Development of a computer system for control and prevention of air pollution in the Valencia Port (Spain)

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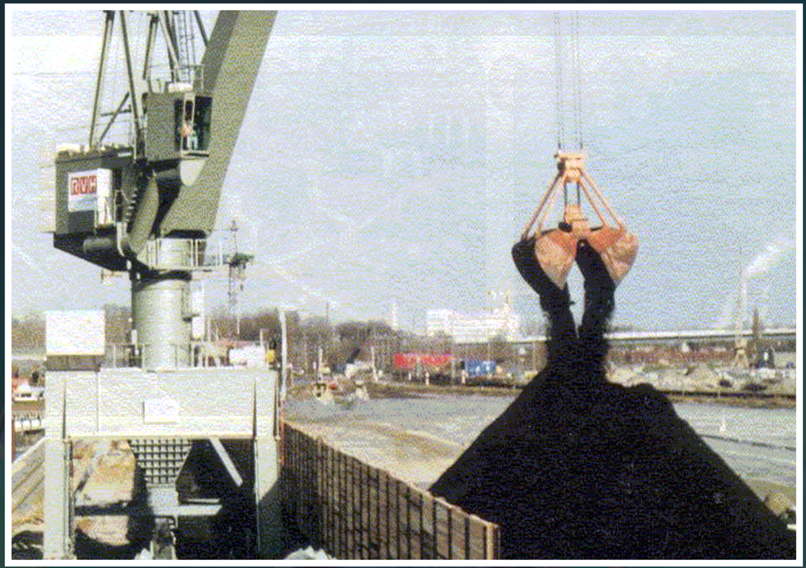
Introduction

- More than 3.8 millions of tons of solid bulks are annually handled in the Valencia Port.
- The handling of cement, clinker, coal, minerals and other food products like soya beans and flour, produce an important contribution to the PM10 concentration in the air.
- There are two factors determining the PM10 levels:
  - How solid bulks are handled.
  - Meteorological conditions.



Objective:

- To show the development of a computer system for control and prevention of the air pollution produced due to the solid bulks handling in the Valencia Port and the previous studies.

- Two phases:
  - Evaluation of the impact of the solid bulk handling in the port and its surrounding areas;
  - Development of modelling tools to control the atmospheric pollution and programming of the computer system.

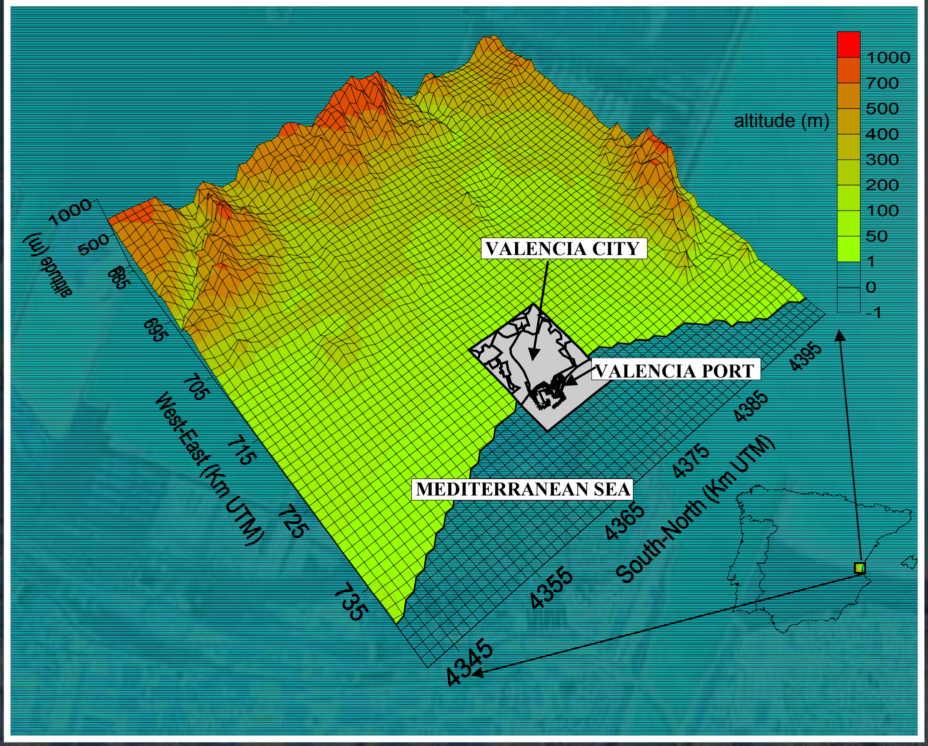
Geographical Aspects

Location:

- Mediterranean coast of Spain.

