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Improved environmental monitoring of surface geothermal features through comparisons of thermal infrared, satellite remote sensing and terrestrial calorimetry

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ABSTRACT

Assessing changes in surface heat-loss at geothermally active areas provides insight into the geothermal reservoirs at depth. Surface temperatures and heat output of steam-heated ground can be inferred through processing of thermal infrared images, as well as by direct measurements using terrestrial calorimetry. In February 2014, a high resolution aerial thermal infrared (TIR) survey and a terrestrial heat-loss survey (excluding fumarole discharge) were carried out over Karapiti (ca. 0.35 Km^2 in the Wairakei-Tauhara Geothermal System) in the Taupo Volcanic Zone, New Zealand. Estimates of heat-loss are compared to those calculated from TIR data collected by the Landsat-8 satellite of the area. This paper discusses the processing techniques for the datasets and compares inferred surface heat losses. The aerial TIR and terrestrial measurements are in reasonable agreement with calculated surface heat-loss values for Karapiti range from 41 MW (theoretical radiation heat loss using aerial TIR) to 58 MW (total heat loss based on an empirical correlation with boiling-point depths). Satellite images show a large variation between day-time and night-time TIR assessments. The assessment of nocturnal (non-solar), radiation heat-loss is an order of magnitude lower than the total heat-loss determined from the other techniques and approximately 1/3 of the inferred radiated component calculated from the aerial TIR data. This is likely to be a consequence of diffuse, advecting-steam heat-loss, combined with an image resolution issue: the pixel resolution of the satellite image (30 × 30 m) is much larger than the typical size of the active geothermal surface manifestations (< 10 m^2). Because the radiated heat-loss is a non-linear function of land surface temperature, the in-pixel averaging under-estimates the radiated heat-loss. These and other problems currently restrict the usefulness of repeat low-resolution satellite imagery for monitoring of surface heat-loss changes in steam-heated ground.

1. Introduction

The discharge of geothermal vapour from underground reservoirs can result in areas of highly-heated and diffusely-steaming ground at the surface. The amount of heat discharged can be indicative of the relative size and recharge characteristics of the underlying geothermal resource (Hochstein and Bromley, 2005). Accurate quantification and monitoring of surface heat-loss in geothermal areas is difficult to achieve, but is important for protecting the resource and its surrounding environment. Such data is also important as an input for reservoir simulation modelling and for improved sustainable management of geothermal fluid utilisation (*e.g.* Newson and O'Sullivan, 2004). Improvements in monitoring tools and techniques are becoming increasingly important in an environmentally conscientious society. Advancements in capabilities, such as remote sensing, provide many benefits to monitoring and assessing geothermal environments. They reduce costs of land-based surveys, and meet increased safety considerations for accessing geothermal areas. This paper compares heat-loss estimations from terrestrial measurements, aerial thermal infrared (TIR) images and satellite thermal imagery (TIRS) collected during 2014–2016, over the geothermal area at Karapiti, New Zealand. The terms heat-loss and heat flux are used often throughout the text, with heat flux referring to a measured surface heat output at a point ($W\,m^{-2}$), and heat-loss referring to the surface heat output over a totalled area (W).

The Karapiti thermal area (also known as "Craters of the Moon") is located within the Wairakei-Tauhara Geothermal System, in the Taupo Volcanic Zone (TVZ), New Zealand (Fig. 1). It encompasses

