# Potential for gas flare characterisation using the SEVIRI SWIR channel

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## Introduction

Between 1994 and 2008, according to data from the DMSP satellite program, ~150 BCM of natural gas was flared annually across the globe [1].

The US market retail value of 140 BCM at 2008 prices was $68 billion and is equivalent to 4% of the 2008 gas production [1].

The 1994 to 2008 flaring represents carbon dioxide equivalent emissions of ~278 million metric tons – the same as the annual emission of 50 million passenger cars [1].

Figure 1 – Gas flare and stack.
Source: http://www.arabianoilandgas.com/pictures/gallery/Gas%20flare.jpg

The GHG emissions from gas flares can be derived from the quantity of methane combusted, which in turn can be derived from the observed flare radiant power [2].

Calculation of flare radiant power from nighttime satellite observations from VIIRS has previously been achieved through fitting the Planck function to spectral radiances at several wavelengths within the visible, NIR, SWIR and MIR spectral regions [3].

Here we attempt to extend the single wavelength MIR radiance approach that has been applied with so much success to estimating the radiative heat released by biomass burning events [4,5,6]. This extension employs the very same approach applied to nighttime SWIR channel data (to avoid solar reflection dominating the SWIR channel) to characterise gas flares in terms of their radiative power and is demonstrated using the VIIRS instrument and evaluated for application to SEVIRI.

## Extension to SWIR channels

The power radiated over all wavelengths from a given blackbody at given temperature is obtained from the Stefan-Boltzmann law,

$$P = A\sigma T^4$$

Where $P$ is the power (W), $A$ the area of the surface (m$^2$), $\sigma$ is the Boltzmann constant (W m$^{-2}$ K$^{-2}$), and $T$ is the temperature of the blackbody (K).

