

## WinDimula model evaluation with the Model Validation Kit

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### ABSTRACT

Dimula is an Italian Gaussian multisource air dispersion model extensively described in Cagnetti and Cirillo, 1982 and Cirillo et al, 1986. The model is specifically designed to deal with wind calms, very frequent in Italian plains. This feature made it very popular in the national modelling community and now Dimula is “de facto” the reference model for most regulatory applications .

WinDimula 2.0, the new version of Dimula, has been tested on Kincaid data set by means of the Model Validation Kit technique (Olesen,1998) and the key results of the comparison are shown. Kincaid data set has been chosen because of its simple orography and its similarity to typical Italian meteorological situations.

The comparison shows that the performances of WinDimula 2.0 are satisfactory in the frame of state-of-the-art regulatory models.

#### *Brief code description*

Dimula is an air dispersion model initially developed by ENEA in the 80s (Cagnetti *et al.*, 1982, Cirillo *et al.*, 1986). Recently MAIND s.r.l. has released the WinDimula 2.0 new version for Windows.

The WinDimula model is based on the gaussian analytic solution of the turbulent diffusion equation. Its main peculiarity is a special algorithm designed to deal with wind calm conditions that are usual in many italian regions (Cirillo et al, 1992).

The model simulates both short-term and climatological concentrations caused by sources with different geometry. Output concentrations are given on regular grids or on user selected receptors. Moreover, in the latest version, the user can choose to take in to account the effects of:

- Improved Gaussian description:
  - treatment of complex terrain
  - concentrations at elevated receptors
  - decay term
  - wet deposition effects
- Down wash:
  - stack aerodynamic effect
  - reduction of plume rise due to the surrounding buildings
- Plume rise:
  - gradual plume rise
  - gradual plume rise in BID computation
  - partial plume penetration through elevated inversion layers.

#### *Data Comparison*

In the frame of Kincaid experiment, model outputs are usually compared with both arc maximum concentrations values and arc maximum positions.

In the following we will focus on the arc maximum concentrations, that is the most significant result for a model to be used for regulatory purposes. The model is therefore oriented to a large spectrum of possible non specialised users to whom a simple data input is more useful than a more

accurate physical description. In this frame we think the sole comparison of maximum concentrations do not lose generality

As suggested by Model Validation Kit standard procedure (Olesen, 1998) we compared observed and estimated values of ARC<sub>MAX</sub>/Q, i.e. arcwise maximum concentrations normalised with emission rates.

To evaluate model performance in different meteorological situations and at different distances from the source we applied standard BOOT statistical tool to the following data blocks:

- ◆ All data
- ◆ Stability categories (4 blocks: A, B,C and D)
- ◆ Distance from the source (3 blocks:  $d \leq 5$  km ;  $5 \text{ km} < d \leq 10$  km;  $d > 10$  km)
- ◆ Both stability and distance ( 12 blocks, 2 of which with no data)

Only data with quality greater or equal than 2 have been included.

The samples have been restricted by discarding events in which effective source height was greater than measured inversion height.

Kincaid data set does not contain any information about "inversion strength". In this case WinDimula postulates total reflection from inversion layer. Consequences of this hypothesis are discussed in the next section.

### *Discussion*

WinDimula 2.0 performances on the whole sample are fully satisfactory if compared with other state-of-the-art regulatory models (Table 2).

Figure 1 shows performance measures and scatter plots for the whole sample.

Figure 2 shows that WinDimula underestimates measures close to the source, performs very well at intermediate distances and slightly overestimates long-distance data. Data contained in Table 1 confirm this trend for all stability classes. Short-distance underestimation could probably mean that the Briggs treatment of vertical sigmas (Briggs, 1973) adopted in WinDimula is not sufficient and other schemas should be considered in order to treat further physical phenomena. Fumigation seems the most likely even if the large inversion heights observed could lead to exclude it. Further investigations are needed in order to deepen this problem. Moreover, total reflection hypothesis does not correspond to real physical situation, in which part of the plume passes through the inversion layer and could lead to the overestimation of large-distance measures. It is therefore strongly recommended to include in the data set more information about the inversion strength.

On the side of the stability classes (Figure 3), WinDimula shows a full agreement with A-class data, also if the number of the data in this class is too small to allow any definitive conclusion. WinDimula performs also very well for C-class data with FB not significantly different from zero, and shows also good values of FB and NMSE in B class. Poorer agreement in D class is mostly caused by the mentioned problem about short distance data.

