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1 **Detection of the Yorkshire power stations from space:**
2 **tropospheric column NO₂**

3
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7
8 **Key Words:** Air Quality, Power Station Emissions, OMI NO₂

9 **1. Introduction:**

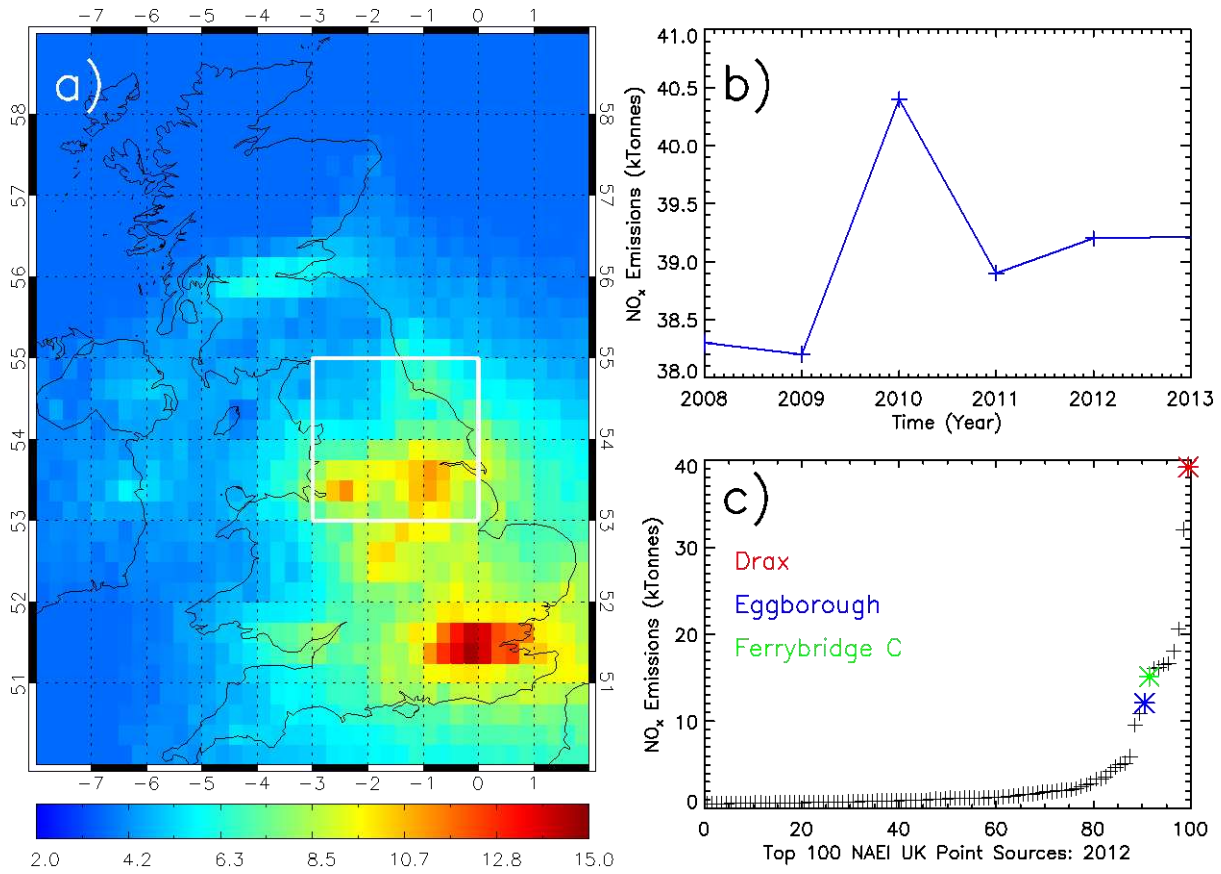
10 Atmospheric pollutants such as NO₂, O₃ and particulate matter (PM₁₀ and PM₂₅ - atmospheric particles
11 with a diameter of less than 10µm and 2.5µm, respectively) at sufficient surface concentrations are
12 detrimental to human health. The World Health Organisation (WHO) state that O₃ can cause breathing
13 and cardiovascular problems. NO₂ can cause reduced lung function and PM can lead to increased
14 mortality and morbidity (WHO, 2014).

