Environmental Impact Assessment.
Air Quality Models.

CEFAP - Codroipo
July 8th, 2013

ARPA FVG – CRMA
Agenzia Regionale per la Protezione dell'Ambiente del Friuli Venezia Giulia
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Regional Agency for Environmental Protection – Friuli Venezia Giulia
Regional Center for Environmental Modelling
Introduction

- Models classification and typical applications
- Why using models?
- Running models: essentials
- Running models: steps
- Running models: initialization files vs data files
- Relevant source characteristics
- Meteorological input data
- Needed and available resources.
Air quality models: essentials

Models classification.
Typical applications.
Air quality models: essentials

Air Quality Models Taxonomy and Applications:

- Air Quality Models
  - Statistical
  - Deterministic
    - Lagrangian: \( r(t) = \ldots \)
    - Eulerian: \( C(x,y,z,t) = \ldots \)
      - Numeric
        - Trajectory
          - Particles: SPRAY ...
        - Analytical
          - Gaussian: AERMOD CALINE ...
        - Puff: CALPUFF ...
      - Numeric
        - Grid
          - CAMx
          - FARM
          - CHIMERE ...

...
Air quality models: essentials

Air Quality Models Taxonomy and Applications:

- Statistical
  - put various MEASURED datasets in relation
  - DONT’T use A PRIORI descriptions of PHYSICAL-CHEMICAL processes («black box»)
  - require «huge» AMOUNTS OF MEASURED DATA
  - learn from measured data: ALREADY EXISTING SITUATIONS
    - e.g.:
      - linear and non-linear regressions
      - neural networks
      - decision trees
      - ...

- Deterministic
  - Eulerian
    - C(x,y,z,t) = ...

- Lagrangian
  - r(t) = ...

- Analytical
  - Gaussian
  - Numeric

- Trajectory
  - Grid
  - CAMx
  - FARM
  - CHIMERE

- Particles
  - SPRAY
  - AERMOD
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- Puff
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Air quality models: essentials

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  - Gaussian
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    - CALINE ...
- Analytical
  - Puff
    - CALPUFF ...
- Numeric
  - Grid
    - CAMx
    - FARM
    - CHIMERE ...

Air quality models require specific METEO and EMISSIONS data to simulate physical-chemical processes of transport, dispersion, and chemical transformation.
Air quality models: essentials

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  - Lagrangian
    - $r(t) = \ldots$
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  - Gaussian: AERMOD, CALINE, \ldots
  - Puff: CALPUFF, \ldots
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  - FARM
  - CHIMERE, \ldots
Air quality models: essentials

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    - Particles
      - SPRAY
      - \ldots
  - Analytical
    - Gaussian
      - AERMOD
      - CALINE
      - \ldots
    - Puff
      - CALPUFF
      - \ldots

\( C_{i,j,t} = F(i,j,t,\ldots) \)
use «functions»

- Grid
  - CAMx
  - FARM
  - CHIMERE
  - \ldots
Air quality models: essentials

Air Quality Models Taxonomy and Applications:

- Industrial sources
- Streets
- ...
Air quality models: essentials

Air Quality Models Taxonomy and Applications:

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  - Lagrangian
    - \( r(t) = \ldots \)
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      - SPRAY
      - \ldots
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      - CALINE
      - \ldots
    - Puff
      - CALPUFF
      - \ldots
  - Analytical
  - Numerical
    - Grid
      - CAMx
      - FARM
      - CHIMERE
      - \ldots
    - All sources
    - Regional scale

- Industrial sources
- Streets
- \ldots
What are (deterministic) Air Quality Models?

Programs capable of simulating the dispersion of the pollutants emitted in ambient-air. They are based on:

- atmospheric physics and photochemistry;
- physics and photochemistry of the emitted pollutants;
- gas and particulate matter dynamics;
- calculation power of modern computers.

Diffuse emissions

Point source emissions
Air quality models: essentials

Why using models?
Why using models?

An evaluation of the environmental impact of a source is needed...

Models can give it:

**IN ADVANCE**: BEFORE a specific source starts emitting

**OVER A WHOLE AREA**: not only in a few specific points

Models can help you to understand the role played by each «actor»:

wind, stack height, nighttime/daytime emissions...
Why using models?

