

Optimization of Fugitive Emissions Sensor Networks

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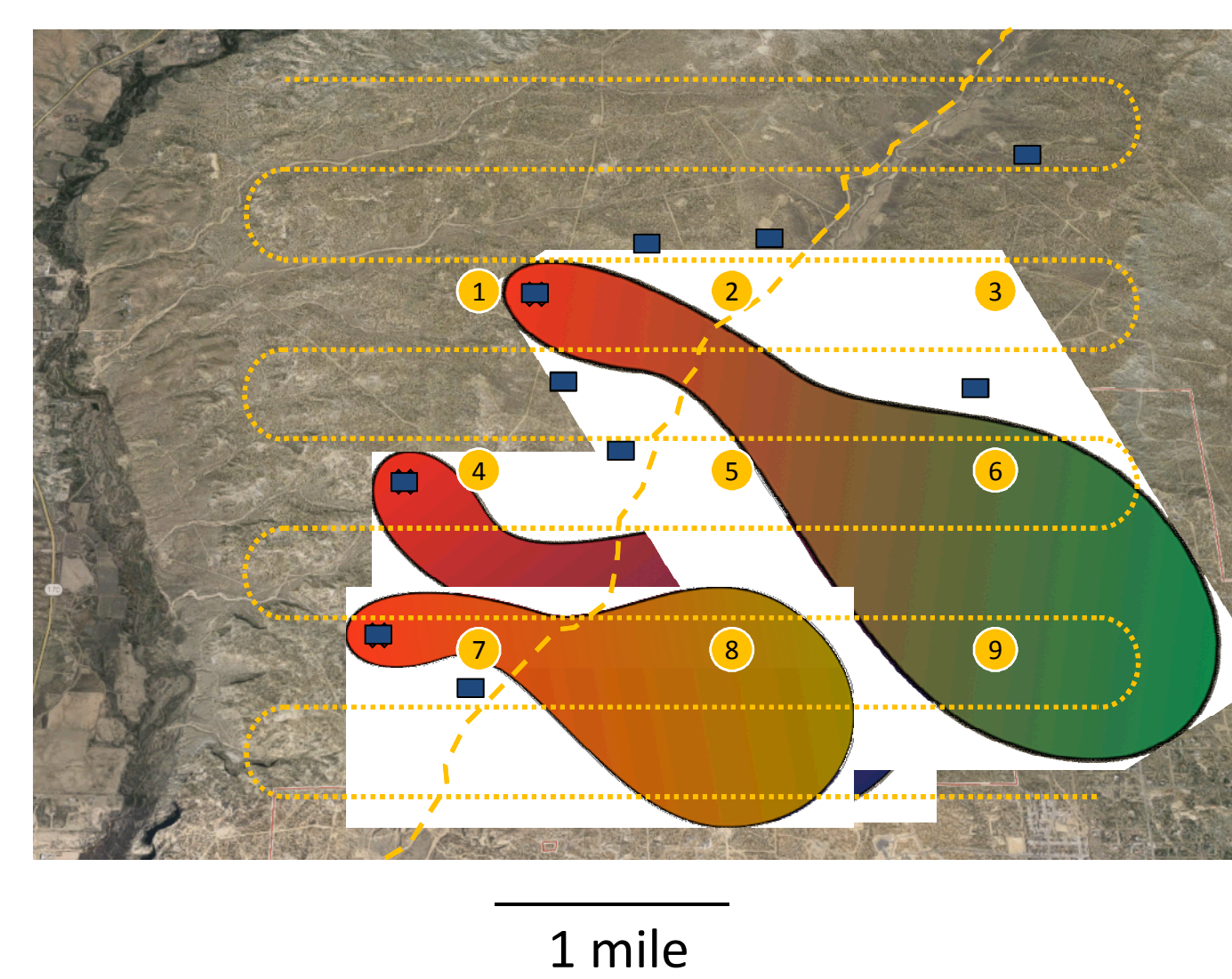
Objective: Develop methods and software to determine optimal sensor placement and sensor technology to improve the effectiveness of monitoring strategies.

Methods: Optimization methods are based on 'P-median facilities location' and coverage formulations which determine the best combination of sensors to place in the field, given a sensor budget. The sensor placement methods were originally developed at Sandia to place sensors in water distribution networks and the methods can be used for a wide range of applications. The formulation below aims to minimize "impact" across an ensemble of scenarios.

