# Monitoring of volcanic eruption (Barren Island) using EO satellites

Barren Island (BI) (12.28°N, 93.86°E), the young and only confirmed active stratovolcano of India, is situated ~135 km northeast of Port Blair, the capital of Andaman and Nicobar Islands within the Andaman Sea. With an elevation of ~350 m amsl, it is located on seismically active subduction zones, wherein the Indian Plate subducts beneath the Burmese Plate along the Andaman Trench. BI is a caldera, that is breached towards the west by various episodes of volcanic eruptions and depositions, resulting in a polygenetic vent at the centre[1,2]. It had experienced several eruptions during the pre-historic, historic (1787–1832) and recent times in 1991, 1995, 2005–2007, 2008–2010, 2013–2016, 2017–2019 (ref. 3). From 1991, this active volcano began its recent active phase and at present, it is in a ‘strombolian’ type of eruption of low to moderate scale, with ash and lava emanating from its central polygenetic vent or secondary vents located on the flanks[1]. The current eruption of the BI volcano is considered to be protraction of the recent eruptive phase that began in 2005 (ref. 2), intermittently spewing lava, pyroclastic material and ash.

In recent decades, temporal satellite data from various platforms are available for real-time/near real-time monitoring and characterization of volcanic materials and associated landforms[3–8]. Recently, we carried out a field investigation (April 2019) and acquired satellite data over BI including those from SENTINEL-2 satellite, which was preferred because of revisit time of five-days and high spatial resolution (~10 m). The SWIR bands of this platform at 20 m/pixel resolution also make it possible to differentiate active volcanic craters, lava flows, and land-cover changes associated or affected by the ongoing eruptions[9,10]. The spectral bands such as the short-wave infrared (SWIR 1–1.610 μm, SWIR-2 μm) with 20 m spatial resolution, Blue (0.490 μm), Green (0.560 μm), Red (0.560 μm), and near infrared (NIR, 0.842 μm) with 10 m spatial resolution were used for monitoring the event during April to December 2019.

The cloud-free datasets from April to December 2019, viz. acquired on 26 April 2019; 28 September 2019; 13 October 2019; 23 October 2019; 2 November 2019; 12 November 2019; 2 December

