GITISA – Summer School 2012

Tecnologie sostenibili per la tutela dell'ambiente

LAGRANGIAN PARTICLE MODELS FOR AIRBORNE POLLULANT DISPERSION

Applications and research purposes

DIIAR

Technical School of Milan

25/06/2012

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Abstract

- Air Quality Models: a brief introduction.
- Overview of a LPDM (SPRAY by Arianet S.r.l.).
- Case study: application of the model to an existing power plant.
- Future research purposes.

Air Quality Models

- Atmospheric dispersion and chemical reactions of air pollutants.
  - Space – time evolution of concentration field $\boldsymbol{C = C(x,y,z,t)}$.

EMISSION SOURCES:

- *Industrial or power plants.*
- *Veichular traffic.*
- *Accidental chemical releases.*

Simulation of dispersion process

EULERIAN approach:

computing the ***C = C(x,y,z,t)***

function as a solution of

General Diffusion Equation.

Gaussian solution (Sutton, 1969).

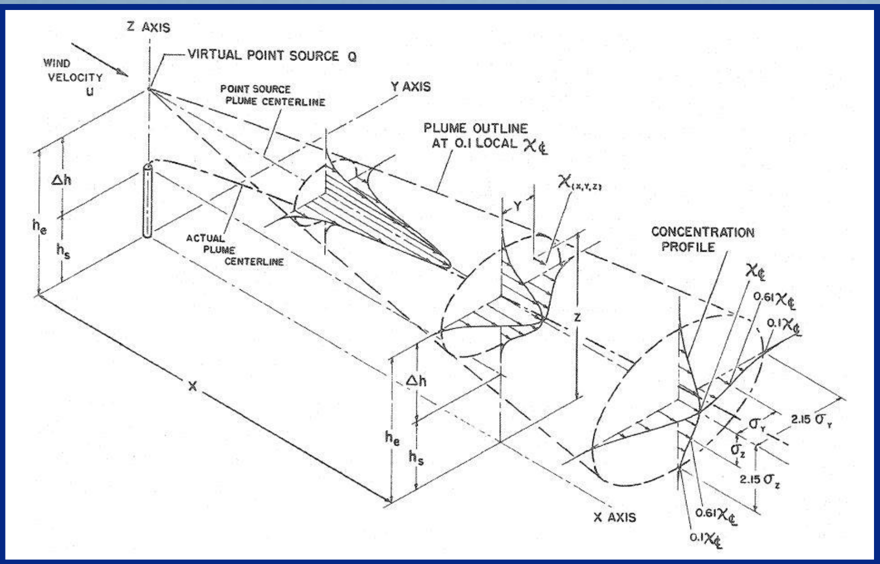
LAGRANGIAN approach:

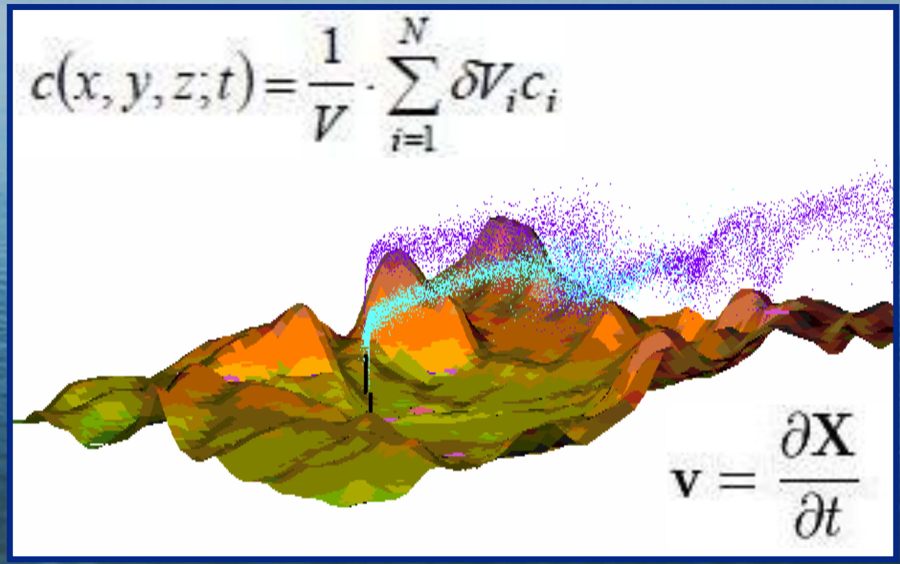
discretizing the pollulant's emission

by a swarm of little particles

following the atmospheric flow.