The climatic conditions:

- Coastal western Mediterranean climate.
- Main factors:
  - Azores subtropical anticyclone and
  - Deepening of the low-pressure systems in the Mediterranean Sea.
- Summer weather is usually dry and hot but temperated by the sea breezes
- Winter, the days are not cold.
- During the fall season, highly intense rain episodes occur.
- Sea breeze is the most dominant feature of the mesoscale flows, specially in summer time.
- Foehn effects are also detected when westerly blows in this region.



Valencia Port

North

South

Evaluation of the impact of the solid bulk handling on PM10 concentration (1)

- By using a dispersion model fed with the meteorological fields estimated by a mesoscale meteorological model.
- 38 meteorological scenarios corresponding to 11 synoptic conditions affecting the studied area and taking into account their seasonal occurrence.
- No measurements of PM10 concentrations in locations in or close enough to the Valencia Port to be used in this study.

Synoptic situation	Winter	Spring	Summer	Autumn
1. Anticyclone over the Iberian Peninsula				
2. Anticyclone over the British Isles or Scandinavian Peninsula				
3. Eastern Atlantic-Mediterranean Anticyclone				
4. Low Pressure over the British Isles				
5. Low Pressure over the Western Mediterranean Sea				
6. Thermal Low Pressure over the Iberian Peninsula				
7. Atlantic Low Pressure				
8. Low Pressure over the Cadiz Gulf				
9. High Pressure System extending from Atlantic Ocean to Europe.				
10. Ibero-African Through				
11. Very low pressure gradient				

Evaluation of the impact of the solid bulk handling on PM10 concentration (2)

Mesoscale Meteorological Model - TVM model:

- Three-dimensional mesoscale vorticity mode numerical model for complex terrain.
- The used version for this study (TVMNH20a) was developed by Thunis (1995).
- Vorticity approach for shallow thermal convection.
- Non-hydrostatic, anelastic and Boussinesq mesoscale model.
- TVM includes a soil model based on the ‘force-restore’ approximation for computing surface soil temperature,
- Penmann-Monteith formulation for the surface soil specific humidity
- Sasamori scheme for radiation.
- The turbulence fluxes are computed by means of a 1.5 order closure based on prognostic equations of turbulent kinetic energy.
- Used in many modelling exercises (including validation and comparison with other models) in Europe and America: Fos (France) (Bornstein, 1996), Athens (Thunis et al., 1993) and Madrid (Martín et al, 2001).

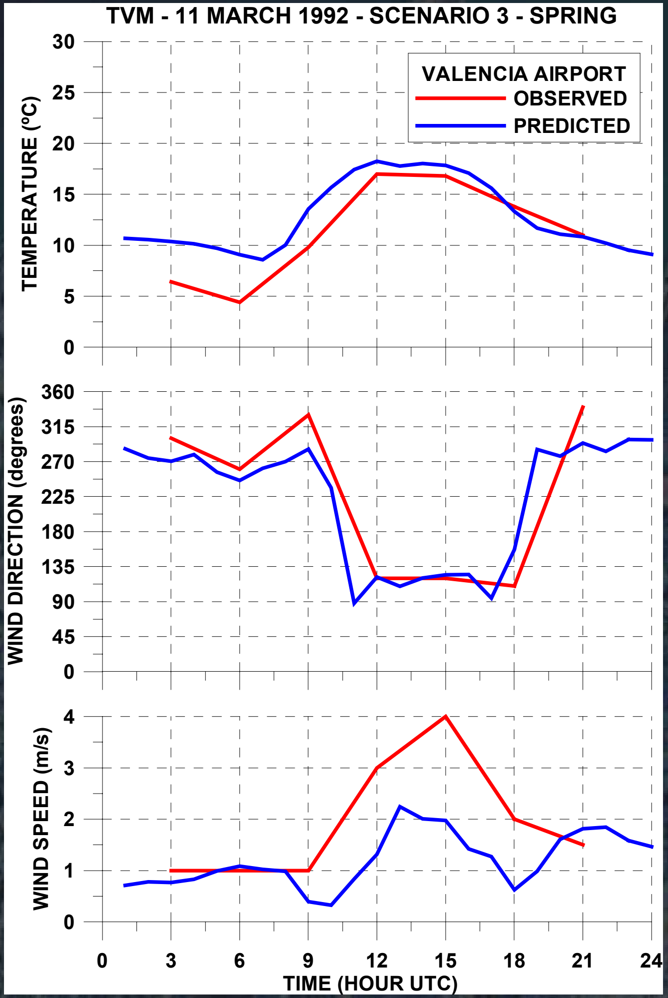
Evaluation of the impact of the solid bulk handling on PM10 concentration (3)

