UAV-Based Gas Sensor Systems Help Control Air Pollution from Ocean-Going

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Abstract

Marine transport accounts for 50% of world trade and 18% of global sulfur oxide (SO_x) and nitrogen oxide (NO_x) emissions. Ocean Going Vessels (OGVs) typically burn 3.5% sulfur fuel which is mostly residual fuel oil (RFO). RFO is the viscous liquid that is left over in an oil refinery after producing light and middle distillates which are used to make higher value commodities (e.g. gasoline, jet fuel, etc.). High concentrations of sulfur, nitrogen, and carbon emissions from RFO cause more than 60,000 premature deaths per year worldwide (Brahic). The use of this fuel in OGVs is hazardous to the coastal environments and port communities.

In 2016, The International Maritime Organization (IMO), an arm of the United Nations, voted to limit sulfur concentration in marine fuels beginning on January 1, 2020. This regulation limits sulfur content in OGV fuel to 0.5% sulfur. In California, the California Air Resources Board (CARB) requires OGVs to burn 0.1% sulfur fuel within 200 nautical miles (nm) of the California baseline. An alternative to burning low-sulfur fuel is the use of abatement technologies (e.g. scrubbers) or liquified natural gas (LNG) to achieve equivalent sulfur emission reductions. The Environmental Protection Agency (EPA) similarly requires OGVs to burn 0.1% sulfur fuel within 200 nm of United States coastlines. Currently, the U.S. Coast Guard—which carries enforcement responsibilities within the 200 nm U.S. baseline—and the Enforcement Division of the California Air Resources Board (CARB)—who carries enforcement responsibilities within the 200 nm California baseline—have insufficient manpower and/or equipment to properly enforce existing regulations.

On behalf of The ADEPT Group, Inc., (ADEPT) the team conducted several activities to share information with interested parties (including CARB, South Coast, and Bay Area Air Quality Management Districts) of a novel technology to conduct aerial monitoring of OGV emissions to enforce fuel-sulfur regulations. This technology uses drones or helicopters equipped with a sensor package payload that can "sniff" emissions from an OGV plume and indicate if the fuel burned by a ship should be targeted for subsequent compliance testing.

Keywords: OGVs, sulfur oxide, sensor package, air quality

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1. Introduction

CARB has proactively enacted policies to reduce emission-based air pollution to meet federal standards—as outlined in the 1963 Federal Clean Air Act. Such policies led to regulations for OGV and other mobile pollution sources. OGVs burn residual fuel oil (RFO). RFO is the leftover viscous residue from a refining process meant to yield gasoline and diesel. This highly toxic fuel has been found to cause over 60,000 premature deaths globally per year, as well as increased morbidity rates. The health impairing mechanisms are the high concentrations of sulfur oxides (SO_x), particulate matter (PM), and nitrogen oxides (NO_x) in OGV exhaust (Corbett et al.).

Southern California is plagued by some of the same air quality issues as many other coastal regions in the world. Communities situated around the ports of Long Beach and Los Angeles experience greater levels of air pollution than others in the region. Most residents living along the ports are low-income people of color, a demographic that also tends to have limited access to healthcare, aggravating an environmental injustice issue. Assembly Bill (AB) 617 was passed by the California Legislature in 2018 to address poor air quality in disadvantaged communities of color. In addition to AB 617, there are existing and impending laws, rules, and regulations that aim to lower air pollution from OGVs. However, without effective enforcement, their favorable intended impact on disadvantaged communities is limited. This report presents a new air quality enforcement enhancement method that has proven effective to lower pollution in the European Union.

Three pieces of legislation restrict sulfur-fuel content in OGVs. As of January 1, 2020, via MARPOL Annex VI, IMO will limit the sulfur concentration in OGV fuel from 3.5% to 0.5% in all shipping lanes. The second is the California Sulfur Rule. This rule was finalized in 2014 and is enforced by CARB. It requires OGVs to burn cleaner marine gas fuels (e.g. max. 0.1% sulfur content) when within 200 nm from the California baseline. The third piece of legislation is the EPA's Sulfur Emission Control Areas (SECA) rule. These controlled areas extend 200 nm from the North American baseline and require OGVs to burn at or below 0.1% sulfur fuel. However, there is now reason to surmise that approximately 1 in 11 ships is not using low-sulfur fuel to meet the California Sulfur Rule or the SECA mandates. To ensure full compliance with these requirements, aerial Unmanned Autonomous Vehicles (UAVs) equipped with specialized sensor packages that fly in an OGV's plume are suggested as a cost-effective enforcement enhancement solution to rapidly detect, calculate, and report elevated sulfur concentrations in OGVs.

