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 Enviromental Protection – Friuli Venezia Giulia
Regional Center for Environmental Modelling

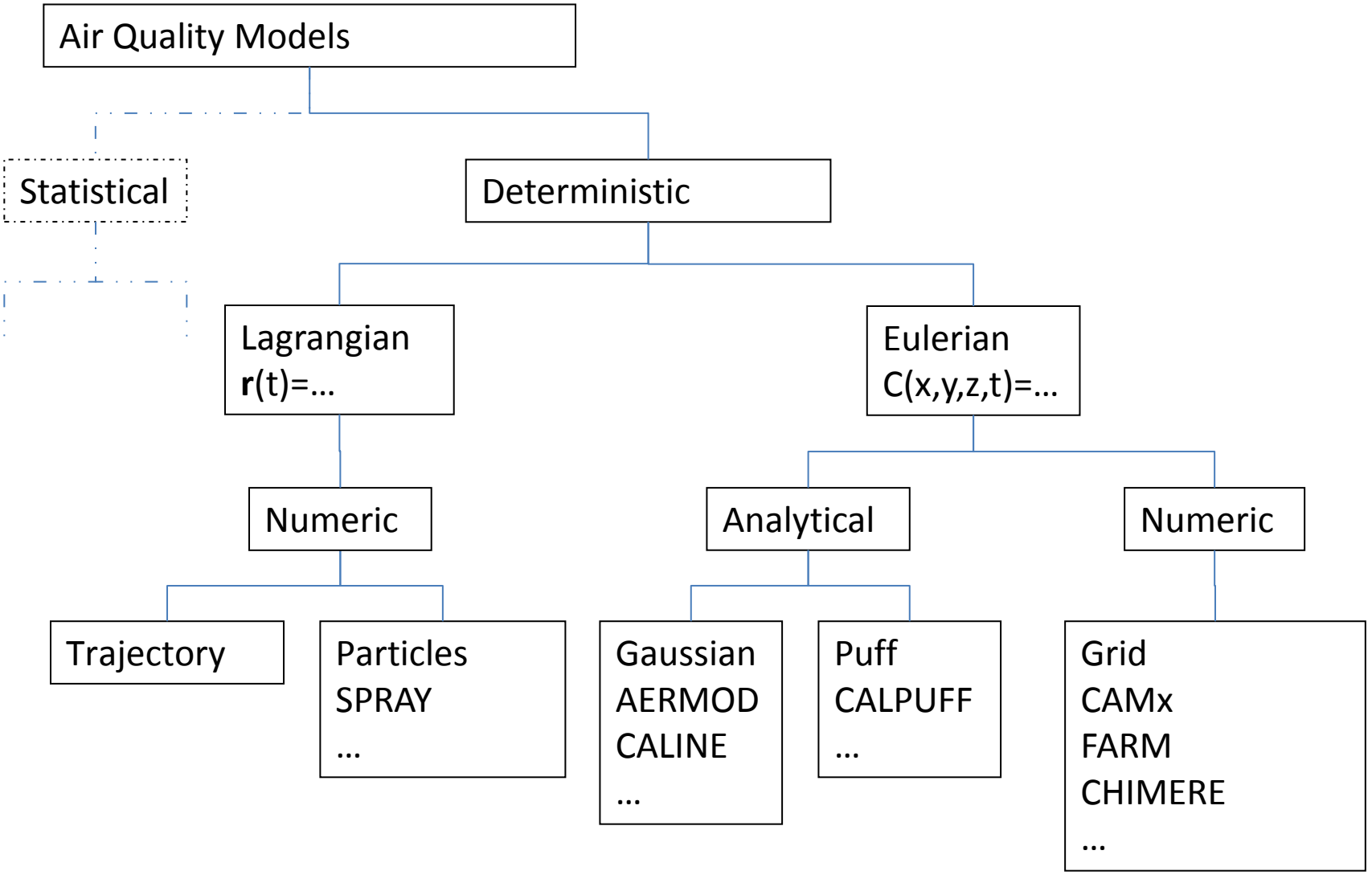
Introduction

- 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.

Models classification.
Typical applications.

Air quality models: essentials

Air Quality Models Taxonomy and Applications:



Air quality models: essentials

Air Quality Models Taxonomy and Applications:

Air Quality M

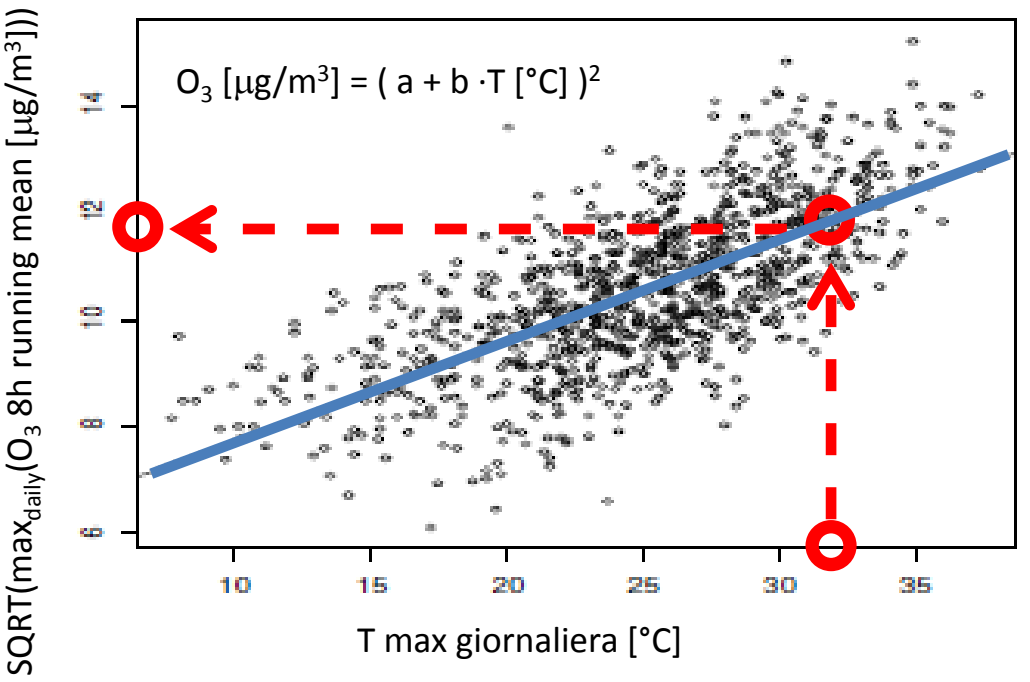
Statistica

- 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
  - ...

Trajectory

Particles
SPRAY
...

Gaussi
AERM
CALIN
...



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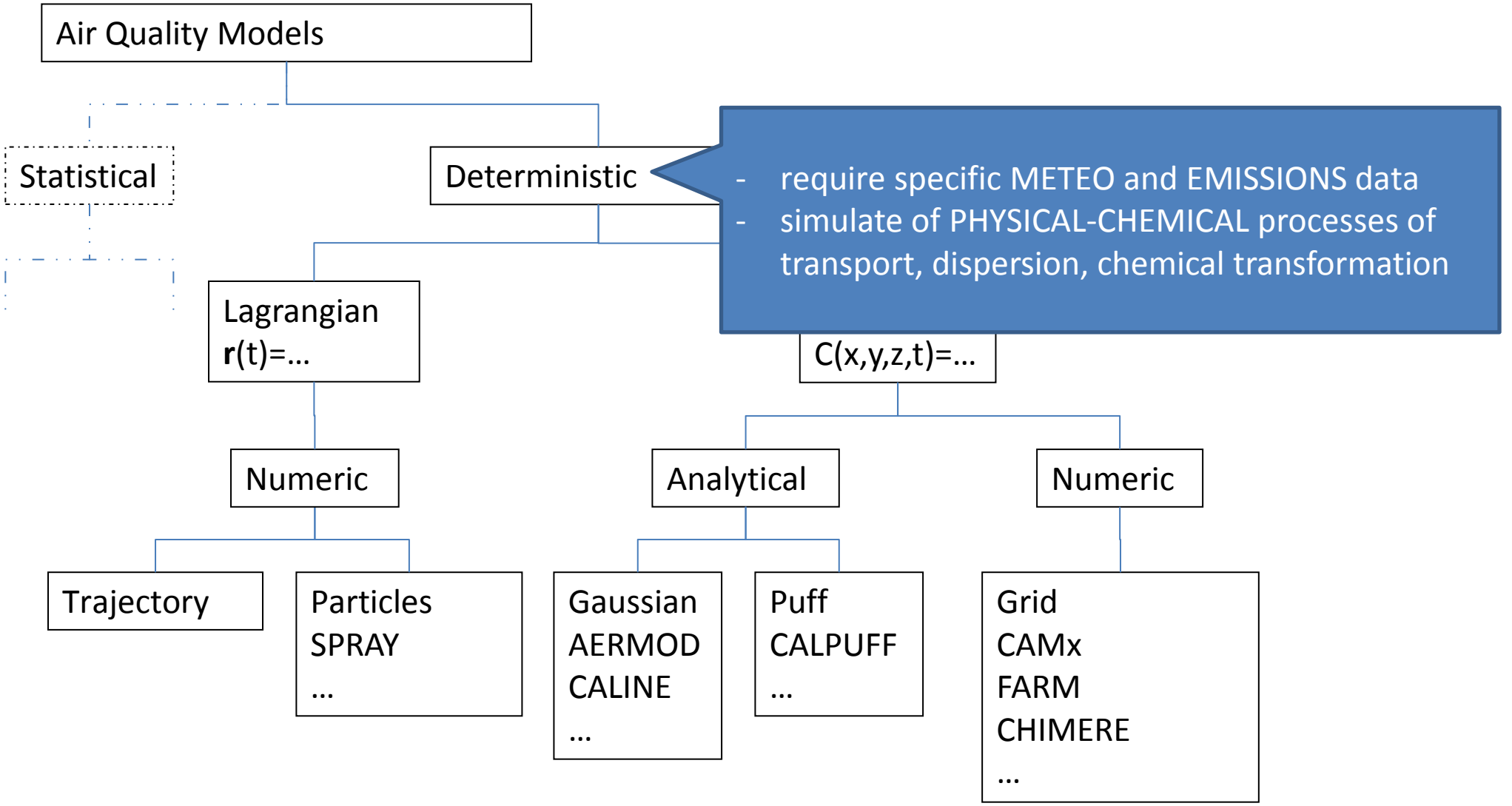

