Testing the Forensic Radionuclide Event Analysis and Reconstruction Tool (FREAR)

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POSTER

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CTBTO PREPARATORY COMMISSION

ABSTRACT

The recently developed open source FREAR tool improves nuclear event analysis by using Bayesian inference principles to estimate key source term parameters using measurements from distant radionuclide monitoring equipment in combination with atmospheric transport and dispersion models (ATDM). Trials on real world reconstructions have demonstrated clear and dramatic improvements over standard correlation techniques, such as the Possible Source Region (PSR) algorithm. The improvements in source characterization are a result of implementing a statistical non-detection model that accurately represents the performance of the radionuclide detection equipment and by using a full ATDM uncertainty model in the reconstruction process. To further test the performance and capabilities of this tool, two blind tests are conducted with synthetic source terms with short- and long-range transport. The test scenarios and the results of the reconstruction are described and assessed to further demonstrate the compelling benefits of using the FREAR statistical tool in event analysis.

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INTRODUCTION

Forensic **R**adionuclide **E**vent **A**nalysis and **R**econstruction

- Robust system for preforming Bayesian statistical inference
- Designed to locate radionuclide source using sampler/sensor data with atmospheric transport and dispersion models (ATDM)
- Code (GPLv3) available in Gitlab repository:
  - https://gitlab.com/trDMt2er/FREAR

- For more information about FREAR, see **P2.4-373** How can we determine the origin of radionuclide observation? Presenting the Bayesian reconstruction algorithm "FREAR"

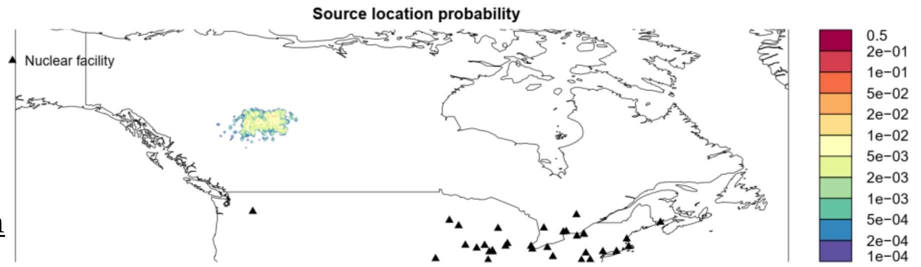

Figure 1: Example of source reconstruction with probabilistic source region

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INTRODUCTION

- The FREAR development project is a multi-national collaboration to develop a state of the art source reconstruction algorithm suitable for CTBTO applications
  - Project partners include Health Canada, Environment and Climate Change Canada, Canadian Nuclear Safety Commission, Defence Research and Development Canada, SCK CEN, United States Air Force Technical Applications Center, and Atomic Weapons Establishment (UK)
- A pair of synthetic source/receptor scenarios were created to support the testing, evaluation, verification, and validation of FREAR with the goals of:
  - Examining the accuracy, consistency, portability, and robustness of the system
  - Evaluating ease of use for reconstruction
  - Investigate performance with various meteorological models and Atmospheric Transport and Dispersion Models (ATDM)
  - Examine short- and long-range FREAR reconstruction

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METHODS

Long Range Model Configuration

- Weather Research and Forecasting (WRF) model v4.2 was used to construct the meteorological environment
- The National Center for Environmental Prediction (NCEP) Global Forecast System (GFS) provided initial and boundary conditions every 6 hours at 0.25° x 0.25° resolution
- The WRF model was initialized using 9 km resolution on 0000 UTC 13 July 2020 and integrated for 240 hours
- Hourly plume concentrations from the transport and dispersion model were output on a 60° x 60° grid centered at 59° N, 95° W with 0.5° resolution
- Transport and dispersion of the unknown plume source was recorded for 120 hours

Table 1. Model physics configuration

	Parameterization	Reference
Land Surface Model	Noah LSM	Chen and Dudhia (2001)
Microphysics	WRF Single Moment 6-class	Hong and Lin (2006)
Cumulus	Kain-Fritsch	Kain (2004)
Longwave/Shortwave Radiation	Rapid Radiative Transfer Model	Collins et al. (2004)
Planetary Boundary Layer	Mellor-Yamada-Janjic (MYJ) *	Janjic (2002)
Surface Layer	Mellor-Yamada-Janjic (MYJ)	Janjic (2002)

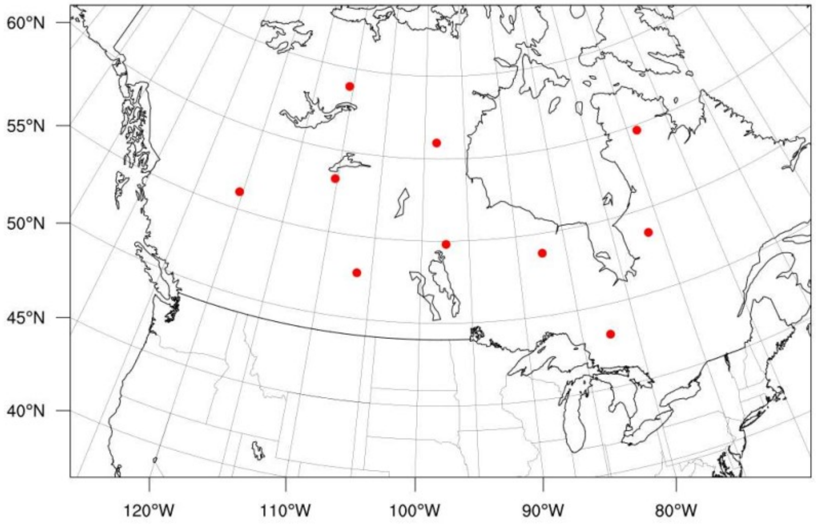

Figure 2: Long Range scenario domain with hypothetical receptor locations indicated with red circles

