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VIIRS Nightfire Remote Sensing Volcanoes

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Abstract

Satellite based remote sensing of active volcanoes has been performed in various forms since 1965. Compared to "on the ground" observations it lets data to be gathered globally at regular pace for long periods of time without the need for local maintenance. Currently existing publicly available volcanoes thermal activity monitoring systems rely on the detection algorithms narrowly specified for volcanoes temperature ranges and operate using the data from previous generation of sensors, which is supported with non-reserved constellation of two satellites. The presented work proposes pipeline (the sequence of actions) based on the clustering of the data received from the Nightfire thermal anomalies detection algorithm, which is not focused on the specific type of infrared sources. Pipeline has been tested on Kamchatka's region 2016 year dataset and proved to produce sound results corresponding to manual observations.

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Keywords: Nightfire ; VIIRS ; Remote sensing ; clustering ; volcanoes

1. Introduction

History of satellite based volcanic activity observations spans as far as 1965. The advantages of such an approach are obvious: good coverage, including hard to get to areas, regularity, cost-effectiveness (considering the coverage).

The first globally available system focused on continuous volcanic activity monitoring is MODVOLC[4], the system is using data received from the MODIS equipped Terra and Aqua satellites. The both satellites were launched as a part of the NASA EOS program in 1999 and 2002 respectively. MODVOLC has been in action for more than 15 years [10], although it has its shortcomings, it may be considered a classic comparison base for similar systems. A more modern example would be Mirova[1] system similarly based on MODIS data the system capitalizes on MODVOLC experience and addresses some of its flaws.

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The short-term mission involving MODIS was intended to fill the gap between the two long-term scientific programs DMSP and JPSS. With the arrival of new satellites equipped with sensors of the new generation it is possible to significantly improve quality of the monitoring. For instance new VIIRS sensor launched on board of Suomi-NPP satellite has better resolution and precision than MODIS. The aforementioned characteristics are crucial for building a more precise spectrogram of the observed source, thus making it possible to estimate additional source characteristics, such as temperature.

Nightfire is the first algorithm successfully taking advantage of the new generation sensors. The algorithm uses VIIRS nighttime data to detect and estimate characteristics of subpixel sized infrared sources[2]. Initially algorithm has been developed to monitor volumes of natural gas burning in the locations of hydrocarbons extraction and refining. Nightfire is using multitude of infrared bands (from short-wave up to long-wave) in conjunction with visible spectrum data whilst the majority of previous solutions is using one or two infrared bands in the mid-wave and long-wave parts of the infrared spectrum.

Nomenclature

MODIS	Moderate Resolution Imaging Spectroradiometer
EOS	Earth Observing System
DMSP	Defense Meteorological Satellites Program
JPSS	Joint Polar Satellite System
VIIRS	Visible Infrared Imaging Radiometer Suite
SDR	Sensor Data Record
SNR	Signal to Noise Ratio
IR	Infrared
SWIR	Short Wave Infrared Range
MWIR	Mid Wave Infrared Range

2. VIIRS Nightfire Detecting Temperature Anomalies

To detect and estimate characteristics of “hotsposts” on the night side of the Earth Nightfire is using the whole infrared spectrum in the range of 1 to 12 μm. The algorithm is using the data from the infrared multispectral radiometer VIIRS. VIIRS provides infrared readings with spatial resolution of 750 m in nadir down to 1500 m at the edge of scan. It was noticed [2] that in nighttime “hotsposts” may be seen in short-wave infrared range (SWIR) with the best signal-to-noise ratio (SNR) characteristic. The SNR difference between SWIR (bands M7, M8 and M10) and MWIR (bands M12 and M13) may be clearly seen in Figure 1. In the day imagery in this range signal from “hotspots” is overpowered by the solar radiation, thus “hotspots” are undetectable in SWIR at the average spatial resolutions of $\approx 1kmpp$. Which explains why since the publication of the “classic” Dozier’s method in 1981 [5], which was used with slight modifications in all the remote Earth sensing algorithms [9] except Nightfire, combustion IR sources are searched in MWIR. However MWIR “hotspots” are always observed with the background heat from the earth surface and clouds, which drastically affects the sensitivity for both size and temperature estimations of the detected combustion sources.

