Birling Gap air quality incident science report

26 October 2017

Summary

This report documents the scientific investigation of the Birling Gap air quality incident of 27 August 2017. The report looks at the nature of the haze, its geographical source, and explores possible causes. The report represents the consensus views of a science group brought together by Defra's Chief Scientific Adviser, Professor Ian Boyd, and has been reviewed by three members of Defra's independent Science Advisory Council, who were also part of the science group throughout the investigation.

At around 5 pm on Sunday 27 August 2017 a visible cloud or haze drifted from the sea onto the Sussex coast at Birling Gap, near Beachy Head. As it reached the busy beach, people started to complain of burning eyes, sore throats and skin irritation, with some people reporting vomiting.

The composition of the gas or aerosol remains unclear. Ozone monitors detected elevated ozone levels and the pattern of these ozone spikes was unusual, with a very rapid increase and then fall in ozone levels as the cloud passed. It is possible that the instruments were responding to a chemical other than ozone, but it is more likely that ozone levels were elevated. Some of the health impacts were not consistent with ozone at the recorded concentrations, suggesting that another irritant chemical was present. This chemical may have caused the elevated levels of ozone. No sample of the cloud was taken and it has not been possible to identify the irritant chemical involved.

There is a high level of confidence that the cloud was generated in the English Channel. The air mass carrying the chemical had travelled along the Channel from the east for the preceding 9 hours and had been moving from the west before that. This rules out a source in France or from the land in the UK.

There was no evidence of an algal bloom in the English Channel and no algae that could have caused a release of gas were found in the water samples taken two days after the event. Given the meteorological evidence and in the absence of a natural cause, it seems most likely that the source of the gas cloud was a ship, lost cargo, or possibly a wreck.

Unless further information is obtained, it may never be possible to identify the precise source of the release.

Contents

1 Introduction

This report documents the scientific investigation of the Birling Gap air quality incident of 27 August 2017. The report considers evidence about the composition of the cloud or haze, its geographical source, and explores possible causes. This report does not investigate individual ships, which are the subject of separate investigation by the Maritime and Coastguard Agency. Operational response is also being reviewed by Defra and the Environment Agency, and this report will contribute to ensuring that any lessons learned influence the management of similar events in future.

This report was compiled by the Environment Agency on behalf of a science group brought together by Defra's Chief Scientific Adviser, Professor Ian Boyd (see Appendix 1 for composition).

2 Background – the event

At around 5 pm on Sunday 27 August 2017 a visible cloud or haze drifted from the sea onto the Sussex coast at Birling Gap, near Beachy Head (figure 1). Birling Gap belongs to the National Trust and is part of the Seven Sister chalk cliffs, one of the longest stretches of undeveloped coastline in south-east England. With a National Trust café, car park, shop and visitor centre, as well as a beach with rock pools, pebbles and sand, this is a popular location and was very busy on the hot, sunny Sunday afternoon of the late summer Bank Holiday weekend.

As the cloud reached the beach, people started to complain of burning eyes, sore throats and skin irritation, with some people reporting vomiting. There were conflicting reports of a smell of burning plastic, chlorine, ammonia or an odourless cloud. A member of the East Sussex Fire and Rescue service reported that after the cloud hit the cliffs at Beach Head, it spread out and then dispersed.

Between 150 and 200 people went to hospital. One elderly patient with a pre-existing condition was admitted. All other patients were assessed and returned home. The Coastguard evacuated around 5 km of beach between Birling Gap and Eastbourne. Both the East Sussex Fire and Rescue Service and the South East Coast Ambulance Service declared a major incident in the hour after 5 pm due to pressures on the local NHS Trust. The major incident was stood down at 0040 on Monday 28 August.

