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MODELING AIR QUALITY IMPACT OF POLLUTANTS EMITTED BY AN OIL/GAS PLANT IN COMPLEX TERRAIN IN VIEW OF A HEALTH IMPACT ASSESSMENT

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Abstract: The present study focuses on estimation of air quality impact of Centro Olio Val d'Agri (COVA) in view of a more comprehensive epidemiological study regarding the inhabitants of two small towns settled in the proximity of the plant. COVA activities involve different types of emissions, not all of them well-defined and controlled, as it is the case of fugitive emissions from flanges, valves, seals, and drains, and the case of atmospheric emissions from flares. We used the modelling system RMS (RAMS/MIRS/SPRAY) to estimate the ground level concentation of SO_2, NOx and CO due to the incineration of residues and to electric and thermic power generation. Simulations were run for one meteorological year. The comparison between meteorological predictions and measured data shows the capabilities of the model system in matching the wind field complexity along the valley. Spatial interpolation of measured H_2S, proxy of the other types of emission, allowed to get a more detailed picture of the plant impact.
Results suggest that the plant affects the inhabitants of the two towns differently. In addition, simulations show that the area impacted by the plumes is much larger than that of the two municipalities very close to the plant, suggesting the need to extend the monitoring area and to include in the health study also the population living in that area.

Key words: *Exposure assesment, oil/gas pre –treatment, dispersion modelling, complex terrain.*

INTRODUCTION

The health effects of air pollution have been studied intensely in recent years. Exposure to pollutants such as nitrogen dioxides (NO_2), sulfur dioxides (SO_2), carbon monoxide (CO), ozone and particulate matter (PM) has been associated with increased mortality and hospital admissions due to health outcomes such as respiratory and cardiovascular diseases. In epidemiological studies the key question concerns the extent of the exposure to various chemicals in absence of a direct measure of exposure. In such a case the exposure is commonly evaluated by three indirect methods: use of the distance from the source as a proxy, dispersion modelling and air monitoring. Dispersion models, including information on meteorology, emission and topography, are a useful tool to predict mean ground level concentration around sources and to identify, on average, areas of maximum and minimum population exposure as well as to contaminants which are emitted in air, but non measured at ground stations. By increasing the spatial and temporal resolution and by providing estimates for pollutants that are not measured, they circumvent limits in monitoring networks due to location, errors, frequency of measurements. However, they require large simulation time, appropriate parameterisations and extensive validation with available measured data. This especially in complex terrain applications, where both mean flow and turbulence, having as a forcing the large scale motion, are heavily modified by the local complex orography; such difficulties have been evidenced in a previous study in a similar valley in Southern Italy (Mangia et al. 2012). On the other hand, when emissions are not well defined and controlled, as in the case of fugitive emissions, flaring and venting activities, measurements of specific contaminants can be fundamental for an estimation of such kind of impact.

The present study focuses on the estimation of the air quality impact of Centro Olio Val d'Agri (COVA) in the frame of a more comprehensive health impact assessment study. COVA operates at the biggest onshore European reservoir (crude oil and gas). It is located in the Agri valley (southern Italy) which is about 30 km long and 12 km wide, with its bottom at about 600 m above sea level. Its activities involve different types of emissions, but only some of these last are controlled with regularity. The modelling system RMS (RAMS-MIRS-SPRAY, Trini Castelli 2000 and 2008) was used for the simulation of atmospheric circulation and pollutant dispersion of regularly monitored emissions linked to stationary combustion. To estimate the impact of the other types of emission an analysis of specific measured contaminants was performed (Gianicolo et al. 2016). The outputs, consisting of the distribution of the concentration data, were then transferred to the partner of the project to be used in the cohort study of the inhabitants of the two small valley towns, Viggiano and Grumento Nova.

The concentration of the pollutants and their distribution are discussed in view of their implications in the epidemiological study. Optimizations of the modelling approach were newly introduced in order to speed up the simulation time; also this methodological aspect is presented and briefly discussed.