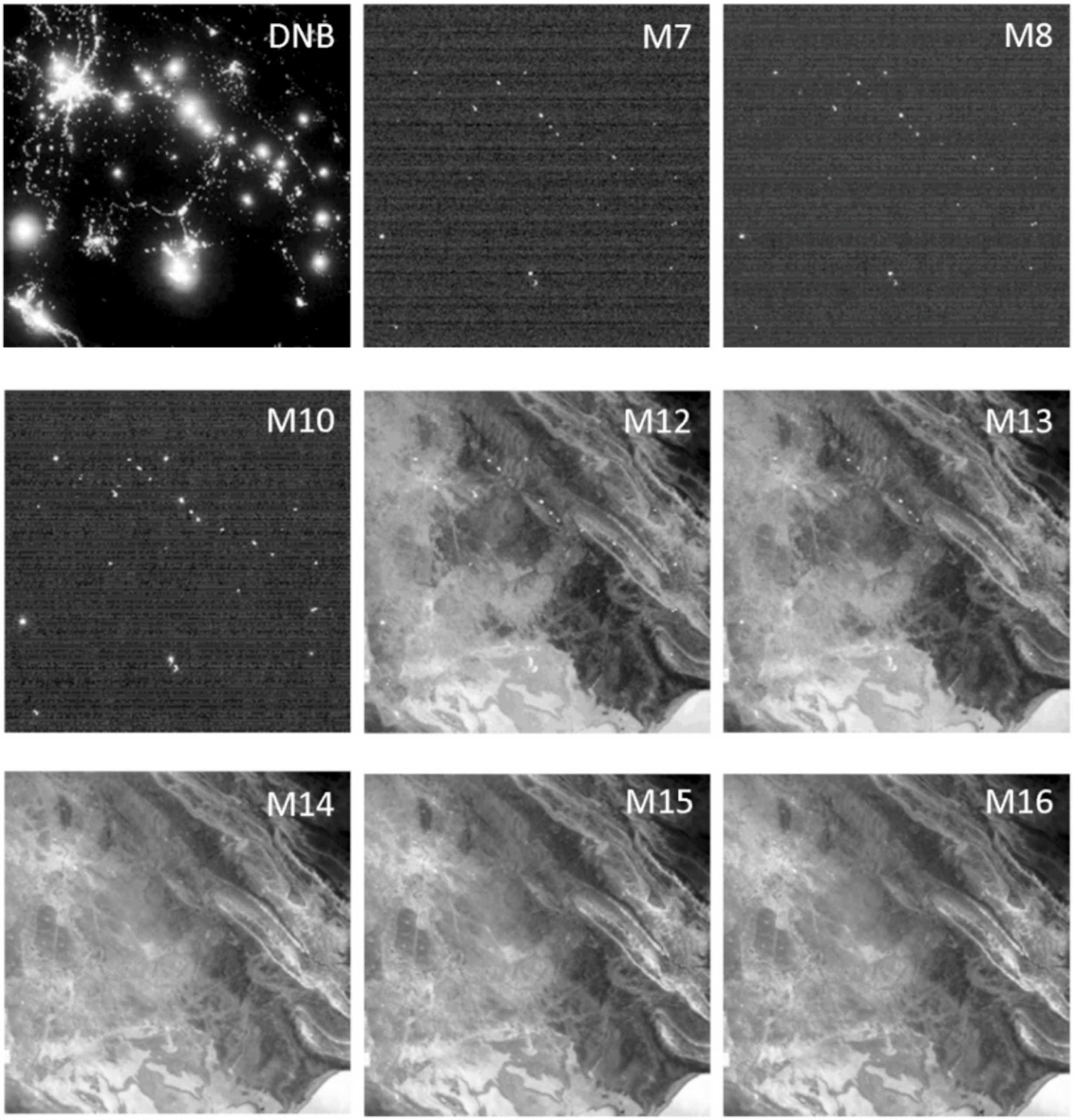

Fig. 1. Visible and infrared imagery of city lights and gas flares in Iraq produced from VIIRS SDR data[7]

As it can be seen in Figure 1, SWIR bands M7, M8 and M10 contain only sensor's thermal noise at night and point signals of heat sources on the Earth surface. Thus it is possible to use threshold detector of the signal, it must be taken in account that threshold should steadily increase from the left to the right edge of an image following the increase of the thermal noise [2]. MWIR based detection algorithm separates "hotspot" signal from background thermal signal by the colder relief, water and clouds. Method is using values correlation between neighboring M12 and M13 bands.

