# Inverse Modeling of April 2013 Radioxenon Detections

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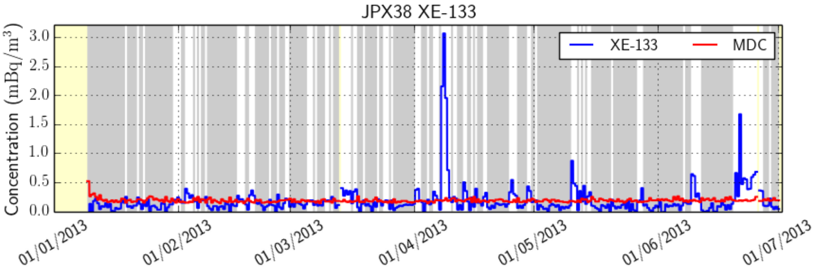
# Introduction

- Our goal is to analyze 3 significant $^{133}\mathrm{Xe}$ detections made between 7-9 April 2013 at Takasaki station (JPX38, CTBTO IMS)
- We attempt to estimate time- and height-dependent source shapes using a state-of-the-art inverse modeling technique and investigate influence of non-detections
- SRS fields and the inversion are performed in a more detailed manner than performed by the CTBTO (computational costs too high for routine calculations)
- Scenarios with both know and unknown source location are studied

# Samples included into inversion

- 3 significant JPX38 detections:
  - 08 April 2013 06:54 UTC collection stop
  - 08 April 2013 18:53 UTC collection stop
  - 09 April 2013 06:54 UTC collection stop




- Spatially we include additional samples from 5 adjacent stations (RUX58, MNX45, CNX20, CNX22 and USX77)
- Temporally we include $\pm 1$ sampling period for JPX38 and $\pm 2$ for other stations

# Source-Receptor Sensitivity (SRS) calculations

- SRS calculated using backward runs of FLEXPART, i.e. 34 runs, each with 1.5M particles, 12 days back
- SRS calculations performed with high accuracy:
  - ECMWF input data 0.25°horizontal resolution, 91 vertical levels, 3 h temporal resolution
  - FLEXPART output on lon-lat grid with $\Delta x = 0.25°$and $\Delta y = 0.2°$every 3 hours
  - Convection enabled in FLEXPART
- We assume 5 vertical levels in order to account for complex terrain at the DPRK test site (100 m, 500 m, 1000 m, 1500 m, and 2000 m)

# Methodology

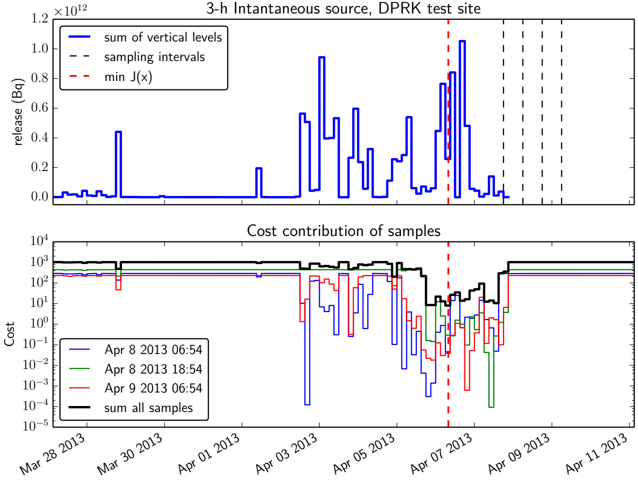
- Problem is ill-conditioned – data do not constraint enough all elements of the source vector $\Rightarrow$ we need **regularization**
- Solution is found via minimizing the cost function

$$J(\mathbf{x}) = (\mathbf{y}-\mathbf{M}\mathbf{x})^T\mathbf{R}^{-1}(\mathbf{y}-\mathbf{M}\mathbf{x})+(\mathbf{x}-\mathbf{x}_a)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_a)+\epsilon(\mathbf{D}\mathbf{x})^T(\mathbf{D}\mathbf{x})$$

- Model error estimated using "pseudo-ensemble" of model runs and added to measurement error
- First-guess solution = all zero; error selected using try-and-error approach
- Negative parts of solution were suppressed via iterative process modifying first guess error
- We assume point releases only (from a single grid cell)

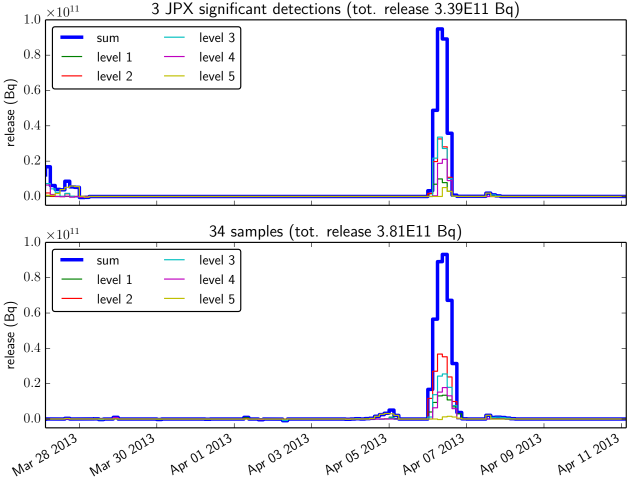
# Case 1: Instantaneous release at the DPRK test site

- Instantaneous (i.e. 3-h) release at the DPRK test site
- min $J(\mathbf{x})$ on Apr 6, 9:00 for the release $\mathbf{x} = 2.58\mathrm{E}11$ Bq



