

# United Nation's Climate & Clean Air Coalition: *Accelerating Methane & Black Carbon Reductions from Oil and Natural Gas Operations*



**Carleton**  
UNIVERSITY

**Canada's Capital University**



United Nations Environment Programme



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

**Prof. Matthew Johnson**

Canada Research Chair in Energy &  
Combustion Generated Pollutant Emissions  
Energy & Emissions Research Lab.,  
Mechanical & Aerospace Engineering,  
Carleton University, Ottawa, ON

- International initiative under United Nations Environmental Programme
- Canada, United States, Mexico, EU, and 42 other countries are signatories
- Focussed on reducing ***methane*** and ***black carbon***
  - Key short-lived climate pollutants (SLCP)
  - Global warming potential (GWP) of fossil methane is 36 on 100-year time horizon and 87 on 20-year time horizon
  - GWP of black carbon is ~100 times greater again
- Recognizes potential for quick benefits by near-term reductions in SLCP

# Importance of Black Carbon (BC) Globally

- Photo shows black carbon deposited on snow in Greenland
  - Global gas flaring identified as most significant contributor (42% of all surface deposition in Arctic)
  - Black carbon on snow changes the surface albedo (increases solar absorption) and is thought to be a key reason for accelerated warming of the Arctic relative to rest of the planet



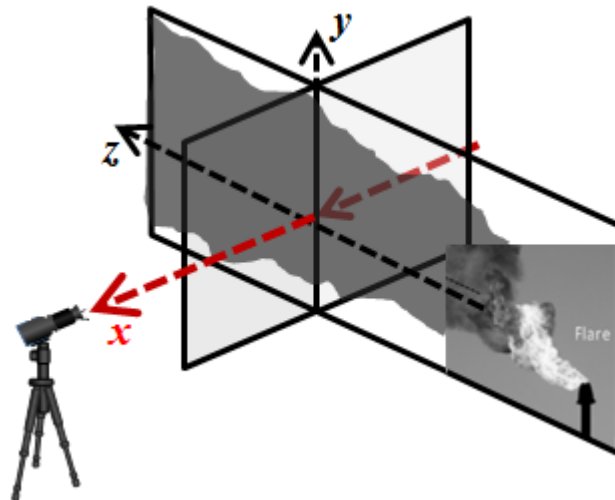
© Henrik Egede Lassen/Alpha Film, from the [Snow, Water, Ice, and Permafrost in the Arctic](#) report from the **U.N. Arctic Monitoring and Assessment Programme**.

# CCAC Project Objectives

- Collaborate with Petróleos Mexicanos (PEMEX) and Petroamazonas (Ecuador) to conduct some of the global first field-measurements of BC yield from flares
  - Field-data for flare generated BC is severely lacking and impedes mitigation efforts
  - Historic inability to quantify BC emissions from flares under field conditions
- Identify economic opportunities for BC reductions
  - Valuable global case study data through CCAC
- Measurement efforts led by Carleton University and Clearstone Engineering Ltd.

# Key BC Measurement Technique: Sky-LOSA

- **Sky-LOSA** = Line-Of-Sight Attenuation of skylight
  - In-situ, optical quantification of BC mass emission rates from an atmospheric plume
  - Developed at Carleton University in collaboration with National Research Council
  - Enables in situ quantification of BC emission rates in plumes