### *Comparison with other models*

Table 2 shows that overall performances of WinDimula are as well as or in selected cases, better than other widely used regulatory state-of-the-art models.

More in detail, top boxes of Figure 4 show as underestimation at short distances (left) and overestimation at long distances from the source (right), are visible also in ISC3 and CALPUFF.

Bottom left box shows the overall agreement of WinDimula, ISC3 and CALPUFF in a typical situation and bottom right box shows as better information on the inversion strength could lead to a better agreement of WinDimula with measures.

### *Conclusions*

The comparison of outputs of WinDimula 2.0 with classical Kincaid data set has been very satisfactory.

As shown in table 2, indexes reveal the model performs as well as or in selected cases, better than widely used regulatory state-of-the-art models.

Dividing the data set in blocks homogeneous according to the distance from the source and/or to stability categories allowed us to focus on critical points of the model, namely the treatment of fumigation and the lack of information about the inversion strength and the plume penetration through the inversion layer.

These critical points seem to be present also in other popular regulatory models, so more studies are needed. As an example, an experiment devoted to the investigation of wind calms, to be set in the Po Valley, could be useful.

**Tab. 1 – ANALISYS OF BOTH STABILITY AND DISTANCE CATEGORIES**

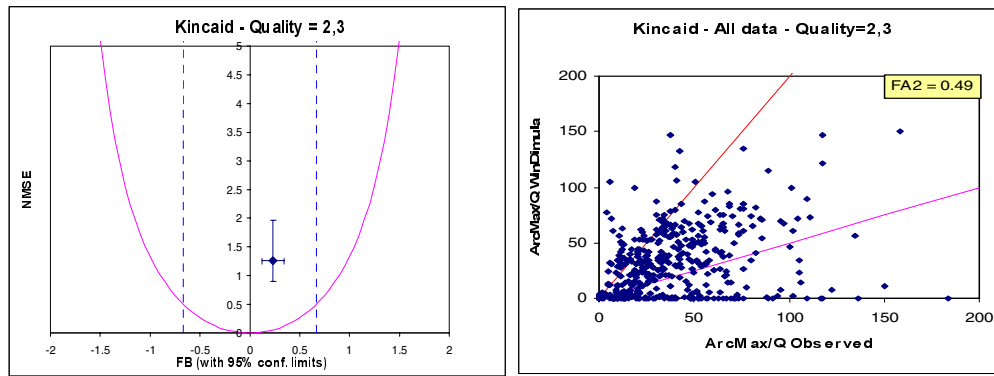
<i>Block 1: Category = A, dist ≤ 5 km (N= 9)</i>								
Model	Mean (ng/m <sup>3</sup> )/(g/s)	Sigma (ng/m <sup>3</sup> )/(g/s)	Bias (ng/m <sup>3</sup> )/(g/s)	Nmse	Cor	Fa2	Fb	Fs
Observ	82.39	37.42	0	0	1	1	0	0
WinDimula	84.44	39.77	-2.05	0.05	0.883	1	-0.025	-0.061
<i>Block 2: Category = B, dist ≤ 5 km (N= 32)</i>								
Observ	54.31	32.86	0	0	1	1	0	0
WinDimula	14.47	22.58	39.83	3.28	0.405	0.219	1.158	0.371
<i>Block 3: Category = B, 5 km &lt; dist ≤ 10 km (N= 9)</i>								
Observ	68.52	27.01	0	0	1	1	0	0
WinDimula	71.04	24.13	-2.51	0.10	0.655	0.889	-0.036	0.112
<i>Block 4: Category = B, dist &gt; 10 km (N= 16)</i>								
Observ	32.56	14.18	0	0	1	1	0	0
WinDimula	50.27	9.68	-17.71	0.30	0.417	0.563	-0.428	0.377
<i>Block 5: Category = C, dist ≤ 5 km (N= 83)</i>								
Observ	49.21	50.10	0	0	1	1	0	0
WinDimula	32.34	36.91	16.87	2.39	0.097	0.467	0.414	0.303
<i>Block 6: Category = C, 5 km &lt; dist ≤ 10 km (N= 61)</i>								
Observ	50.07	23.14	0	0	1	1	0	0
WinDimula	56.02	26.01	-5.95	0.46	-0.029	0.689	-0.112	-0.117
<i>Block 7: Category = C, dist &gt; 10 km (N= 58)</i>								
Observ	26.94	14.16	0	0	1	1	0	0
WinDimula	33.78	14.04	-6.85	0.42	0.155	0.724	-0.225	0.009
<i>Block 8: Category = D, dist ≤ 5 km (N= 63)</i>								
Observ	30.21	25.30	0	0	1	1	0	0
WinDimula	2.31	4.89	27.90	20.04	0.166	0.058	1.715	1.352
<i>Block 9: Category = D, 5 km &lt; dist ≤ 10 km (N= 42)</i>								
Observ	33.30	24.90	0	0	1	1	0	0
WinDimula	16.08	15.43	17.22	1.89	0.185	0.452	0.697	0.469
<i>Block 10: Category = D, dist &gt; 10 km (N= 53)</i>								
Observ	24.95	15.81	0	0	1	1	0	0
WinDimula	34.26	16.20	-9.31	0.51	0.326	0.509	-0.314	-0.024