AREA OF STUDY

The upper Agri valley (Figure 1), in the south-western sector of Basilicata (southern Italy), is orientated NW-SE with an average altitude of about 600 m above sea level and is bordered on both sides by the Apennine Mountains. The valley houses the largest European oil on-shore reservoirs that has produced a significant increase of the anthropogenic activities related to the extraction of hydrocarbons (crude oil and natural gas) which are pre-treated in the Centro Olio Val d'Agri (COVA) before being conveyed to the refinery. COVA plant is the largest existing oil/gas pre-treatment plant located in an anthropized area (Trippetta et al. 2013; the nominal treatment capacity of the entire plant is 16 500 m^3d^{-1} of crude oil and 3 100 000 Sm^3d^{-1} of associated gas). The COVA pre-treatment processes imply different types of emissions due to i) incineration of residues and to electric and thermic power generation (stationary combustion), ii) flaring and venting activities, iii) fugitive emissions from oil tanks. Not all the emissions are well-defined and controlled. In this study we consider monitored emissions of SO_2, NOx, CO due to stationary combustion (Table 1).

Figure 1. Area of study

Table 1. Emissions (tons in the year 2013) of SO_2, NOx, CO for each COVA's stack, together with stack location, height (h), diameter (d), flue-gas temperature (t) and exit speed (V).

Stack	X-UTM(km)	Y-UTM(km)	h(m)	d(m)	t (K)	V (ms^{-1})	SO_2(t)	NOx(t)	CO(t)
E03	576.487	4462.96	12	0.93	658	4.5		4.9	0.2
E04bis	576.537	4462.861	27.5	2.1	655	3.1	5.6	4.4	0.2
E11a			17	2	615	20.5		47.3	4.3
E11b	576.453	4462.861	17	2	615	20.5		23.5	2.6
E11c	576.431	4462.826	17	2	613	21.4		34.5	N.A.
E12b	576.381	4462.81	15	1.2	680	19.3		52.8	1.3
E12c	576.414	4462.794	15	1.2	694	16.3		44.7	1.3
E20	576.045	4463.085	33	2.5	1204	7.2	30.7	47.7	2.7

In the area there is a monitoring network of 5 stations (Figure 1c) which measures both concentration and meteorological data with some regularity since 2013. The stations VIG and GRU are located close to Viggiano and Grumento towns, respectively. Unfortunately, some bias were present in wind speed and concentrations measured data, which made the comparison with simulations more difficult. To evaluate the impact of different type of emissions we considered H_2S being specific for industrial activity and related to flares and fugitive emissions from oil tanks.

THE MODELLING SYSTEM AND SETUP

RMS is a modelling suite composed by the atmospheric model RAMS (Pielke et al., 1992), the boundary-layer parameterization code MIRS (Trini Castelli, 2000) and the Lagrangian particle model SPRAY (Tinarelli et al., 2000). In RMS suite, RAMS has been modified including alternative turbulence closure schemes, also for specific simulations at the microscale. MIRS processes the meteorological RAMS output fields or, alternatively, other kinds of data fields deriving by observations or diagnostic models, then calculates the boundary-layer quantities and the Lagrangian turbulence fields. SPRAY is a three dimensional model designed to simulate the airborne pollutant dispersion, able to take into account the spatial and temporal inhomogeneities of both the mean flow and turbulence. Concentration fields generated by point, areal or volume sources can be reproduced by the model. The trajectory of the airborne pollutant is simulated through virtual particles: the mean motion is defined by the local wind and the dispersion is determined solving the Langevin stochastic differential equations for the velocity fluctuations, reproducing the statistical characteristics of the turbulent flow. SPRAY allows realistic reproductions of complex phenomena, such as low wind-speed conditions, strong temperature inversions, flow over topography, landuse and terrain variability.