Particle position equation





Input - output data for AQMs

EMISSION DATA

- Source: *stack height* and *section.*
- Pollutants: *Temperature, exit speed, emission ratio.*

METEOROLOGY

- *Wind speed* and *temperature field.*
- *Turbulence scale parameters.*

DOMAIN

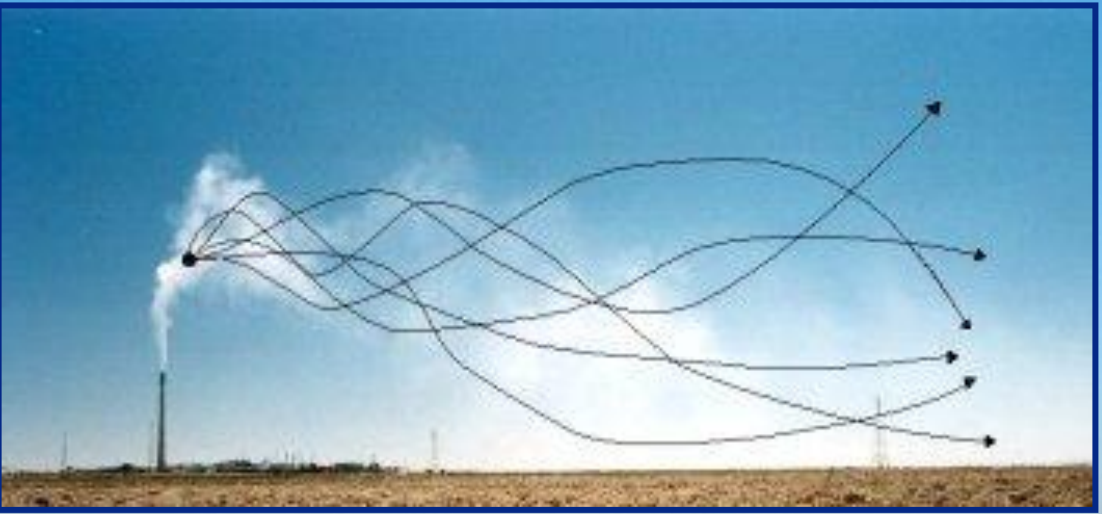
- *Topography* and *land use data.*
- *Computational spatial – time grid.*

Air Quality Models

OUTPUT

Concentration field.

Lagrangian particle models (1)



$$u(t) = \overline{u} + u'(t)$$
$$v(t) = \overline{v} + v'(t)$$
$$w(t) = \overline{w} + w'(t)$$

Mean wind velocity

(meteo dataset)

Velocity fluctuation

(turbulent flows)

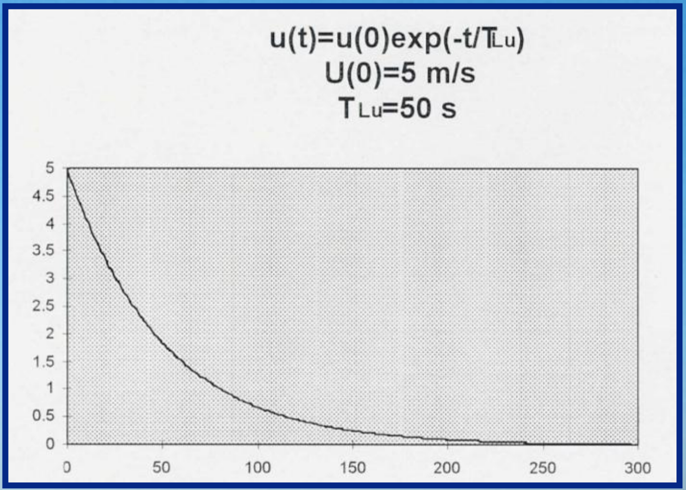
$$x(t+\Delta t) = x(t) + \left[\overline{u} + u'(t)\right]\Delta t$$
$$y(t+\Delta t) = y(t) + \left[\overline{v} + v'(t)\right]\Delta t$$
$$z(t+\Delta t) = z(t) + \left[\overline{w} + w'(t)\right]\Delta t$$