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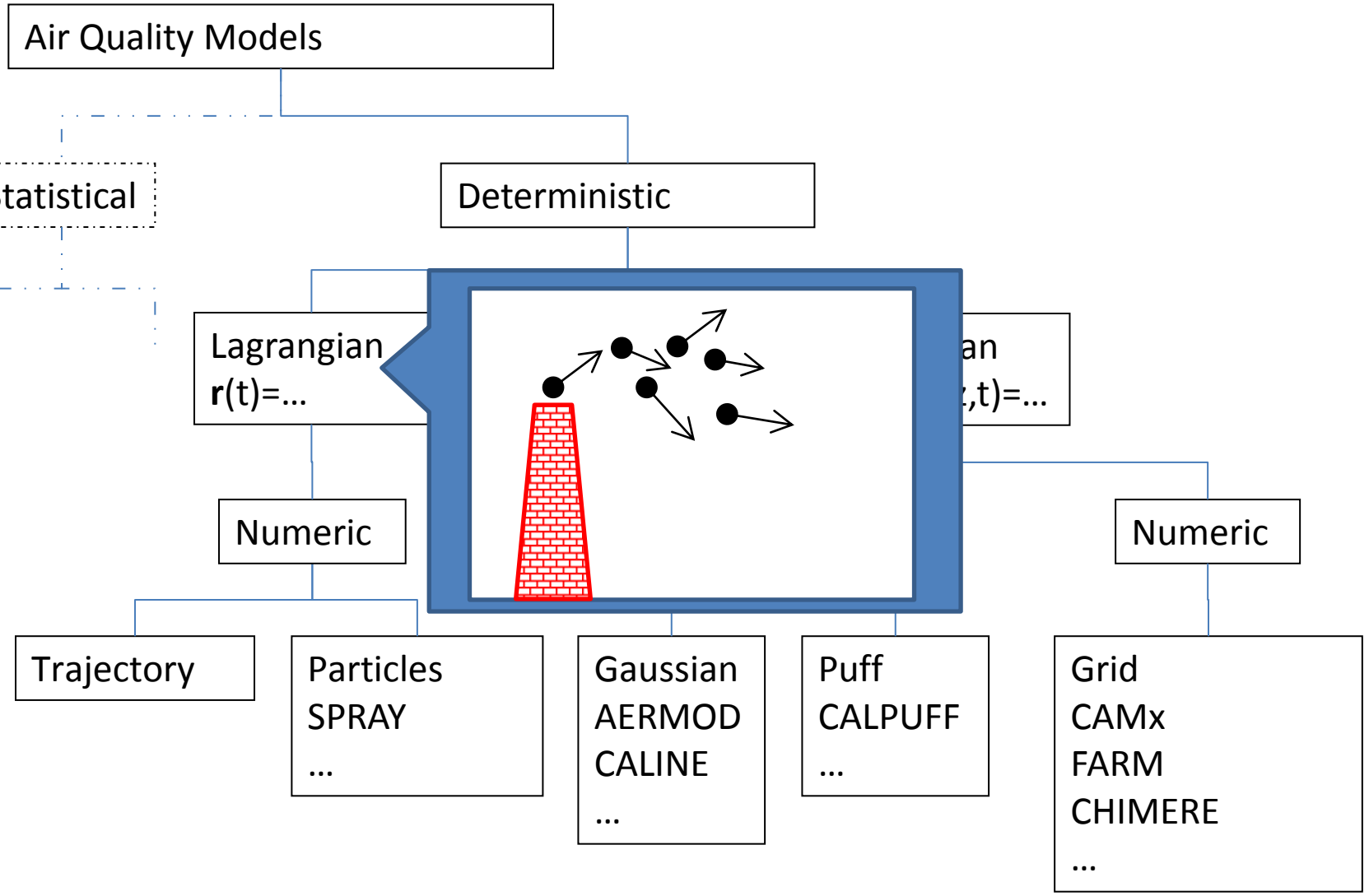

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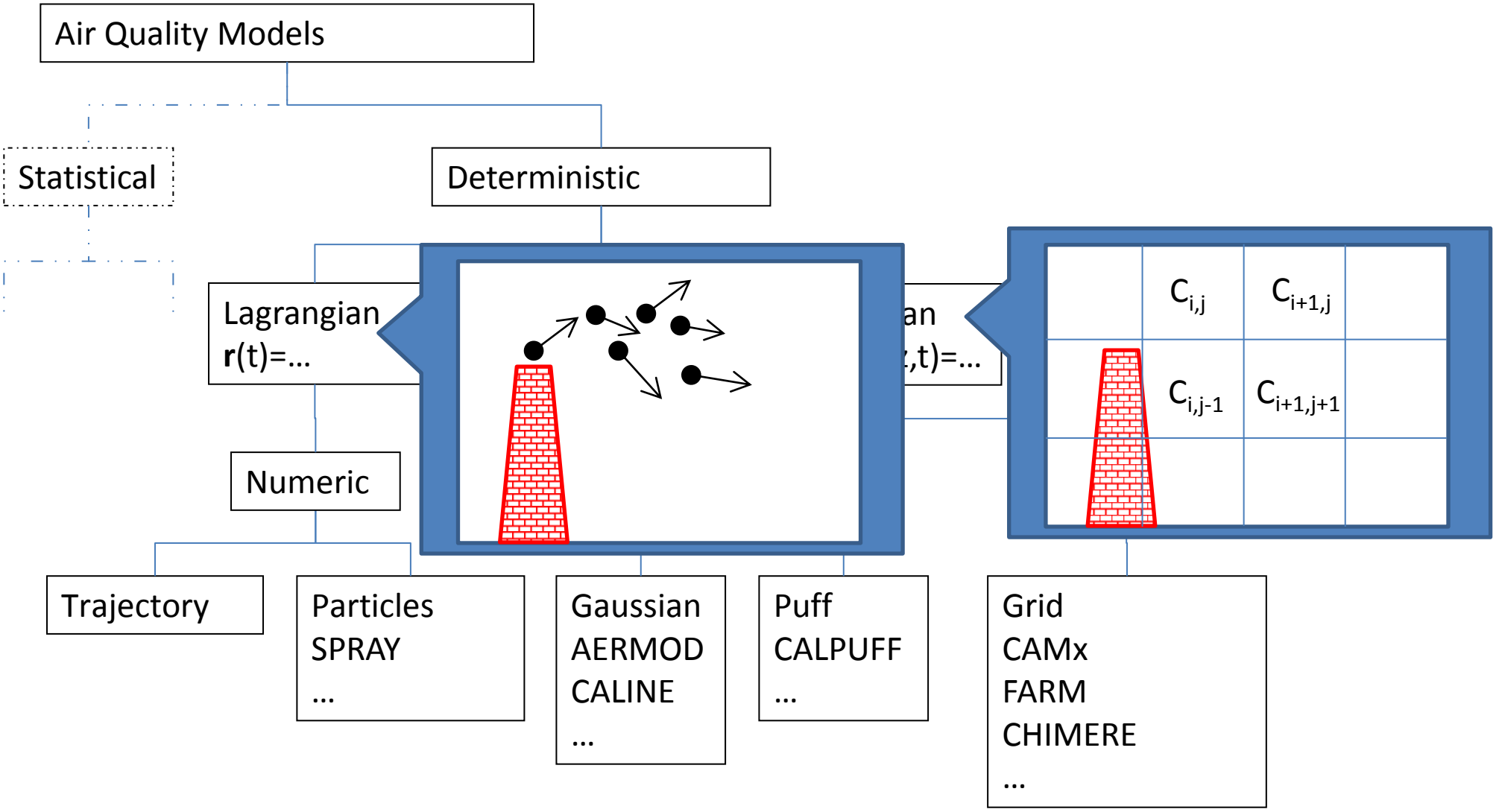

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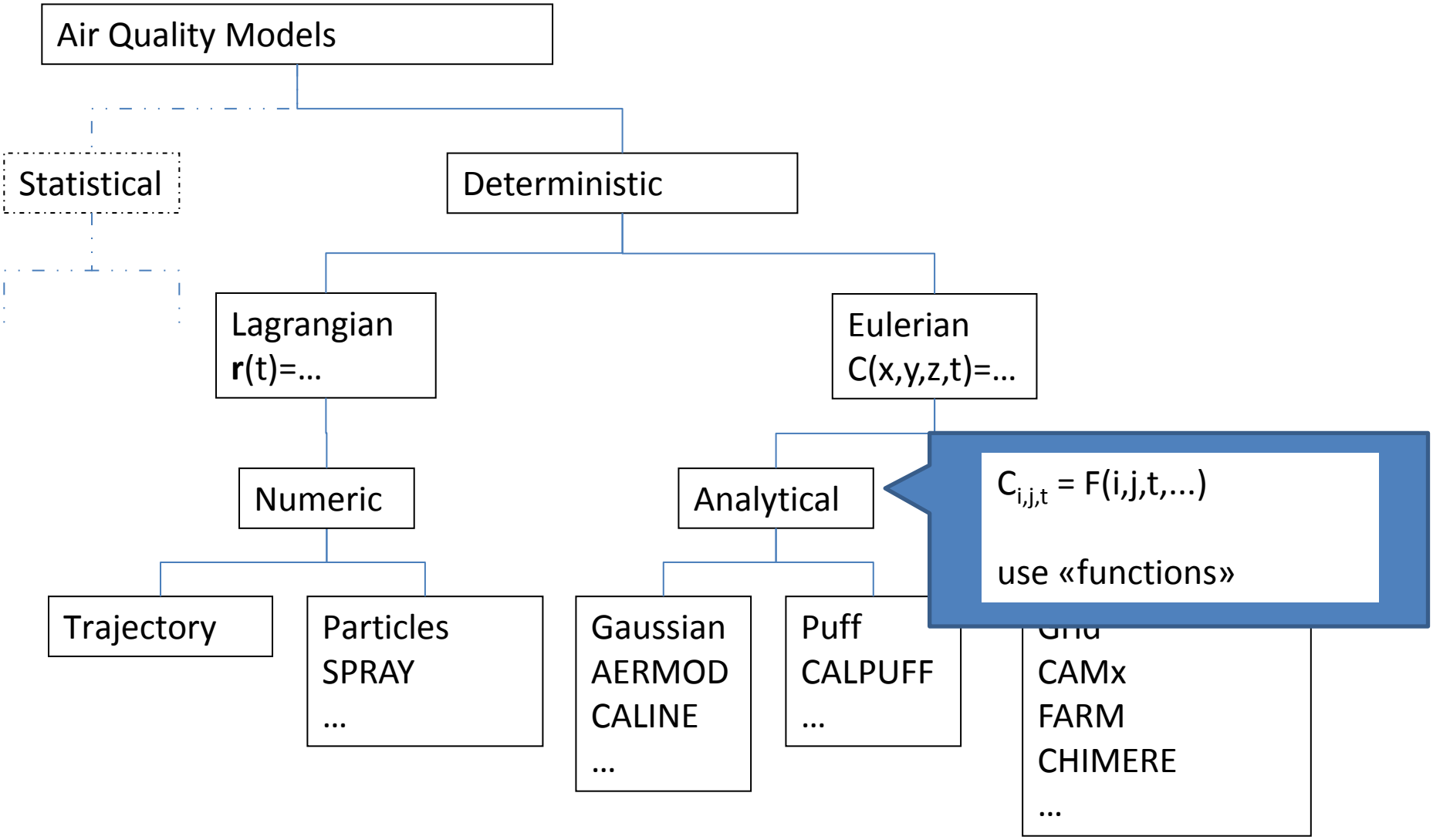