A related team objective was to solicit and acquire funding to implement and conduct a test and demonstration project for such technology [e.g. the Explicit Mini Sniffer System (EMSS)] in California waters. The EMSS, made by Explicit ApS of Denmark, is one of several drone and sensor payload products which have been shown to capably target violators of fuel sulfur rules in the European Union (EU). Another team objective was to convince the appropriate regulatory and/or enforcement agencies (CARB, SCAQMD, BAAQMD, USEPA, USCG, etc.) to test drone-based monitoring as a viable enforcement enhancement method. One of the Practicum team's deliverables was to complete a co-funding application to the Technology Advancement Program as part of the San Pedro Bay Ports' Clean Air Action Plan. Another goal was to use the CALPUFF modeling system to estimate emission rate profiles along the coast of California as well as in the ports of Long Beach and Los Angeles. The projected reduction in emissions was used to assess the potential health benefits of implementing such a drone-based monitoring system.

2. Emissions

2.1 Emissions Reduction Model

To quantify the effects of implementing an aerial monitoring system, the team used two cases to compare compliant vs. non-compliant OGV emission scenarios. The COO of Explicit ApS informed the team that data Explicit collected indicates that approximately 10% of OGVs burn fuel that exceeds applicable EU maximum sulfur content rules (e.g. 0.1% sulfur). Based on this reported rate of sulfur rule violations in air-monitored waters, two separate scenarios were created to illustrate the compliant and non-compliant OGV emission conditions.

A surprising finding was that the baseline emission data provided by the South Coast Air Quality Management District (SCAQMD) assumed that all ships traveling in the District's waters were in full compliance. Dr. Marc Carreras, Air Quality Specialist at SCAQMD, was the principal contact for the team. Dr. Carreras expedited the public records request and kindly transferred one complete year of mobile source emission data to an FTP site constructed by the team advisor, Dr. Pablo Saide. This emission data included OGV-sourced emissions and all other land and sea mobile sources.

The team's "clean case" scenario directly mirrors the SCAQMD OGV emission data. This data assumes that all ships are compliant under the California Sulfur Rule, meaning that they burn 0.1% sulfur fuel within 24 nm of the California baseline. The implementation of the aerial monitoring system scenario assumes that all ships burn low-sulfur fuel.

The "dirty case" scenario assumes 10% of OGVs burn non-compliant fuel within the 24 nm of California's baseline. To calculate the "dirty case" emissions, the team used an online Access Database provided by CARB. This database allowed the team to adjust emission scenarios with the California Sulfur Rule enforced and not enforced. In other words, net OGV emissions for the two scenarios were computed, one for OGVs burning exclusively high-sulfur fuel within coastal waters and one for OGVs burning exclusively low-sulfur fuel. The dirty case was computed by multiplying the clean case by 0.9 and the dirty case by 0.1, and adding together the two values. This provided the team with an emission scenario of 90% of ships burning compliant fuel and 10% of ships burning non-compliant fuel. Under this scenario, SO_x emissions increased by a factor of 2.909, and total particulate matter emissions increased by a factor of 1.5. These ratios were then multiplied by the original emission data to compute the dirty case.

2.2 Emissions Domains

Two domains were used to model how concentrations of major pollutants like SO_x, NO_x, and PM change after the introduction of an aerial monitoring system.

The first domain spans the entirety of the United States west coast and overlaps with the North America Emission Control Area. The team used a 4 km by 4 km resolution grid, which is relatively coarse for small scale turbulence processes, but can capture large scale atmospheric waves (e.g. Rossby and Kelvin waves) that propagate pollutants over long distances. The second domain focuses on the source of emissions and covers only the Ports of Long Beach and Los Angeles region. A finer grid of 100 m by 100 m was used. Some forms of SO_x and NO_x have short atmospheric residence times, so they tend to quickly deposit in proximity to the source.

