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Improving the Quality and Spatial Resolution of Aerially-Collected Data Using Spatially-Variant Deconvolution

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Motivation

- **Develop data processing techniques that produce high-quality, high-precision survey maps detailing the extent, nature, and magnitude of radiological sources on the ground**
  - Correct distortions due to terrain, flight path, and vehicle altitude
  - Provide maps in the field within minutes
  - Improve the spatial resolution of the maps
- **Provide a lightweight detection system that can be flown aboard a small unmanned aircraft and be readily deployed**

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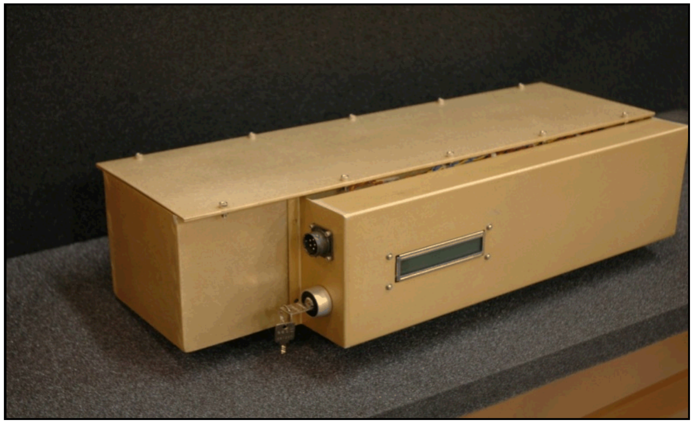
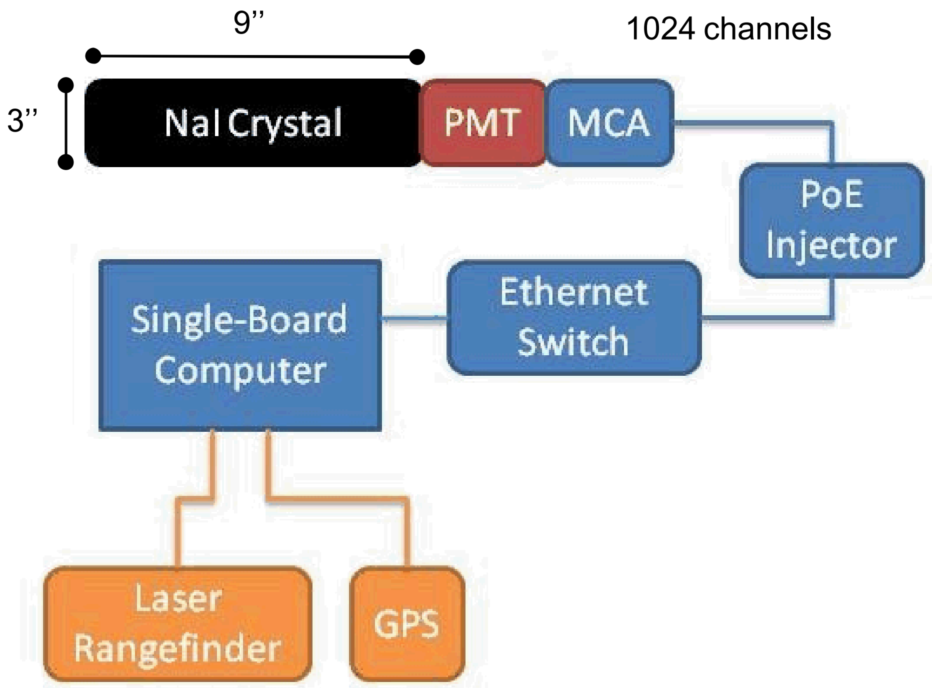
Sensor overview

