Quantifying Flare Generated Black Carbon: *Sky-LOSA Measurement of a Gas Flare in Campeche, Mexico*

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Canada's Capital University

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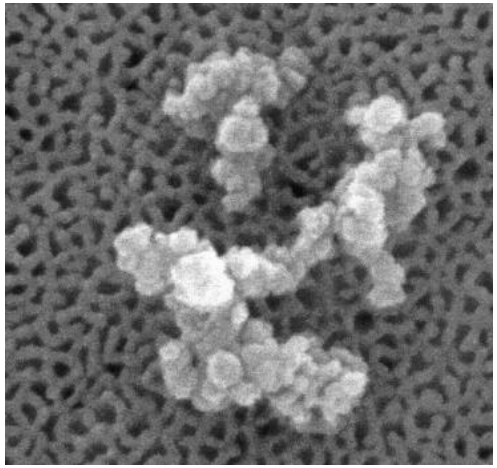
BC Emissions from Gas Flaring

- Black carbon (BC) component of soot is an important anthropogenic climate forcer
- Global gas flaring is ~140-170 billion m^3 annually
- Emission factor data relating BC emissions, flare conditions, and flared volumes are largely unreliable



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Project Objectives

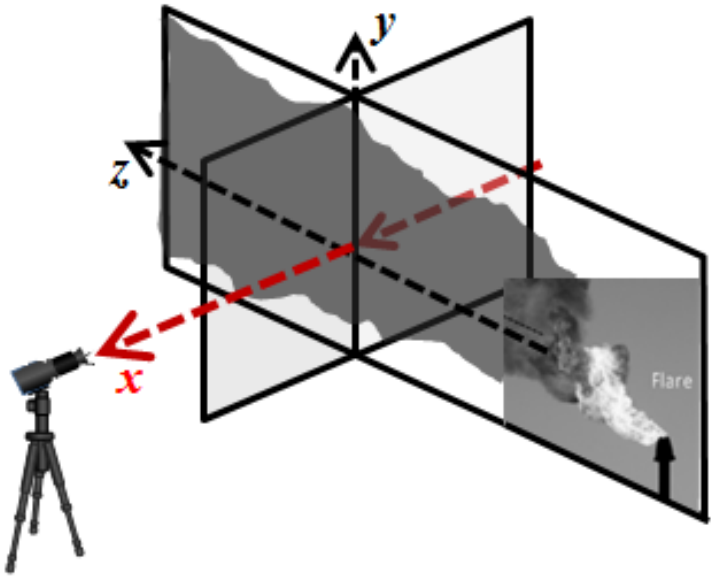
- Quantify BC yield (mass BC per mass of fuel) of an in-field flare
  - Field-data for flare generated BC is severely lacking and impedes mitigation efforts
  - Historic inability to quantify BC emissions from flares under field conditions
- Collaborate with CCAC and Petróleos Mexicanos (PEMEX) to conduct some of the global first field-measurements of BC yield from flares
- Identify economic opportunities for BC reductions
  - Valuable global case study data through CCAC
- Improve climate models through the development of field-derived emission factors

Project Challenges

- Field measurements originally planned at the Dos Bocas Marine Terminal (TMDB)
  - Site access precluded at last minute due to unexpected operational upsets
- Vital efforts in the field by PEMEX personnel enabled measurements at an alternative site: *Atasta Compressor Station*
  - Special thanks to Abril Moreno, Jorge Plauchù, and Benito Mendoza
- No access to flare lines at Atasta to collect flare gas samples for detailed composition analysis
- Field measurements had to be suspended after only a few hours due to protests in the area

Basic Principle of Sky-LOSA

- **Sky-LOSA** = **L**ine-**O**f-**S**ight **A**ttenuation of skylight
  - In-situ, optical quantification of BC mass emission rates from an atmospheric plume
  - Methodology based in Rayleigh-Debye-Gans theory for Polydisperse Fractal Aggregates (RDG-PFA)