In RAMS, four nested 3D grids were used: the largest one (4272 x 3696 km^2) had a horizontal grid resolution of 48 km, the second one (1452x1596 km^2) a 12 km grid-mesh, while grid 3 (136x136 km^2) and grid 4 (45x30 km^2) had 4 km and 1 km grid meshes, respectively. In the vertical, 35 levels on a stretched grid were used, the first level being at 25 m height and the top of the domain at 22 km. The smallest domain, where SPRAY was run (Figure 1b) was covering the most part of the Agri Valley including the area where the two small towns (Viggiano and Grumento Nova) subject of the epidemiological study are settled.

The simulations were carried out for the 2013 as both meteorology and emission scenario were representative of the typical conditions in the area. The year 2013 has also the highest number of valid data on emissions and concentrations. In order to reduce the time needed to perform the yearly simulation, the RAMS analysis fields from previous runs over Italy were acquired for the two coarse domains of 48 and 12 km resolution. These analyses were then used as input and nudging on hourly basis for the two nested domains at 4 and 1 km resolution. This approach allowed reducing the simulation time to more than one-tenth of a full prognostic run over four nested domains. This is an important aspect when dealing with time restricions in environmental impact studies. The drawback is that the two-way nesting cannot work from the two finest to the two coarsest grids. However, based on a preliminary assessment comparing this ”nudging” approach with a full 4-grids run, it was shown that the outputs are very similar and the quality of the simulation holds.

RESULTS

Simulated wind roses at the 5 station for the year 2013 evidence that in the area the prevailing directions with even greater intensity are those coming from the western sectors, in good agreement with the data analysis for the following years 2014 and 2015. Due to some anomalies in the observed data for several months in 2013, it was not possible to make a quantitative and scientifically significant comparison between observations and predictions throughout the year 2013. As a matter of example, Figure 2 shows a comparison between the wind rose of simulated hourly data at MDB station (year 2013) and the same of observed hourly data for the years 2014-2015.

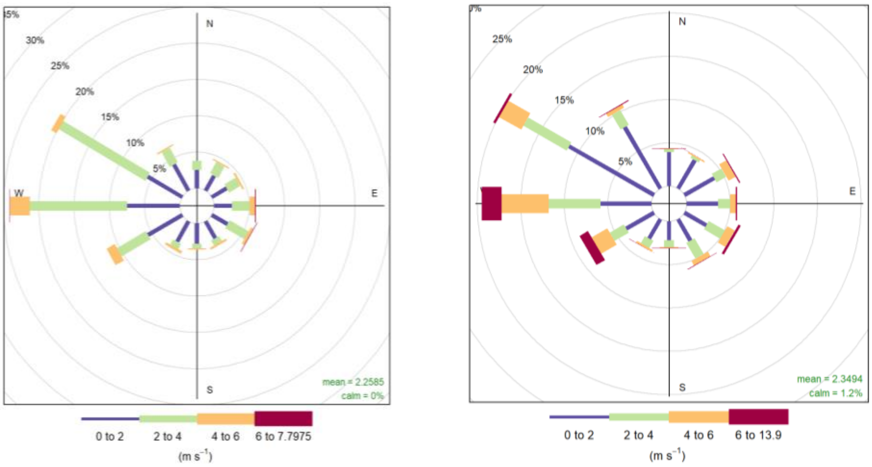

Figure 2. Wind roses at the MDB station. (left) Simulated hourly data in 2013; (right) measured hourly data with the station anemometer, 2014-15.

Figure 3 shows the simulated annual mean ground level concentration for NOx and SO_2. The spatial distribution of pollutants shows: a larger impact of the plant in the eastern-north-eastern sector; the two municipalities of Grumento Nova (GRNO) and Viggiano (VIGG) differently impacted by the plant; and the highest concentration values beyond the two towns' sites. This is coherent with the prevailing wind directions and stacks characteristics, in particular plume temperatures and exit speed (Table 1). The orography drives the distribution of pollutants at the ground, where maximum values are found on the slopes. This also is related to the height of the release points and to the additional strong plume rise, originated by the high temperature and exit velocity of the plumes.