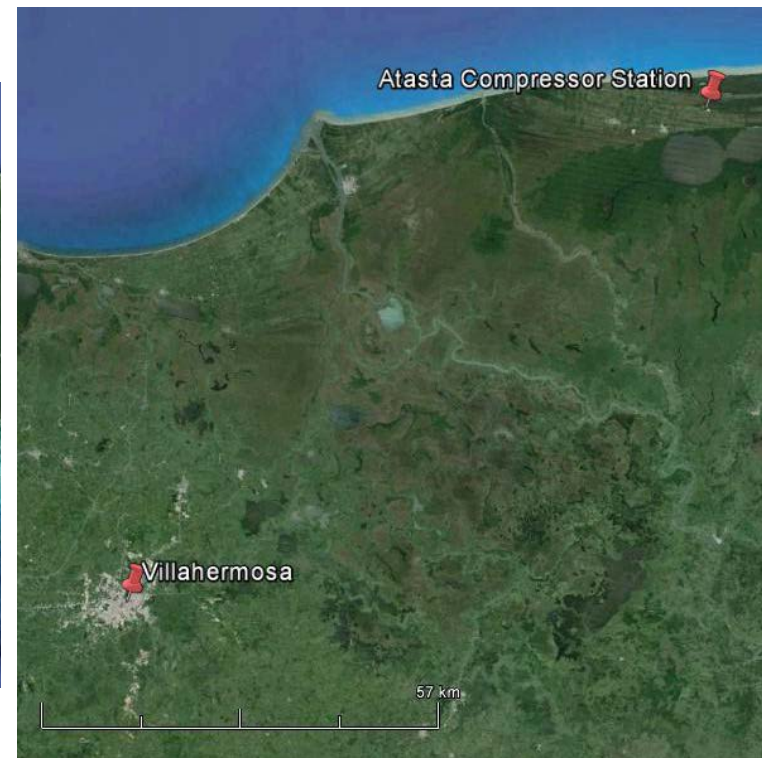
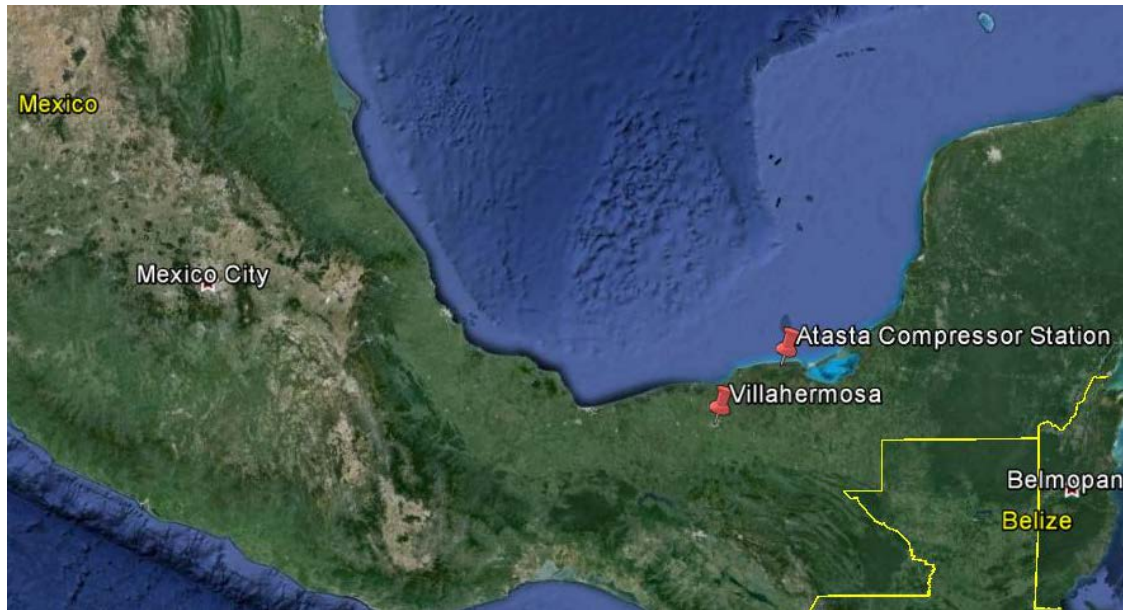
# Project Challenges

- Field measurements originally planned at the Dos Bocas Marine Terminal (TMDB)
  - Site access precluded at last minute due to unexpected operational upsets
- Efforts in the field by PEMEX personnel enabled measurements at an alternative site: *Atasta Compressor Station*
- 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

# 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 ( $\approx 50$  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 estimates of flare gas composition
  - Performed by Clearstone Engineering Ltd.
  - Real-time measurement of C1-C5 hydrocarbon composition
  - Tunable Filter Spectroscopy measurement technique



# Preliminary Results

- Clearstone Engineering Ltd. has performed measurements in Columbia and Mexico to identify mitigation opportunities
  - Results for Columbia are currently being processed
- Details of reduction measures in Mexico are protected by confidentiality agreements but approximately **90 million USD/year** in potential economically viable reductions have been identified and specific actions are now being taken on largest opportunities

