Back-trajectory Based Methods for Source Parameter Estimation

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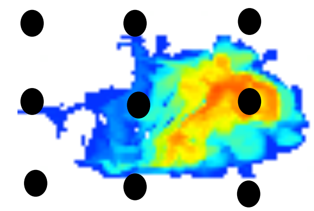
Overview of Inverse AT&D Frameworks

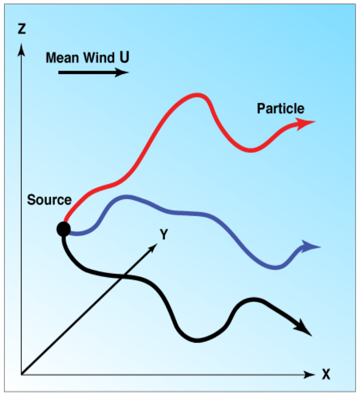
- **Eulerian**
  - **Model entire concentration field**

$$\frac{\partial C}{\partial t} = F\left(u, u_i, C\right)$$



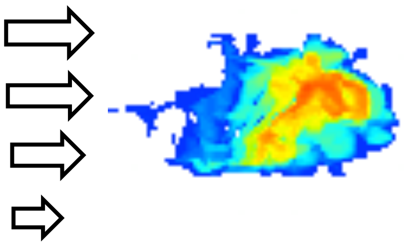
- **Lagrangian**
  - **Lagrangian particle modeling**

$$\sum_{i=1}^{N} \frac{dx_i}{dt} = f\left(x_i, u_i\right)$$



  - **Lagrangian puff modeling**

$$\sum_{i=1}^{N} \frac{d\overline{x_i}}{dt} = \iiint_{\Omega} C u_i \, d\Omega$$



Outline

- **Basic backward trajectory approach**
  - Pure Lagrangian particle trajectory from reversed winds
  - Source determined through particle clustering
- **Reverse Eulerian approach**
  - Winds reversed
  - Forward model run on reversed winds
  - Source determined in post-processing analysis
- **Reverse Eulerian/Lagrangian puff formulation**
  - Fit a puff model to sensor observations
  - Determine when spread approaches zero along puff trajectory to infer source location
- **Summary**

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Basic Backward Trajectory Approach

(Methodology Description)

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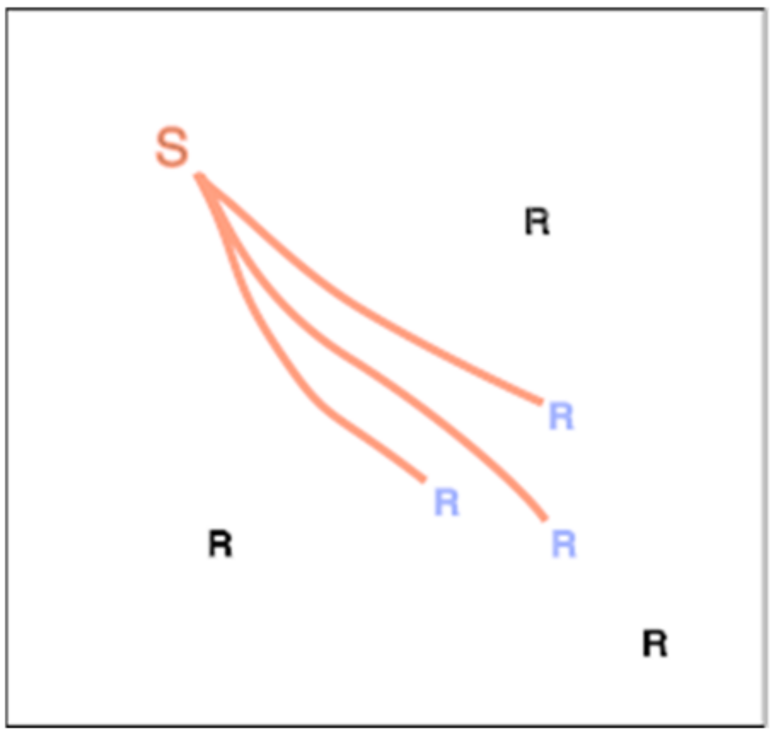
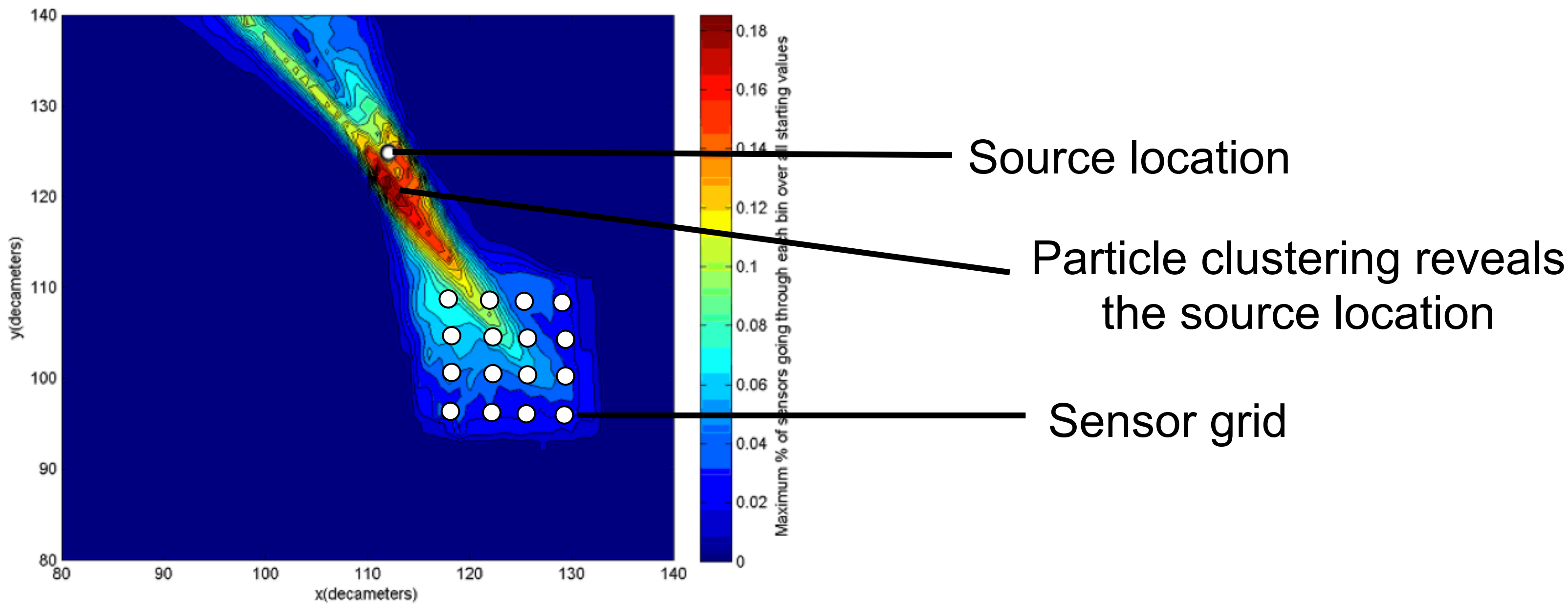
- **Track contaminant filled fluid parcel trajectories backwards in time**
- **Reverse parcel trajectory originates at the observation location**