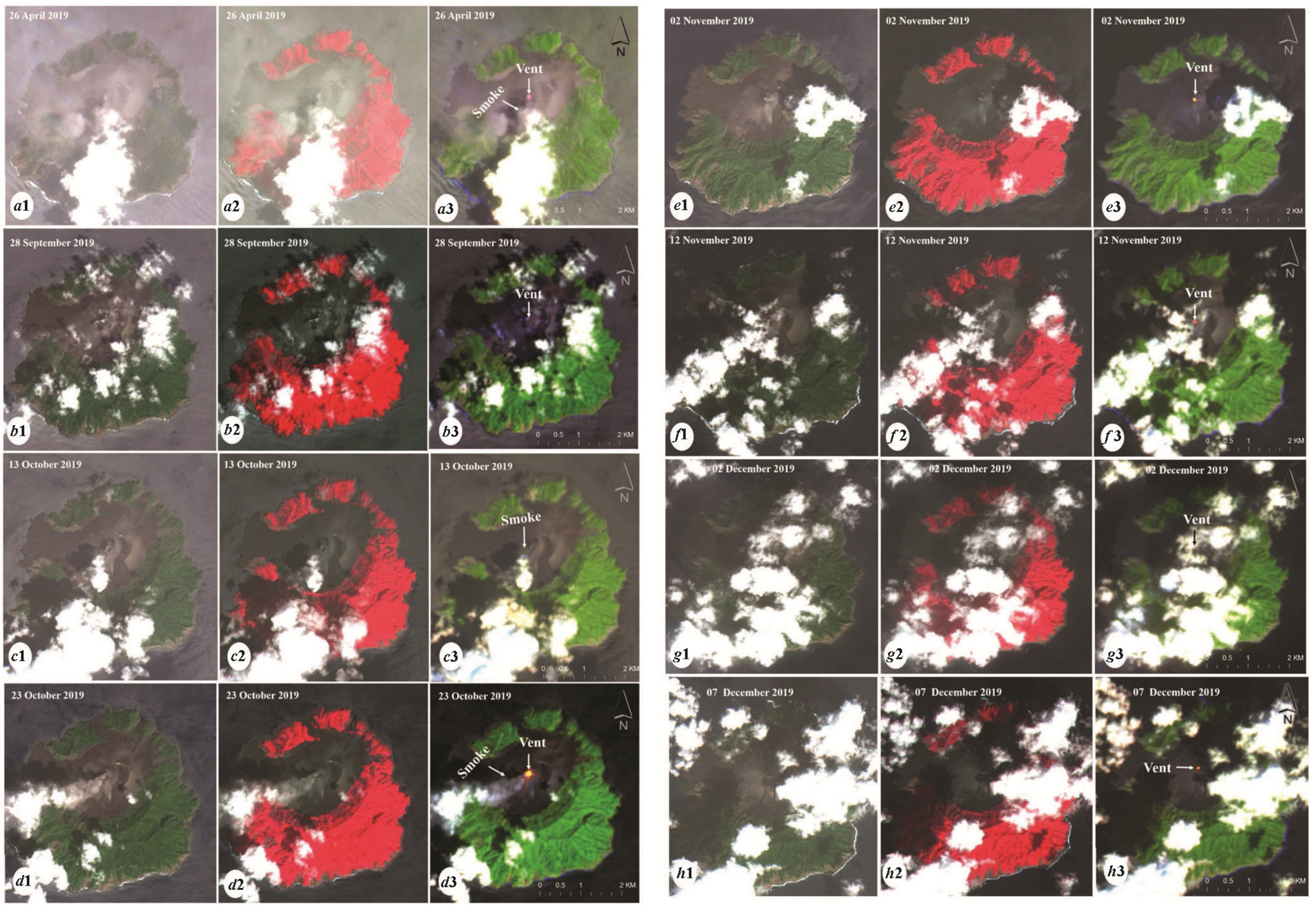


**Figure 1.** SENTINEL-2 satellite images from 20 April 2019 to 7 December 2019 showing the vent and lava flows. Images ***a***1–***h***1 are represented in their natural colour composite (R : G : B = Red : Green : Blue) where black colour represents volcanic deposits. Images ***a***2–***h***2 are in colour infrared (vegetation) composite (R : G : B = NIR : Red : Green), where vegetation is denoted by red colour. Images ***a***3–***h***3 are in false colour composite (R : G : B = SWIR2 : SWIR1 : Red), where orange colour denotes the vent with smoke (indicated by arrow).

2019 and 7 December 2019 were selected. For further analysis, false colour composites (FCC) with different band combinations were used to identify the vent, plumes and lava flows (Figure 1). On 26 April 2019, the glowing vent at the centre and ash plume were moving towards the southern direction from the cinder cone, probably due to the explosive style of eruption. On 28 September 2019, the glowing vent was visible without any lava flow at the centre of the cinder cone, whereas on 13 October 2019, it again emitted ash plumes into the sky towards the southern direction. On 23 October 2019, it became very active with glowing vent and emitted lava flows in the southern direction and ash plumes in the west-southwest direction. On 2 November 2019, 12 November 2019, 2 December 2019 and 7 December 2019 no lava flow and ash plume were observed, but only glowing vent was visible.

Furthermore, thermal data obtained from visible infrared imaging radiometer suite (VIIRS, VNP14IMGT) at 375 m resolution from NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) satellite (available at the Fire Information for Resource Management System (FIRMS): https://firms.modaps.eosdis.nasa.gov/) were used. The thermal anomaly was observed in the form of anomalous fire pixels for 13 days starting from 20 April 2019 to 7 December 2019 in the FIRMS database that are correlated with the latest volcanic eruption activity (Figure 2 *a*). The SENTINEL-2 satellite images with FCC (R : G : B = SWIR2 : SWIR1 : Red) show the glowing vent during two out of the 13 fire days. The correlation for the remaining days could not be performed due to unavailability of either cloud-free data or satellite pass. Since BI is situated in a seismically active zone, the observed eruptive events were further compared with seismic data of the region from 15 April 2019 to 7 December 2019 as available at the United States Geological Survey (https://earthquake.usgs.gov/earthquakes/search/) (Figure 2 *b*). The seismic cluster was observed close to the Great Nicobar region near the West Andaman Fault (WAF), and BI is situated on the extension of WAF.

