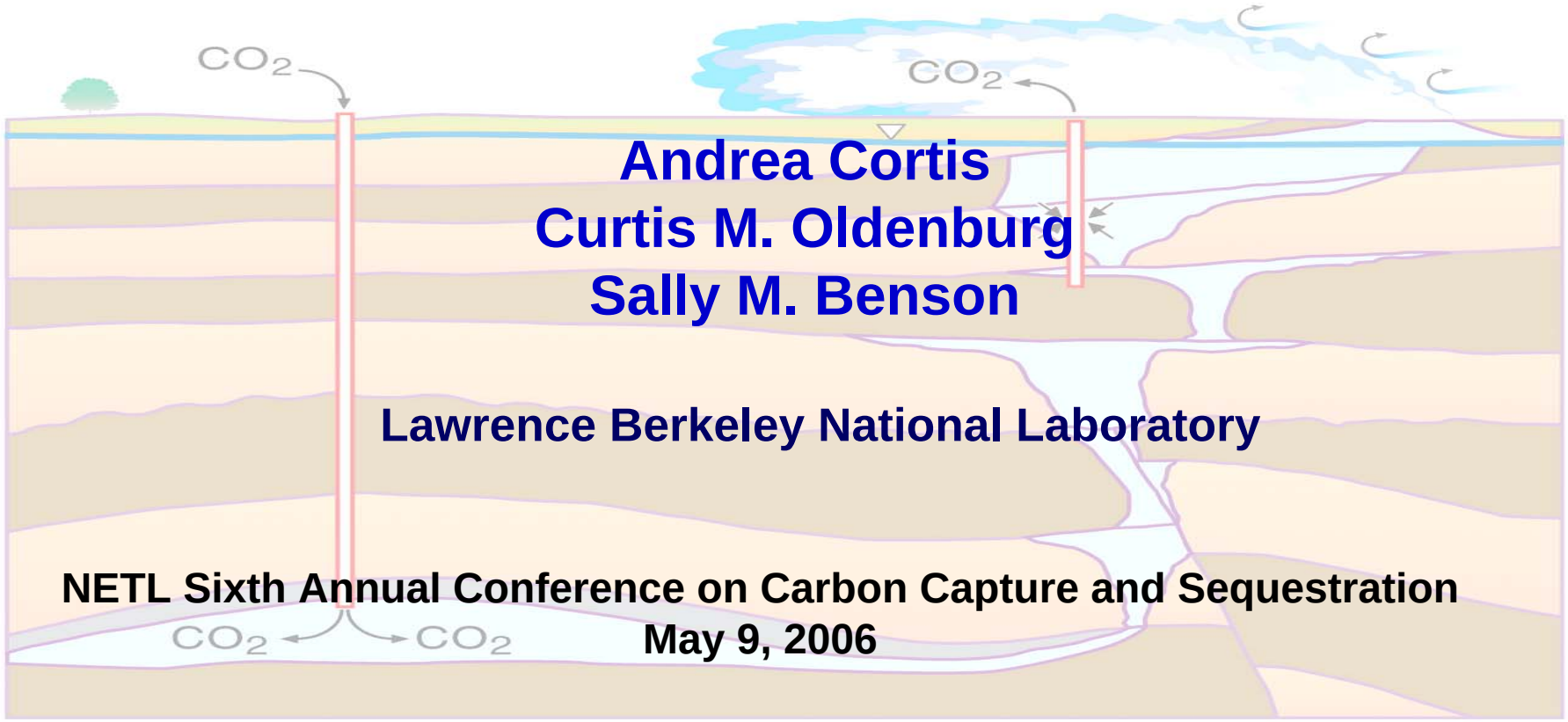
On the Optimality of Above-Ground Monitoring Networks for Carbon Capture and Storage



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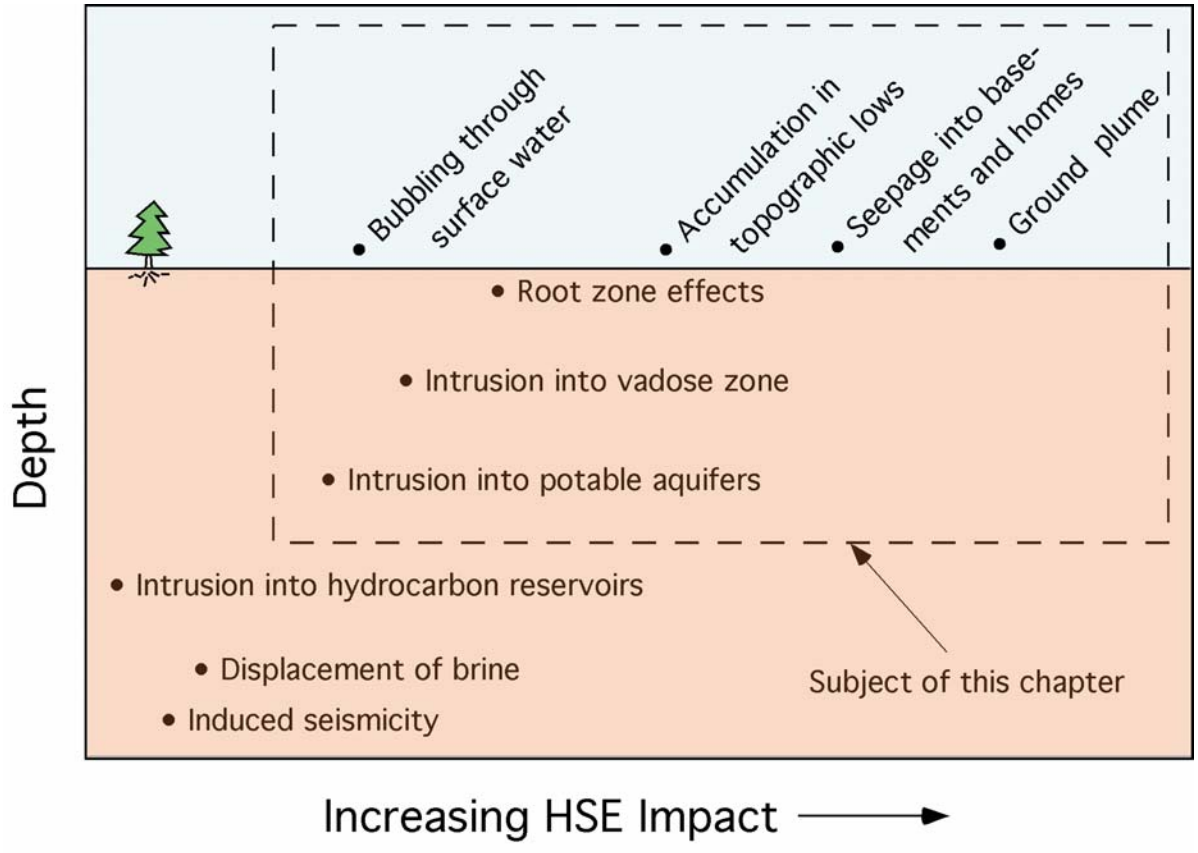
NETL Sixth Annual Conference on Carbon Capture and Sequestration
May 9, 2006