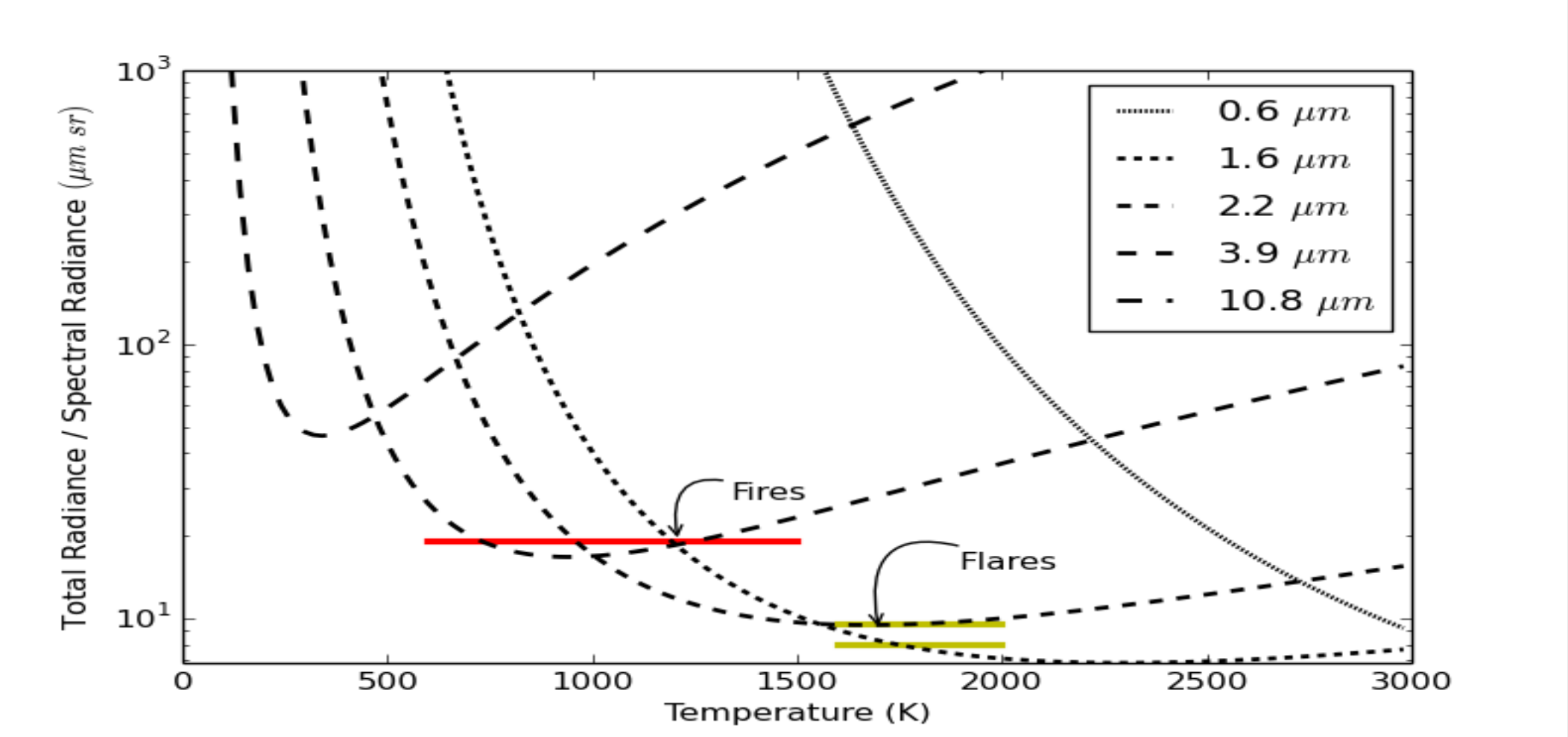

Figure 2 – This figure plots the ratio of the total radiance (W m$^{-2}$) over the spectral radiance (W m$^{-2}$ sr$^{-1}$ μm$^{-1}$) for four common EO channels. Where the ratio is approximately constant it demonstrates that the Planck function can be approximated by a 4th order power law.

From a satellite sensor, we do not directly observe $A$ or $T$, so cannot directly infer $P$. Rather we observe spectral radiance, $L$ (W m$^{-2}$ sr$^{-1}$ μm$^{-1}$), over some spectral response function. The Planck function shows that $L$ is a function of $T$ and observation wavelength, $\lambda$,

$$L(\lambda, T) = \frac{C_1}{\lambda^5\left(e^{\frac{C_2}{\lambda T}} - 1\right)}$$

For a defined temperature range, the Planck function can be approximated by a power law,

$$L(\lambda, T) = aT^b$$

If the index, $b$, is 4, then the power law has the same form as Stefan-Boltzmann's law, which in turn allows the direct inference of P from L as follows:

$$P = \frac{A\sigma}{a} L_\lambda$$

In summary, for the approach to work for a given wavelength of observation we need to find the temperature range where the Planck function is approximated by a 4th order power law. For wildfires this occurs at ~4μm for temperatures between 600-1300K. At 1.6μm this occurs between 1500-2800K and at 2.2μm between 1000-2100K – which are typical flare combustion temperatures (see Figs. 2 & 3). Hotter temperatures allows SWIR to be used!