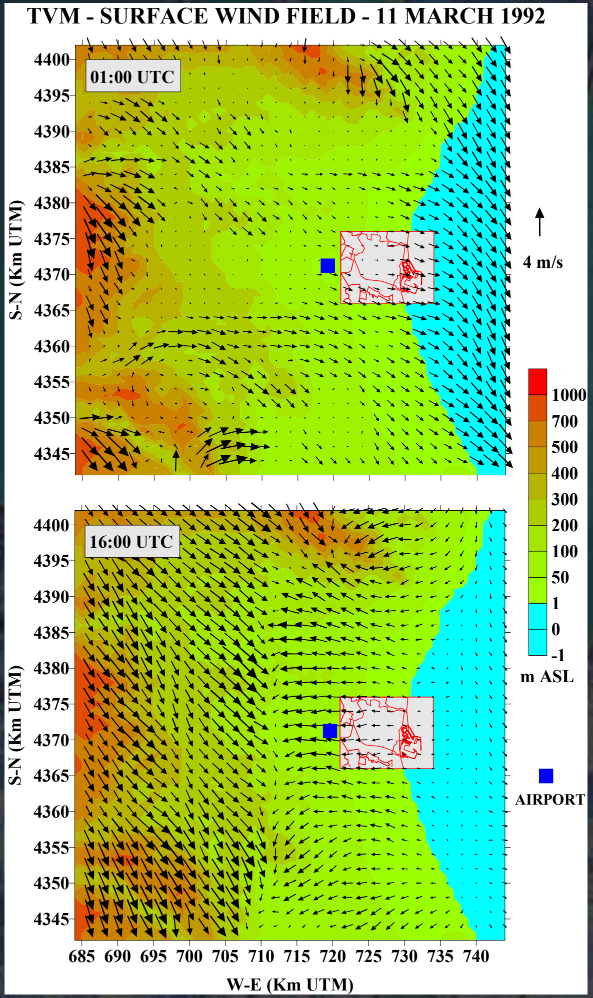
Meteorological modelling:

- TVM model was used to simulate the meteorological field evolution during a complete day corresponding to each of the 38 scenarios.
- The meteorological domain was 60x60 Km with a resolution of 2x2 Km and with 24 vertical levels.
- The top of the domain was 7600 m above mean sea level.
- The minimum vertical separation was 20 m for the lower levels and 600 m for the highest ones.
- The period of simulation was 27 hours
- Initialised at 2100 UTC with the potential temperature and wind profiles extracted from the NCEP reanalysis for the reference year (1992).
- Surface station data was used to complete the initialisation of the model.

Evaluation of the impact of the solid bulk handling on PM10 concentration (4)

TVM modelling - Eastern Atlantic-Mediterranean Anticyclone - scenario 3 -spring





Evaluation of the impact of the solid bulk handling on PM10 concentration (5)

Atmospheric dispersion model - MELPUFF model (1):

- MEsoscale Lagrangian PUFF model (Martín et al, 1999 and 2001)
- The puffs are considered as following a Gaussian distribution of pollutant concentration.
- MELPUFF compute the dispersion of pollutant emitted from multiple point sources.
- Interaction with the mixing layer top and the ground ==> reflections and virtual sources.
- MELPUFF can be initialised by the observed pollutant concentration.
- Building-wake effects on pollutant dispersion are also included (Cagnetti and Ferrara, 1980).
- The estimation of dry deposition of pollutant ===> a source depletion dry deposition model (deposition velocities as function of the aerodynamic, quasi-laminar and surface resistances).
- Wet deposition is also estimated by a simple washout model.