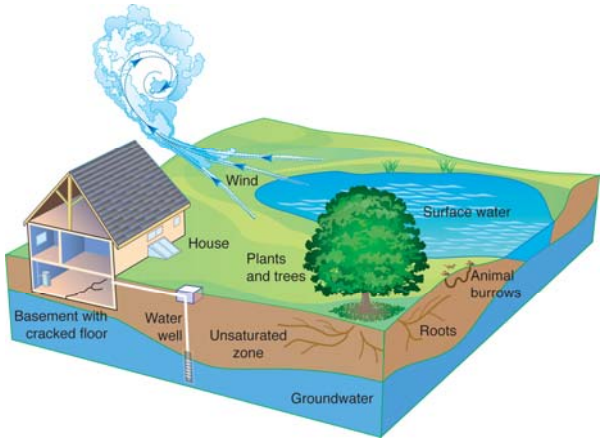
Motivations for Detection

Health, Safety, and Environmental (HSE) Impact

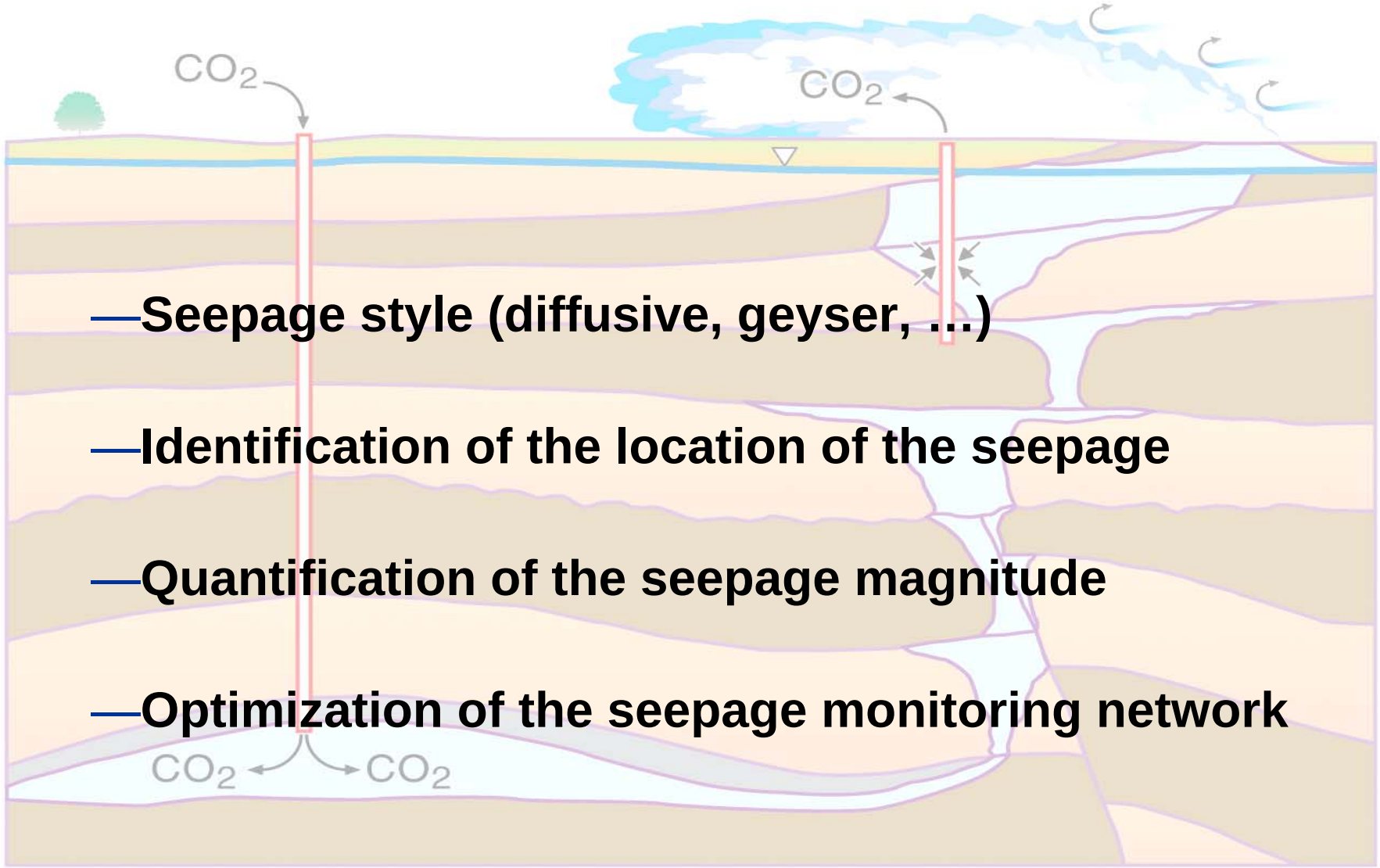


Others include:

- **Storage verification**
- **Storage credits**

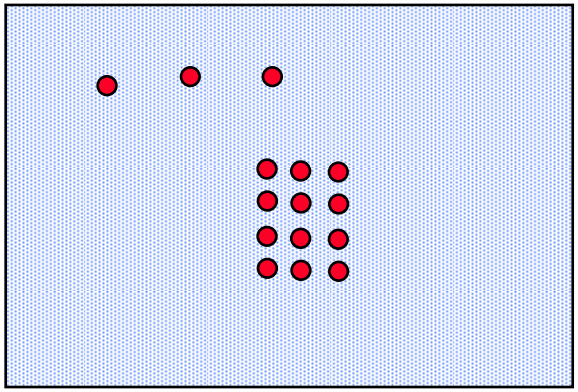


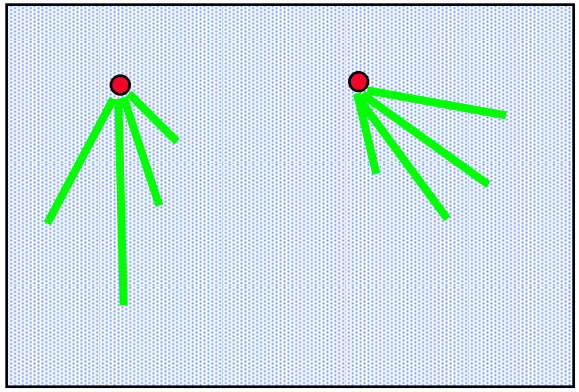
The Problems

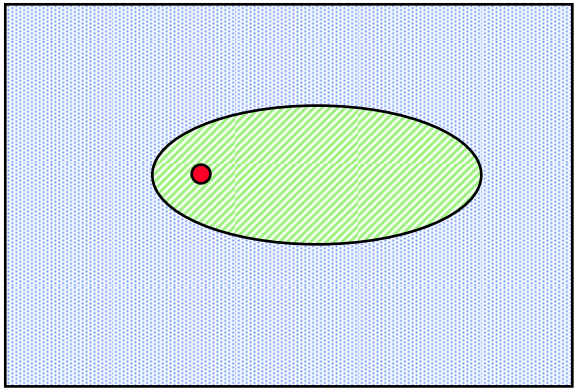


- Seepage style (diffusive, geyser, …)
- Identification of the location of the seepage
- Quantification of the seepage magnitude
- Optimization of the seepage monitoring network