P-median formulation

$$\begin{aligned} & \text{minimize } \sum_{a \in \mathcal{A}} \alpha_a \sum_{i \in \mathcal{L}_a} d_{a,i} x_{a,i} && \text{Minimize the expected impact across all scenarios} \\ & \text{subject to } \sum_{i \in \mathcal{L}_a} x_{a,i} = 1 && \forall a \in \mathcal{A} \quad \text{Constraint forcing one sensor location to be the 'first to detect'} \\ & x_{a,i} \leq s_i && \forall a \in \mathcal{A}, i \in \mathcal{L}_a \quad \text{A sensor location can only detect if a sensor exists in that location} \\ & \sum_{i \in \mathcal{L}} s_i \leq p && \text{Constraint limiting the number of sensors allowed} \\ & s_i \in \{0,1\} && \forall i \in \mathcal{L} \quad \text{Binary variable reflecting existence of a sensor} \\ & 0 \leq x_{a,i} \leq 1 && \forall a \in \mathcal{A}, i \in \mathcal{L}_a \quad \text{Continuous variable representing the 'first to detect'} \end{aligned}$$

Schematic diagram of leak scenarios and candidate sensors

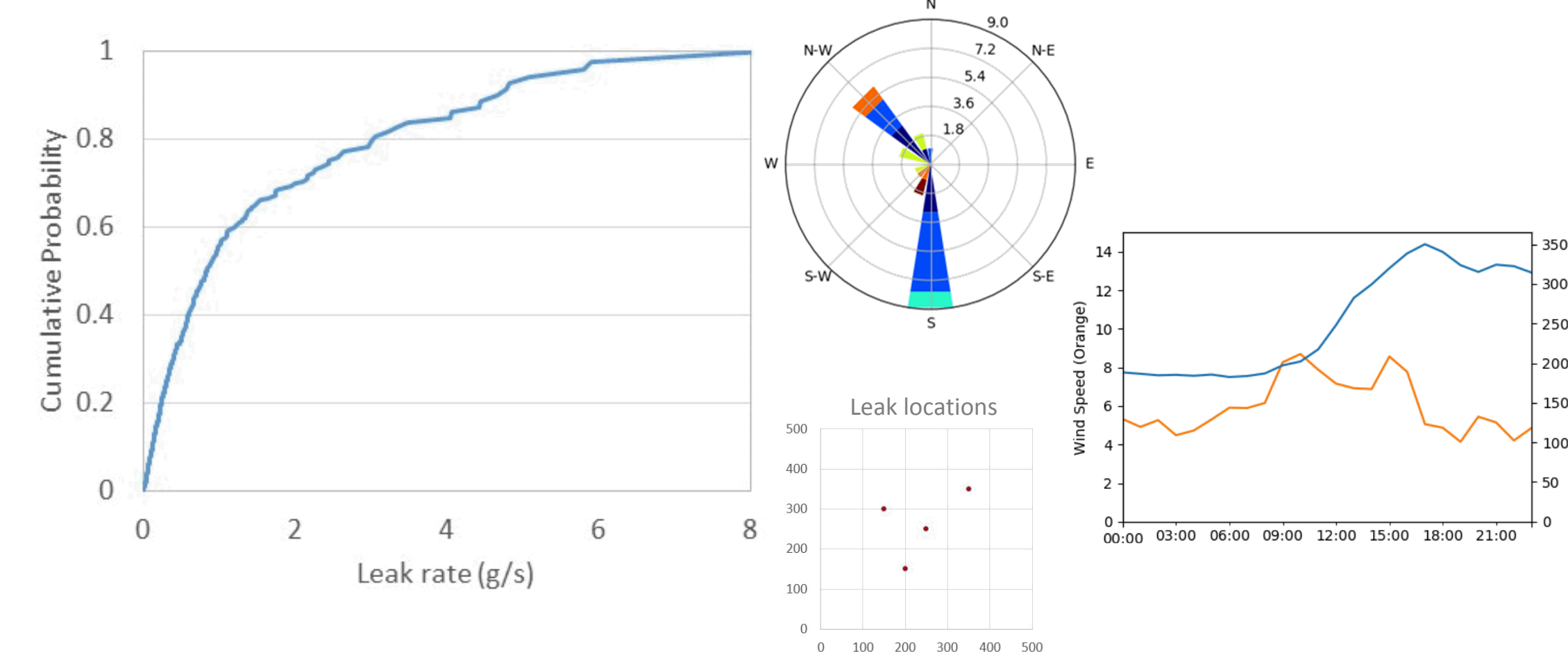


- Sensor characteristics
- Fixed or mobile
 - Point or camera
 - Detection threshold
 - Sensor cost
 - Sample times
 - Failure rate

