Institution: Lancaster University		
Unit of Assessment: 7, Earth Systems and Environmental Sciences.		
Title of case study: Innovative sampling and attribution of industrial air pollution to resolve and reduce impacts from complex sources for improving health, compliance, industrial efficiency and public confidence.		
Period when the underpinning research was undertaken: 2005-2017		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Professor J. Duncan Whyatt	Professor of Geographical Information Science	01/04/98 – present
Professor Roger Timmis	Lead Scientist for Air Quality Research, Environment Agency and Honorary Professor	01/04/06 – present
Professor Kevin Jones	Distinguished Professor	01/02/85 – present
Period when the claimed impact occurred: August 2013-2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Air pollution is a major health concern and international policy driver. Effective control of local air-pollution sources needs new reconnaissance techniques for ambient monitoring and analysis that practitioners in industry and government can readily adopt to improve health, compliance, business efficiency and public confidence. Existing techniques lack directional information, so cannot resolve sources. Lancaster researchers have invented a simple-to-use reconnaissance monitor that needs no power supply, but resolves wind directions and integrates pollution, so practitioners can discriminate sources. They have also developed new directional and conditional analyses that clarify source signals and give earlier evidence of source-specific trends. Their novel, patented monitor is being used under exclusive license by SGS, the world's leading inspection, verification, testing and certification company, to monitor fenceline concentrations of benzene (a known carcinogen) for major Gulf Coast oil refineries to check operator compliance with new United States Environmental Protection Agency (EPA) legislation. Their directional analysis techniques have also been used to isolate, target and reduce problematic fugitive sources of particulates across several complex industrial sites in the UK, leading to significant improvements in air quality and the avoidance of GBP30.0 million in European Union fines. Lancaster methods have resolved nitrogen dioxide pollution from transport and are expanding to agricultural applications such as resolving ammonia from intensive farming.

2. Underpinning research

2.1 Co-design of Directional Passive Air Sampler

The underpinning research has been co-designed by the case authors. Timmis has been based at Lancaster University since 2004, when the Environment Agency (EA) co-located him as its Lead Scientist for Air Quality Research to the Lancaster Environment Centre. Timmis's role in the EA, and his insights into end-users' needs, complemented the fundamental research interests of Jones (pollution sampling) and Whyatt (spatial analysis). These complementary interests have shaped how the directional monitoring and analysis research has been planned, tested and applied in real-world situations.

Formal collaboration between Jones and Timmis began in 2005 with patents and a NERC Connect B Fellowship. The Fellowship developed a patented Directional Passive Air-quality Sampler (DPAS) for deployment around local air-pollution sources to identify source contributions to ambient air pollution. It involved sampler design, wind tunnel testing, development of sampling media and chemical analysis procedures [3.1], and field trials in urban and roadway situations [3.2].

The scope was expanded by Jones and Timmis in 2007 by a project for the British Oxygen Company which analysed air quality and meteorological data together, to develop new methods that exploit more of the information from monitoring. It included field studies at power stations and landfills to explore the strengths and weaknesses of different analysis methods. Later in 2007 another study analysed directional air-quality at two landfills, as part of a wider study by Government and the Waste Industry to assess possible impacts on nearby residents.

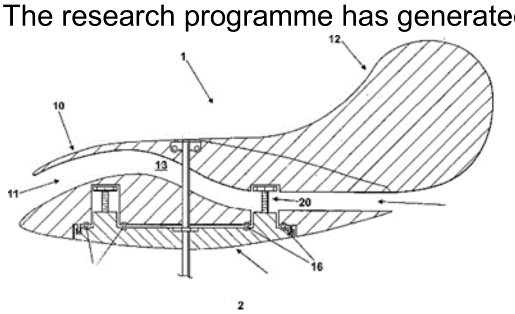
2.2 Development and Dissemination of Directional Methods of Air Quality Analysis
Between 2005 and 2009, Whyatt and Timmis used a PhD project and subsequent NERC KE grant to investigate how weather variations and climate change alters the dispersion of air pollutants from industrial and urban sources. Specifically, they investigated how such variations and changes affect sources' compliance with air-quality standards and regulatory permits. New techniques for displaying and analysing air-quality data were developed and trialled. These included a 'Dispersion Calendar' for showing air-quality data in its meteorological context, and conditional analyses for tracking how the impacts of individual sources have evolved over different periods.