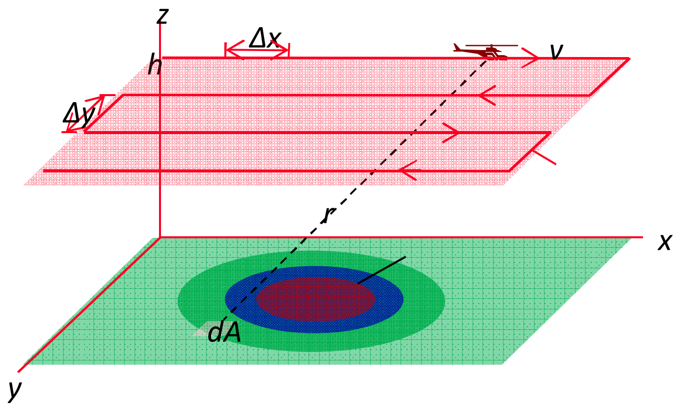
- Lightweight, < 20lbs (no shielding)
- Onboard 486 Low-Power SBC with solid-state memory
- dsciSpec MCA from iCX Radiation
- Laser AGL Sensor from Latitude Eng.
- Radiological Threat Search and Mapping Software (RTSMS)
- PostgreSQL database stores data until downloaded post-flight





Radiation surveys

- **Conducted in June 2010 at a site consisting of a long earthen dam**
- **Sensor was mounted to a small, unmanned helicopter**
  - Flown at 6 m/s with 6 m between scan lines
  - A 1024 channel spectrum was collected at a rate of 1 Hz
- **Two survey regions:**
  - 190 meter square centered over the dam
    - Used with a single source place on top of the dam in the center of the square
  - 150 meter by 240 meter rectangle nearly centered over the dam
    - Used on background surveys and with two sources



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Surveys

Source(s)	Location	Helicopter AGL	Survey Pattern
0.85 Ci ^{192}Ir	Top of dam	40 meters	square
0.85 Ci ^{192}Ir	Top of dam	60 meters	square
6.70 Ci ^{192}Ir	Top of dam	60 meters	square
6.70 Ci ^{192}Ir	Top of dam	80 meters	square
0.03 Ci ^{60}Co 0.85 Ci ^{192}Ir	Top of dam Bottom of dam	40 meters	rectangular
0.03 Ci ^{60}Co 0.85 Ci ^{192}Ir	Top of dam Bottom of dam	60 meters	rectangular

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Deconvolution: Motivation

- **The raw maps can be sharpened via deconvolution to better answer**
  - *Where* is the radiological material located?
  - *How much* source material is present?
  - *What* isotopes are present?
- **Allows us to eliminate the assumptions made by traditional solutions**
  - Fixed footprint
  - All points within the footprint share the same level of radiation
  - All points within the footprint share the same elevation
  - Static background
- **Proven technique for signal reconstruction**
  - Hubble Space Telescope mirror flaw
  - Medical imaging

Deconvolution: Definition

Convolution Equation: $h = f * g + \varepsilon$

Where

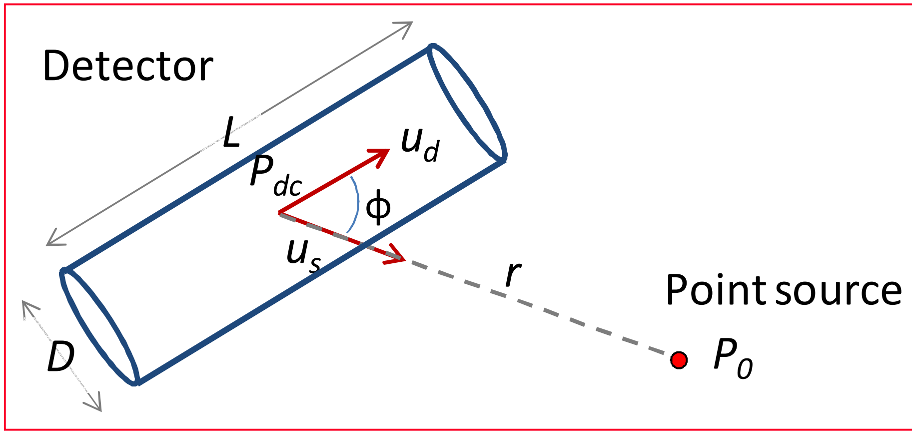
- f = the dataset to be estimated
  - *the actual size, shape and location of sources distributed across the area surveyed*
- g = the convolution kernel or point spread function
  - *the detector response model*
- h = the measured data
  - *gross counts*
- ε = the error
  - *noise*

Traditionally, deconvolution has been used with an invariant point-spread function.