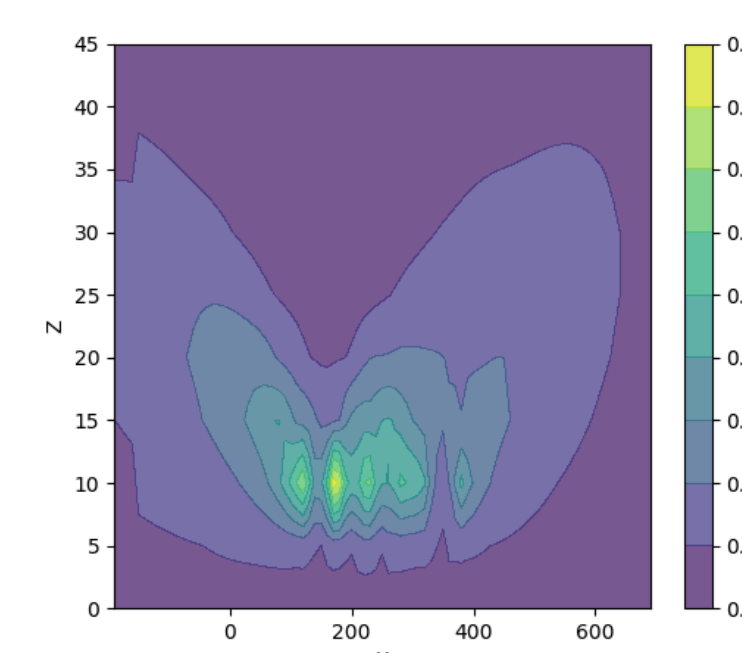
Open source software: *Chama* is an open source Python package for sensor placement optimization. *Chama* is available at <https://github.com/sandialabs/chama>. Documentation is available at <https://chama.readthedocs.io>.

Example application: Sensor placement for methane emissions in Barnett Shale outside Fort Worth.

Field data: Leak rate distribution from the Fort Worth Natural Gas Air Quality Study (Eastern Research Group) and atmospheric conditions for Fort Worth (NOAA).