Between 2009 and 2012 Whyatt and Timmis were supported by a NERC KE grant for the 'Air Track' project, which demonstrated the new air-quality analysis techniques and transferred them to practitioners. They delivered this by presenting a series of practical case studies [3.3] to professional bodies, national committees and regulatory agencies, and by collaborating with other academic partners (e.g. Leeds, Hertfordshire) and maintaining a website.

2.3 Validation and Application to Industrial Processes with the Environment Agency
In 2011, the Lancaster Environment Centre and the EA collaborated on a project called 'Breathe Easier', which continues to this day. It was through this project that applications of the researchers' patented DPAS technology were (2.i and 2.ii). Over the last 7 years multiple projects (including those detailed in 4.1 and 4.2) have adapted and validated the DPAS technology e.g. initial trials for nitrogen dioxide from traffic were adapted to other pollutants emitted by regulated industries such as fugitive particulates from steelworks [3.4] and ammonia from intensive farming [3.5].

The methods have diversified over 7 years to cover other air quality situations including tracking sources of elevated benzene concentrations from refineries, and nuisance dusts from waste/recycling processes [3.6]. The research has also addressed other aerometric challenges such as the design of monitoring networks, inter-comparison of monitoring methods, comparisons of incoming and outgoing air pollution across a site, and new methods of normalizing air quality data for dispersion conditions and seasonal cycles. Since 2008, researchers have shared their findings with the global research and regulatory communities, specifically at annual international workshops on air quality involving the US EPA, the Department for Environment, Food and Rural Affairs (DEFRA), and other research organizations in the UK and US.

2.4 Patents Developed for Directional Passive Air Sampling
The research programme has generated 2 patents for passive (unpowered) directional samplers of air quality, which environmental instrument manufacturers appreciate for their novel potential to provide directionally resolved, integrated, and more practical (cheaper, easier to deploy) information on air pollution impacts and sources. The samplers have been patented internationally and were licensed to SGS Galson (formerly, Société Générale de Surveillance) on 1st April 2017 for commercial applications.



Technical drawing of the Fluid Sampling Device. Figure taken from abstract of International Patent Application PCT/GB2007/050537 filed 13th September 2007.

2.i. Fluid sampling device: US 8776620. Granted 15th July 2014, Timmis and Jones. Priority date 13th September 2007

2.ii. Fluid sampling device: US 8413527. Granted 9th April 2013 and EP2062025 Granted 15th June 2016 Timmis and Jones. Priority date 13th September 2006.

3. References to the research

Authors in bold were employed by Lancaster University at the time of publication.

[3.1]. Lin, C., Becker, S., **Timmis, R.J**. and **Jones, K.C**., 2011. A new flow-through directional passive air sampler: design, performance and laboratory testing for monitoring ambient nitrogen dioxide. Atmospheric Pollution Research (2) 1-8.

[3.2]. Lin, C., **McKenna, P**., **Timmis, R.J**. and **Jones**, **K.C**., 2010. Field testing of a new flow-through directional passive air sampler applied to monitoring ambient nitrogen dioxide. Journal of Environmental Monitoring (12) 1430-1436.

[3.3]. Malby, A.R., **Whyatt, J.D**. and **Timmis, R.J**., 2013. Conditional extraction of air pollutant source signals from air quality monitoring. Atmospheric Environment (74) 112-122.

[3.4]. Lin, C., **Solera Garcia, M.A**., **Timmis, R.J**. and **Jones, K.C**., 2011. Design and laboratory testing of a new flow-through directional passive air sampler for ambient particulate matter. Journal of Environmental Monitoring (13) 753-761.

[3.5]. Solera Garcia, M.A., **Timmis, R.J**., Van Dijk, N., **Whyatt, J.D**., Leith, I.D., Leeson, S.R., Braban, C.F., Sheppard, L.J., Sutton, M.A. and Tang, Y.S, 2017. Directional passive ambient air monitoring of ammonia for fugitive source attribution; a field trial with wind tunnel characteristics. Atmospheric Environment (167) 576-585.

[3.6]. Ferranti, E.J.S., Fryer, M., **Sweetman, A.J., Solera Garcia, M.A**. and **Timmis, R.J**., 2014. Field-testing a new directional passive air sampler for fugitive dust in a complex industrial source environment. Environmental Science Processes and Impacts (16) 159-168.

Quality Indicator:

Whyatt, J.D, Jones, K.C and Sokhi, R. 2008 to 2011. Demonstrating Techniques for Air Pollution Source Performance Assessment. NERC (Knowledge Transfer). GBP275,614 plus GBP91,000 in kind contribution from Environment Agency. NE/G001138/1.

