLUSIONS

Visual examination of the thermal IR imagery collected over Rotorua reveals all the major thermal areas, with excellent ground resolution. As part of the documentation of the survey, and to assist users, tables have been prepared listing features of interest alongside their location on the video tapes and the flight line number. Ground-truth temperature calibration measurements were obtained at 62 sites and have also been tabulated along with locations and times. A total of 126 images, covering most of the thermal areas, have been frame-grabbed from the videos and saved as 512 x 512 8-bit digitized images on floppy disk. These images can be readily retrieved, enhanced and printed for specific purposes. Images presented in this paper are grey-level laser prints produced at Wairakei. Photographic and laser-writer reproduction can produce higher quality hardcopies, including colour.

As well as accurately mapping the more familiar thermal reserves, the survey has also located some lesser known thermal features, particularly in the forest south of Whakarewarewa (near a fault passing Pohaturoa Trig), and also previously unknown springs on the bed of Lake Rotorua. From Ngapuna to Ohinemutu there are many hot seepages located along the lake edge. In addition, there are several localised hot spots on the surface of the lake that are presumed to overlie lake bed hot springs. One is situated about 200m offshore from the Puarenga Stream mouth, two are located about 70m and 200m from the Utuhina Stream mouth (Figure 5), and there are several located in the shallow waters and on some of the small islands in Sulphur Bay.

Previous measurements of the chloride concentrations of known inflows and outflows from Lake Rotorua have identified a substantial chloride flux imbalance. Approximately 50% of the total chloride flux leaving the lake has not yet been accounted for (Hoare, 1985: Glover, pers. comm; 1990). The Rotorua IR results suggest that a substantial portion of the unknown chloride input may be coming from these hot springs in the bed of the lake, especially in the Sulphur Bay area. Confirmation of this discovery would result in a substantial increase in the estimation of natural heat and mass outflow from the Rotorua Geothermal Field which, in turn, would have important implications for reservoir simulation models and field management.

Another result of the IR survey is the identification of hot spots within sealed roads and carparks built over thermal areas. Examples can be found in the Geyserland carpark at the end of Fenton Street (Figure 2), Old Taupo Road between the Thermal Motor Camp and Arikikapakapa (Figure 3), a carpark on the north side of Rotorua Hospital, and Lake Road opposite Korokai Street.

Hot water discharges through culverts and drains, both covered and uncovered, are also revealed. Examples include an open drain from Taharangi Marae to Utuhina Stream, a drain through the Motutara Golf Course, covered drains under the junction of Tarewa Road and **Kuirau** Street (Figure 4), and a covered drain from Queen Elizabeth Hospital to the lake. The IR imagery has sufficient resolution to identifv hot man-hole covers (about lm diameter) over thermal drains near the lake front. In addition, a large number of uncovered heated swimming pools can be identified.

The *primary* objective of this survey, to establish a baseline for comparison with future infrared surveys to monitor changes in surface activity, has been successfully met. Ground truth and imagery calibration played an essential role in this work. Using the ground truth data, the calibrated Inframetrics imagery obtained in this survey was determined to cover the surface temperature range of 15° - 30°C. Comparison of this imagery with calibrated imagery obtained on repeat future surveys should then allow absolute temperature changes at least within this 15°C range to be measured. The FLIR imagery is not internally calibrated, though laboratory testing and analysis of the ground truthed Rotorua images demonstrated that it covered a ground surface temperam range of about 22°C. Consequently, relative temperature changes at least within this range should be detectable on repeat FLIR surveys. However, image processing techniques could allow absolute temperatures and temperature changes to be determined if detailed calibration procedures were performed.

FUTURE DIRECTIONS

1. Accurate navigation at the flight altitude of about 610m has been a problem, which we hope to solve in future helicopter-borne surveys by using GPS, a satellite based global positioning system.

2. We plan to extend the use of thermal IR to active volcano monitoring applications, mapping changes in surface thermal anomalies.

3. The technique should also prove useful in the study of thermal plumes created by the discharge of hot water from thermal power stations into rivers, lakes or oceans.

4. Image processing techniques can assist interpretation of a wide range of gridded data sets, such as gravity, magnetics and resistivity, as well as captured video images, and SPOT satellite imagery. We plan to provide a facility for the enhancement and comparison of gridded data bases from a variety of sources.

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Figure 2. Thermal anomalies in the Geyserland Resort and Arikikapakapa Golf Course carparks at the southern end of Fenton Street (looking north). The bright features at the left are thermal lakes. The image is filtered and enhanced to clearly illustrate the carpark anomalies. Brightness interval (0,185) was stretched to (0,250) and interval (186,255) shifted and compressed to (251,255).