Types of Measurements



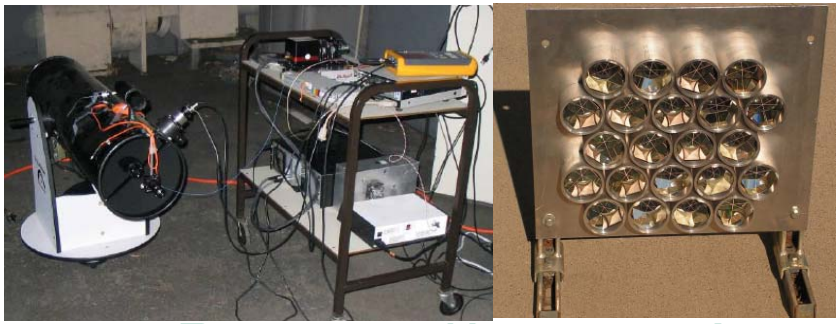




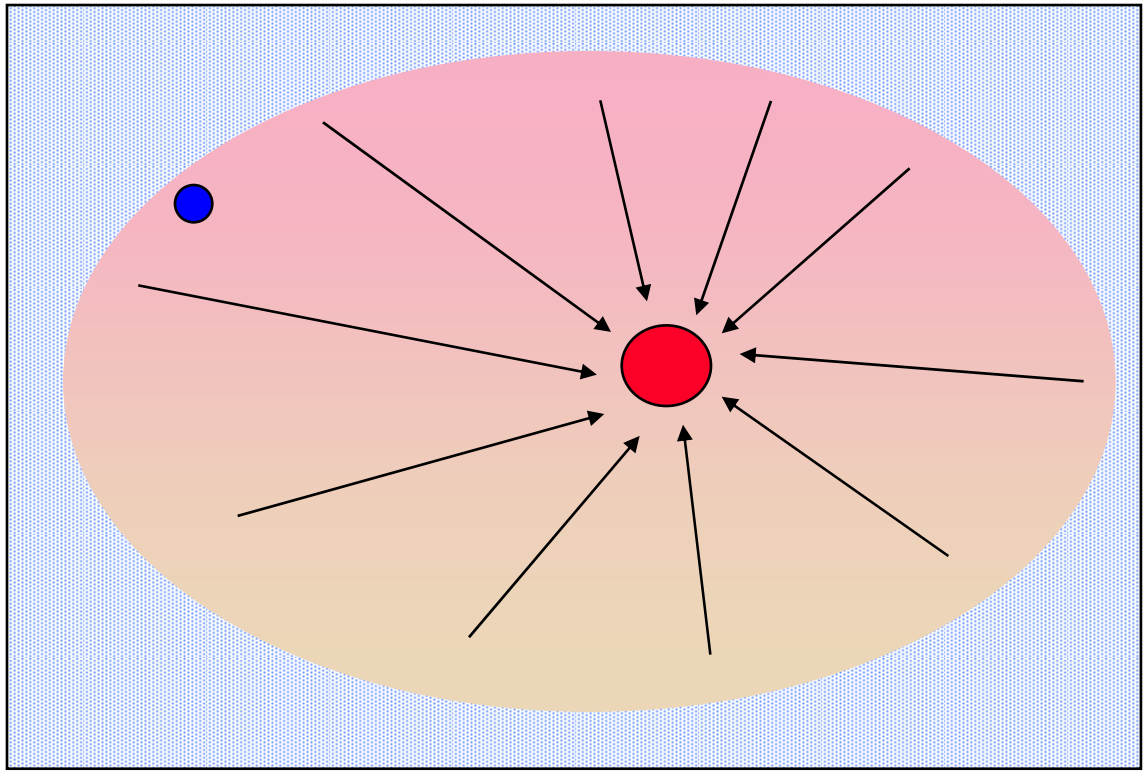
Lycor

Lidar

Eddy-covariance tower



The Length Scales (i)

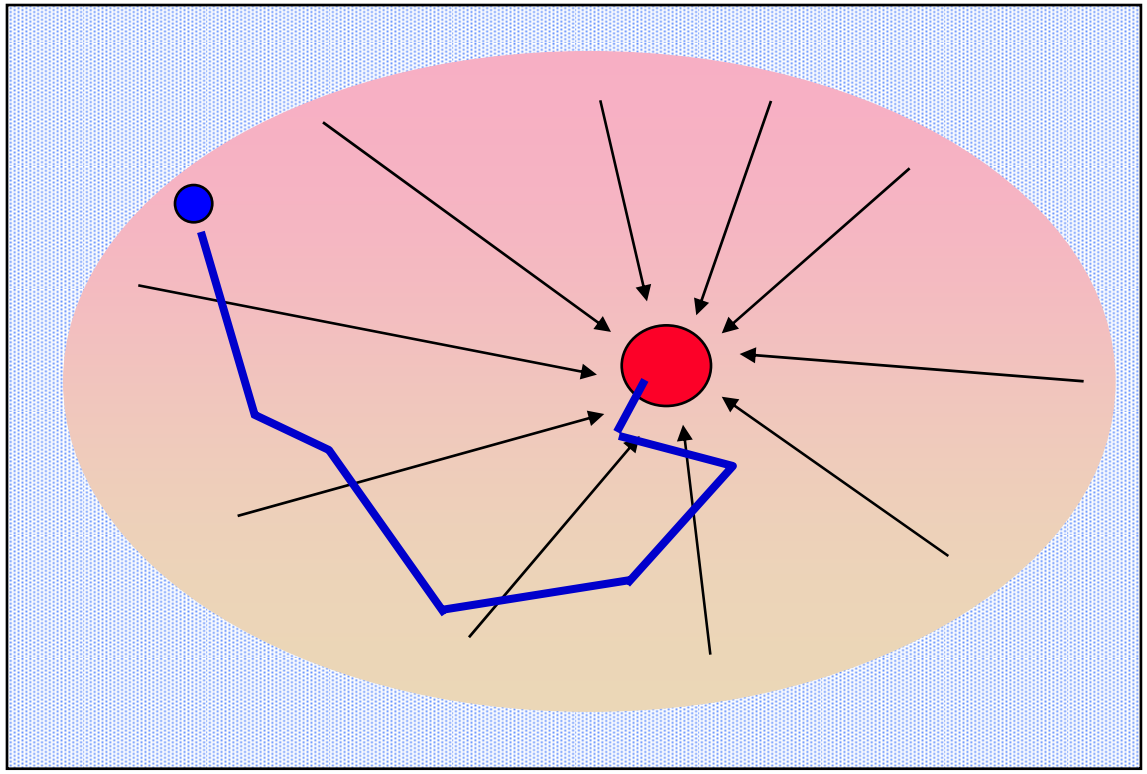


L_s

L_{db}

L_x

The Length Scales (i)