4. Details of the impact

4.1. Delivering worldwide regulatory compliance in collaboration with SGS Galson

Since 2017 the researchers have engaged closely with SGS who are the world's leading inspection, verification, testing and certification company (94,000 employees and 2,600 offices and laboratories). Specifically, they have been working with their US subsidiary SGS Galson whose Environmental Health and Safety business approached them for our patented directional passive air sampler (DPAS) and associated know-how [5.1]. Their interest stemmed from a new US regulation (EPA325, 1st February 2016) that required oil refineries to start monitoring 'fenceline' levels of volatile organic compounds (VOCs) by 1st February 2018. EPA325 requires monitoring of benzene, a known carcinogen and indicates other harmful VOCs such as those contributing to photochemical smog, or methane which affects climate [5.3a, 5.3b]. The EPA 325 compliance monitoring market in the US is already worth several million dollars. This market value reflects the costs of non-compliance, as evidenced by a USD4.64 million fine that the EPA served on Valero Energy in October 2020 [5.3b].

SGS Galson recognised that the new US requirement was driven by health concerns and would be replicated internationally particularly in China. Having read about the success of Lancaster's sampler at Low Santon (4.2, 5.2), they recognised it as a "*unique monitoring system*" that could give them a "*marketable edge*" which could create "*new commercial opportunities*"' and improve the environment [5.1a]. They swiftly acquired exclusive licenses to both directional sampling patents (1st April 2017) and started manufacturing and advertising (June 2017). They also developed bespoke software ('Terrabase') to visualise monitored plumes and undertook field trials at several Gulf Coast oil refineries. For safety reasons, refineries must minimise on-site electrical equipment, so Lancaster's passive (unpowered) DPAS technique was particularly suitable. SGS Galson's commercial name for Lancaster's sampler is the 'AIHR Shark' [5.3a]. There are about 180 oil refineries in the US, of which 140 need to measure fenceline concentrations. Around 10% of these have problems with exceeding the fenceline limit, and 'Sharks' have been deployed at a quarter of the 'problem' refineries. Conventional sampling strategies failed to identify the sources of 'problem' emissions, despite months of costly monitoring and increasing risk of environmental non-compliance. But 'Sharks' pinpointed them after only approximately 10 days. The refineries then targeted controls directly at these sources so they complied with EPA325, saved on previous monitoring costs, and eliminated the environmental and reputational risks. Therefore, the Shark has proven to be an "*invaluable*" tool for the industry, health and the environment as it has enabled "*Top 10 US Worst Petroleum Refinery Super Polluters to significantly reduce annual cancer-causing benzene emissions being released into the atmosphere*" [5.1a]. Operators were impressed by 'Shark's' performance at resolving complex source geometries, calling it "*a simply genius technology*" and "*by far the best, most cost-effective tool we have used to date*" [5.1a] Similarly, the Shark has a 100% success rate with SGS Galson highlighting that the sampler has "*yet to fail to identify an emission source to date*" [5.1a]. The Shark now forms the basis of their fenceline monitoring programme and has enabled them to "*revolutionize how industry approaches emission reduction*" [5.1a]

SGS Galson AIHR Shark a) monitoring fenceline VOC impacts at a major Gulf Coast oil refinery and b) on display at the American Industrial Hygiene Conference and Exposition, Seattle, June 2017. Images kindly provided by SGS Galson.

In summary, Shark has shown "*an incredible real-world track record of performance*" [5.1a] in identifying pollution problems and their sources faster and more cheaply than any other device. This helps refineries to avoid reputational damage and also negative economic outcomes e.g. due to leakage of valuable products, fines for non-compliance, and associated reductions in share-price. A refinery operator commented "*The sharks have enabled us to alter our processes at our marine terminal and a production unit at the refinery to eliminate exceedances. Last year our refinery was named on the EPA's 325 list of 10 worst performers, thanks to the sharks, there is no chance of making the list this year*" [5.1b].

SGS are currently promoting the Shark globally because similar fenceline monitoring regulations are expected soon in several countries including Canada and Australia. There has also been interest in Shark from the Middle East where many companies have US interests. Shark was exhibited at ADIPEC, the world's largest oil and gas exhibition held in Abu Dhabi in 2019 with around 150,000 attendees, and at Envirocon, in London in 2019 plus many other countries across western Europe. Beyond the oil and gas industries, Sharks have also been deployed at mining sites in the US and another global company has commissioned the Shark technology to measure how well their new material absorbs roadside NO2 [5.1a]. SGS Galson are also developing an extension to the "Shark" technique to incorporate miniature sensors so that directional pollution signals can be measured and transmitted in real time to a data centre.