**Tab. 2 – PERFORMANCE COMPARISONS WITH OTHER REGULATORY MODELS**

model	Mean (ng/m <sup>3</sup> )/(g/s)	sigma (ng/m <sup>3</sup> )/(g/s)	Bias (ng/m <sup>3</sup> )/(g/s)	nmse	cor	fa2	fb	fs
WinDimula <sup>(*)</sup>	31.37	30.01	8.4	1.25	0.249	0.494	0.236	0.094
ADMS 3 <sup>(**)</sup>	43.2	33.5	-2.2	0.8	0.49	0.58	-0.05	0.16
AERMOD <sup>(**)</sup>	20.3	24.1	20.7	2.3	0.35	0.33	0.68	0.48
ISCST3 <sup>(**)</sup>	23.1	53.3	17.9	3.8	0.26	0.26	0.56	-0.3

(\*) Statistics over the Kincaid dataset cases with effective simulated stack height less then inversion height

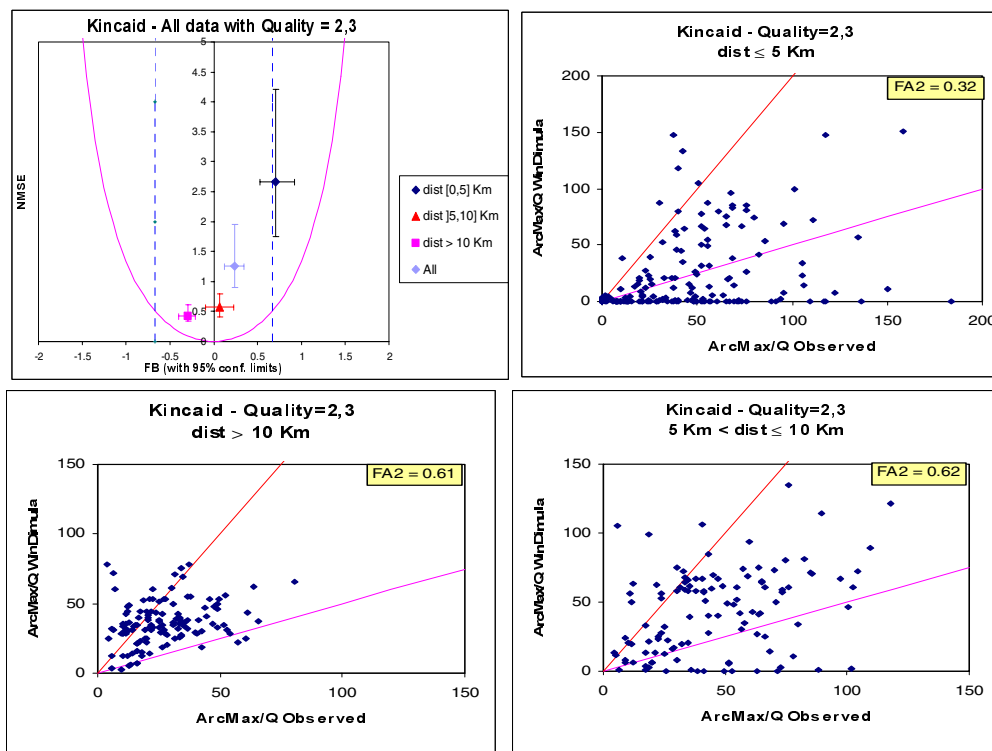
(\*\*) Statistics over the entire Kincaid dataset