Models are expected to **GUIDE THE FORMULATION OF MONITORING PLANS** in Environmental Impact Assessment Studies... *(can you remember this slide...?!!)*
Why use numerical models: what do we expect from them?

From models we expect quantitative informations on dispersed pollutants concentration [pollutant mass / volume of ambient-air], as a function of time and space.

Which benefits respect to field measures?
- detailed spatial coverage
- process reproducibility
- can work both in
  - diagnosis
  and
  - prognosis

Which drawbacks:
- it’s just a model of reality! => needs validation ( = monitoring plan);
- quality of results strongly depends from the correct usage of the WHOLE model system
DPSIR: ΔState assessment by models

scenario analysis by altering Pressures (es: Environmental Impact Studies, 2020 scenarios, etc.) => instruments that allow to plan Responses
Running models: essentials
Air quality models: essentials

US EPA page... here you can download some free and widely used models for Impact Assessment Studies!!

Preferred/Recommended Models

You will need Adobe Acrobat Reader to view the Adobe PDF files on this page. See EPA's PDF page for more information about getting and using the free Acrobat Reader.

These refined dispersion models are listed in Appendix W and are required to be used for State Implementation Plan (SIP) revisions for existing sources and for New Source Review (NSR) and Prevention of Significant Deterioration (PSD) programs. The models in this section include the following:

AERMOD Modeling System - A steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain.

CALPUFF Modeling System - A non-steady-state puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollution transport, transformation, and removal. CALPUFF can be applied for long-range transport and for complex terrain.

Other Models - Other dispersion models including BLP, CALINE3, CAL3QHC/CAL3QHCR, CTDPLUS, and OCD.

AERMOD Modeling System

The American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC) was formed to introduce state-of-the-art modeling concepts into the EPA's air quality models. Through AERMIC, a modeling system, AERMOD, was introduced that incorporated air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain.

There are two input data processors that are regulatory components of the AERMOD modeling system: AERMET, a meteorological data preprocessor that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, and AERMAP, a terrain data preprocessor that incorporates complex terrain using
Air quality models: essentials
A «NUMERICAL MODEL» is an ENGINE.

Once you install it, you still have to plan, build and put together everything else…
… from brakes to pilot!
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Air quality models: essentials

Usually air quality models are written in FORTRAN: they are compiled and an executable file is produced.

Sometimes a Graphical User Interface is available.

But in most cases they are executed from command line (Windows DOS or Linux BASH).
Air quality models: essentials

Don’t be afraid of command line...! 😊
Running models: steps
Application steps

PRELIMINARLY…

1. Choose an appropriate model for Impact Evaluation
2. Buy/download the model
3. Install/compile and run on the Test Case

THEN…

4. Orography and land use input preparation
5. Meteorology input preparation (meteo pre-processing)
6. Emissions input preparation
7. Definition of dispersion parameters
8. **Simulation execution**
9. Post elaboration
Methodology (details - a)

Questions for which an answer is needed

Choices:
- pollutants to be considered;
- area of interest;
- time interval;
- spatial resolution (temporal resolution is defined consequently);

Model (modelling system) choice based on:
- previous choices;
- orography;
- available resources (calculation, knowledge and input data)

Meteorological model

Pre-processing of meteorological informations needed by the dispersion model

Finding meteo measures and simulations already available
I need to evaluate some impact index derived from current legislation (air quality limits)...

That impact index is computed on annual base (e.g. yearly mean) so probably...

my simulation will have a time domain of a whole year!

(once again... can you remember the following slide?!!!)

To calculate **immission** you must consider a set of parameters:
- average annual PM10 (µg/m3);
- number of exceedances of the daily average PM10: 50 µg/m3;
- number of exceedances of the hourly average NO₂: 200 µg/m3
- average annual NO₂: 40 µg/m3;
- average annual NOₓ: 30 µg/m3;
- average annual C6H6: 5 µg/m3.

You can use an atmospheric dispersion model

[http://www.epa.gov/scram001/](http://www.epa.gov/scram001/)
Methodology (details - b)

Data preparation:
- source characteristics
- which pollutants?
- temporal resolution;

Model execution

Pre-processed meteorological data

Emissions source data
Methodology (details -c)

**Post elaborations:**
- statistical indices calculation (means, medians, percentiles, etc.);
- summation of background concentration values;
- regulation limits check;
- synthesis instruments (maps, plots, tables, etc.);

Write a document containing:
- initial questions
- choices (simulation must be **reproducible**)
- cite all of your data and information sources
- answers to the initial questions

Archive the simulation and related informations
Running models: control files and data files
Air quality models: essentials

Running models: control files and data files

**Inizialization** (.ini, .dat...):
- files path and format
- simulation domain definition
- time domain definition
- ...