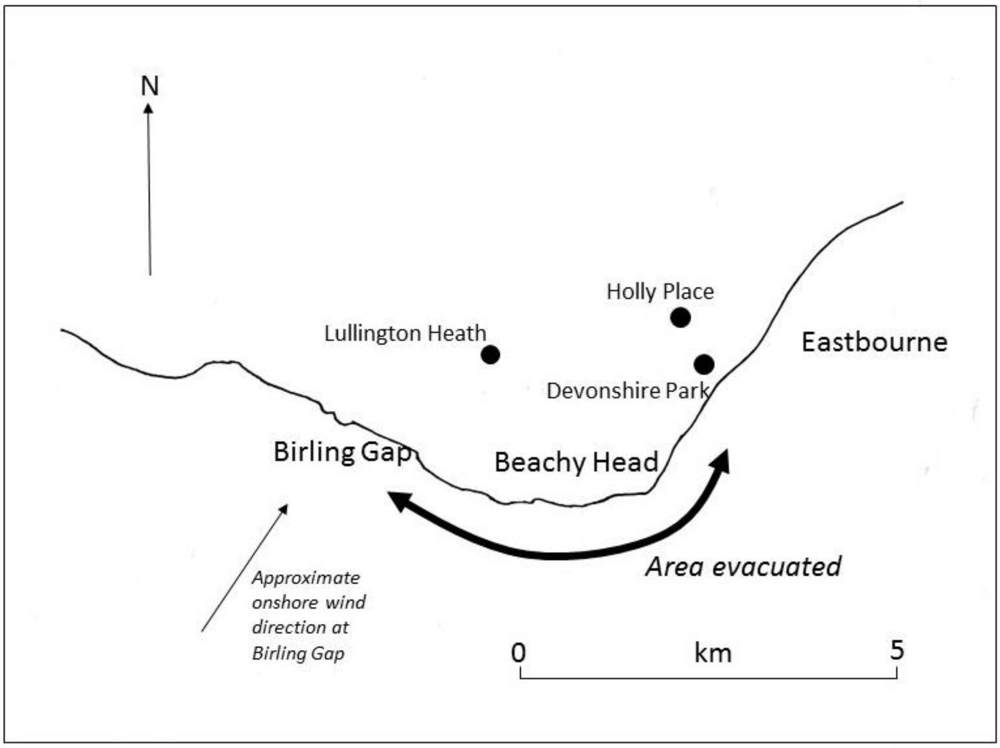


Figure 1. Map showing the coast around, Birling Gap, indicating area evacuated (broad black arrow), locations of local air quality monitoring sites (black circles) and approximate wind direction at Birling Gap (light black arrow).

3 Chemical composition: what was in the cloud?

There are three main sources of information about the composition of the cloud:

- Symptoms and smell
- Gas tests performed during the incident
- Air quality monitoring stations

3.1 Symptoms and smell

People reported nausea, vomiting, and skin and eye irritation. The cloud was reported to smell of chlorine, ammonia, burning plastic or to be odourless. The symptoms do not point towards any specific chemical. The NHS and Public Health England (PHE) have reported few subsequent patients or queries, suggesting that symptoms were short-lived and that there may be few continuing effects. The reports of different odours may suggest that the cloud was a mix of different chemicals.

3.2 Gas tests performed during the incident

East Sussex Fire and Rescue Service (FRS) deployed Zellweger Impact Pro gas detectors at the scene. The detectors were calibrated to detect carbon monoxide (CO), flammable gas or vapour, oxygen (O_2) and hydrogen sulphide (H_2S). East Sussex FRS also monitored for the presence of ammonia (NH_3) and chlorine (Cl_2). East Sussex FRS reports that early in the incident a single reading of 6% LEL (lower explosive limit[1]) flammable gas was recorded, but this dispersed very quickly. Later in the incident a single reading of 3 ppm of ammonia was recorded. Humans can detect the smell of ammonia at around 5 ppm, with irritation occurring at exposures of around 30 to 50 ppm for 10 minutes or more, so this single reading was at a low level. As isolated readings, neither the flammable gas nor ammonia levels caused any concern. Elevated levels of other gases or vapours were not detected. No samples of the gas were taken.

3.3 Air quality monitoring stations

There are 3 fixed monitoring stations in the immediate area (Table 1). The nearest, at Lullington Heath, about 7 km inland to the north of Birling Gap, is part of the Defra Automatic Urban and Rural Network (AURN). The monitor at Eastbourne Devonshire Park, near the coast around 8 km to the east, is operated by King's College London on behalf of the Sussex Air Quality Partnership. King's College London also operates a monitor at Eastbourne Holly Place. The cloud had an estimated width of 5 km and lasted for at least an hour. With an onshore breeze of 7-10 km h^{-1}, both Lullington Heath and Eastbourne Devonshire Park were in the path of the cloud and would have received the air mass within an hour of its arrival on the beach.

