Nightfire method to track volcanic eruptions from multispectral satellite images

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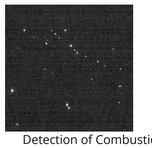
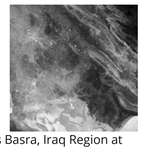
Nightfire : independent SWIR and MWIR detection of hotspots

Nightfire algorithm has been developed to play along with a Suomi-NPP polar satellite multispectral radiometer VIIRS with the main goal to detect gas flares related to the upstream and downstream production of oil and natural gas. Simultaneously using nighttime data in SWIR, MWIR, and LWIR sensor bands the algorithm is able to estimate hotspots temperature, size and radiant heat. The nighttime M10 SWIR band has a remarkable ability to detect “hot” spots (T ~ 1600K) by simple 4σ threshold! We have developed a new MWIR detector using de-correlation in M12-M13 bands to detect “cool” sources (T ~ 800K).

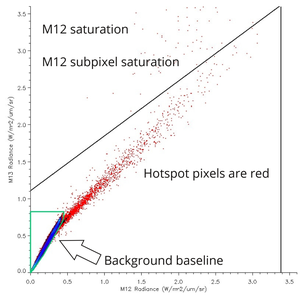
MWIR M13 “Fire Band”, 4 um



MWIR M13 “Fire Band”, 4 um



Detection of Combustion Sources Basra, Iraq Region at Night July 17, 2012

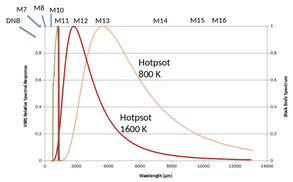


Estimating hotspot temperature, size and radiant heat

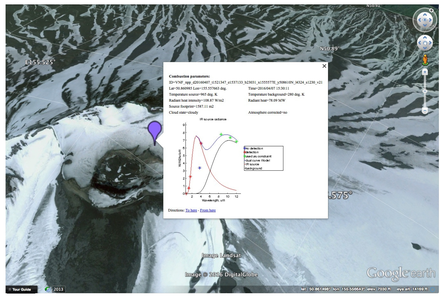
Planck curve is fit using a simplex algorithm to match the radiances with temperature and size for sum of a subpixel hot source and background

$$B_\lambda(T) = \varepsilon \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$
$$S_{source} = \varepsilon S_{pixel},\ J = \varepsilon \sigma T^4$$
$$RH = J \times S_{pixel} \sim \sigma T^4 \times S_{source}$$

B is the spectral radiance
λ is wavelength, um
kB, h, σ are the Boltzmann, Planck, and Stefan-Botzmann constants
c is the speed of light, m/s
T is hotspot temperature, degrees K
ε is the emission scaling factor (ESF)
J is the radiant heat intensity, W/m2/s
S is the subpixel fire footprint, m2
RH is the radiant heat, W/m2



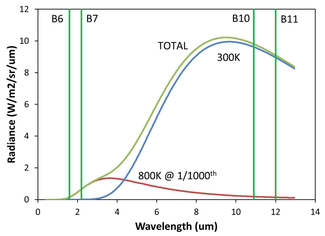
Detection of Alaid volcano eruption, Kuril islands, April 7, 2016



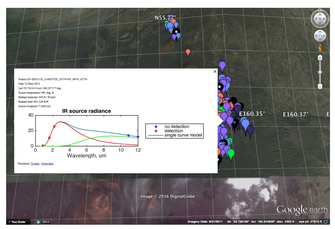
Nighttime Landsat 8

Volcanic activity can be detected and analyzed within individual pixels observed with the Landsat 8 sensor at night. There are several favorable characteristics of nighttime Landsat for the volcano remote sensing research. The pixel footprints are small compared to systems such as MODIS and VIIRS. With sunlight eliminated, lava can be readily detected in the shortwave infrared (SWIR) bands centered at 1.6 and 2.2 um. In addition, the full observed SWIR radiance can be attributed to the volcanic source. However, nighttime Landsat 8 images are only acquired upon special request.