Basic Backward Trajectory Approach

(Methodology Description)

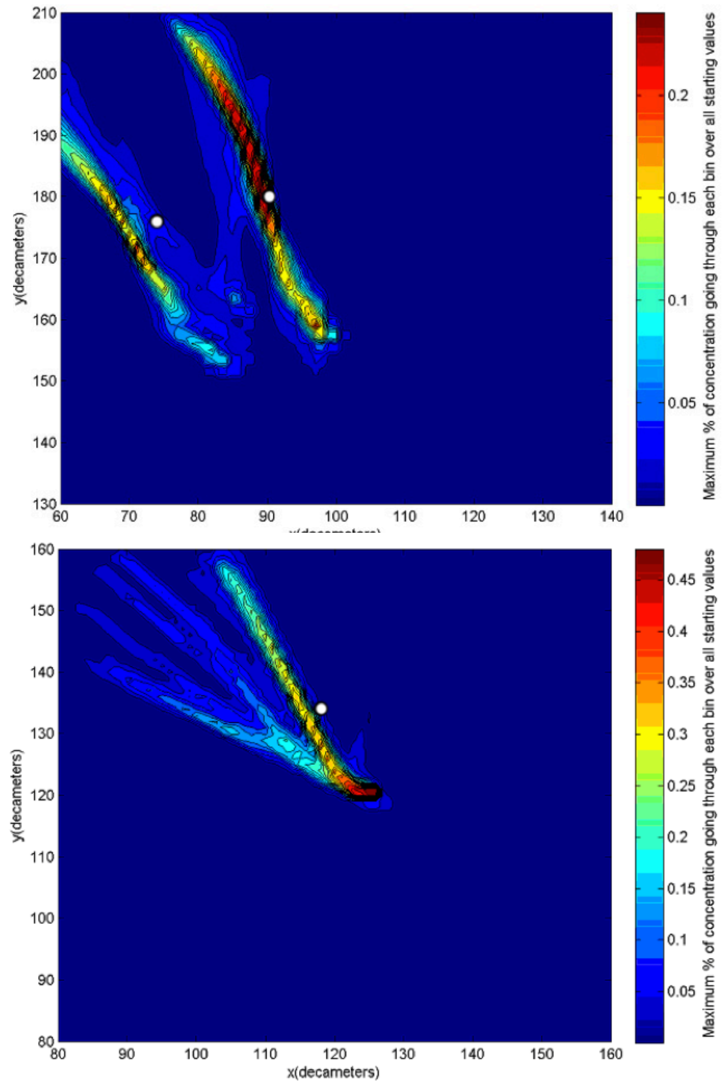
- **Assuming a passive tracer, either numerical weather prediction output or wind observations determine the reverse parcel trajectory**
- **The source location is inferred from parcel convergence**



Basic Backward Trajectory Approach
(Strengths and Weaknesses)

- **Strengths**
  - Can naturally handle multiple release events
  - Approach does not match concentration observations (no optimization necessary)

- **Weaknesses**
  - Extensive weather observations or high resolution NWP needed for successful source term estimation
  - Not a natural method to determine the source mass
  - Faulty estimates if the flow field in reverse time is divergent



