Assimilation of LIDAR Backscatter and Wind Data into an Atmospheric Transport and Dispersion Model

Paul Bieringer[1], Scott Higdon[2], George Bieberbach[1],
Jonathan Hurst[1], Shane Mayor[3], Josh Moellenkamp[1], and Aaron Piña[1]
[1]Aeris LLC, [2]Spectral Science Solutions, [3]California State University - Chico

BACKGROUND AND OBJECTIVES

Timely and accurate downwind hazard predictions are essential to minimize the collateral human effects associated with the intentional or accidental airborne release of a toxic agent. Unfortunately, the ability to rapidly generate these predictions is often limited by a lack of essential information related to the toxic release itself (e.g. location, release rate, plume geometry) and the ambient meteorological conditions impacting the material transport. Additionally, development and analysis of these predictions can be a manually intensive process for even a trained CBRN analyst to complete in a reasonable amount of time. For releases involving the release of aerosols and particulates, the Real-time Eyesafe Visualization, Evaluation and Analysis Lidar (REVEAL) technology, developed by Spectral Sensor Solutions (S3) holds promise to better inform detection and subsequent specification of the atmospheric release and characterization of the evolving cloud propagation, while also providing estimates of the in-situ wind velocities. This real time information could then be directly utilized to provide initial conditions to a downstream Atmospheric Transport and Dispersion (AT&D) prediction system to provide rapid downwind hazard predictions. Given these potential benefits, a 6-month development, evaluation, and demonstration effort was executed to a) develop and exercise methods for assimilating REVEAL derived products into an operational Atmospheric Transport and Dispersion (AT&D) system; b) perform a quantitative evaluation to determine relative value added of LIDAR-AT&D system, and c) demonstrate the fully integrated real time LIDAR-AT&D system during a major field experiment.

ENABLING TECHNOLOGIES

REVEAL

Innovative eye-safe backscatter LIDAR system that enables the capability to simultaneously detect, map, and track aerosol plumes out to ranges of > 5 km, and to derive wide-area 2-D horizontal vector wind field information by applying advanced algorithms to the motion of aerosol features in the plumes and the surrounding atmosphere (Figure 1).

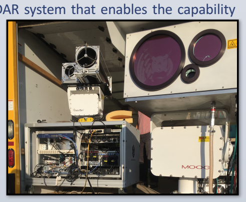


Figure 1. REVEAL System Hardware

Wavelet Based Optical Flow (OF) Wind Retrieval Algorithm (TYPHOON)

Estimates the wind field from a scan pair using a displaced frame difference data model (Figure 2).

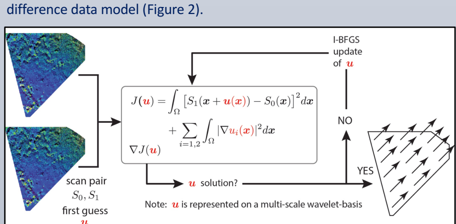
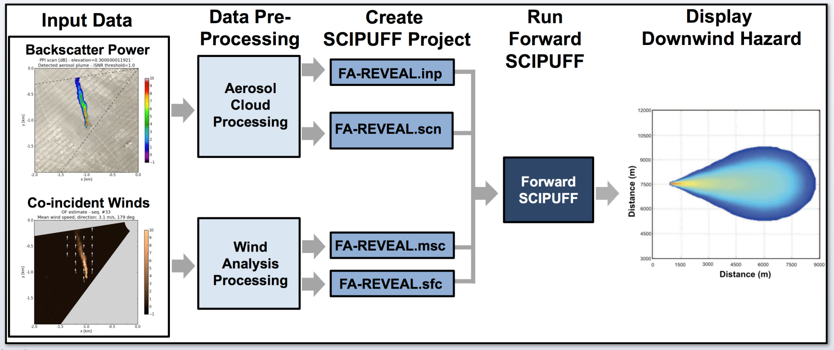


Figure 2. TYPHOON Algorithm Process Flow (Derian et al 2013)

Second order Closure Integrated PUFF (SCIPUFF) Model

Core atmospheric transport and dispersion modeling engine of the Hazard Prediction and Assessment Capability (HPAC), which utilizes a Lagrangian Gaussian puff formulation to represent and evolve a time-varying 3-dimensional concentration field (Sykes et al 2016).

METHODOLOGY



Aerosol Cloud Processing

REVEAL estimates of the detected plume boundary and pixels of backscattered power were translated into individual SCIPUFF Guassian puffs (Figure 3). We utilized a simple backscatter power (P) to mass conversion factor to derive individual instantaneous puff release masses (Q). Individual puff spread moments were based on REVEAL specific range gate length and beam diameter. Polar coordinate based location of each pixel centroid used to define Cartesian coordinates of corresponding puff centroid.

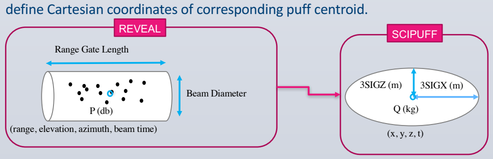


Figure 3. Translation of REVEAL backscatter power to SCIPUFF gaussian puff formulation

Wind Analysis Processing

Wind velocity estimates, derived by the OF wind retrieval algorithm, were directly translated into a SCIPUFF compatible weather input file (Figure 4).