15 Power station emissions can have a significant impact on regional and local air quality (NO₂, SO₂ and
16 PM). In Beijing, Hao et al. (2007) estimate that power stations emit 49%, 27% and 11% of city SO₂,
17 NO_x (NO + NO₂) and PM₁₀, respectively. Mauzerall et al. (2005) show that emissions of NO_x from
18 larger point sources (power stations) can significantly influence surface O₃ concentrations leeward of
19 the source, which can be detrimental to human health in populated regions. Webb and Hunter (1998)
20 found that between 1992 and 1996 UK power stations in the short term (hourly concentrations) rarely
21 resulted in the exceedance of the WHO safe exposure limit of 104.6 ppb (approximately 200 µg/m³ –
22 WHO present day safety limit (WHO, 2014)) for NO₂. They suggest the risk of exceeding the WHO
23 NO₂ limit was low and only likely in the case the power station NO_x plume coincided with an extreme
24 ozone event.

25 In Yorkshire, UK, there are three large power stations; Drax, Eggborough and Ferrybridge. They have
26 generating capacities of 3960 (Drax, 2014), 2000 (Eggborough Power Limited, 2014) and 980 MW
27 (SSE, 2014), respectively. Figure 1a shows average UK tropospheric column NO₂ from the Ozone
28 Monitoring Instrument (OMI) between 2005 and 2011. The peak concentrations are located over
29 London ranging between 12 and 15 x 10¹⁵ molecules/cm². Both Manchester and Birmingham have
30 significant tropospheric column NO₂ around 8-11 x 10¹⁵ molecules/cm². North East Yorkshire has
31 similarly large concentrations, but there are no large cities nearby. We hypothesise that the higher
32 levels of tropospheric column NO₂ here come from these power stations. Emissions data from Drax
33 (Figure 1b) show that between 2008 and 2013 it produces approximately 38-40 kTonnes of NO_x
34 annually (Drax, 2013). For 2012, according to the National Atmospheric Emissions Inventory (NAEI)
35 (NAEI, 2014), Drax was the highest point source emitter of NO_x in the UK (Figure 1c). Ferrybridge C
36 and Eggborough were the 9th and 10th highest point source emitters of NO_x.

37 Assessing the influence of these power stations on air quality is difficult as there are limited
38 observations of pollutants in the North East Yorkshire region. The Department for Environment, Food
39 and Rural Affairs (DEFRA) Automated Urban and Rural Network (AURN) (DEFRA, 2012) has no
40 nearby sites and measurements from NO₂ diffusion tubes, recorded by local authorities, are limited to
41 monthly sampling and are provided through DEFRA as raw, biased-uncorrected, data (DEFRA,
42 2015). Particulate matter was monitored around Drax, but stopped in 2008 (Selby Council, 2015).
43 Therefore, satellite observations of air pollutants (OMI tropospheric column NO₂) are used in this

44 study to investigate air pollution sources in the region. The white box in Figure 1a highlights the
 45 region of interest.



46
 47 **Figure 1:** a) OMI tropospheric column NO₂ (x10¹⁵ molecules/cm²) between 2005-2011 over the UK,
 48 b) Drax NO_x emissions between 2008-2013 and c) top 100 NAEI NO_x point source emissions for
 49 2012 (kTonnes).