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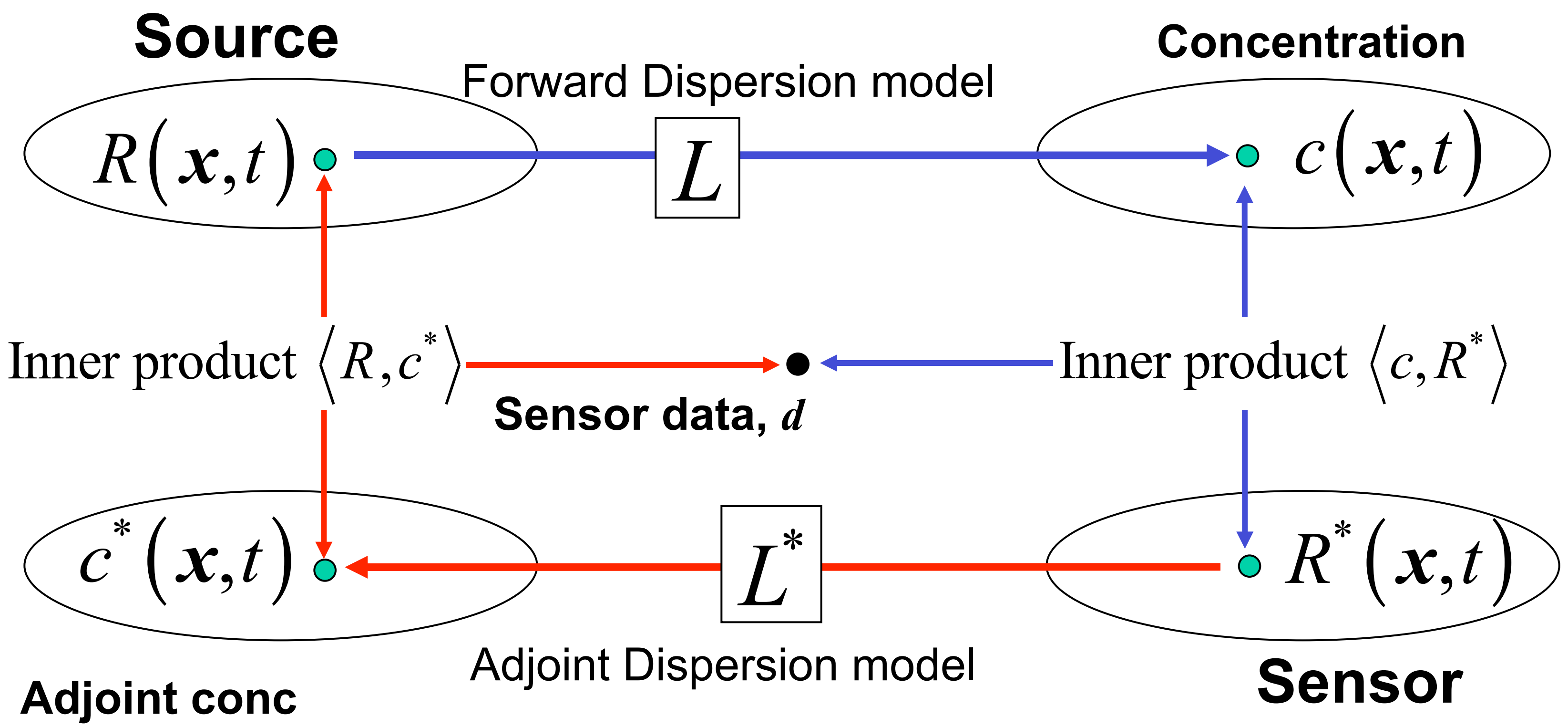
Reverse Eulerian Approach



Reverse Eulerian Approach
(with SCIPUFF)

- **This Reverse Eulerian approach using SCIPUFF is an informal adjoint technique**

$$\left\langle \left(Lc, c^* \right) \right\rangle = \left\langle \left(c, L^* c^* \right) \right\rangle$$ where…

Lc is related to the source response function, and

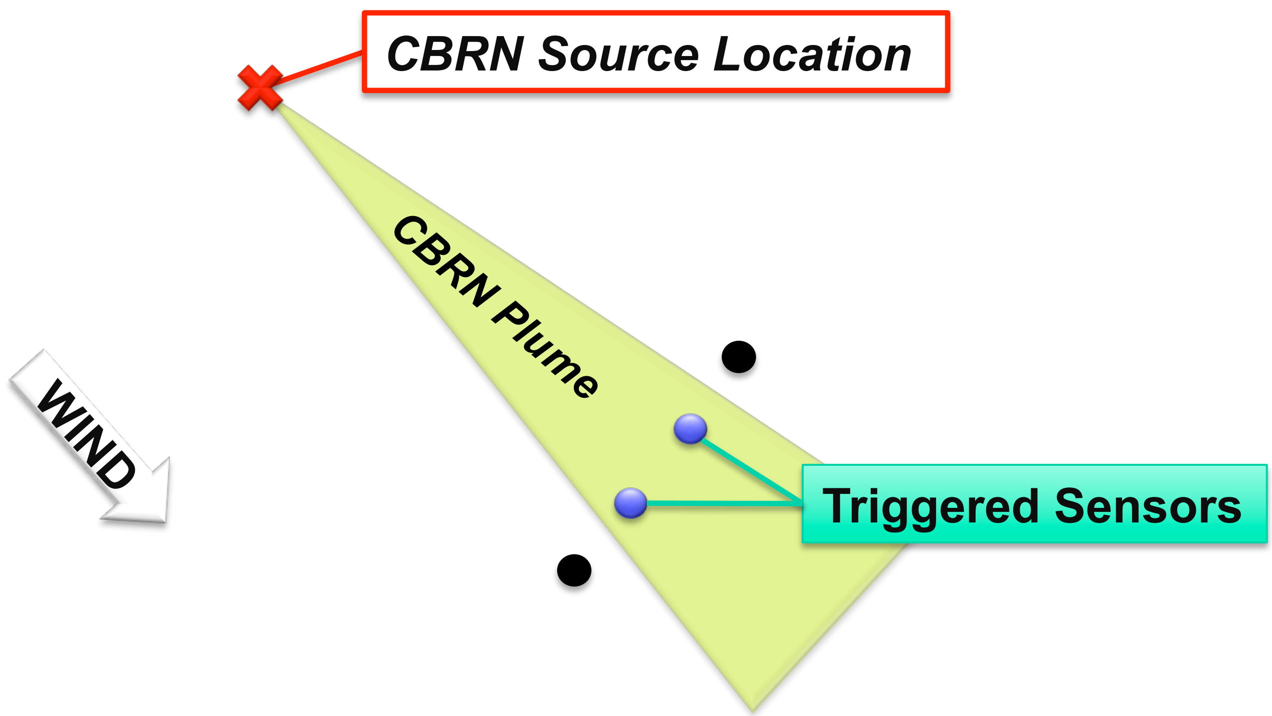
$L^* c^*$ is related to the observations at the sensor locations