# Field Measurements in Ecuador

- Large flare at upstream production site burning rich gas
  - Two 4" and two 6" lines feeding flare
  - More than 2.3 MMSCFD of heavy flare gas
  - Challenging measurement conditions



# Advancement of Sky-LOSA Technique

- New algorithm developed to enable accurate measurements in adverse sky conditions
  - Motion of sky/clouds and plume separately tracked
  - Background sky-light intensities obtained via scalar transport of intensity behind the plume
  - Extremely computationally intensive, but results are compelling



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

# Quantified BC Emission Rates

**Petroamazonas EP  
Bloque 61  
Auca 27**

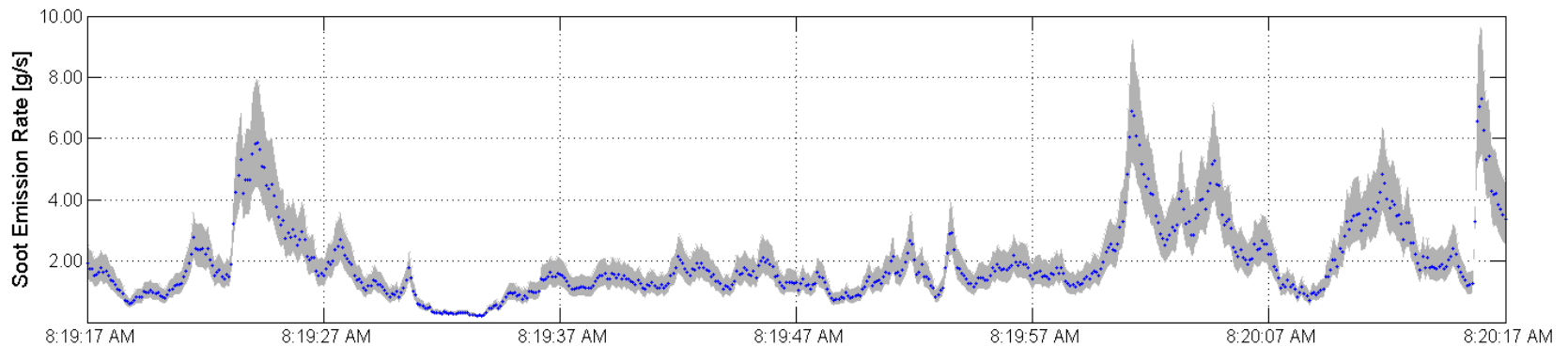
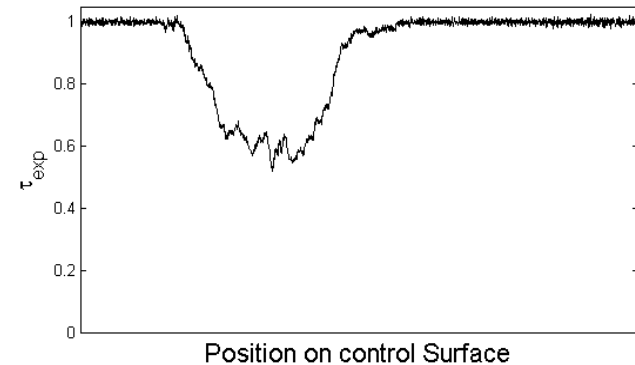
**04-JUN-2014  
Local Time: 8:20:17 AM**

**Instantaneous Soot Emission Rate:  
3.3700 g/s [-25.0% / +35.8%]**

sCMOS Image



Experimental Transmissivity



# Estimated Electricity Generation Potential

Site(s)	Electricity Gen. (MW <sub>e</sub> )	Capital Cost <sup>1</sup> (\$M-USD)	Based on Average Value of Electricity Alone in Ecuador <sup>2</sup>		Based on Offsetting Current Diesel Generated Electricity <sup>3</sup>	
			Annual Income (\$M-USD)	Simple Payback (Months)	Annual Income (\$M-USD)	Simple Payback (Months)
Auca 27	16.13	15.12	4.95	~36.7	23.55	~7.7
All 4 Sites	31.67	27.60	9.71	~34.1	46.23	~7.2