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METHODS

Short Range Model Configuration

- The Weather Research and Forecasting model v4.2 was used to construct the meteorological environment
- The NCEP Global Forecast System (GFS) provided initial and boundary conditions every 6 hours at 0.25° x 0.25° resolution
- The WRF model was initialized on three nested domains with 9, 3, and 1 km resolution on 0000 UTC 15 July 2020 and integrated for 120 hours
- Hourly concentrations were output on a 5° x 5° grid centered at 54° N, 97° W with 0.01° resolution
- 6 hour sample resolution provided for each hypothetical monitoring site
- Transport and dispersion of the plume was recorded for 24 hours

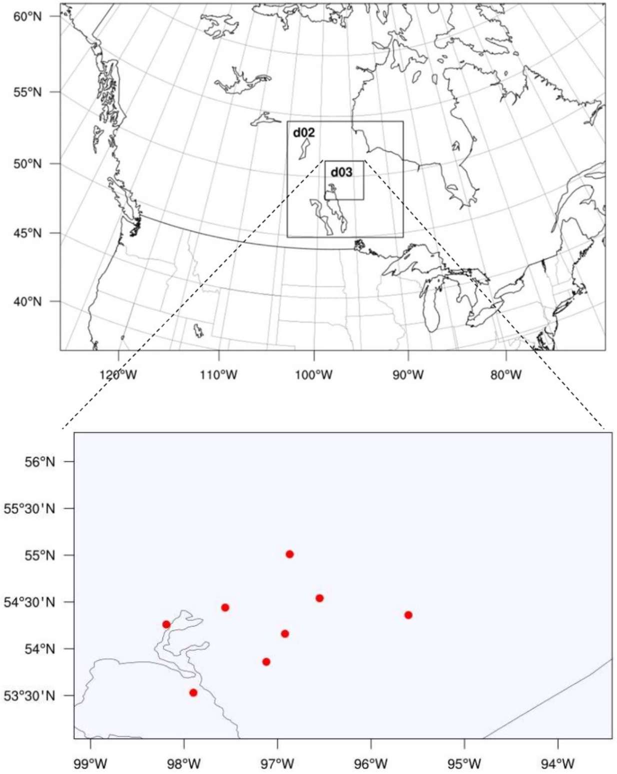

Figure 3: Short Range scenario domain with hypothetical receptor locations indicated with red circles

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METHODS

Plume Configuration

- HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory model) were used to drive a 12-member ensemble with WRF-provided met data
  - Release configured in 3-D with 100,000 particles released per hour, decreasing in number throughout the release duration
  - 12 alternative outcomes were generated using perturbed dispersion parameters for both scenarios
  - For the long range scenario ensemble members were averaged hourly to provide 12 hour sampler concentrations
  - For the short range scenario ensemble members was averaged hourly to provide 6 hour sampler concentrations
  - Raw WRF ensemble member values are also available for visualization/analysis of meteorological fields or for generating additional dispersion models (e.g. HYSPLIT, SCIPUFF, FLEXPART)
  - Sampler observation files containing "positive" samples and files containing all synthetic sample results (including non-detection) were created

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METHODS

Experimental Design

Two blind simulation experiment scenarios:

1) A long-range (synoptic) transport case (hundreds to thousands of km)
   - Plume transport is CTBT scale but with an increased density of detectors (allows for more detailed study of non-detects)
   - Similar in scale to several recent radionuclide events and detections
2) A short range transport case (tens to hundreds of km)
   - Typical nuclear emergency response scale

Data files supplied for reconstruction include ensemble and mean concentrations observed at each detector site location

- Inert tracer used – no radioactive decay considered

Participants are required to perform their own ATDM for reconstruction

- An estimate of ATDM uncertainty is also required for FREAR operation
- Cost function or Bayesian inference

Initial focus is on the long-range trial

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SUMMARY

Scenario reconstruction is currently underway by participants beginning with long range trial. Expected outputs from each reconstruction:

- Source latitude, longitude
- Release start time and stop time
- Release quantity
- FREAR configuration file used with reconstruction

Reconstruction results will be inter-compared among participants. Key elements included in review:

- User parameters specified in reconstruction
- Use of detects and non-detects in reconstruction
- Uncertainty model selection and parameters
- Bugs, problems, improvements
- Cost function versus Bayesian approach (if conducted)

Peer-reviewed publication will be prepared detailing scenario and evaluation of the blind test results.

