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Observing UK Bonfire Night Pollution from Space: Analysis of Atmospheric Aerosol

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Abstract:

UK Bonfire Night (BFN) is an annual event on the 5th November to celebrate the failed gunpowder plot of Guy Fawkes to blow up the Houses of Parliament. This event is celebrated with firework and bonfire displays, which reduce visibility and increase air pollutant concentrations. A 2-4 fold increase in particulate matter concentrations was seen at some surface monitoring sites. Satellite measurements of aerosol optical depth found increases of 10-90% between days before and after BFN.

Key Words: Air Quality, MODIS Aerosol Optical Depth, Particulate Matter, Bonfire Night

1. Introduction:

In the United Kingdom (UK), Guy Fawkes Night or Bonfire Night (BFN) is an annual event on the 5th November to celebrate the failed gunpowder plot of Guy Fawkes to blow up the Houses of Parliament in 1605. BFN night is typically celebrated by the general public across the UK with bonfires and firework displays. These bonfires and firework explosions (both surface and lower troposphere) generate large dense smoke plumes resulting in significantly reduced visibility and increased emissions of air pollutants. These air pollutants typically include nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and particulate matter ($PM_{2.5\ \&\ 10}$ – atmospheric aerosols with diameters less than 2.5 and 10 microns, respectively). These pollutants are monitored by national and local government for public health reasons (i.e. they can cause respiratory and cardiovascular problems (WHO, 2014a)). Pollutants such as NO_2 and CO also act as precursor gases to secondary air pollutants such as ozone (O_3 – Wayne, 2000).

Multiple studies have found links between BFN and increased air pollution. Singh et al., (2015) found both large decreases in visibility across the UK on BFN relative to previous days, as well as increased air pollutants at a monitoring site in Nottingham. High relative humidity increased the size of aerosols from BFN night, which further reduced visibility. Dyke et al., (1997) found a four-fold increase in dioxin concentrations (WHO, 2014b) in Oxford on BFN in 1994. Harrison et al., (1999) and Godri et al., (2010) also found large increases in air pollution (e.g. PM_{10}) on BFN. Large celebratory events using fireworks, such as Diwali in India, which last several days, enhance air pollutant concentrations sufficiently that it can be detected from space through tropospheric column NO_2 and aerosol optical depth (AOD) measurements (Sati and Mohan, 2014; Devara et al., 2015). This is despite the large uncertainties/errors associated with satellite measurements. As far as this study is aware, satellite measurements have not been used before to detect enhanced pollution from BFN, which is presented here as well as investigation of several UK surface sites.

2. Observations:

We investigated the influence of BFN on levels of surface air pollution using four monitoring sites that measured hourly PM_{10} and $PM_{2.5}$ concentrations (30th October – 11th November, 2011-2015), which were situated near well-known bonfire/firework displays. These monitoring sites included Leeds Headingley Kerbside, Aberdeen, Newcastle Centre, and Birmingham Tyburn, which were located near Woodhouse Moore (Leeds, 0.9 miles), the Beach Boulevard and Beach Esplanade (Aberdeen, 0.7 miles), Fort Segedunum (Newcastle, 3.5 miles) and Pype Hayes Park (Birmingham, 0.4 miles), respectively. These monitoring sites are part of the Automated Urban Rural Network (AURN), funded by the Department for Environment, Food & Rural Affairs (DEFRA), and are available at http://uk-air.defra.gov.uk/networks/network-info?view=aurn (DEFRA, 2015).

Satellite measurements of AOD, measured at a wavelength of 550 nm in the electromagnetic spectrum, were from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments, which are on the NASA EOS AQUA and TERRA satellites (http://reverb.echo.nasa.gov/reverb/). The AOD represents the degree to which aerosols prevent the transmission of light through the atmosphere. Where there is more aerosol, say from pollution sources (e.g. traffic), this will increase the retrieved AOD. AQUA and TERRA have approximate overpass times of 13.30 LT and 10.30 LT (Remer et al., 2005). Therefore~~,~~ AOD data~~,~~ between 08:30 LT – 15:30 LT (overpass times +/- 2 hours), was interpolated onto a daily 0.5° x 0.5° longitudinal latitudinal grid over the UK between 3rd and 8th November 2002 – 2015. This provided comparisons of AOD before and after the UK BFN. All data were filtered for poor quality data flags and satellite pixels where the cloud cover was greater than 50%.

MODIS AOD measurements were cross referenced with several AErosol RObtic NETwork (AERONET; Dubovik et al., 2000) sites (co-located in time and space), available at http://aeronet.gsfc.nasa.gov/, across the UK for November. Both data sets had similar absolute AOD averages, which were within the variability of each other, giving confidence in the MODIS AOD product.