High background levels of SO_x and NO_x are proven to cause more cardiovascular diseases and premature death. As a result, a finer domain is used to more closely estimate the public health effects among underrepresented, low-income communities near the ports of Los Angeles and Long Beach.

2.2 Data Collections

Annual ship vessel density data is required to acquire a sufficiently accurate model to represent OGV emissions. The National Oceanic and Atmospheric Administration's Department of Commerce has been conducting annual ship transit counts along US coastlines since 2009 via Automatic Identification Systems (AIS). Ships are monitored and tracked to populate 100 m grid cells for the collected emissions data. The entire geographical extent of the data received by SCAQMD fits within the space delineated by the coordinates 132W to 60W, 10.7S to 51.5N on the World Geodetic System 1984. Each single transit is defined as a vessel passes from one 100 m grid cell to another 100 m grid cell. The available traffic data, published in December 2018, can then be used in conjunction with the emission data.

3. Emissions Modeling

One of the practicum's initial goals was to run an atmospheric pollution dispersion model using CALPUFF. CALPUFF is an advanced non-steady-state meteorological and air quality modeling system developed by scientists at Exponent, Inc. This modeling system was chosen because it is listed by the EPA as an alternative model to assess the long-range transport of pollutants. The team planned to use CARB's emission data to determine the ambient concentrations of pollutants for a clean case and a dirty case.

While this modeling software would have been a good fit for this project, the team experienced difficulties with the software. To run CALPUFF, nine preprocessors are needed. These preprocessors can be divided into two groups: (i) preprocessing terrain data and (ii) preprocessing meteorological data. Both steps proved to be more difficult than anticipated. The available terrain and meteorological data were only available up to 2010, yet the available emissions data covered only 2016. While this approach would have included some inherent error, it was the best option available at the time. The second aspect that proved difficult was the complex format of preprocessor input data. Since none of the practicum members had sufficient background in computer science, major delays ensued. Luckily, the team was able to convert the emissions data to the correct format. However, the team could not convert the terrain or the meteorological data to the correct format. Consequently, the CALPUFF model could not be run to determine ambient concentrations. Instead, these ambient concentrations were estimated based on prior emissions research (see section below titled "Ambient Air Quality Estimation").

If another practicum team wishes to run the CALPUFF model to more accurately determine ambient air quality concentrations, two strategies are suggested. The first is to purchase CALPUFF View, which comes with a more detailed guide and an easier-to-understand user interface for environmental scientists that are inexperienced in computer science. The other is to find and work closely with a person that has either used CALPUFF or a similar modeling software. The preprocessing execution is straightforward, but the input format conversion requires extensive background knowledge. In either case, it is suggested that running the CALPUFF model can more accurately determine air quality concentrations, and consequently the health effects of implementing an aerial monitoring system.

4. Health Effects

4.1 Health Impact Assessment Methodology

Relations between the incidence of specific human diseases and illnesses (e.g. adult mortality, child asthma morbidity, and asthma-related hospitalizations) and OGV emissions were analyzed for the South Coast Air Basin. Using similar studies (Krewski et al. & Delameter et al.), the team calculated the expected change in health effects due to changes in the amount of $PM_{2.5}$ generated by OGVs. Health impact evaluations were estimated using population data published by the American Chemical Society (American Chemical Society), for Los Angeles County, Orange County, San Bernardino County, and Riverside County. This data was categorized by age, cohorts, and county.

The relative change in adult mortality in the South Coast Air Basin associated with PM air concentrations was calculated using CARB's baseline mortality incidence rate (CARB). The adult population, persons between the ages of 30 and 99, was calculated by multiplying the percentage of persons within this age group by the total population. This approach is similar to the approach taken by Krewski in a study that analyzed mortality rates of Los Angeles adults aged 30 to 99. The change in incidence rate was calculated for each county using a β coefficient provided by the same study (Krewski et al.).

Asthma morbidity rates in children under 17 due to ambient PM concentrations was also calculated. The sample size was derived by multiplying the percentage of persons under 17 by the total population. Data on total asthma morbidity in children is published by the California Department of Health (CAPH). The percentage of the affected population was used to calculate the percentage of asthma morbidity in children. The β coefficient for the incidence rate of asthma morbidity was found in a 2018 study by Sofiev et al. The change in asthma morbidity was computed for each county using the same β.