BI has been active since September 2018 and is continuing its eruption sporadically till date. The SENTINEL-2 datasets with different band combinations have successfully revealed the glowing vent of the BI volcano and FIRMS data have confirmed the same. Due to its remote location and several restrictions (security reasons), regular observation of this active volcano on the ground is not possible. Hence remote sensing techniques were used for continuous and real-time monitoring of the Island, which revealed unprecedented active nature of the volcano preceded by seismic activity in the near vicinity of a known fault. This calls for detailed studies to establish coupling mechanism between seismicity and volcanism in BI. Further, at present, there is no seismic station in close proximity to BI and so the results based on satellite data could not be corroborated with seismic monitoring data. A seismic survey using geophones was also not possible due to restrictions in the study area. However, in the near future seismic survey could be planned for detailed information. Communication will be established with the agencies/organizations which may install seismometers for future research in BI.

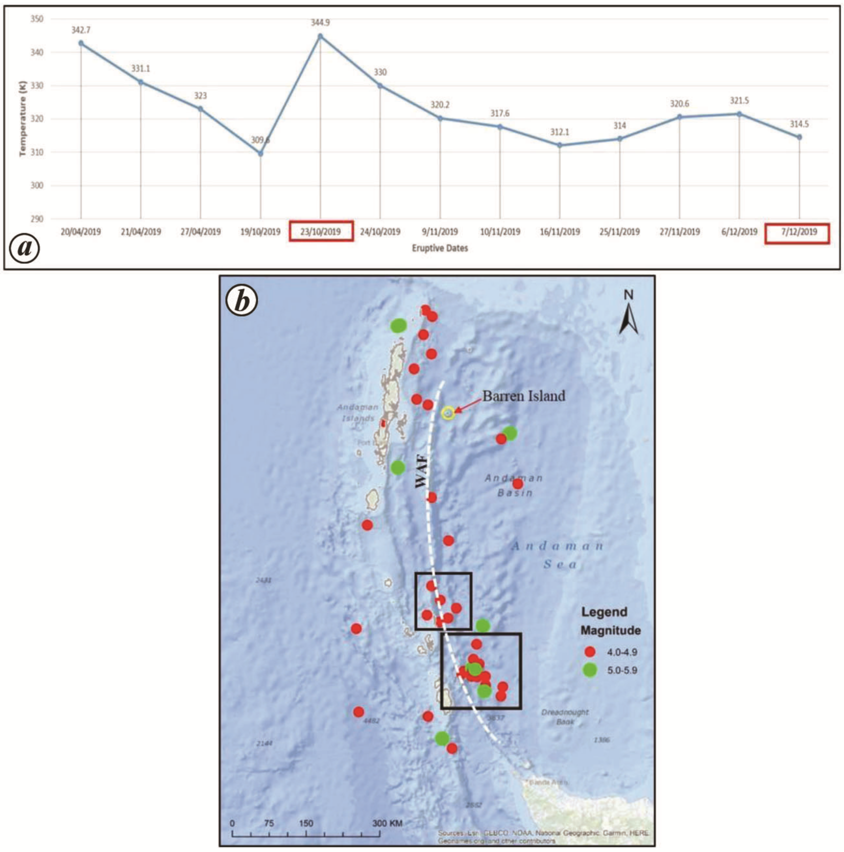


**Figure 2.** ***a***, Thermal anomalies from 20 April 2018 to 7 December 2018. Red colour boxes indicates the thermal anomaly correlated with eruptive episodes as observed in satellite images. ***b***, Earthquake epicentre during 15 April 2019 to 7 December 2019 close to West Andaman Fault (WAF) (white dashed line) shows closer association with eruptions at Barren Island; Black colour squares indicate earthquake swarm near the Great Nicobar region.