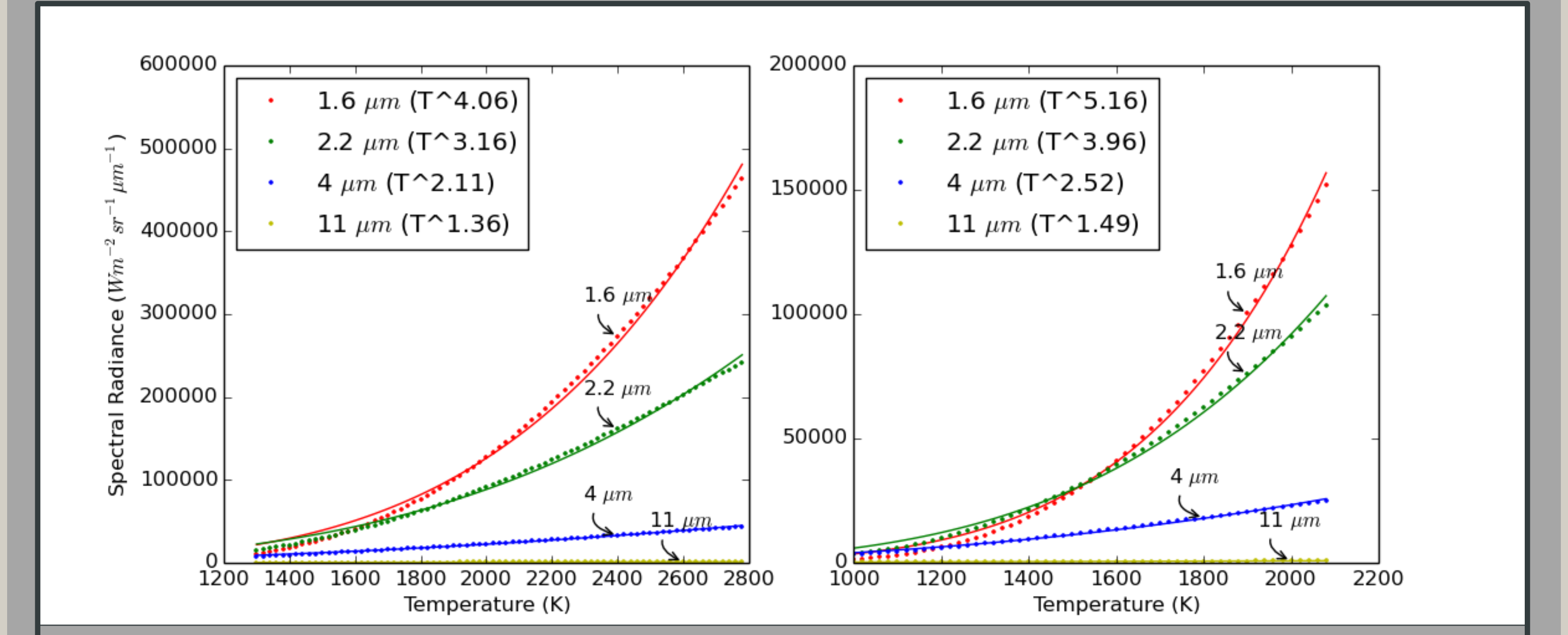

Figure 3 – The dotted lines are the Planck function outputs for common EO channels. The solid lines are the power law fits. Between 1300-2800K the for 1.6μm and 1000-2100K for 2.2μm the Planck function is a ~4th order power law.

## Application to VIIRS

To provide a initial validation of the method we performed an inter-comparison using the VIIRS Nightfire dataset [3]. This dataset characterises gas flares by fitting the Planck function to spectral radiance measurements from the VIS through MIR VIIRS channels at night (solar reflection dominates these channels during the day and so the flares are not detectable). The outputs from the Planck fitting are flare emissivity and temperature, which are in turn used to compute other flare characteristics such as radiant power.

In Fig. 4, we compare the radiant power computed using the Planck fit temperature against the radiant power derived from the SWIR (1.6 μm) spectral radiance using one month's worth of Nightfire data. Excellent agreement is demonstrated (see statistics inset in figure).