	Eastbourne Devonshire Park	Lullington Heath	Eastbourne Holly Place
Chemical constituents measured	Nitric Oxide (ppb) Nitrogen Dioxide (ppb) Oxides of nitrogen (ppb) Ozone (ppb) PM10 (µg/m^3)	Nitric Oxide (ppb) Nitrogen Dioxide (ppb) Oxides of nitrogen (ppb) Ozone (ppb) Sulphur Dioxide (ppb)	Nitric Oxide (ppb) Nitrogen Dioxide (ppb) Oxides of nitrogen (ppb) PM10 (µg/m^3) PM2.5 (µg/m^3)

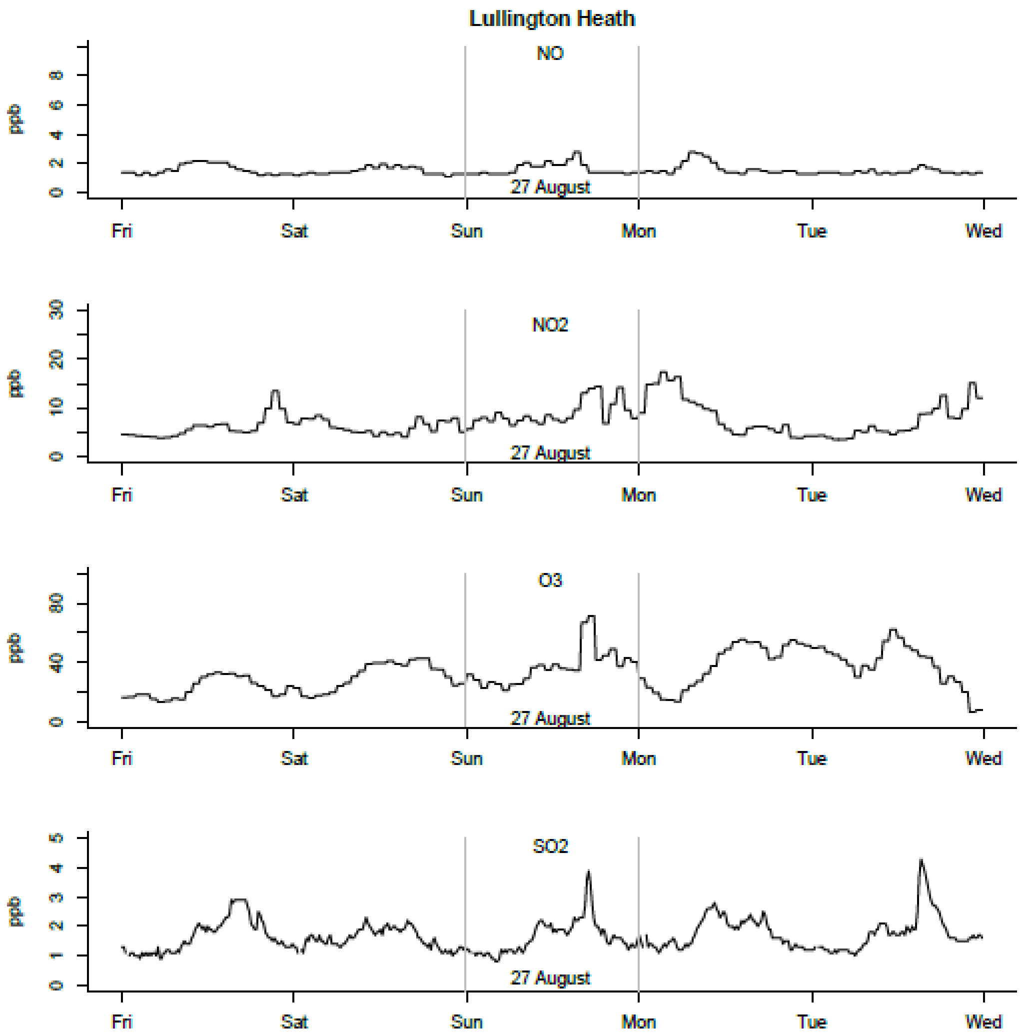
Table 1 The chemicals measured at each of three fixed air quality monitoring sites near Birlng Gap. All parameters were measured at 15 minute resolution. ppb = parts per billion. PM10 = particles of 10 µm or less; PM2.5 = particles of 2.5 µm or less. 1 µm = 10^{-6} m or one thousandth of 1 mm.

[1] Lower explosive limit is the lowest concentration of a gas or vapour in air that is capable of producing a flash of fire if ignited

The Environment Agency also had two temporary monitors at Newhaven, some 15 km to the west of Birling Gap, measuring particulates (PM10, PM4, PM2.5, PM1) and nitrogen oxides.