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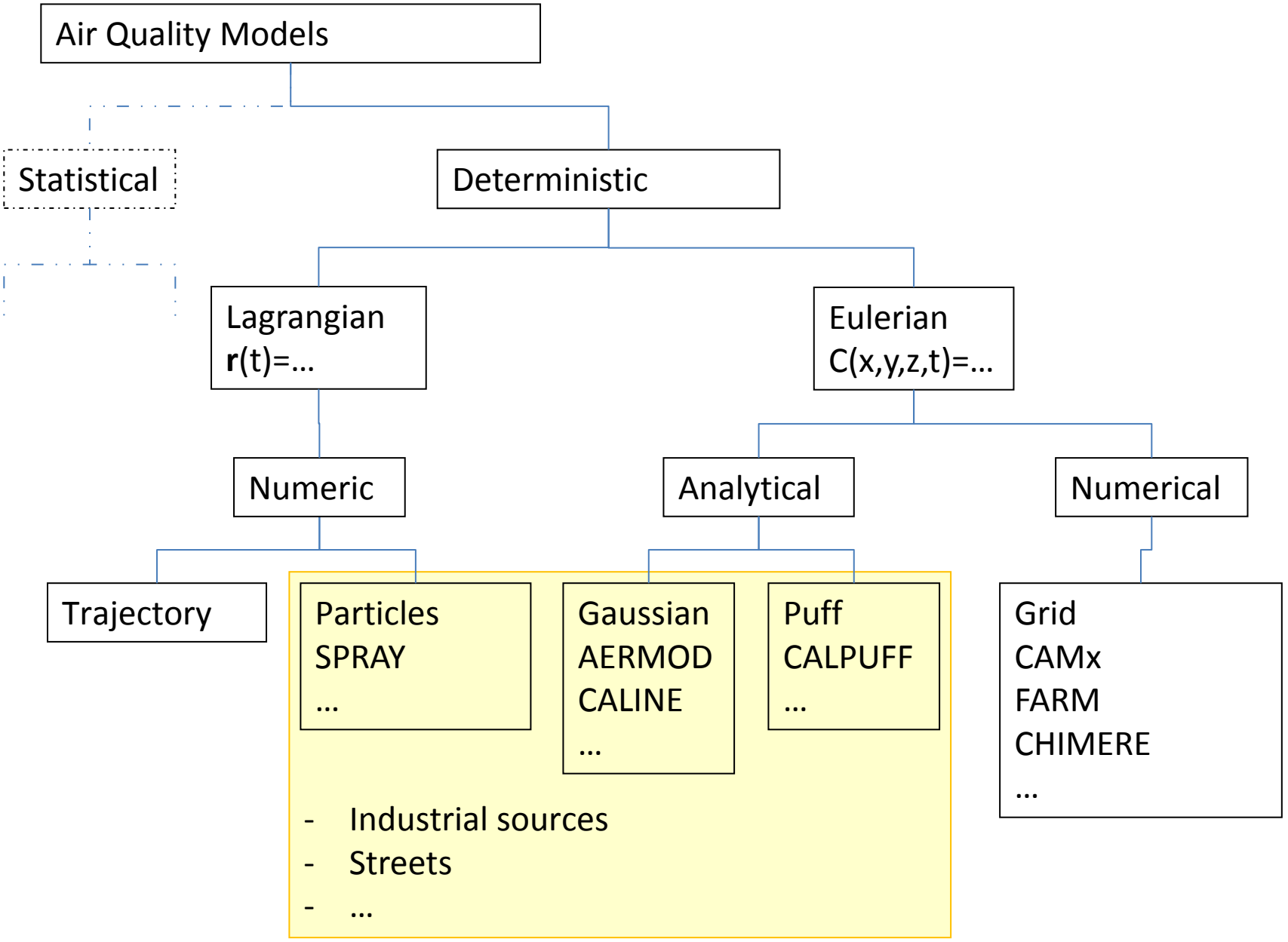

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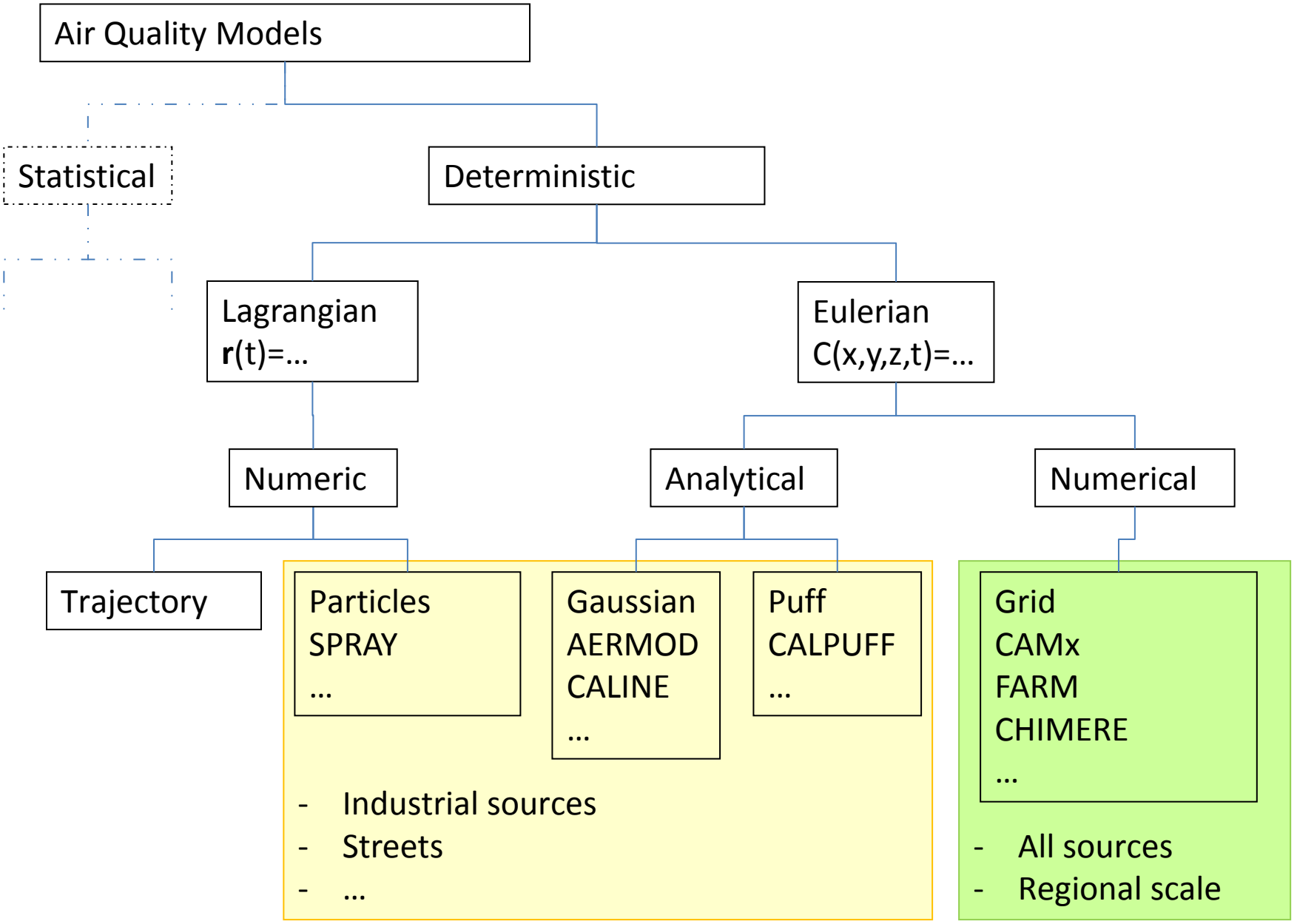


What are (deterministic) Air Quality Models?

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

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

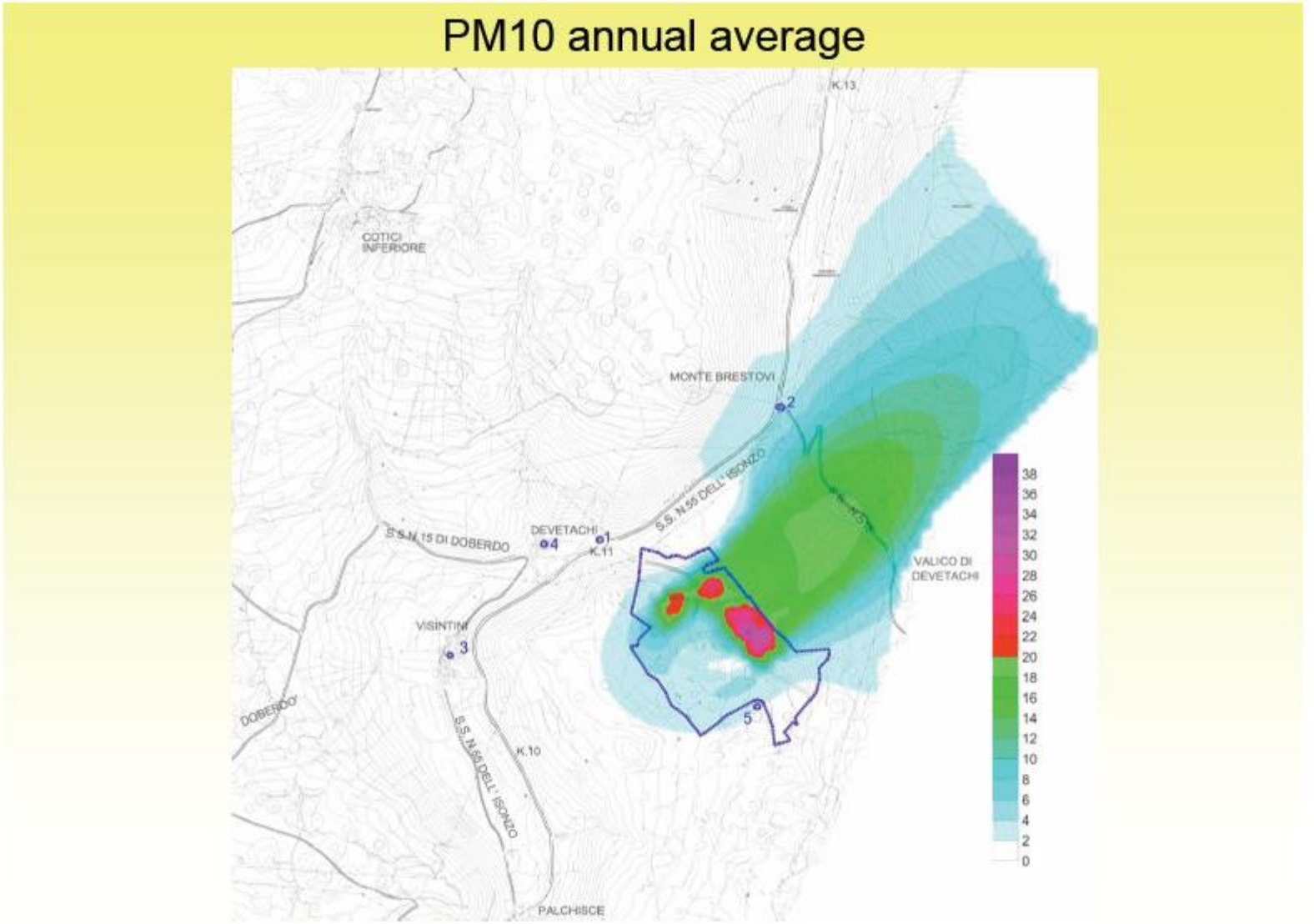
Models can help you to understand the role played by each «actor»:

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.