50 Multiple studies have looked at the use of satellite data, i.e. NO₂ tropospheric columns, to monitor air
 51 quality. Pope et al. (2014) investigated OMI tropospheric column NO₂ over the UK, 2005-2011, and
 52 found that under anticyclonic conditions there is an accumulation of tropospheric column NO₂ over
 53 source regions, while under cyclonic conditions tropospheric column NO₂ is reduced. Zhou et al.
 54 (2012) used OMI tropospheric column NO₂, 2004-2009, to detect the UK days of maximum
 55 (Wednesday-Thursday) and minimum (Saturday-Sunday) tropospheric column NO₂. They also show
 56 that peak UK tropospheric column NO₂ is in February-March and minimum is in June-July. Beirle et
 57 al. (2011) used OMI tropospheric column NO₂ and wind forecasts (below 500m) to analyse NO₂
 58 transport from the isolated megacity Riyadh, Saudi Arabia, detecting leeward NO₂ plume transport.
 59 Hayn et al., (2009) undertook a similar analysis of wind direction and tropospheric column NO₂ over
 60 Johannesburg, South Africa.

61
 62 **2. Satellite data:**

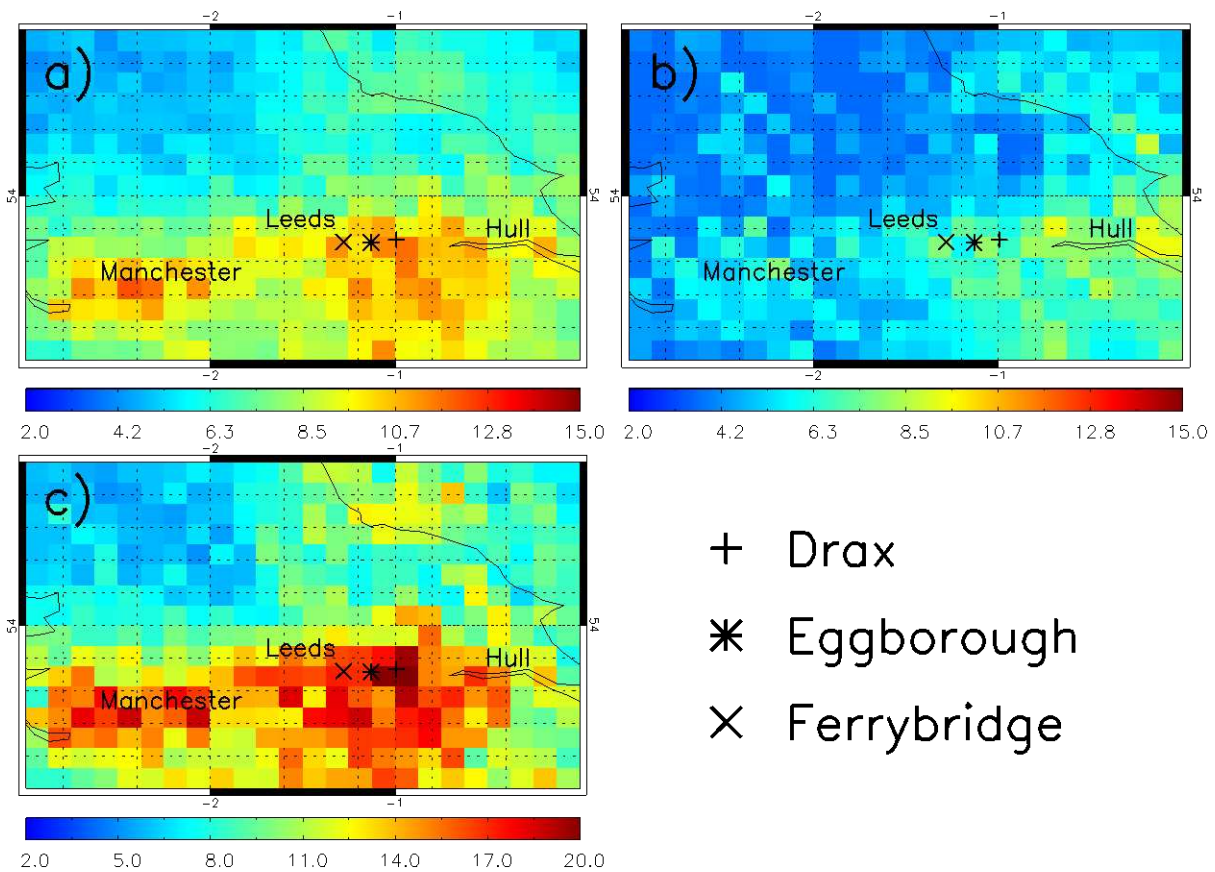
63 OMI is mounted on NASA's EOS-Aura satellite and has an approximate London daytime overpass at
 64 13:00 local time (LT). It is a nadir-viewing instrument with an average pixel size of 312 km². We have
 65 taken the DOMINO tropospheric column NO₂ product, version 2.0, from the TEMIS (Tropospheric
 66 Emissions Monitoring Internet Service) website, <http://www.temis.nl/airpollution/no2.html> (Boersma
 67 et al., 2011a & b). We have interpolated NO₂ swath data from 1st January 2005 to 31st December