All observations, (N= 426)

Model	Mean (ng/m <sup>3</sup> )/(g/s)	Sigma (ng/m <sup>3</sup> )/(g/s)	Bias (ng/m <sup>3</sup> )/(g/s)	nmse	cor	fa2	Fb	fs
Observ	39.77	32.97	0	0	1	1	0	0
WinDimula	31.37	30.01	8.4	1.25	0.249	0.494	0.236	0.094

**Figure 1:** Performance measures and scatter plot for comparison of WinDimula with Kincaid data set (data quality  $\geq 2$ ). In NMSE versus FB plot, curve of minimum NMSE is shown and error bars are "seductive" 95% confidence limits. Straight lines in scatter plot represent overestimation or underestimation by a factor of two.



Block 1: dist  $\leq 5$  km (N= 187)

Model	Mean (ng/m <sup>3</sup> )/(g/s)	Sigma (ng/m <sup>3</sup> )/(g/s)	Bias (ng/m <sup>3</sup> )/(g/s)	Nmse	Cor	Fa2	Fb	Fs
Observ	45.28	41.78	0	0	1	1	0	0
WinDimula	21.67	33.93	23.60	2.66	0.296	0.321	0.705	0.207

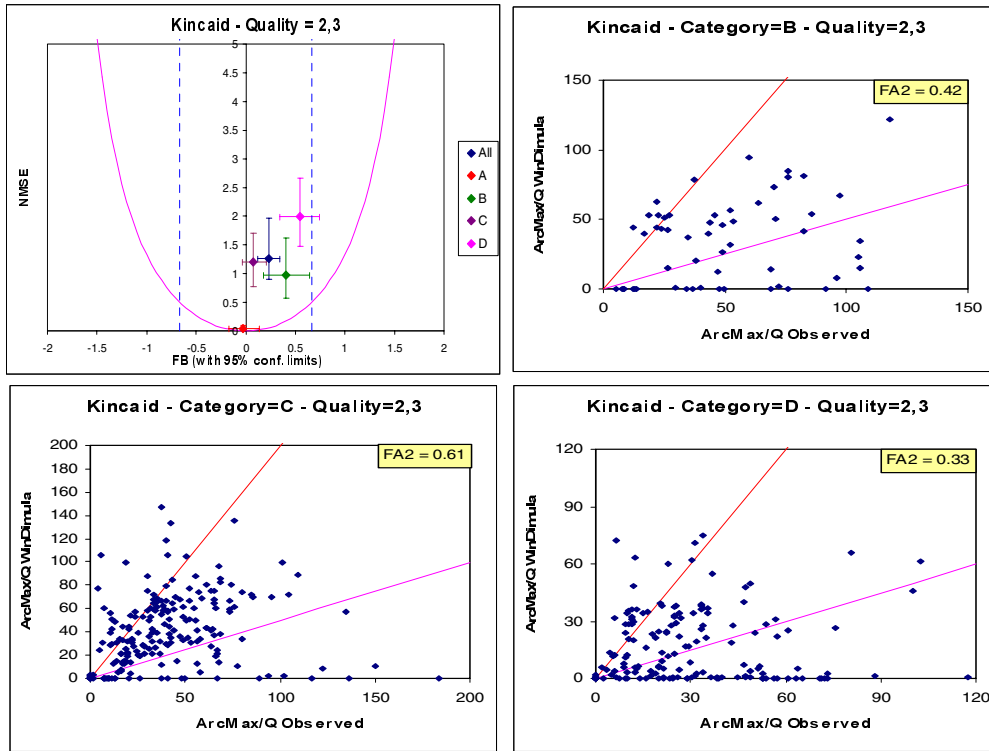
Block 2: 5 km < dist  $\leq 10$  km (N= 112)

Observ	45.27	26.32	0	0	1	1	0	0
WinDimula	42.25	30.52	3.02	0.58	0.322	0.616	0.069	-0.148

Block 3: dist > 10 km (N= 127)

Observ	26.82	15.06	0	0	1	1	0	0
WinDimula	36.06	15.51	-9.24	0.43	0.290	0.614	-0.294	-0.029

**Figure 2:** Performance measures and scatter plots for short- medium- and long- distance data blocks.



Block 1: Category = A (N= 9)