This study also investigated tropospheric column NO_2 from the Ozone Monitoring Instrument (OMI; Boersma et al., 2011) and CO profiles from the Tropospheric Emissions Spectrometer (TES; Luo et al., 2007). However~~,~~ there was no clear signal in either dataset. NO_2 has an approximate lifetime of several hours, so the majority of BFN related NO_2 would have been chemically converted, transported away or lost via deposition before OMI's 13.30 LT overpass the following day. TES CO, though having a much longer lifetime, had very limited spatial coverage, so the UK sample sizes were too small on and after BFN to detect any signal.

Similar~~rly,~~ to Singh et al., (2015)~~,~~ this study used SYNOP measurement of visibility, 2005-2011, to assess the impact of BFN. Past Weather Code (PWC) data was downloaded from the HadISD dataset (Dunn et al., 2012), which is available at http://www.metoffice.gov.uk/hadobs/hadisd/. PWC code 4 represents “Fog or ice fog or thick haze” and was used to detect increased reports of phenomena linked to reduced visibility below 1000m from BFN. Over the 7 year period the number of sites which reported PWC 4 between 08:30 and 15:30 LT (which match the AQUA and TERRA overpass periods), on days within the week before and after BFN, were totalled up. This acted as validation of MODIS AOD to see if similar patterns were seen in the daytime when satellite AODs were retrieved.

3. Results:

From the surface measurements, a sharp jump in PM$_{10\ \&\ 2.5}$ concentrations occurred just before 00:00 LT 6th November (dashed green line), coinciding with BFN across each site (Figure 1). The largest enhancements in hourly-recorded pollution were at Leeds Headingley Kerbside and Birmingham Tyburn, which increased from approximately 10-20 μg/m^3 to over 150 and 200 μg/m^3, respectively. Increased PM concentrations at Aberdeen and Fort Segedunum were smaller and peaked at 60-70 μg/m^3. At Leeds Headingley Kerbside and Birmingham Tyburn, the PM concentrations peaked above the 24 hour mean safe exposure threshold (WHO, 2014a) of 25 μg/m^3 and 50 μg/m^3 for PM$_{2.5}$ and PM$_{10}$, respectively. Therefore, air pollution from BFN exceeded the WHO safe exposure thresholds, even nearly 1 mile away from the pollution source.

