The Role of Unmanned Aerial Systems/Sensors in Air Quality Research

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- To describe the application of new miniature sensors and aerial sampling technology to better quantify emissions from hard-to-sample, open area sources.
- To explain the status of the technology
- To highlight recent applications



- Prescribed forest and agricultural burns
- Wildfires
- Landfills
- Lagoons
- Industrial complexes
- Agricultural operations
- Oil and gas fields
- Disposal of obsolete military ordnance

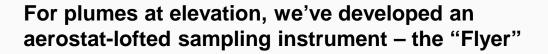


- Open area sampling, vs. stack sampling, is becoming more important as
 - Industrial point sources are now more wellcharacterized
 - Open area sources are recognized for their importance to air shed pollution management
 - Global climate impacts from these source are of growing concern



- What are the target analytes, their concentrations, and their temporal history?
 - What sampler type is needed?
 - How much sample volume is needed to exceed detection limits?
 - How quickly must the sampler respond to changes in concentration?
- What are the emission plume characteristics: height, breadth, duration, accessibility?
 - Is an aerial sampler needed?
 - Is the plume discrete or broad?
 - Will the terrain, biota, and structures allow access?
- What are the safety considerations, equipment and personnel?

Aerial Sampler



- Total weight ~ 21 kg (46 lb)
- Onboard computer with data transmission
- User-set CO₂ triggering of samplers
- GPS, CO₂, CO
- Semi-Volatile Organic Compounds (SVOCs)
- Volatile Organic Compounds (VOCs)
- Black carbon (BC)
- Brown carbon
- PM by filter (PM_{2.5}, PM₁₀)
- Continuous PM_{2.5}, PM₁₀
- 3D-anemometer





The "Flyer"

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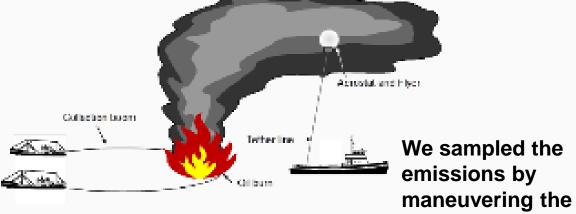
Examples of Open Area Emission Sampling with the Flyer



Sampling the plumes from the in situ oil burns in the Gulf of Mexico during the BP Deepwater Horizon disaster.

The surface oil was gathered by two trawlers towing a floating boom. It was then ignited.

The marginal combustion and the presence of CI from (at least) the seawater raised the question of whether formation of chlorinated dioxins and furans was possible.







plume.

Flyer into the

Examples of Open Area Emission Sampling with the Flyer



Sampling prescribed fires: forests and agricultural fields.



Use of two tethers attached to electric winches and mounted on two ATVs allows some optimization of the aerostat/Flyer position in the plume.





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Examples of Open Area Emission Sampling with the Flyer



 Obsolete military ordnance is often disposed via open burning and open detonation





10-20 seconds in the plume
High volume sampling rate
Trigger samplers with CO2 conc.
"spin up" sampling pumps prior to the plume



Tethered aerostat sampling has worked well, but has constraints:

- Maneuverability.
 - Tethers (trees, power lines)
 - ATVs
 - Limited 3D range (wind shifts, plume drift)
 - Terrain and boundary limits
- Resource requirements.
 - Large team
 - Large equipment (and helium) Cost
- Response time is weeks+

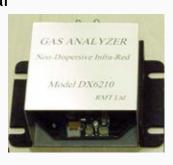
New Sensor and UAS Technologies



The confluence of developments in miniaturized sensor technology and unmanned aircraft systems (UASs) has promise for enabling new methods of open area emission sampling.