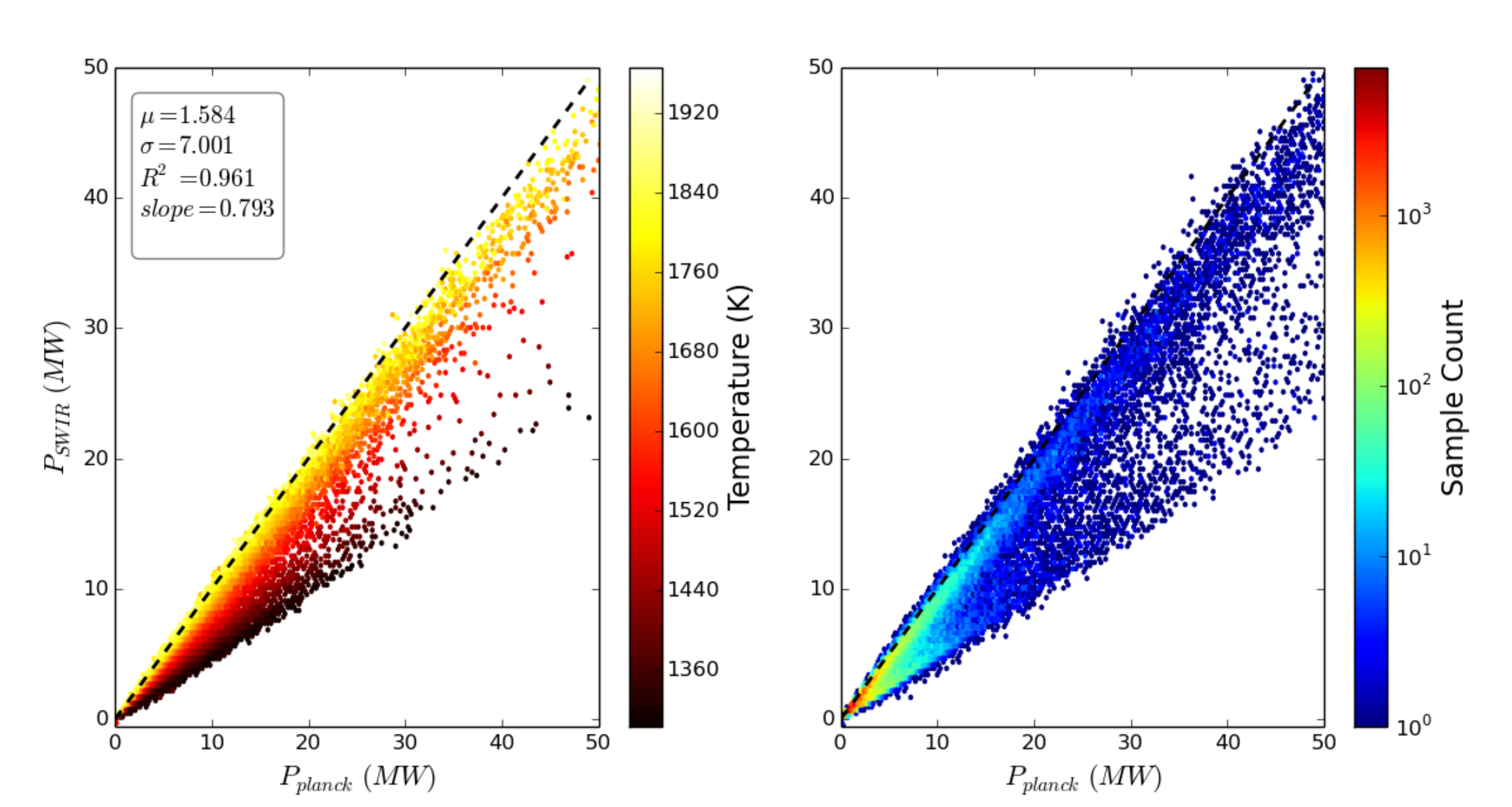

Figure 4 – These plots plot the VIIRS Planck fit outputs against the SWIR waveband method, as a function of temperature and also the histogram output.

## Application to SEVIRI

Given the size of the SEVIRI pixel (9 km$^2$ at nadir), only the very largest of flare events are observed by SEVIRI (see Figure 5 for a comparison with VIIRS) – precluding its usefulness in the characterisation of most gas flares.

Most gas flares have areas of < 25m$^2$ according to VIIRS observations (see Figure 6). With such areas the flares have to combust above 2200K to be detected above the SEVIRI noise floor (see Figure 7). According to [3] most flares combust between 1600-2000K.