Spatially Variant Deconvolution

- **Invariant point spread functions do not work for our mission**
  - Variations in the altitude and/or terrain can cause dramatic changes in the response of the detector to sources that might be present on the ground.
- **In order to accurately reconstruct the source distribution on the ground, we must use a spatially-variant point-spread function.**
  - For each location of the detector during the flight, we compute a different point-spread function. We term deconvolution performed with this type of point spread function ***spatially variant deconvolution***.

Detector Response Model



$$R_{det}(r,m,\phi,D,L) = \sum_{m} N(m)F(m,\phi)e^{-\alpha(m)r}\left(\frac{DL|sin\phi| + \pi(D/2)^2|cos\phi|}{4\pi r^2}\right)$$

where:

- N(m) is the count rate emitted by the source at energy m
- F(m, ϕ) is the efficiency of the detector at energy m and incident angle ϕ
- $\alpha(m)$ is the atmospheric attenuation coefficient at energy m
- r is the source-to-detector distance
- D is the diameter of the cylindrical detector
- L is the length of the cylindrical detector

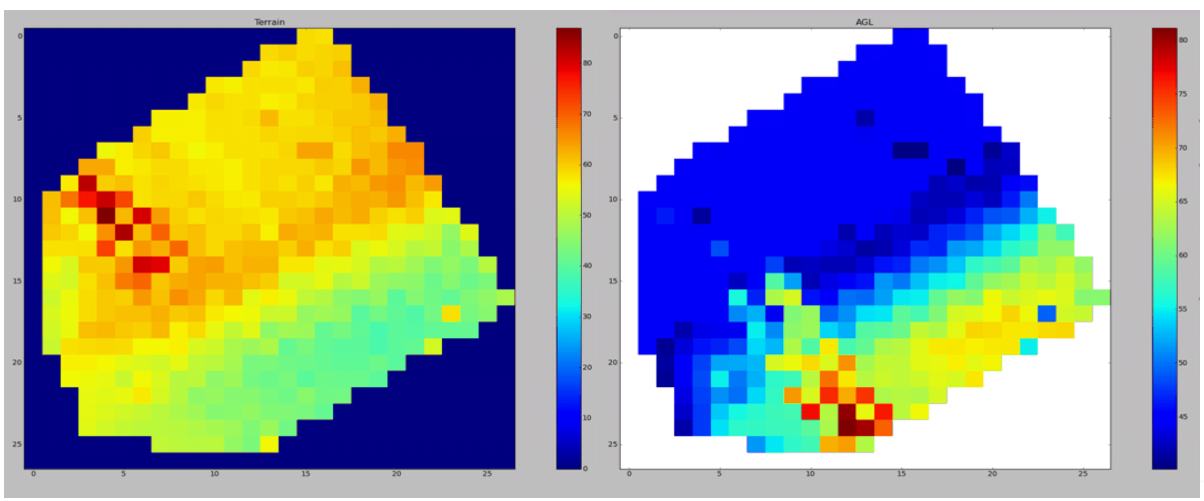
Spatially variant point spread function

- **As the detector flies its mission, it measures its altitude both above ground (AGL) and above mean sea level (MSL)**

$$\text{terrain} = \text{MSL - AGL}$$

- **From the terrain we construct a distance matrix,**

$$D = \begin{pmatrix} |x_1 - x_1|_2 & \cdots & |x_1 - x_n|_2 \\ \vdots & \ddots & \vdots \\ |x_n - x_1|_2 & \cdots & |x_n - x_n|_2 \end{pmatrix}$$



Terrain MSL elevation (left) and sensor AGL elevation (right)

Spatially variant point spread function

- **By evaluating the detector response model equation for each element of the matrix D for the energy level of each channel in the spectrum produced by the detector, we obtain a three dimensional matrix K, which is our spatially variant point spread function**

Each element K_{XYZ} represents the fraction of gamma particles emitted from location x that are successfully measured by the detector at location y, provided the particles are emitted with an energy of z.

