Use of Night time VIIRS data for Fire Mapping

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Lights At Night!

Cities and human settlements

Industrial Sites

Gas Flares

Boats

Fires
The Visible Infrared Imaging Radiometer Suite (VIIRS) primary mission is weather.
Physical Laws for fire remote sensing

• Planck’s Law – calculates radiant emission spectra for objects based on temperature and emissivity.

• Wein’s Displacement Law: Defines the shift in peak radiant emissions to shorter wavelengths as temperature increases. Used to calculate fire temperatures.

• Stefan-Boltzmann Law: Calculates the total radiant output (radiant heat) based on temperature and source size. Radiant heat is proportional to $T^4$. 
If the IR emitter fills the field of view, temperature can be calculated with a single spectral band. This is the principle behind hand held thermal radiometers that read out temperatures.
Fires are always subpixel in coarse resolution metsat data. The temperature and source area cannot be calculated if detection is in a single spectral band.
The case for multispectral fire remote sensing

• With km scale pixels from meteorological sensors – fires never fill the field of view – they are subpixel elements. The fire radiant emissions are mixed in with the background radiant emissions.

• If the fire algorithm only uses one spectral band for detection – it is impossible to calculate the temperature or radiant heat using physical laws. This is the case for the standard satellite fire products – which use a midwave infrared channel at 4 um. This limitation lead to the development of “fire radiative power” (FRP) which is rooted in an empirical calibration.

• If the fire is detected in two spectral bands it is possible to solve for the fire temperature and source area, assuming a single temperature. This is the Dozier method.

• With additional spectral bands, it is possible to solve for two combustion phases in a single pixel – flaming and non-flaming. This is an ongoing R&D development at EOG. The value of this development comes from the fact that smoldering combustion produces more smoke and air pollution than flaming combustion.
VIIRS Collects Two Styles of Low Light Imaging Data

1. Signal intensification to detect faint radiant emissions in the visible and near infrared – the Day Night Band (DNB).

2. Daytime channels at night – enabling the detection of radiant emissions that are obscured by reflected sunlight. VIIRS collects the following at night:
   - M7 at 0.865 um
   - M8 at 1.24 um
   - M10 at 1.61 um
   - M11 at 2.25 um
VIIRS Nightfire (VNF): A global multispectral fire product
Nine channels of data collected at night

Nighttime collection of channel 11 is expected to start in 2017
VIIRS low light imaging at night: DNB detects electric lighting, fires and flares. M7 to M11 detect combustion sources. M12 – M16 are dominated by background.
For gas flares – the nighttime is the right time!
Bakken Oil Field, North Dakota

Shortwave infrared (1.63 um) day

Same band, same area, next night

Gas flare peak radiant emissions are near 1.63 micrometers. The flare radiance is lost during the day due to sunlight.
Midwave infrared fire detector

Background pixels form a diagonal. Pixels with fires depart from the diagonal.
Why Multispectral?

To get at the Planck curves!

Daily files are in csv and kmz formats.
Typical Biomass Burning Detection

Lower temperature than gas flaring. Often these have larger source size than gas flares.
Daily VNF data are available at:
http://ngdc.noaa.gov/eog/viirs/download_viirs_fire.html

Current processing typically runs with a four hour delay
VIIRS Nightfire: Satellite Pyrometry at Night

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Abstract

The Nightfire algorithm detects and characterizes sub-pixel hot sources using multispectral data collected globally, each night, by the Suomi National Polar Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS). The spectral bands utilized span visible, near-infrared (NIR), short-wave infrared (SWIR), and mid-wave infrared (MWIR). The primary detection band is in the SWIR, centered at 1.6 µm. Without solar input, the SWIR spectral band records sensor noise, punctuated by high radiant emissions associated with gas flares, biomass burning, volcanoes, and industrial sites such as steel mills. Planck curve fitting of the hot source radiance yields temperature (T) and emission scaling factor (ESF). Additional calculations are done to
Long-wave infrared identification of smoldering peat fires in Indonesia with nighttime Landsat data

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Keywords: Landsat, fire detection, peat fire, smoldering, flaming, Indonesia