Both the Lullington Heath and Eastbourne Devonshire Park ozone monitors recorded a rapid rise in ozone (O_3) concentration at the time of the incident (figure 2). King's College London analysed the response and reported that at Eastbourne, ozone concentration rose from 26 parts per billion (ppb) at 16.30 to 128 ppb at 17.15. At Lullington Heath, ozone concentration went from 44 ppb at 17.00 to 88 ppb at 18.00. At both sites the elevated readings lasted over an hour, falling back to normal by 18.45 at Eastbourne and 19.00 at Lullington Heath (figure 2). At both Lullington Heath and Devonshire Park, the early part of the increase in ozone was associated with a decrease in nitric oxide (NO). This is a characteristic feature of the chemical reaction between O_3 and NO that forms nitrogen dioxide (NO_2).

At Lullington Heath, the only site with a sulphur dioxide (SO_2) monitor, there was an increase in SO_2 coincident with the O_3 peak. Similar peaks of SO_2 occurred in the late afternoon of the preceding and following days. It is likely that the SO_2 originated from the exhaust fumes of ships burning sulphurous fuels in the shipping lane, further supporting the meteorological evidence that the gas cloud originated offshore.


Lullington Heath
NO
ppb
0
2
4
6
8
27 August
Fri
Sat
Sun
Mon
Tue
Wed
NO2
ppb
0
10
20
30
27 August
Fri
Sat
Sun
Mon
Tue
Wed
O3
ppb
0
40
80
27 August
Fri
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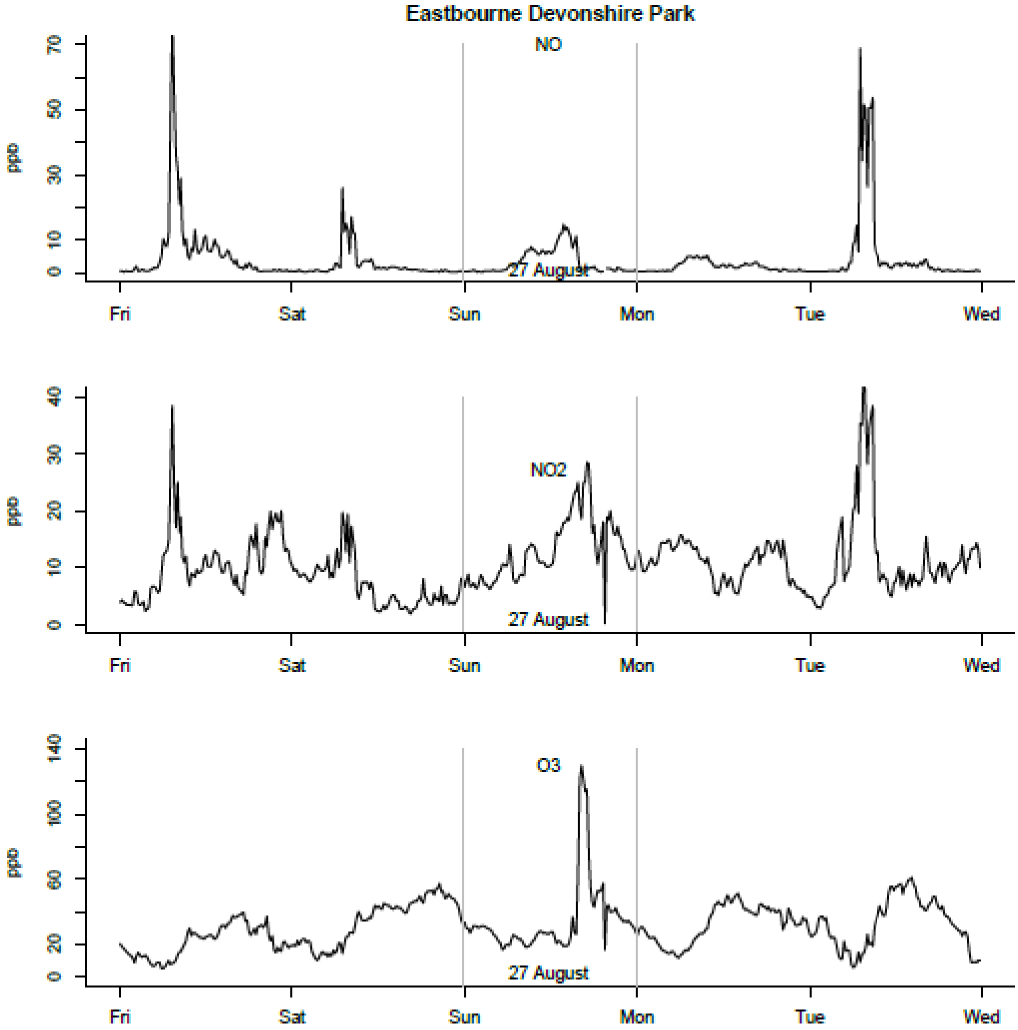