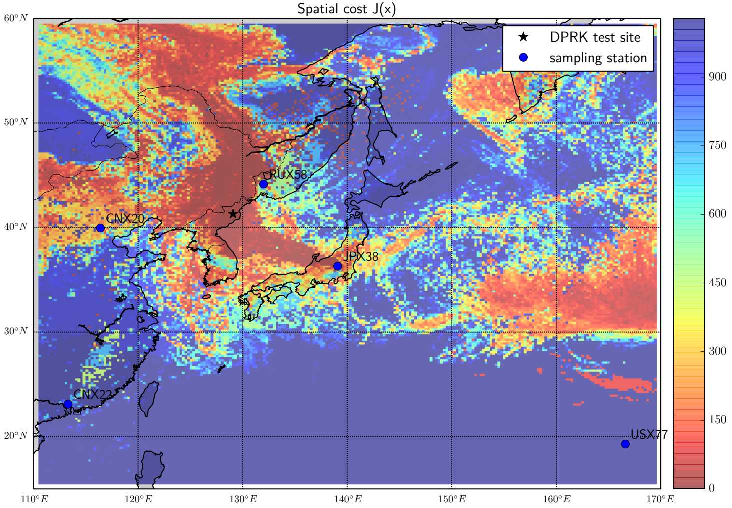
# Case 2: Continuous release at the DPRK test site

- Simultaneous estimation of the source strength as a function of release time and height
- Addition of non-detections suppressed releases at the beginning of assumed interval



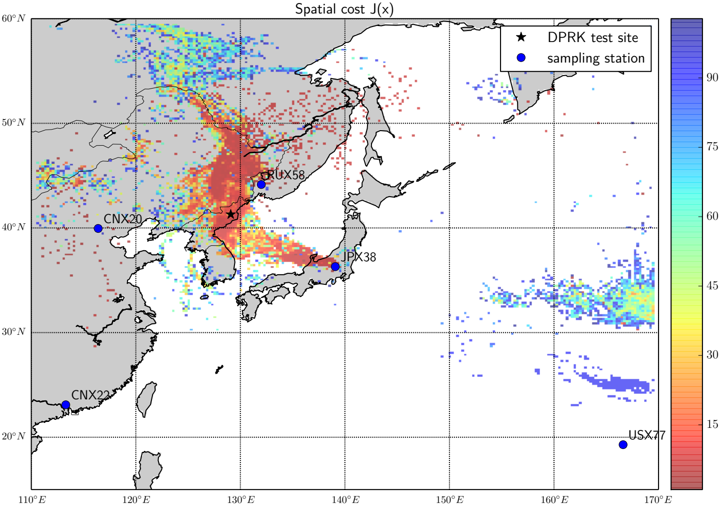
# Case 3: Cost function all over the domain

- Cost function evaluated for all grid cells in the domain as candidate source location, time/shape determined by inversion



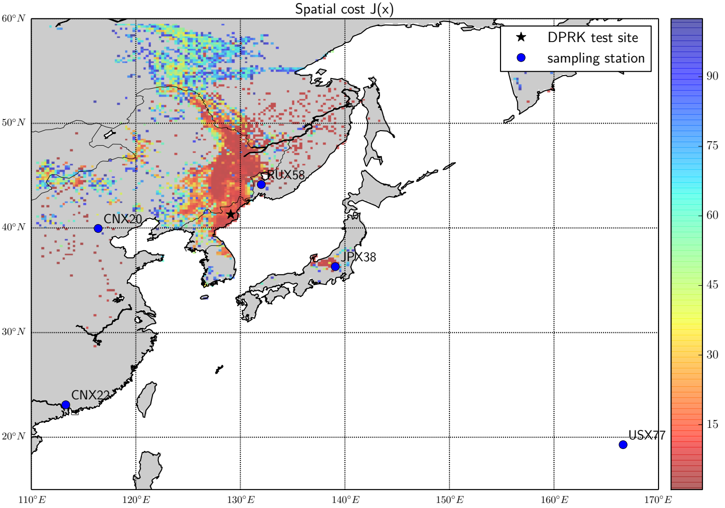
# Case 3: Cost function all over the domain

- Clipped at 10% of the maximum cost value



# Case 3: Cost function all over the domain

- Clipped at 10% of the maximum cost value and oceans masked



# Conclusion

- The problem is heavily ill-conditioned (34 samples, mostly non-detections, 605 unknowns), regularization methods for obtaining physically reasonable solution must be employed.
- Release shape and overall magnitude (2.58E11-3.81E11 Bq) estimated using different variants of the method are consistent and appear to be stable features.
- Magnitude of release is lower than previously suggested due to different inversion strategy and settings.

Ringbom et al.: *Radioxenon detections in the CTBT international monitoring system likely related to the announced test in North Korea on Feb 12, 2013*, J. Environ. Rad., (2013) estimated 2 releases of Xe-131m, each 7.0E11 Bq, where expected ratio $^{131m}\mathrm{Xe}/^{133}\mathrm{Xe} \approx 10^{-1} - 1$ after 55-60 days since fission

- Source location cannot be pinpointed to a small area with this amount of detections. However, the possible source area is still small enough to be useful for data fusion.

# Future plans

- Better treatment of model error (more types of NWP data, different ATM models, off-diagonal terms)
- Try to include known background radioxenon sources into inversion
- Include also $^{131m}\mathrm{Xe}$ data into the inversion

# Thank you!

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