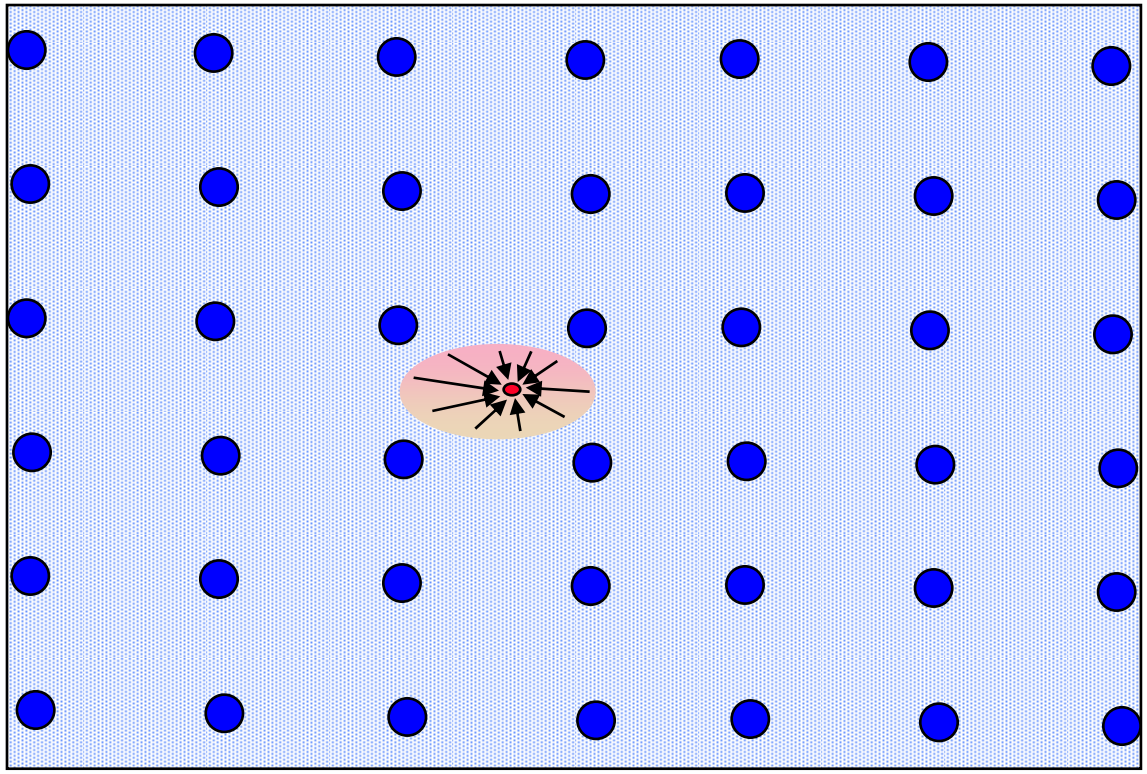


L_s

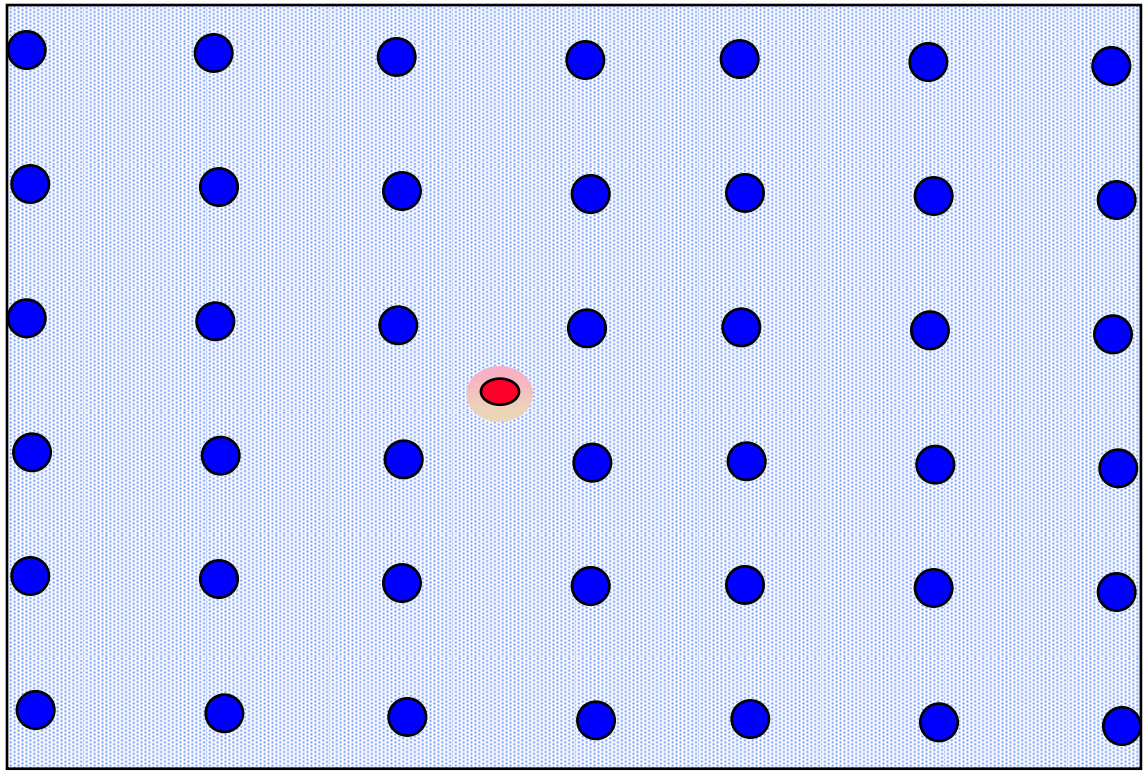
L_{db}

L_x

The Length Scales (ii)



The Length Scales (iii)