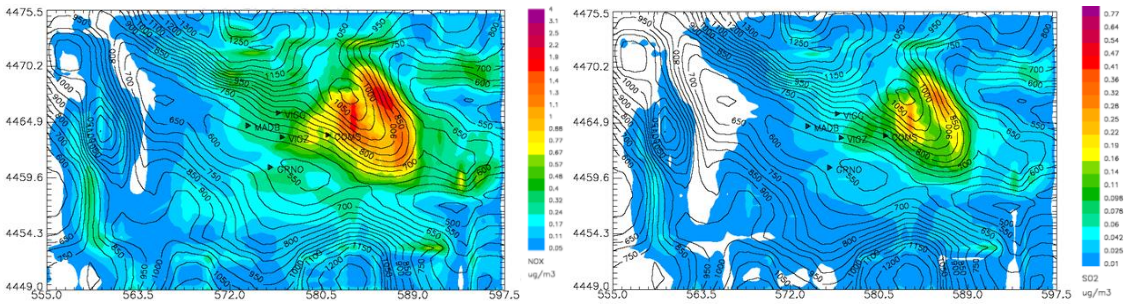

Figure 3. Simulated ground level concentration map of NOx (left) and SO_2 (right, μg/m^3)

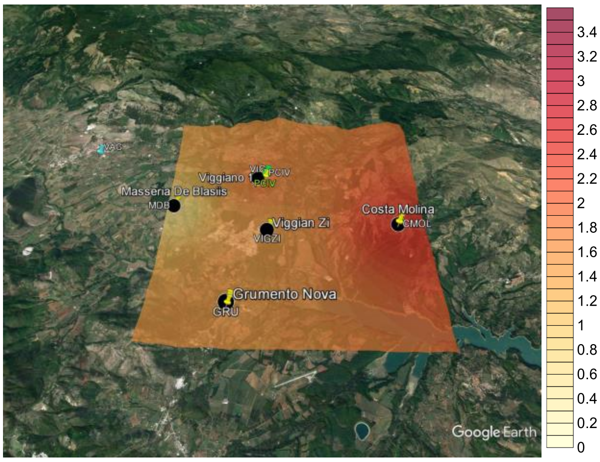

Figure 4. Interpolation of measured H_2S data (μg/m^3) at the five monitoring stations. Image data: Google, Landsat/Copernicus, SIO, NOAA, U.S. Navy, NGA, GEBCO.

Figura 4 shows the spatial pattern of H_2S concentrations averaged over the years 2013-2015 obtained by interpolation of data measured at the 5 monitoring stations. As well as for simulated concentration a spatial gradient is evident with highest values found in the eastern sector; the correlation index between modelled NOx and measured H_2S maps is 0.65. All gridded NOx, SO_2, CO, H_2S concentration data were delivered to the project partners to be evaluated as a proxy of individual residential average annual exposure to COVA emissions.

CONCLUSIONS

In the case of industrial plant characterized by different types of emissions not all well-defined and controlled, as a pre-treatments gas oil center, the integration of model studies and measurements is necessary for a better exposure assessment of a population affected by the impacts of such a plant. Concentration maps obtained with the modelling system identify the most affected areas east of the industrial zone over 5 km, which is consistent with the prevailing direction of western winds and the vertical rise of exhaust plumes. The analysis of experimental data of substances such as hydrogen sulfide shows a similar distribution.

The results suggest that on average, the releases from the plant differently affect the inhabitants of the two cities, involved in the epidemiological study. In addition, simulations show that the area impacted by the plumes is much larger than that of the two municipalities very close to the plant, suggesting the need to extend the monitoring area and to include in the health study the population living in that area.

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Conflict of interests. none

ERRATA - CORRIGE

This is the corrected version (the flue gas mean temperature for each stack) of Table 1.

Table 1. Emissions (tons in the year 2013) of SO_2, NOx, CO for each COVA's stack, together with stack location, height (h), diameter (d), flue-gas mean temperature (t) and mean exit speed (V).

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