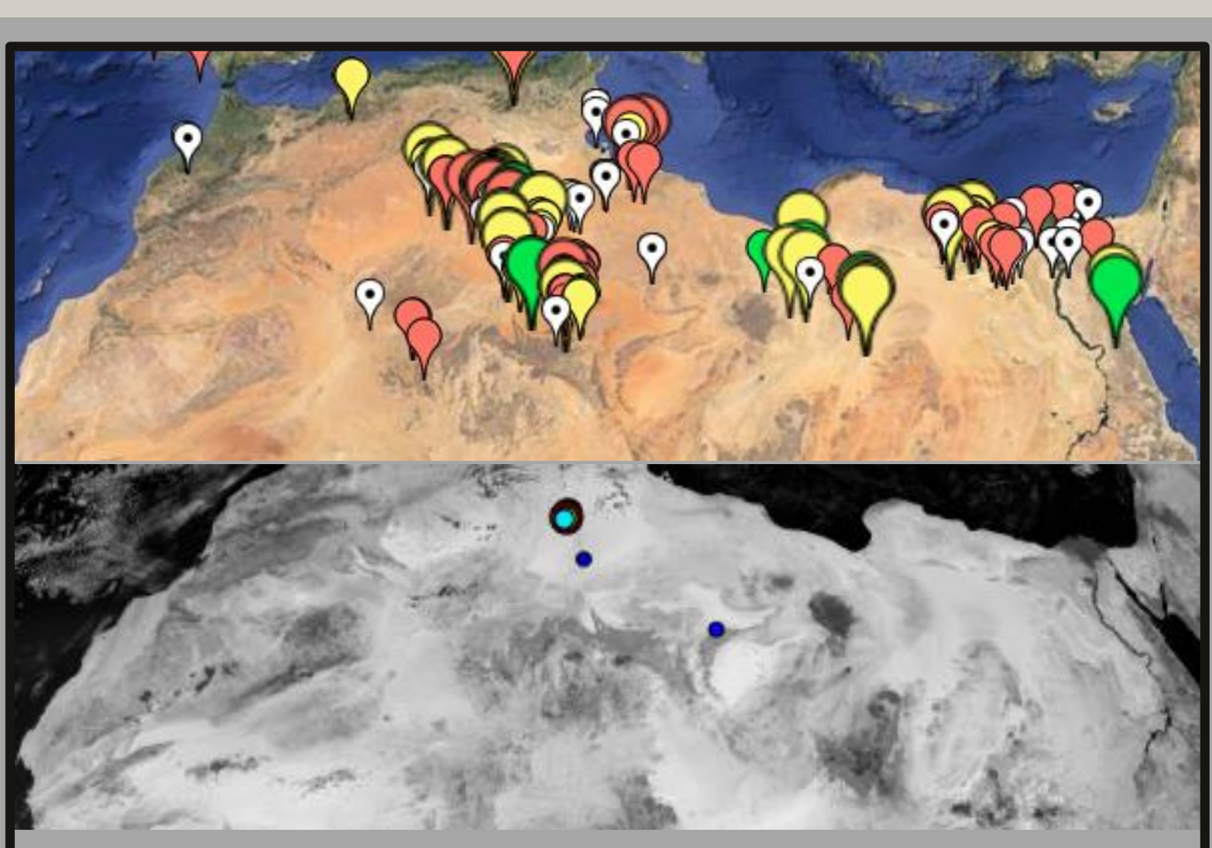

Figure 5 – Flare detection on 10th Aug 2014 from VIIRS (upper) and SEVIRI (lower). SEVIRI misses almost all the flares.