68 2011 onto a daily 13:00 LT $0.125^\circ \times 0.125^\circ$ grid between $53^\circ - 55^\circ\text{N}$ and $3^\circ\text{W} - 0^\circ$. All satellite
 69 retrievals have been quality controlled for retrievals with cloud cover greater than 20% and poor
 70 quality data flags.

71

72 **3. Results:**

73 Figure 2a shows the 7-year average of OMI tropospheric column NO_2 over northern England. The
 74 background tropospheric column NO_2 ranges from below 2×10^{15} to 5×10^{15} molecules/ cm^2 over the
 75 rural areas. The peak tropospheric column NO_2 is approximately $10\text{-}13 \times 10^{15}$ molecules/ cm^2 over the
 76 urban regions such as Manchester and North East Yorkshire. The North East Yorkshire peak
 77 tropospheric column NO_2 is located over the cluster of large Yorkshire power stations; Drax,
 78 Eggborough and Ferrybridge. The location of these power stations has been over plotted in Figure 2,
 79 correlating with the OMI peak tropospheric column NO_2 . Therefore, this study hypothesises that it is
 80 the emissions of NO_x from these power stations, which are primary emitted or chemically converted,
 81 which result in the peak tropospheric column NO_2 in the region.



82

83 **Figure 2:** OMI tropospheric column NO_2 ($\times 10^{15}$ molecules/ cm^2), 2005-2011, over northern England:
 84 a) 7-year average, b) sampled under high wind speeds (>7.5 m/s) and c) sampled under low
 85 wind speeds (<2.5 m/s).

86 To see if these power stations are the cause of the elevated tropospheric column NO_2 in North East
 87 Yorkshire, the OMI data were sampled under days of high and low wind speeds. In the case of high
 88 wind speeds, leeward transport of tropospheric column NO_2 from the power stations would be
 89 expected. Under low wind speed conditions, accumulation of tropospheric column NO_2 would be
 90 expected over the power stations, as there would be limited transport of the pollution. To classify
 91 “low” and “high” wind speed days (wind speed sampled at midday to match the OMI overpass),

92 surface wind speed data was taken from the Met Office HadISD database (Dunn et al., 2012 –
93 available at <http://www.metoffice.gov.uk/hadobs/hadisd/>). Stations between 2°- 0.5°W and 53°-
94 54.5°N were selected (16 stations in total) to approximately represent the average wind speed over
95 Yorkshire each day. Days when the average wind speed was less than 2.5 m/s and greater than 7.5 m/s
96 were classed as “low” and “high” wind speed days, respectively. Over the full time period, there were
97 242 and 506 days classed as “low” and “high” wind speed days.