Lagrangian particle models (2)

Computing velocity fluctuations:

Langevin equation

$$\frac{du'}{dt} = -\frac{1}{T_{Lu}} u'(t) + \eta(t) \qquad (\eta \text{ indipendent from } u')$$



Thus, discretizing:

$$u'(t+\Delta t) = u'(t) - \frac{u'(t)}{T_{Lu'}}\Delta t + \eta \Delta t \quad = \quad \left(1 - \frac{\Delta t}{T_{Lu'}}\right) u'(t) + u''(t)$$

Defining: $r = e^{-\frac{\Delta t}{T_{Lu'}}} \cong 1 - \frac{\Delta t}{T_{Lu'}} \qquad (\Delta t << T_{Lu'})$

$$u'(t+\Delta t) = r\, u'(t) + u''(t)$$

$$\left(\overline{u'^2(t+\Delta t)} = r^2 \overline{u'^2(t)} + \overline{u''^2} + \overline{2r\, u'(t)\, u''} \quad \text{then,} \quad \sigma_{u''} = \sigma_{u'}\sqrt{1 - r^2}\right)$$

Lagrangian particle models (3)

$$u'(t+\Delta t) = r_u\, u'(t) + u''(t+\Delta t)\,\sigma_{u'}\sqrt{1-r_u^2}$$

$$v'(t+\Delta t) = r_v\, v'(t) + v''(t+\Delta t)\,\sigma_{v'}\sqrt{1-r_v^2}$$

$$w'(t+\Delta t) = r_w\, w'(t) + w''(t+\Delta t)\,\sigma_{w'}\sqrt{1-r_w^2}$$

$r_i = e^{-\frac{\Delta t}{T_{Li}}}$ and $i = u, v, w$

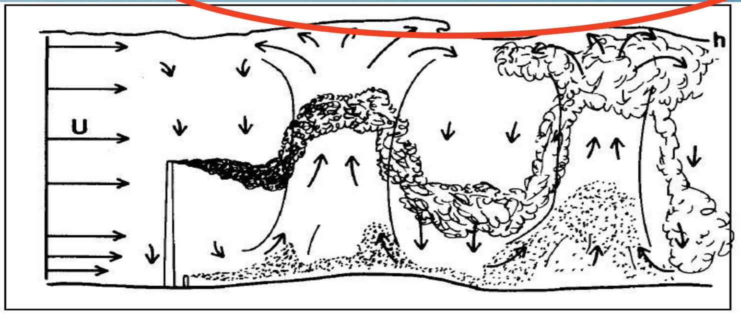
u″, v″, w″ random terms from a *Wiener process* (mean = 0, σ = 1)

Gaussian turbulence model for *homogeneous* and *steady - state* conditions.

More complex schemes for *inhomogeneous* and *NON – Gaussian turbulence*.