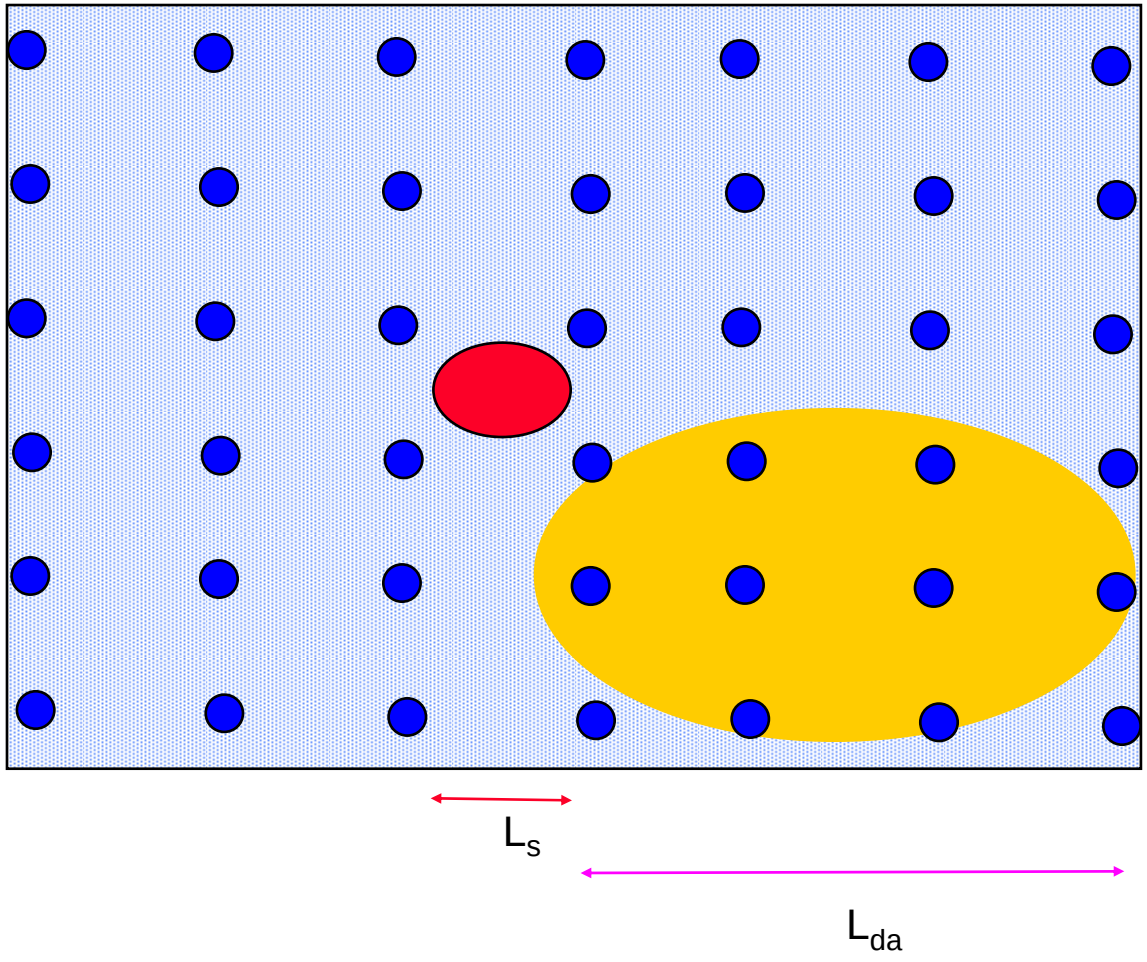


L_s

L_{db}

L_x

The Length Scales (iv)



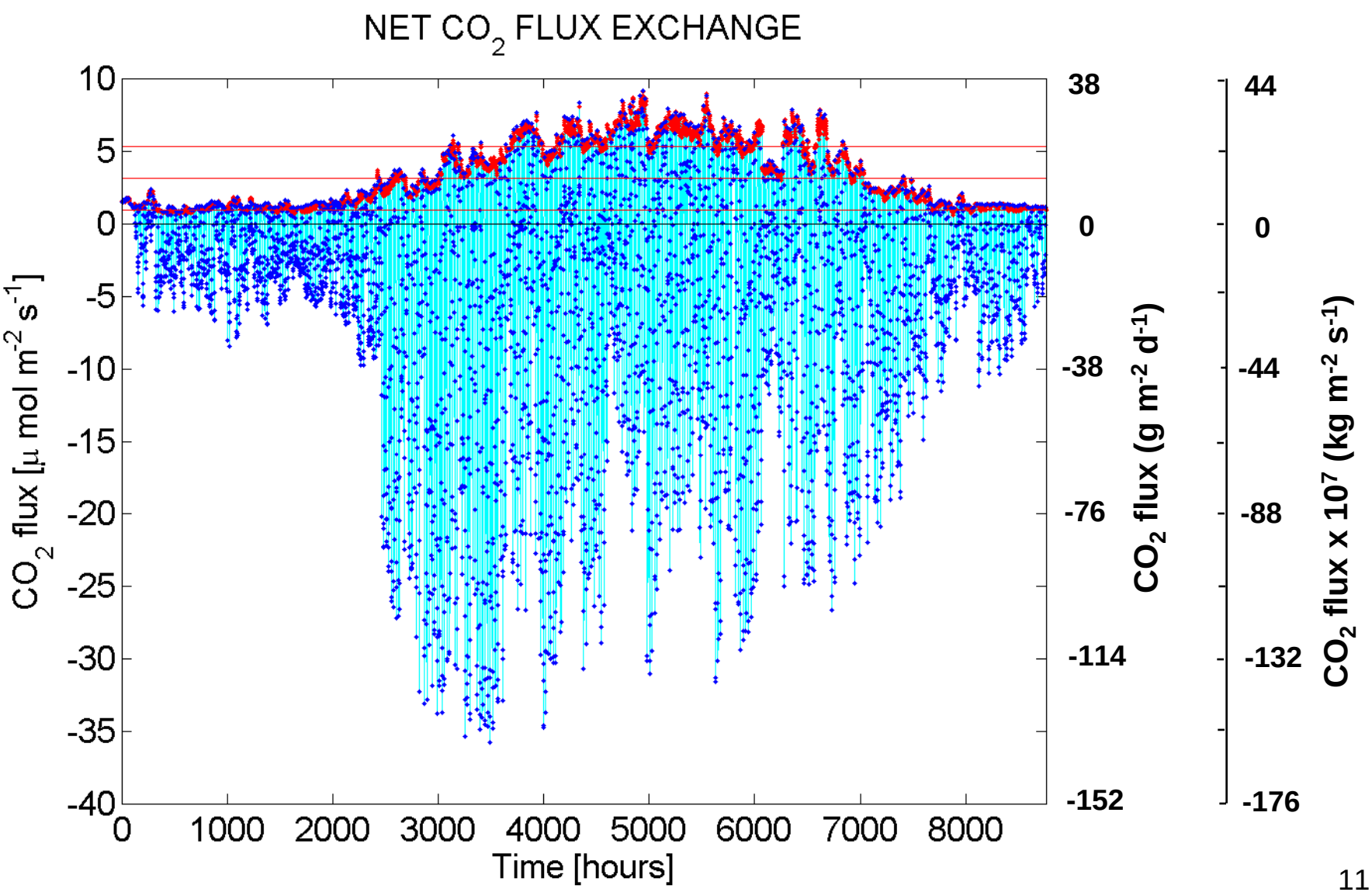
Seepage as an Anomaly

- Importance of Baseline measurements (prior to injection!)
- **Seepage**: ANOMALY with respect to an expected or measured BASELINE
- **Integrated Baseline**: a set of CO_2 measurements in a region with no seepage as a function of parameters such as: *elevation, soil moisture, air and soil temperature, vegetation cover, solar irradiation, etc*.
- Assumptions:

(1) Stationarity in space;
(2) Stationarity in time (time-series analysis)

