HARMO 18

18TH INTERNATIONAL CONFERENCE
ON HARMONISATION WITHIN ATMOSPHERIC DISPERSION MODELLING FOR REGULATORY PURPOSES

PROCEEDINGS

9-12 October 2017

CNR Research Area
Bologna
Italy

National Research Council of Italy
Institute of Atmospheric Sciences and Climate

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
DIPARTIMENTO DI FISICA E ASTRONOMIA

18th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
9-12 October 2017, Bologna, Italy

MODELLING THE DISPERSION OF SHIP EMISSIONS WITH DIFFERENT PLUME RISE APPROACHES AND SENSITIVITY ANALYSIS

Silvia Trini Castelli[1], Gianni Tinarelli[2], Giuseppe Carlino[3], Paola Radice[2], Luca Mortarini[1], Cristina Pozzi[2]

[1] Institute of Atmospheric Sciences and Climate - CNR, Torino, Italy
[2] ARIANET Srl, Milano, Italy; [3] Simularia Srl, Torino, Italy

Abstract: Different parameterizations for the plume rise were investigated with the aim of properly describing the pollutant emissions from moving ships and related ground level concentration fields. The study was conducted in the frame of an environmental impact assessment for the pollutant dispersion of ship emissions in the Venice Lagoon.

Key words: *plume rise, ship emission, environmental impact assessment.*

INTRODUCTION

In the frame of a modelling study assessing the dispersion of ship emissions in the canals of Venice Lagoon, the plume rise algorithm, used to elaborate the source term in dispersion models, was modified in order to properly describe the pollutant emissions from moving ships. The RMS (RAMS-MIRS-SPRAY, Trini Castelli 2000 and 2008) modelling system was used and a hybrid configuration for the atmospheric model RAMS (Pielke et al., 1992) was adopted and tested, combining a prognostic with a diagnostic approach. Further downscaling of the meteorological fields were performed with MINERVE/Swift diagnostic model (Moussafir et al., 2004). In order to account for the motion of the ships in the dispersion simulation, a modified plume-rise module in the Lagrangian particle dispersion model SPRAY (Tinarelli et al., 2000) was implemented. Together with the effect of the mean wind, also the effect of the movement of the ship, generating an 'apparent wind', is thus accounted for.

Two different emission scenarios were considered, the present one and one with a possible future variation of the ships' itinerary. One-year-long simulations, for 2013, were performed and the evaluation of the results was carried out by comparisons with both meteorological and pollutant concentration observed data. For both scenarios, here we assess and quantify the differences in the concentration field due to the choice of the plume rise, the original one and the modified one. The response of the modified plume rise to the wind direction along the trajectory of the ship is also investigated and discussed.
The modification of the plume rise to account for the ships motion has sensible effects on the concentration field. The results represent the basis for assessing the effectiveness of the method and for further improvement in better representing the real physical processes.

THE CASE STUDY AND THE SIMULATIONS

Two scenarios corresponding to different routes for the ships were considered. The "present" one, S0, corresponds to the ship emissions inventory for year 2013. In the "future" scenario, S1, the trajectory of the Passenger Ships heavier than 40.000 tons (40 kTon hereafter) will be moved from the Giudecca Canal to the Malamocco-Marghera Canal, then landing through a new canal, here named as Tresse, and hoteling in the same harbour as S0 (Figure 1).