4.2 Enabling reductions in pollution from UK industrial sites to improve community health
Many industrial sites emit fugitive pollutants from the handling, storage and processing of materials including steelworks, waste sites and recycling processes. The pollution comes from diffuse area sources that are difficult to resolve - especially in complex situations involving adjoining sites. Local communities are increasingly exposed to these pollutants because of land-use pressures and increased recycling rates. The researchers' directional sampling and analysis methods have resolved, quantified, characterised and managed these sources in several communities where air quality health standards were exceeded and/or there were sustained dust complaints.

Since 2009, the researchers have worked with the EA around Scunthorpe Steelworks and applied their novel directional methods to the nearby Low Santon residential area - an area designated as an Air Quality Management Area (AQMA) in need of improvement. The researchers' directional techniques were used to identify the culpable sources from their distinctive spatial and temporal characteristics and the EA Site Inspector, Peter Borrell, confirmed that the analysis helped focus controls successfully on fugitive emissions across the Steelworks and adjoining industrial sites leading to an "*80% reduction in the total dust signal"* [5.4]. He said the research "*provided information that helped to inform the AQ improvements, prioritise regular intervention and provide evidence…. at Low Santon where the PM10 limit was being exceeded, but where the limits is now being met*". The controls reduced PM10 to below the limit so the AQMA was revoked in March 2018, and a risk of fines of approximately GBP30.0 million from the EU was avoided [5.4]. These novel methods were highlighted by DEFRA's Air Quality Expert Group who invited the researchers to contribute case studies to their report on linking emission inventories and ambient measurements [5.5].

Between 2013 and 2015, Lancaster's patented samplers were deployed at the Harsco Metals and Tarmac/Lafarge sites adjoining Scunthorpe Steelworks. Directional particulate samples were analysed gravimetrically and magnetically, which clarified the impact of particulate-generating processes and the fluxes of particulates between sites. These studies raised site operators' awareness of dust issues [3.6], leading to the adoption of new management strategies [5.4] that reduced particulates at Low Santon.

Between 2017 and 2018, the EA has used Lancaster's methods to investigate dust complaints at European Metal Recycling (EMR)'s metal fragmentiser works in Newhaven, East Sussex. The passive sampler was able to provide unique insights into dust imports and exports at the EMR site. Matt Shutt, leader of the EA's ambient monitoring team, commended our passive directional sampler for "*allowing monitoring to take place far from power sources, where batteries or generators are impractical*" and for "*providing knowledge and understanding where other more conventional techniques could not*". [5.6].

The Lancaster technology is already successfully resolving air pollution from industrial-scale situations with fugitive emissions. The technology is applicable to multiple sources and pollutants, and is increasingly being used in other areas, including in relation to the growing issue of nitrogen dioxide from motor vehicles. Looking ahead, the researchers see these wider uses developing rapidly, and expanding, for example to address ammonia from intensive agriculture sites.

5. Sources to corroborate the impact

[5.1]. (a) Testimonial and (b) email from Chris Schepcoff (Business Development Manager), SGS Galson. Dated 26th November 2020 and 16th September 2020 corroborating the impact of Shark on SGS Galson and their clients.

[5.2] AIHR Shark: SGS EHS Passive Directional Sampler. 2016 PowerPoint presentation including a screen dump of a new story featured on the Lancaster Environment Centre website titled 'Shark shaped sampler to hunt down fugitive air pollution'.

[5.3]. (a) 'SGS AIHR Shark 2019' PowerPoint presentation including a summary of EPA325 and the requirement for fenceline monitoring of benzene, (b) Violation Tracker website and EPA report, October 2020, showing penalty issued to Valero Energy for breaching benzene emission limits.

[5.4]. Testimonial from Peter Borrell, Senior Regulated Industry Officer, Environment Agency, to corroborate air quality improvements around Low Santon residential area and the fine avoided. Dated 17th November 2020.

[5.5]. Air Quality Expert Group, 2015. Linking Emission Inventories and Ambient Measurements. Prepared for DEFRA, Scottish Executive, Welsh Government and Department of the Environment in Northern Ireland. Contribution to Section 9.2.2 (Inverse Modelling Techniques).

[5.6]. Matt Shutt, Team Leader, EA Ambient Air Monitoring Team to corroborate value of DPAS at Newhaven EMR (email chain provided). 23rd September 2019.