בס"ד

Hough - Transform-based Interpolation Scheme for Generating Dense Spatial Maps of Air Pollutants from Sparse Sensing

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Air Pollution: Public Health and the Effects on the Environment

- Significant risk factor for multiple health situations including eye irritation, breathing difficulties, lung cancer, heart diseases and respiratory infections.
- Cause many negative effects on the environment: decreased visibility, acid rain, global warming, climate change, water quality deterioration and ecosystems destruction.
- Importance of assessing air-quality

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Air Quality Monitoring (AQM) Station and Sensors

- Today, many air-pollution studies based on data acquired from AQM.
- Provides continuous and accurate measurements.
- Expansive to build and operate
- Sited mainly near ‘hot- spots’- where the pollution level might be high or near places of interest
- Sensors – many benefits same problem

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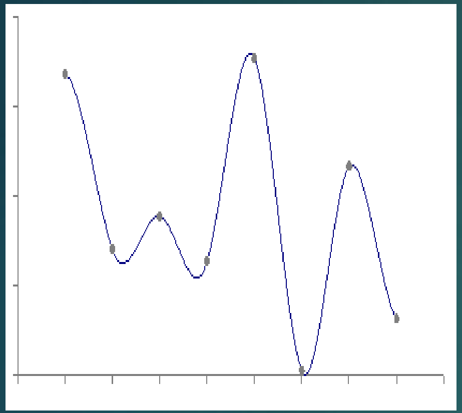
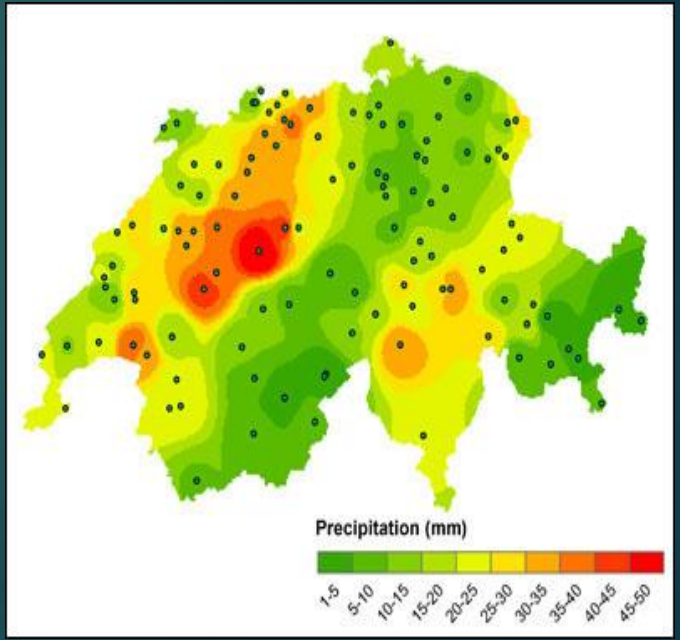
Information obtained from AQM has to be generalized with mathematical methods

Spatial Coverage - Interpolation Schemes



paulbourke.net

- Interpolation is a mathematical method of constructing continuous function within the range of measured points.
- Environmental interpolation:
  - Deterministic: influence diminishes with distance (IDW, Nearest Neighbor)
  - Geostatistical: autocorrelation, asses the statistical relationships among the measured points (Kriging)
- Focus on: IDW and Ordinary Kriging



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http://www.ripublication.com/ ijeem.htm

Applying Kriging Approach on Pollution Data Using GIS Software

Aman Tyagi[1] and Preetvanti Singh[2]
Dayal Bagh Educational Institute, Dayal Bagh, Agra – 282005.

Int Arch Occup Environ Health (2011) 84:251–257
DOI 10.1007/s00420-010-0545-z

ORIGINAL ARTICLE

PM10 air pollution exposure during pregnancy and term low birth weight in Allegheny County, PA, 1994–2000

Xiaohui Xu · Ravi K. Sharma · Evelyn O. Tal... · Jeanne V. Zborowski ·
Judy Rager · Vincent C. Arena · ...

Spatial Analysis of Air Pollution and Mortality in California

Michael Jerrett[1], Richard T. Burnett[2], Bernardo S. Beckerman[1], Michelle C. Turner[3], Daniel Krewski[3,4], George Thurston[5], Randall V. Martin[6], Aaron van Donkelaar[6], Edward Hughes[7], Yuanli Shi[3], Susan M. Gapstur[8], Michael J. Thun[8], and C. Arden Pope III[9]

Matern Child Health J (2013) 17:545–555
DOI 10.1007/s10995-012-1028-5

First Trimester Exposure to Ambient Air Pollution, Pregnancy Complications and Adverse Birth Outcomes in Allegheny County, PA

Pei-Chen Lee · James M. Roberts · Janet M. Catov ·
Evelyn O. Talbott · Beate Ritz

Research | Children's Health

Effect of Early Life Exposure to Air Pollution on Development of Childhood Asthma

Nina Annika Clark,[1] Paul A. Demers,[1,2] Catherine J. Karr,[3] Mieke Koehoorn,[1,2] Cornel Lencar,[2] Lil...
and Michael Brauer[2]