The last calculated health metric was asthma-related hospitalization rates. To this end, the team used asthma prevalence data published by the California Department of Health (CAPH, 2017). The number of people with asthma in each county was calculated by multiplying the prevalence by the total county population. The California Department of Health also provides the baseline number of hospitalization rates. The same source served for emergency room visits data (CAPH, 2017). Finally, the β coefficient used to calculate the change in health impacts, which looked at hospitalization rates in Los Angeles, comes from a 2012 study by Delameter et al.

5. Executive Meetings

5.1 South Coast Air Quality Management District

On November 15, 2018, the team participated in its first executive meeting at SCAQMD headquarters in Diamond Bar, CA. Team members Anthony Rosas and Ryan Hallman were joined by faculty advisor Dr. Pablo Saide, and client representatives Messrs. Alex Spataru and William Hamelin. Several high ranking SCAQMD air quality experts and/or executives attended. This meeting was a success in that SCAQMD staff agreed to provide initial support to further investigate this technology. The initiation of closer relationships with SCAQMD experts additionally benefited the team during the course of the modeling effort as SCAQMD staff kindly provided emissions data for the South Coast Air Basin.

5.2 Port of Long Beach

On February 5, 2019, Luna Bai, Victor Vu, and Anthony participated in an executive meeting at the Port of Long Beach (POLB) Headquarters. In attendance were the Executive Director of the Port of Long Beach, Mr. Mario Cordero, Managing Director of the Planning and Environmental Affairs Bureau at the POLB, Ms.Heather Tomley, Executive Director of Planning and Development at the POLB, Mr. Richard D. Cameron, Mr. Alex Spataru of ADEPT, and Mr. Robert Wimmer of the SCAQMD. This meeting was to bring this project to the attention of the Port of LB's staff so they may be more inclined to support an impending Technological Advancement Program (TAP) co-funding application. At this meeting, the practicum team presented the potential benefits of utilizing the aerial monitoring system to help regulate OGVs in and around the San Pedro Bay area. Some insight on TAP was gained. This included the reality that the project may not qualify for TAP funding because it may be claimed that it's not like an engine technology that directly reduces ship emissions (although the net effect of its implementation would bring about immediate air pollution reductions in the Ports of San Pedro Bay – which is the expressed intent of TAP). Mr. Cordero expressed reservations about the implications of drone use in the port's airspace, noting privacy and safety risks.

5.3 Bay Area Air Quality Management District

On the morning of March 7, 2019, an executive-level meeting was held at the Bay Area Air Quality Management District (BAAQMD) headquarters in San Francisco, CA. In attendance were team members Ryan Hallman and Sherry Yan; Client Representative Mr. Alex Spataru; BAAQMD Executive Director, Mr. Jack Broadbent; BAAQMD Deputy Air Pollution Control Officer, Mr. Damien Breen; and Captain Sam Pecota of the California State University Maritime Academy, and also Captain of the Training Ship Golden Bear (TSGB).

Ryan and Sherry started the meeting with pertinent background information and emphasized the environmental and business fairness benefits that can be anticipated from utilizing aerial monitoring to help target OGVs who violate emission regulations in and around commercial ports. An overview of the Test and Demo Project methodology was also delivered. Follow-up technical questions were addressed by Mr. Spataru. Messrs. Broadbent and-Breen showed strong interest in aerial monitoring in general and in the proposed test and demonstration project. There was a general consensus that introducing more effective monitoring of OGV emissions holds the potential to significantly enhance compliance with EPA's SECA Rule, California's Sulfur Rule, and the impending IMO sulfur rule, as well as rapidly lower OGV generated emissions.

BAAQMD staff kindly agreed to attend the May 7, 2019 aerial monitoring system demo and the follow-up reception aboard the TSGB. Messrs. Broadbent and Breen agreed that BAAQMD will co-fund the proposed test and demo project in 2020 to the tune of $275,000. Mention was made that this may be a good allocation of AB 617 funding. BAAQMD staff was encouraged to help publicize the May 7, 2019 event.

6. Emissions Data and Maps

6.1 South Coast Air Basin Mobile Source Emissions Data

Table 1 below represents the mobile source emissions data in the South Coast Air Basin. The SCAQMD provided emission data is shown as a spatially distributed grid made up of squares measuring 4 km by 4 km. The total air pollution constituents in each square are expressed in tons per day. Longitude and latitude are shown in decimal degrees and the LWMASK (Land Water Mask) indicates if the emissions source is over land (1) or over water (0).