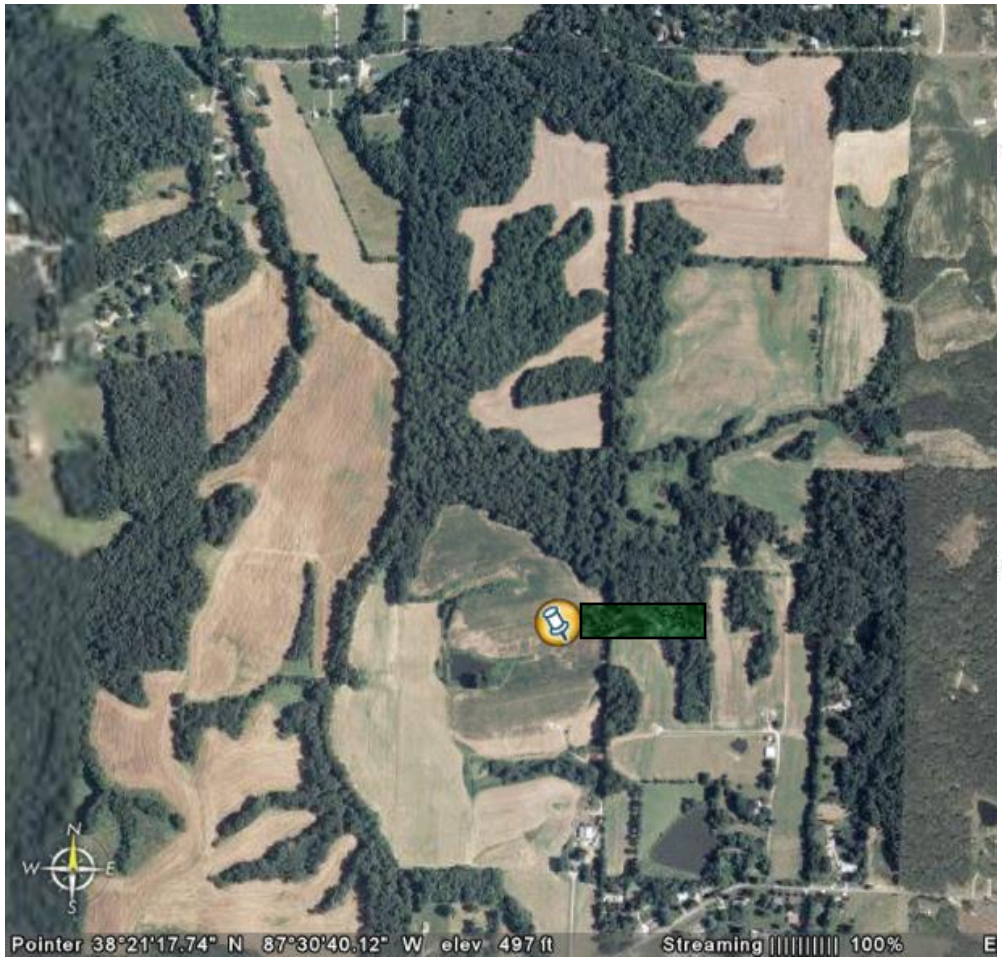
- **Detectability**

Photosynthesis and Respiration

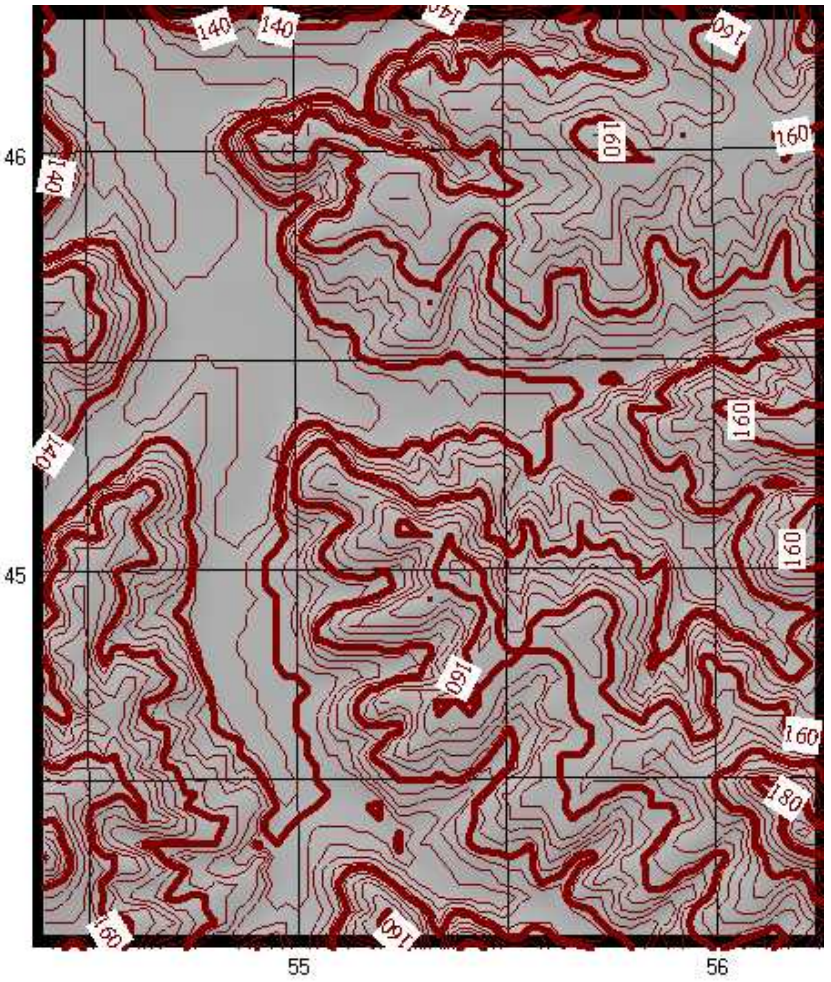


Example Midwestern Site

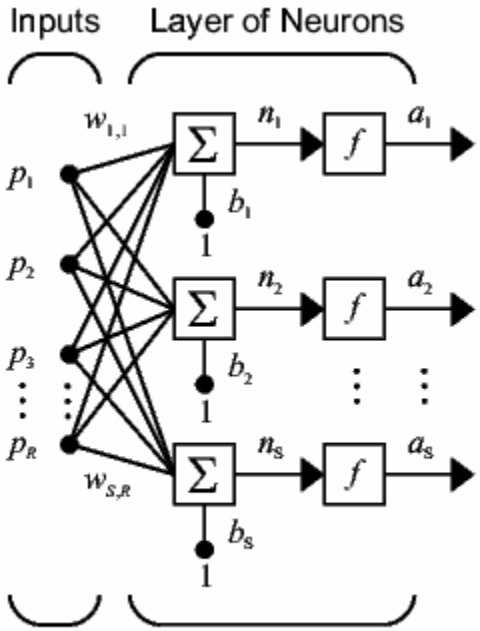
Aerial view



Topo map from DEM



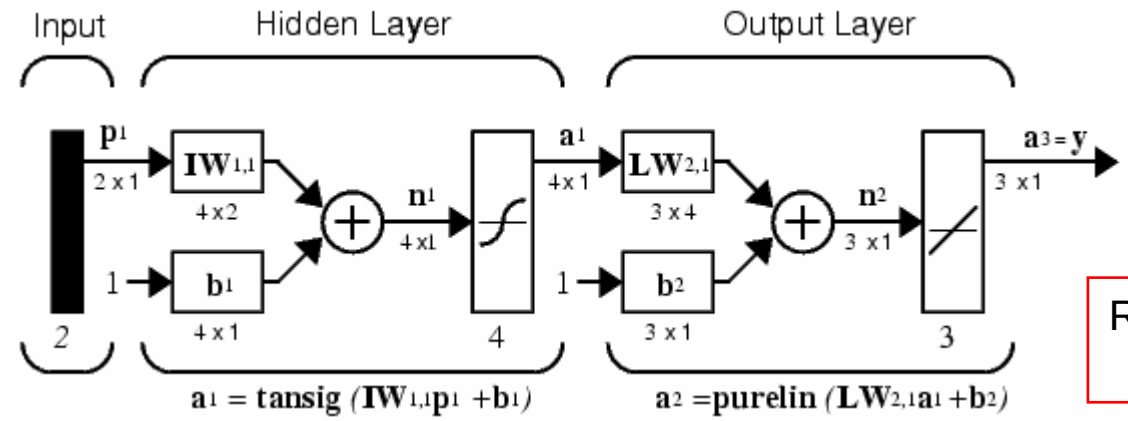
Artificial Neural Networks



Where

R = number of elements in input vector

S = number of neurons in layer



p_k = {*topography, soil water saturation, vegetation, etc.*}