- **The complexity of SCIPUFF makes calculation of a formal adjoint difficult**

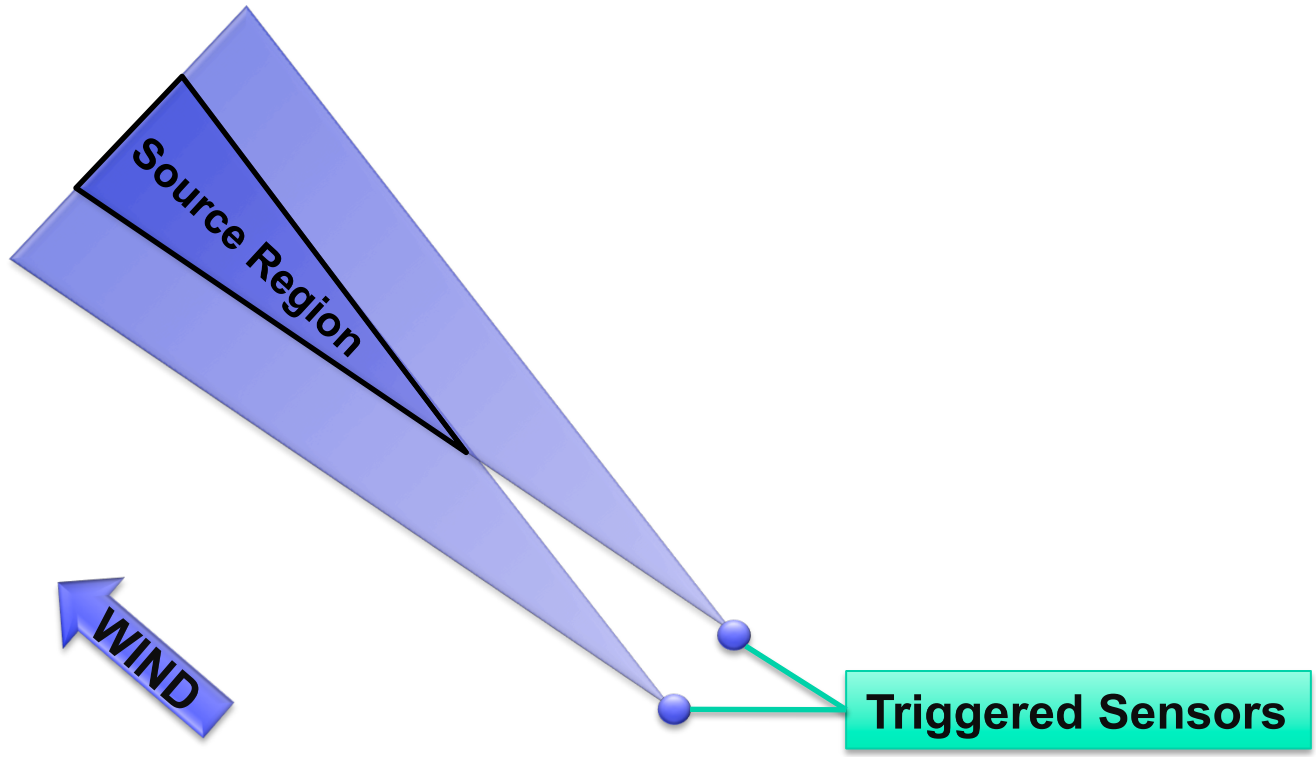
- **Thus SCIPUFF is run in reverse mode to provide a 'retroplume'**

Reverse Eulerian Approach

(Methodology Description)



Reverse Eulerian Approach
(Methodology Description)



Reverse Eulerian Approach

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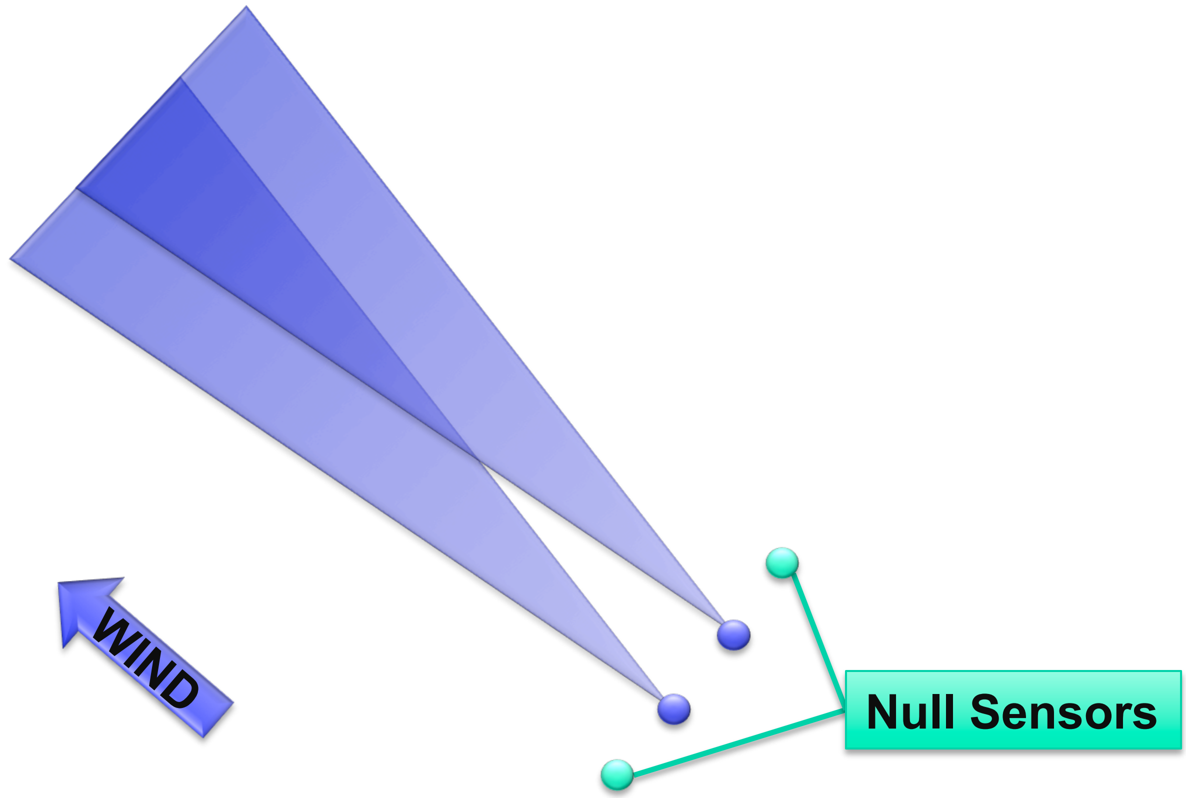