![Image of a mechanical component]
Air quality models: essentials

Running models: control files and data files

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CALPUFF Operational Run
(ARPA FVG - CRMA)
Regional Center for Environmental Modeling

-------------- Run title (3 lines) ---------------------

CALPUFF MODEL CONTROL FILE

--------------------------

INPUT GROUP: 0 -- Input and Output File Names

Default Name Type File Name
-------- ---- ----------
CALMET.DAT input ! METDAT = $CALMETFILE ! or
ISCMET.DAT input * ISCDAT = * or
PLMMET.DAT input * PLMDAT = * or
PROFILE.DAT input * PRFDAT = * or
SURFACE.DAT input * SFCDAT = * or
RESTARTB.DAT input $TRUE_RESTIN

CALPUFF.LST output ! PUFLST = ./calpuff.lst !
CONC.DAT output ! CONDAT = $CONCFILE !
DFLX.DAT output * DFDAT = *
WFLX.DAT output * WFDAT = *
DFLX.DAT output $TRUE_DRYDATA
WFLX.DAT output $TRUE_WETDATA
...
Running models: control files and data files

**Inizialization** (.ini, .dat...):
- files path and format
- simulation domain definition
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- ...

**«Not-evolving» data**:
- Orography
- Buildings
- Chemical reactions constants
- ...
Running models: control files and data files

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Air quality models: essentials

Running models: control files and data files
Air quality models: essentials

Running models: control files and data files

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**Input data**
- Source description
- Meteo data
Air quality models: essentials