Figure 2: Samples of records from the air quality monitoring sites at Lullington Heath and Devonshire Park, Eastbourne from 25 to 29 August 2017. The period of the event of 27 August lies between the two vertical lines. Except for ozone (O3) the recorded concentrations of all other chemicals 27 August lie within the normal range across the 5-day record. Other chemical records shown are for nitrous oxide (NO), nitrogen dioxide (NO2), sulphur dioxide (SO2). Concentrations are expressed as parts per billion (ppb). All times UTC (BST-1). Note different scales for clarity.

Eastbourne Holly Place does not monitor ozone or SO_2 but did not record any unusual traces in other substances on 27 August. The Environment Agency monitors at Newhaven did not record any unusual chemical traces, confirming the localised nature of the cloud.

The rapid rise and subsequent fall in ozone concentrations at Eastbourne and Lullington Heath was not the normal pattern seen at these sites, where ozone levels build gradually through the day as sunlight acts on nitrogen dioxide (NO_2) and volatile organic compounds (VOCs) that mainly originate from traffic fumes. The peak levels of ozone recorded were not exceptionally high but the rapid rise and fall in ozone levels was unusual. It is possible that the ozone analysers were responding to a chemical not normally seen in air that triggers a similar response in the instrument. Volatile organic compounds (VOCs) and gases like chlorine (Cl) can affect ozone readings, though the covariance of O_3, NO_2 and NO tends to indicate that high levels of O_3 were present. Ozone spikes similar to this are very unusual but not entirely unprecedented along the Sussex coast: depending on definition, they have been seen every few years. The Eastbourne Devonshire Park spike was particularly unusual because of its magnitude.

Ozone is an irritant, producing inflammation of the respiratory tract and at high concentrations irritating the eyes, nose and throat. High ozone pollution incidents may exacerbate asthma or trigger asthma attacks, and some people without asthma may also experience discomfort while breathing, especially during vigorous exercise. The US Environmental Protection Agency (EPA) suggests that skin and eyes are only affected at high concentrations of ozone (1000 to 5000 ppb). Ozone concentrations at Eastbourne Devonshire Park peaked at just under 130 ppb. Neither of the ozone monitors was in the precise location where most symptoms were reported, though Eastbourne Devonshire Park is on the edge of the area evacuated. It is possible that ozone levels were lower at the monitoring sites than at Birling Gap. However, even allowing for this, it is likely that ozone concentrations at Birling Gap were too low to produce skin irritation. If ozone concentrations had been sufficiently high for skin irritation, more serious respiratory symptoms would also have been experienced.

The temperature inversion and onshore sea breeze on the afternoon of 27 August 2017 would be expected to lead to mist and fog blowing in from the sea. Taking account of symptoms and measured ozone concentrations, there are three possible explanations for the Birling Gap cloud and its effect on people's health:

- The cloud could have been an air mass with a high level of normally-formed ozone blown onto the shore. However, the recorded ozone levels were not sufficiently high to cause the level of discomfort reported. Respiratory symptoms were not consistent with the very high levels of ozone that would cause skin irritation. It is unlikely that the irritant in the cloud was only ozone.
- The cloud could have been an air mass with a high level of ozone caused or partially caused by the presence of another chemical that is also a severe irritant to people. This is the most plausible explanation for the high level of ozone and the health impact occurring together. Ozone is formed when an oxygen atom combines with an oxygen molecule. Other chemical reactions can free oxygen atoms for such a reaction, for example when an acid reacts with water. An irritant chemical could have freed oxygen atoms to create ozone.
- The cloud could have been an air mass with a high level of ozone that also coincidentally contained another irritant chemical. This is less likely because

the ozone level of the cloud was much higher than the surrounding air mass and the coincidence of the cloud and the ozone spike suggest that the ozone and irritant arrived together.