Sensors and Small Samplers

- Electrochemical
- Metal oxide
- Small IR
- Filter-based
- optical













UASs

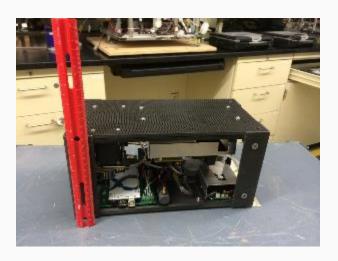
- Advances in GPS, carbon fiber, computer, and battery technologies
- Varied in size and capability; some as small as a dollar bill.
- Operator controlled or fly programmed paths
- They have auto-return, boundary, and auto-land features
- Personnel are safely at a distance
- Recent designs can carry payloads of 5 kg for 15-20 minutes.
- They are portable (fold up) and fast to deploy
- They do not have a disturbance footprint
- Require only two people
- Costs range from \$50 \$20K



Development of a Sensor/Small Sampler Platforms



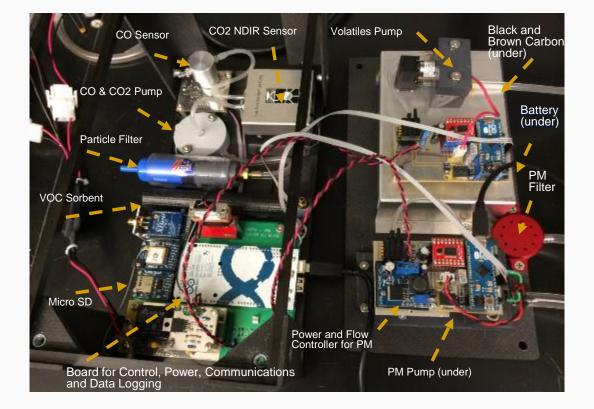
The "Kolibri"



The Kolibri is 3.56 kg and measures (for now)

- CO2,
- CO,
- PM2.5 (& metals),
- Volatile organics
- Black Carbon,
- Brown Carbon.

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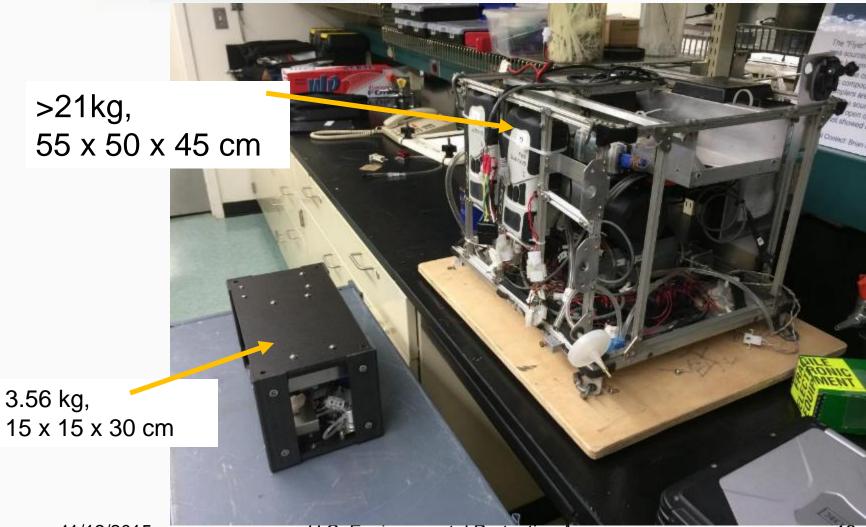


Future developments:

- Semi-volatile sampler
- •S, N, HC sensors
- Optical PM sensor

Kolibri vs. Flyer



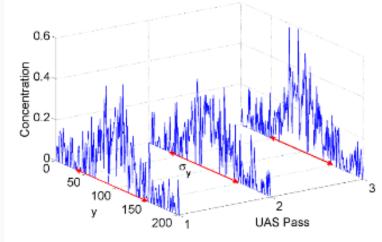


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Application: Plume Quantification by UAS







Multiple passes of the UAS through the plume determines concentration profile and dispersion coefficients; allows calculation of source strength, S.

Application of the Kolibri/UAS: **Detonations in Alaska Detonation Plume Emissions**? What are the residues from low-Residue on snow? order (incomplete) detonations?