Abstract
Smoldering peat fires in Indonesia are responsible for large quantities of trace gas and particulate emissions. However, to date no satellite remote sensing technique has been demonstrated for the identification of smoldering peat fires. Fires have two distinct combustion phases: a high temperature flaming and low temperature smoldering phases. The flaming phase temperature is approximately twice that of the smoldering phase. This temperature differential results in a spectral displacement of the primary radiant emissions of the two combustion phases. It is possible to exploit this spectral displacement using widely separated wavelength ranges. This paper examines active fire features.
Extending Nighttime Combustion Source Detection Limits with Short Wavelength VIIRS Data

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Abstract

The Visible Infrared Imaging Radiometer Suite (VIIRS) collects low light imaging data at night in five spectral bands. The best known of these is the day/night band (DNB) which uses light intensification for imaging of
VIIRS Nightfire Data Flow

VIIRS in 101 minute long orbit

Data arrive at Mines about 2 hours from the collection

Download once per orbit at Svalbard ground station

Via undersea data cables

National Satellite Operations Facility (NSOF), Suitland, Maryland

VIIRS Nightfire data on www

NOAA National Weather Service
Temperatures are bimodal

Fires

Flares
Temperature versus source area for VNF from January 2018
Overlayed are detection limit lines for VIIRS spectral bands
Temperature versus source area for VNF from January 2018 for detections having M12 & M13
Temperature versus source area for VNF from January 2018 for detections lacking M12 & M13
DNB detects many fires invisible to the longer wavelength channels

2015 cloud-free composite

Fires detected by VNF

Fires not detected by VNF
Flaming vs Smoldering

• The original VNF made the same assumption as the Dozier method – that all the fires in the pixel have the same temperature.
• This is obviously not true.
• We began to do research on resolving two temperature phases from individual pixels – a hot flaming phase and a cooler non-flaming phase.
• Initial prototyping done with nighttime Landsat collected of peat fires in Indonesia.
• The second stage prototyping has been done with nighttime VIIRS test set data collected on September 27, 2014 on peat burning in Indonesia.
# VNF Detection Types

The flaming vs smoldering analysis can be done with Type 4

<table>
<thead>
<tr>
<th>Type</th>
<th>Spectral bands</th>
<th>Fitting</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>M11</td>
<td>None</td>
<td>Filter out solitary pixels</td>
</tr>
<tr>
<td>1</td>
<td>M7, 8, 10, 11</td>
<td>Single Planck curve fitting</td>
<td>Flaming phase combustion – primarily natural gas flares.</td>
</tr>
<tr>
<td>2</td>
<td>M11,12,13</td>
<td>Dual Planck curve fitting for IR emitter and background</td>
<td>Flameless glowing embers?</td>
</tr>
<tr>
<td>3</td>
<td>M12,13</td>
<td>Dual Planck curve fitting for IR emitter and background</td>
<td>Rare occurrences.</td>
</tr>
<tr>
<td>4</td>
<td>M7,8,10,11,12,13</td>
<td>Triple phase fitting for two IR emitters and background</td>
<td>Solve for temperature and source area for a flaming and a cooler combustion phases plus background.</td>
</tr>
<tr>
<td>5</td>
<td>M7,8,10,11,12,13</td>
<td>Dual Planck curve fitting for IR emitter and background</td>
<td>Assembled from Type 4 detections that yielded spurious results in triple phase analysis.</td>
</tr>
</tbody>
</table>
Pie chart of the VNF types

- Type 1: 159
- Type 2: 125
- Type 3: 3
- Type 4: 92
- Type 5: 21
- Type 0: 84
Temperature distribution of the types
Comparison on VNF and VNF+ for a single pixel
Temperature histogram from September 27, 2014 test data set
Same day Landsat 8 data shows regional scale smoke plume coming from the location of VNF smoldering pixels.
Summary

• The standard satellite “hotspot” algorithm was developed in the 1980’s and is based on detection in a single midwave infrared (4 um) channel. No temperature can be calculated and fire radiative power is calculated based on empirical calibration set for typical fire temperatures.

• In 2012 EOG developed a multispectral fire detection algorithm, VIIRS nightfire (VNF), that calculates temperature, source size and radiant heat using physical laws. However, the original VNF solves for a single temperature sub-pixel IR emitter.

• In 2015 EOG prototyped a flaming versus smoldering VNF-like algorithm based on Landsat 8 data.

• In 2018-19 a flaming versus smoldering version of VNF was prototyped. Four combustion phases have been identified: flaring, flaming, embers, and smoldering.

• EOG is continuing refinement of VNF+ for operational product generation.