- Capital cost determined from assumed net power output on an average \$/kW basis<sup>1</sup>
- Electricity value assuming Ecuador-based pricing of 35 USD per MWh generated<sup>2</sup>
- Diesel offset considers \$2 USD/gallon & 12 MW<sub>e</sub>/gallon local generation costs<sup>3</sup>

<sup>1</sup> D. Pauschert, "Study of Equipment Prices in the Power Sector," Energy Sector Management Assistance Program, Washington, DC, Rep: 122/09, 2009.

<sup>2</sup> G. Salazar and H. Rudnick, "Hydro Power Plants in Ecuador: A Technical and Economical analysis," *IEEE Power Energy Soc. 2008 Gen. Meet. Convers. Deliv. Electr. Energy 21st Century, PES*, 2008.

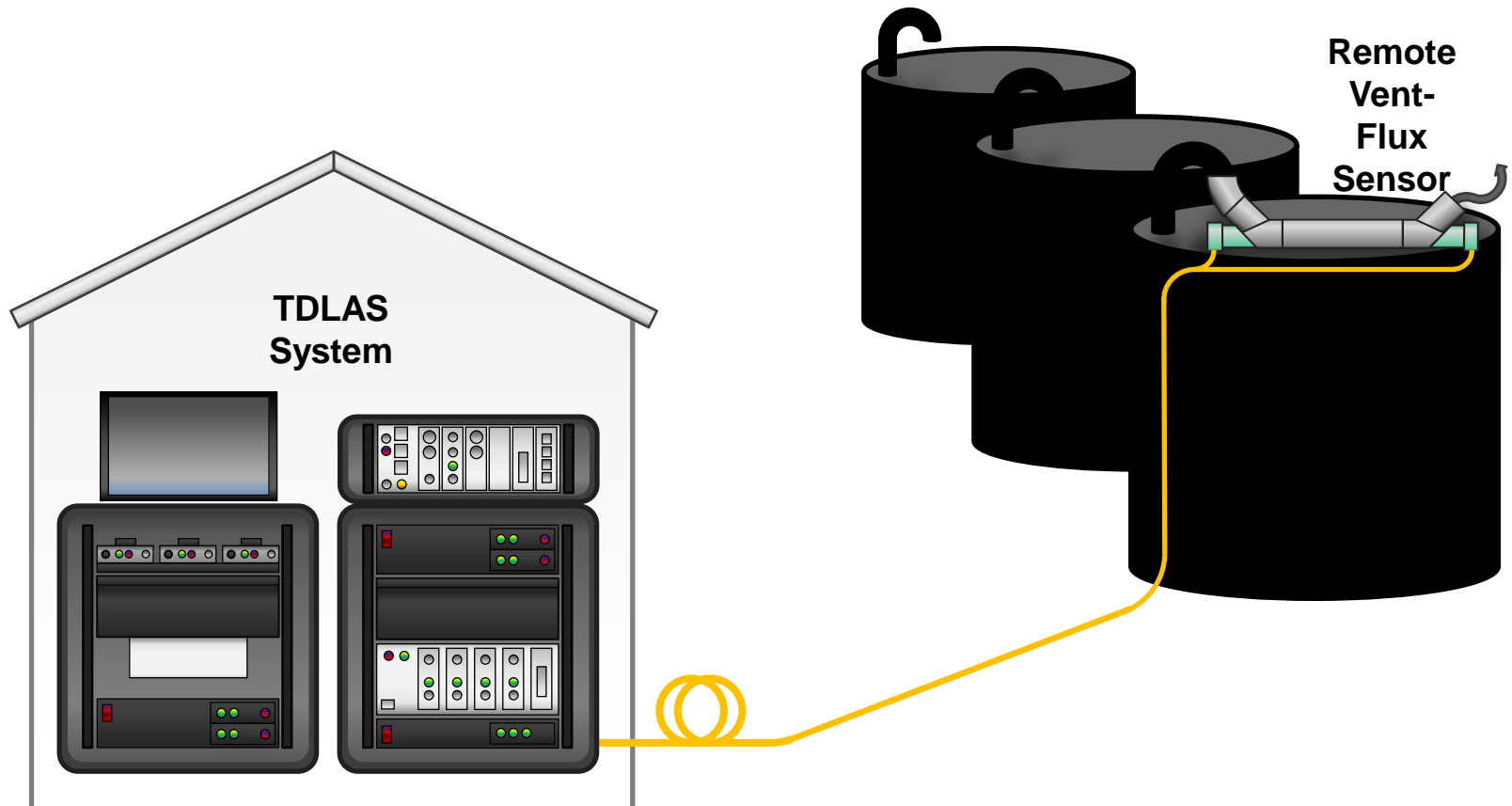
# Conclusions

- CCAC, World Bank, and International Industry Partners helping tackle the globally significant issue of BC emissions from flares
- 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
- Very significant and economically viable mitigation opportunities are being identified
- Much potential remains

# Future / Related Work

- Black carbon mitigation opportunities may be significant but what about methane and VOCs?
- Ambitious effort currently underway to attempt optical measurements of liquid storage tank emissions
  - Collaboration with Greatario Covers Ltd. And Natural Resources Canada CanmetENERGY-Devon
  - Pioneering a novel optical measurement approach
  - Key objective is to quantify mitigation performance of Greatario Hexacovers on fixed-roof liquid storage tanks

# Optical Tank Emission Measurement System



# Tanks at CanmetENERGY-Devon Pilot Plant

- Potential for controlled measurements and continuous measurement during normal plant operations
- Perfect opportunity to test new measurement technology and design experiments to evaluate current tanks models and quantify mitigation performance of Greatario Hexacovers