Evaluation of the impact of the solid bulk handling on PM10 concentration (6)

Atmospheric dispersion model - MELPUFF model (2)

- Two main versions depending on the meteorological inputs:

  MELPUFF-A
  - Three-dimensional meteorological fields (wind speed and direction, temperature, mixing depth and turbulence parameters) provided by mesoscale prognostic meteorological models (CSUMM or TVM).
  - MELPUFF assimilates the diffusivity coefficients estimated by the outputs mesoscale prognostic meteorological models by means of the Draxler parameterisation for dispersion.

  MELPUFF-B
  - Meteorological stations data ==> diagnostic wind field model included in MELPUFF. (Used in real-time computer systems as SICAH or the explained in this paper)
  - MELPUFF uses classical parameterisations (such as “Open Country”, “Desert”, “US NRC” or “US Army”) based on stability categories for dispersion.
- MELPUFF outputs:
  - Surface pollutant concentration and deposition distribution,
  - Surface wind fields
  - Concentration of pollutant in user-selected point receptors,
  - Estimates of the contribution of every pollutant source to the pollution in selected receptors.

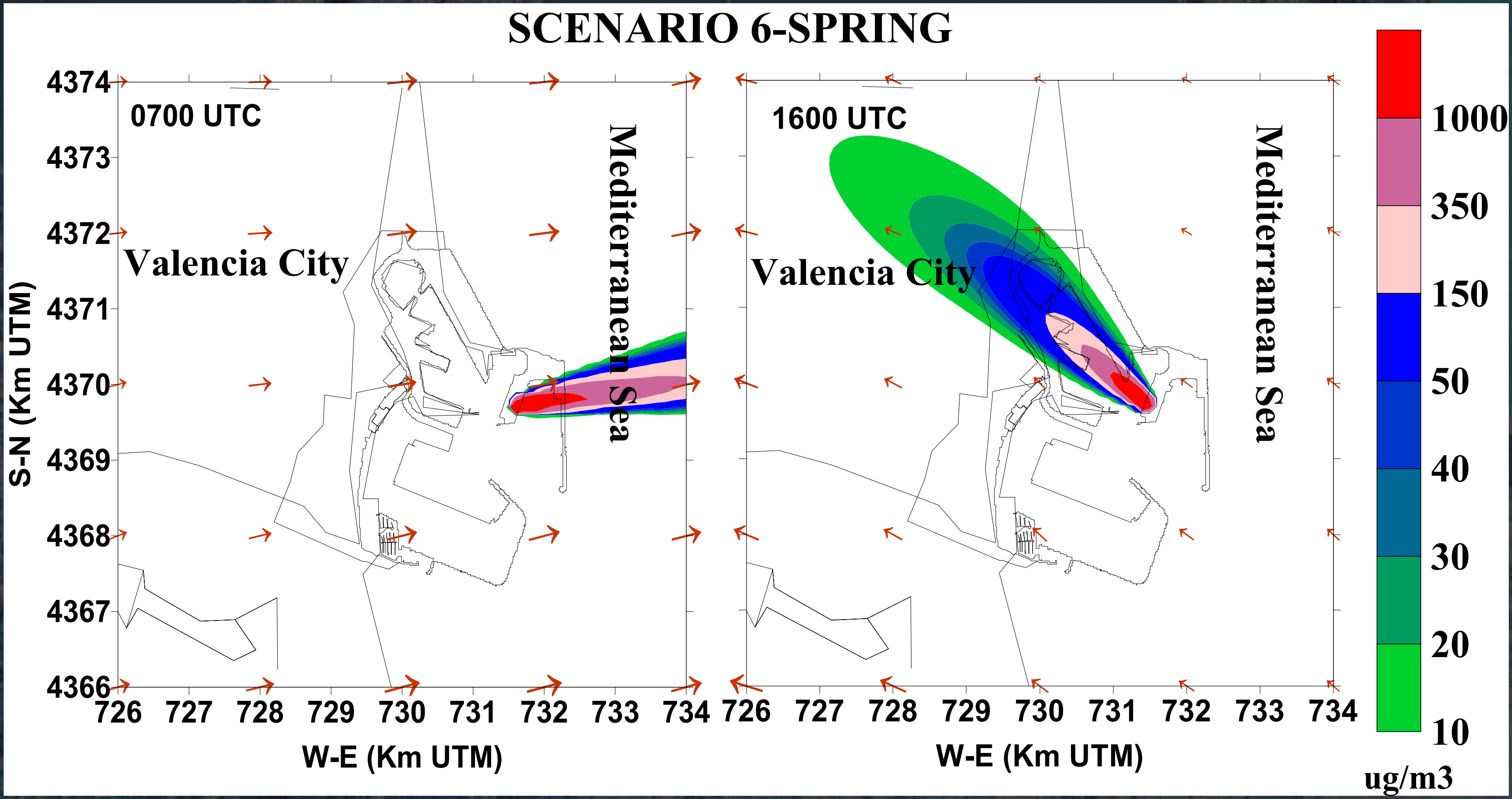
Evaluation of the impact of the solid bulk handling on PM10 concentration (7)