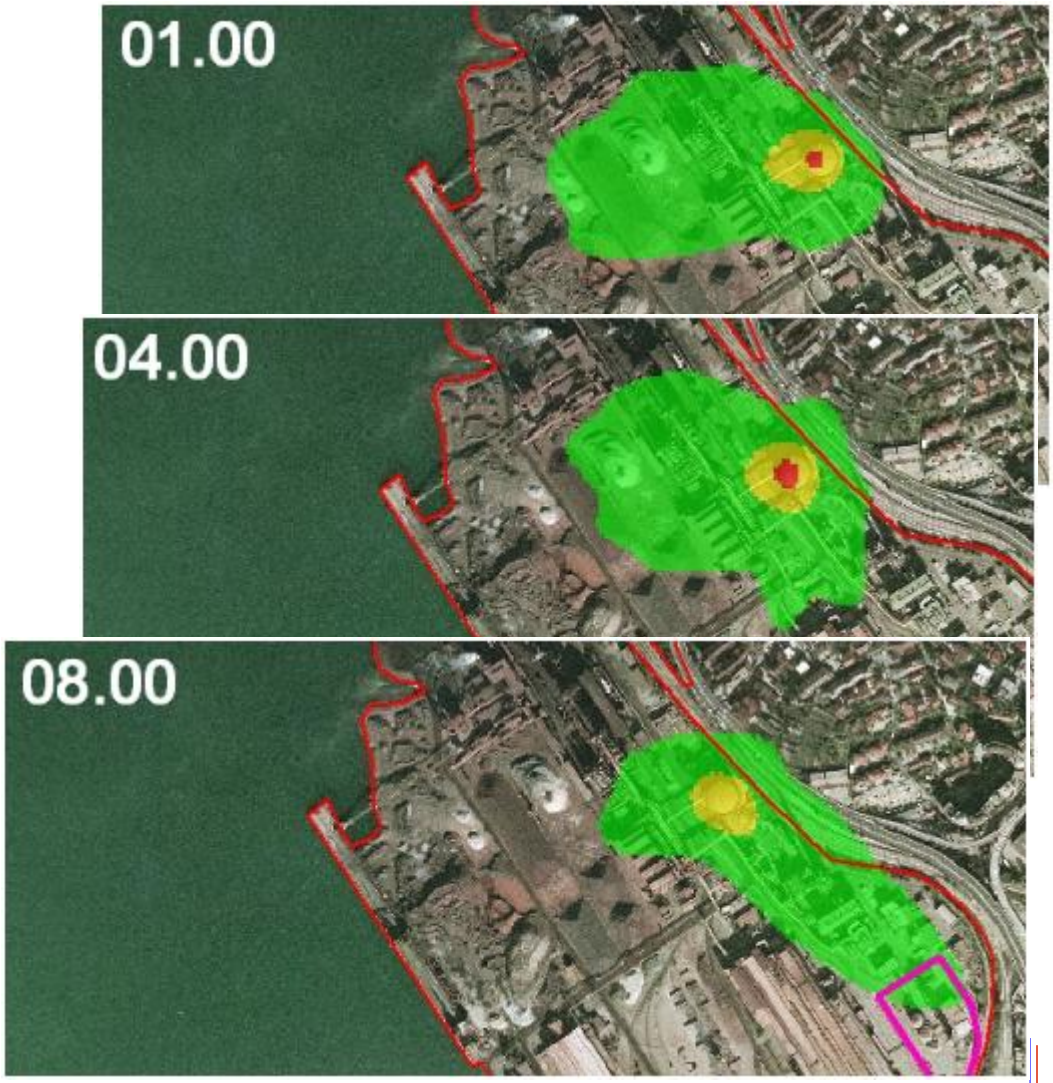
Which benefits respect to field measures?

- 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



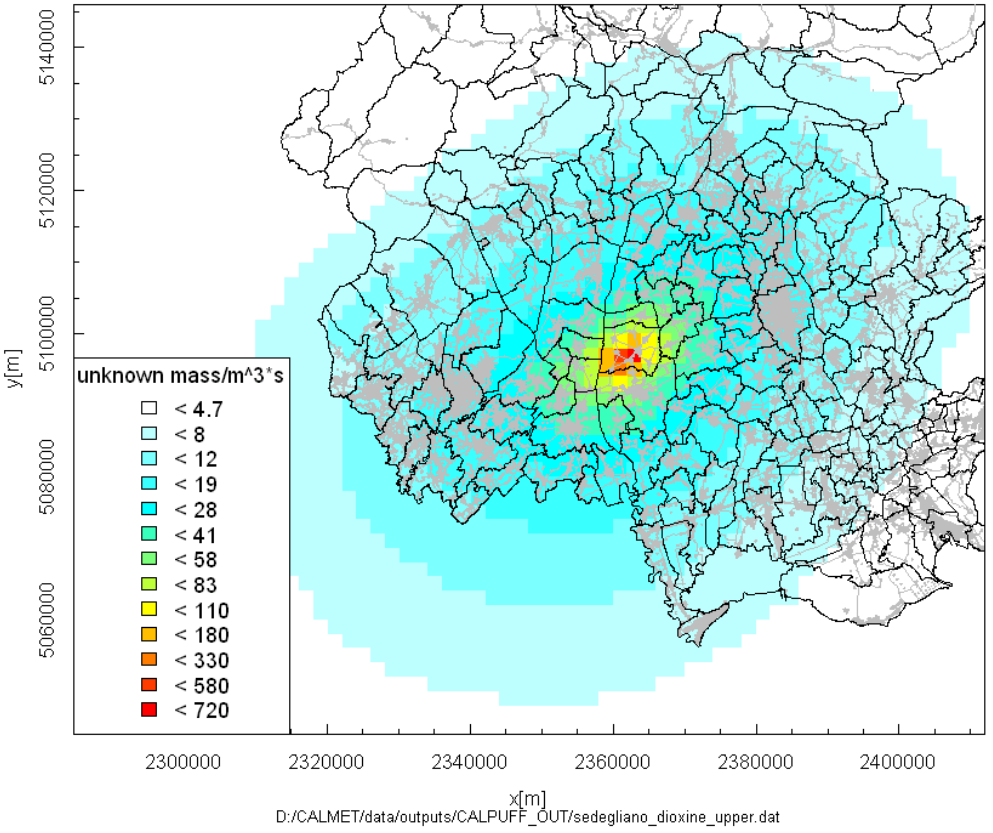
DPSIR: ΔState assessment by models

scenario analysis by <u>altering Pressures</u>

(es: Environmental Impact Studies, 2020 scenarios, etc.)

=> instruments that allow to plan Responses

UNKNOWN



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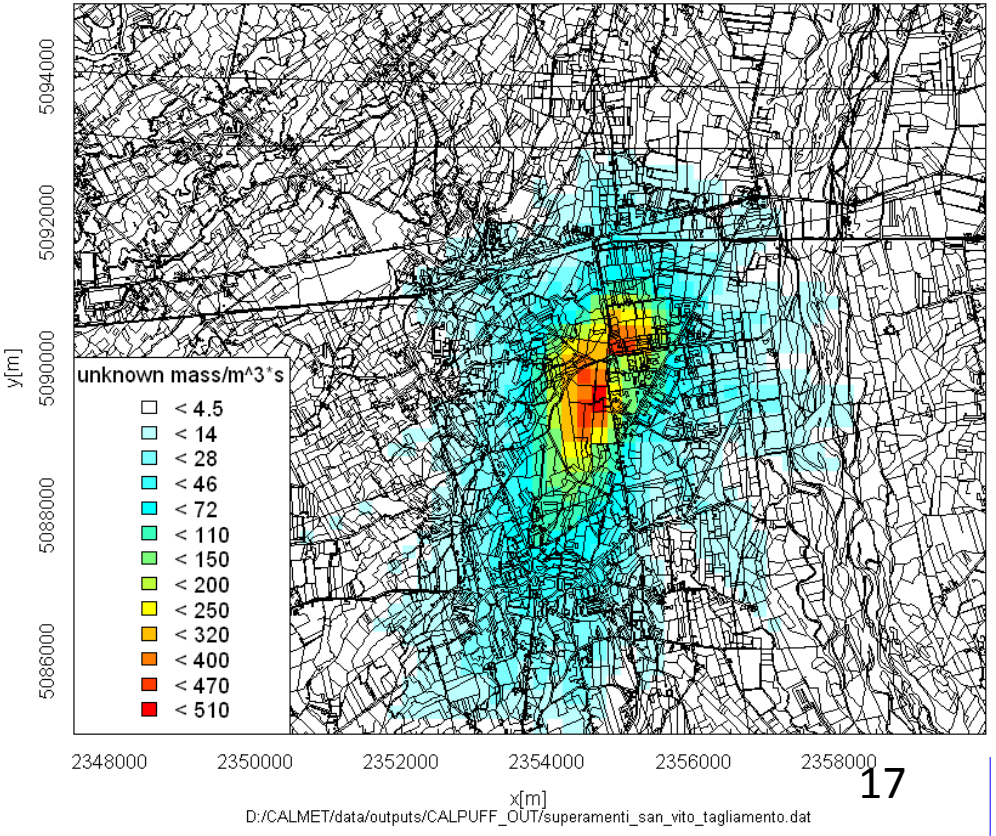
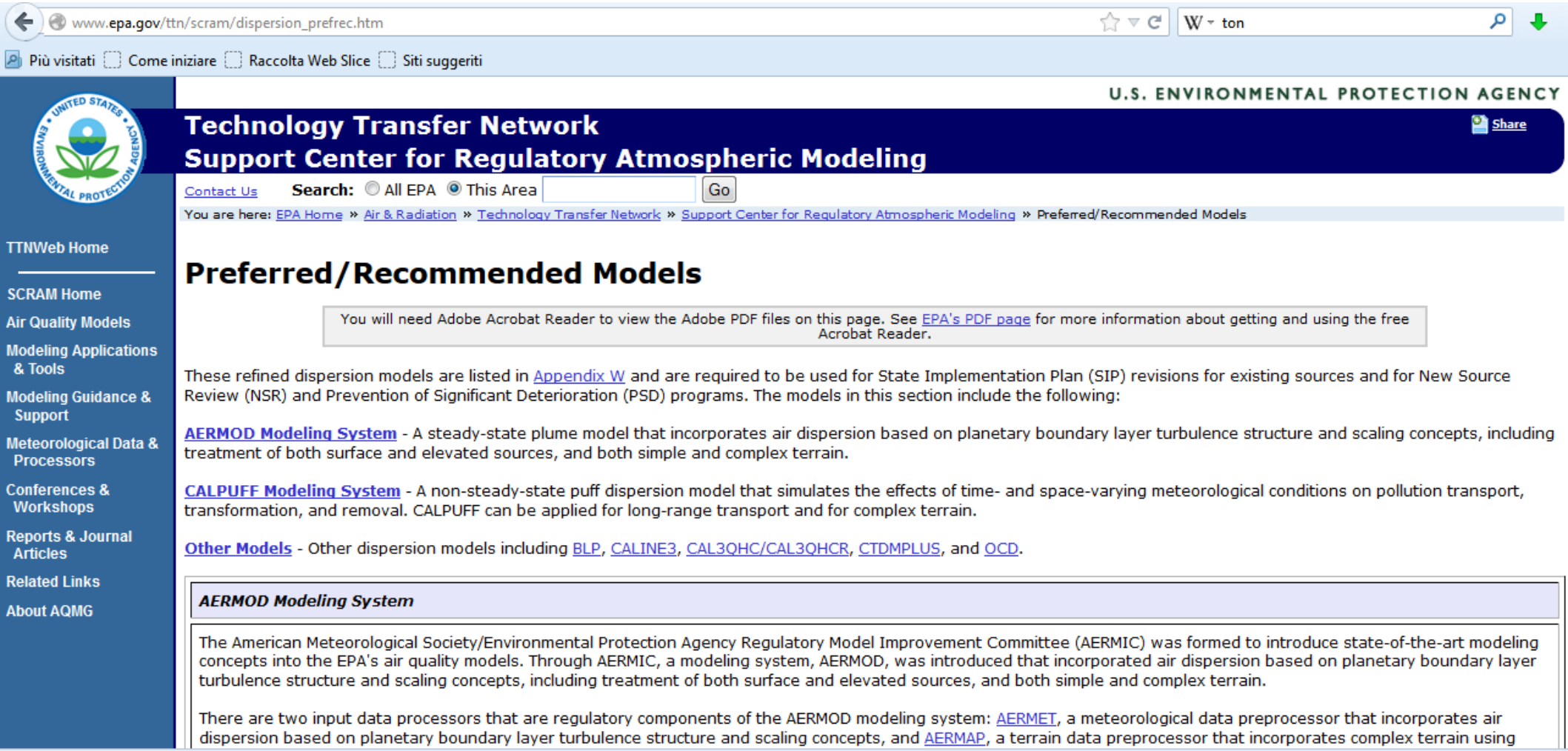