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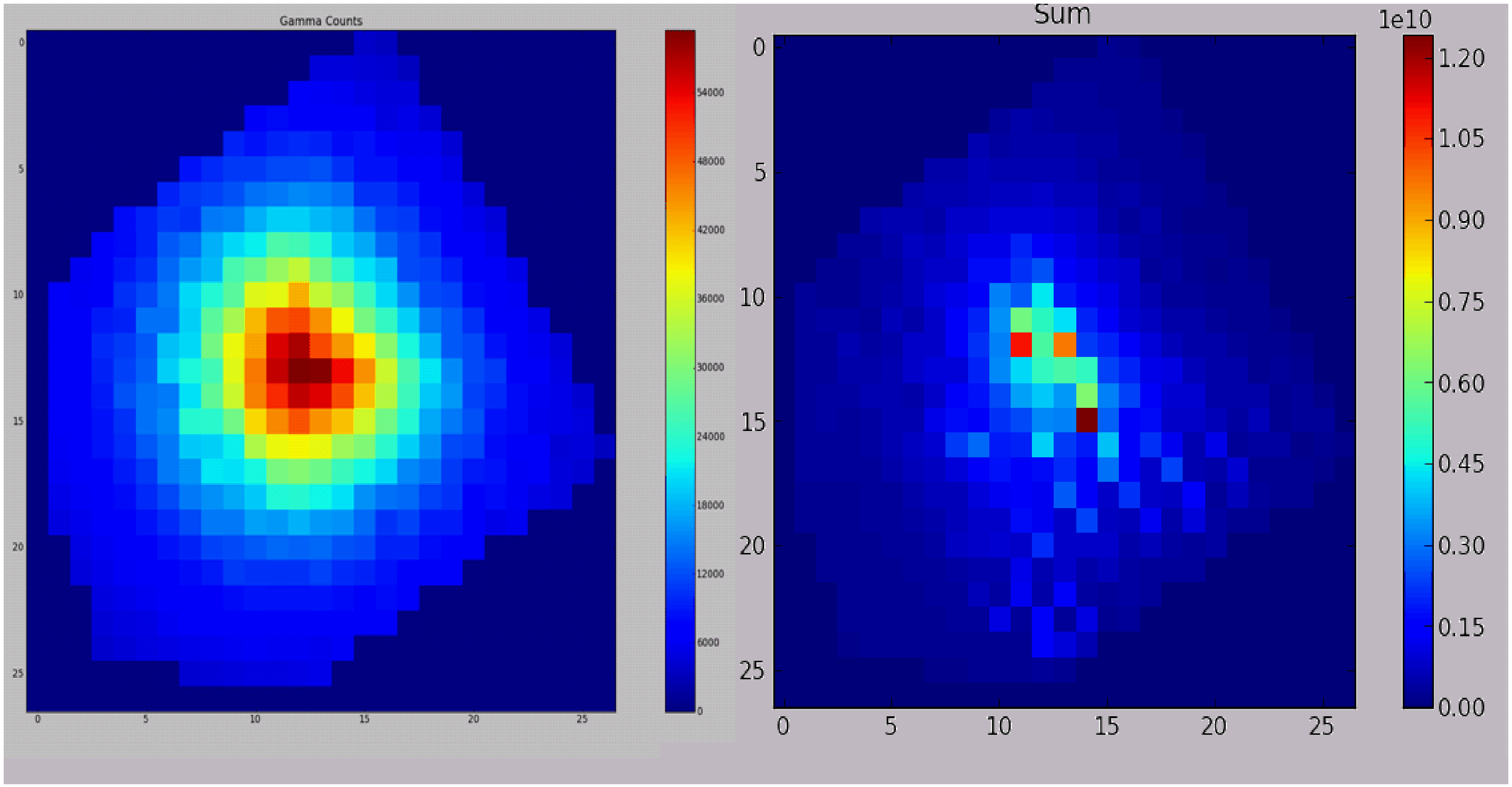
Deconvolution algorithms