Pollutant dispersion modelling:

- The simulation period is 24 hours starting at 00:00 UTC.
- Single point source.
- Constant emission rate of 100 Kg/hour. 1 puff per minute.
- Height of source equals to 10 m above the ground.
- The location of the source corresponds to the dock were the solid bulks handling is made by a method that implies the highest emission of particles to the atmosphere.
- Meteorological fields estimated by TVM are used as input.
- Spatial domain is the same used in meteorological modelling.
- Outputs are hourly averaged concentrations of PM10 with a resolution of 100x100 m.

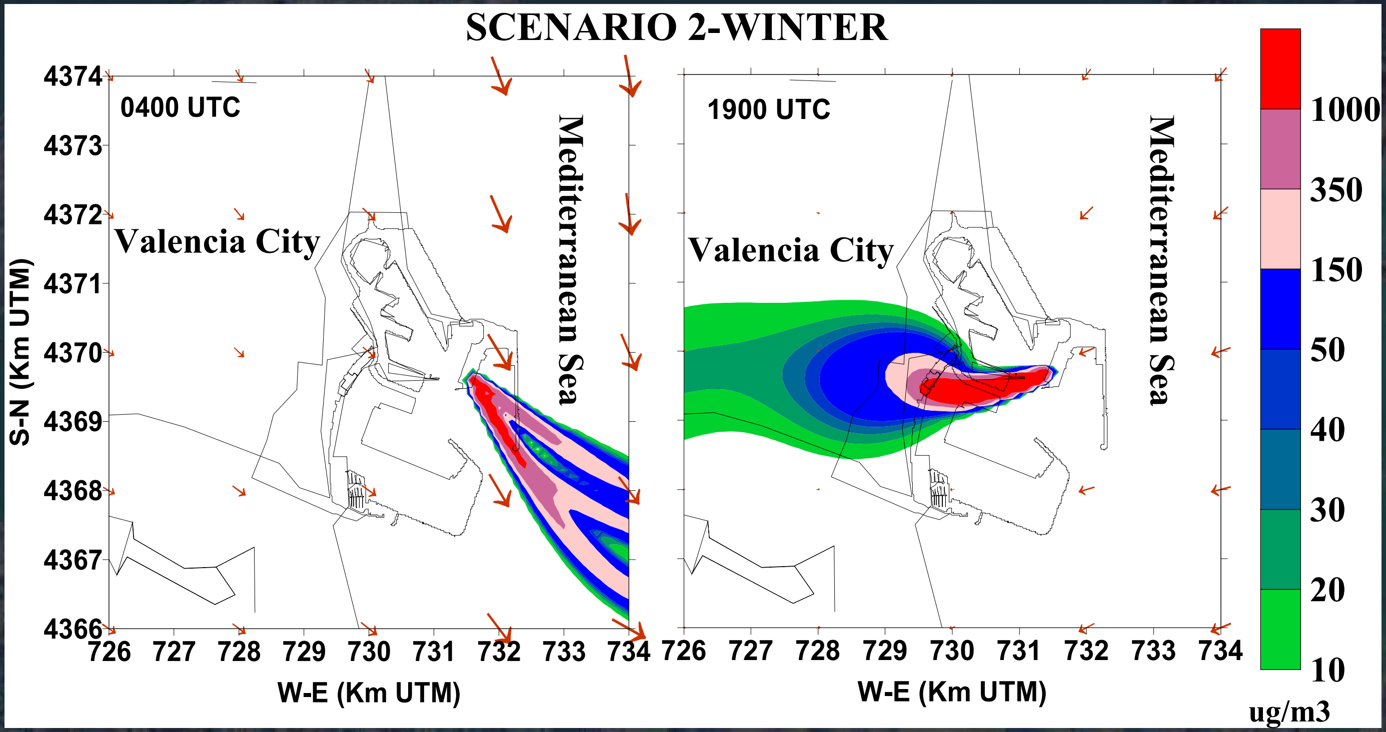
Evaluation of the impact of the solid bulk handling on PM10 concentration (8)