A RAMS prognostic simulation was run for the two large nested grids with a coarse resolution of 48 and 12 km respectively. Then, the ISAN (ISentropic ANalysis package) module of RAMS was used to downscale the output fields over two further nested grids, with resolutions of 4 and 1 km zooming on the lagoon area, at the same time assimilating the meteorological observations available in the area. A further downscaling was then made with the diagnostic mass-consistent model MINERVE/Swift, down to the final computational domain at the target resolution of 200 m. In the downscale modelling a high-resolution (100 m) database for the orography and a refined landuse database, reformulating the CORINE data in classes that are more representative of the topographical variability in the area at 200-m resolution, were used to obtain a more detailed description of the heterogeneity in the area. In addition, to properly account for the spatial heterogeneity when calculating the surface fluxes and turbulence variables, the Sea Surface Temperature (SST) have been re-calculated using the measured data available at eight stations in the lagoon area. Hourly homogeneous 2D 200-m grid resolution fields were elaborated from the median values of the measurements, then they have been spatially re-modulated using the observed data with a data-assimilation technique based on successive corrections. The meteorological fields and the refined databases have been then used in input for SPRAY dispersion model simulations.

Figure 1. Itinerary of the ships > 40kTon in the Venice Lagoon. Red line: present S0 scenario (Giudecca canal); green line: future S1 scenario (Malamocco- new Tresse canal); red circles: locations of the measuring stations; yellow circles: additional analysis sites

In SPRAY, in order to reproduce the emission from moving ships, the plume rise algorithm has been modified. The idea is to consider, together with the effect of the mean wind, also the effect of the movement of the ship, generating an 'apparent wind'. Thus, in the source term, besides the geometrical and thermodynamic characteristics of the emission, the speed u_{SHIP} of the ship is assigned to each released particle. The original plume rise algorithm defines the time-dependent emission height $H_e(t)$ as a function of the wind speed and buoyancy force as follows (Anfossi et al., 1993):

$$H_e(t) = f(F_b, u, t, s) = 2.6\left(F_b t^2 / u\right)^{1/3}\left(t^2 s + 4.3\right)^{-1/3} \quad (1)$$

where $F_b = g w_0 r_0^2 \frac{T_f - T_a}{T_a}$ is the buoyancy flux and $s = \frac{g}{\vartheta}\frac{\partial \vartheta}{\partial z}$ is the stability parameter, being g the gravity acceleration, w_0 the plume exit velocity, T_f the plume exit temperature, T_a the ambient temperature, r_0 the radius of the stack or emission point, ϑ the potential temperature and where, in this case, the assigned velocity reads as:

$$\vec{u} = \vec{u}_{WIND} + \vec{u}_{SHIP} \quad (2).$$

Therefore, in the plume rise algorithm the final apparent wind velocity seen by the particle during its trajectory is given by the sum of the wind velocity and the ship source velocity. This approach should better account for the source motion. In this application, along their trajectory ships are supposed to move following opposite directions in an equal proportion. A composition of the apparent wind is separately made for the two possible directions of the motion.

RESULTS AND CONCLUSIONS

The effect of the modifications to the plume rise algorithms are firstly assessed looking at the difference in the concentration fields generated by the passenger ships >40 kTon for both scenarios S0 and S1. In Figure 2 the monthly means of the ground level concentration distribution are reported for the month of August, characterized by a peak in the naval traffic along the canals. In both scenarios, a general increase of the concentration is registered when using the modified plume rise, accounting for the ship motion. This can be related to an average flattening of the plume rise due to the "relative velocity" to which the Lagrangian particles are subjected. To investigate this possible interpretation, and to evaluate how the relative direction between the ship motion and the wind affects the plume rise, we selected two sites in proximity of the canals, about 200 m in the leeward of the ship trajectories. In Site 1 the trajectory of the ship is about 17° clockwise the east-west direction and the wind direction tends to be orthogonal to it, in Site 2 the trajectory of the ship is about 8° clockwise the north-south and the wind direction is mostly parallel to it. In both the arcs, the ships are supposed to be moving with a speed of about 3.3 m/s.