Environ Monit Assess (2008) 136:87–99
DOI 10.1007/s10661-007-9725-z

Multi-objective optimization of air quality monitoring

Dimosthenis A. Sarigiannis · Michaela Saisana

Health & Place 34 (2015) 287–295
Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/healthplace
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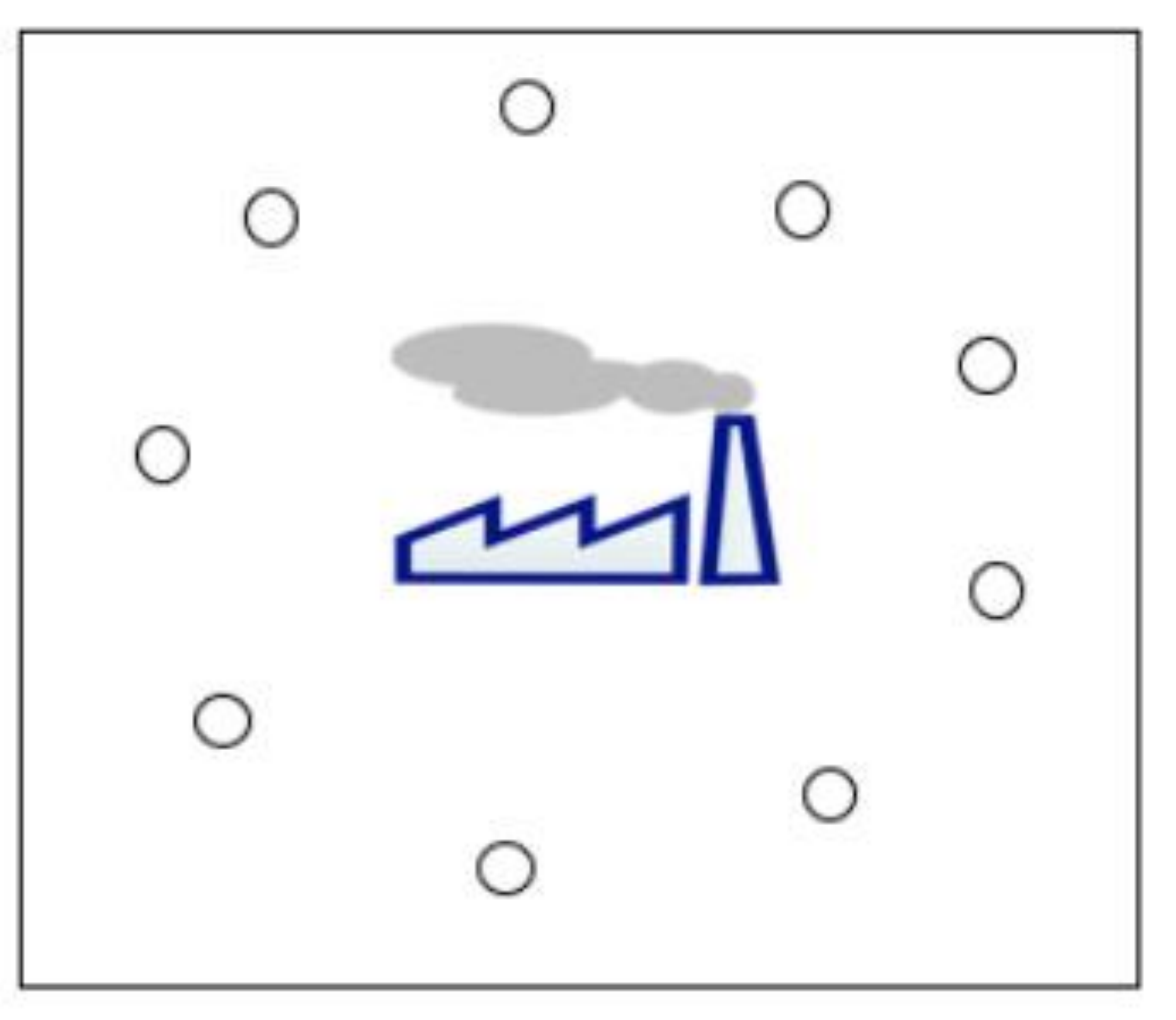
Spatial analysis of exposure to traffic-related air pollution at birth and childhood atopic asthma in Toronto, Ontario

... Jerrett[c], S.D. Dell[d,e], R. Foty[f], D. Stieb[g]