Reverse Eulerian Approach

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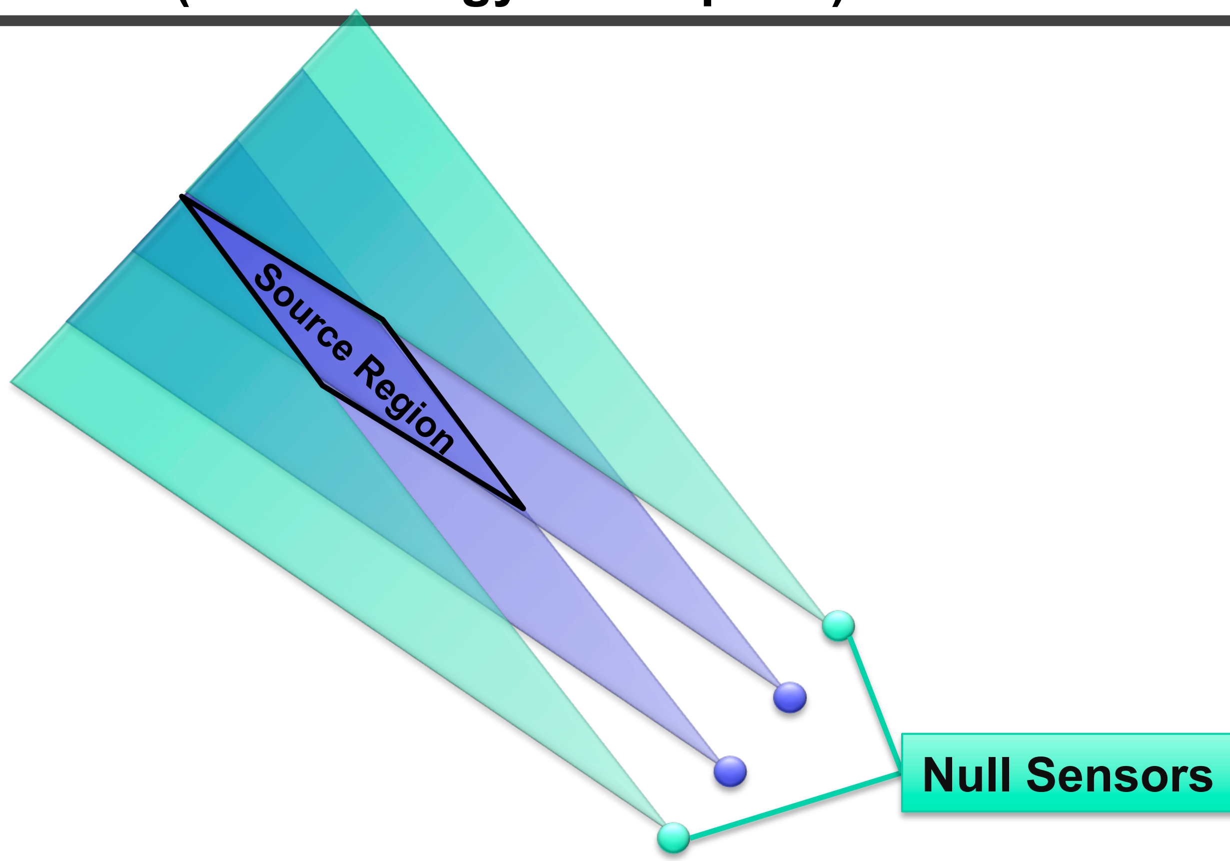
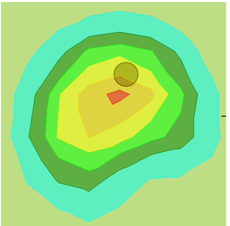


Reverse Eulerian Approach

(Post-Processing to Determine Source Term Parameters)

- **Source parameter estimate**
  - **The reverse SCIPUFF calculations produce a hazard area where the source is likely to be located**



  - **For a source location we can obtain a mass estimate of the contaminant release for each retroplume**

$$Q_i = {d_i}\Big/{c_i^*(x_r)}$$

  - **Consistency amongst the mass estimates provides insight on the source location**

Reverse Eulerian Approach

(Example with ETEX data)