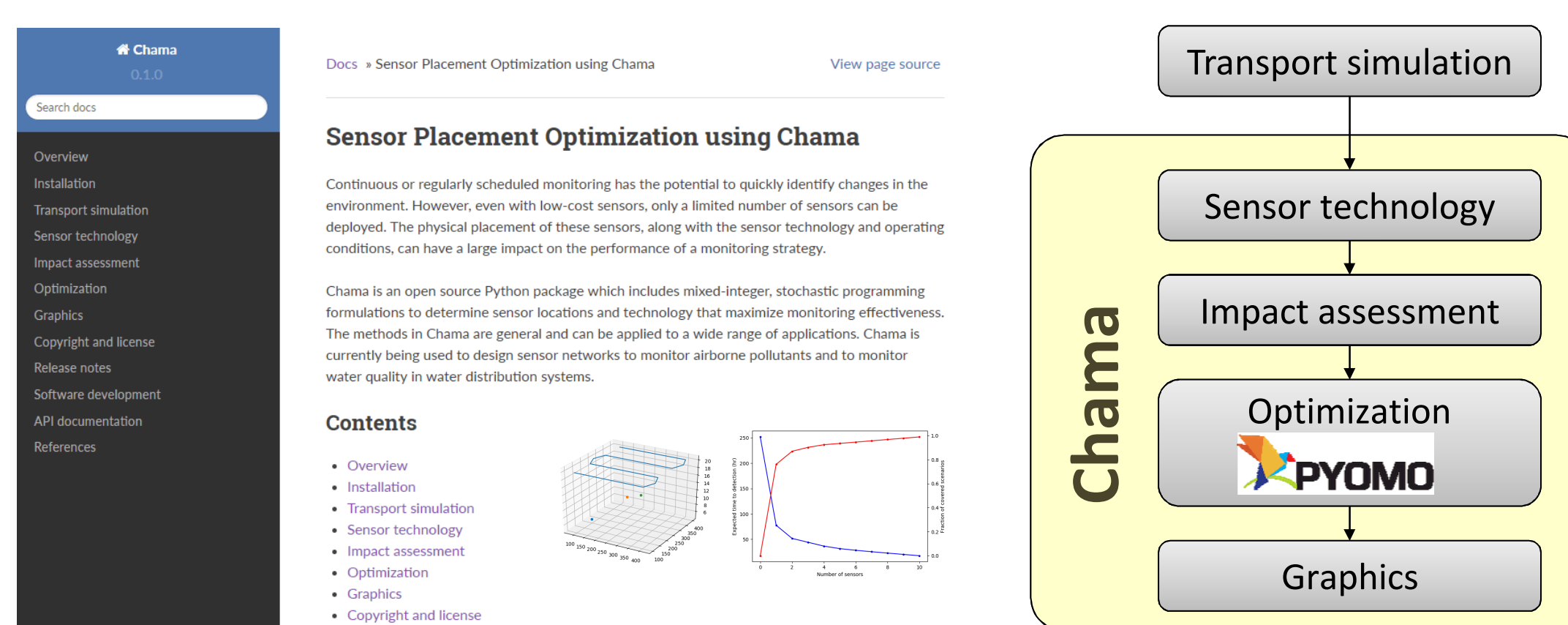
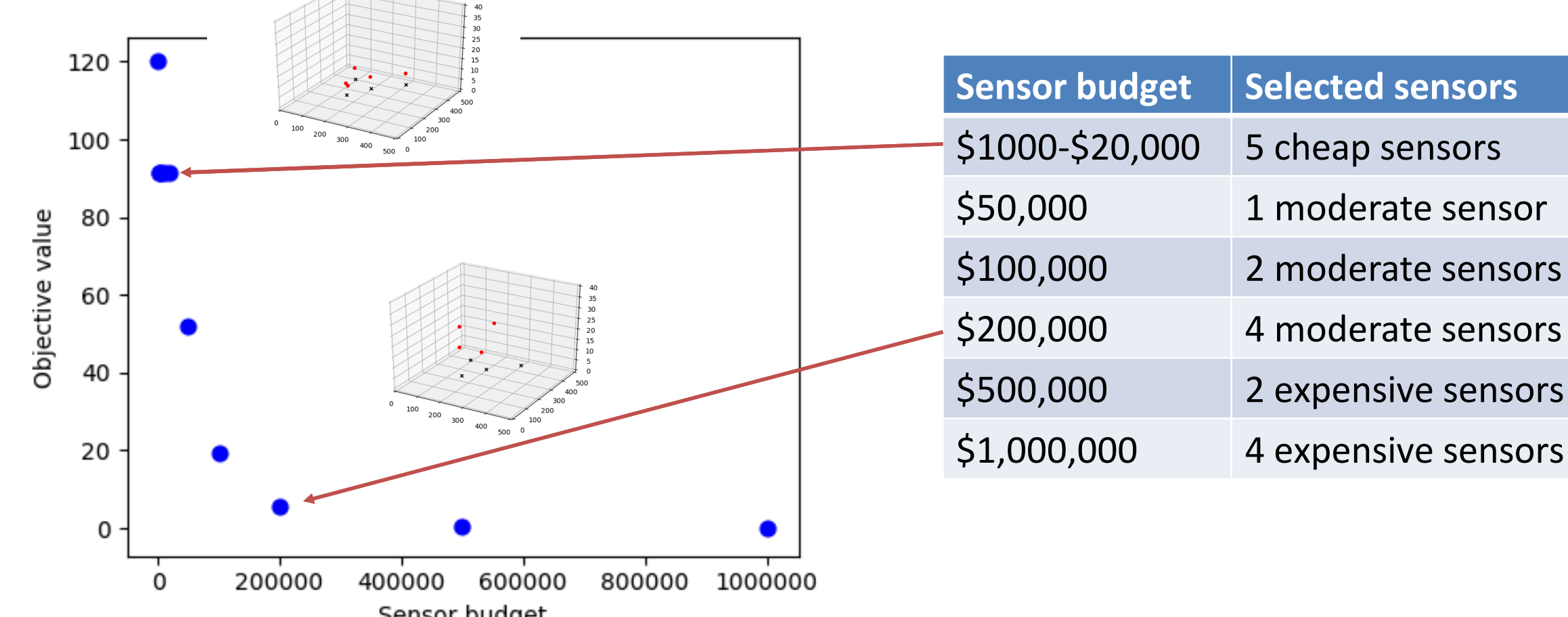


Simulation: 120 leak scenarios from 4 wellpads based on field data, over 200 feasible sensor locations using 3 sensor technologies.



Sensor category	Detection threshold	Approximate cost
Cheap (surrounding the wellpads)	100 ppm	\$200
Moderate	1 ppm	\$50,000
Expensive	1 ppb	\$250,000

Sensor placement optimization: Tradeoff curve and selected sensors to minimize time to detection.



- Additional sensor technologies and optimization formulations can be easily added.
- Methods are general and can be used for a wide range of applications (i.e. to monitor drinking water, contaminated groundwater, seismic activity). Third party simulators can be used to generate input.
- Utilizes efficient scientific Python Packages (Numpy, Scipy, Pandas, and Matplotlib) along with Sandia developed Pyomo software for optimization, <http://www.pyomo.org/>.