Landsat-8 Spectral Response



Tolbachik 12-May-2013

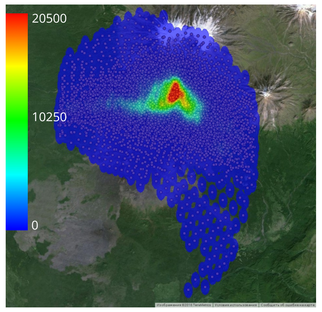


Active eruption observation NightVolc and MODVOLC

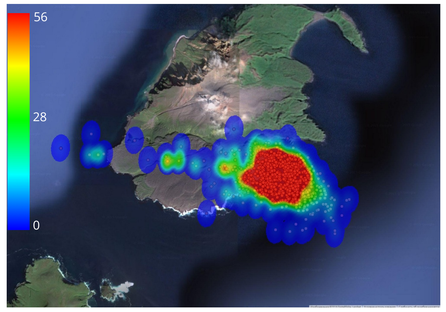
Chirpoi volcano 46.53°N / 150.88°E forms a small island in the central Kuril Islands, Russia. It has a 8-9 km wide partially submerged caldera with several volcanic centers inside the caldera. Volcano is constantly erupting for almost 4 years with short periods of silence. Since April 2012 VIIRS Nightfire has detected 699 IR sources in the Chirpoi caldera with average temperature of 900K. For the same time period MODVOLC has detected only 77 events.

Plosky (flat) Tolbachik 55.83°N / 160.33°E is one of the Kamchatka’s largest and most active volcanoes. It is located at the southern end of the andesitic Kliuchevskaya volcano group. Its eruptive history stretches back thousands of years, but the most notable eruption occurred in 1975, commonly known as "The Great Tolbachik Fissure Eruption". On November 27, 2012 a new eruption started from 2 fissures of a strombolian type. Eruption continued for several months, as lava continued to flow from the fissures on southern flank up to 20 km. During this eruption VIIRS has detected 18900 IR sources. In the active eruption phase their temperature varied within large margins from 600K to 2500K. The second less active phase had more consistent temperatures around 800K. For the same eruption MODVOLC has 8521 detections. All of them are in the first, most active phase.

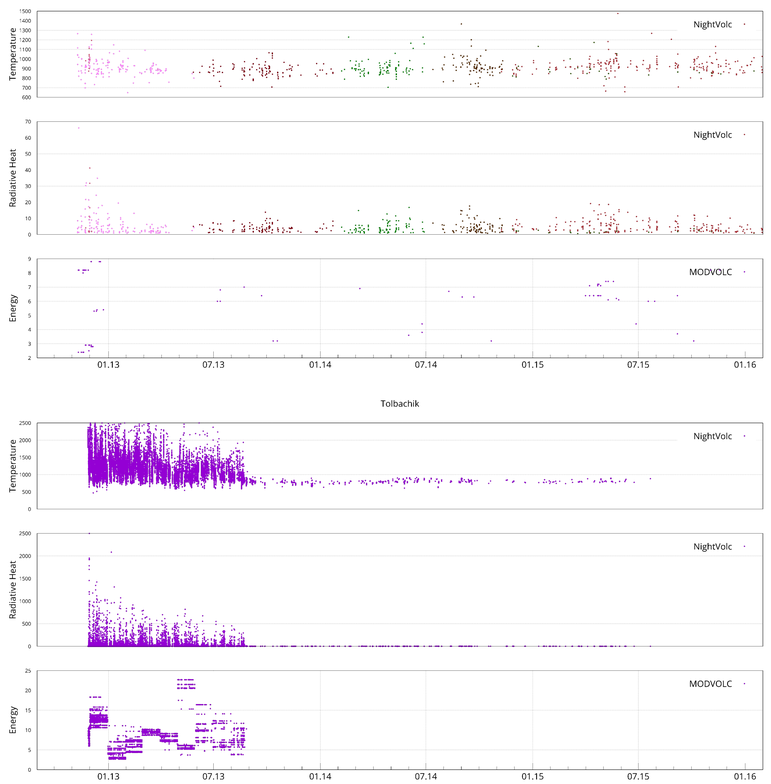
Tolbachik RH heatmap for all detections in 4 years