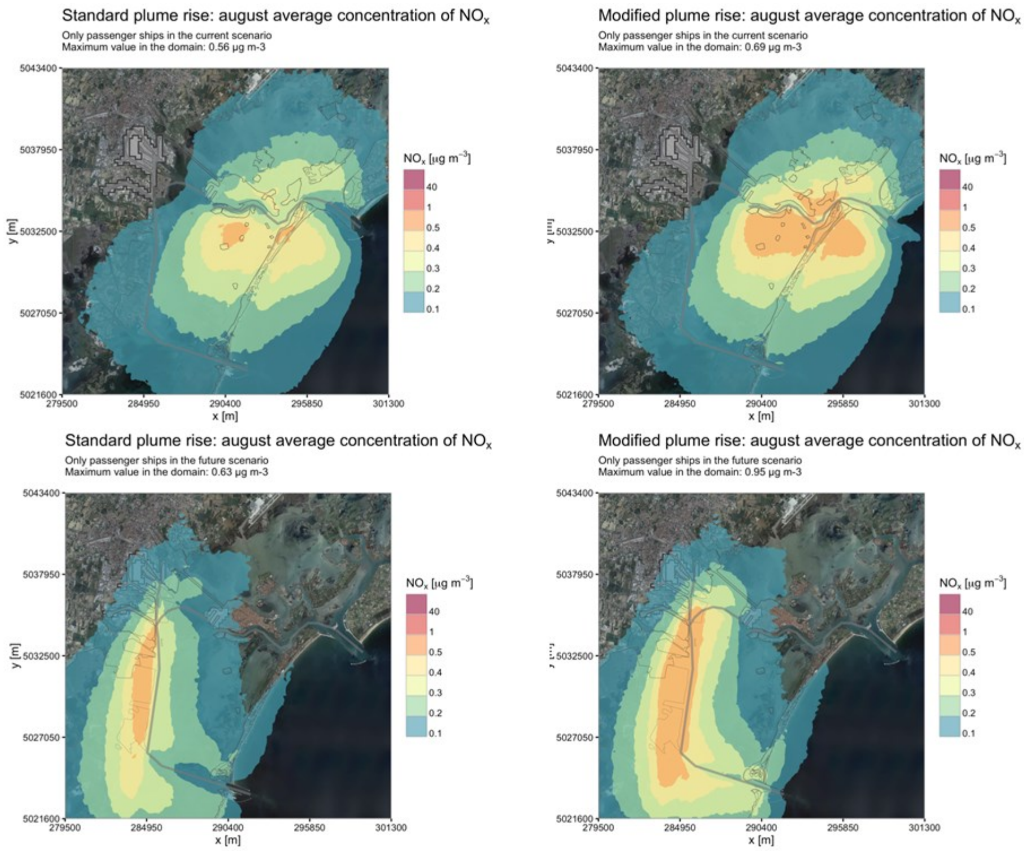

Figure 2. RMS simulation, only passenger ships >40 kTon. Monthly averaged concentration for August. Standard plume rise (left) vs modified plume rise (right) for the S0 present (top) and S1 future (bottom) scenarios.

In Figure 3 the simulated wind roses are plotted for the two selected sites for two months characterized by the peak of naval traffic, July and August, for the future scenario S1. The most frequent incoming wind directions are in the north-east sector, where the highest wind-speed values are recorded, then in the south-east one. In Figure 4 the polar plots of the difference in NOx concentration between the runs with the modified and the original plume rise algorithm are reported. The polar plots refer to the difference in degree between the wind direction and the ship motion direction. For both sites, an increase in the concentration occurs with the modified algorithm when the wind velocity and the ship trajectory are parallel (Δdir = 0° and 180°). When the angle between the ship trajectory and the wind direction tends towards orthogonality (Δdir = 90° and 270°), the difference in concentration decreases (Site 1) and in some cases the modified plume rise algorithm produces even lower concentrations (Site 2). This result seems to confirm the hypothesis that when the ships are moving on a trajectory aligned with the wind velocity direction, the plume tends to be flatten and its reduced rising induces higher ground level concentrations. Instead, when the wind blows in the orthogonal direction with respect to the ship trajectory, on average the modification of the plume rise to account for moving ships is less effective, mainly due to a smaller contribution of the ship motion to the apparent velocity.