- The scenarios resulting in a significant impact on urban areas are related to:
  - persistent easterly flows (for example, scenarios 10-all seasons) or
  - sea breeze conditions during daytime (scenarios 3, 6, 7 and 11).



Evaluation of the impact of the solid bulk handling on PM10 concentration (9)

- The highest impact was estimated for scenarios 2-winter, 3-autum, 10-winter, spring and autumn and 11-summer during the evening, when inland flows and stable stratification occur.



- Low PM10 concentrations are expected in rainy scenarios due to the wet deposition.
- Scenarios, in which offshore winds are dominant, corresponds to non-impact in urban areas.

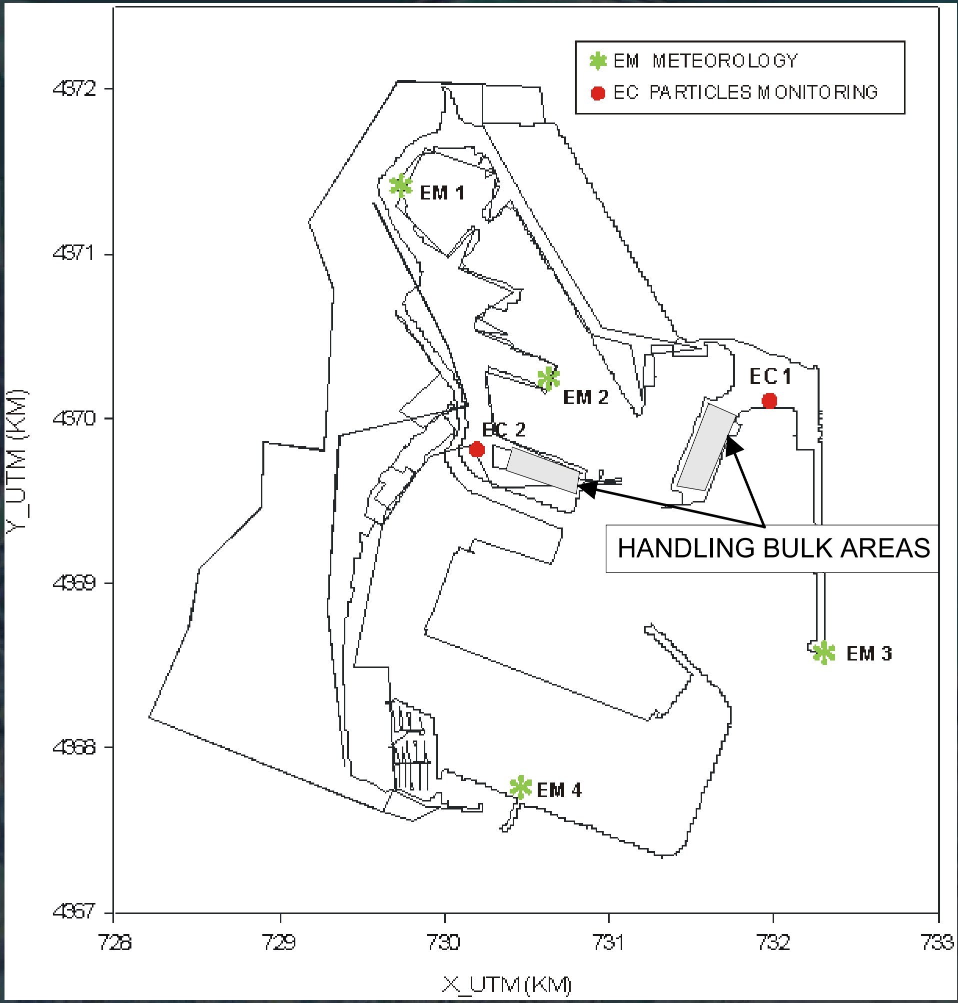
Computer system for control and prevention of air pollution in the Valencia Port (1)