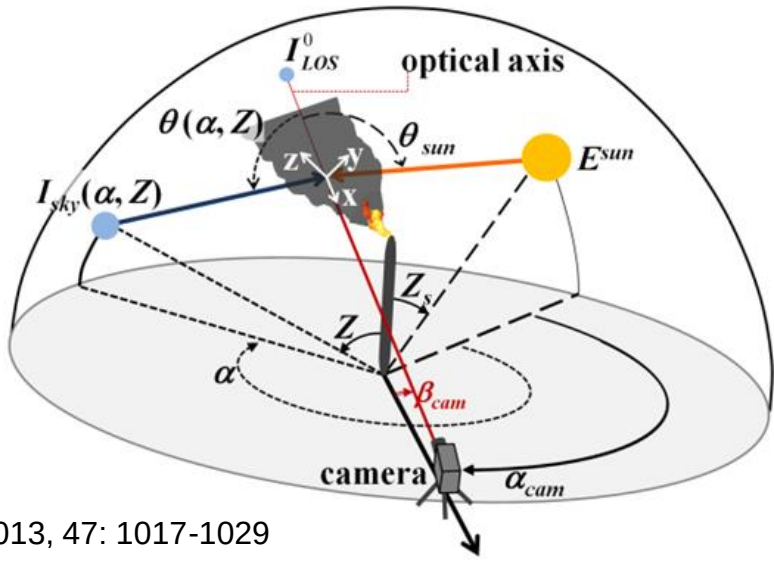


Basic Principle of Sky-LOSA

- Mathematical basis:

$$\dot{m}_{soot} = \frac{\rho_{soot}\lambda}{6\pi(1+\rho_{sa})E_{(m)_\lambda}} \int \left\{ \hat{u} \left[-\ln \left(\frac{\tau_{exp} - \frac{B}{AI^0_{LOS}} - \frac{C}{AI^0_{LOS}}}{1 - \frac{B}{AI^0_{LOS}} - \frac{C}{AI^0_{LOS}}} \right) \right] \right\} dy$$

  - Measured transmissivity, corrected for scattering effects, relates to BC concentrations in plume
  - Simultaneous image correlation velocimetry allows time resolved integration
  - Soot properties are incorporated via Monte Carlo analysis to enable quantified uncertainties



M.R. Johnson et. al., Aerosol Sci. Technol., 2013, 47: 1017-1029

Sky-LOSA Processing

- Four major steps
  1) Image correlation velocimetry to determine velocity of atmospheric plume
  2) Calculation of mathematically complex light-scattering parameters (A,B,C)
  3) Reconstruction of background skylight intensity
  4) Computation of time-resolved BC emission rate and uncertainties using a brute-force Monte Carlo method

Extremely computationally expensive under overcast or broken skylight conditions

Background Skylight Intensity

$$\dot{m}_{soot} = \frac{\rho_{soot}\lambda}{6\pi(1+\rho_{sa})E_{(m)_\lambda}} \int \left\{ \hat{u} \left[-\ln \left(\frac{\tau_{exp} - \frac{B}{AI^0_{LOS}} - \frac{C}{AI^0_{LOS}}}{1 - \frac{B}{AI^0_{LOS}} - \frac{C}{AI^0_{LOS}}} \right) \right] \right\} dy$$

For overcast/broken sky conditions:

Artificial advection of cloud structures behind plume

B.M. Conrad & M.R. Johnson, AWMA ACE (2015)