Running models: essentials

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



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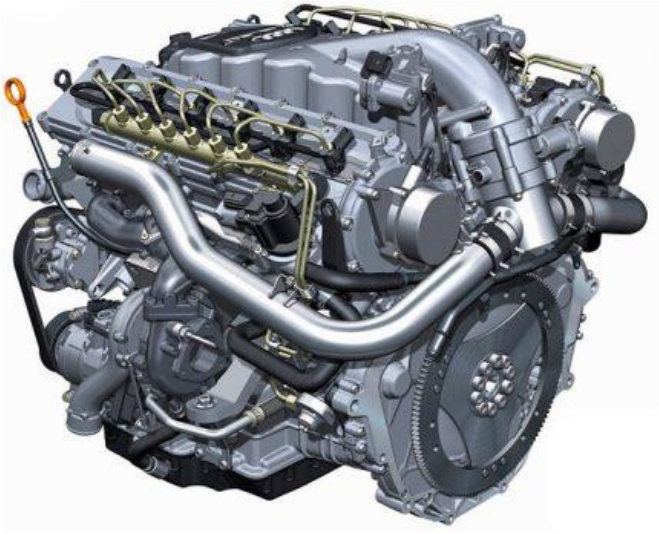
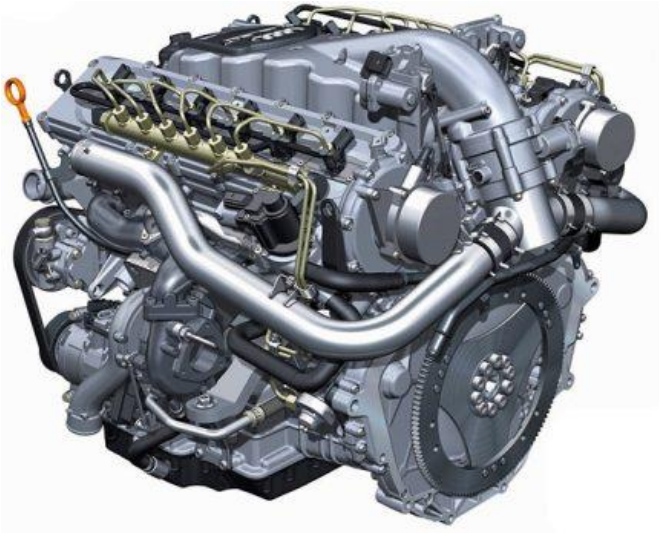


Air quality models: essentials

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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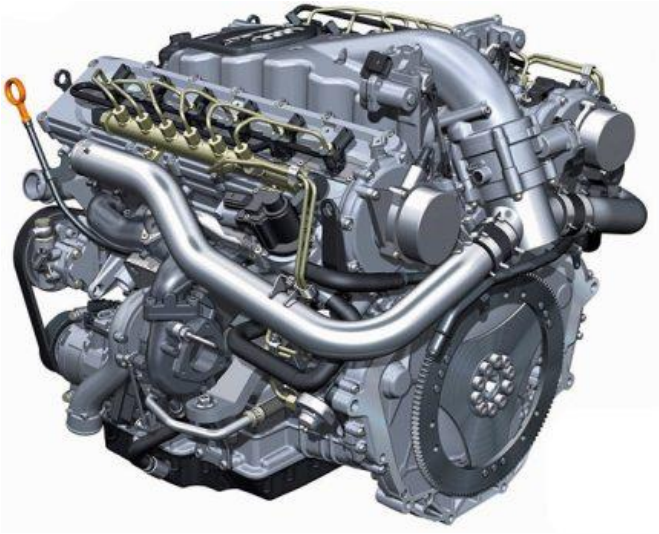

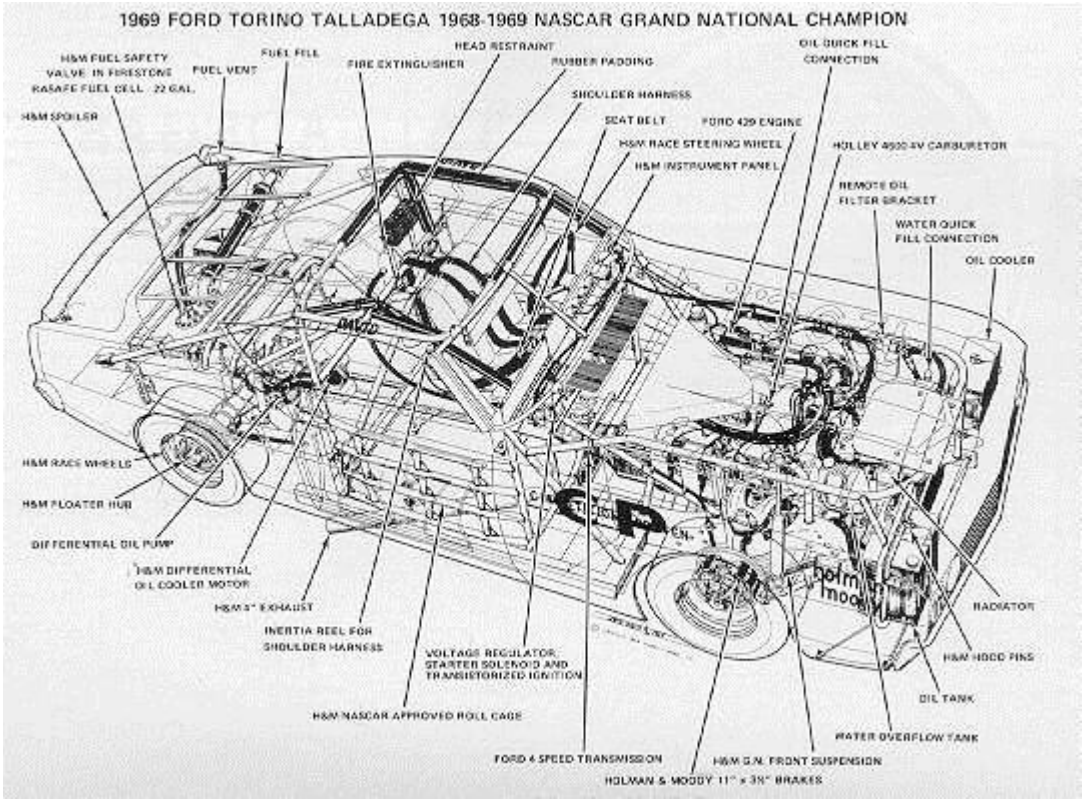

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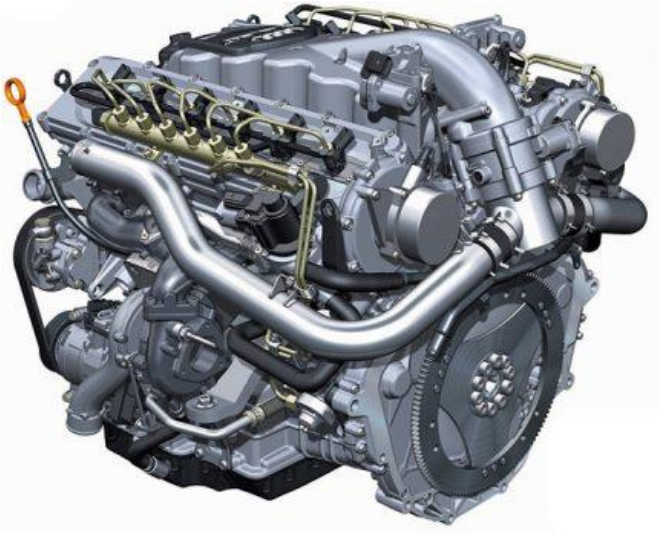
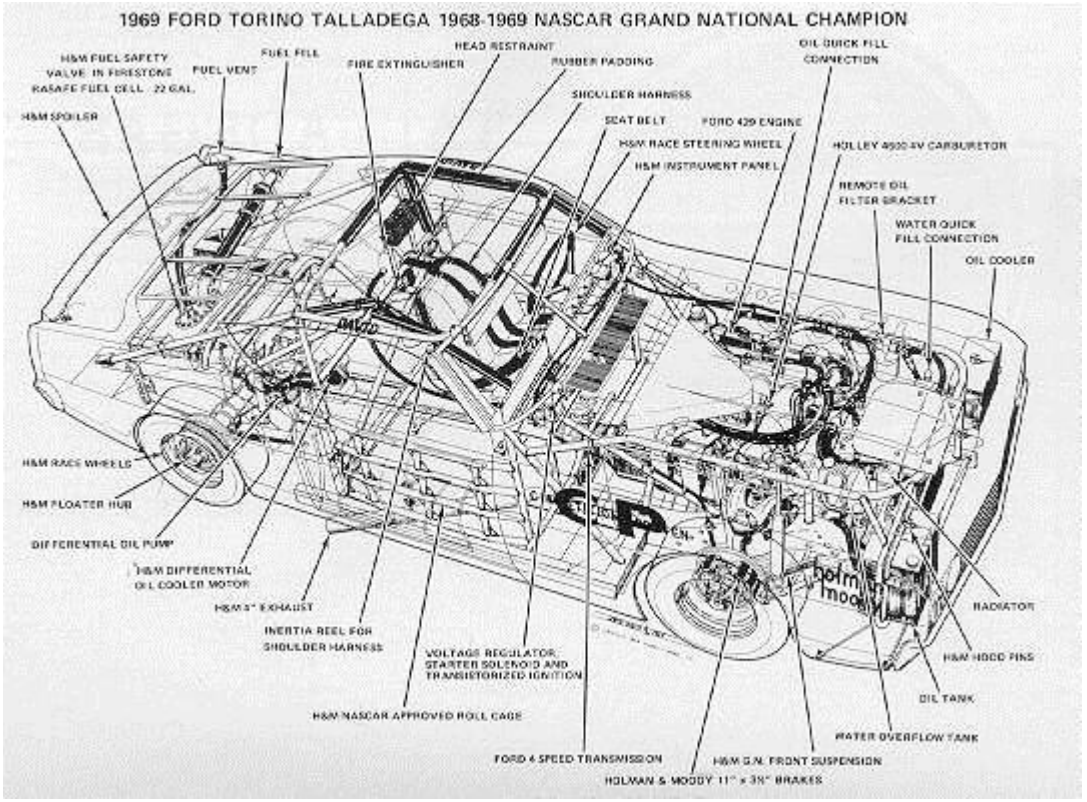