- A computer system (CS) has been developed for control and prevention of PM10 concentrations in the Valencia Port (Crespí et al., 2000 and 2001).
- The core of this system is the MELPUFF dispersion model working with a resolution of 1x1 Km.
- A postprocessor is included to make computations of surface instantaneous (every 10 minutes), hourly and 24-hour averaged PM10 concentrations for a high spatial resolution grid (100x100 m) and for the PM10 monitoring locations.
- Three different types of scenarios: real-time, past and hypothetical cases.
- A maximum of 20 simultaneously working sources.
- Maximum simulation period is 24 hours running efficiently in the presently conventional desktop personal computers.
- Estimates of emission rates.
- Contribution of the extra-port activities to the PM10 concentrations.
- A friendly-user interface has been developed for this system, which includes several types of graphics (surface concentration, surface wind fields, predictions versus observations plots, port maps, animations, etc.).

Computer system for control and prevention of air pollution in the Valencia Port (2)

Meteorological and air quality monitoring stations:

- 3 meteorological stations. 1 level
  - temperature
  - wind speed and direction
- 1 complete meteorological station. 2 levels
  - temperature
  - wind speed and direction (sonic anemometer)
  - solar radiation
  - sea temperature
  - pressure
  - relative humidity
  - precipitation
- 2 monitors for particles:
  - 15 channels ranging from 0.3 to 20 µm.
- Recording period 10 minutes.
- Data are saved in a data base.



Computer system for control and prevention of air pollution in the Valencia Port (3)

Modes of operations of the computer system:

- **Real-time cases.** Short range predictions of the pollution due to PM10. MELPUFF-B
  - Set-up of the emission points. (location, type, starting time and duration of operation, type of handled bulk, etc).
  - Real-time meteorological data measured at the stations.
  - Real-time PM10 concentrations measured at the monitors.
- **Past cases**. Evaluation of the impact of past operations. MELPUFF-B
  - Set-up of the emission points. (location, type, starting time and duration of operation, type of handled bulk, etc).
  - Meteorological data measured at the stations.
  - PM10 concentrations measured at the monitors.
- **Hypothetical cases**. Evaluation of the impact of operations under different meteorological conditions. It can be used for planning of the solid bulk operations. MELPUFF-A.
  - Set-up of the emission points. (location, type, starting time and duration of operation, type of handled bulk, etc).
  - Selection of the synoptic meteorological chart and season ===> associated daily evolution of the mesoscale meteorological fields in the database. 38 cases corresponding to the scenarios in first part of the presentation. Meteorological fields correspond to previous simulations of TVM.

Computer system for control and prevention of air pollution in the Valencia Port (4)

Boundary layer height estimates:

- MELPUFF-A.
  - TVM estimates based on the turbulent kinetic energy.
- MELPUFF-B.
  - Neutral conditions: $h = C\frac{U_*}{f}$ (Deardorff, 1972)
  - Stable conditions: $h = c\sqrt{\frac{L\,u_*}{f}}$ (Zilitinkevich, 1972)
  - Unstable conditions: $h = \left(\frac{2\int_0^t Q_s\,dt}{\rho\,C_p\,\gamma}\right)^{\frac{1}{2}}$ (Tennekes, 1973). If no enough data, h=500 m

Computer system for control and prevention of air pollution in the Valencia Port (5)

Estimates of the emission rates:

- Few available data concerning the emission rates of particles depending on the type of operation, meteorological and solid bulk conditions.
- Development of a procedure to estimate automatically the emission rates, which fit better the observed PM10 concentration recorded in the monitors.
- It is based on:
  - The capacity of the MELPUFF model to label the pollutant puffs depending on the source from where they were released and then to evaluate the contribution of every source to the estimated pollution in the PM10 monitors locations.
  - Under the assumption that the distribution of the pollutant concentration follows a Gaussian distribution inside every puff, the estimated pollutant concentration is proportional to the emission rate (*Q*).
- The new emission rate (*Q'*) is done by:

$$Q' = \left(\frac{Co - Cb}{Cf} \right) Q$$

C_f, C_o and C_b are predicted, observed and background concentration.