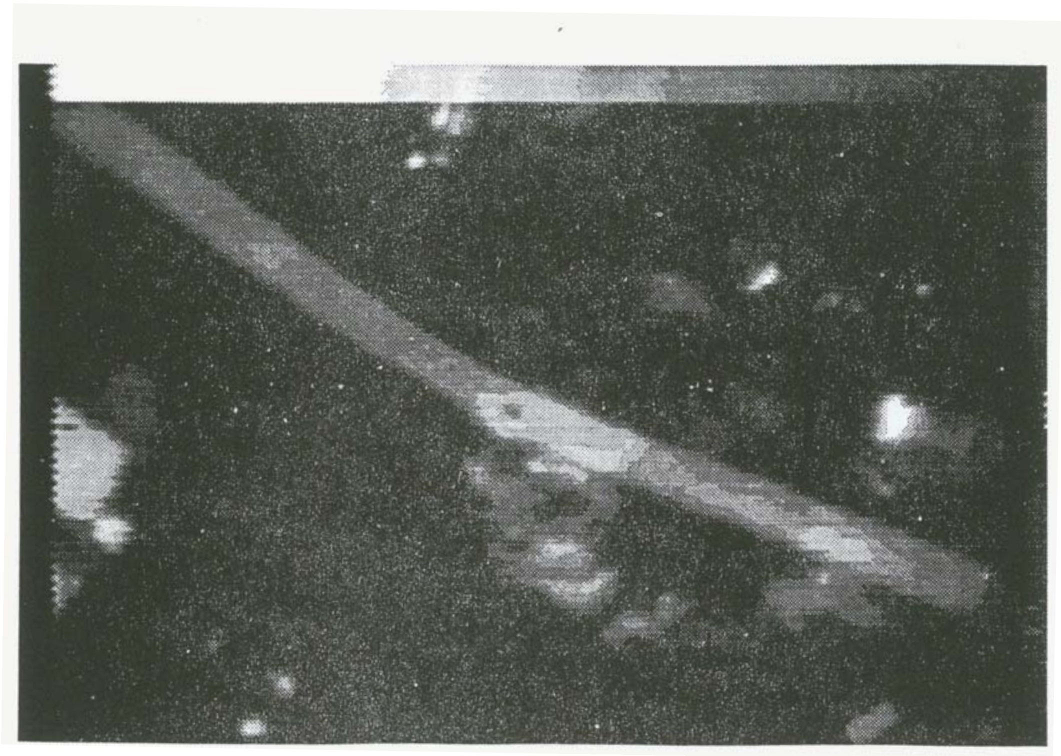

Figure 3. Thermal anomaly on Old Taupo Road between Arikikapakapa Golf Course and the Thermal Motor Camp (looking north). Near surface ground temperatures of up to 40 °C occur within the hottest portions of the anomaly south of the road. The bright area at the extreme left of the image is part of Lake Tangatarua. The motor camp swimming pool (bottom edge, far right) has a temperature of 25.8 °C. Imagery is corrected, filtered and level-sliced (2 °C intervals).