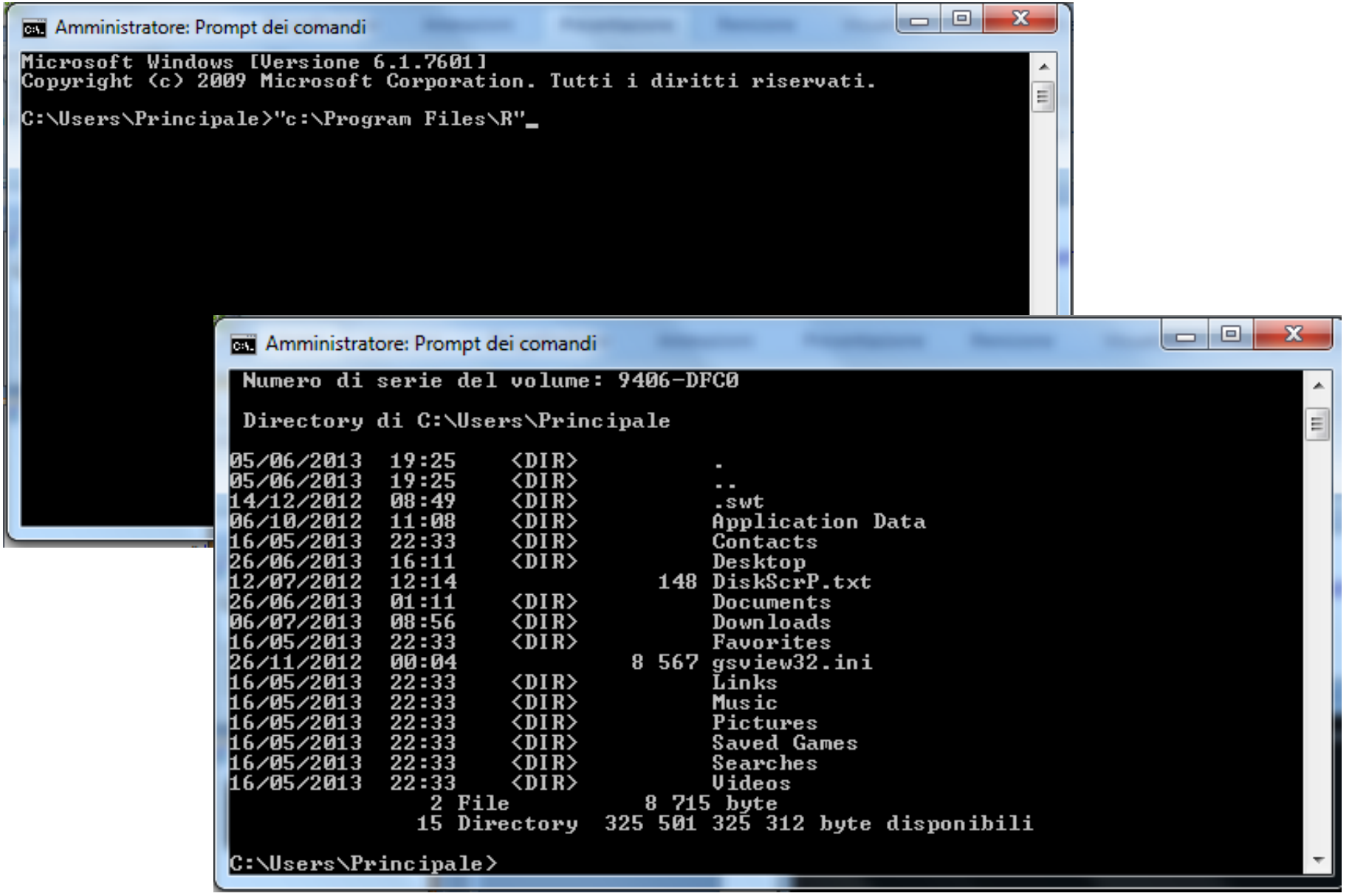


Usually air quality models are written in FORTRAN: they are compiled and an executable file is produced.

Sometimes a Graphical User Interface is available.

But in most cases they are executed from command line (Windows DOS or Linux BASH).

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

Example of good «questions»...

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?!!!)

Impacts Calculated in EIS

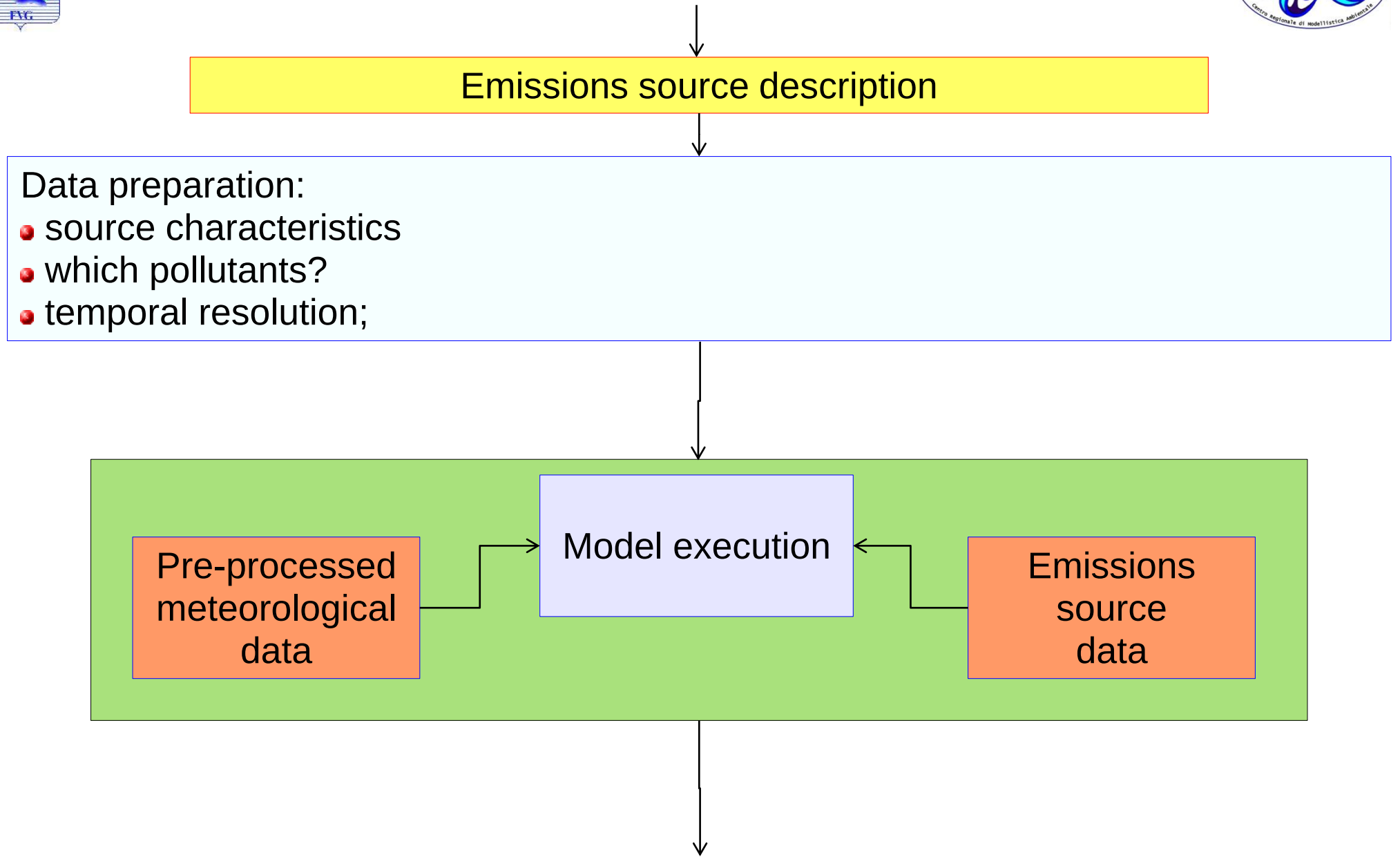
To calculate **immission** you must consider a set of parameters:

- **average annual PM10 (µg/m3);**
- **number of exceedances of the daily average PM10: 50 µg/m3;**
- number of exceedances of the hourly average NO_2: 200 µg/m3
- average annual NO_2 : 40 µg/m^3;
- average annual NO_x 30 µg/m^3;
- average annual C6H6: 5 µg/m^3.

You can use an atmospheric dispersion model

http://www.epa.gov./scram001/

Methodology (details - b)



Methodology (details -c)

Post elaborations:

- statistical indeces calculation (means, medians, percentiles, etc.);
- summation of background concentration values;
- regulation limits check;
- syntesis instruments (maps, plots, tables, etc.);

Write a documente containing:

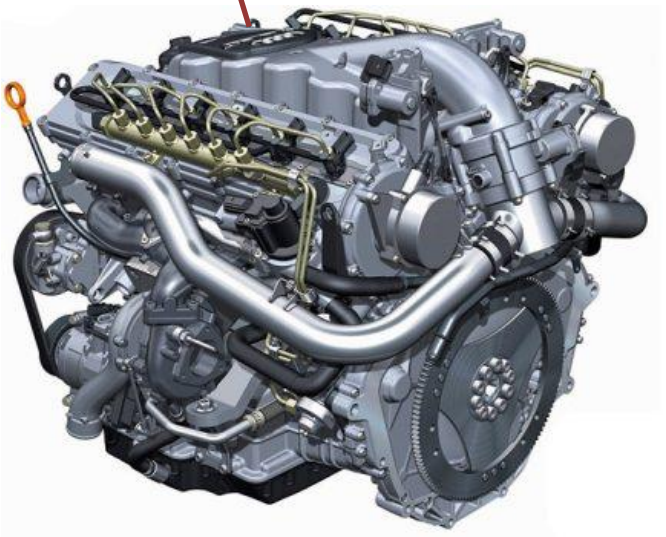
- initial questions
- choiches (simulation must be **reproducible**)
- **cite all of your data and information sources**
- answers to the initial questions