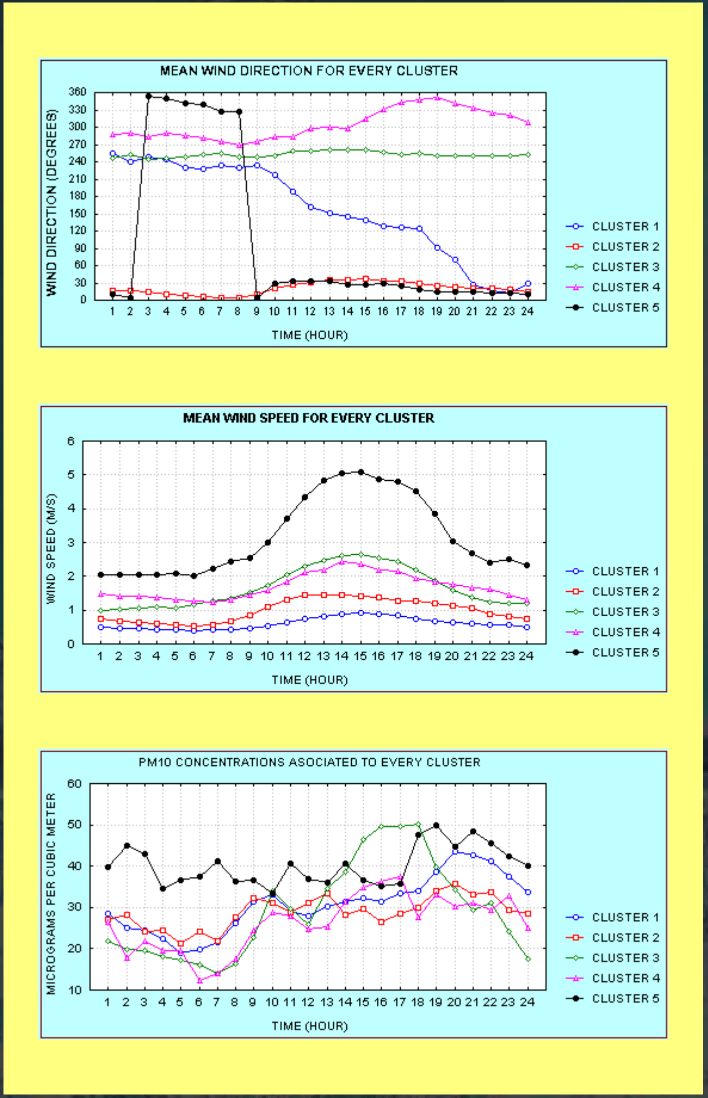
Initial emission rate, Q =100 Kg/m^3

- At least, a monitor station affected by the pollutant plume is needed.

Computer system for control and prevention of air pollution in the Valencia Port (6)

Contribution C_b of the Valencia City to the PM10 levels:

- Using data from the closest urban pollution station.
  Presently, no available data in real-time.
- Using data from a pollution station of the Valencia Port being free of the impact of any plume.
  It cannot happen in some cases.
- Statistical estimate of C_b by processing time series of PM10 concentrations and meteorological variables recorded in the urban air quality network during several years.
- K-means clustering analysis applied to the hourly surface wind components recorded in a station of the Valencia City
  (January 1995 - December 1998).
- 5 clusters of daily wind evolution.
- Associated daily evolution of PM10 concentration for every cluster by computing the geometric mean of the hourly PM10 concentration data from the closest urban station falling in every one. ===> (5 daily evolution of C_b).
- After receiving the wind data from meteorological stations, the computer system checks what wind cluster fits better the observations and then it uses the corresponding C_b daily evolution.



Computer system for control and prevention of air pollution in the Valencia Port (7)

Computer requirements and other details:

- Programming language: DELPHI 5.0.
- Hardware: PENTIUM III, 400 MHz, 128 Mb RAM.
- Data Base: SQL SERVER 7.0
- Graphics in formats JPG, GIF, BMP, animated GIF and compatible with AUTOCAD.