# Questions?



United Nations Environment Programme



CLIMATE &  
CLEAN AIR  
COALITION

TO REDUCE SHORT-LIVED  
CLIMATE POLLUTANTS



PETROAMAZONAS



PEMEX



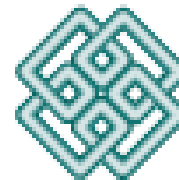
THE  
WORLD  
BANK



GGFR  
Global Gas Flaring Reduction  
A Public-Private Partnership



Natural Resources  
Canada



PTAC

GREATARIO  
COVERS



NSERC  
CRSNG

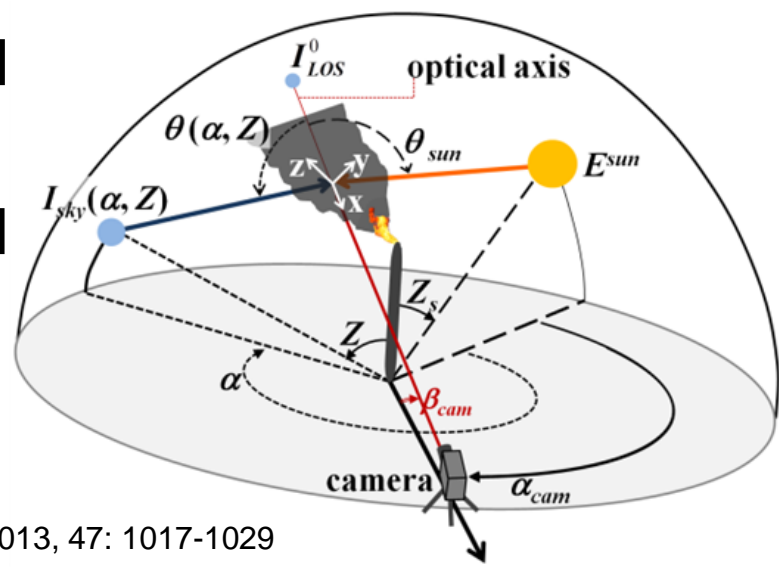
**Questions?**

# Basic Principle of Sky-LOSA

## ■ Mathematical basis:

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