Chirpoi RH heatmap for all detections in 4 years



Chirpoi



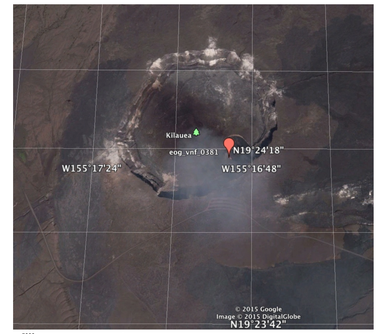
Tolbachik

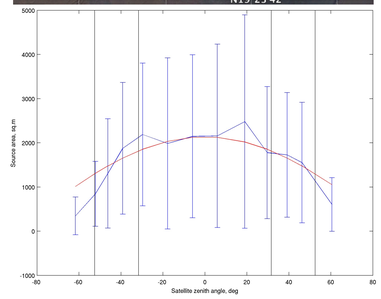
3D geometry of lava lake inside volcanic crater

VIIRS observes earth surface features at satellite zenith angles ranging from zero (nadir) to 70 degrees (edge of scan). Examining the hotspot detection history, we have found that flares tend to have higher radiance when viewed at high satellite zenith angles. In opposite, lava lakes deep in the volcano crater tend to have higher radiance when viewed from nadir.

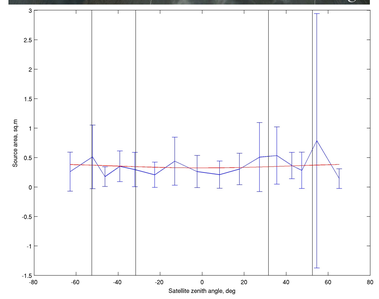
The 3D shape of hotspots can be modeled as an ellipsoid. Based on the the apparent source size versus satellite zenith angle, it is possible to derive the hotspot ellipticity or height H versus width R ratio.

Kilauea crater, Hawaii. Ellipticity H/R = 10^{-4}



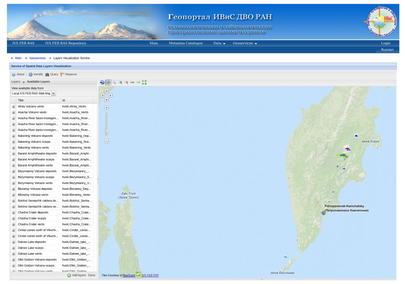


Etna lava lake, Italy. Ellipticity H/R = 1



Real-time processing at receiving station

NightVolc is a production software package ready to be deployed at any VIIRS receiving station. It will produce KML map and CSV table for all the IR detections with T, Lat, Lon and Area within 1 hr after the nighttime satellite readout (around 1AM local time). Detections are stored in PostgreSQL+PostGIS database and mapped by WMS server. In addition we provide a database of all “historical” detections starting from April 2012.



Starting from April 2016 NightVolc is operationally running on VIIRS receiving station at the Volcanology and Seismology Institute Russian Acad. Sci. in Petropavlovsk-Kamchatsky (http://www.kscnet.ru/ivs/)

Related Research

- Elvidge, C.D., Zhizhin, M., Baugh, K.E., Hsu, F.-C. and Gosh, T. Methods for Global Survey of Natural Gas Flaring from Visible Infrared Imaging Radiometer Suite Data, Energies, 2016, 9(1), 14; DOI:10.3390/en9010014 http://www.mdpi.com/1996-1073/9/1/14
- Elvidge, C.D., Zhizhin, M., Hsu, F.-C., Baugh, K., Rokhis Khomarudin, M.; Vetrita, Y., Sofan, P., Suwarsono., Hilman, D. Long-wave infrared identification of smoldering peat fires in Indonesia with nighttime Landsat data, Environmental Research Letters, 2015, 10 (6), article id. 065002
- Elvidge, C.D.; Zhizhin, M.; Hsu, F.-C.; Baugh, K.E. VIIRS Nightfire: Satellite Pyrometry at Night. Remote Sensing, 2013, 5, 4423-4449. DOI: 10.3390/rs5094423 http://www.mdpi.com/2072-4292/5/9/4423
- Christopher D. Elvidge, Danie Ziskinl, Kimberly E. Baugh, Benjamin T. Tuttle, Tilottama Ghosh, Dee W. Pack, Edward H. Erwin and Mikhail Zhizhin. A Fifteen Year Record of Global Natural Gas Flaring Derived from Satellite Data. Energies 2009, 2(3), 595-622; doi:10.3390/en20300595