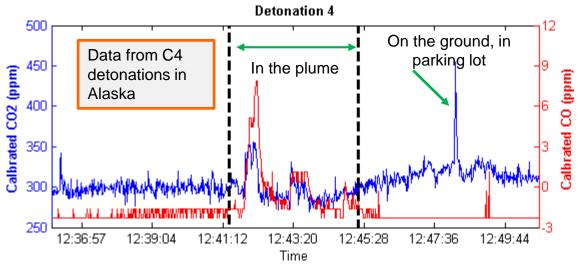
Development of lightweight sensor packages for aerial measurements





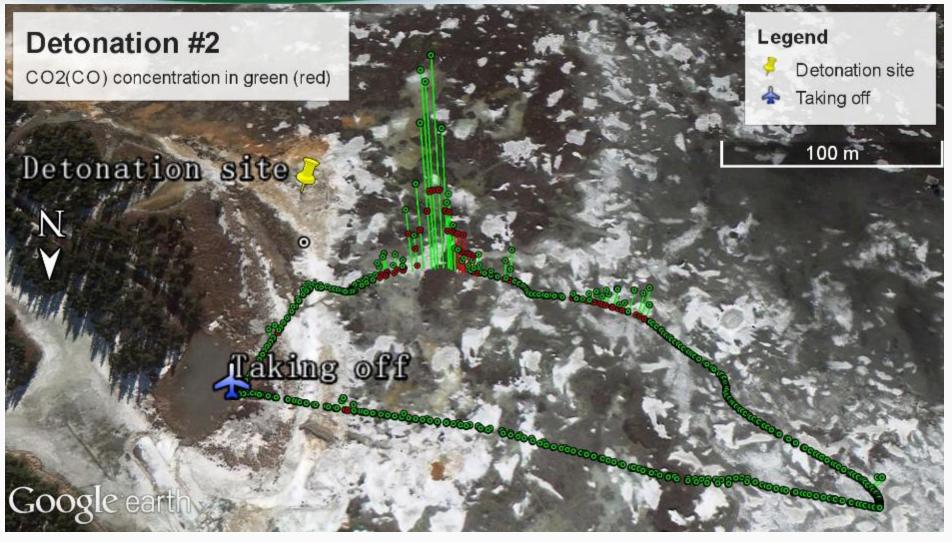
First flight in Anchorage, AK, Feb. 11, 2015 with Univ. AK-Fairbanks hexacopter on U.S. Army-sponsored project.

Gas sensor data from the plume:



UAS Flight in AK with EPA Sensor







- Significant safety advantage due to personnel set back distance
- Small "footprint" reduces response time to 1 day
- Decreases personnel from 6 to 2 (aerostat sampling)
- Mobility allows for more efficient source sampling
- Increases ability to characterize difficult sources
- Significantly reduces cost of field sampling by improving
- Complementary to fenceline, stack, and mobile source methods

Publications on Aerial Sampling



Environ Sci Technol 2010 44 9431-9437

Aerostat Sampling of PCDD/PCDF Emissions from the Gulf Oil Spill In Situ Burns

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Received October 21, 2010. Revised manuscript received October 28, 2010. Accepted October 28, 2010.

Emissions from the in situ burning of oil in the Gulf of Mexico after the catastrophic failure of the Deepwater Horizon deline alatform ware exposed for polychlorinated dibenzodioxins drilling platform were sampled for polychlorinated diberzodioxins and polychlorinated diberzodiraxis (PCDD/PCDF). A battery-operated instrument package was lofted into the plumes of 27 surface oil fires over a period of four days via a tethered aerostat to determine and characterize emissions of PCDD/ PCDF. A single composite sample resulted in an emission factor of 2.0 ng toxic equivalency (TEO) per kg of carbon burned, or 1.7 ng TEO per kg of oil burned, determined by a carbon balance method. Carbon was measured as CO_2 plus particulate matter, the latter of which has an emission factor of 0.088 kg/ ko carbon burned. The average plume concentration approximately 200-300 m from the fire and about 75-200 m above sea level was <0.0002 ng TEQ/m³