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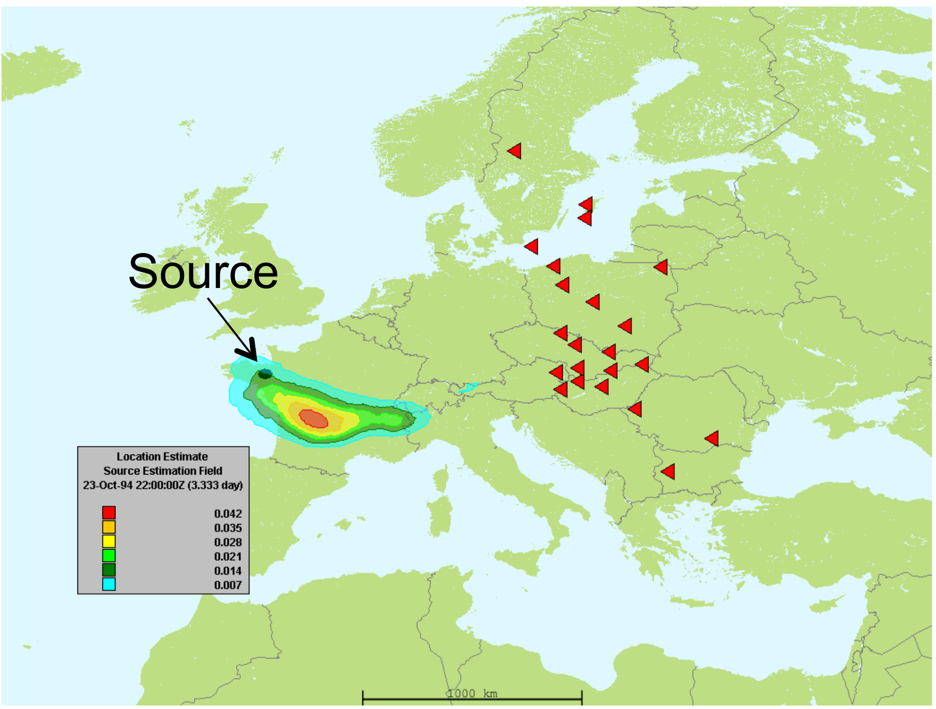
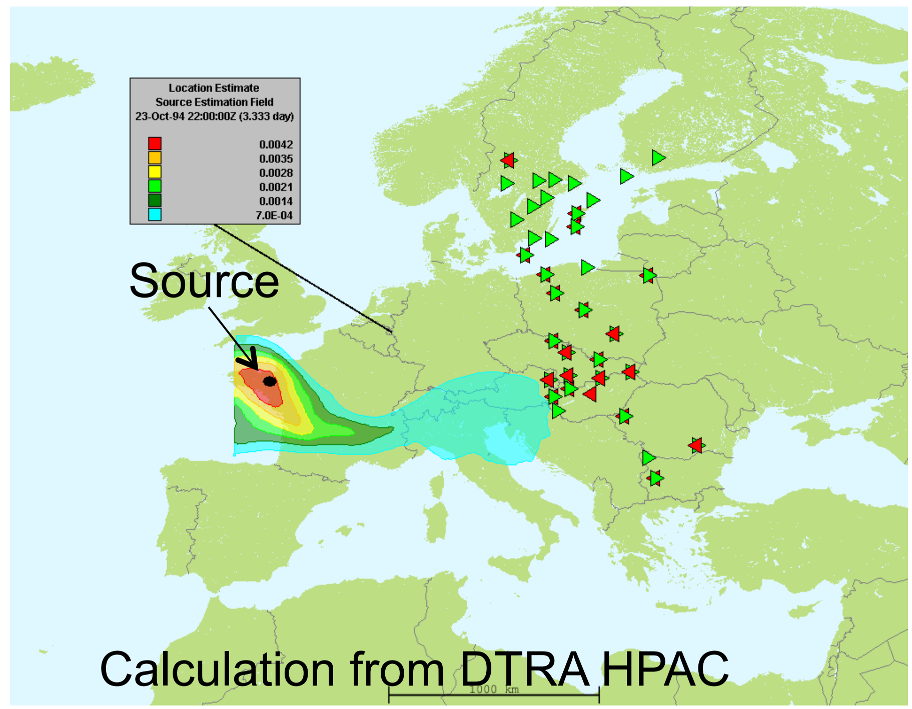
Source Location Estimate Using Only Sensor Hits

Source Location Estimate Using Sensor Hits and Null Hits





From Sykes 2006

Reverse Eulerian Approach

(Strengths and Weaknesses)

- **Strengths**
  - **Practical, robust framework for source term estimation**
  - **Can readily handle multiple contaminant release events**
  - **Approach also does not require minimization of a functional**
  - **Works seamlessly across a wind range of meteorological scales**

- **Weaknesses**
  - **Large computational effort is needed for**
    - **Dense sensor arrays**
    - **Long duration release**
  - **High resolution NWP or meteorological observations are needed, however, not as dense as the traditional Lagrangian approach**
  - **Sensitive to faulty measurements**

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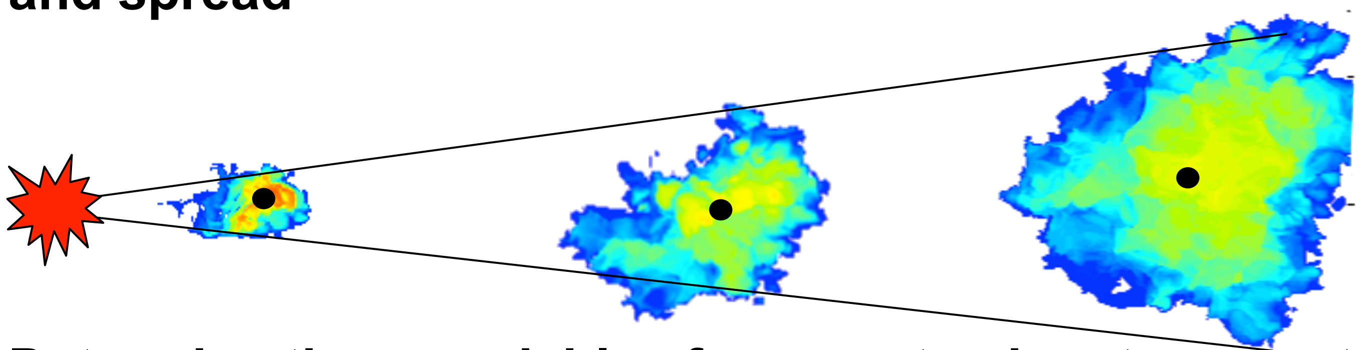
Eulerian/Lagrangian Puff