What’s the problem with IDW

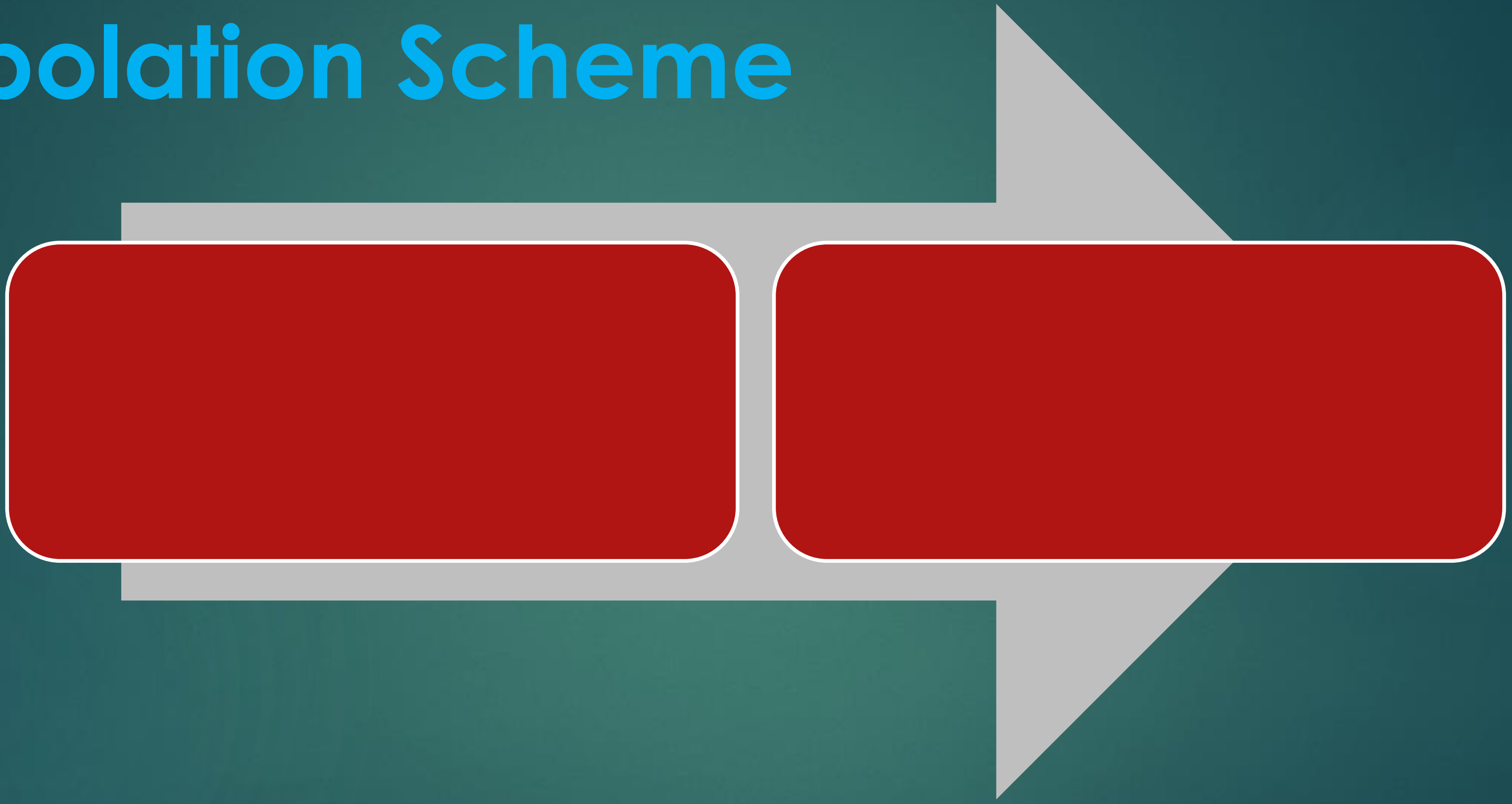
IDW: Equation Analysis

- Let c_j be t… …wn value, d_{ij} is the c…
- The interp… …$\neq 0)$:

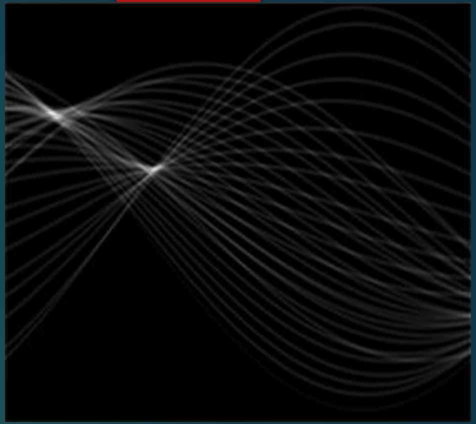


- All interpo… …weighted average c…
- Extremum… …tions only
- Not consic…
- Not considering physicochemical characteristics of pollutant