Two other possibilities have been considered: sensor malfunction and the sensor responding to a chemical other than ozone. The ozone spike was recorded at two separate sites and both instruments were recording normally before and after the spike. It is extremely unlikely that both instruments failed in the same way for around an hour and then recovered. The sensors may have responded to a chemical other than ozone, but the nature of the spikes and the covariance of ozone with NO before and after the event tend to suggest that the instruments were recording elevated levels of ozone. The elevated SO_2 levels at the same time point to an air mass originating in the offshore shipping lane, where SO_2 is a normal product of fuel combustion.

This leads to the conclusion that it is most likely that the cloud included elevated levels of ozone caused or partially caused by another chemical source.

4 Meteorology: where did the cloud originate?

On 27 August 2017 winds were light and variable in the English Channel, with areas of fog trapped at the surface under a warmer air layer above (called a temperature inversion). Late in the afternoon there were gentle breezes blowing from the sea to the land (sea breezes).

The Met Office operational UK weather forecast model, UKV, has a horizontal resolution of 1.5 km and includes sophisticated data assimilation of an extensive range of observations from across the UK and surrounding geographic area to help ensure that it captures the detailed meteorology. It has been confirmed that UKV captured the land and sea breezes accurately on this day.

The Met Office used its Numerical Atmospheric-dispersion Modelling Environment (NAME) to analyse the UKV data and identify the source of the air that reached Birling Gap on the afternoon of 27 August. This type of analysis is called a “back analysis” because it works backwards from the final position to identify where the air was at earlier times.

These back analyses for the afternoon of 27 August show that the surface air had come over the sea from an easterly direction for the previous 9 hours but before that the wind had been parallel to the coast from the west (figure 3). This strongly suggests an offshore source in the northern part of the English Channel, and effectively rules out France or onshore sources in southern England. The defined nature of the cloud may suggest that it was formed in the previous six or so hours. An earlier release would probably have been more dispersed.