Running models: control files and data files

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Input data
- Source description
- Meteo data

```
SF_ID: 14735 OS_ID: 99999 VERSION: 11059
88 3 1 61 2 -3.5 0.069 -9.000 -9.000 -999.
35. 7.9 0.7500 1.50 1.00 0.80 317.5 10.0 273.8 10.0 0 -9.00 999. 1003.
88 3 1 61 3 -1.6 0.046 -9.000 -9.000 -999.
42. 8.5 0.7500 1.50 1.00 0.90 273.1 10.0 273.5 10.0 0 -9.00 999. 1003.
88 3 1 61 4 -1.0 0.034 -9.000 -9.000 -999.
23. 5.7 0.7500 1.50 1.00 0.60 276.5 10.0 272.4 10.0 0 -9.00 999. 1003.
88 3 1 61 4 -1.0 0.034 -9.000 -9.000 -999.
15. 3.6 0.3000 0.80 1.00 0.60 199.7 10.0 271.5 10.0 0 -9.00 999. 1003.
89 ...```
Air quality models: essentials

Running models: control files and data files

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Input data
- Source description
- Meteo data

REMEMBER: try to AUTOMATE most part of the process!

This is NOT a good MODELLISTIC CHAIN!!
Air quality models: essentials

Running models: control files and data files

**Inizialization** (.ini, .dat...):
- files path and format
- simulation domain definition
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- ...

**«Not-evolving» data**:
- Orography
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- Chemical reactions constants
- ...

**Input data**
- Source description
- Meteo data

First USE A «WORKING-RUN» AND then REPLACE ONE «PART» AT A TIME
- if you download a model for free, there is ALWAYS a ready-to-run Case Study in the «package»
- if you buy a model, remember to require the execution of a specific Case Study of your interest!!!
**Input files formats**

All DATA must be put in a WELL DEFINED text format, provided in the model Guide:
- well defined units of measure for each variable
- columns are fixed-width, or comma, or space separated
- missing data are specified by a code (e.g. “-999”)
- ...

<table>
<thead>
<tr>
<th>Data</th>
<th>Units</th>
<th>Measure</th>
<th>Code</th>
<th>Columns Width</th>
<th>Missing Data</th>
<th>NAD-OS</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.3N</td>
<td>74.0W</td>
<td>UA_ID: 00014735</td>
<td>SF_ID: 14735</td>
<td>OS_ID: 99999</td>
<td>VERSION: 11059</td>
<td>4 NAD-OS</td>
</tr>
<tr>
<td>88 3 1 61 1</td>
<td>-2.7</td>
<td>0.062</td>
<td>-9.000</td>
<td>-9.000</td>
<td>-999.</td>
<td>35.</td>
</tr>
<tr>
<td>88 3 1 61 2</td>
<td>-3.5</td>
<td>0.069</td>
<td>-9.000</td>
<td>-9.000</td>
<td>-999.</td>
<td>42.</td>
</tr>
<tr>
<td>88 3 1 61 3</td>
<td>-1.6</td>
<td>0.046</td>
<td>-9.000</td>
<td>-9.000</td>
<td>-999.</td>
<td>23.</td>
</tr>
<tr>
<td>88 3 1 61 4</td>
<td>-1.0</td>
<td>0.034</td>
<td>-9.000</td>
<td>-9.000</td>
<td>-999.</td>
<td>15.</td>
</tr>
<tr>
<td>89 ...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
Impact assessment of specific sources: relevant source characteristics
Source characteristics

- Height (e.g. [m])
- Geometry (can be an extended surface...)
- Emissions temperature (e.g. °K)
- Emissions velocity (e.g. [m/s])

} cause an initial «plume rise»... just like an additional stack height

and, of course...
- mass flux of each pollutant (e.g. [g/h])

... that can evolve in time (a time profile is needed?)
Impact assessment of specific sources: meteorological input data to gaussian and puff models
**Meteorological input data**

**Specific sources** impact assessment:
AERMOD, CALPUFF, ISC3, CALINE, DIMULA, SPRAY…

Respective **meteorologic pre-processors**:

Point (and vertical *profile*):
MPRM(ISC3), PCRAMMET(ISC3), MET(ADMS), AERMET(AERMOD)…

Domain:
CALMET(CALPUFF), MINERVE+SURFPRO (SPRAY)…
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**Why is it so difficult to provide meteo input to models?!!**
Meteorological input data

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**Why is it so difficult to provide meteo input to models?!**

1. usually we miss information on what happens *at heights*
Meteorological input data

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AERMOD, CALPUFF, ISC3, CALINE, DIMULA, SPRAY...

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Domain:
CALMET(CALPUFF), MINERVE+SURFPRO (SPRAY)...

Why is it so difficult to provide meteo input to models?!!

1. usually we miss information on what happens at heights
2. because dispersion «strength» of the atmosphere depends on TURBULENCE... and TURBULENCE is how we call WHAT WE DON’T MEASURE e what we don’t explain precisely!!!

TURBULENCE = NOISE
(in terms of signal, not strictly acoustics...)
Importance of turbulence

Fig. 2.16: spettro della velocità del vento al suolo.
Importance of turbulence

Why TURBULENCE is so fundamental... even if we don’t measure it?

E.g.: “sensible heat” flux
Atmosphere is like a «pot on the burner»…

- u,v horizontal wind speed
- w vertical wind speed

\[ q = \rho C_p T u \]

\[
\left( dQ_w = \rho \cdot C_p \cdot T \cdot dS_w \cdot w \cdot dt \right)
\]

\[ \Rightarrow q_w = \rho C_p \bar{T} \cdot \bar{w} = 0 \]

\[ \bar{w} = 0 \text{ near ground!} \]

\[ \Rightarrow \text{NET VERTICAL HEAT FLOW comes form TURBULENCE} \]

(as a mean, vertical movement of air can be null...)
Importance of turbulence