- Isolates main STE variables; the contaminant mass, axis and spread



- Determine these variables from contaminant concentration observations

- Determine evolution of these variables in reverse time

- Determine the location where the spread approaches zero

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Eulerian/Lagrangian Puff

(Source Estimation Process)

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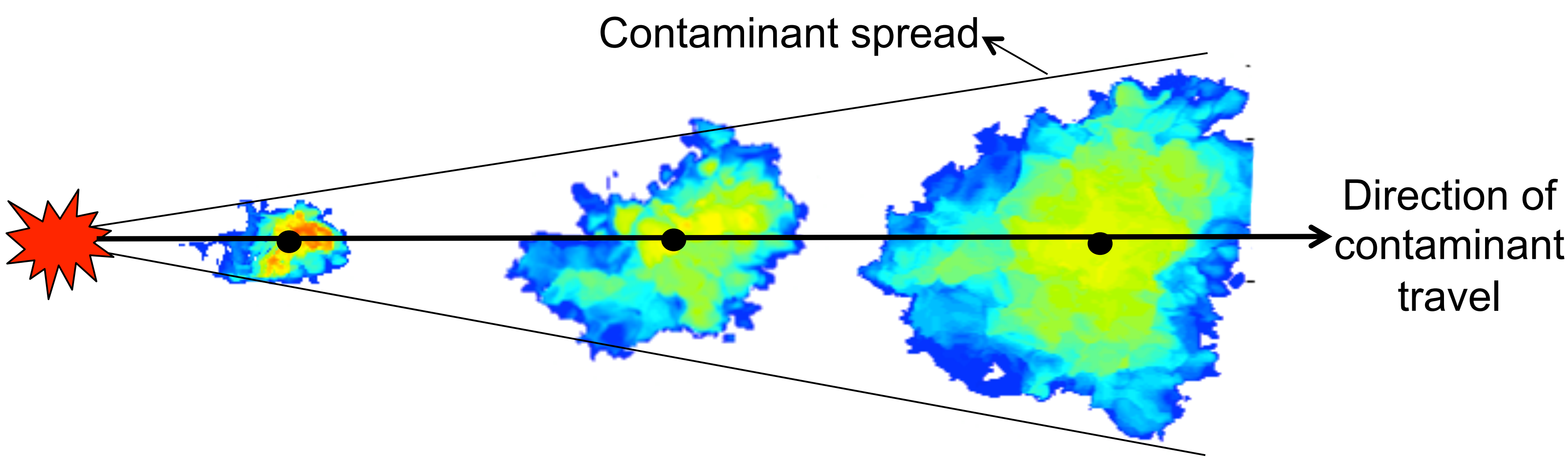
- **Optimization: Determine mass, location and spread of a puff from surface concentration observations**
- **Association: For multiple release locations associate locations and spread observations with a puff trajectory**
- **Estimation: Determine where the spread approaches zero along the puff trajectory**



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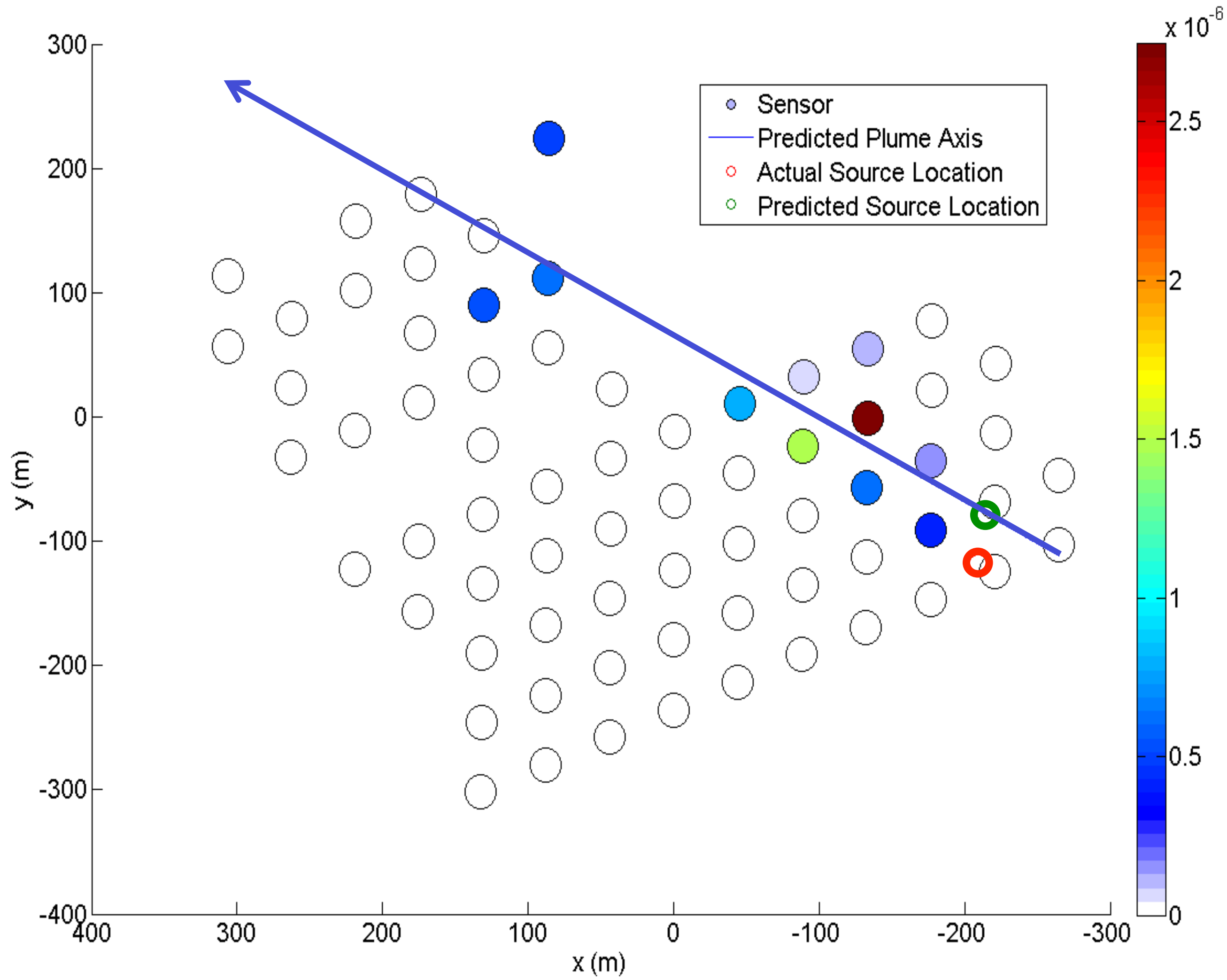
Example
(Continuous Release Example)