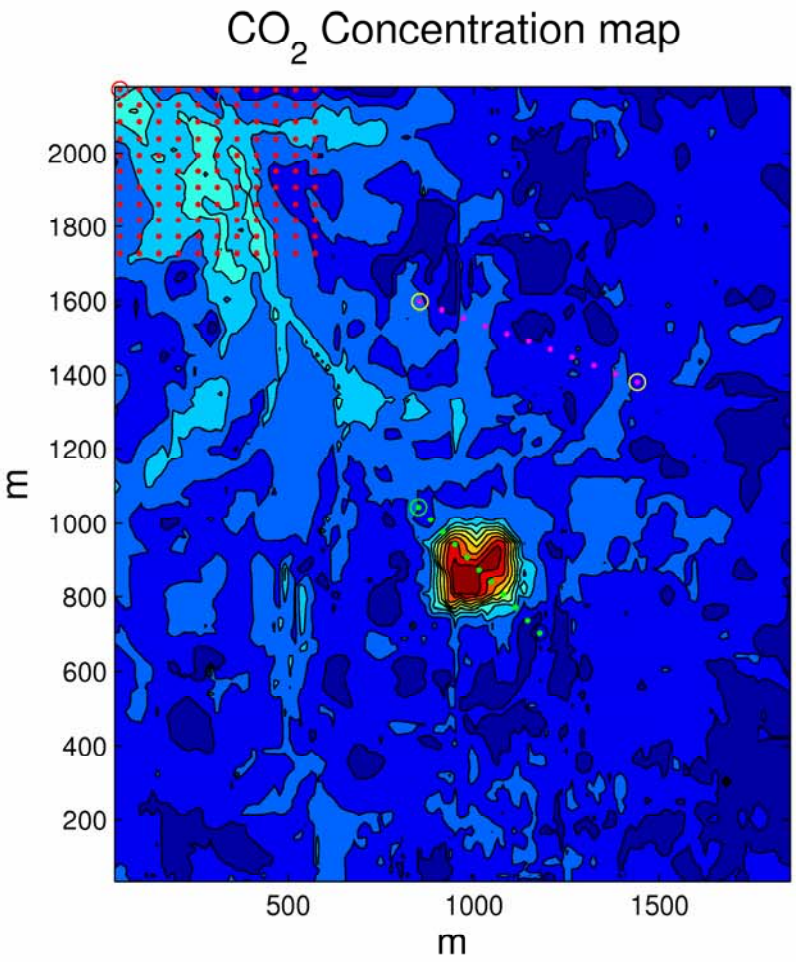
y = {*concentration, flux*}

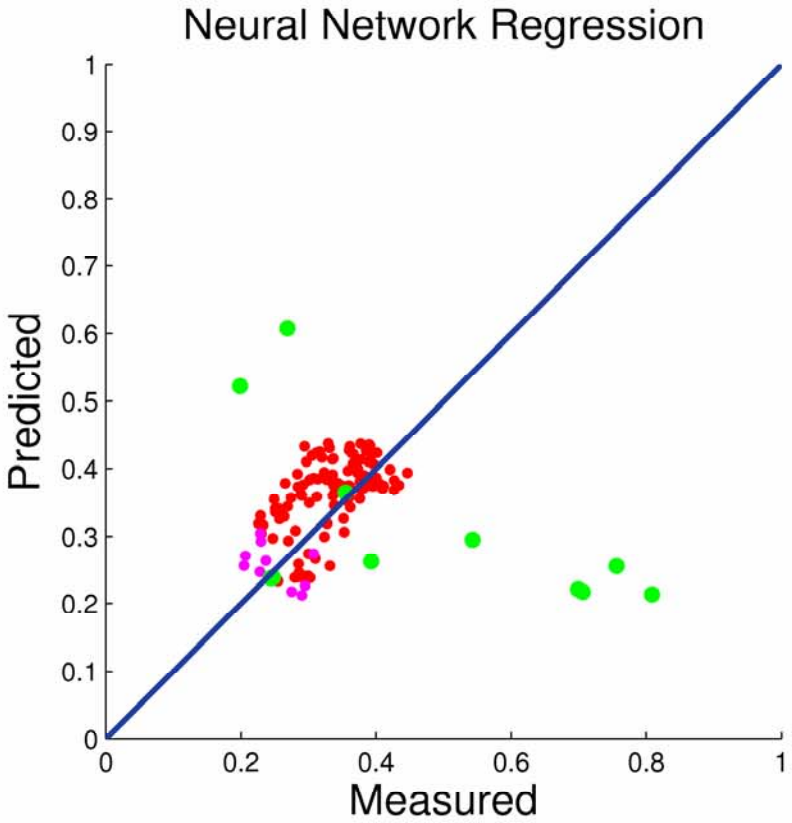
$y = ANN(p_k)$

Note that the ANN is Measurement-based => no model needed

Ref: The Neural Network Toolbox for MATLAB.

Search for Anomalies





TOUGH2 simulation of CO_2 upwards migration.

Particle Swarm Optimization

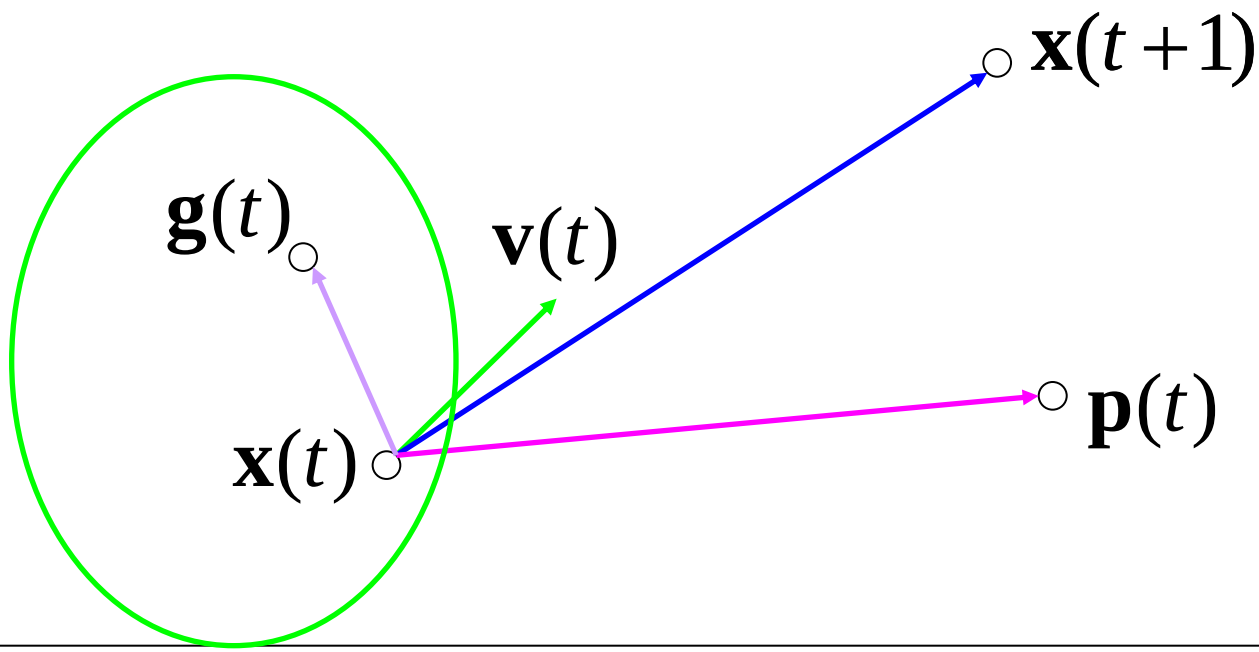
(Eberhart and Kennedy, 1995)