Model	Mean (ng/m <sup>3</sup> )/(g/s)	sigma (ng/m <sup>3</sup> )/(g/s)	Bias (ng/m <sup>3</sup> )/(g/s)	nmse	cor	Fa2	Fb	Fs
Observ	82.39	37.42	0	0	1	1	0	0
WinDimula	84.44	39.77	-2.05	0.05	0.883	1	-0.025	-0.061

Block 2: Category = B (N= 57)

Observ	50.45	30.46	0	0	1	1	0	0
WinDimula	33.45	30.15	17	0.98	0.254	0.421	0.405	0.01

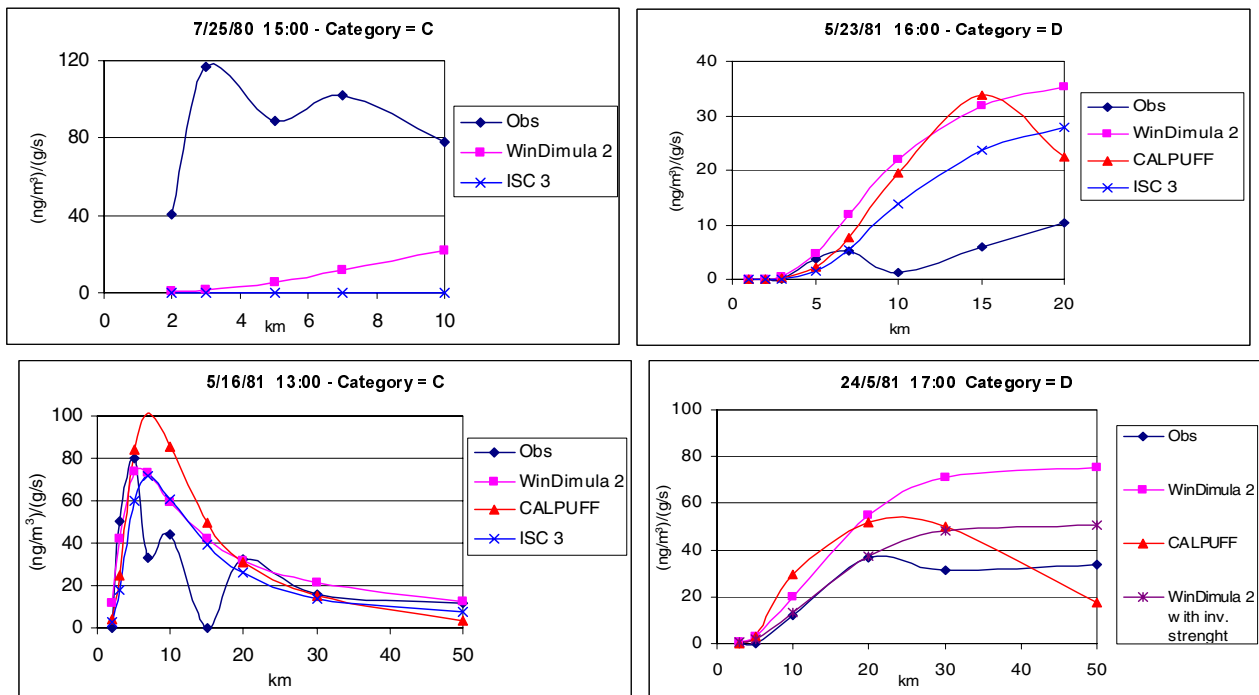
Block 3: Category = C (N= 202)

Observ	43.07	36.82	0	0	1	1	0	0
WinDimula	39.9	30.55	3.17	1.2	0.108	0.613	0.076	0.186

Block 4: Category = D (N= 158)

Observ	29.27	22.69	0	0	1	1	0	0
WinDimula	16.69	18.63	12.58	1.99	0.056	0.333	0.547	0.197

**Figure 3:** Performance measures and scatter plots for B, C and D stability categories data blocks.



**Figure 4:** 7/25/80 (top left): underestimation of short-distance measures (WinDimula and ISC3)  
 23/5/81 (top right): overestimation of long-distance measures (WinDimula, ISC3 and CALPUFF)  
 16/5/81 (bottom left): overall agreement between WinDimula, CALPUFF and ISC3  
 24/5/81 (bottom right): Influence of inversion strength on WinDimula performances.

## References

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