Monitoring precursory unrest and the 2009 eruption of Redoubt Volcano, AK by high-resolution satellite and airborne thermal infrared imaging

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We use a combination of satellite and airborne high-resolution visible/near-infrared and thermal infrared (TIR) image data to detect and measure changes at Redoubt Volcano before, during, and after the 2008-2009 unrest and eruption. The high-resolution TIR remote sensing response initially focused on detecting and monitoring changes in possible thermal areas and other surface features to assess the extent of unrest and the likelihood and timing of an eruption. As the eruption commenced, the TIR response changed to measuring and monitoring eruptive products and surveying edifice for any new features. During the effusion of lava domes and flows, the TIR data readily identify areas of active lava and gas effusion as well as providing a means to measure dimensions, assess flow structures and textures.

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) TIR images show that the permanently ice-covered stratovolcano began to develop persistent weak thermal anomalies in areas of ice-melt holes and crevasses in the ice-filled summit crater in late 2008 until mid-March 2009. On 23 January 2009, mudflows began to sporadically discharge from below the summit fumaroles down the Drift Glacier and into the Drift River as the level of seismicity and gas emissions rose significantly. A phreatic explosion on 15 March was followed one week later (23 March-4 April) by a series of at least 19 magmatic explosive events that produced high-altitude ash clouds and large lahars. Two (or three) lava domes extruded and were destroyed between 23 March and 4 April. After 4 April, the eruption extruded a large lava dome that continued to grow until at least late June 2009.

Satellite TIR data from the ASTER, Landsat 5 TM and Landsat 7 ETM+ imaged the summit over 250 times from September 2007 through May 2011. ASTER has five TIR bands at 90-m resolution while Landsat 5 TM and 7 ETM+ have one broadband TIR band at 120-m and 60-m resolution respectively. A survey of ASTER nighttime TIR data detected no obvious thermal features on the upper flanks or at the summit of Redoubt from 2000 to late 2007. A weak thermal feature first appears in ASTER TIR nighttime data from 2007. These initial weak thermal anomalies, midway down Drift Glacier, were possibly caused by small outbreaks of melt water flowing from the summit above. By October 2008, low temperature summit thermal features began to appear in ASTER TIR and persisted through the first explosions on 15 and 23 March 2009. Though clouds and ash plumes obscured the summit during most of the explosive phase, frequent satellite TIR data acquired during the post-April 4 effusive phase of the eruption show persistently high thermal emission from the growing dome and the hot talus on the slope below. The variations in thermal emissions paralleled the measured variations in lava effusion rates. The hot areas persist after the eruption ceased around 1 July and continued until at least December 2009 (Fig. 1).

Airborne Forward-Looking Infrared (FLIR) images from 14 field missions flown between November 2008 and August 2010 provide higher resolution details of the thermal features. Pre-eruption FLIR surveys in November 2008 and February 2009 documented two warm summit areas and a waterfall on the north flank below the summit crater. Areas of warm exposed rock expanded as temperatures gradually increased. While the summit was mostly covered in thick clouds and ash plumes for most of the explosive phase of the eruption, a 31 March FLIR survey captured partial glimpses of the lava dome beneath the ash plume. FLIR surveys after 4 April document the gradual growth and cooling of the final lava dome. The most recent FLIR data from August 2010 show that fumaroles along the southeast flank of the cooling dome still had temperatures over 300°C.

Beyond temperatures, the high-resolution TIR data were used to monitor changes in the lava dome textures and measure the dimensions of the growing final dome. Retrospective analysis of archived high-resolution satellite TIR data detected subtle, small-scale changes in surface thermal activity more than 16 months before the 2009 eruption of Redoubt Volcano. While a few of the infrequent individual ASTER TIR scenes were able to detect these subtle temperature anomalies, robust detection and identification of early thermal precursors at active volcanoes requires new high resolution multispectral TIR satellite sensors with frequent, at least daily, night and day acquisitions.