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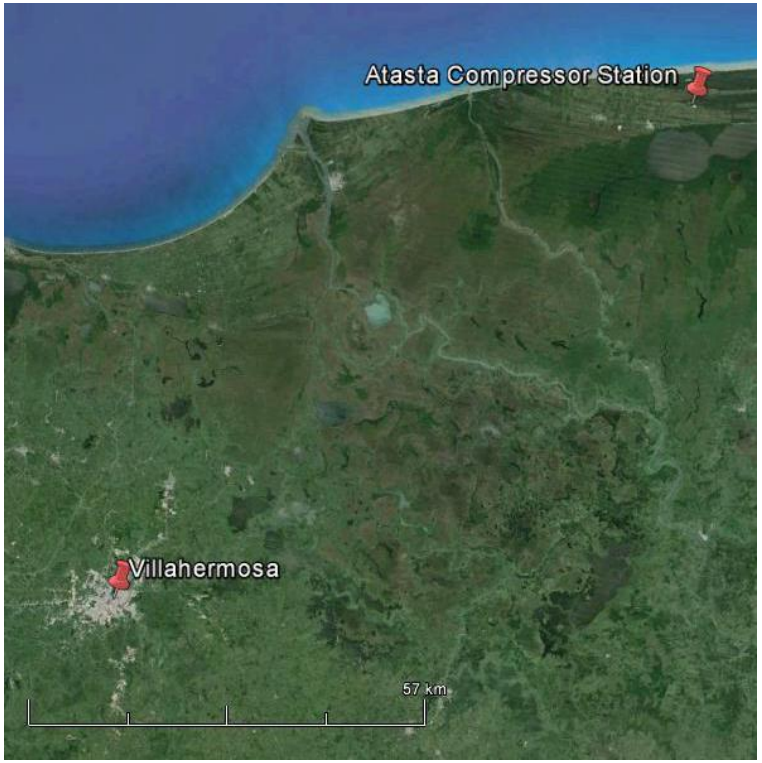
Field Measurements in Mexico

PEMEX's Atasta Compressor Station – June 30, 2015

Objective: Compute Black Carbon Emission Rate and Black Carbon Yield of an In-Field Flare



Site Flaring

Flaring activities occur in the Northwest corner of the site

Active Site Flaring

1) Emergency flare system
   - Two vertical (≈50 m) flares

Active Site Flaring

2) Compressor purge flare system
   - Horizontal pit flare

Horizontal Pit Flare

Sky-LOSA Data Acquisition

- Pit flare selected for BC emission rate analysis
  - Acquired two 10 minute sky-LOSA image sets
    - Totaling 60,000 images (618 GB)

Sky-LOSA Data Acquisition

- Subsequent measurements of the emergency flare system could not be performed
  - Damage to sky-LOSA's power supply system
  - Nearby protest and road blockade