In a sunny day, the lifting air bubble is slightly hotter than the one coming down a moment later, or a few meters away…

To measure it... we should SIMULTANEOUSLY measure w e T at 10, 20, 50 Hz:

\[ H = \bar{q}_z = \rho C_p \sum_i \left( w_i - \bar{w} \right) \left( T_i - \bar{T} \right) \]

(it’s a covariance, between a component of wind speed (w) and a scalar (T)

(it can be done, by means of sonic anemometers…)


Reynolds theory, ergodicity, stationarity…
### Importance of Turbulence

Similarly, plume dispersion depends on turbulence

<table>
<thead>
<tr>
<th>Mean wind</th>
<th>Transport (Signal)</th>
<th>(Measure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbulence</td>
<td>Diffusion (Noise)</td>
<td>(Parametric estimate)</td>
</tr>
</tbody>
</table>

So what?

We need parametric links between turbulence and measured variables

⇒ we use semi-empirical relations
Most of the effort in gaussian and puff models is in **PARAMETRIZATION**, that allows having an **ANALITICAL** (NOT NUMERICAL) model… that can be a simple **GAUSSIAN** curve!!

Importance of turbulence depends on turbulence intensity!

depends on mean wind speed and direction

MORE…
Importance of turbulence

Planetary Boundary Layer (PBL)

The **planetary boundary layer (PBL)** is defined as the part of the atmosphere that is strongly influenced directly by the presence of the surface of the earth, and responds to surface forcings with a timescale of about an hour or less. (Stull, R. B., 1988: *An Introduction to Boundary Layer Meteorology*. Kluwer Academic, 666 pp.)

Atmosphere is like a «pot on the burner»…
Heat flux from surface causes turbulent vertical motion…

**Pollutants emitted near the surface are confined in the PBL!!!**

**PBL height range: ~ 50 – 2500 m !!!**

depends on available heat at surface!!
Most of the effort in gaussian and puff models is in **PARAMETRIZATION**, that allows having an ANALITICAL (NOT NUMERICAL) model… that can be a simple GAUSSIAN curve!!

To do this…

most recent models base their description of the Planetary Boundary Layer (PBL) on Monin-Obukhov Similarity Theory

‘older’ models use Pasquill-Gifford Stability Classes

Anyway…

informations on **radiative surface balance** are needed (even **nighttime**… net radiation, cloud cover…)

Importance of turbulence
Meteorological input data

Needed resources
Available resources
To use a model you need...

**Calculus**
For most Impact Evaluation applications, a PC is all you need

**Costs**
Many models are free of charge (open source).
Other ones can be buyed (~ from 1,000 to some 10,000 euros).

**Knowledge**
You are expected to provide:
- rational PC use (not only trial clicks...);
- some knowledge on pollutants that must be considered;
- «a few» knowledge of atmospheric physics and chemistry;
- detailed knowledge of the source you want to treat;
- much logics to plan, build and execute everything you need (questions and answers)

**Data:**
- meteorological data;
- background concentration of the pollutants you are considering;
- source characteristics;
Not-to-do list

Spend a few time and concentration on «questions»

«Don’t waste time! Make something run... we need some numbers and figures to put in the document!»

Develop my own model

«I don’t have time to learn using available models... I can do some calculations by myself!»

Trial and error

«I put some maps in the document, full up some hundred pages... and wait if they ask for more»
Where you can find data and informations

**Meteorology**
- Friuli Venezia Giulia: ARPA FVG – CRMA ([crma@arpa.fvg.it](mailto:crma@arpa.fvg.it))
- Italy and world: Aeronautica Militare Italiana
- In general: specialized private sector

**Air quality (background concentrations)**
- Friuli Venezia Giulia: ARPA FVG – CRMA ([crma@arpa.fvg.it](mailto:crma@arpa.fvg.it))
- In general: specialized private sector

**How to use models**
- User’s Guides
- Courses

**Which are the right «questions» for a specific Impact Evaluation Study...?**
- ARPA FVG – CRMA ([crma@arpa.fvg.it](mailto:crma@arpa.fvg.it)) – ask for a meeting
- Current air quality legislation (regional, national and european)
- Air quality plans
Essential bibliography


EPA SCRAM:  
http://www.epa.gov/ttn/scram/  
(Important: Title 40, Code of Federal Regulations (CFR) section 51, Appendix W...  
deals with using models for **Environmental Impact Assessment!!**)

**In Europe...**

**communities:**  
FAIRMODE, Forum for Air quality Modelling  
HARMO, Initiative on "Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes"

**actions:**  
COST 715 - Urban meteorology applied to air pollution problems  
COST 728 - Enhancing meso-scale meteorological modelling capabilities for air pollution and dispersion applications  
FP5 FUMAPEX - Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure
ARPA CRMA SERVICES

crma@arpa.fvg.it

ARPA CRMA (Centro Regionale di Modellistica Ambientale) can provide:

- the needed meteo variables
- the background concentration estimation of the most relevant pollutants (PM$_{10}$, PM$_{2.5}$, NO$_x$, C$_6$H$_6$...)

(at least ONE YEAR and over the WHOLE FVG REGION)