- 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



# 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

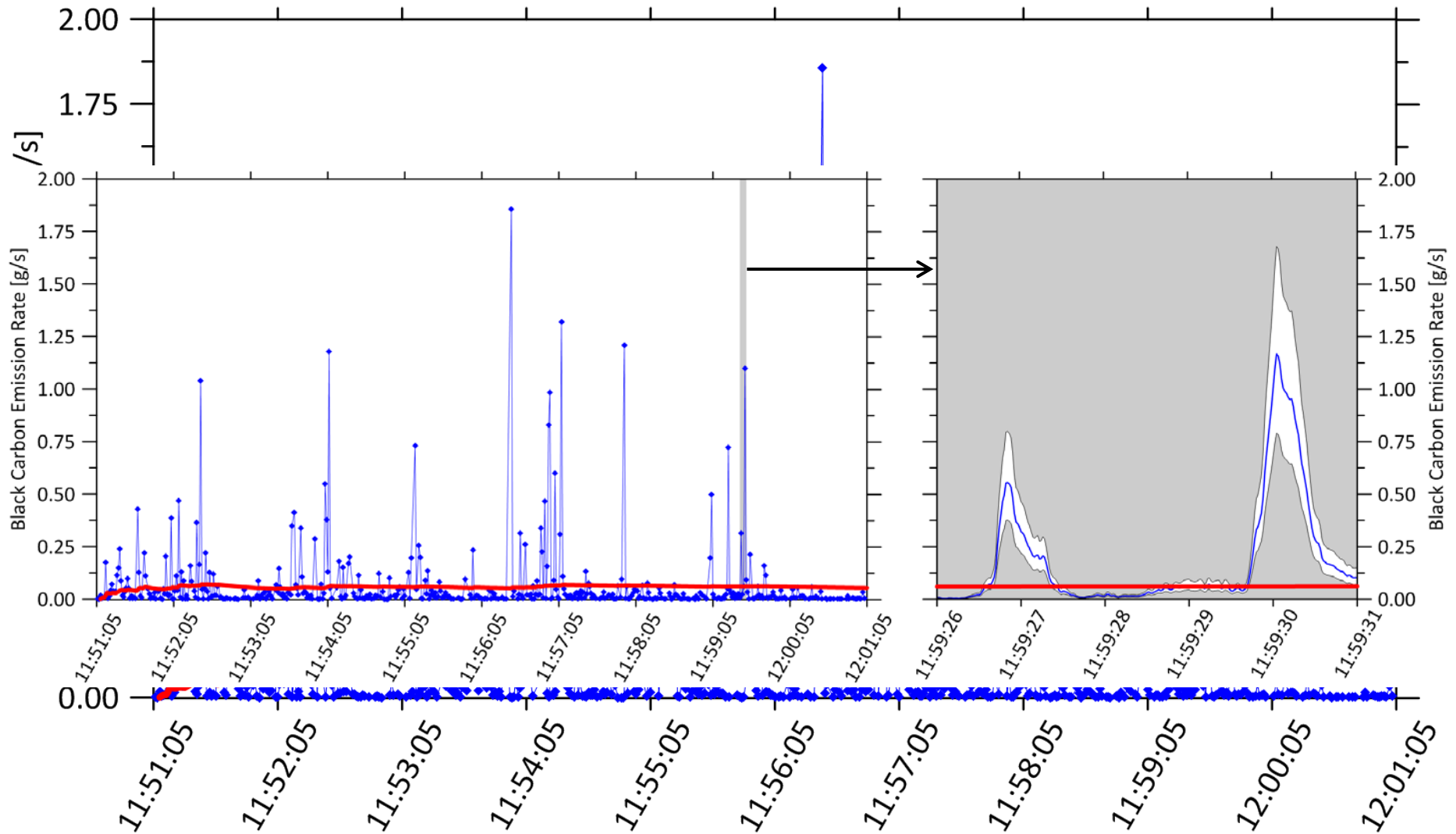
$$\dot{m}_{\text{soot}} = \frac{\rho_{\text{soot}}\lambda}{6\pi(1 + \rho_{\text{sa}})E_{(m)\lambda}} \int \left\{ \hat{u} \left[ -\ln \left( \frac{\tau_{\text{exp}} - \frac{B}{AI_{\text{LOS}}^0} - \frac{C}{AI_{\text{LOS}}^0}}{1 - \frac{B}{AI_{\text{LOS}}^0} - \frac{C}{AI_{\text{LOS}}^0}} \right) \right]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

