Air quality in Trieste, Italy

A hybrid Eulerian-Lagrangian-statistical approach to evaluate air quality in a mixed residential-industrial environment

Giovanni Bonafè, Francesco Montanari, Fulvio Stel
Agenzia Regionale per la Protezione dell'Ambiente del Friuli Venezia Giulia
objectives

- to assess the air quality in the south-eastern part of Trieste, specifically the **daily exceedances of PM$_{10}$**, in a residential district close to a large iron plant
- to evaluate the effectiveness of possible emissions reductions
Trieste is a port city with about 200,000 inhabitants. It is located in the northern part of the Adriatic Sea, between the Italian peninsula and the Istrian peninsula. The urban territory lies on the Gulf of Trieste, at the foot of the Karst Plateau. Reliefs included in the urban area exceed 400 m of height. Wind regimes are characterized by local scale sea breezes and by the Bora, a north-to-northwest katabatic wind.
- emissions in the urban area:
  - urban roads,
  - highway,
  - harbour area,
  - industrial area
- primary and secondary pollutants advected from:
  - Venetian-Friulan Plain
  - Po Valley
  - Slovenia (~ 8 km from the city center)
  - Croatia (~ 20 km)
"Ferriera di Servola" is an **industrial complex for iron production**, established in year 1896 – when Trieste was part of the Austro-Hungarian Empire – in order to provide the steel to the flourishing shipbuilding industry of Trieste.

Today, the main activity of the plant is the manufacture of **pig iron**, **cast iron**, **hard coke**, **slag** and **tar**.
method and models
assumptions

1. daily PM10 concentrations considered as the sum of 3 components: regional background, urban background, hotspots additional concentration

2. hotspot contribution considered as passive tracer (chemistry negligible on this scale)

3. traffic, harbour and other urban sources affects only urban background, not hotspots (hotspots affected only by the plant)
1. daily PM10 concentrations considered as the sum of 3 components: regional background, urban background, hotspots additional concentration

2. hotspot contribution considered as passive tracer (chemistry negligible on this scale)

3. traffic, harbour and other urban sources affects only urban background, not hotspots (hotspots affected only by the plant)

→ assumption 3 is weak, see final remarks
modeling hybrid approach

regional scale: \( c_{bckg} = f_{\text{Universal Kriging}}(c_{bckg\, \text{stations}}, c_{CTM}) \)

local scale: \( \Delta c_{\text{hotspot}} = f_{\text{Universal Kriging}}(\Delta c_{\text{other stations}}, c_{\text{Lagrangian Model}}) \) \( \text{where} \Delta \) denotes the residual with respect to \( c_{bckg} \)

total: \( c_{\text{tot}} = c_{bckg} + \Delta c_{\text{hotspot}} \)
Eulerian Chemistry-Transport model (CTM)

- **FARM** model (*Silibello* et al., 2008)
- domain: Friuli Venezia Giulia, Gulf of Trieste, part of Istria, Slovenia and Veneto
- horizontal resolution: 2 km
- boundary conditions: FARM covering Italy¹
- chemistry: SAPRC99 (gas), CMAQ/AERO3 (aerosol)
- meteorological input: **WRF**² (Gladich *et al.*, 2008)
- emission input is based on regional³, national (*De Lauretis* *et al.*, 2009) and EMEP inventories

---

¹www.aria-net.it/qualearia/en
²https://www.mmm.ucar.edu/weather-research-and-forecasting-model
³www.arpa.fvg.it/cms/tema/aria/presioni/Catasto_emissioni/catasto.html
post-processing of the CTM

- on a daily basis, data fusion of average PM10 concentrations is performed
- values measured at the background stations are interpolated
- horizontal resolution: 500 m
- **Universal Kriging** technique with the output of the CTM as spatial trend (Hiemstra *et al*, 2009; Wackernagel, 2003)

\[ c_{\text{bckg}} = f_{\text{Universal Kriging}}(c_{\text{bckg.stations}}, c_{\text{CTM}}) \]

**Figure:** CTM domain over Friuli Venezia Giulia + background AQ stations
Lagrangian model

- Lagrangian model (LM) **SPRAY** (Tinarelli et al., 2000)
- meteorological input: **WRF** + turbulence postprocessor
- domain: Trieste area
- horizontal resolution: 50 m
- emissions estimates based on production indicators
- emission sources are represented, with some approximations, with three rectangular sources: blast furnace (height 40 m), casthouse (6 m) and coking (20 m)

![Graph showing emission sources: 66.7% from blast furnace, 4.8% from casthouse, and 28.6% from coking]
postprocessing of the LM

- differences between concentrations measured in Trieste and the interpolated background concentrations are again interpolated
- **Universal Kriging** technique with the output of the LM as spatial trend

\[
\Delta c_{\text{hotspot}} = f_{\text{Universal Kriging}}(\Delta c_{\text{other stations}}, c_{\text{Lagrangian Model}})
\]

\[
c_{\text{tot}} = c_{\text{bckg}} + \Delta c_{\text{hotspot}}
\]

**Figure:** Green: CTM domain + backgr. AQ stations. Red: LM domain + other stations
assessment
PM10
superamenti giornalieri della soglia di 50µg/m²
periodo: 01/01/2016 – 31/12/2016
PM10
superamenti giornalieri della soglia di 50μg/m²
periodo: 01/01/2017 – 30/09/2017
evaluation
daily concentrations