Due to the high IR sources detection sensitivity Nightfire produces considerable amount of point data for each night. The amount varies from night to night, however an average number of detections per night is about 20 thousands, these include both "hot" (electric lights, gas flares) and "warm" (wildfires, volcanoes, high-temperature production).

Spatio-temporal aggregation of observations makes it possible to estimate the location of a heat source with a 50 m accuracy. Data subsampling and aggregation for stationary sources such as volcanoes may be used for source monitoring. In Figure 2 the detections connected with volcanic activity can be seen.

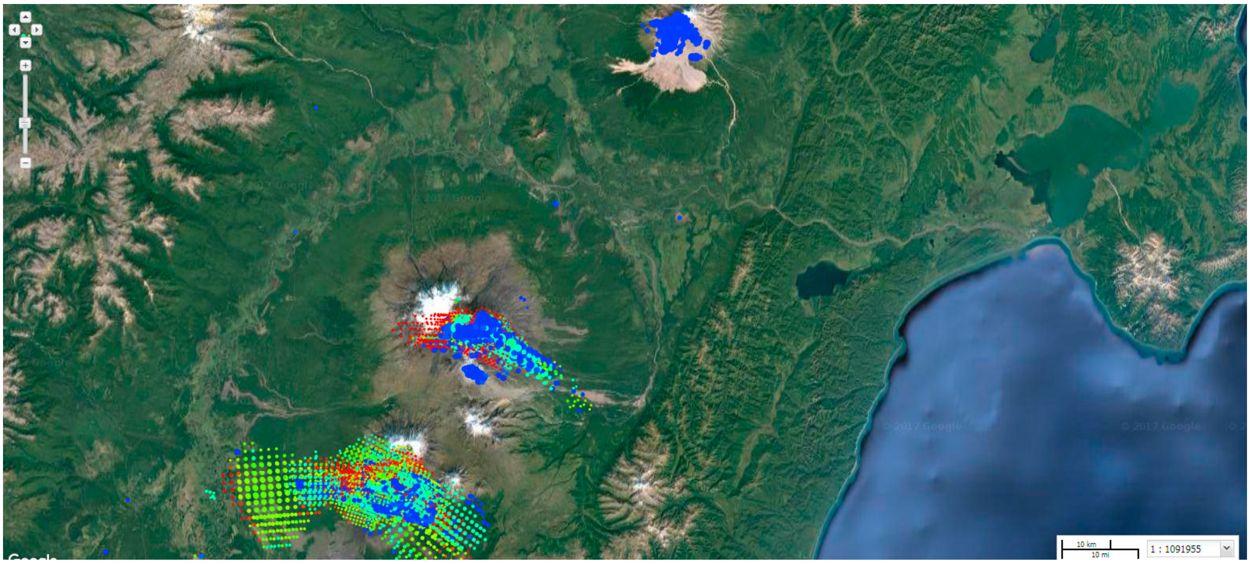

Fig. 2. Volcanic activity detections colored by temperature (blue coldest, red hottest) around Sheveluch(top group), Tolbachik(bottom group), Klyuchevskaya Sopka(middle group) volcanoes. Based on 2012-2016 Nightfire data[6]

3. Monitoring Volcanic Activity with Nightfire

To monitor volcanic eruptions the following pipeline has been employed:

1. Satellite data retrieval (either from base station or NOAA servers)
2. Nightfire "hotspots" detection
3. "hotspots" clusterization
4. Events identification
5. Volcanic activity events attribution

To work with volcanoes of the Kamchatka region, data received from the direct access station located in IVS FEB RAS (Petropavlovsk-Kamchatsky) was used.

Since Nightfire is tailored for subpixel pyrometry the second stage of the pipeline produces multiple neighboring "hotspots" for each thermal anomaly covering more than one pixel. The pixel size in M-bands is small enough for lava flows to cover multiple pixels at once. To aggregate "hotspots" belonging to the same thermal anomaly DBSCAN clustering algorithm with the ϵ of 2000 m and *minPts* equal to 1 is employed. While it is possible to calculate the precise size of each pixel the equation is somewhat complicated, since not only it needs to account for the pixel size increase at the edge of scan, but for VIIRS pixel aggregation mechanism. Thus ϵ equal to 2000 m has been chosen as a "good enough" pixel size approximation value. DBSCAN is used in its degenerate form with the specified *minPts* setting, which does not differ from maximum distance grouping. The algorithm is used for the ability to filter out all the spatially small anomalies if required.

