What is so great about nighttime VIIRS data for the
detection and characterization of combustion sources?

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Abstract:
The Suomi National Polar Partnership (SNPP) is a satellite operated jointly by the United States
National Aeronautics and Space Administration (NASA) and the National Oceanic and
Atmospheric Administration (NOAA). The primary imaging sensor on SNPP is the Visible
Infrared Imaging Radiometer Suite (VIIRS). Among imaging meteorological satellite sensors
the VIIRS is unique in collecting visible, near-infrared and short-wave infrared spectral
radiiances at night. With sunlight eliminated, these spectral bands make it possible to observe the
radiant emissions from gas flares, biomass burning, industrial sites and volcanoes worldwide
with at least one coverage every 24 hours. With multispectral detections it is possible to model
the blackbody emission curve (also known as a Planck curve), which can then be used to
estimate the temperature or the source, radiative output (W/m²), radiant heat (MW), and size of
the source (m²). This is a substantial advance over satellite fire products based on detection in a
single spectral band.

Keywords: Suomi NPP, VIIRS, gas flaring, biomass burning, Nightfire.
1. Introduction

Combustion sources such as wildfires, agricultural burning and gas flares emit a broad range of electromagnetic radiation. The simplest way to calculate the size, temperature and radiant heat of combustion sources is to determine the emitted radiance at the wavelength of peak radiant emission and applying the Stefan-Boltzmann Law. Since there is substantial temperature variation between combustion sources it is not possible to select a single spectral band to measure the radiant peak. The radiant peak shifts to shorter wavelengths as temperature increases (Wein’s displacement law). Thus it is necessary to measure combustion source at multiple wavelengths and then model the Planck curve. If the combustion source can be detected in three or more wavelength ranges it is generally possible to fit a Planck curve to the data, making it possible to derive the wavelength of peak radiant emission and solve for the radiative output, even without a direct measurement of the radiant peak.

The problem with most satellite derived fire products is that the detection rely only on single/dual spectral bands, an underdetermined situation in terms of modeling the Planck curve. This is the case for combustion source detections made with low light imaging data collected in the VNIR (visible and near-infrared) by the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System [1] and the operational fire products derived from NASA Moderate Resolution Imaging Spectrometer (MODIS) [2] and SNPP VIIRS [3]. The active fire products from both MODIS and VIIRS rely on a 4 um and 11 um channels. No temperature of source size is calculated. There is a calculation made for Fire Radiative Power (FRP) with an assumption that the source temperature is in the typical range for biomass burning. If the combustion source is in the range of 700-750 K the peak radiant emission will be in the 4 um bands collected by sensors for as the (MODIS) and the VIIRS, yielding reasonable estimates of FRP. However, if the combustion source is at a substantially hotter temperature, the 4 um band will underestimate the temperature and radiant output (Figure 1).

The VIIRS was designed to improve the low light imaging capabilities of the DMSP and continue collection of the core set of spectral bands flown on MODIS. Thus the VIIRS has a nighttime fire and light detection capability in the VNIR. In addition, the VIIRS is operated in a unique manner. At night the VIIRS continues to collect NIR and SWIR data at night (bands M7, M8 and M10 shown on Figure 1). With sunlight eliminated, the background signal is essentially the system dark current. Combustion sources radiant emissions can then be readily detected relative to the dark background. In the short wavelength bands (DNB, M7, M8, M10) the entire signal for hot pixels can be attributed to the combustion source at night. This is the basis of the NGDC Nightfire data service. In this paper we contrast daytime and nighttime VIIRS images in an area with numerous gas flares to explain the advantages of the nighttime data for the detection and characterization of combustion sources. The paper then reviews output from the NGDC VIIRS Nightfire system.
Figure 1. The VIIRS collects data in nine spectral bands at night: DNB, M7, M8, M10, M12, M13, M14, M15 and M16. This chart shows the wavelength placement of these bands. Overlaid is the blackbody emission curve for an object at 2223 K, the temperature of pure methane burning in air. Note that the M7, M8 and M10 are well placed to sample the peak radiance portion of the emission spectrum of burning methane. The M13 band, which is used in the operational VIIRS fire product is on the tail end of the emission spectrum.

2. Methods and Results

Comparison of Daytime and Nighttime VIIRS Data: To explore the detectability of combustion sources with nighttime VIIRS data we examine daytime and nighttime VIIRS data collected over Southern Iraq, Kuwait, and Western Iran on March 28, 2012. The data were gridded to 24 arc seconds, with the removal of bow tie duplications. Figure 2-10 show daytime and nighttime pairs with the nighttime image on top and the matching daytime image on the bottom.
At night the DNB (Figure 2) detects urban lights and combustion sources. When moonlight is present the DNB also detects clouds and terrain features. The daytime DNB has no ability to detect combustion sources and most artificial lighting is only used at night.

The daytime imaging bands (M7, M8 and M10) that VIIRS collects at night (Figures 3-5) provide an astonishing capability to detect gas flares and other combustion sources. The background is the system noise floor. The combustion sources stand out clearly against the noise floor. No electric lighting is detected, so these bands are free of the confusion associated with discriminating combustion sources in the DNB. An important aspect of this is that the entire radiance observed for hot pixels can be attributed to the combustion source. The daytime M7 and M8 data did not reveal any combustion sources due to the signal being heavily dominated by reflected sunlight. Several of the largest gas flares had faint signals in the daytime M10.