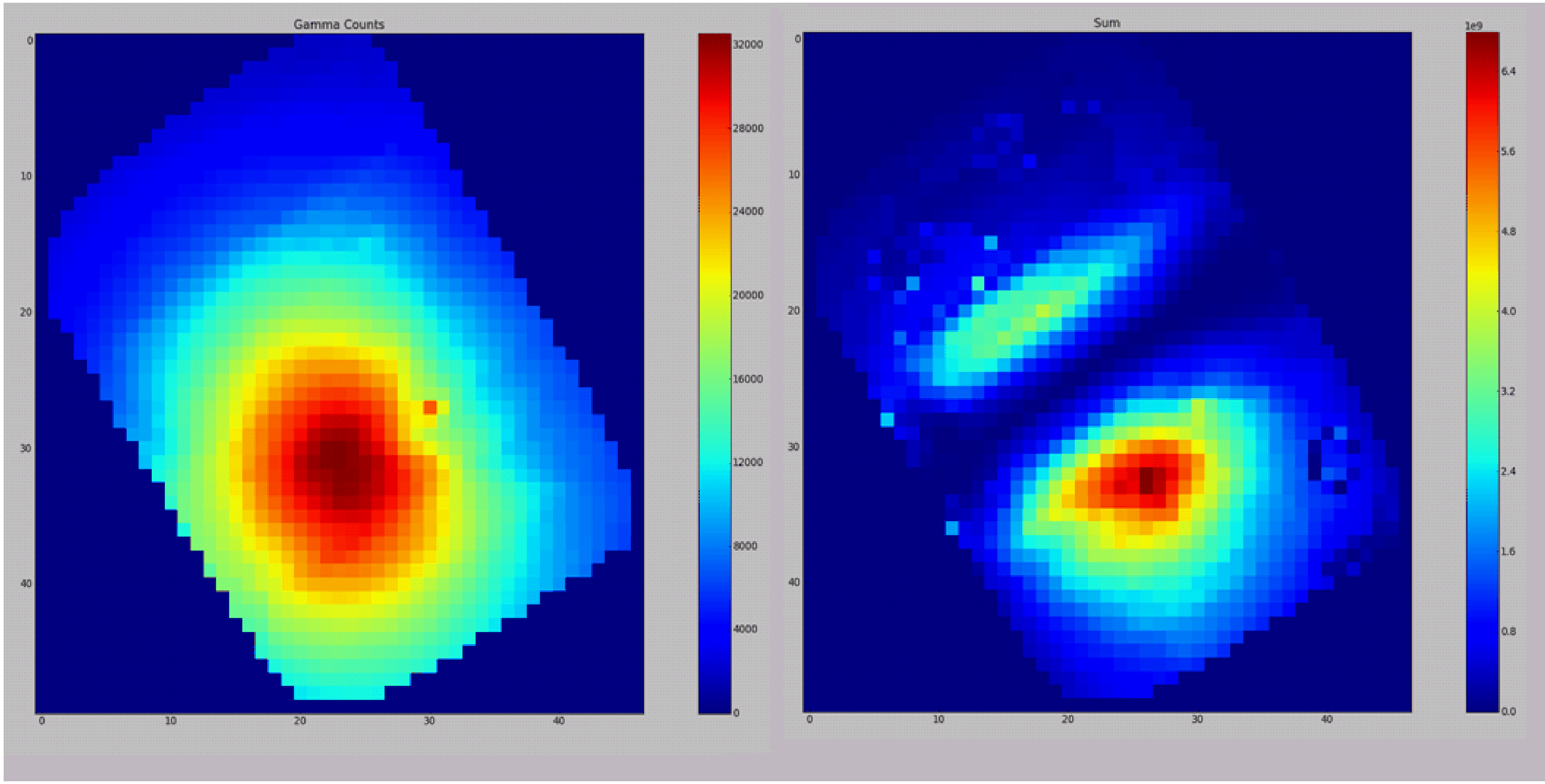
- Measured Reading = (Ground Truth x **PSF**) + Noise
- How do you back out ground truth? Iteratively
  - assume ground truth estimate and calculate what the measured response would be
  - determine error with measured response
  - correct estimate
- Two algorithms seem the most promising
  - Maximum Likelihood Estimation (MLE)
  - Positive Iterative Deconvolution (aka Basic Iterative Deconvolution, Non-Negative or BID-NN)