Met Office

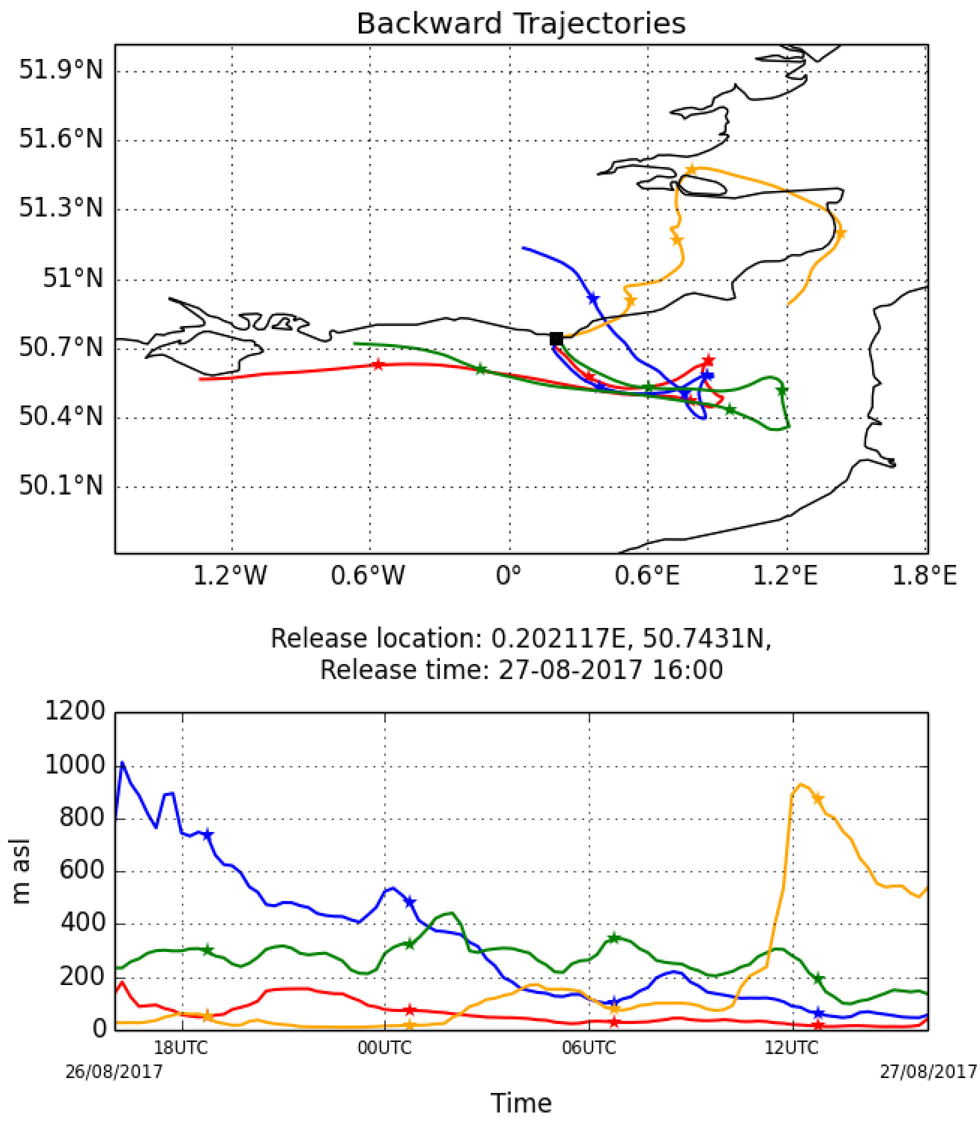

Figure 3: The movement of air masses in the region of Birling Gap for 24 hours in advance of the event. The two diagrams show a maps of back trajectories (back analysis) for the air mass appearing at Birling Gap at 16.00 UTC (17.00 BST) on 27 August (top diagram) and the height in metres above sea level (m asl) of the air masses shown in different colours. Red, blue and green traces are for air arriving at 5 m, 20 m and 100 m above sea level. All the trajectories show air coming from the sea since at least midnight 26 August. The orange trace is for air at 500 m above sea level which is above the temperature inversion and would, therefore, be too high to be the source of the ground level cloud.

5 Possible causes

Many possible causes of the cloud have been examined. This section explores these and the evidence about each.

5.2 Land-based pollution

A land-based source could include an emission from a regulated point source (a factory or chemicals facility), an accidental discharge of gas, for example from a water treatment works, or an illegal activity such as burning waste. The Environment Agency checked all regulated sites in the area and found no evidence of any activity that could have caused this event. Despite widespread publicity for this event there were no reports of a land-based source and no accidents at likely sources such as water treatment works. Coupled with the strong meteorological indications of an offshore source, it seems that a land-based pollution incident was unlikely to be the source of the cloud.

5.3 Marine algal bloom

There are recorded examples of natural algal blooms releasing gases that cause skin inflammation and respiratory problems for beach users. However, all the reported cases have been in much warmer waters than the English Channel, and a wide review of academic journals and government reports as well as newspapers and other media revealed no reports of marine algal blooms causing such problems in northern latitudes. Water samples taken on 29 August showed no bloom-causing algae in the English Channel and satellite images, which provided good cloud-free coverage, showed no sign of such a bloom. It seems unlikely that an algal bloom was the source of the cloud.

5.4 Ships, lost cargo or wrecks

The English Channel is one of the busiest shipping lanes in the world, with over 500 vessel movements every day. Those moving south, from the North Sea to the Atlantic, travel on the English side, while vessels move north on the French side. Chemicals that could be released directly or cause a release of gas are used in refrigeration systems, for cleaning, and carried as cargo both in specialised chemical carrying ships and in containers. There were around 180 ships in this part of the English Channel on 27 August 2017. Those nearest the Sussex coast were heading towards the Atlantic with few of them docking in UK ports.

A ship could release gas during cleaning, through a failure of a gas-containing system such as a refrigeration unit, or through an accidental release of part of a gas or chemical cargo. There have been no reports of such releases or accidents on board ships in the area.

Containers lost overboard could release gas either immediately or days, weeks or even months later as the container corroded. Containers lost in, or close to, UK waters may not be reported to UK authorities, as the loss may remain unnoticed for some time: there are no reports of losses in the Channel on 27 August.

While there have been no reports of releases of gas from ships or lost cargos, this does not allow us to rule out this source. A ship's crew might not realise that a cloud had been released, and ships in the Channel are kept apart to avoid collision, so it is quite possible that such a release could be made without it being reported or witnessed by another ship.