For overcast/broken sky conditions:

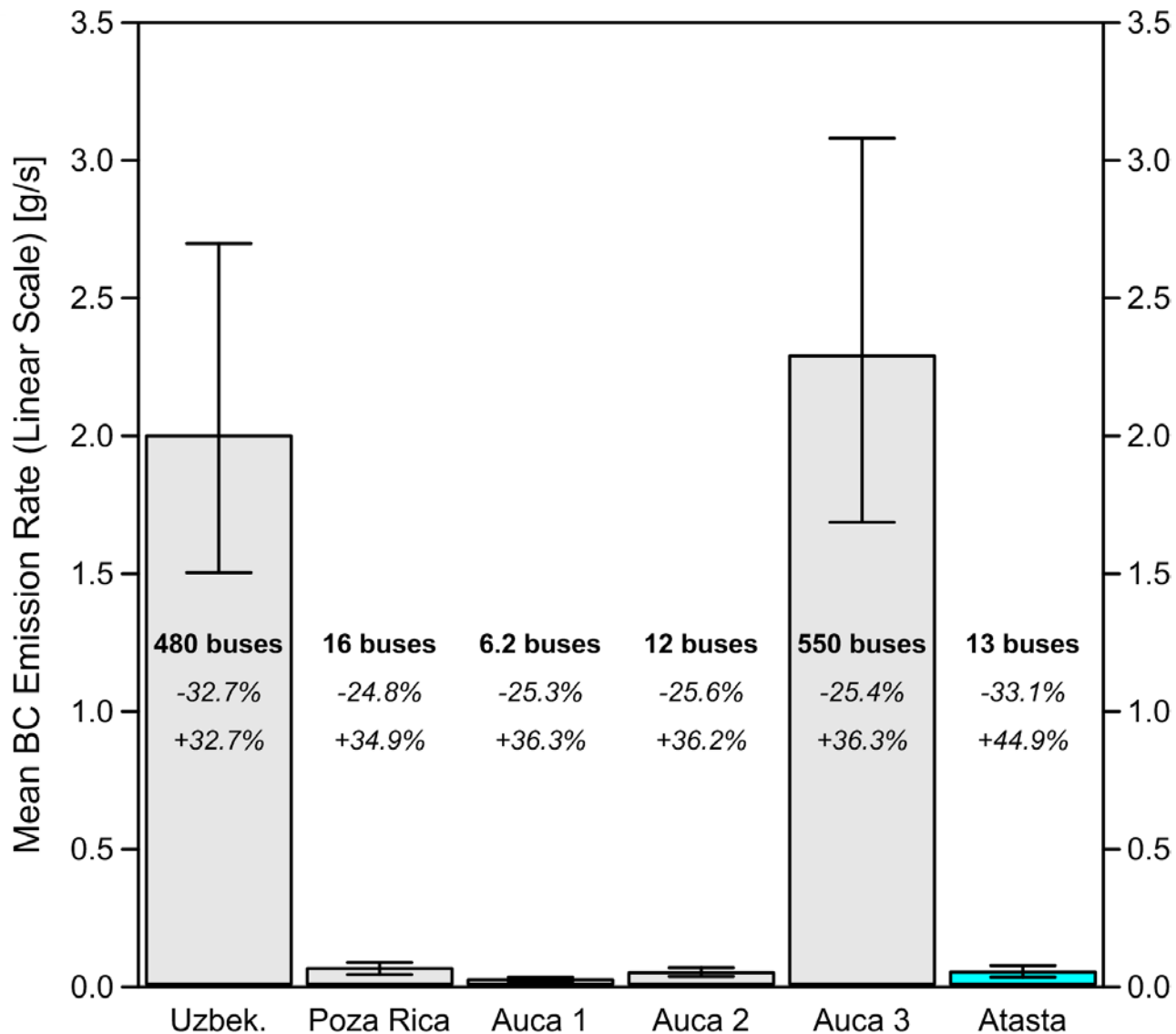
Artificial advection of cloud structures behind plume



# Preliminary Results



# Comparison of BC Emission Rates



# 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