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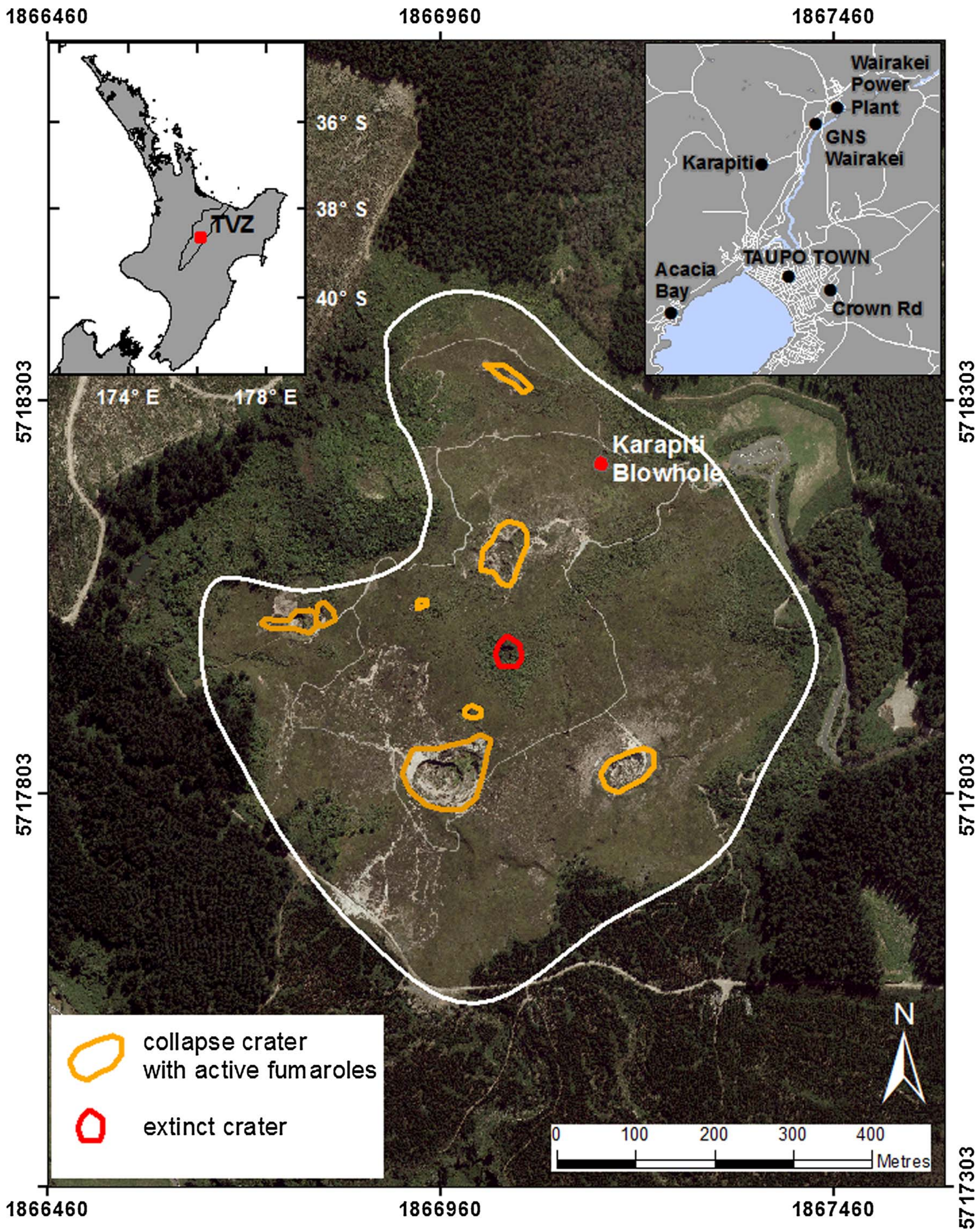

Fig. 1. Aerial image of Karapiti taken in 2012, with areas of active and historic fumarole activity shown in orange and yellow shades (adapted from Hochstein and Bromley, 2001). White line highlights the extent of the heated area. Insert left: location of Karapiti within the TVZ. Insert right: regional map showing Karapiti in relation to the Township of Taupo and Wairakei Power Plant. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

approximately 0.35 km^2 of hot and steaming ground and is one of the better studied areas of steam-heated thermal ground in the world, with approximately 60 years of reported heat-loss measurements (Ledger, 1950; Mongillo and Allis, 1988; Bromley and Hochstein, 2001, 2005; Hochstein and Bromley, 2001, 2005, 2007; Mia et al., 2012). The area is popular with tourists attracting over 50,000 visitors per year (Environment Waikato, 2002). Exploration drilling for the Wairakei Geothermal Power Station, located approximately 3 km north of Karapiti, commenced in the early 1950′s. Prior to that time, thermal surface features of Karapiti consisted mainly of small areas of geothermal activity, including hot ground, several mud pools, one extinct hydrothermal eruption crater and one large fumarole, known as the Karapiti Blowhole (Fig. 1) (Mongillo and Allis, 1988). Changes in vegetation, new hydrothermal eruptions and new fumaroles, and an increase in the size of steaming ground at Karapiti were reported since testing the geothermal bores for the Wairakei Geothermal Power Station in the 1950′s (Banwell, 1954; Dawson and Dickinson, 1970). Since 1950, the heat output of Karapiti has been repeatedly surveyed,