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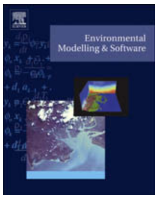

# Using meteorological data to model pollutant dispersion in the atmosphere

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## ABSTRACT

The use of meteorological data is essential for environmental analysis of the diffusion of pollutants in the atmosphere and it is very important to have data that are relevant over long-time periods. Normally, a set of statistical data is used to describe the conditions over a long period of time.

In this paper we show that the classical approach is not adequate for modelling pollutant dispersion in the atmosphere. In addition, we explore the possibility of using an environmental Test Reference Year (TRY), i.e. a set of real, contemporaneous and hourly meteorological variables "extracted" from an hourly series of at least 10 years. We compare the results of simulations with three different data sets:

- the multi-year data set: the hourly data set of 10 years (in this case the simulation can be considered a 'brute force' approach, since it requires a huge amount of data and processing time),
- the long-term data set: the statistical set derived from the full 10-year data set (in this case the simulation is that usually done by analysts),
- the TRY data set, which can be regarded as an innovative procedure.

It is demonstrated that the results obtained using the TRY are much better than the long-term data, and show good agreement with the results obtained with the multi-year simulation of the 10-year data. In addition, the long-term approach (described above as 'usual') turns out to be unreliable and not adequate to correctly predict pollutant dispersion in the atmosphere, despite its frequent use worldwide.

## 1. Introduction

The use of meteorological data for environmental purposes has been a very well-established practice since the 1960s. Meteorological data have been used in several kinds of analyses with different goals. In particular, they are often required to simulate the diffusion of gases in the atmosphere and such a simulation should provide an acceptable estimate of pollutant concentrations at ground level. Information like the annual (seasonal, monthly, etc.) average concentrations, percentiles and maximum concentrations and times at which the threshold is exceeded must be obtained and, crucially, these must be representative of a long period of time (10 years at least). In other words, it should be emphasized that:

- the pollutant dispersion in the atmosphere is strongly dependent on meteorological conditions,
- the meteorological conditions vary significantly from year to year, so that many years (10 at least) must be considered in order to have a complete representation of the site characteristics,
- the simulation of one or two specific years is representative only of those particular cases (in general not significant),
- the common approach to this problem is the use of long-term data set, obtained using a statistical synthesis of at least 10 years; in this way, it is supposed that the results are representative of a long-time period.

As already stressed, the approach generally followed consists of using, for the site to be analysed, meteorological data summarized into joint frequencies of occurrence for atmospheric stability categories (usually the seven Pasquill conditions), appropriate wind speed classes and wind direction sectors (Turner, 1970; Stern, 1976; ISC3, 1995b). Additional information must be provided to complete the input data, such as the air temperature, which is necessary to compute the plume rise; this is usually done in a very approximate manner, simply using average ambient temperatures for each one of the seven stability categories.

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In this paper, this kind of meteorological data is referred to as "long-term data", and it is obtained through basic statistical processing of original hourly data.

Two losses of information are implied in the approach just outlined:

- with long-term data it is not possible to have simultaneous meteorological variables (i.e., wind velocity/direction, temperature, solar radiation, etc. measured at the same time),
- with long-term data the hourly, daily, etc, sequences are lost (i.e., we do not have any information relevant to the link – whether proximal or not – between the data from different times).

With these limitations accepted, a drastic reduction of data and simulation time is obtained, since the alternative to long-term data is the entire set of hourly measures, e.g. a period of 10 (or more) years. A data set of this size results in a massive increase in simulation times and the size of input/output data sets (we will refer to the simulations carried out using the entire set of hourly data as "multi-year").

The question that is addressed in this paper is: "Given that we accept the previous limitations of the long-term approach for meteorological data input to gas pollutant diffusion simulations, are the results acceptable?" In other words, are the results obtained using the simplified approach close enough to those obtained based on a simulation using hourly data over a 10-year period? The answer given in the next paragraphs is "No".

## 2. The classical approach

A reference case of the classical approach used in environmental impact assessment studies for pollutant diffusion in the atmosphere is provided by the "Industrial Source Complex (ISC3) Dispersion Models", developed by the U.S. Environmental Protection Agency. ISC3 has two different versions: the short-term (ISCST3) and the long-term (ISCLT3) versions (ISC3, 1995a,b). Both versions are Gaussian models but while the short-term uses as input an hourly meteorological file, the long one uses joint frequency distributions of wind speed classes, by wind direction sectors, by stability category.