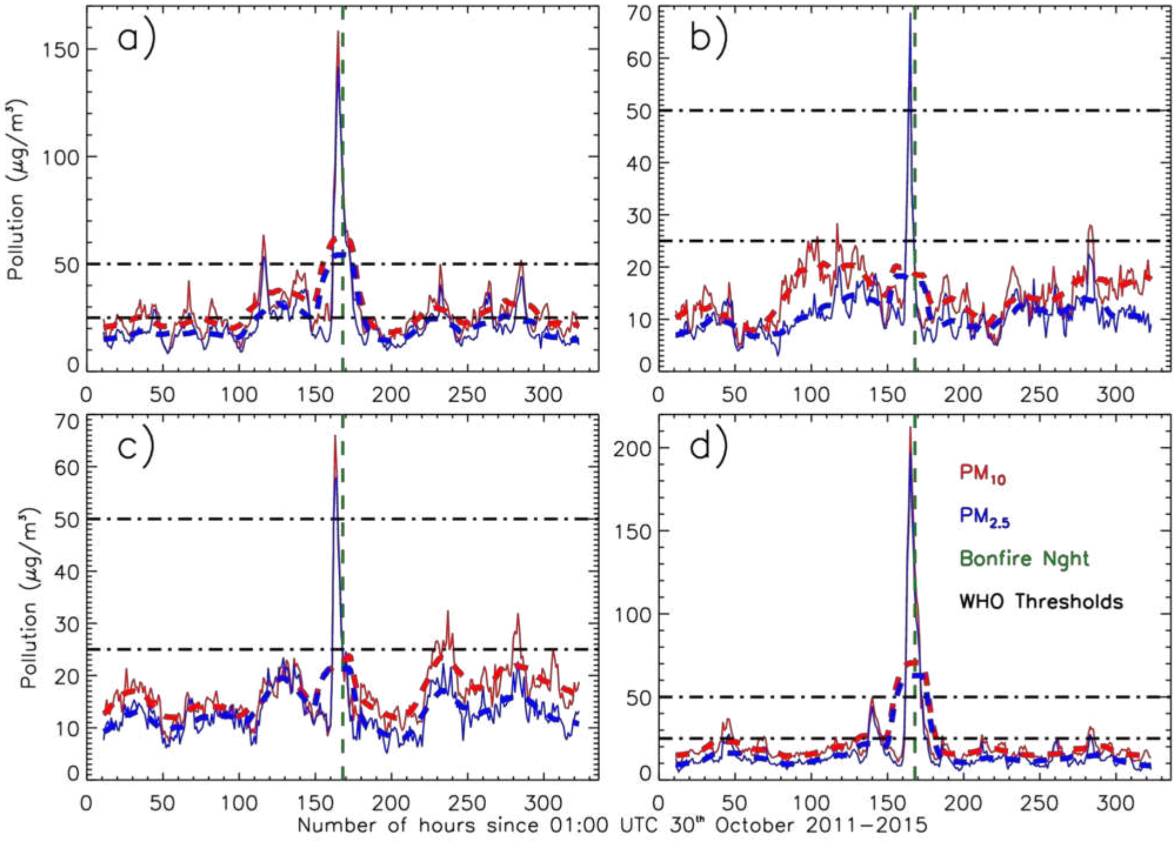


Figure 1: Particulate matter (PM$_{2.5\ (\mathrm{blue})\ \&\ 10\ (\mathrm{red})}$) measurements between the 30th October and 12th November (one week before and after Bonfire Night) averaged over 5 years (2011-

2015). Solid (dashed) lines represent hourly (24-hour running average) time steps. Green and black dashed lines show the time step of bonfire night (00:00 LT 6th November) and the World Health Organisation (WHO) 24 hour mean safe exposure limit ($PM_{2.5}$ = 25 µg/m^3 and PM_{10} = 50 µg/m^3). a) Leeds Headingley Kerbside, b) Aberdeen, c) Newcastle Centre and d) Birmingham Tyburn.

MODIS AOD composites, especially on short time scales (i.e. a few days), can be extremely noisy with no clear signal in the data. Here~~,~~ we used MODIS AOD data from both the AQUA and TERRA satellites, over a long period of 14 years, which built up suitable composite sample sizes to find a more robust signal. Within the 2002-2015 period, 2008, 2009, 2010 and 2013 were removed because either the 5th or 6th November experienced cyclonic weather conditions, as shown by the Lamb Weather Types (LWT; Jones et al., 2013). The LWT are a daily classification of UK atmospheric circulation patterns (see Pope et al., 2014). Cyclonic conditions are typically associated with unstable wet weather. Therefore, atmospheric aerosols from BFN are likely to be washed out (wet deposition) and/or transported away from the source regions. Figures 2a and 2b show the median MODIS AOD composites for 3rd – 5th November (pre-BFN) and 6th – 8th November (post-BFN). Typically, the arithmetic mean is used when calculating a composite average. However, individual retrievals of AOD are subject to large uncertainties. Therefore, by using the median, any anomalous retrievals in the composite sample are not included in the average. We use the median as anomalous AOD values in the sample were excluded from the composite average. Three-day windows were used as they increased the composite samples sizes. Shorter (longer) sample windows resulted in reduced spatial coverage (smoothed BFN signals). Across the years sampled, the three-day windows either side of BFN equally intersect with weekend celebrations (years where BFN is during the week (Monday-Friday)). Therefore, any signal seen in the satellite data from celebrations at the weekends were balanced out and the primary BFN night signal dominates. Grid pixels with less than three observations were also filtered out as anomalous observations potentially would skew the AOD. Since the MODIS observations ranged from mid-morning to early afternoon, AOD values on the 5th November were unlikely to be linked to BFN.