Latitude	Longitude	SO2	PSO4	NO	NO2	PNO3	PMC	LWMASK
31.97	-120.14	2.12E-06	6.08E-06	0.011172	0.001269	2.65E-07	1.61E-05	0
31.895	-116.72	0.006596	0.000656	0.038492	0.004683	1.19E-05	0.00067	0
31.893	-116.68	1.5126	0.15045	8.8272	1.0739	0.002737	0.15357	1
31.891	-116.63	0.003484	0.000346	0.02064	0.002474	6.33E-06	0.000354	1
31.889	-116.59	0.001307	0.00013	0.007625	0.000928	2.35E-06	0.000133	1
31.888	-116.55	0.005879	0.000585	0.034578	0.004174	1.06E-05	0.000597	1
31.886	-116.51	0.001089	0.000108	0.006832	0.000773	2.01E-06	0.000111	1
31.884	-116.46	0.000653	6.50E-05	0.004555	0.000464	1.19E-06	6.63E-05	1
31.875	-116.25	0.000218	2.17E-05	0.00158	0.000155	4.30E-07	2.21E-05	1
31.871	-116.16	0.000435	4.32E-05	0.002736	0.000309	7.83E-07	4.42E-05	1
31.869	-116.12	0.000871	8.66E-05	0.005283	0.000618	1.59E-06	8.84E-05	1
31.867	-116.08	0.000435	4.32E-05	0.002868	0.000309	7.83E-07	4.42E-05	1
31.859	-115.91	0.00043	4.27E-05	0.003303	0.000305	7.83E-07	4.36E-05	1
31.857	-115.87	0.000106	1.06E-05	0.001131	7.50E-05	1.87E-07	1.08E-05	1
31.821	-115.18	3.29E-05	1.53E-05	0.000849	9.65E-05	1.26E-05	0.013881	1
31.818	-115.14	4.32E-05	8.62E-06	0.001134	0.000129	1.36E-06	2.01E-05	1
32.007	-120.48	2.12E-06	6.08E-06	0.011172	0.001269	2.65E-07	1.61E-05	0
31.981	-118.3	9.26E-07	9.69E-06	0.011793	0.00134	5.29E-07	2.50E-05	0
31.978	-118.17	9.26E-07	9.69E-06	0.011793	0.00134	5.29E-07	2.50E-05	0

Table 1: South Coast Air Basin Mobile Source Emissions Data

As seen in Table 1, the data fields were stored in the order of SO_2, PSO_4, NO, NO_2, PNO_3, PMC, and LWMASK on nine separate sheets. The team used MATLAB functions to combine the nine spreadsheets into a cohesive data table. These functions overlay the nine sheets and assign each constituent to its corresponding latitude and longitude. Following this compiling process, the longitude and latitude coordinates were converted from decimal degrees to UTM to make it possible to run the CALPUFF model.

6.2 Emissions Scenarios: "Clean Case" and "Dirty Case"

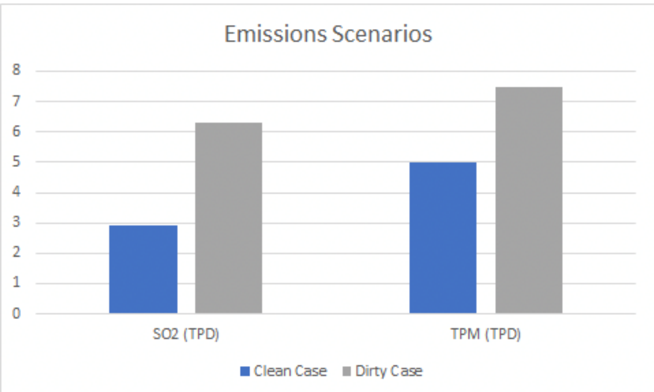

Figure 1: Emissions Scenarios: "Clean Case" and "Dirty Case"

The bar graph in Figure 1 illustrates the two emission scenarios: the clean case and the dirty case. The Sulfur Dioxide (SO_2) and Total Particulate Matter (TPM) emissions in each case were computed using the formerly mentioned methodology. These computations indicate that at the estimated 10% OGV non-compliance rate, SO_2 emissions increase by a factor of 2.2 and TPM increases by a factor of 1.5.