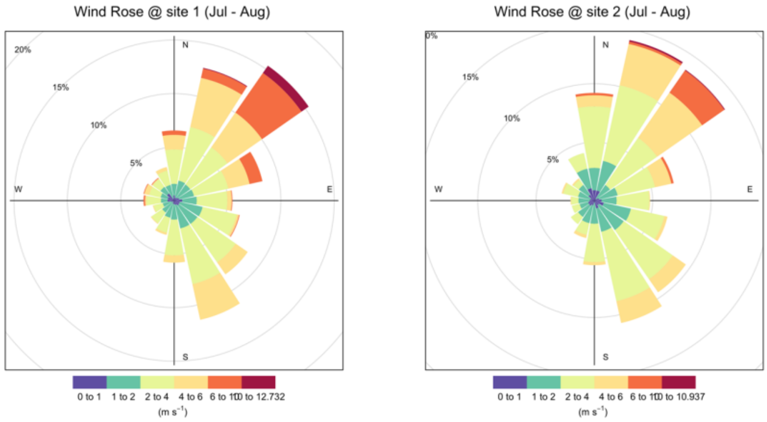

Figure 3. RMS simulation, S1. Wind roses at the two selected sites, Site 1 (left) and Site 2 (right), for the months of July and August 2013.

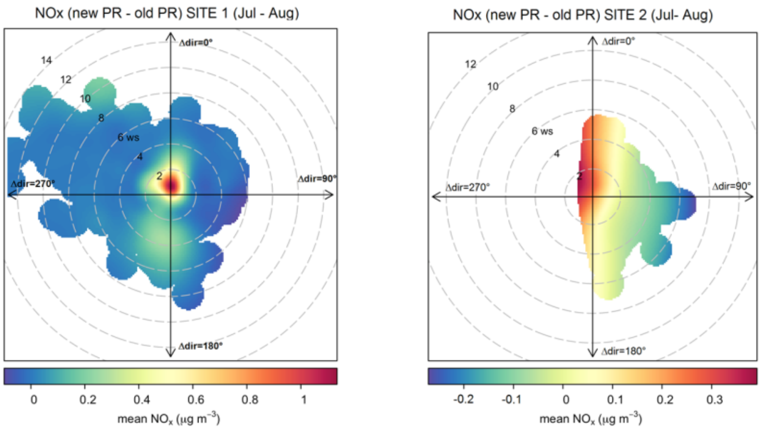

Figure 4. RMS simulation, S1. Polar plot of the ground level concentrations at the two selected sites, Site 1 (left) and Site 2 (right), for the months of July and August 2013.

To evaluate the effect of the modified plume rise at measuring stations, in Figures 5 and 6 the wind roses and the polar plots for the difference in concentration, this time referred to the geographical system, are reported respectively for Sacca Fisola and Malcontenta locations (see Figure 1). The effect of the new plume rise, increasing the concentration, is clearly seen at Sacca Fisola in the NW sector, which includes the arc of the Tresse canal from where the ships arrive at the harbour close to the station. In Malcontenta the effect is less enhanced (notice the different scale in the concentration values), since this station is farther away from the canal and the ship emissions. Overall, the modification of the plume rise, to account for the ships motion for better representing the real physical processes, has non-negligible effects on the concentration field.

In this study, the ship emissions were treated as time-dependent linear sources. Therefore, it was not possible to detail the behaviour of a single plume when the ship is moving in the same or in the opposite direction with respect to the wind velocity one. As future work to investigate and assess this issue, simulations for moving point sources should be performed.