Deconvolution results



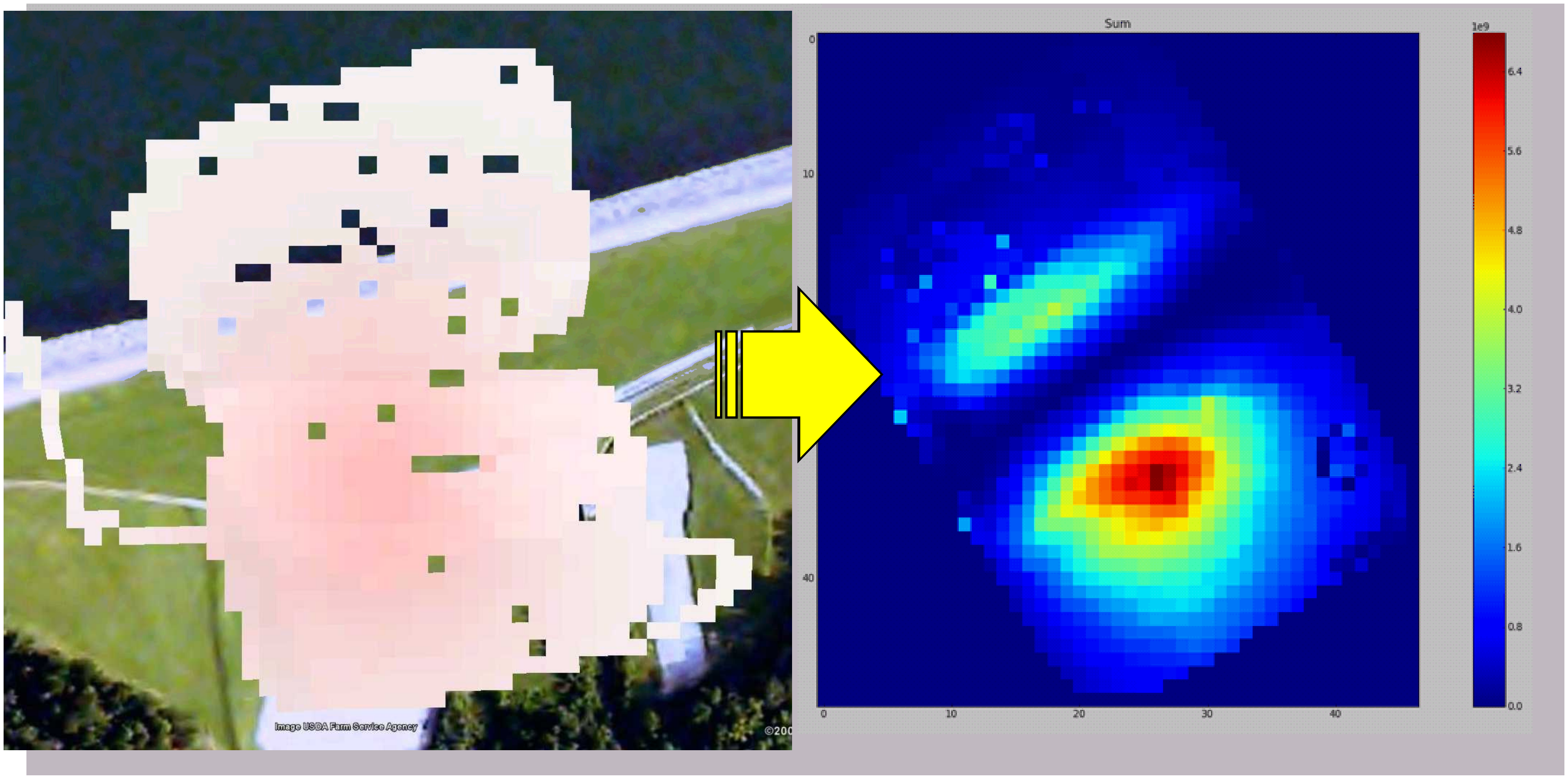
Square survey pattern; single Ir-192 source (0.85 Ci); BID-NN deconvolution