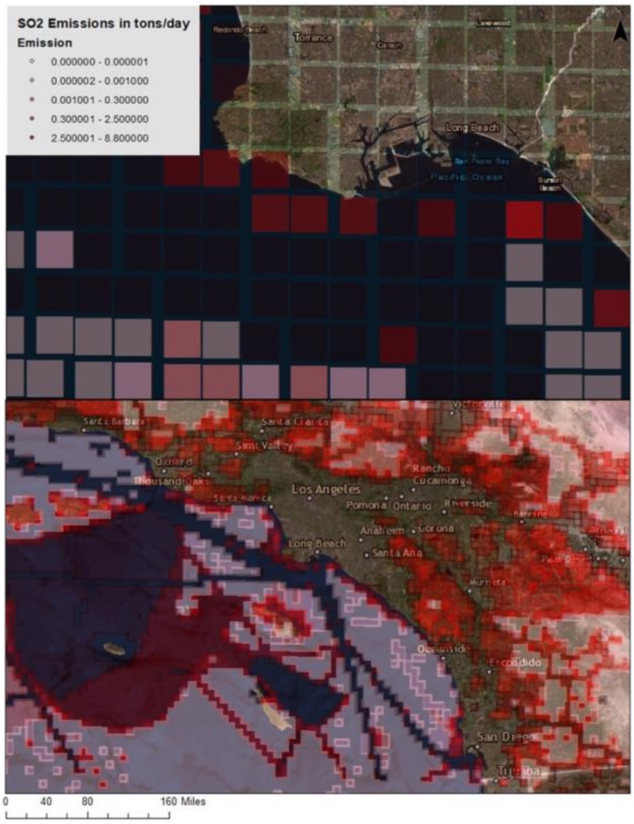

Figure 2: 24 Hours SO2 Emissions (tons/day) in 4 km x 4 km Grid Cells

The map above displays the emissions from the data collected without applying a clean or dirty scenario.

Figure 3: 2016 Vessel Transit Counts in 100m x 100m Grid Cells. The map above displays vessel transit count without applying a clean or dirty scenario.

7. Ambient Air Quality Estimation

7.1 Alternate Approach

Due to unexpected time constraints, data scarcity and data mismatch, and due to the lack of the full range of coding competencies to undertake the primary approach to calculate ambient air quality, the team pivoted to an estimation method (instead of running the CALPUFF model). This alternate approach is a critical path step to estimate the health implications of using the enhanced air monitoring and targeting "sniffer" technology (e.g. the "clean" case) vs. the case where 10% of the OGV's cheat, a.k.a. the "dirty" case.

According to a Vutukuru & Dabdub study, due to OGV emissions, in 2020, the Particulate Matter Sulfate (PSO_4) concentration will rise by a maximum of 2.5 μg/m^3 in SCAB. This study assumed full OGV compliance with California's Sulfur Rule (Vutukuru & Dabdub, 2007). Thus, it is posited that for the clean case, in 2020, the rise in sulfate concentration will be 2.5 μg/m^3.

Working through the emissions scenarios for the dirty and clean cases indicates that in 2020 the total emission of Sulfur Dioxide (SO_2) for the dirty case is 2.2 times the total emission of SO_2 of the clean case. Since the conversion from SO_2 to SO_4 is relatively fast in the atmosphere, full conversion is assumed.

$$2\,SO_2 + O_2 = 2\,SO_3$$
$$2\,SO_3 + O_2 = 2\,SO_4$$

Given the estimate for the clean case as 2.5 μg/m^3 – the estimated SO_4 emissions in the dirty case are calculated to be 5.5 μg/m^3. It is thought that this SO_4 emissions estimate is conservative knowing there are other PM components in an OGV's plume. This Total PM (TPM) estimate was used to approximate the health impacts of OGV's emissions in the dirty scenario.