In Kamchatka's region year 2016 data DBSCAN detects from 0 up to 187 clusters each night, the majority of which consist of a single "hotspot". The total amount of clusters detected for the whole year worth of data is about 12 thousand.

Next spatial clusters produced in the previous step are aggregated into time series so it would be possible to detect continuous events. The aggregation is performed based on the cluster extent (or minimal bounding rectangle) overlap see Figure 3. In Kamchatka region for the year 2016 there were 9074 events detected, the majority of this events are degenerate ones with one (7694) or two (1146) “hotspots” detected throughout the year. However among the rest 234 were the ones observed throughout the whole year and maximum number of “hotspots” was 5871. The total amount of “hotspots” in all the events is 24630. Long-lived events with a significant number of “hotspots” are the ones attributed to stable thermal anomalies.

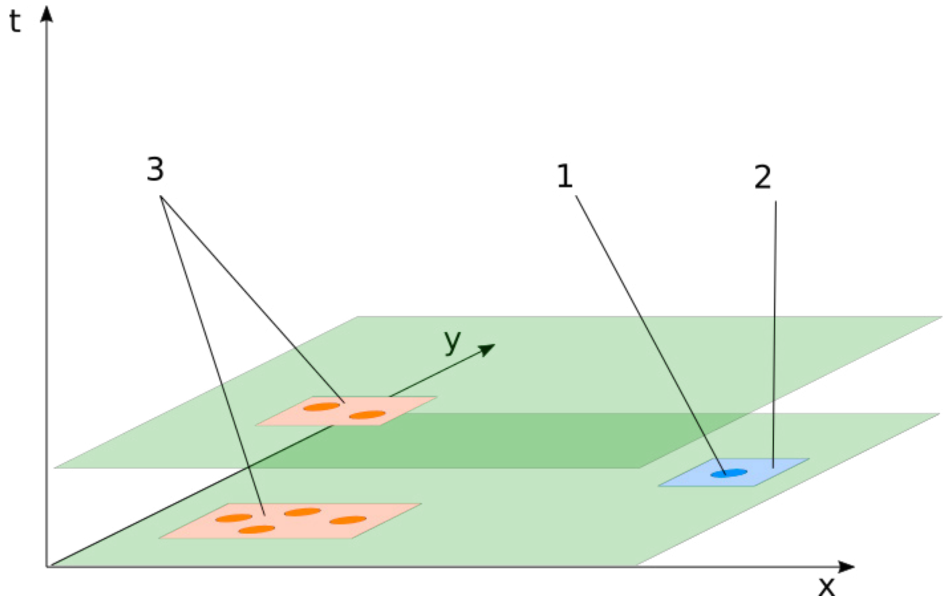

Fig. 3. Aggregation of cluster time series. 1) “hotspot”; 2) DBSCAN detected cluster; 3) clusters with overlapping extent, related to the same event.

Next system attributes events to volcanic activity. To do so the system matches locations of the detected events and the locations of volcanoes summits. The two systems discussed in the Section 1 are using fixed regions centered on the volcanoes summits. This approach however has a flaw, large detection regions may overlap for neighboring summits and produce duplicate detections attributed to two or more summits, while smaller detection region may not be enough to cover the entire lava field.

The authors propose using the late binding of thermal anomalies to summits. Each thermal anomaly may be represented as an event (time series of observations – spatial clusters of hot pixels with different extent). Event summit attribution is performed by checking if summit is in extent of each event’s observation. The event is attributed towards the summit it has the most overlaps with. Such an approach lets attribute pixels in a more precise fashion and prevents multiple attributions for the same pixel.

Events detected in Kamchatka 2016 data set were attributed to the following volcanoes: Alaid, Barkhatnay Sopka, Belenkaya, Bezymianny, Karymsky, Kekurny, Klyuchevskaya Sopka, Kozyrevsky, Kronotsky, Mutnovsky, Piratkovsky, Fuss Peak, Sheveluch. Among the listed volcanoes significantly active were: Alaid Figure, Bezymianny, Klyuchevskaya Sopka, Sheveluch. This results are consistent with the KVERT report [3] and manual data analysis [8].