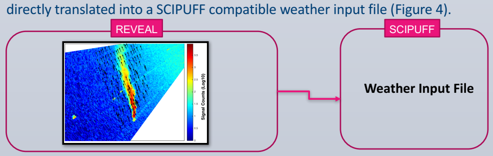


Figure 4. Translation of REVEAL OF wind velocities to SCIPUFF compatible weather input file

Proof of Concept Quantitative Evaluation

REVEAL data collected during the 2015 Sophos-Kydoimos (S/K) Challenge II field experiment (Figure 5), Trial 22, were used to evaluate the potential "added value" of the REVEAL-SCIPUFF proof of concept. A "control" hazard prediction, based on Trial 22 referee data, was generated to serve as ground truth. A set of operational hazard predictions, which only utilized standard operational information, were generated. REVEAL based hazard predictions were then generated for each and every REVEAL scan collected during Trial 22 (63 scans/predictions). A comparison of the hazard prediction accuracies between the operational and REVEAL based simulations, as compared to the "ground truth" simulation was performed utilizing a Measure of Effectiveness (MOE) metric (Figure 6).

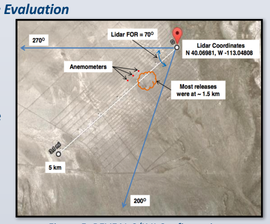
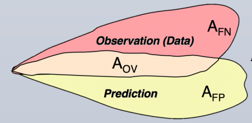


Figure 5. REVEAL S/K II Configuration



$$MOE = \frac{A_{OV}}{(A_{OV} + A_{FN} + A_{FP})}$$

Figure 6. MOE metric formulation (Warner et al 2011)

RESULTS

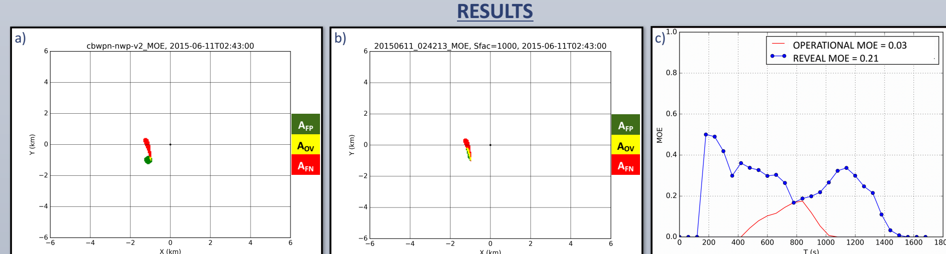


Figure 7. An example of graphical MOE areas derived from a a) standard operational scenario prediction and b) REVEAL generated prediction valid 8 minutes from the start of the Trial 22 release. c) MOE values versus time from the start of Trial 22 for the operational scenario (red) and REVEAL (blue) predictions. MOE Values in the text box represent total area under each MOE curve.

SUMMARY AND CONCLUSIONS

The feasibility of utilizing observed and derived products (backscattered power, wind velocities) from an operational LIDAR system (REVEAL) to provide improved and rapid downwind hazard predictions, via an operational AT&D model (SCIPUFF) has been investigated, evaluated, and demonstrated. A limited quantitative evaluation of the potential "value added" of a REVEAL-SCIPUFF integrated system was performed and indicated a potential six-fold improvement in accuracy, as compared to utilizing operational predictions based on limited information. Given this potential benefit, an operational REVEAL-SCIPUFF prototype was developed and demonstrated at the 2016 S/K Challenge III field experiment, held at Dugway Proving Grounds (DPG), UT. The demonstration successfully illustrated the operational feasibility of rapidly generating and updating new hazard predictions based on each live streamed REVEAL scan, available every 10-15 seconds (Figure 8).

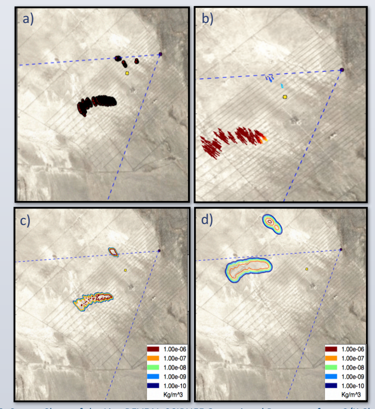


Figure 8. Screen Shots of the Live REVEAL-SCIPUFF Operational Prototype from S/K Challenge III, August 26, 2016. Output screens illustrate the a) REVEAL detected plume boundaries, b) REVEAL OF derived wind velocities, and REVEAL-SCIPUFF 2 and 6 minute concentration predictions, c) and d), respectively.

REFERENCES

Derian, P., P. Heas, C. Herzet, and E. Memin, 2013: Wavelets and Optical Flow Motion Estimation, *Numerical Mathematics: Theory, Methods, and Applications*, **6**, 116-137

Sykes, R.I., S.F. Parker, D.S. Henn, and B. Chowdhury, 2016: SCIPUFF Version 3.0 Technical Documentation

Warner, S., N. Platt, J.F. Heagy, G. Bradley, G. Bieberbach, G. Sugiyama, J.S. Nasstrom, K.T. Foster, and D. Larson, 2001: User-oriented measures of effectiveness for the evaluation of transport and dispersion models, *Institute for Defense Analysis*, P-3554.

ACKNOWLEDGMENTS

The work described here was funded by the US Defense Threat Reduction Agency under Contract No. HDTRA2-16-R-0001. The authors would like to thank Mr. Bruce A. Hinds (J9-TST) for his leadership and assistance in this endeavor. We would also like to thank Dr. Jerry Glasow (J9-CBI) and Mr. Richard Fry (J9-CBI) for providing invaluable technical guidance over the course of this project.

CONTACT

Aeris LLC
1314 Main Street, Suite 101
Louisville, CO 80027
http://www.aerisllc.com
Paul E. Bieringer: paulb@aerisllc.com

DTRA Funded Research