Archive the simulation and related informations

Running models: control files and data files

Running models: control files and data files

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



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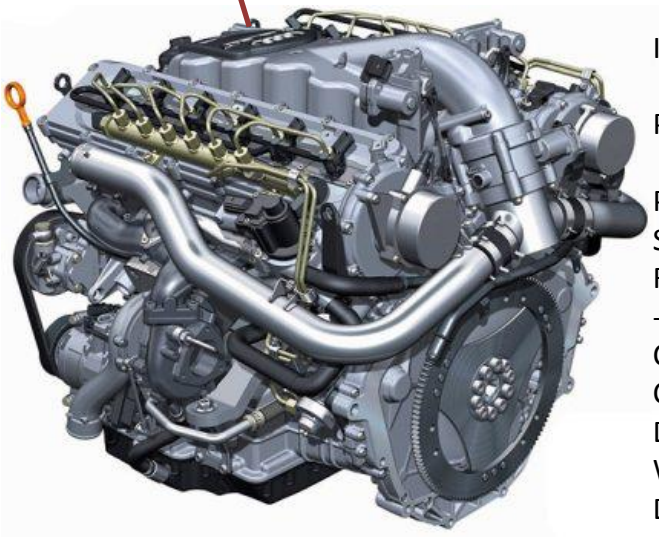

```
CALPUFF Operational Run
 (ARPA FVG - CRMA)
 Regional Center for Environmental Modeling
---------- Run title (3 lines) ------------------------------------

                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 =           *
SURFACE.DAT   input    * SFCDAT =           *
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
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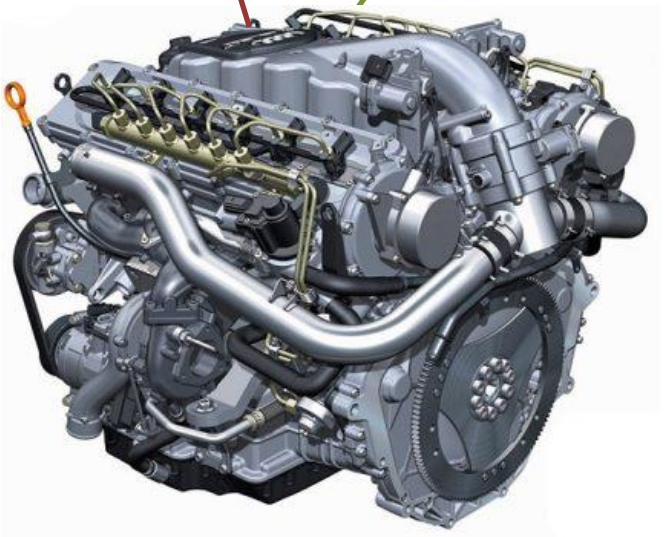
- …

«Not-evolving» data:
- Orography
- Buildings
- Chemical reactions constants
- …



Air quality models: essentials

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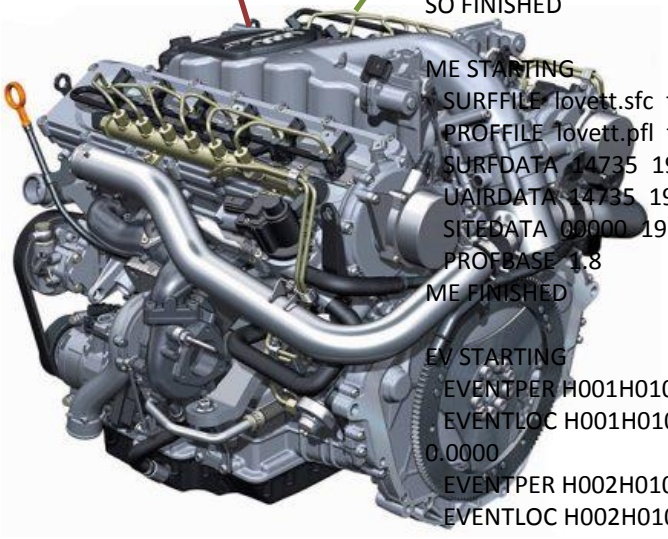

```
CO STARTING
  TITLEONE  AERMOD Test Case - Lovett Complex Terrain Study
  TITLETWO  Includes both ELEV and FLAT source
  MODELOPT  CONC   FLAT  ELEV
  AVERTIME  1  3  8  24  PERIOD
  POLLUTID  SO2
  RUNORNOT  RUN
  ERRORFIL  ERRORS.OUT
CO FINISH
SO STARTI
SO ELEVUN
SO LOCATI
  SRCPARA
SO LOCATI
  SRCPARA
  SRCGROU
  SRCGROU
SO FINISHED
ME STARTING
  SURFFILE  lovett.sfc  free
  PROFFILE  lovett.pfl  free
  SURFDATA  14735  1988  albany
  UAIRDATA  14735  1988  albany
  SITEDATA  00000  1988  LOVETT
  PROFBASE  1.8
ME FINISHED
EV STARTING
  EVENTPER H001H01001   1  ELEV_STK   88011214       311.63192
  EVENTLOC H001H01001 XR=    5110.000000 YR=   70850.000000   319.8000   322.6600
0.0000
  EVENTPER H002H01001   1  ELEV_STK   88011214       295.69667
  EVENTLOC H002H01001 XR=    4780.000000 YR=   70700.000000   324.8000   329.0200
0.0000
  EVENTPER H003H01001   1  ELEV_STK   88011710       250.02218
  EVENTLOC H003H01001 XR=    4780.000000 YR=   70700.000000   324.8000   329.0200
0.0000
  EVENTPER H001H01002   1  FLAT_STK   88092010       92.34208
```

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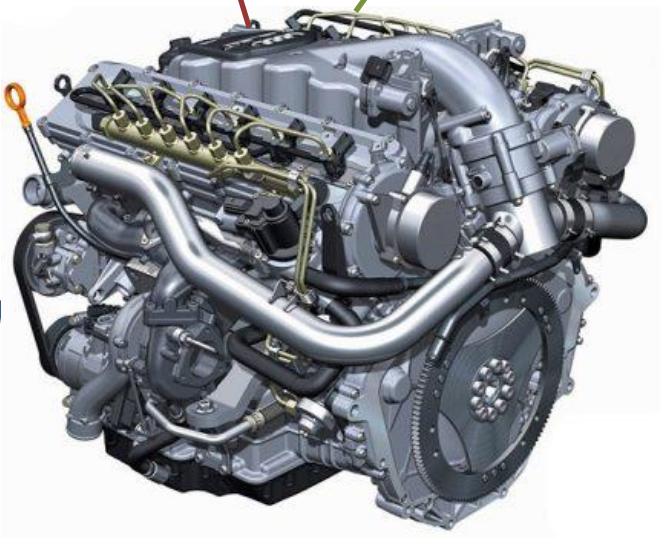

Input data

- Source description
- Meteo data

Air quality models: essentials

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Input data

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SF_ID: 14735 OS_ID: 99999 VERSION: 11059

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-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. 4 NAD-OS
88	3	1	61	2	-3.5	0.069	-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. 1 NAD-OS
88	3	1	61	3	-1.6	0.046	-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. 1 NAD-OS
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. 1 NAD-OS
89 …																				
…																				

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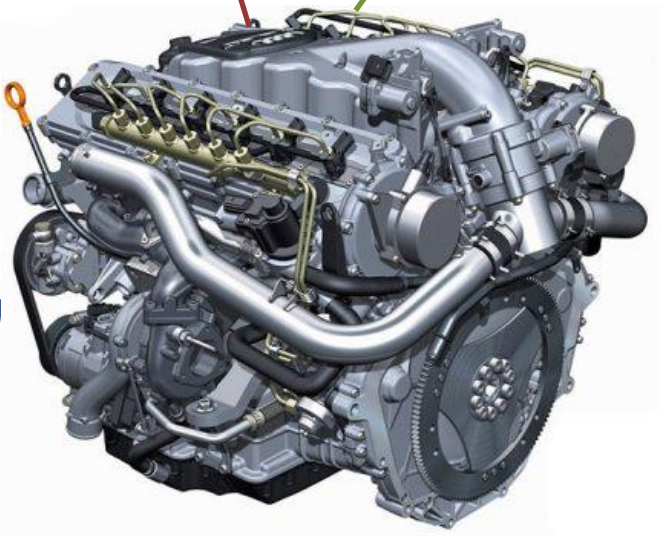

Input data

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REMEMBER: try to AUTOMATE most part of the process!

This is NOT a good MODELLISTIC **CHAIN!**!

Running models: control files and data files

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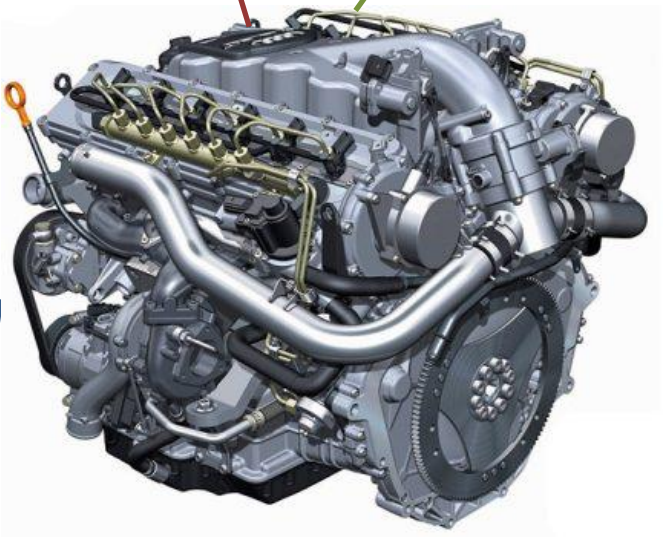

Input data

- 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”)
- …