Sheveluch is consistently active andesitic volcano, in Figures 4 and 5 it can be clearly seen that its activity has a lower temperature than basaltic volcano (Klyuchevskoy), which shows that relative temperature estimations are inline with expected.

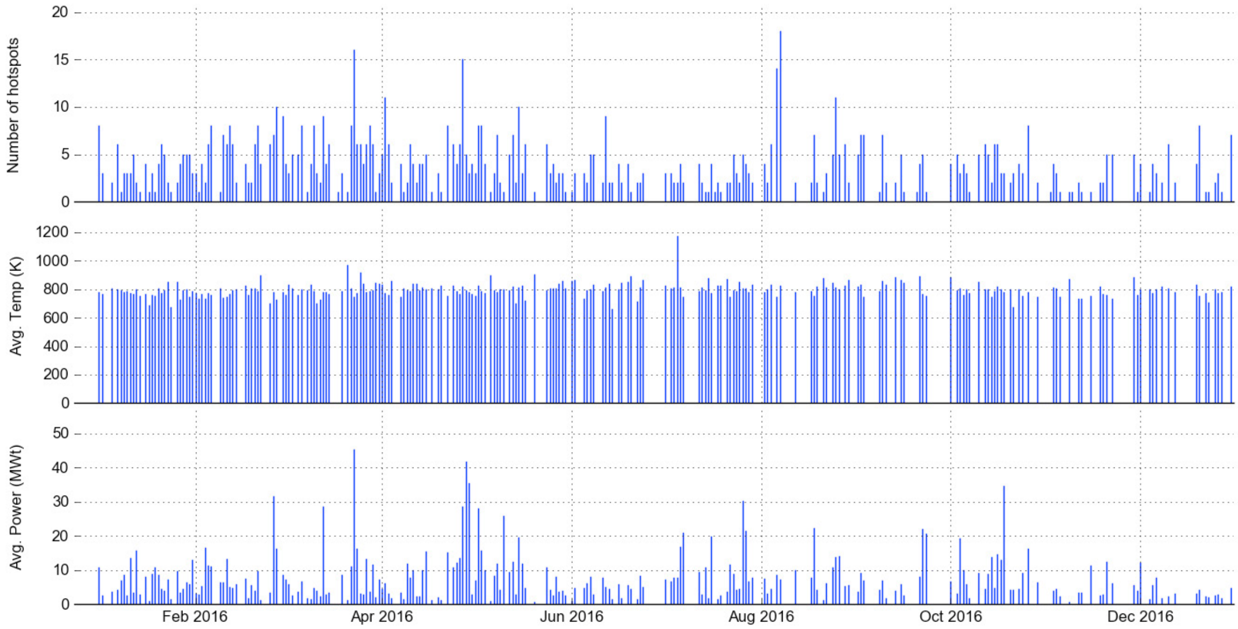

Fig. 4. Sheveluch attributed event statistics

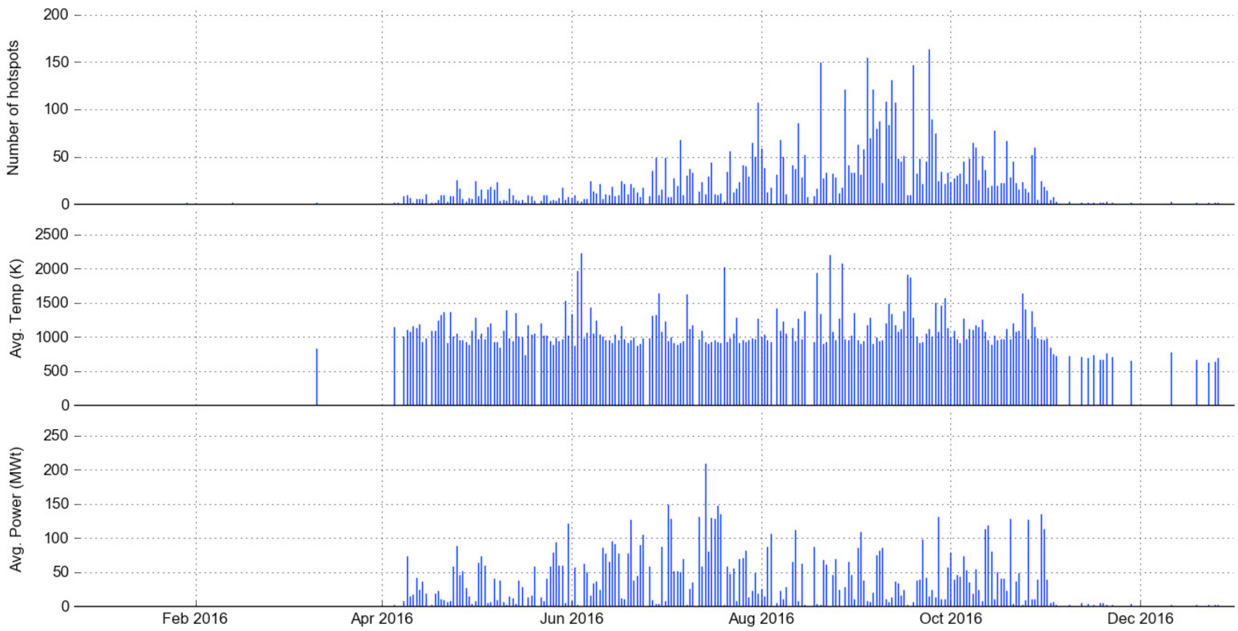

Fig. 5. Klyuchevskaya Sopka attributed event statistics

The Figures 5 and 6 illustrate that clustering successfully separated detections for the two nearby volcanoes Figure 7, this is a significant difference of the proposed method from the alternatives [4, 1], which duplicate statistics for the both volcanoes.

Fig. 6. Bezymianny attributed event statistics

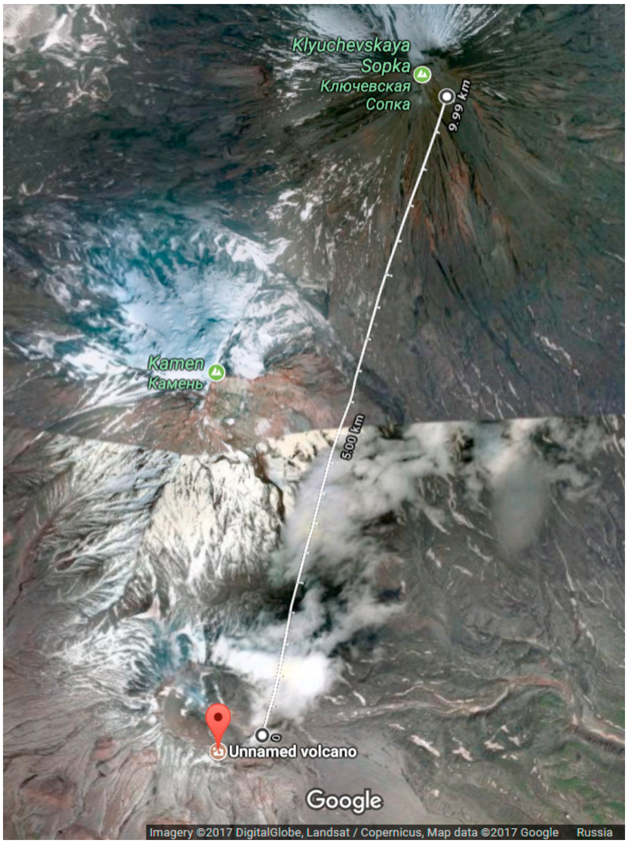

Fig. 7. Bezymianny(Unnamed) and Klyuchevskoy volcanoes are located roughly 10km from each other

4. Conclusion and Future Work

Throughout the year of operation volcanic activity detected 9074 events, some of largest of which were attributed to volcanoes activity.

Considerable difficulties were caused by the fact that in summer nights are short and bright at Kamchatka, which adds a lot of noise. Algorithm needs to address this issue.

The presented work employed Nightfire[2, 9] algorithm to detect infrared radiation sources and attribute them to volcanic activity. This led to creation of a prototype volcanoes eruption monitoring system, which unlike the previous solutions[4, 1] not only does not require specific tuning in order not to mix thermal anomaly attribution but does provide extended information such as temperature and area.

The prototype system worked only in the limited region of Kamchatka. Future work will expand coverage to the entire Earth.

In the nearest future it is expected for the additional M11 (2.1 μm) band to be activate in VIIRS at night. The band is close to the peak wavelength of the temperature range common for volcanoes thermal activity. This will significantly increase quality of monitoring. Moreover an additional VIIRS equipped satellite is due to be launched by the end of this year, which will double the temporal resolution.

Acknowledgments

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