HTBI: Hough-Transform-based Interpolation Scheme

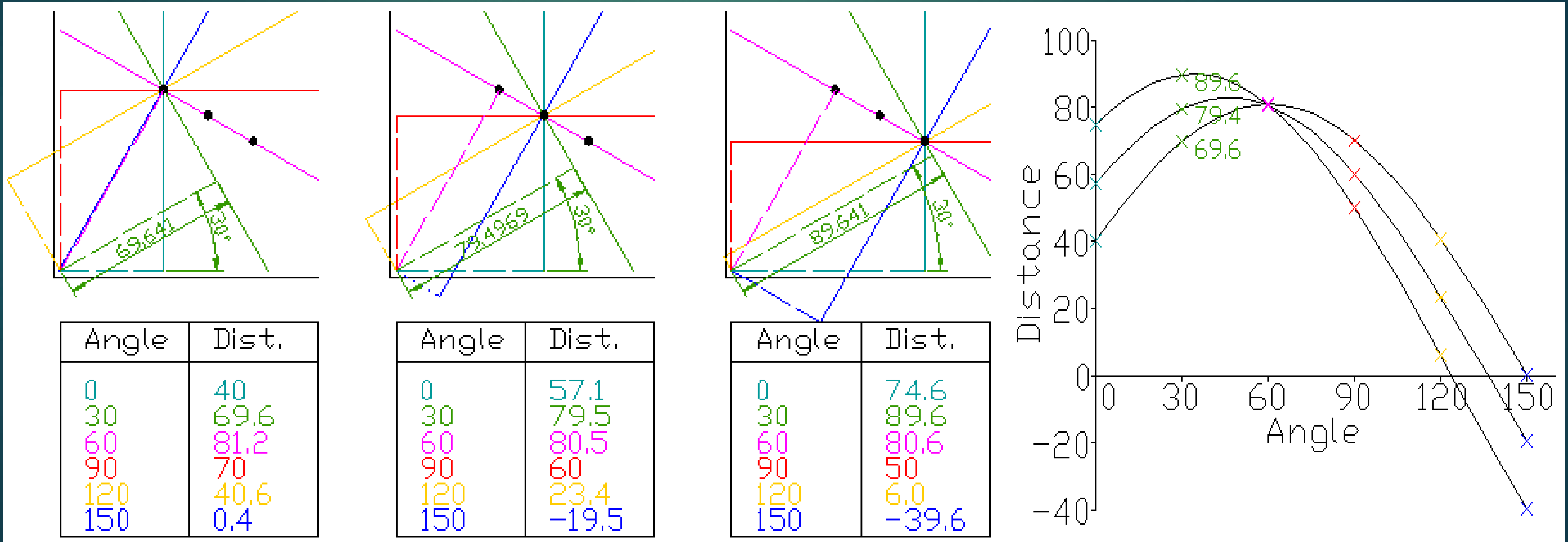


Hough Transform



quora.com.

- Cartesian space → Parametric space



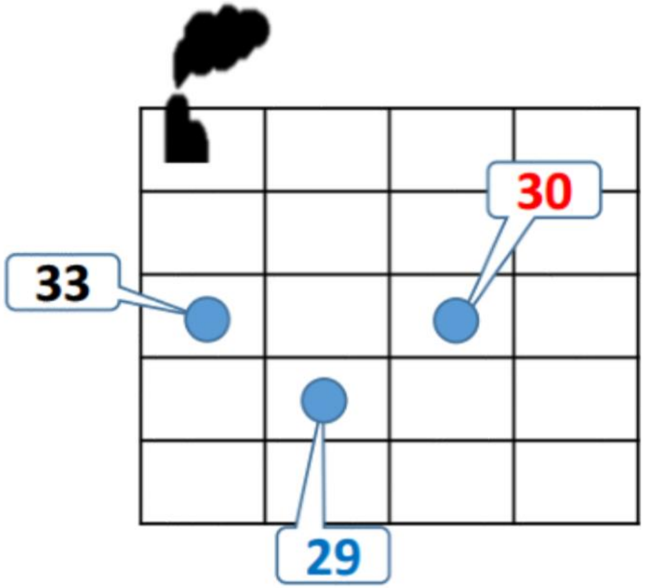
Angle	Dist.
0	40
30	69.6
60	81.2
90	70
120	40.6
150	0.4

Angle	Dist.
0	57.1
30	79.5
60	80.5
90	60
120	23.4
150	-19.5

Angle	Dist.
0	74.6
30	89.6
60	80.6
90	50
120	6.0
150	-39.6

http://lab.must.or.kr

Proof of Concept – Source Detection



(a)

HTBI Notation

Let $\{S\}$ be a set of sources of specific pollutant, with emission rates $\{Q\}$.

Let A be a continues pollution signal generated by $\{S\}$, defined over a geographical area Ω.

$\{S\}$ are located at $\vec{\gamma}\epsilon\Omega$.

Let $\{a\}$ be a finite set of samples of signal A, taken in locations $\{\omega\} \subset \Omega$.

Interpolation aims at estimating A over the entire space Ω, based on the set of samples $\{a\}$

We assume A is complies with a uniform model over entire Ω.

Stage #1 Source Detection by HTBI

- Each sample a_i is a weighted combination of the contributions from all the sources emissions, $\vec{Q}$, under some dispersion model, M. Hence a_i is given by:

$$a_i = \vec{M}_i \cdot \vec{Q}^T$$

- All sensors' measurements can be represented by the following matrices multiplication:

$$\vec{a} = [M] \cdot \vec{Q}^T$$

- Given $[M]$, we assume that there exists matrix E, which satisfies :

$$\vec{Q} = [E]\, \vec{a}^T$$

Source Detection by HTBI cont.

- Focus on single source detection
- We divide the feature space Ω into N disjoint catchments, $C_n \subseteq \Omega$
- For each of the catchments, an estimated emission rate $\hat{Q}^i{}_n$ is calculated, based on accepted measurements from single sample a_i:

$$\hat{Q}^i{}_n = e \cdot a_i$$

where e is a single row of E

- A full hypothetical emission rate:

$$\vec{\hat{Q}}_n = [E] \cdot \vec{a}^T$$

Source Detection by HTBI cont.