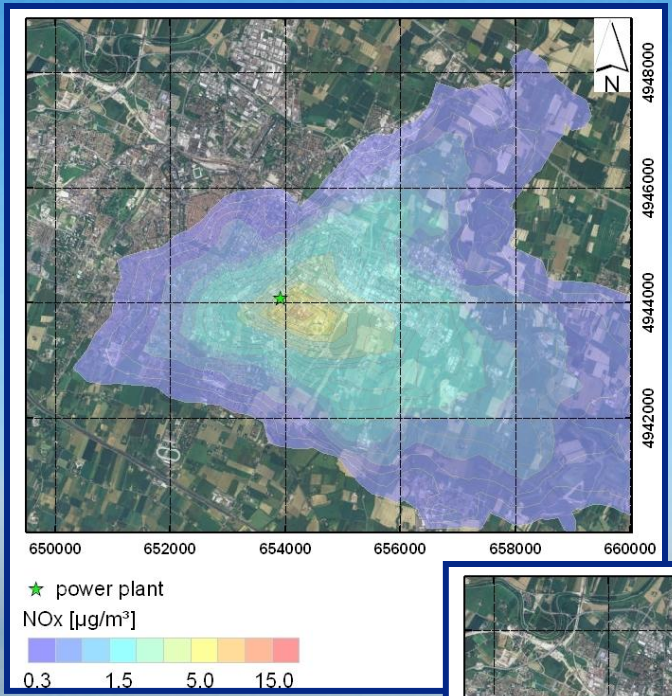
Fokker – Plank equation for PDF
***Well – mixed* criterion**
(J. D. Thomson, 1987)

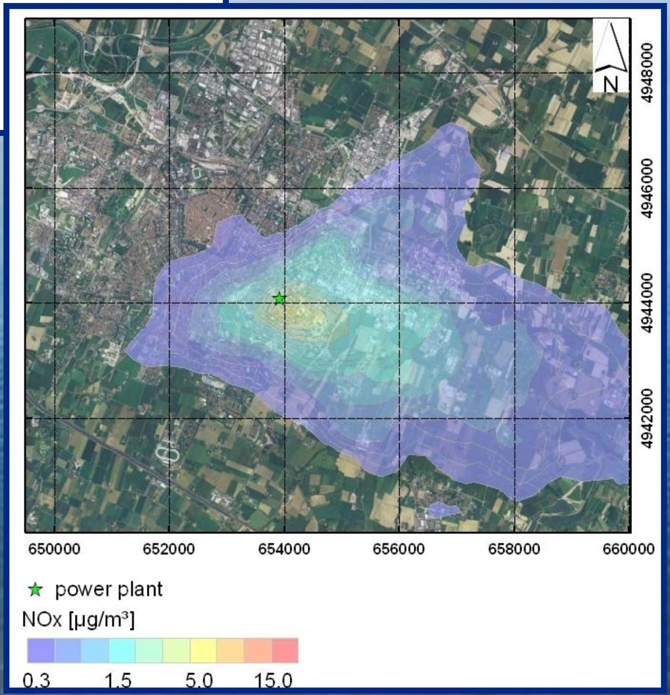
$$\frac{\partial}{\partial t}P_a(z,w,t) + \frac{\partial}{\partial z}\left[w \cdot P_a(z,w,t)\right] = -\frac{\partial}{\partial w}\left[a_w \cdot P_a(z,w,t)\right] + \frac{1}{2}\frac{\partial^2}{\partial w^2}\left[b_w^2 \cdot P_a(z,w,t)\right]$$



3rd and 4th order moments for PDF.
(*Bi - Gaussian* or *Gram – Charlier* PDF)

Application: comparing *emission scenarios*





General Hospital of Modena

- **EXISTING PLANT**
  conventional ***boilers***
  for heat production.

- **NEW PLANT**
  Tri-generator
  and *auxiliary* **boliers**.

- ***Mean average concentration fields***
  in *winter* season.