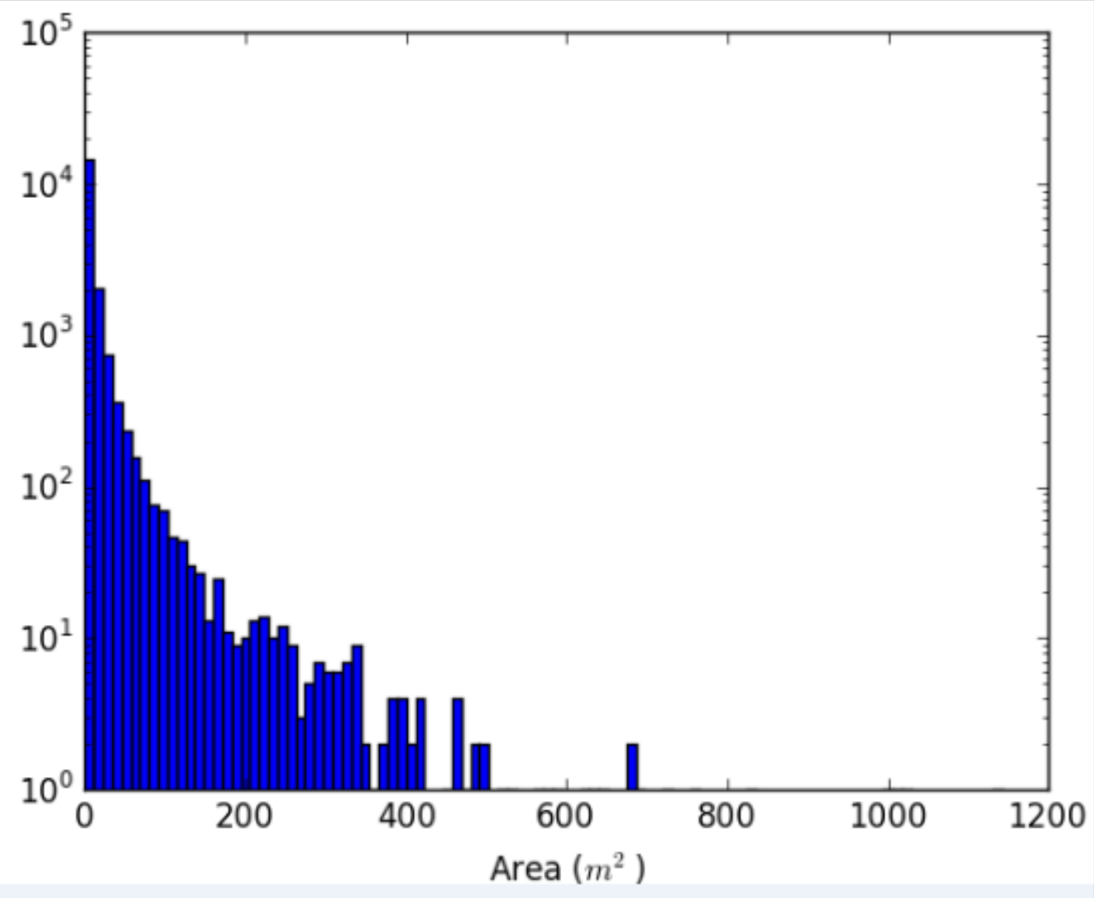

Figure 6 – VIIRS gas flare area data for the 10th Aug 2014. Note that most gas flares have areas of 25 m$^2$ or less.