Wrecks may also contain gas or chemicals that could be released suddenly, either through corrosion or if the wreck is disturbed. Plymouth Marine Laboratory (PML) identified from satellite images a possible release on 27 August from the wreck of the SS Mira. The Mira, an armed tanker, was torpedoed 4 miles off Beachy Head in 1917. However, with winds blowing from the east for most of 27 August, the Mira lies in the wrong direction to be the source of the Birling Gap cloud. Additionally, the plume shown in satellite images is of sediment in the water, and there is no evidence that it was accompanied by a chemical release.

To help to identify the scale of the possible release, the Environment Agency has made an approximate calculation of the mass of chemical that would be needed to cause a cloud of the size reported at Birling Gap (table 2). This calculation, as guide for a concentration that might cause irritation, assumes that the recommended Public Health England workplace exposure limit was reached. This is a very rough estimate but provides a guide of the scale of any loss from a vessel. All of these are plausible masses for accidental release from a ship except perhaps for LPG, where the mass of gas would be particularly large.

Chemical	PHE recommended exposure limit, mg m^{-3}	estimated source release (tonnes per hour)	range (5 to 95%ile)	
ammonia	22.5	31	2.3	86
chlorine	0.5	0.7	0.05	1.9
sulphuric acid	0.2	0.3	0.02	0.8
nitric acid	0.44	0.6	0.05	2
Liquid petroleum gas	13400	18706	1374	51300
Acrolein	0.23	0.3	0.02	0.88

Table 2: The estimated mass of different chemicals that would need to be released in order to form a cloud of the dimensions estimated to be present at Birling Gap on 27 August 2017. These is only illustrative and other chemicals not mentioned here could have been responsible for the cloud.

6 Conclusions

Much of the evidence around the Birling Gap gas cloud remains uncertain. However, we can draw the following conclusions:

- There is high confidence that the gas cloud was generated in the English Channel. Back analysis by the Met Office shows that the air had travelled along the Channel from the east for the preceding 9 hours and had been moving from the west before that. The meteorological evidence rules out a source in France or from the land in the UK.
- Despite much publicity and investigations of regulated sites, there have been no reports of releases from UK land sources. This supports the conclusion that the source was marine.
- There is no evidence of an algal bloom in the English Channel and no toxic algae were found in the water samples taken on 29 August 2017. There are no previously reported cases of algal blooms releasing gas in this way in UK waters. This leads to the conclusion that the source was not a naturally-occurring algal bloom.
- The nature of the gas remains unclear. Ozone sensors detected elevated ozone levels but the pattern of these ozone spikes was unusual. This suggests that either the sensors were responding to another gas with similar properties or, more probably, that the enhanced ozone levels were a response to a chemical reaction with another gas. Health impacts are not consistent with ozone at the concentrations recorded, suggesting that another irritant gas was present. No sample of the cloud was taken.
- Given the meteorological evidence and in the absence of a natural cause, it seems most likely that the source of the gas was a ship, lost cargo, or possibly a wreck.
- As PHE reports few follow-up queries from GPs or other health professionals, it seems that most health effects were of a short duration.

Unless further information is obtained, it may never be possible to identify the precise source of the release. There were around 180 ships in this part of the English Channel on 27 August 2017. Those nearest the Sussex coast were heading towards the Atlantic with few of them docking in UK ports. It is possible that the ship's crew could have been unaware of the incident. If the origin was in a previously lost cargo, the loss may have happened weeks or months before August 2017.

The Birling Gap event seems to be very unusual. The weather was particularly still and warm, giving conditions that prevented dispersal of the cloud until it reached land. The beach was crowded on a Bank Holiday weekend, increasing the number of people exposed. Should such an event occur again, a sample of the gas would be of great help in understanding the hazard to people and in tracking down the source.

Appendix 1: Defra's science group for the investigation.

The group was convened by Professor Ian Boyd, Chief Scientific Adviser, and had members from:

- Defra (the Department for Environment, Food and Rural Affairs)
- Cefas (the Centre for Environment, Fisheries and Aquaculture Science)
- Met Office
- Maritime and Coastguard Agency (MCA)
- Public Health England (PHE)
- Environment Agency

The group included three members of Defra's Science Advisory Council, who also reviewed this report:

- Professor Paul Monks, Professor of Atmospheric Chemistry and Earth Observation Science, University of Leicester
- Professor Tim Jickells, Professor of Environmental Sciences, University of East Anglia
- Professor Charles Godfray, Hope Professor and Director of the Oxford Martin Programme on the Future of Food, University of Oxford.