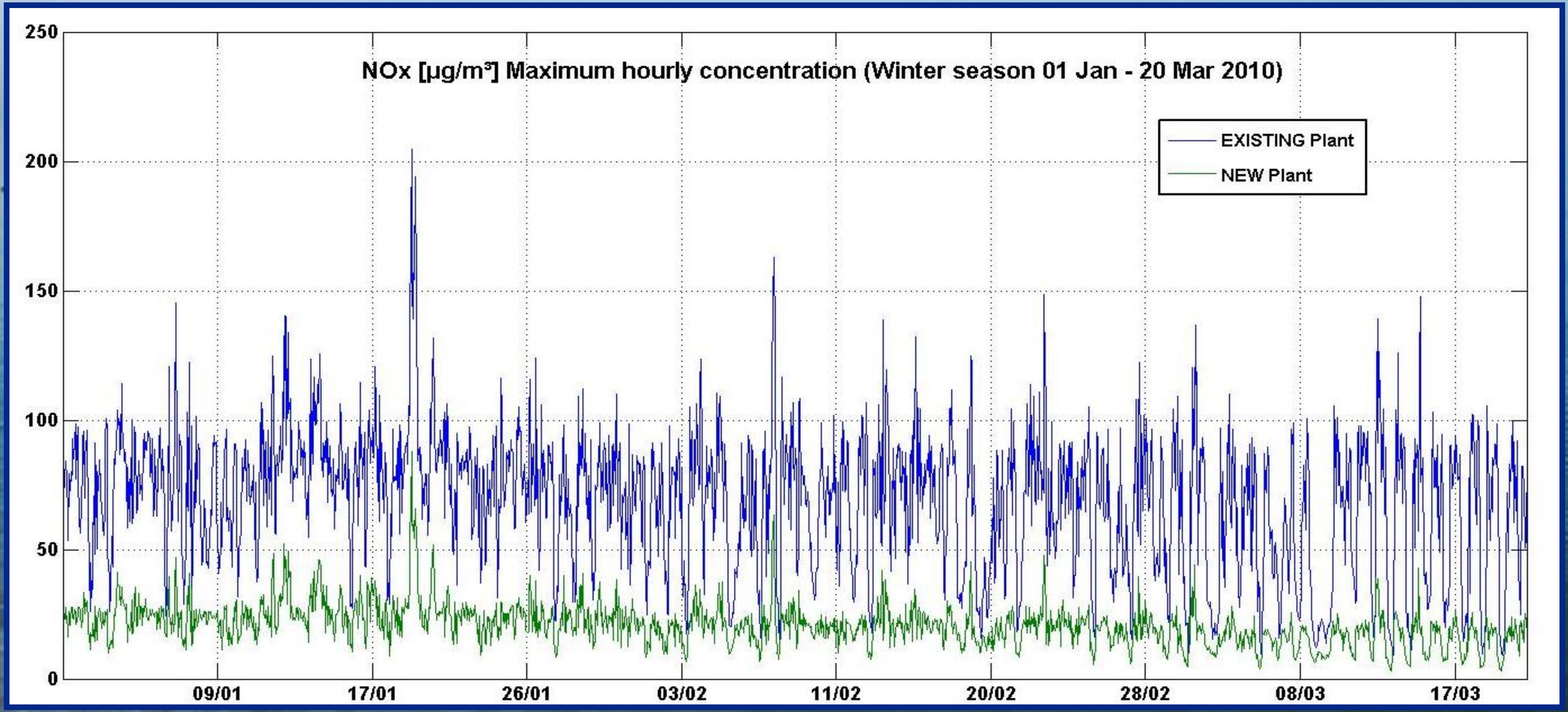
Environmental performances of two plant's installations.

Application: compliance with *regulatory limits*

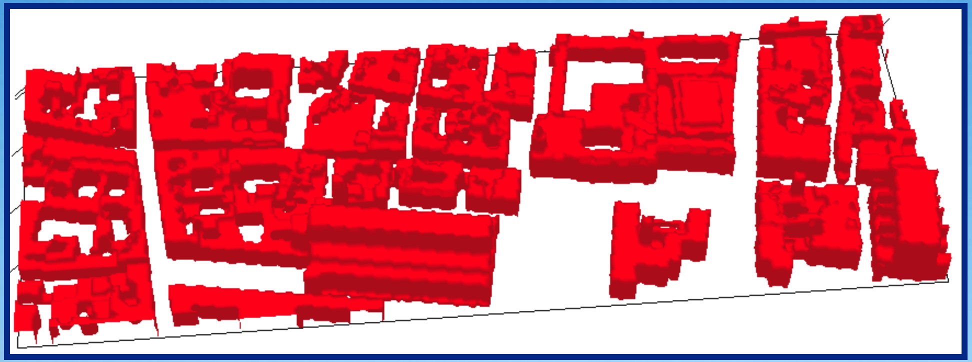
NO_x: 200 µg/Nm³ Maximum hourly concentration (D.lgs. 155/2010)