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Example

(Continuous Release Example)

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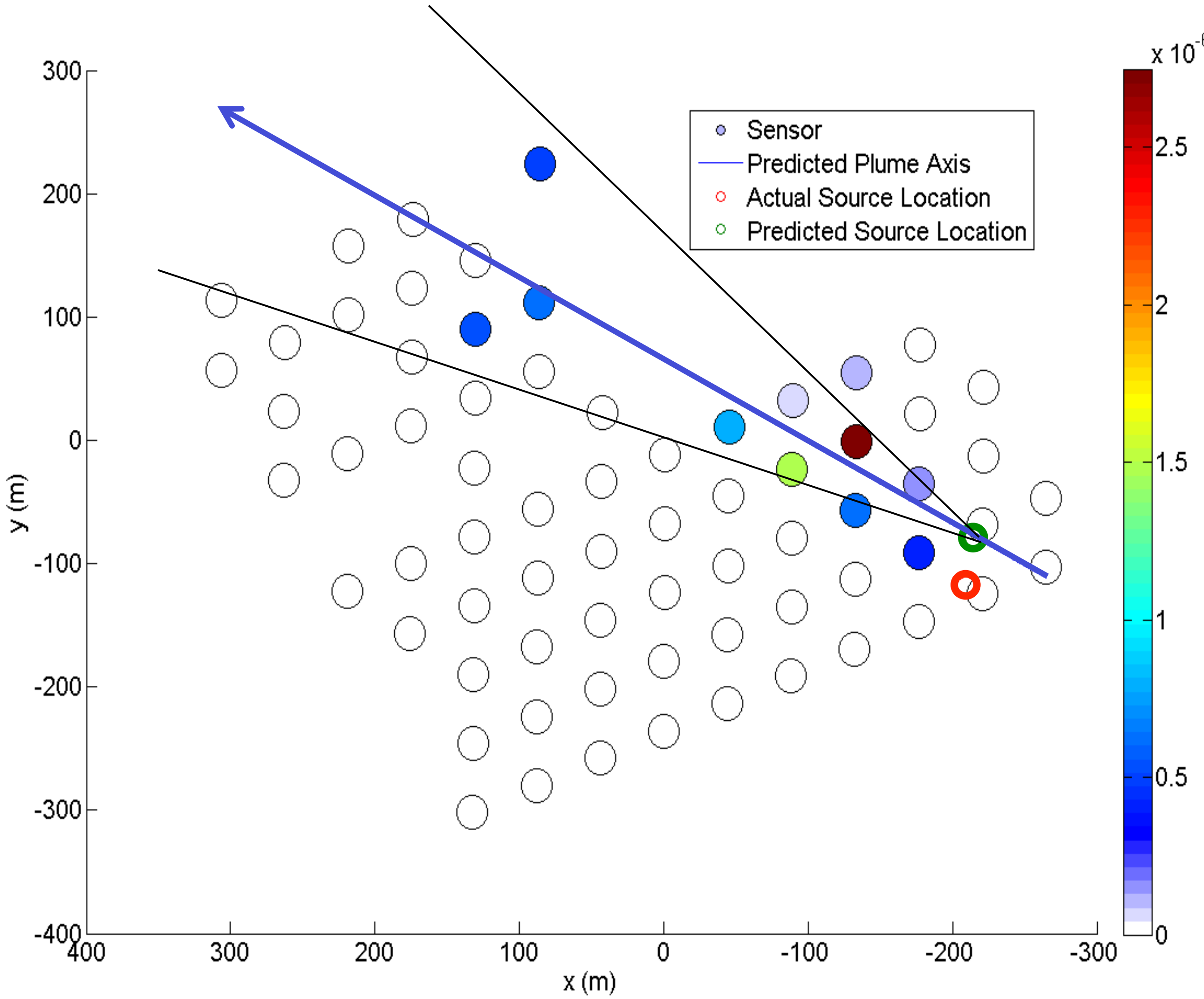

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Reverse Eulerian Approach

(Strengths and Weaknesses)

- Strengths
  - Isolates the variables most crucial for source term estimation (mass, location and spread)
  - Readily handles multiple release events
  - Can infer meteorological forcing variables if sufficient concentration data is present
  - Computationally efficient for single release events

- Weaknesses
  - Number of approximating functions constrained by the number of observation locations
  - Requires minimization between approximating function and the concentration observations
  - Complexity increases with multiple source locations, but still more manageable than when working with forward dispersion models

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Summary

- Back trajectory methods seamlessly capture the source term estimation across multiple meteorological scales
- These methods are practical, and are easy to implement
- Information on the source mass requires work in the Eulerian reference frame