- Let σ_n be the standard deviation (STD) of $\vec{\hat{Q}}_n$:

$$\sigma_n = STD(\vec{\hat{Q}}_n)$$

- The catchment with the lowest σ is the approximate location of S, i.e. γ:

$$\gamma = MIN\ (\sigma_n)$$

- Once the source location, γ, is obtained, the emission rate of S is estimated by the average of the catchment's estimates:

$$\hat{Q}_\gamma = \bar{\vec{\hat{Q}}}_\gamma$$

Dispersion Models

- Radial :

$$a_i = Q \cdot e^{-\lambda|r|}$$

(Buhmann, 2003)

- Gaussian Plume Dispersion (GPD) model :

$$a_i = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}} \exp(-\frac{y^2}{2\sigma_y^2})[\exp(-\frac{(z-H)^2}{2\sigma_z^2}) + \exp(-\frac{(z+H)^2}{2\sigma_z^2})]$$

(Ermak, 1977)

Stage #2: Creation of Dense Spatial Pollution Map

- We can now estimate the entire Ω:

$$C_n = \overrightarrow{M} \cdot \hat{Q}_\gamma$$

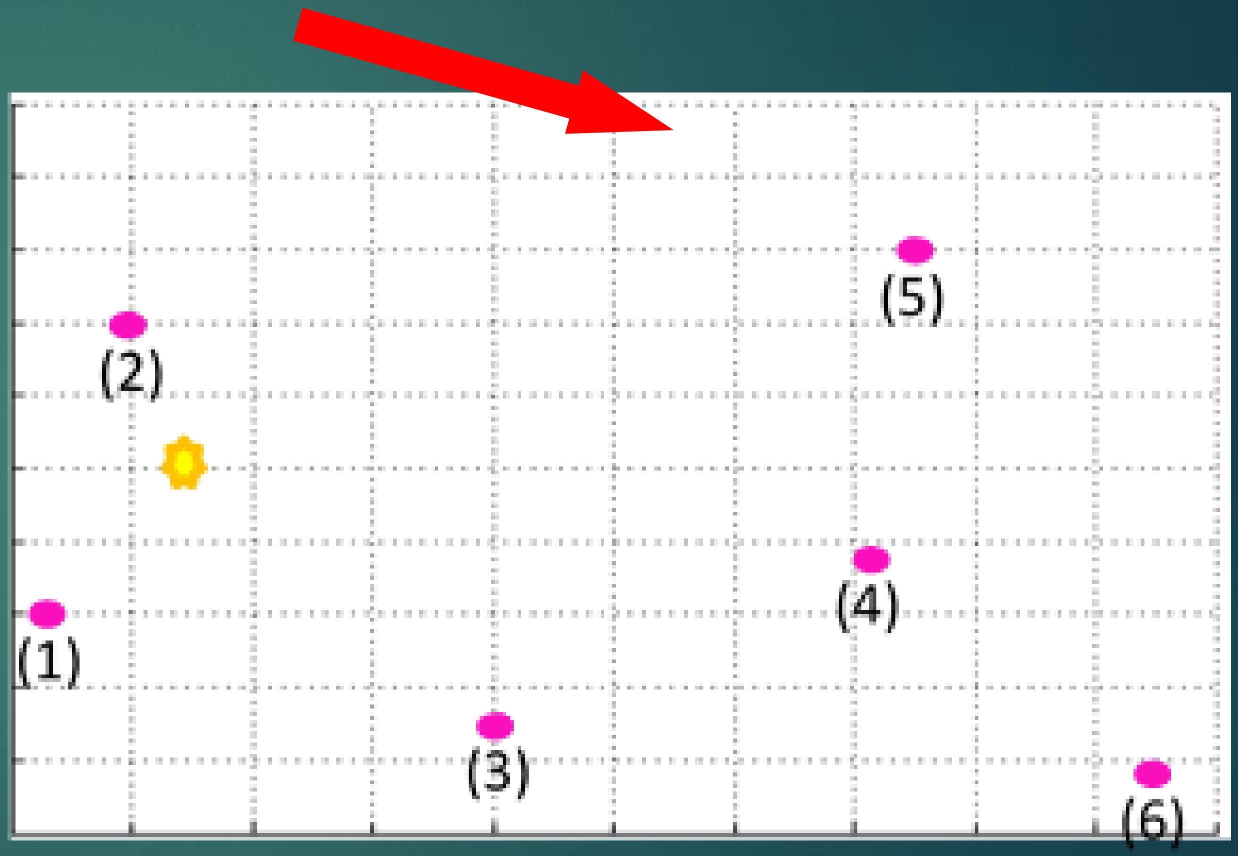
Computational Simulation

- Geographical area Ω with a size of 20km^2
- Q = 8 ton/hour
- For Gaussian plume model:
  - Effective stack-height: 120m
  - Wind:

