Investigating local and regional air pollution from shipping

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Introduction

Shipping is a growing sector but one of the least regulated sources of emissions of atmospheric pollutants. Ships generally burn low-quality, high-sulphur fuel and the high temperature combustion in ship engines produce emissions high in nitrogen oxides ($NO + NO_2 = NO_x$) but low in other photo-pollutants such as carbon monoxide (CO) and volatile organic compounds (VOCs). It has been estimated that shipping accounts for between 12 and 17% of all NO_x sources globally, and up to 28% of anthropogenic sources (Charlton-Perez et al., 2009). Shipping emissions are particularly important because whereas most NO_x sources are to be found over land, emissions from shipping occur within the marine boundary layer (MBL) and constitute the only large primary NO_x source in these regions. The presence of NO_x and VOCs in ship emissions means there is also effect on ozone (O_3). Model studies have shown that shipping potentially contribute around 6% to the tropospheric ozone burden, which in turn leads to a radiative forcing increase of around 8% compared to pre-industrial times (Mertens et al., 2018). The chemistry that forms O_3 in ship plumes is highly non-linear and therefore it is important to understand how realistic reduced chemical mechanisms used by global models to assess the effect of ship emissions are (Chen et al., 2005).

Currently, the Sulphur Emission Control Area (SECA), which covers the English Channel and North Sea, dictates that ships must emit no more than 0.1% of sulphur by fuel mass. Currently, outside of this area ships are allowed to emit 3.5% sulphur, however in 2020 this is reducing to 0.5% in all international waters. Whilst this will have an obvious effect on the amount of sulphur emitted, it is currently unclear what the effect will be on other gas and aerosol emissions. This is largely due to uncertainties in the means of achieving compliance (sulphur abatement either by using low sulphur fuel or by using scrubbers).

Shipping is also an important source of gaseous and particulate air pollution in coastal regions, causing up to 400,000 premature deaths per year globally (Sofiev et al., 2018). In the UK, it is estimated that 0.54 and 1.24 µg m^{-3} of UK population-weighted background NO_x derives, respectively, from local and regional shipping sources, which correspond to 2.0% and 4.6% of background NO_x. The contributions from shipping to background NO_x and SO_2 over the UK are greatest towards the south and south-east coast of England but also extend well inland, particularly for SO_2. It has been shown by measurements near shipping lanes that there was a 3 fold decrease of SO_2 from 2014 to 2015 in response to new regulations on sulphur emissions in the SECA (Yang et al., 2016). There are currently no such regulations for NO_x or particulate emissions. It is therefore important to better understand the effect shipping has on UK air pollution, especially in coastal areas and in particular in ports.

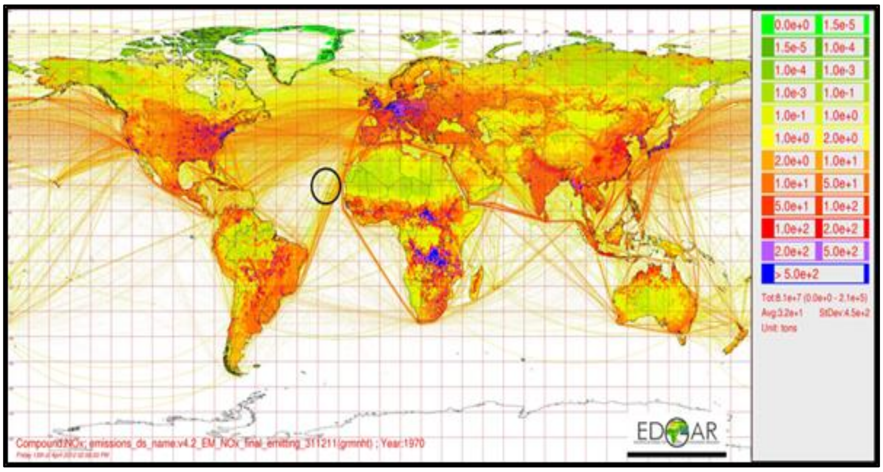
Project Aims

The PhD project will aim to improve understanding of the effect of shipping on both local UK and regional air pollution. To achieve this, there are three specific activities.

i.) Investigate ozone formation chemistry in ship plumes.

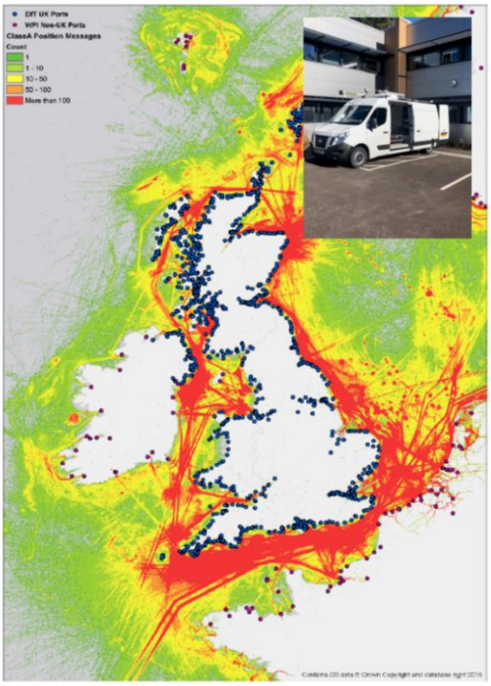
Measurements of gaseous of chemical species (O3, CO, NO_x, CO_2, CH_4, SO_2 and a range of VOCs) will be made in a series of ship plumes using the FAAM research aircraft (see picture above). Flights will take place in both North Atlantic shipping lanes off the Iberian peninsula and in the English Channel. The measurements will allow O_3 formation to be investigated in the plumes from close to source to several hours downwind (see panel above for an example taken from Chen et al. 2009). Flights will be carried out in late 2019 and summer 2020 to allow investigation of the effect of the new sulphur emission regulation in international waters on the content and O_3 production in the plumes. Modelling of O_3 production will be carried out using a box model based on the Master Chemical Mechanism (MCM) in order to assess the dominant O_3 formation pathways in the various plumes. Tests will also be carried out on how effectively reduced mechanisms (such as those used in global models like GEOS-CHEM) can reproduce O_3 formation in the plumes.