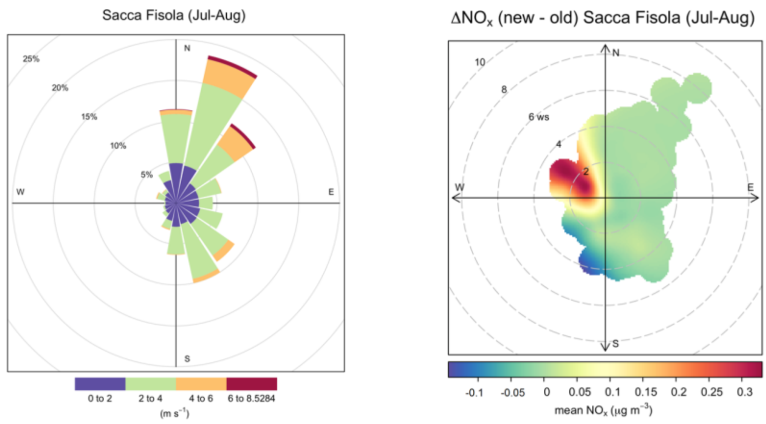

Figure 5. RMS simulation, S1. Wind rose (left) and concentration polar plot (right) at Sacca Fisola station, for the months of July and August 2013.

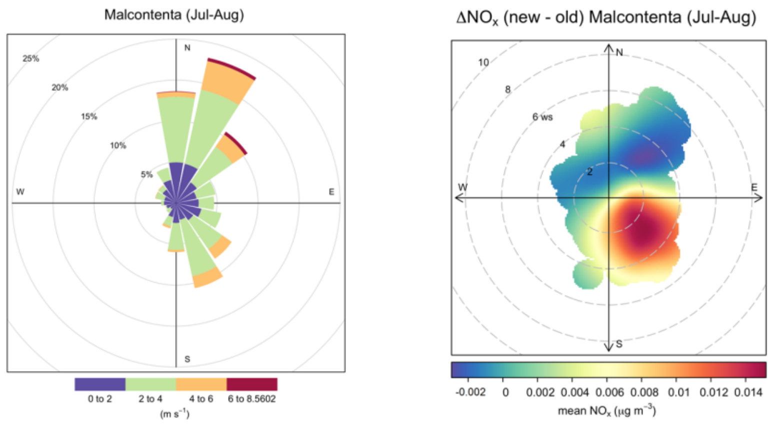

Figure 6. As in Figure 5 but for Malcontenta station.

REFERENCES

Anfossi D., Ferrero E., Brusasca G., Marzorati A., Tinarelli G., 1993. A simple way of computing buoyant plume rise in Lagrangian stocastic dispersion models, Atmospheric Environment 27A, 1443-1451.

Moussafir J., Oldrini O., Tinarelli G, Sontowski J, Dougherty C., 2004. A new operational approach to deal with dispersion around obstacles: the MSS (Micro-Swift-Spray) software suite, 9th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes Garmisch 1-4 June 2004.

Pielke R.A., Cotton W.R., Walko R.L., Tremback C.J., Lyons W.A., Grasso L.D., Nicholls M.E., Moran M.D., Wesley D.A., Lee T.J. and Copeland J.H., 1992. A comprehensive meteorological modeling system - RAMS. Meteorology and Atmospheric Physics, 49, 69

Tinarelli G., Anfossi D., Bider M., Ferrero E. and Trini Castelli S., 2000. A new high performance version of the Lagrangian particle dispersion model SPRAY, some case studies. Air Pollution Modelling and its Application XIII, Gryning S.E.and Batchvarova E. Eds., Plenum Press, New York, 23, 499-506. ISBN: 0-306-46188-9

Trini Castelli S., 2000. MIRS: a turbulence parameterisation model interfacing RAMS and SPRAY in a transport and diffusion modelling system. Internal Report. ICGF/C.N.R. No 412/2000.

Trini Castelli S., 2008. Integrated modelling at CNR/ISAC Torino. Section 4.8.3 in Overview of Existing Integrated (off-line and on-line) Mesoscale Meteorological and Chemical Transport Modelling Systems in Europe. Joint Report of COST Action 728 and GURME”. Baklanov A., Fay B., Kaminski J. and Sokhi. Eds. GAW Report No. 177. World Meteorological Organization and COST Office Publications.