Speed = 4 m/sec

Direction = 285^o

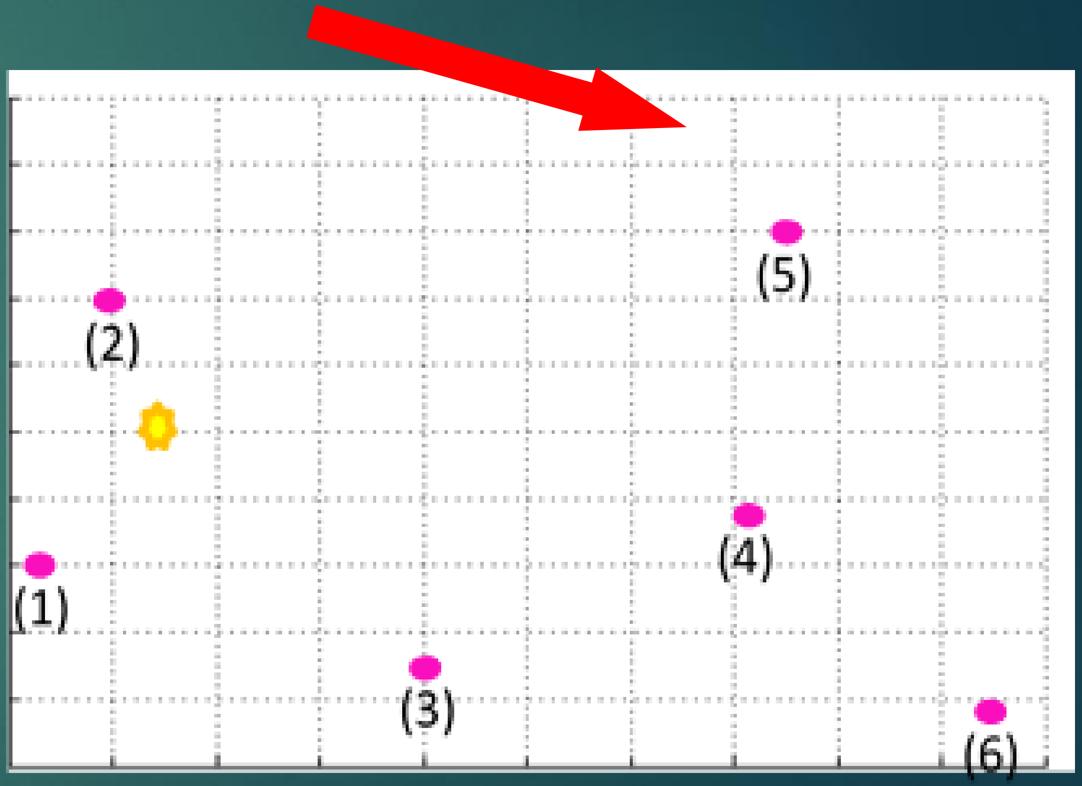
Stability class: stable



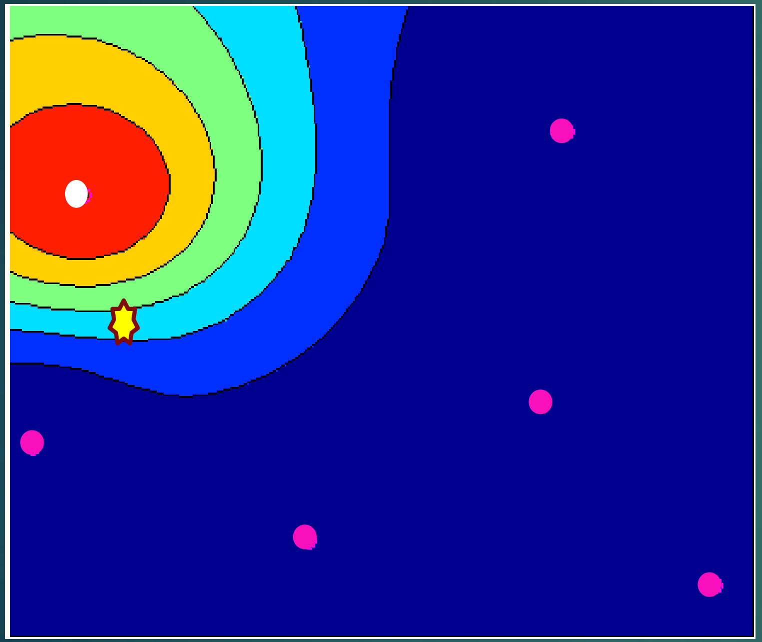
Additive white Gaussian noise with SNR of 10%

Computational Simulation -

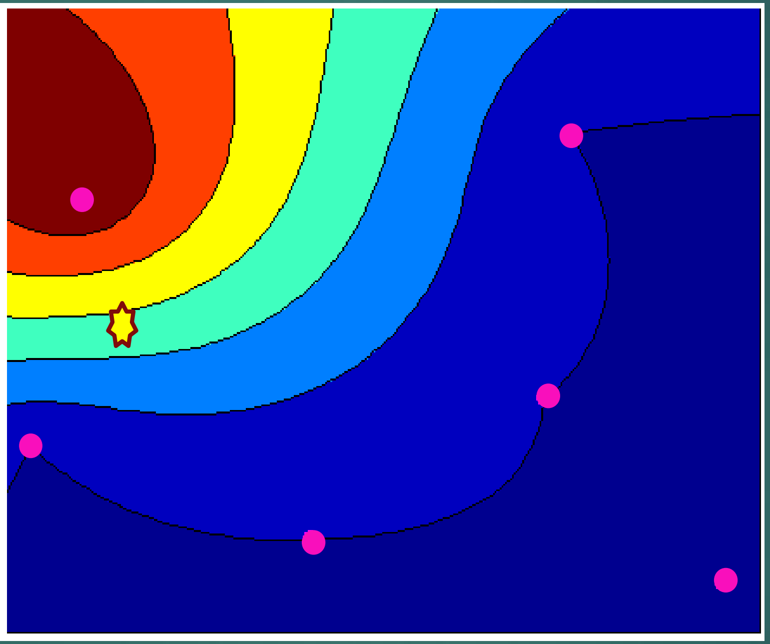
Sensor #	Radial ($\mu g/m^3$)	GPD ($\mu g/m^3$)
(1)	0.180	0
(2)	2.586	0
(3)	3.35*e-10	6.59*e-30
(4)	1.60*e-16	282.5981
(5)	1.65*e-20	6.20*e-17
(6)	1.23*e-30	1.1097