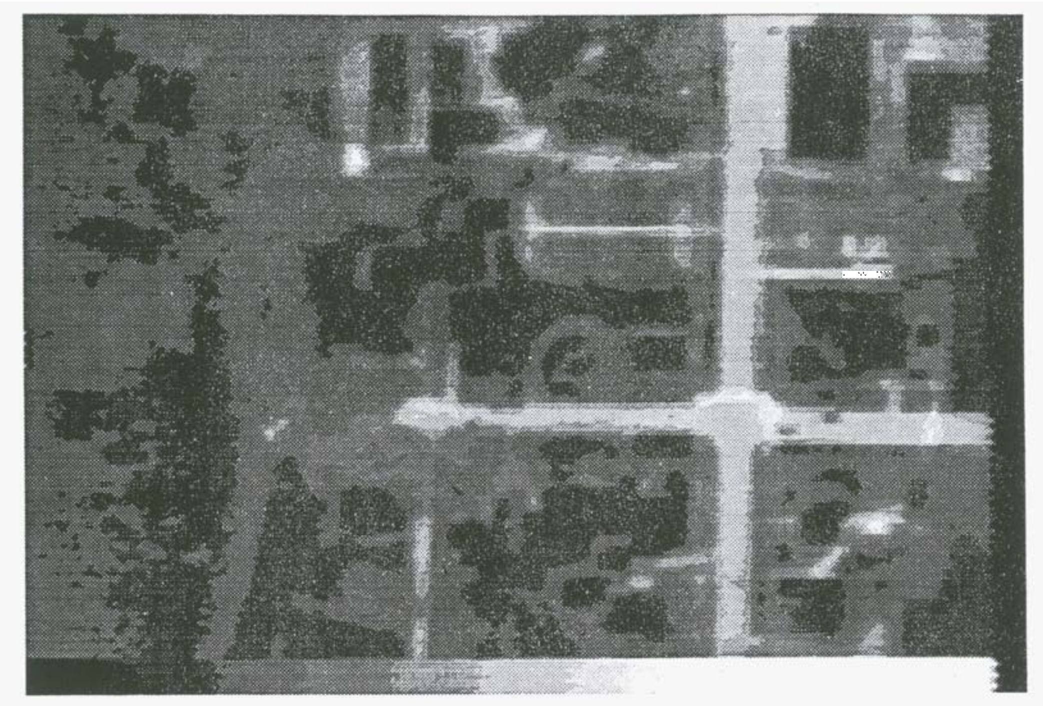

Figure 4. Three linear thermal features near the junction of Tarewa Road (north trending) and Kuirau Street are caused by hot geothermal water flowing through culverts under the roads. A backyard *hangi* (geothermal steam cooking device) can be seen in the bottom right corner, and a thermal swimming pool is at the upper left of centre (just east of the Utuhina Stream). This image is corrected, filtered and level-sliced (2 °C intervals). Ground area covered by this image is about 190 m by 150 m.

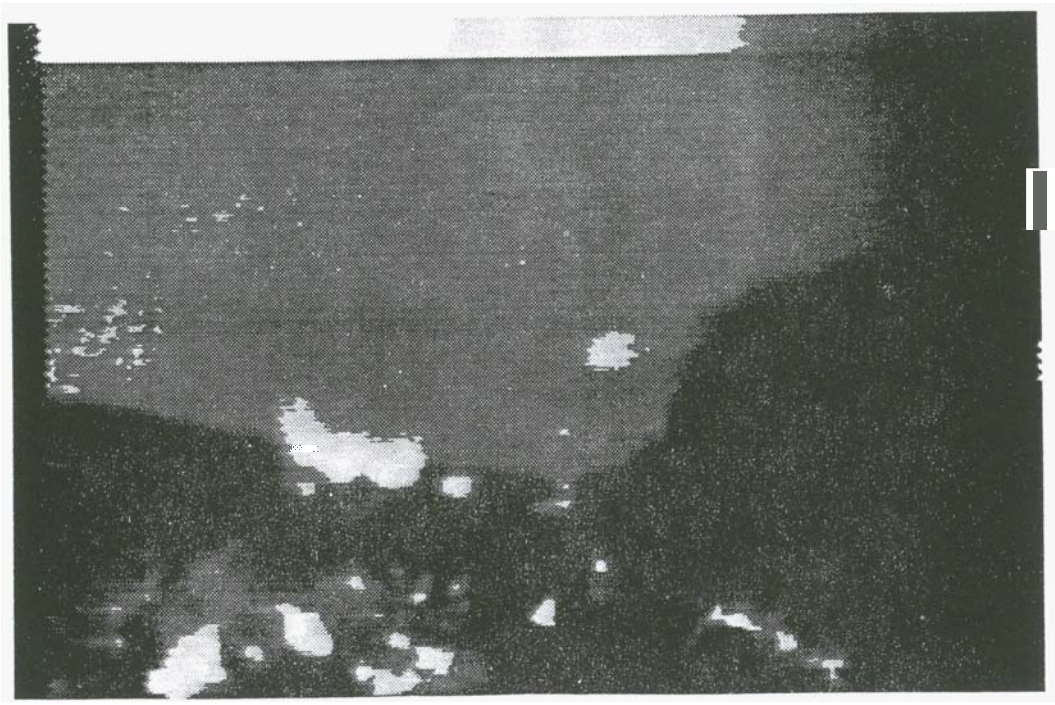

Figure 5. Infrared imagery of the mouth of the Utuhina Stream (Ohinemutu). The cold stream water (17.5 °C) produces a dark plume into warmer Lake Rotorua (22 °C). A hot spring in the lake bed can be clearly seen, along with hot seepages at the lake edge on either side of the stream mouth. The bright areas on land correspond to thermal ground. The image is corrected, filtered and enhanced so that brightness levels (0,114) remain unchanged. To highlight the seeps and hot spots, the higher brightness intervals have been shifted and compressed in two segments: (115,139) to (200,220) and (140,255) to (221,255).