98 Under the high wind speed conditions (Figure 2b), the domain tropospheric column NO₂ decreases to
99 approximately 2-4 x10¹⁵ and 6-10 x10¹⁵ molecules/cm² in the rural and urban regions, respectively.
100 The concentrations over the power stations range between approximately 6-9 x10¹⁵ molecules/cm²
101 and there appears to be a leeward transport of tropospheric column NO₂ away from the power stations
102 and Hull out into the North Sea and over Lincolnshire. Though this study focuses on wind speed, not
103 direction, climatologically speaking, the UK experiences westerly winds on average (Wheeler, 2013).
104 The elevated NO₂ concentrations downwind of the power stations can also be caused by the reaction
105 of NO with O₃ to produce more NO₂. Depending on the NO/NO₂ emission ratio from the power
106 stations, this can enhance both NO₂ and O₃ concentrations downwind of the NO_x source.

107 As for low wind speed events (Figure 2c), the concentrations are much higher. Over the rural and
108 urban regions, tropospheric column NO₂ ranges between 5-8 x10¹⁵ and 15-20 x10¹⁵ molecules/cm²,
109 respectively. Note that the colour bar range for Figure 2c is larger than the other panels. The peak
110 tropospheric column NO₂ is actually located over the Yorkshire power stations ranging between 18-20
111 x10¹⁵ molecules/cm². As the transport influences are reduced in this case, the peak values, which are
112 directly over Drax and Eggborough, are unlikely to be linked with transport of tropospheric column
113 NO₂ from elsewhere in the domain. This suggests that these high concentrations are due to power
114 station NO_x emissions. There are no large cities nearby (Doncaster is approximately 20 miles away)
115 and the M62 NO_x emissions will not be as large (in the order of 0-10 kTonnes per year – NAEI,
116 2014). Therefore, this study suggests that NO_x emissions from Drax and Eggborough power stations
117 are generating the largest regional NO₂ concentrations. Unfortunately, as the satellite product provides
118 column concentrations, it is difficult to comment on surface NO₂ from these results. However, the
119 emission of NO_x from the power stations will be in the boundary layer and quantities will be mixed
120 down to the surface affecting air quality. The impact of power station emissions on local air quality
121 (e.g. in-situ NO₂ and O₃ generated downwind (Mauzerall et al., 2005)) could be assessed in the future
122 if surface measurements near the power stations became available (e.g. DEFRA AURN stations).

123 **4. Conclusions:**

124 This study uses surface wind data from Yorkshire weather stations to composite OMI tropospheric
125 column NO₂ data (satellite data) under low and high wind speeds to investigate the impact of NO_x
126 emissions from the large Yorkshire power stations on regional air quality. On average in the period
127 2005-2011, peak tropospheric column NO₂ is located over the urban regions (e.g. Manchester and
128 Yorkshire power stations) in the domain. Under high wind speed conditions, reduced tropospheric
129 column NO₂ exists across the domain, including the power stations, as it is transported away from
130 source regions. The low wind speed events show peak tropospheric column NO₂ over Drax and
131 Eggborough, where the lack of transport infers that these peak concentrations are linked to the power
132 stations. These high tropospheric column concentrations of NO₂ from the power stations (largest
133 levels in the domain) have the potential to significantly influence regional air quality. However,
134 surface observations are required to assess the impact of the power stations on surface air quality.

135 **Acknowledgements:**

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137 data from the Met Office. Also, we acknowledge the National Atmospheric Emissions Inventory
138 (DEFRA) and Drax for their NO_x emissions data.

139 **References:**

140 **Beirle S, Boersma KF, Platt U, Lawrence MG, Wagner T.** 2011. Megacity Emissions and
141 Lifetimes of Nitrogen Oxides Probed from Space. *Science*, **333**: 1737–1739.

142

143 **Boersma K, Eskes H, Dirksen R, Veefkind J, Stammes P, Huijnen V, Kleipool Q, Sneep M,**
144 **Claas J, Leit˜ao J, et al.** 2011a. An improved tropospheric NO₂ column retrieval algorithm for the
145 Ozone Monitoring Instrument. *Atmospheric Measurement Techniques Discussions*, **4**: 2329–2388.