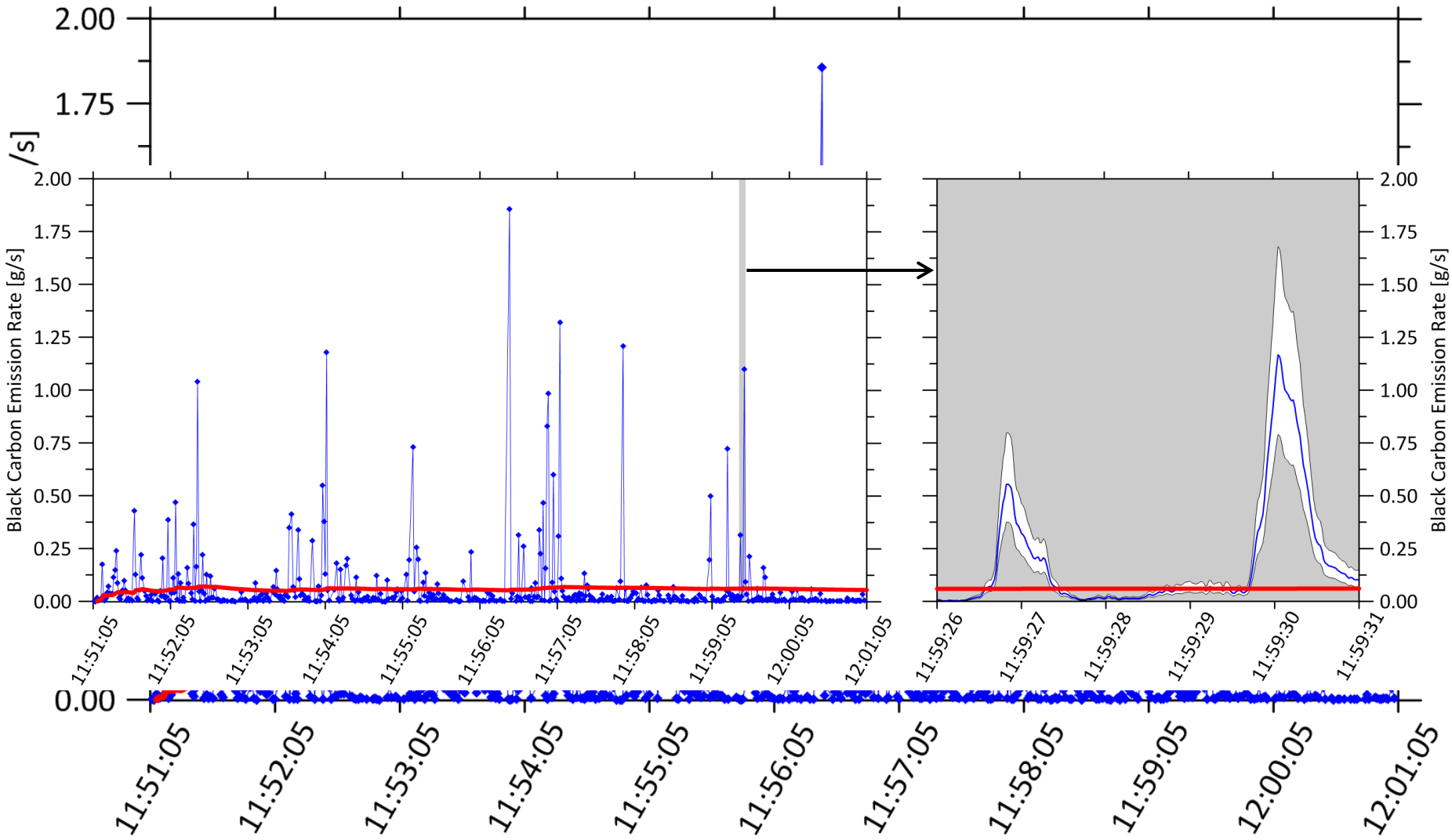
Flare Gas Flow Rate and Composition

- Simultaneous measurement of flare gas flow rate
  - Performed by Clearstone Engineering Ltd.
  - Mass flow rate directly measured via tracer-dilution technique
- Simultaneous measurement of flare gas composition
  - Performed by Clearstone Engineering Ltd.
  - Real-time measurement of C1-C5 hydrocarbon composition
  - Tunable Filter Spectroscopy measurement technique