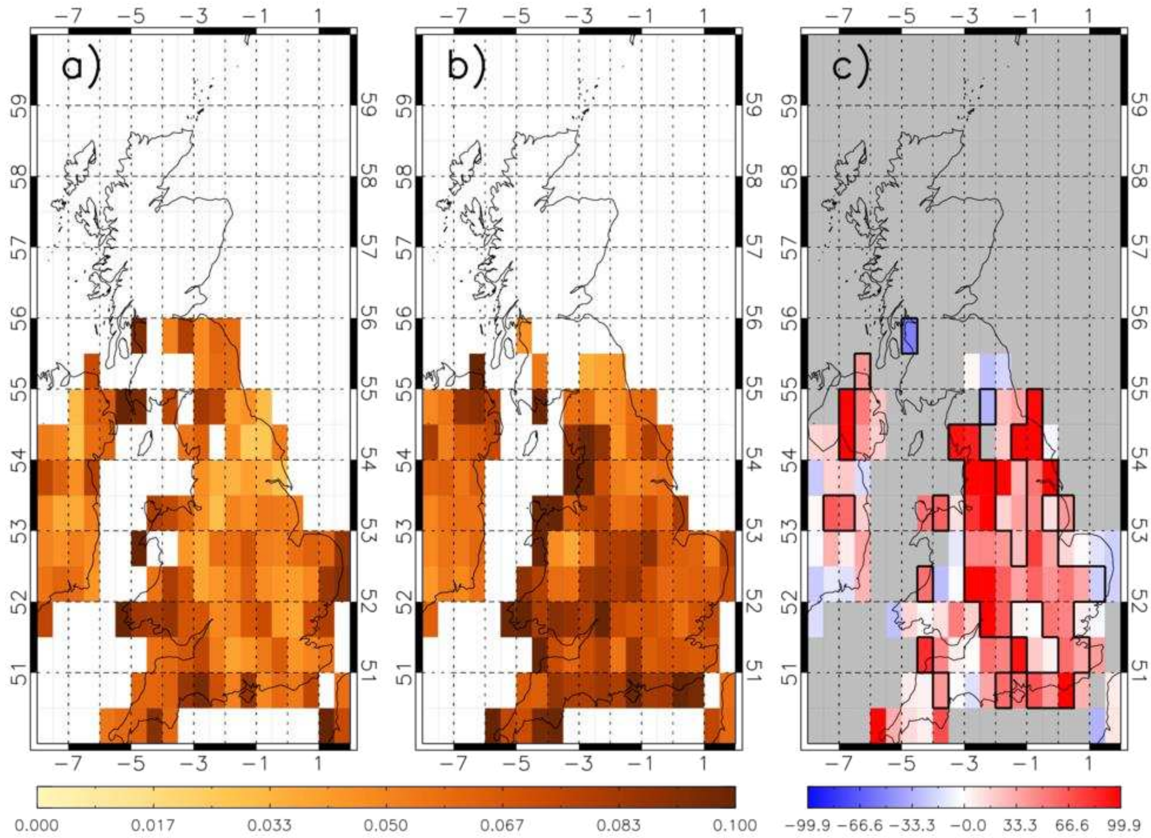
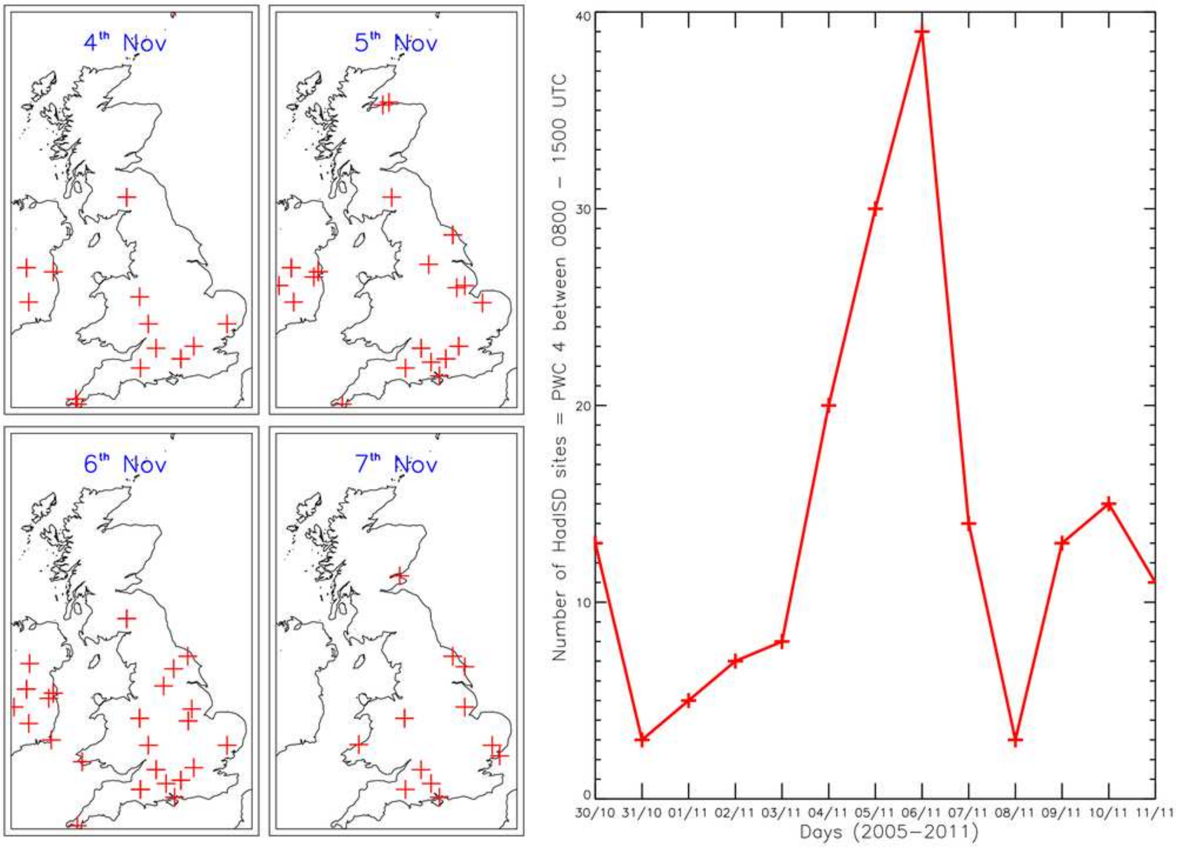