146

147 **Boersma K, Braak R, van der A R.** 2011b. Dutch OMI NO₂ (DOMINO) data product v2.0.
148 Tropospheric Emissions Monitoring Internet Service on-line documentation,
149 http://www.temis.nl/docs/OMI_NO2_HE5_2.0_2011.pdf.

150

151 **DEFRA.** 2012. Automatic Urban and Rural Network (AURN).

152 <http://ukair.defra.gov.uk/networks/network-info?view=aur> (last accessed June 2014).

153

154 **DEFRA.** 2014. Diffusion Tubes. <http://laqm.defra.gov.uk/diffusion-tubes/datacentre> (last accessed
155 June 2014).

156

157 **Drax.** 2013. Annual review of Environmental Performance.

158 <http://www.drax.com/media/56551/Environmental-Performance-Review-2013.pdf> (last accessed June
159 2015).

160

161 **Drax.** 2014. Our history. <http://www.drax.com/about-us/our-history/> (last accessed May 2014).

162

163 **Dunn R, Willett K, Thorne P, Woodley E, Durre I, Dai A, Parker D, Vose R.** 2012. HadISD: a
164 quality controlled global synoptic report database for selected variables at long-term stations from
165 1973-2010. *Climate of the Past*, **8**: 1763-1833.

166

167 **Eggborough Power Ltd.** 2014. Welcome to Eggborough Power.

168 <http://www.eggboroughpower.co.uk/> (last accessed May 2014).

169

170 **Hao J, Wang L, Shen M, Li L, Hu J.** 2007. Air quality impacts of power plant emissions in Beijing.
171 *Environmental Pollution*, **147**: 401-408.

172

173 **Hayn M, Beirle S, Hamprecht FA, Platt U, Menze BH, Wagner T.** 2009. Analysing spatio-temporal
174 patterns of the global NO₂-distribution retrieved from GOME satellite observations using a
175 generalised additive model. *Atmospheric Chemistry and Physics*, **9**: 6459–6477.

176

177 **Mauzerall D, Sultan B, Kim N, Bradford D.** 2005. NO_x emissions from large point sources:
178 variability in ozone production, resulting health damages and economic costs. *Atmospheric
179 Environment*, **39**: 2851-2866.

180
181 **NAEI. 2014.** Emission maps for the UK and DAs. <http://naei.defra.gov.uk/data/map-uk-das> (last
182 accessed June 2015).
183
184 **Pope RJ, Savage NH, Chipperfield MP, Arnold SR, Osborn TJ. 2014.** The influence of synoptic
185 weather regimes on UK air quality: analysis of satellite column NO₂. *Atmos. Sci. Lett.*, **15**: 211–217.
186
187 **SSE. 2014.** Ferrybridge C. <http://sse.com/whatwedo/ourprojectsandassets/thermal/ferrybridge/> (last
188 accessed May 2014).
189
190 **Selby Council. 2015.** Air quality – monitoring and pollution control. [http://www.selby.gov.uk/air-](http://www.selby.gov.uk/air-quality-monitoring-and-pollution-control)
191 [quality-monitoring-and-pollution-control](http://www.selby.gov.uk/air-quality-monitoring-and-pollution-control) (accessed April 2015).
192
193 **Webb A, Hunter G. 1998.** Power station contributions to local concentrations of NO₂ at ground
194 level. *Environmental Pollution*, 102: 283-288.
195
196 **Wheeler D. 2013.** Regional weather and climates of the British Isles – Part 4: North East England and
197 Yorkshire. *Weather*, **1**: 68-74.
198
199 **WHO. 2014.** Ambient (outdoor) air quality and health.
200 <http://www.who.int/mediacentre/factsheets/fs313/en/> (last accessed April 2015).
201
202 **Zhou Y, Brunner D, Hueglin C, Henne S, Staehelin J. 2012.** Changes in OMI tropospheric NO₂
203 columns over Europe from 2004 to 2009 and the influence of meteorological variability. *Atmospheric*
204 *Environment*, **46**: 482–495.
205
206 **Word Count: 2217**