Deconvolution results



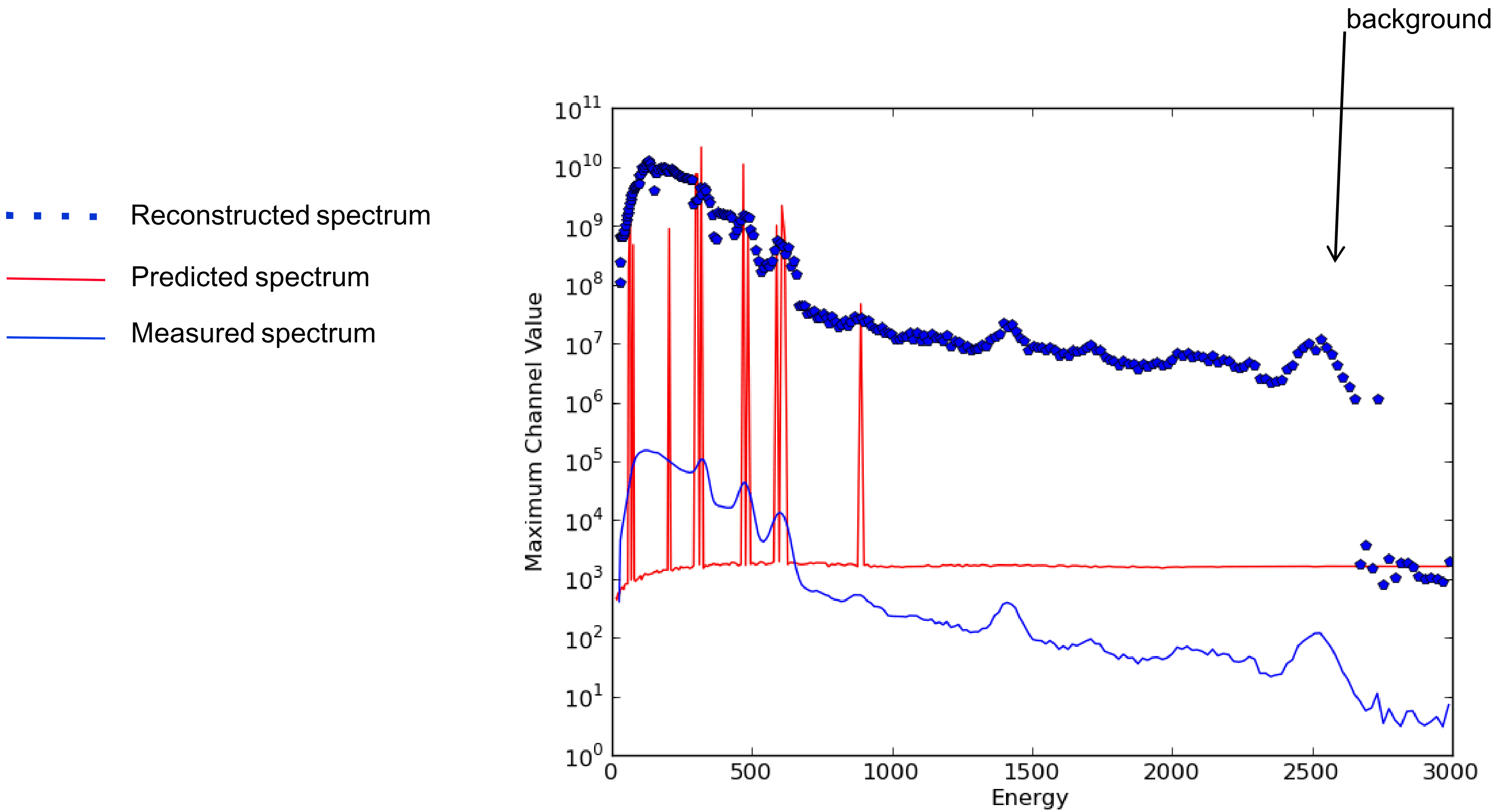
Rectangular survey pattern; Ir-192 source (0.85 Ci) and Co-60 source (0.03 Ci); MLE deconvolution

Before and After Deconvolution



Significant sharpening of image with 40 meter, 2 source survey

Deconvolution results: spectrum reconstruction



Conclusion

- **Spatially variant deconvolution offers improvements over current processing methods for aerial radiation surveys**
- **This technique can improve map products generated by aerial radiation detection platforms**
  - Location and identification of hot spots
  - Maps are generated in minutes in the field
- **Particularly well suited to surveys taken from low flying UAV platforms**
- **More data will help refine the algorithm**