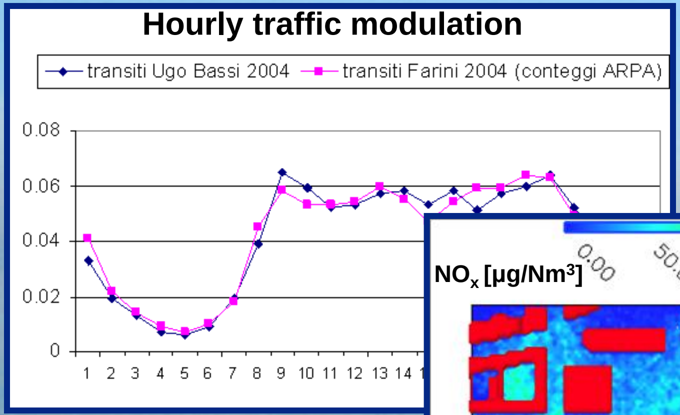
Average of maximum NO_x hourly concentration:

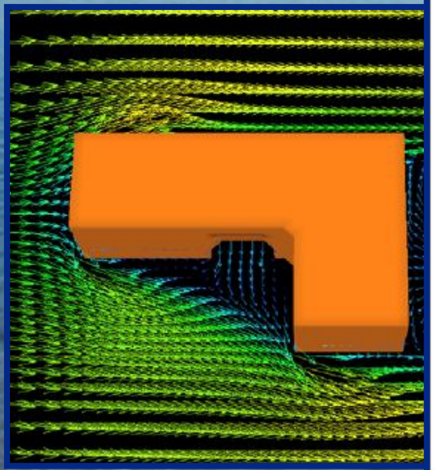
- **EXISTING PLANT: 69 µg/Nm³** (34,5 % of the regulatory limit).
- **NEW PLANT: 21 µg/Nm³** (10 % of the regulatory limit).

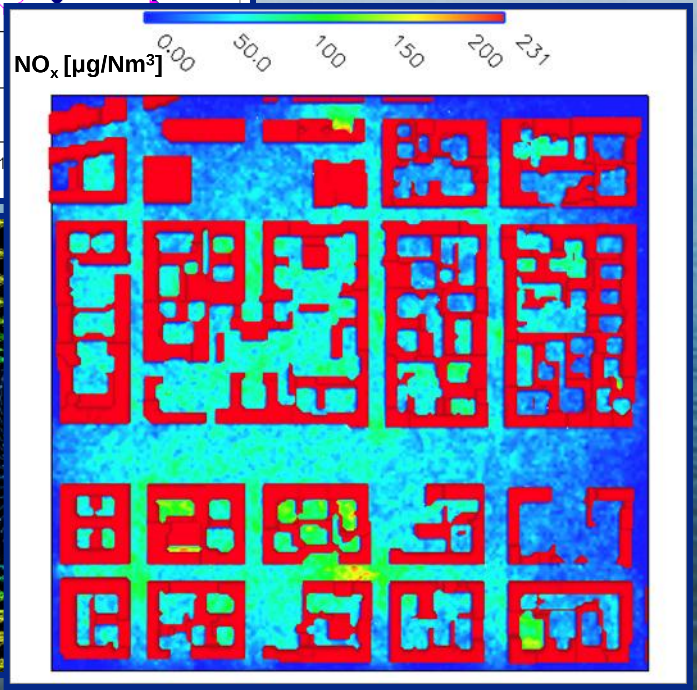


Future application: *microscale simulation*









Microscale: 10 – 100 m.

- **Urban pollution sources**

(*power* or *industrial plants*, *TRAFFIC*).

- **Emission inventories**

(Local Environmental Agencies).

- **Urban topography:**

air flow around buildings.

- **Concentration fields:**

contribution of every source.

- **Policies** and **startegies**:

improving urban air quality.

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THANKS FOR YOUR ATTENTION!!!

Marco Zaccanti

… any questions?

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