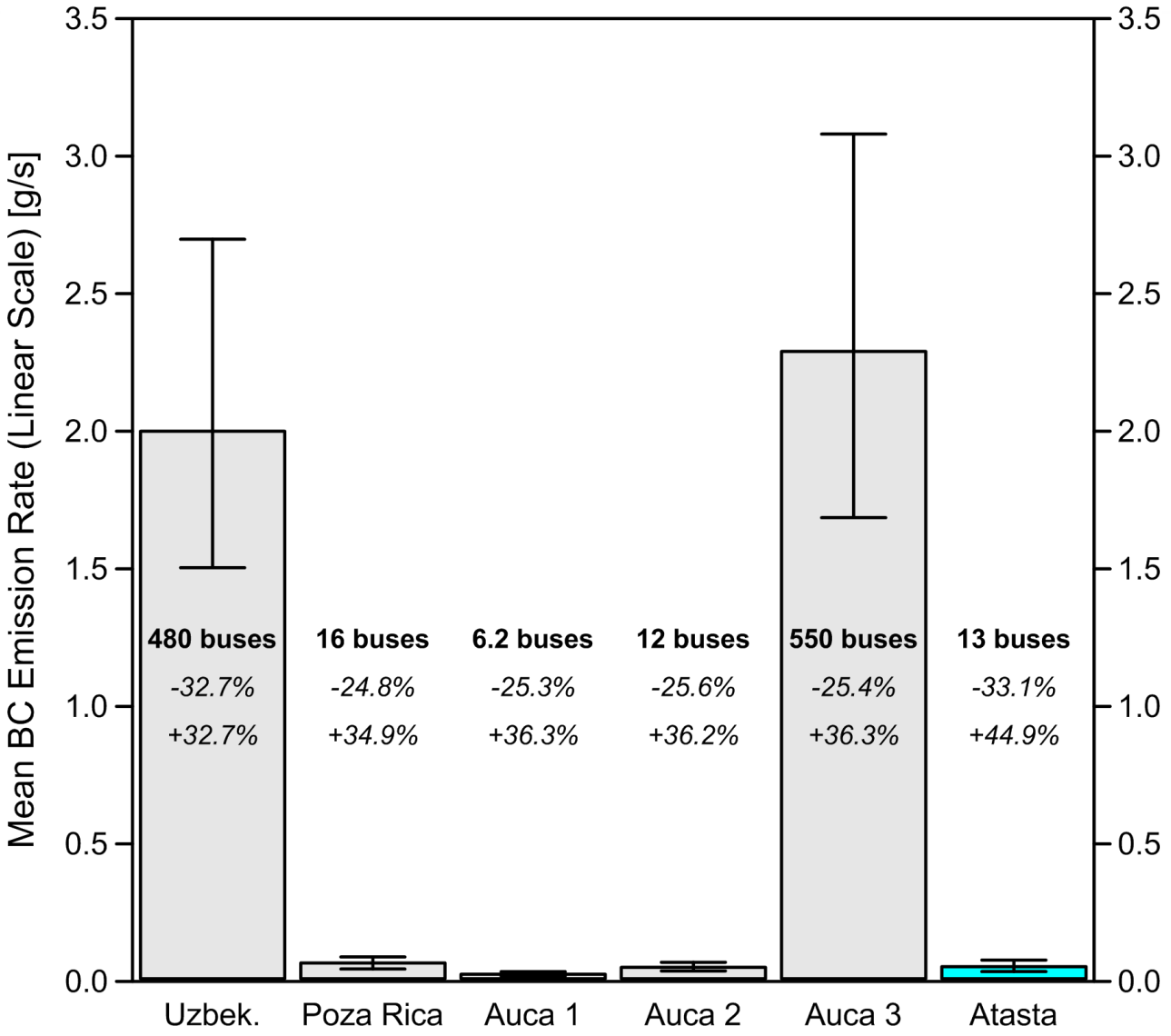
New / Enhanced Processing Algorithms

- Exceptionally difficult sky-conditions for image processing
- Project outcomes include development of enhanced sky-LOSA processing algorithms:
  - Separate tracking of cloudy sky and plume
  - Measurements achieved even though BC concentrations are quite low and a vast range of sky intensities exist
  - Work ongoing, but project is helping make sky-LOSA significantly more robust

Preliminary Results



Comparison of BC Emission Rates



Conclusions & Future Work

- Leadership of CCAC and PEMEX is helping tackle the globally significant issue of BC emissions from flares
  - Despite significant access challenges in the field, BC measurements achieved at alternate Atasta site
- Critical need for further measurements on broader range of flares and operating conditions
  - Wide range of field measurement data, including simultaneous composition, flow, and BC, are imperative for developing robust emission factors and inventories
- Continued collaboration with CCAC, PEMEX, World Bank and others fundamental to quantifying and mitigating flare emissions globally

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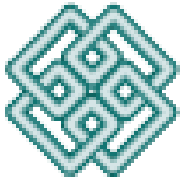
Acknowledgements

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

PEMEX

THE WORLD BANK



PTAC

Environment Canada

Natural Resources Canada

NSERC
CRSNG

Questions?