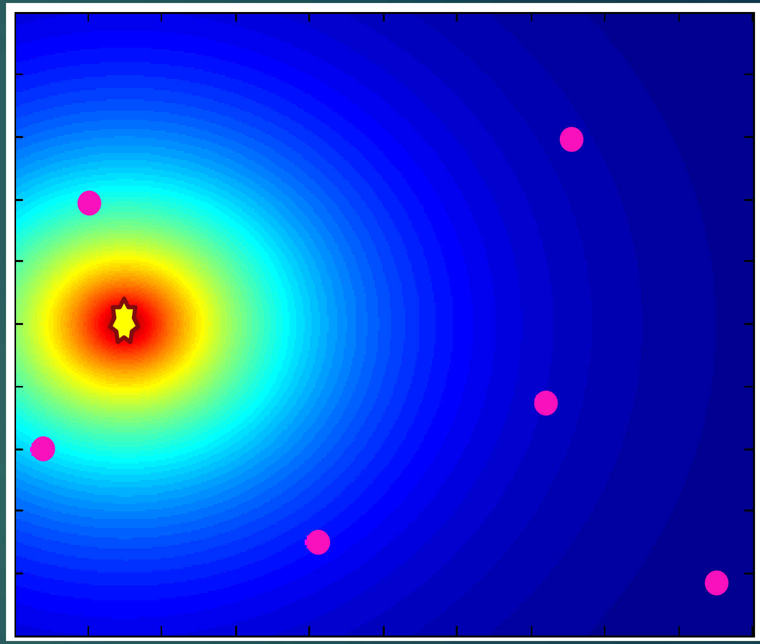
Results #1: Radial Dispersion Model



IDW

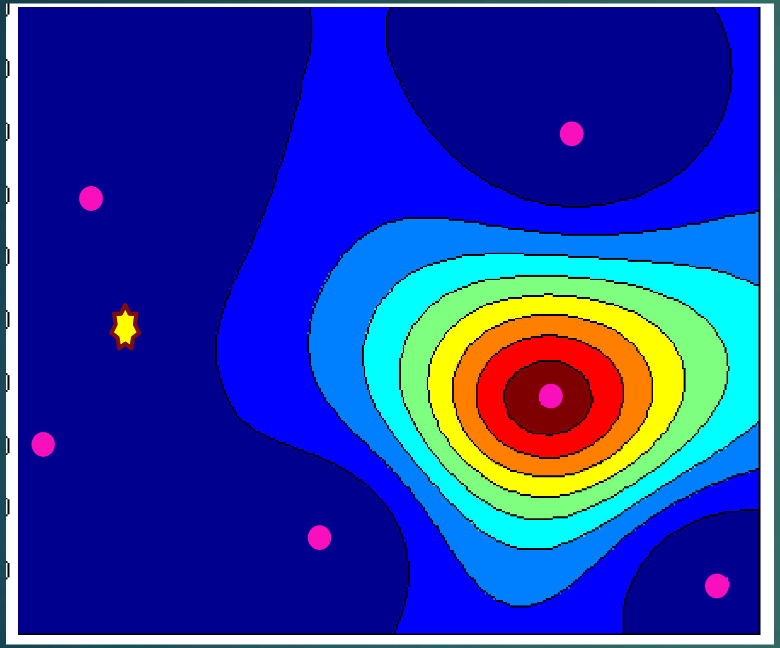


Kriging

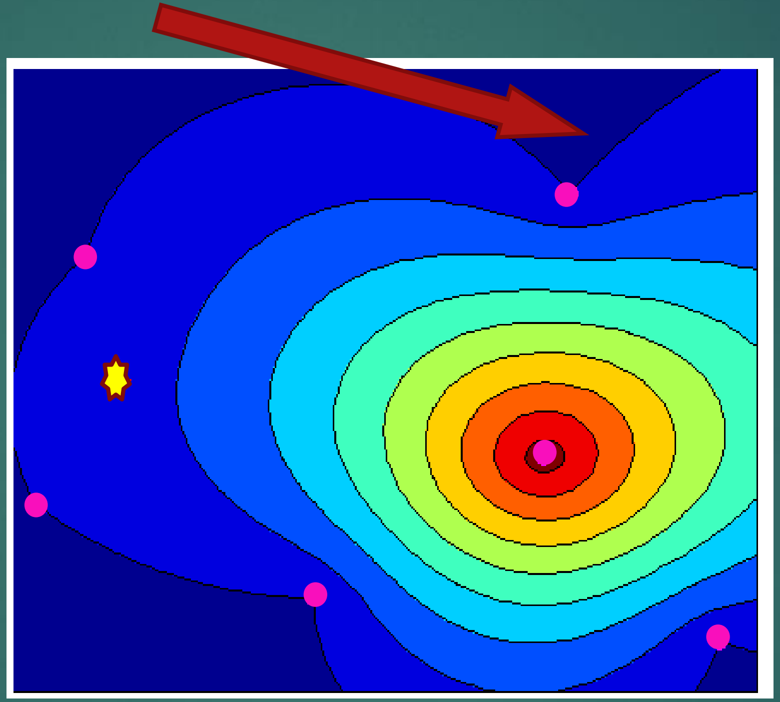


HTBI

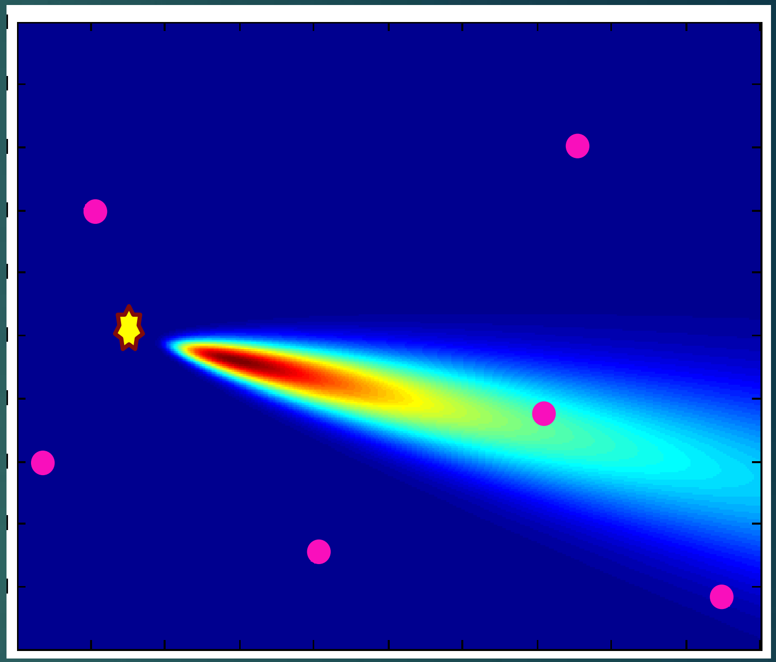
Results #2: Gaussian Dispersion Model



IDW



Kriging



HTBI

Uncertainty of the Models

- Additive white Gaussian noise on both ambient concentrations, wind speed and direction with differential SNR
- Radial Model: shows stability even with SNR > 50% (SNR of 3dB)
- Gaussian Model: Shows dependency on the catchments size:

  For cell size of $40m^2$, our algorithm showed stability

  up to 10% SNR.