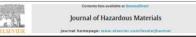
most comprehensive at-sea effort being the Newfoundland offshore burn experiments (2). Particle and gas concentra-tions sampled by aircraft-borne instruments were developed into emission factors (3) using a carbon balance approach (mass of pollutant per mass of fuel carbon). Other measurements were made using samplers aboard remotely controlled marine vessels and tethered aerostats (4). Emissions of polychlorinated dibenzodioxins and poly-chlorinated dibenzofurans (PCDD/PCDF) from the oil burns are of interest due to their health effects (5) including immunotoxicity, carcinogenicity, and teratogenicity. The potential for PCDD/PCDF emissions from the Gulf in situ potential for PCDD/PCDF emissions from the GaIT a simular barran exists due to the apparent presence of the preparation conditions for homotoxic barrange of the second states of the second-resonance of the second states of the pre-ber made from all fires and only ene (10 to our knowledge Heuristic Second Second Second Second Second Second Second individual states of the second second states of the conclusion in APCID/PCDF were second second second second conclusion in APCID/PCDF were reported as individual second emissions anaphress second s

dertaken to quantify the emissions from in situ burns, th

To measure the potential emissions of PCDD/PCDF fr the Gulf in situ oil burns, an aerostat-lofted instrum package was used to sample the plume emissions determine PCDD/PCDF concentrations and an emiss

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Aerostat-based sampling of emissions from open burning and open detonation of military ordnance

GRAPHICAL ABSTRACT

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 Large amounts of soil were ejected during detonations and entrained into the plumes. Energetics in the detonation plumes were less than 0.0005% of original Al-containing AP propellants showed that 7-17% of Al partitioned to the

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Emission Factors from Aerial and Ground Measurements of Field and Laboratory Forest Burns in the Southeastern U.S.: PM2.5, Black and Brown Carbon, VOC, and PCDD/PCDF

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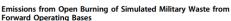
Supporting Information



INTRODUCTION

INTRODUCTION Presenbed forest turns are used to avoid widdlin coological sustainability to maintain ecosystem generates complexity and the sustainability of the pollutation are particulate matter (PM) such as PMC as aerodynamic dimeter less than or equal to 2.3 and another the summary of the summary of the validle segnatic compounds (VOCs), and semival compounds (VOCs) such as polychloritated doction (PCDD) and polychloritated approximated approximate (PCDD) and polychloritated approximate (PCDD) a (CCDF). Measurement of polisitate trainion for prediction of opposite and possible haums to huma the environment, and use in emission inversion (however, debauting emission factors from us maintained for personnel and explorent adery) must must intro the sampling explorent matery must must intro the sampling explorent matery must must intro the sampling explorent matery must supervise the sampling explorent matery must practicasis of representatives and the locater sampled, particularly by charge-parametiry graval-ings. These challenges, together with the related for meaning emissions from field forst human for emission ampling However, the labeatory human for emission amplitude the starty human for emission for the haloatory human for emission amplitude the starty human for emission for the starty human for emission amplitude the starty human for the starty human for emission for the starty human for emission for the starty human for the starty human for emission for the starty human for emission for the starty human for th

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Article

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Supporting Information

ABSTRACT. Ensistent from open burning of simulated military waste from forward operating bases (FOBs) were extensively characteristic as an initial drag in assessing Emission from two different burning screasion, so-scields" humour the parameter of the strained from the strained section screasion of the strained from the strained section screasion of the strained from the strained section of the strained secti polychlorinated dibenzodioxins and starans (second, and starans dibenzodioxins and starans (PBDDs/PBDFs), and metals. In general, so neral, smoldering amentoausons and entrans (PoLOP/FD/F), and metas: in general, smootening conditions in the burn box and the burn pile led to similar emissions. However, when the burn box underwent periodic wate charging to maintain sustained combustion, PM_{20} , VOCs, and PAH emissions dropped considerably compared to smoldering conditions and the overall burn pile results. The PCDD/PCDF and PBDD/PBDF

emission factors for the burn piles were 50 times higher than those from the burn box likely due to the dominance of smoldering combustion in the burn piles.