- **Optimization heuristic inspired by social behavior of bird flocking or fish schooling with similarities to Evolutionary Algorithms**
- **Is based on attraction of solutions to best-found solutions**
- **Proposed by Eberhart and Kennedy in 1995**

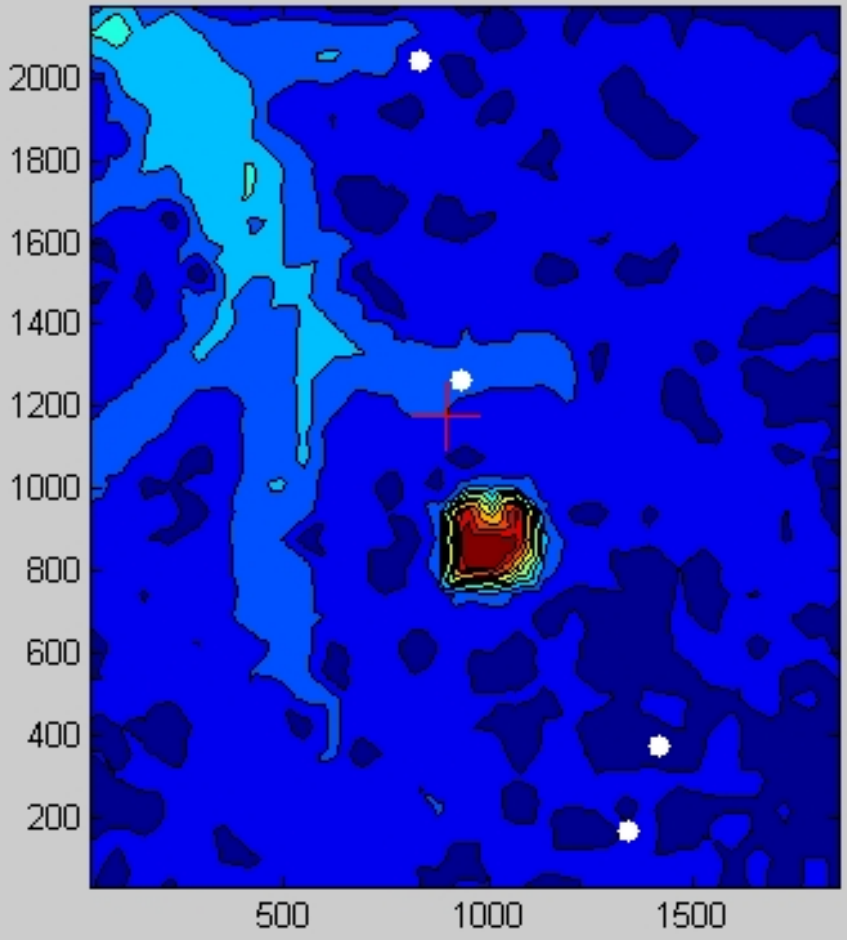
Particle Swarm Optimization, the guts

$$\mathbf{v}_i(t+1) = \alpha \cdot \mathbf{v}_i(t) + \beta\left(\rho(\mathbf{p}_i - \mathbf{x}_i) + \varphi(\mathbf{g} - \mathbf{x}_i)\right)$$

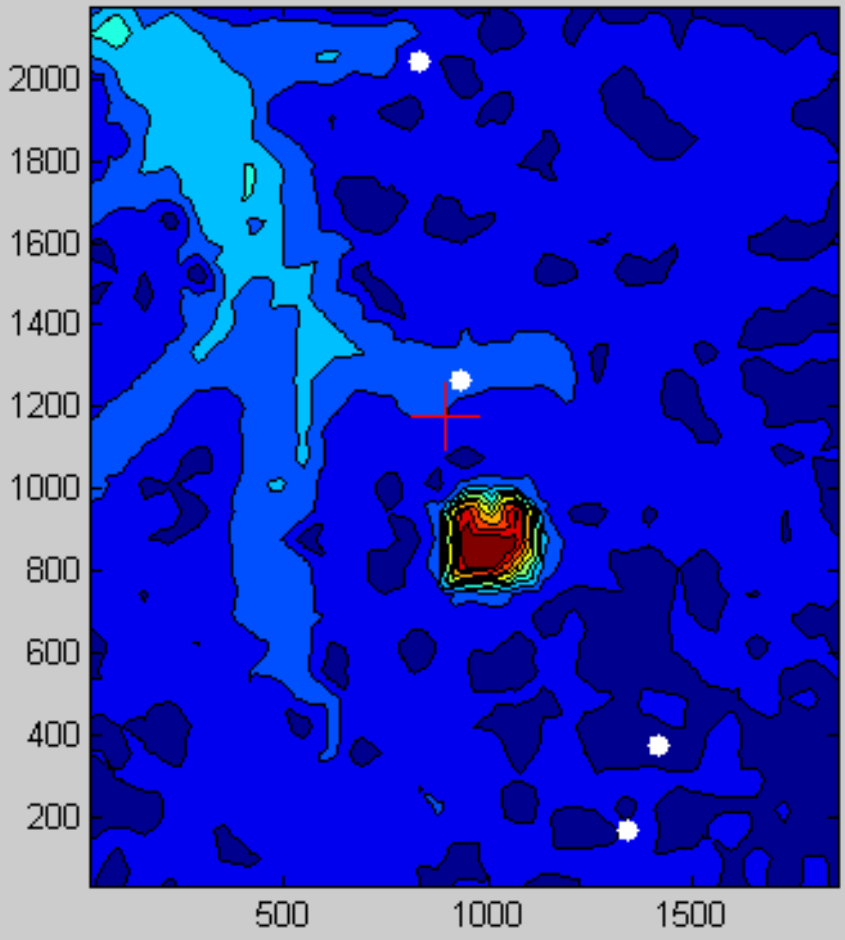
$$\mathbf{x}_i(t+1) = \mathbf{x}_i(t) + \mathbf{v}_i(t+1)dt$$



Example of PSO search



Example of PSO search



Conclusions

1. **Effective monitoring is an essential component of CCS**
2. **Modeling can place limits on characteristic length scales**
3. **Identify constraints in terms of detection limit and resources**
4. **The ANN approach is model independent (i.e., based on field meas.)**
5. **Seepage is treated as an anomaly with respect to an Integrated Baseline**
6. **Static Networks can be optimized only in a loose sense**
7. **Dynamic Networks can be optimized for search strategy**

Acknowledgments

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