PM10 daily concentrations
model vs observations

CAR
LIB
MUG

PCA
PIT
PON

PVG
RFI
SVE

0 50 100 150
0 50 100 150
0 50 100 150

model
obs
model vs observations
PM10 daily concentrations

somedatafilteredoutbyQC
∼100mfromtheplant
HARMO18,Bologna9-12Oct2017
Bonafè,MontanarieStel 17/27
daily concentrations

PM10 daily concentrations
model vs observations

some data filtered out by QC
daily concentrations

PM10 daily concentrations
model vs observations

CAR
LIB
MUG
PCA
PIT
PON

somedatafilteredoutbyQC

∼ 100 m from the plant

Bonafè, MontanarieStel 17/27
**daily concentrations**

### PM10 daily concentrations

**model vs observations**

<table>
<thead>
<tr>
<th>CAR</th>
<th>LIB</th>
<th>MUG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PCA</th>
<th>PIT</th>
<th>PON</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PVG</th>
<th>RFI</th>
<th>SVE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Some data filtered out by QC**
- **∼ 100 m from the plant**
- **Not used in the kriging**

---

HARMO18, Bologna 9-12 Oct 2017

Bonafè, Montanari e Stel
PM10 monthly mean
model vs observations

<table>
<thead>
<tr>
<th>CAR</th>
<th>LIB</th>
<th>MUG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PCA</th>
<th>PIT</th>
<th>PON</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PVG</th>
<th>RFI</th>
<th>SVE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

concentrations ($\mu g/m^3$) vs month

Jan: many missing data not used in the kriging

HARMO18, Bologna 9-12 Oct 2017
Bonafè, Montanari Stele 18/27
Jan: many missing data

not used in the kriging
total 2016 exceedances

PM10 annual exceedances
model vs observations

- all days
- excluded days with missing observation

site
- CAR
- LIB
- MUG
- PCA
- PIT
- PON
- PVG
- RFI
- SVE

HARMO18, Bologna 9-12 Oct 2017
source attribution
every day, for each cell, residuals are attributed to each of the 3 sources proportionally to the impact calculated by the LM

$$\Delta c_{source} = \Delta c_{tot} \cdot \frac{c_{SPRAY,source}}{c_{SPRAY,tot}}$$

scenarios: for each source, the emission has been progressively decreased

on annual basis, the indicator “area with more than 35 daily exceedances” has been calculated
results

area with more than 35 days of exceedance (m²)

reduction

target

- blast furnace
- casthouse
- coking
- plant
- regional background
results

most effective reductions: casthouse and background

area with more than 35 days of exceedance ($m^2$)

target
- blast furnace
- casthouse
- coking
- plant
- regional background

HARMO18, Bologna 9-12 Oct 2017

Bonafè, Montanari e Stel
final remarks
conclusions

- due to the prevailing wind regimes, the most critical areas for PM10 pollution are in the industrial area itself and over the sea
- the hill of Servola (to the north-east of the plant) acts to some extent as a shield for the residential area
- the buildings closest to the plant are exposed (in 2016) to 5-10 exceedances more than the rest of the neighbourhood
conclusions

- due to the prevailing wind regimes, the most critical areas for PM10 pollution are in the industrial area itself and over the sea
- the hill of Servola (to the north-east of the plant) acts to some extent as a shield for the residential area
- the buildings closest to the plant are exposed (in 2016) to 5-10 exceedances more than the rest of the neighbourhood
- the hybrid Eulerian-Lagrangian-statistical approach performs good not only in the monitoring stations used for the interpolation, but also in a station which had been kept out from the calculation
due to the prevailing wind regimes, the most critical areas for PM10 pollution are in the industrial area itself and over the sea

the hill of Servola (to the north-east of the plant) acts to some extent as a shield for the residential area

the buildings closest to the plant are exposed (in 2016) to 5-10 exceedances more than the rest of the neighbourhood

the hybrid Eulerian-Lagrangian-statistical approach performs good not only in the monitoring stations used for the interpolation, but also in a station which had been kept out from the calculation

different emission reduction strategies have been evaluated; the most effective are the reduction of the emissions of the casthouse, the reduction of all the emissions of the plant and the reduction of the background (regional and urban)
conclusions

- due to the prevailing wind regimes, the most critical areas for PM10 pollution are in the industrial area itself and over the sea.
- the hill of Servola (to the north-east of the plant) acts to some extent as a shield for the residential area.
- the buildings closest to the plant are exposed (in 2016) to 5-10 exceedances more than the rest of the neighbourhood.
- the hybrid Eulerian-Lagrangian-statistical approach performs good not only in the monitoring stations used for the interpolation, but also in a station which had been kept out from the calculation.
- different emission reduction strategies have been evaluated; the most effective are the reduction of the emissions of the casthouse, the reduction of all the emissions of the plant and the reduction of the background (regional and urban) → this conclusion may be pretty sensitive to our assumptions regarding the emissions of the plant, see next slide.
Next steps:

- additional model for the other local relevant sources (vehicles, home heating, harbor and ships), maybe *Land Use Regression* method
- extension to benzene (maybe using benzene/toluene ratio to distinguish between traffic and plant contributions)
- more accurate information about emissions (hopefully)


Thank you for your attention.
Thank you for your attention.

- questions?
- suggestions?

Figure: Left to right: L. Euler, J.-L. Lagrange and D. G. Krige