  For cell size of $20m^2$, the HTBI showed higher

  sensitivity to noise - only up to 5% SNR (13 dB).

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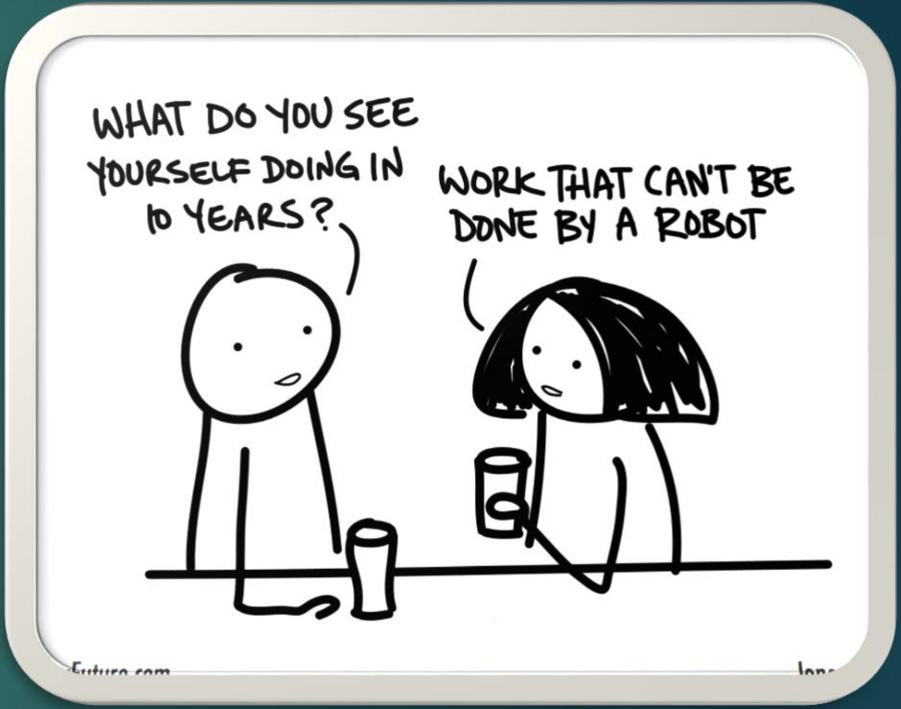
Future Work

- Future work, carried out these days, is focusing on the implementation of the method on a real-world problem.
- Preliminary results obtained, reveal the high potential inherent in our method
- Much work to be done to adapt HTBI to real conditions
- In particularly, the existing dispersion models are based on several preliminary assumptions that are not always consistent with the actual situation



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