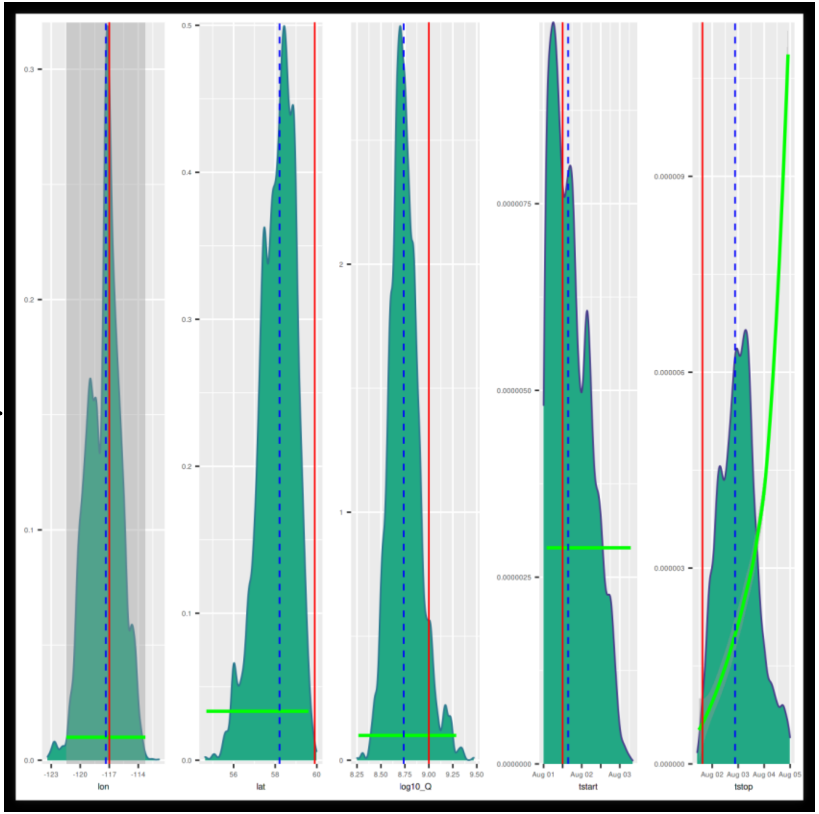

Figure 4: Monovariate marginal posterior kernel density estimates from FREAR reconstruction

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SUMMARY

After initial blind tests, examine Multiple Source-Receptor Sensitivity (SRS) ensemble reconstruction (combining participants models).

Scenario data will eventually be part of FREAR code repository as an additional example for new users

- Provide any participant contributed SRS files

Project close-out report due to funding body

- Summary of project development, capabilities, performance, outcomes, project transition
- Collect new project ideas to build capabilities for future project proposal options (e.g. noble gas reconstruction)

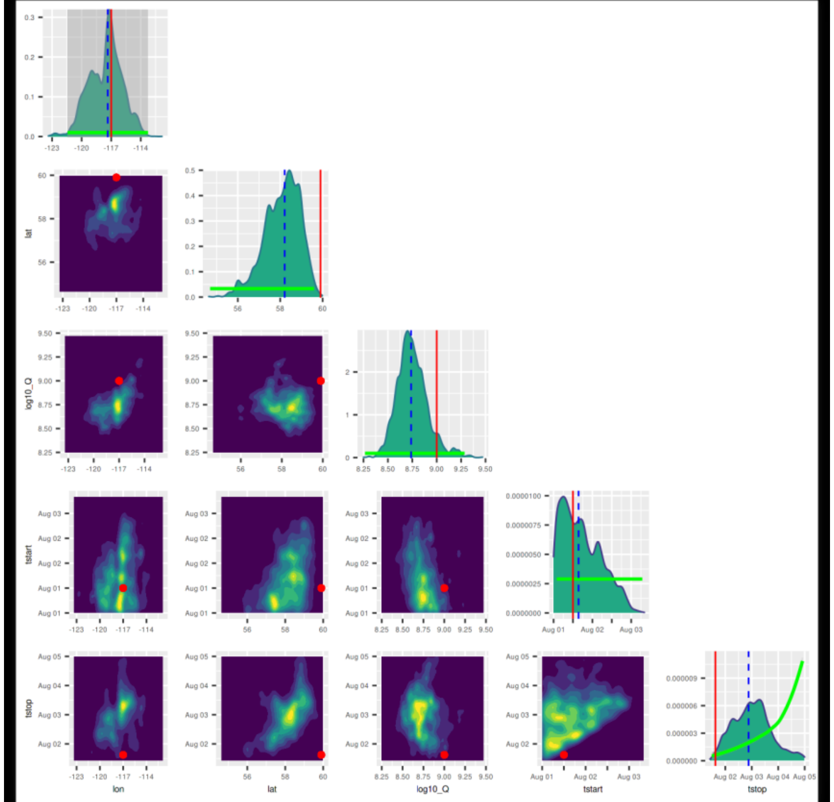

Figure 5: Bivariate marginal posterior kernel density estimates from FREAR reconstruction