Mortalility	Asthma Hospitilization	Childhood Morbidity
53	2658	4060

Table 2: Annual maximum health effects of compliance (total PM-related health effects)

8. Conclusions

Air quality regulatory entities—with the knowledge that OGVs burning high-sulfur fuel have a drastic effect on public health in Southern California—have created and enacted rules to minimize OGV emissions. Yet, there is strong motivation to flout these rules. The current risk versus reward ratio is clearly in favor of cheating. Components of this unfortunate misdirection include, and are not limited to:

I. Overly lenient fines for those who are caught cheating;
II. Small risk of being caught, as the percentage of OGVs inspected is small (e.g. <7%);
III. All OGV inspections are at pier—whereas the SECA rule covers an area that extends 200nm from shore.
IV. OGV are inspected at random;
V. Very few inspections at sea;
VI. Huge reward for cheating based on a large price difference between a ton of very low sulfur fuel and and HFO (>$300 per ton); and
VII. It is common knowledge that these rules are readily gamed coming into port (for most OGVs—only have to switch to clean fuel at about 20 nm from the port), and can be completely disregarded when leaving port.

Based on current enforcement practices and data collected to date from such practices, CARB has reported a very high OGV compliance rate (97 to 99%).

Further, in the absence of caught-in-the-act evidence of a greater rate of violations, air quality modelers—and their clients (CARB, EPA, SCAQMD, The Ports of LA and Long Beach) have assumed full compliance of these rules.

If in fact the violation rates are as high (approximately 10%) or higher than in the European Union—where aerial monitoring has been used for the past 5 years—and the number of fixed monitoring stations dwarfs what is in place in the U.S.—then the air models used to date in CA— as well as the SIP's that rely on such models are materially incorrect.

Worse, the negative health effects of OGVs violating such rules have been shown to be high and unfortunately unrecognized. And as they are unrecognized—they sadly continue to go uncorrected.

Compelling circumstantial evidence and hard data collected so far indicate that in the U.S., federal and state agencies (e.g. CARB, EPA, USCG, etc.) charged to enforce OGV state, federal and international fuel-sulfur regulations (e.g. California Sulfur Rule, SECA Rule, etc.) are stretched staff-wise and do not possess the full range of monitoring equipment and related more effective and broader practices available to their EU counterparts to properly enforce such mandates.

Three EU based UAV-based emissions monitoring systems have been shown to provide effective and reliable means to timely target and fine sulfur rule violators.
One such system (in Norway) has reportedly paid for itself in one year from the collected fines.

The deployment of an UAV with suitable sensor packages on board (which is flown in the plume of the OGV to be inspected, where it lingers for a short period of time) allows for several OGVs to be surveyed at low cost within a short period of time in high OGV traffic density areas. Battery life limits long-term monitoring missions and hybrid UAV's and helicopter-mounted sensor systems run the risk of cross-contamination of the in-plume sample with their own exhaust.

There is reason to anticipate that a California-adapted variant of such UAV and specific sensor package can rapidly provide numerous benefits. These include, and are not limited to:

(1) an immediate and significant rise in the air quality in disadvantaged communities in and near commercial ports,
(2) a fairer playing field for those OGV operators who observe air quality rules, and
(3) more funding for SEP projects in disadvantaged communities.

Air pollution data collected in Denmark has shown a significant drop (e.g. 50%) in PM after five years of air monitoring of OGV emissions, although there is more than one reason for such improvement.

Initial estimates indicate that if OGVs do comply with fuel-sulfur regulations, the region will experience notable reductions in adult mortality; child asthma morbidity; and asthma-related hospitalizations.
Note: Given that the health effect calculations conducted by the team were at a large spatial scale, a more substantial analysis can further define the adverse effects of 10% of the OGV's burning high-sulfur fuel. It is suggested that next year's team develop a proper air model that projects ambient $PM_{2.5}$ concentrations at specific locations within the South Coast Air Basin. With this information in hand, the aforementioned health impacts may be assessed for individual communities, while providing a greater degree of understanding of the negative health impacts of OGV emissions—and equally important—stimulate the implementation of appropriate and timely corrective actions.

In light of the clear mandate of AB 617 to focus resources towards lowering air pollution in California's disadvantaged communities, it is suggested that such funds may be well spent to test and demonstrate at least one of the EU developed "sniffer" technologies as well as to develop and/or demonstrate clean (e.g. fuel cell) propulsion with long dwell-over-target UAV systems that are specifically designed for such long-range air quality monitoring missions.

9. Acknowledgements

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