■ INTRODUCTION

Military operations at forward operating bases (FOBs) generate significant amounts of solid waste, requiring field-expedient methods to dispose of the waste with minimal risk to personnel and the environment. The U.S. Department of Defense (DOD) estimated that 3.6-4.5 kg of waste is generated per day per U.S. soldier deployed at FOBs, or about 90 000-180 000 kg of soldier deployed at PORs, er alson 90000-181000b ge of water per dryfor am POB unds as at the previously used Bald Air Base, Iraq.² A common solution has been the use of open mering on site to reduce the water worksome. Typically this has a solution of the solution of the solution of the solution of (use-called "hum pitc), White eliminating the risk of travel outside of the POI for disposed operation (a.e., backhauling), personnel near the burn site may be exposed to the emissions from the burning pler/site, Cancenn has been raised that these in toxics which may present airborne inhalation emissions contain toxics which may present airborne inhalation hazards and result in an adverse effect on personnel health.² A recent study indicated that military deployers have increased rates of reported respiratory symptoms, with "significant associations with deployment location that were more strongly associations with deployment location that were more strongly noted among presens deployed exclusively to inag.⁴ and that "inconsistency in risk for new-onset respiratory conditions and cumulative exposures: mather than deployment in general, as determinants of post-deployment respiratory illness.³ Further, the 2008 Rhancel Patricular Batter Surveillance Porgram Final Report lists burn pit smoke as one of the three primary air Published: September 19, 2012

Medicine (IOM), at the request of the Veteran's Admin-istration formed a committee to investigate long-term health effects of burn pit emissions exposure. Their report concluded that insufficient exposure data prevented a determination of whether long-term health effects are attributable to burn pits and that additional research to characterize exposures is tecessary.¹ Emissions of concern from waste burning typically include zmissions of concern from waste burning typically indude particulate matter (PM) volatile organic compounds (VOCJ), polyaromatic hydrocarbons (PAHs), and polychlorinated dihenrodosins and -furans (PCDD4/PCDFs). PM is of particular interest due to the high levels from open burning, the predominance of the inhalable size fraction, and the ability

pollutant types.⁴ Also, the 2008 health risk screening report from US. Army Corter for Health Promotion and Preventive Medicine (now the US. Arm Jinthine to Public Health) and Ar Force Sahool of Arropsec Medicario Jindiao Detrons Health Board comments indicating strong interest in multivatile for constants are been exposure and health effects, and relationships between genoremand location and reporter. More recently, be Monad Academous of Science Institute of these recording the Monad Academous Patient Bendre

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Aerostat-lofted instrument and sampling method for determination of emissions from open area sources

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point samplers. In addition, although ground-based samplers are often positioned on towers to improve their possibility for sam-plin, higher plumes and wind shifts may result in ionaficient sample size to exceed detection limits. Optical remote sensing methods using "line" sight" measurements: Often benefit of path-integrated, rather than single point measurements. These sample methods are also ground-based and may be limited by a can be used to determine n of source strength, atmo-spersion modeling, down-1 to human health and the ficant for developing emissample methods are also ground-based and may be limited by their maneuvershifty as well as their applicability for some ana-hytes, such as polycyclic aromatic hydrocarbons (PAHs). Aerial sampling methods, with capabilities for vertical and horizontal maneuverability, overcome concerns in sampling lofted plumes. These methods can employ arighanes, helicopters, miniature re-mote control helicopters, and umanmed airshippJaerostatis (Lund de Concernor the source of the source ins, and for use in emi ces such as industrial sources such as industrial m burning. Typical sources b fires, structural fires, agri-ind grassland burns. Sam-t sources is particularly ing the need for proximity and Starkey, 1990; Laursen et al., 1992; Frick and Hoppel, 1993 aes for personnel. Further Li et al., 1995; Imhoff et al., 1995; Fingas et al., 1996). While airch preclude sampling until planes and helicopters can carry heavy payloads, pilots are often quite reticent to fly through combustion plumes due to visibility it the representativeness of quite exticent to fly through combastion plannes due to visibility and intributience concerns. The use of algues and beliesopters often and transformer concerns. The use of algues and beliesopters often in the near-source planne, timiting the amount of sample that can be collected, the construction of the same of the construction of the same of the same of the same of the construction of the same of the same of the same of the provide same of the intation have been used for source characteristics and I conditions, such as wind hallenges for ground-based ; fax: +1 919 541 0554. ilett).

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Thank you!