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# Occurrence of Nuclear Polyhedrosis Virus of invasive fall armyworm, *Spodoptera frugiperda* (J. E. Smith) in Meghalaya, North East India

The American fall armyworm (FAW), *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) invaded Asia in 2018, causing huge damage to maize and other host crops in different countries[1]. The invasive FAW is a highly polyphagous pest known to feed on 353 host plants across the globe[2]. FAW was found in a severe form in maize fields of North East (NE) India after March 2019 (ref. 3). Due to distinct climatic conditions, NE India is considered the most diverse region of the country, which harbours a great diversity of flora and fauna. Moreover, NE India is organic by default and the majority of agricultural practices in the region are mainly natural and based on local resources. As a result, the region is being promoted by the Indian Government for natural/organic farming. Given the highly devastating nature of FAW, about 2–4 sprays of chemical pesticides are vital to reduce its population below the economic threshold level (ETL)[4]. However, due to limitations on the use of chemical pesticides for management of pests in the region, there is an urgent need to find cheaper, economically and ecologically viable options for the management of invasive pests like FAW.

Native strains or populations of natural biocontrol agents are reported to be more effective under such circumstances. Several entomopathogens, including viruses, fungi, protozoa, bacteria and nematodes are known to infect FAW life stages[5–7]. In our experimental fields of maize at Umiam, Meghalaya, India, we found large-scale mortality of FAW larvae due to entomopathogenic fungus, *Metarhizium* (=*Nomuraea*) *rileyi* (Farlow) Samson and unknown pathogen symptomatically similar to Nuclear Polyhedrosis Virus (NPV) of lepidopteran larvae. Later, the causal agent responsible for such symptoms in FAW appeared to be *Spodoptera frugiperda* Nuclear Polyhedrosis Virus (SpfrNPV). Due to humid climatic conditions, the *M. rileyi* is an important biocontrol agent of *Spodoptera* species in NE India. Therefore infection of *M. rileyi* to the larvae of related host species, i.e. *S. frugiperda* is expected. However, natural occurrence of SpfrNPV among FAW larvae in Meghalaya may provide additional opportunity to the farmers of the region to utilize this potential biocontrol agent against invasive FAW. Entomopathogenic viruses, especially NPVs are one of the most extensively studied and commercially exploited baculovirus group for pest management. FAW is basically infected by two baculovirus species, viz. NPVs (which are mainly multicapsid variants) and granulovirus[8]. Thus, SpfrNPV from Meghalaya is also expected to have multiple nucleocapsids in the virion of occlusion bodies (OBs), which can only be confirmed after detailed characterization. Worldwide, several NPVs have been isolated from FAW and several isolates have been used for the control of the pest with >80% efficacy, indicating its role as a potent biopesticide against this notorious pest[9–12].

Field observations of FAW in maize crop revealed that the SpfrNPV infected larvae stopped feeding and came out from the whorl on the leaf surface of maize plants. In certain cases, dead caterpillars were found hanging on the maize plants showing symptoms of typical NPV attack (Figure 1). Other diagnostic symptoms include sluggishness, initial lighter colour of the body which later becomes darkened, regurgitation and liquefaction of the body. Dead caterpillars of FAW (showing symptoms of typical NPV infection) were collected from the maize fields. Examination of the larval discharge in phase contrast illumination at 400× magnification showed typical polyhedral inclusion bodies of NPV (Figure 2). Using transmission electron microscopy, the aggregation of typical crystalline OBs was clearly observed in the discharge of SpfrNPV infected FAW caterpillars. Subsequently, a total of 687 caterpillars of FAW (second to fourth instars) were also collected from the maize fields of the locality and placed individually into the sterilized plastic containers (make: Tarsons®) for further development in the laboratory (at 25° ± 1°C temperature, 75% ± 5% relative humidity and 12 : 12 light : dark period). Fresh primordial leaves of maize were provided as larval food throughout development. Maize leaves were surface-sterilized with an aqueous solution of sodium hypochlorite (0.05%) and cleaned with sterile distilled water to avoid external contamination through food. Among the field-collected larvae, 23.67% could not reach up to adult stage due to NPV infection. Surviving adults were allowed to mate and lay eggs on the substrate (filter paper) inside the oviposition cages. Honey solution was provided as adult food. After hatching from the eggs, 300 neonate larvae from the second generation were placed individually into sterilized plastic containers (make: Tarsons®) for further development on maize leaves. The FAW rearing process was continued until the third generation. The mortality trend was found to be increased in the second and third generations. A total of 39.33% and