```
 41.3N    74.0W        UA_ID: 00014735  SF_ID:    14735  OS_ID:    99999    VERSION: 11059
88  3  1  61  1   -2.7  0.062 -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.    4 NAD-OS
88  3  1  61  2   -3.5  0.069 -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.    1 NAD-OS
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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.    1 NAD-OS
89 …
…
```

Impact assessment of **specific sources**:

relevant source characteristics

Source characteristics

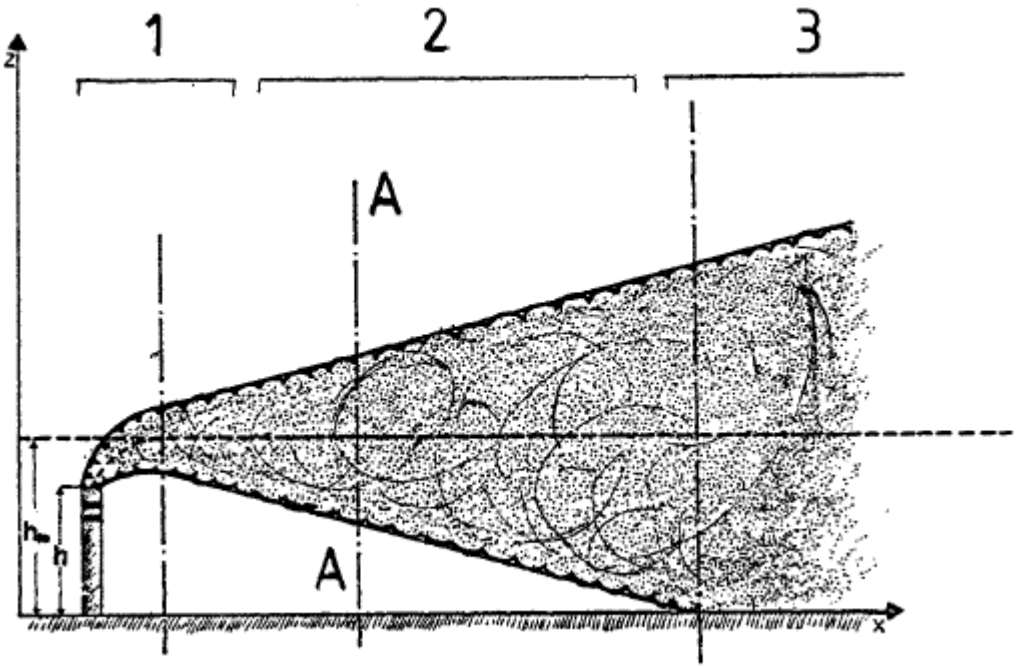
- Height (e.g. [m])
- Geometry (can be an extended surface…)
- Emissions temperature (e.g. °K) } cause an initial «plume rise»...
- Emissions velocity (e.g. [m/s])

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)…

Meteorological input data

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

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

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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**

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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**
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

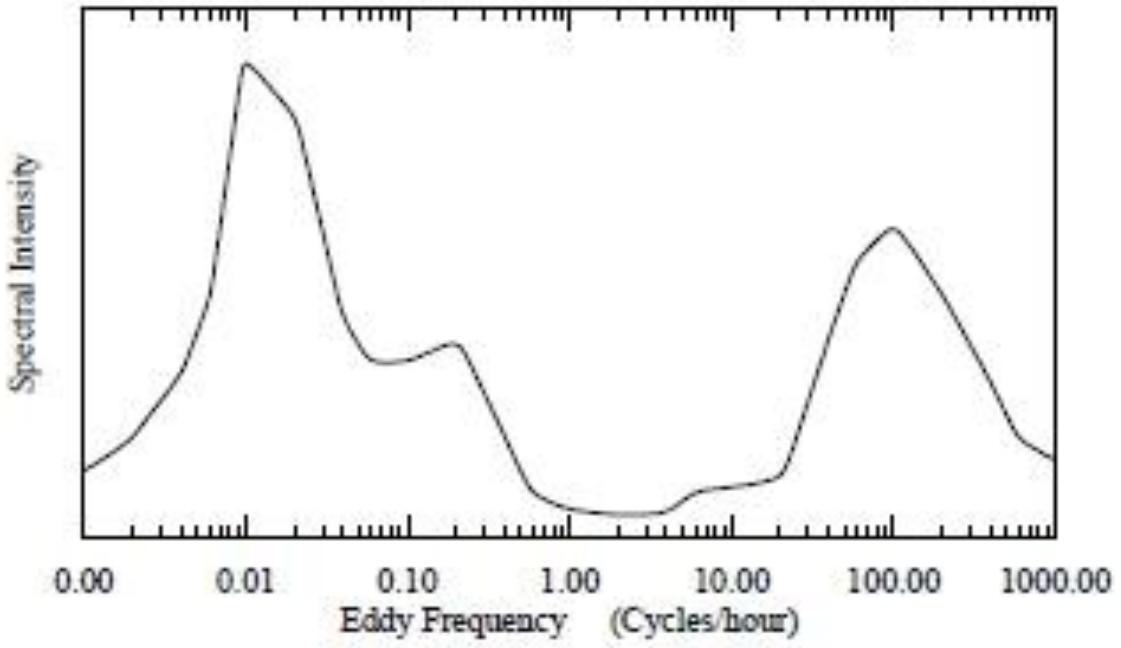


Fig.2.16: spettro della velocità del vento al suolo.

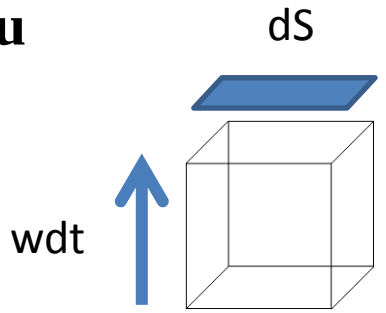
Why TURBULENCE is so fundamental… even if we don't measure it?

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

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

$$\mathbf{q} = \rho C_p T \mathbf{u}$$

$$\begin{pmatrix} dQ_w = \rho \cdot C_p \cdot T \cdot dS_w \cdot w \cdot dt \\ \dots \\ \dots \end{pmatrix}$$



$$q_w \left[kW \cdot s^{-1} \cdot m^{-2} \right] = \rho C_p T \cdot w \Rightarrow \overline{q_w} = \rho C_p \overline{T} \cdot \overline{w} = 0$$

$$\overline{w} = 0 \text{ near ground!}$$

$\Rightarrow$ 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:

$$H = \overline{q_z} = \rho C_p \sum_i \left(w_i - \overline{w}\right) \cdot \left(T_i - \overline{T}\right)$$

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

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

Roberto Sozzi, *La Micrometeorologia e la Dispersione degli Inquinanti in Aria*, APAT, RTI CTN_ACE XX/2003 (2004):

Reynolds theory, ergodicity, stationarity…

Importance of turbulence

Similarly, plume dispersion depends on turbulence

Mean wind -> **Trasport**	(Signal)	(Measure)
Turbulence -> **Diffusion**	(Noise)	(Parametric estimate)

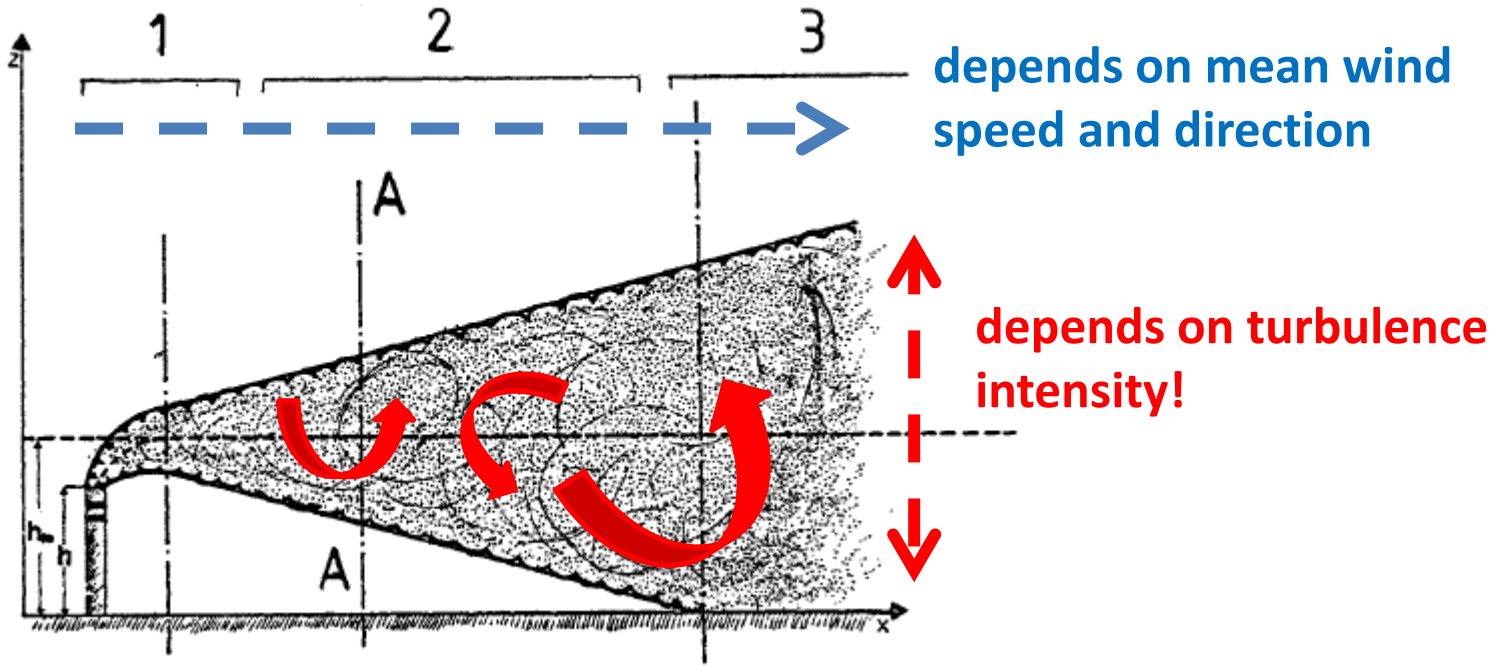
So what?

We need parametric links between turbulence and measured variables

$\Rightarrow$ we use semi-empirical relations

Importance of turbulence

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!!



depends on mean wind speed and direction

depends on turbulence intensity!

MORE...

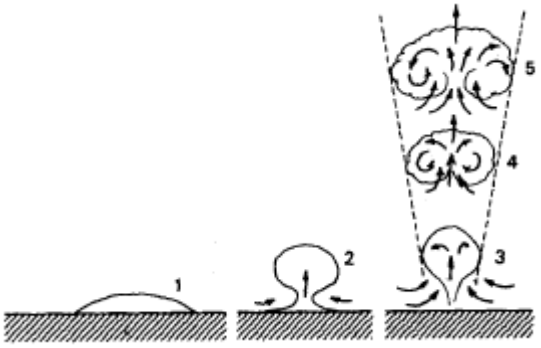
Planetary Boundary Layer (PBL)

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.)

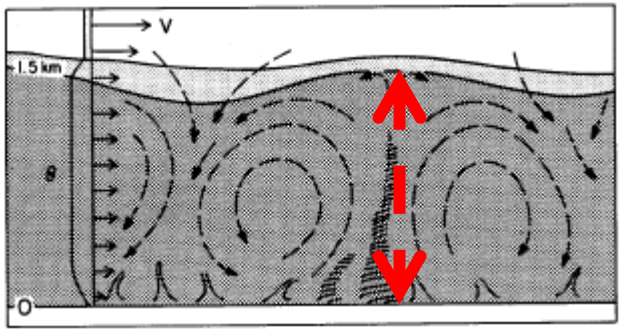
Atmosphere is like a «pot on the burner»…
Heat flux from surface causes turbulent vertical motion...

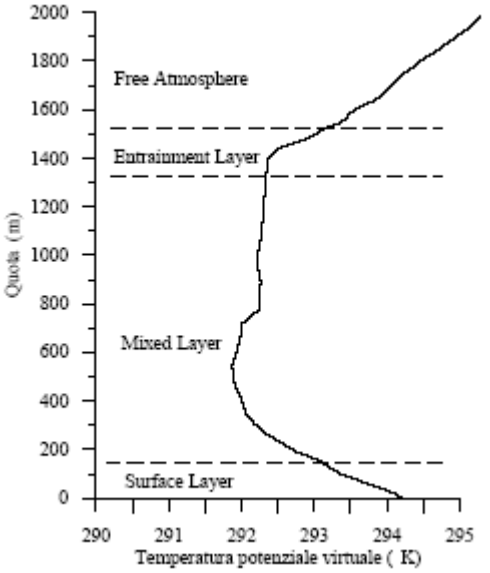
Pollutants emitted near the surface are confined in the PBL!!!

PBL height range: ~ 50 – 2500 m !!!



depends on available heat at surface!!





Importance of turbulence

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…)

Needed resources
Available resources

To use a model you need...

Calculus

For most Impact Evalutation 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)
- 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)
- 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) – ask for a meeting
- Current air quality legislation (regional, national and european)
- Air quality plans

Essential bibliography

Roberto Sozzi, *La Micrometeorologia e la Dispersione degli Inquinanti in Aria*, APAT, RTI CTN_ACE XX/2003 (2004)

EPA (2000): Meteorological Monitoring Guidance for Regulatory Modeling Applications, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-454/R-99-005

Resources

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}, $PM_{2.5}$, NOx, C_6H_6…)

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