Figure 2: MODIS (TERRA, 10.30 LT and AQUA, 13.30 LT) Aerosol Optical Depth (AOD) between 2002 and 2015: a) 3rd – 5th November and b) 6th – 8th November. c) is the percentage difference between b) and a). Black polygonned regions show significant differences where the instrument uncertainty ranges do not overlap.

Pre-BFN, AOD over the UK ranges between 0.015 and 0.1, with peak AOD on the western coastline and Northern Ireland (Figure 2a). In central England, the AOD ranges between 0.02 and 0.07. The MODIS AOD composite after BFN (Figure 2b) shows higher AOD values across the domain peaking above 0.1 on the western and southern coastlines. We hypothesis that peak AOD along the coastlines is related to marine aerosol (sea salt). Over central England, the AOD is 0.05-0.09. Even though there is limited spatial coherent pattern, there are clear increases in UK AOD between 10-90% (Figure 2c). This suggests an increase in atmospheric aerosol loading, which coincides with BFN known to decrease visibility and increase particulate concentrations. The black polygonned regions show where the differences between a) and b) are significant as the composites averages +/- their uncertainties do not overlap. Therefore, large swaths of the UK show significant percentage increases in AOD in the following few days after BFN.



<u>Figure 3:</u> Number of sites recording Past Weather Code (PWC) 4 occurrences, between 08:30 and 15:30 LT, over the 2005-2011 period on days before and after Bonfire Night (5th November; right panel). The maps (left panels) show the location of PWC 4 occurrences over the 7-year period on days surrounding and including BFN.

The number of sites which record PWC 4 between 08:30 and 15:30 LT over the period 2005-2011 on the days 30th October – 11th November are shown in Figure 3 (right panel). Over the 7-year period, the 30th October – 3rd November and 7th-11th November windows had 2-15 sites, which recorded at least one PWC 4 event. Between the 4th and 6th November, there was an increase to over 20 sites, which have recorded PWC 4 peaking at 39 on the 6th November (Figure 3). The 5th November 08:30 – 15:30 LT window showed lower frequencies as the main BFN event had not yet occurred. Therefore, in the same window on the 6th November, peak frequencies occurred after BFN had happened. This was similar to what MODIS AOD saw during the day and gives further confidence to the results shown in Figure 2. It should be noted that reporting of the PWC at night was less frequent than during the day creating a day-night time reporting bias. In theory, the peak recording of PWC 4 would be on BFN and in the early hours of the 6th November. However, as there is limited recording in this period, the BFN signal was not seen~~,~~ so this study focussed on daytime observations coinciding with the MODIS overpass window.

4. Conclusions:

This study has shown that air pollution from Bonfire Night (BFN; 5th November) can be detected using a range of observations. Surface monitoring sites near large firework/bonfire displays showed large increases in particulate matter ($PM_{2.5 \& 10}$) concentrations during BFN night. In particular, pollution at Leeds Headingley Kerbside and Birmingham Tyburn peaked above World Health Organisation safe pollutant exposure thresholds. Satellite measurements of aerosol optical depth (AOD), despite the large errors and uncertainties, have been used for the first time, as far as this study is aware, to successfully detect the impact of BFN on levels of UK air pollution. On days after BFN, significantly elevated AOD values between 50-90% are detectable.

Overall, BFN decreases air quality across the UK and this study aims to increase the awareness of general public, especially those with pre-existing respiratory and cardiovascular problems, to the risks of enhanced pollution levels in close proximity to firework/bonfire displays. However, given the correct precautions from both the public and local authorises, this should not detract from the fun and enjoyment experienced during the celebration of this annual national event.

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