M12 and M13 (Figures 6-7) detect clouds and terrain features, with some ability to detect gas flares. The nighttime M12 detects most, but not all of the combustion sources detected with the nighttime M10. Then nighttime M13 detects fewer of the nighttime M10 hot pixels. In both cases fewer gas flares are detected in the daytime with M12 and M13.

The long wave thermal infrared bands (M14, M15 and M16) are able to make faint detections of the largest gas flares at night, with the ability declining as wavelength increases (Figures 8-10). The gas flares are not detected in the daytime data.

**Nightfire Results:**

The VIIRS Nightfire system identifies hot pixels in in M10 data, pulls the radiances for all nine of the spectral bands collected at night and seeks to confirm the M10 detections in DNB, M7, M8, M12 and M13. The analysis includes fitting a Planck curve to the combustion source radiances. From this it is possible to estimate the combustion source temperature, radiative output (W/m²), radiant heat (MW), and size of the source (m²). Data are output on 24 hour increments and are available at [http://www.ngdc.noaa.gov/dmsp/data/viirs_fire/viirs_html/download_viirs_fire.html](http://www.ngdc.noaa.gov/dmsp/data/viirs_fire/viirs_html/download_viirs_fire.html).
Figure 2. The day / night band (DNB) straddles the visible and near-infrared (VNIR) and is centered at 0.7 um. At night the signal is intensified for the detection of moonlit clouds. The light intensification enables the detection of urban lighting, gas flares and other combustion sources. None of the surface lighting features are visible in daytime DNB data.
Figure 3. The VIIRS M7 band in the near-infrared (NIR), centered at 0.865 um. At night the image is dominated by background noise. Combustion sources can be readily detected at night, but not electric lighting. Data collected during the day shows no evidence of combustion sources.
Figure 4. The VIIRS M8 band in the near-infrared (NIR), centered at 1.24 um. At night the image is dominated by background noise. Combustion sources can be readily detected at night, but not electric lighting. Data collected during the day shows no evidence of combustion sources.
Figure 5. The VIIRS M10 band in the short-wave infrared (SWIR), centered at 1.61 μm. At night the image is dominated by background noise. Combustion sources can be readily detected at night, but not electric lighting. Data collected during the day generally shows no evidence of combustion sources. Several of the largest flares show faint detections in daytime M10 image data.
Figure 6. The VIIRS M12 band in the mid-infrared (MIR), centered at 3.7 um. M12 detects clouds and earth surface features, plus combustion sources. Many, but not all of the M10 hot pixels are also detected in M12 at night. Far fewer hot pixels are detected in the daytime.
Figure 7. The VIIRS M13 band in the mid-infrared (MIR), centered at 4.05 um. M13 detects clouds and earth surface features, plus combustion sources. Some of the M10 hot pixels are also detected in M13 at night. Far fewer hot pixels are detected in the daytime.
Figure 8. The VIIRS M14 band in the thermal infrared (TIR), centered at 8.55 um. M14 detects clouds and earth surface features, plus combustion sources. Several of the largest flares are detected in M14 at night. No hot pixels are detected in the daytime.
Figure 9. The VIIRS M15 band in the thermal infrared (TIR), centered at 10.8 um. M15 detects clouds and earth surface features, plus combustion sources. Several of the largest flares are faintly detected in M15 at night. No hot pixels are detected in the daytime.
Figure 10. The VIIRS M14 band in the thermal infrared (TIR), centered at 12.0 um. M16 detects clouds and earth surface features. Several of the largest flares are faintly detected in M16 at night. No hot pixels are detected in the daytime.
Figure 11. An example of VIIRS Nightfire KMZ data output for a Gulf of Mexico gas flare with a temperature estimated at 1720 K.
4. Conclusions

Nighttime data collected in the NIR and SWIR provide unambiguous detections of combustion sources with global coverage every 24 hours. By using detections from six spectral bands spread from the visible (DNB 0.5 to 0.9 um) through the MIR (4 um) it is possible to model Planck curves for combustion sources spanning from biomass burning through gas flares (1600 to 2000+ K). Having the Planck curve modeled makes it possible to estimate the temperature or the source, radiative output (W/m²), radiant heat (MW), and size of the source (m²). The radiant heat variable is key to estimating fuel consumption and CO2 emissions.
Nightfire achieves a 5,000 fold data reduction on the VIIRS data stream. The typical daily input to Nightfire is 200 GB. The daily output is about 40 MB. The Nightfire files are available at no cost and no registration or password is required. This vastly reduces the bandwidth and processing infrastructure required to conduct project and research on combustion sources with VIIRS data.

We anticipate that the VIIRS Nightfire data will provide substantial improvements in the estimation of flared natural gas volumes and the severity of biomass burning in the pre-dawn hours, a critical planning time for fire managers. Currently NASA and NOAA are building the second VIIRS instrument. There are plans to fly VIIRS or similar instruments for several decades. Thus there is the possibility that a long time series of Nightfire style data will be produced, revealing spatial and temporal trends in combustion sources that will complement other observing system data related to climate change and human impacts on natural systems.

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References and Notes


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