ii.) Examine the effect of shipping on remote marine boundary layer NO_x and O_3.



A 12 year and on-going time series of NO_x and O_3 has been taken at the Cape Verde Atmospheric Observatory (CVAO), a remote measurement site in the tropical North Atlantic Ocean managed by the University of York. Regular spikes of NOx have been observed in the data. One possible explanation for these is the presence of shipping in the area, with Cape Verde being close to a major shipping lane between Europe and South Africa - see figure above showing global NOx emissions with the Cape Verde area circled. Previous data will be investigated to assess whether there has been a change in ship originated peaks over the past 12 years and whether this coincides with any change in shipping patterns. In addition, an instrument to measure SO_2 (which is a marker for shipping emissions in a marine environment) has recently been installed at CVAO and this data will be used to ascertain whether shipping is indeed the source of the NO_x spikes. The effect of any change in NO_x attributable to shipping on O_3 will also be investigated.

iii.) Investigate the effect of ship emissions on air pollution in UK ports.



The UK is surrounded by very busy shipping lanes and has a number of large ports (see picture to the right)). The relative contribution of emissions from shipping is greater around the UK than elsewhere in Europe because of this. Measurements will be made using the University of York mobile laboratory (see picture to the right), in coastal regions and around a series of UK ports to assess the impact of shipping on air quality. The mobile laboratory will be equipped with instruments to measure NO_x, SO_2, O_3, CH_4, CO_2, C_2H_6 and a range of other VOCs. The Automatic Identification System (AIS) database (via the marine-traffic.com website) will be used to inform on ship traffic in the area and in the ports, which will allow background measurements to be made when ship traffic in the area is light or when ships are not in port. Different types of ports will be targeted (e.g. Felixstowe for container ships, Southampton for cruise liners and Grangemouth for oil tankers). Using the mobile observatory allows observations to be made while moving and gives the much needed flexibility to enable individual ship plumes to be sampled while in or close to port.

Training

The student will work under the supervision of **Prof. James Lee, Dr. Sarah Moller and Dr. Jim Hopkins** (University of York) and will be based at the Wolfson Atmospheric Chemistry Laboratories, part of the Department of Chemistry, University of York. Here, the student will develop transferable skills in making atmospheric measurements using spectroscopic and chromatography techniques (e.g. of NO_x, O3, CO and VOCs for both ground and aircraft based measurements), chemical mechanism development and evaluation, numerical and data skills associated with model/measurement comparison and analysis of long term trends of atmospheric gases using a variety of statistical techniques. They will also develop a wider view of what is important for local and global air quality, and the role of international policy in controlling local, regional and global air pollution.

The University of York and the wider NERC PANORAMA DTP provide comprehensive training programmes for PhD students with a range of courses on both hard and soft skills. **Prof. Lee, Dr Moller and Dr Hopkins** all work for the National Centre for Atmospheric Science (NCAS), and thus the student will have access to the wider resources that NCAS provides. The student will also have access to training provided by NCAS such as the Arran instrumental Summer School, the Earth System Science Summer School (ES4), and future further developments in computations and data analysis. In addition, **Dr Moller** works works closely with Defra as an embedded academic partly for DEFRA, hence the student will be encouraged to develop an awareness of the role of science in policy making, and where relevant opportunities can be sought to discuss findings with those directly involved in designing and assessing policy options.

The student will work in the Wolfson Atmospheric Chemistry Laboratories, part of the department of Chemistry, University of York. These were established in 2013 and comprise a state of the art 800 m2 dedicated research building, the first of its kind in the UK. Supported by a large award from the Wolfson Foundation and a private donor, the Laboratories enable experimental and theoretical studies relating to the science of local and global air pollution, stratospheric ozone depletion and climate change. The Laboratories are operated as collaborative venture between the University of York and the National Centre for Atmospheric Science (NCAS), co-locating around 40 researchers from seven academic groups and from NCAS. The Laboratories are also home to independent research fellows, postdoctoral researchers, PhD students and final year undergraduate research projects.

The student will have the opportunity to present their work to the scientific community at national and international meetings and conferences. They will also be encouraged to take part in outreach events organised by both WACL and NCAS in order to disseminate the research beyond the immediate scientific community (e.g. to policymakers and the general public).

We appreciate that this PhD project encompasses several different science and technology areas, and we don't expect applicants to have experience in many of these fields. The project is very well supported with experienced scientists and training in these new techniques and disciplines is all part of the PhD.

Useful References

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