The Gaussian model for the short-term uses Eq. (1) to calculate hourly concentration:

$$C = \frac{QKVD(x)}{2\pi u_s \sigma_y \sigma_z} \exp\left[-\frac{y^2}{2\sigma_y^2}\right] \quad (1)$$

where

- $x$ = downwind distance (m), positive in the downwind direction,
- $y$ = crosswind distance (m),
- $Q$ = pollutant emission rate (mass per unit time),
- $K$ = a scaling coefficient to convert calculated concentration to desired units,
- $V$ = vertical term (dimensionless),
- $D(x)$ = decay term (dimensionless) (in this paper assumed equal to 1),
- $\sigma_y$, $\sigma_z$ = standard deviation of lateral and vertical concentration distribution (m),
- $u_s$ = mean wind speed (m/s) at release height.

Eq. (1) is strongly dependent on meteorological conditions, not only through $u_s$, which appears explicitly in the formula. In fact, it must be pointed out that:

- the vertical term $V$ is a function of the mixing height $H$ (m), the plume rise $\Delta h$ (m) and $\sigma_z$,
- $H = H(\text{SC},u,x)$, where SC (dimensionless) is the stability class and $u$ is the wind speed,
- $\Delta h = \Delta h(T, u_s, \text{SC})$, where $T$ (°C) is the air temperature,
- $\sigma_z = \sigma_z(\text{SC},x)$,
- $\sigma_y = \sigma_y(\text{SC},x)$,
- $\text{SC} = \text{SC}(u, \text{SR})$, where SR (W/m$^2$) is the total solar radiation on the horizontal plane.

It should be pointed out that the Gaussian model (Eq. (1)) depends on time $t$ only through the meteorological variables (and eventually through $Q$). In addition, the model is a steady state one, as long as the transition effects are considered negligible.

The long-term model uses a Gaussian sector-average equation (ISC3, 1995b).

There are six wind speed categories, usually they are defined by their upper bound as follows: 1.54, 3.09, 5.14, 8.23, 10.8 m/s; the sixth category is assumed to have no upper bound. There are 16 wind direction sectors, corresponding to the 16 standard compass points.

In addition to this statistical file (long-term data set), ISCLT also requires average values for temperature and for mixing height. In general, to be as accurate as possible, these average values should be evaluated also in connection with the stability class and the wind speed category. Common practice is to use the average daily maximum temperature for stability classes A, B and C, the average daily minimum temperature for classes E and F, while for class D the average temperature over the day's hourly measurements should be used. Even more complex is the calculation of the average values for the mixing height. These averages should be calculated, given a stability class, for each of the six wind speed categories (ISC3, 1995a). As long as we have six stability classes and six wind speed categories, the average mixing heights turn out to be 36.

The equation used is the following:

$$\chi_l = \frac{K}{\sqrt{2\pi} R \Delta\theta'} \sum_{i,j,k} \frac{QfSVD}{u_s \sigma_z} \quad (2)$$

where

- $\chi_l$ = mean seasonal pollutant concentration,
- $l$ = $l$th season,
- $j$ = $j$th wind direction category,
- $k$ = $k$th stability category,
- $i$ = $i$th wind speed category,
- $f$ is the frequency of occurrence of the $i$th wind speed category, the $j$th wind direction category and the $k$th stability category for the $l$th season,
- $\Delta\theta'$ is the sector width in radians,
- $R$ (m) is the radial distance from lateral virtual point source (for building downwash) to receptors, in this case considered equal to 1,
- $S$ is a smoothing function to smooth discontinuities in the concentration at the boundaries of the adjacent sectors.

All the other parameters are the same as in Eq. (1), but they are now defined for discrete categories of wind speed, wind direction, stability and season.

The crucial point for the long-term approach *versus* the short-term one is that the results obtained with the first should be "close enough" to those obtained with the latter, applied to the entire 10-year period and appropriately averaged.

## 3. Comparison between the multi-year simulation and the long-term approach

Two different types of simulations have been done to evaluate the use of meteorological statistical data for environmental