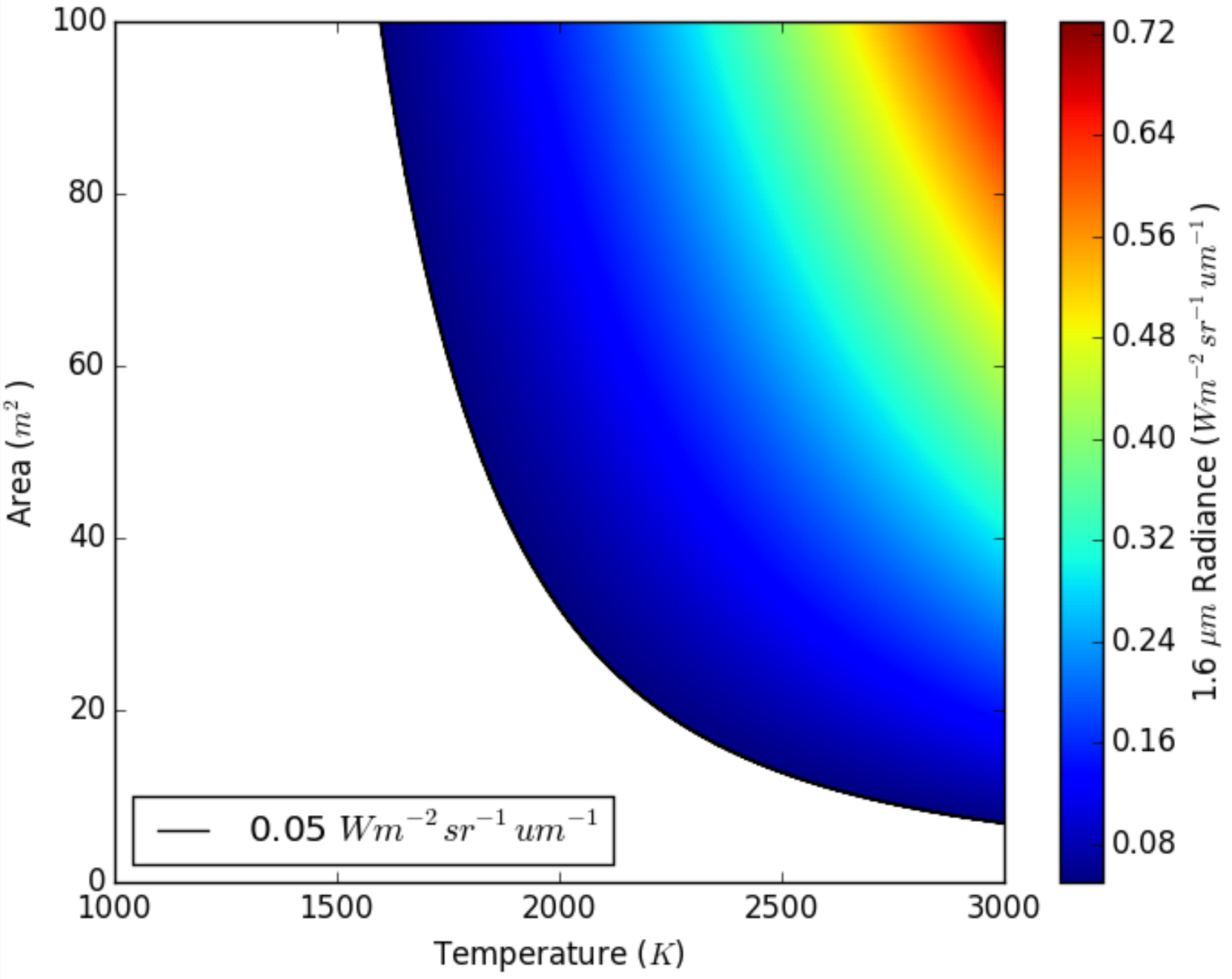

Figure 7 – Assuming a SEVIRI noise floor of 0.05 W m$^{-2}$ sr$^{-1}$ μm$^{-1}$, most gas flares will be missed according to Figure 6, as their areas are typically too small.

## Conclusions

We have demonstrated an extension of the MIR radiance FRP method to the SWIR for the characterisation of gas flare radiant power using night time imagery. The approach is based on the fact that at certain wavelengths and temperature ranges the Planck function can be approximated by a fourth order power law. This allows, due to the fourth order behavior of the Stefan-Boltzmann law, direct inference of radiant power from spectral radiances.

We have demonstrated this approach on the polar orbiting VIIRS satellite, where we compared gas flare power derived through fitting the Planck function to various VIIRS observations of spectral radiance to gas flare power derived from the SWIR channel. Excellent agreement was demonstrated. When applied to SEVIRI the pixel size, even at nadir, precludes the detection of all but the largest and hottest of flares. However, application to higher resolution (e.g. <=1km$^2$) sensors with SWIR channels operating at night is feasible.

**References**

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