Mercury dynamics in a changing coastal area over industrial and post-industrial phases

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Study area – The Venice Lagoon

- shallow coastal lagoon in the Northern Adriatic Sea (Mediterranean Sea)
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https://www.shorthistory.org/
Study area – The Venice Lagoon

- shallow coastal lagoon in the Northern Adriatic Sea (Mediterranean Sea)
- urbanization of the Venice City since XIII century
- industries were settled in the mainland since 1920s (metallurgical industries), a chlor-alkali plant active since 1951
Past industrial and urban activities led to Hg accumulation in sediment, with highest concentrations in the central area. 

Open Mediterranean Sea range 0.04 - 0.07 ug g\(^{-1}\) 

[Ogrinc et al. 2007]
Through a box model (WASP7), we investigated the impacts on the Venice Lagoon from changing drivers at local and global scale:

- dynamic simulations of transport and transformations of Hg species
- 200 years long runs, from preindustrial setting to the end of the century (1900-2100)
The Hg model (WASP7)

Through a box model (WASP7), we investigated the impacts on the Venice Lagoon from changing drivers at local and global scale:

- 10 box configuration based on hydrodynamic modeling [Solidoro et al., 2004]
We estimated historical, present and future Hg inputs to the Venice Lagoon (1900 – 2100)

[Rosati et al., under review]
Hg inputs to the lagoon – Rivers

- **Preindustrial**: background load [Collavini et al., 2005; Molinaroli et al., 2013]
- **Industrial**: 2002 load scaled following Hg Enrichment Factors for European Rivers [Amos et al., 2014]
- **Observational constraint**: load estimated for 2002 [Bloom et al., 2004]
- **Future**: progressive decrease to background load

[Rosati et al., under review]
**Observational constraint:** load estimated for 2002 ~9.4 kg y\(^{-1}\) [Bloom et al., 2004]

**Historical evolution:** 2002 data scaled according to global course of atmospheric deposition [Amos et al., 2015]

**Future evolution:** 2002 data scaled according to 4 alternative scenarios of atmospheric deposition [Chen et al., 2018]

[Rosati et al., under review]
Hg inputs to the lagoon – Industrial

- Chlor-alkali and zinc melting plant
- Time variable Emission Factors \([\text{kg-} \text{Hg}_{\text{em}}/\text{Mg}_{\text{prod}}] \) \([\text{Streets et al., 2017, 2011; EU 2001}]\)
- Data of industrial production
- MeHg assumed to be 1% of Hg\(_T\) \([\text{Bloom et al., 2004}]\)
Hg inputs to the lagoon

- Estimated cumulative emissions $\sim 66$ Mg:
  - $\sim 36\%$ to the atmosphere
  - $\sim 64\%$ to the water
- Industrial period: industrial wastewater $> 80\%$ of Hg loads
- Post-industrial period: residual industry emissions (20\% - 10\%); increasing importance of atmospheric deposition

[Rosati et al., under review]
Environmental drivers of change

Main changes in environmental conditions are taken into account.
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1980s Eutrophication
Environmental drivers of change

Main changes in environmental conditions are taken into account:

1980s
Eutrophication

1990s enhanced sediment resuspension (uncontrolled Manila clam harvesting)

Manila clam harvest
Modeled and observed $\text{Hg}_T$ in sediments

Modeled concentrations (1900 – 2100)

Observed concentrations

[Donazzolo et al., 1984], [MAV, 1995] [Zonta et al., 2018]

[Rosati et al., under review]
Modeled and observed $\text{Hg}_T$ in sediments

- Modeled concentrations (2008)
- Observed concentrations (2008) [Zonta et al., 2018]

[Rosati et al., under review]
Modeled and observed MeHg in sediments

Modeled sediment MeHg\textsubscript{T} concentrations

Observed sediment MeHg\textsubscript{T} concentrations

[Han et al., 2007] [Guédron et al, 2012]

[Rosati et al., under review]
Modeled and observed Hg species in water

Model observations
[Bloom et al., 2004]
Modeled Hg Fluxes and Reservoirs

**Hg\textsubscript{T} Inputs:**
- maximum in 1970, then decrease

**Hg\textsubscript{T} Outputs:**
- decline during the 1980s
- maximum during the 1990s, driven by high sediment resuspension that mobilize Hg to the water column
Modeled Hg Fluxes and Reservoirs

Hg\textsubscript{T} surface sediment reservoir:

- maximum during the eutrophication phase (1980s), ~10 years after the maximum in Hg inputs.
- sharp decrease during sediment resuspension, then slower decreasing trend to the end of the century
Spatial Variability

• Highest Hg_T and MeHg_T sediment concentrations at the end of the 1970s in the central box 6 which receives industrial dumping
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- 1980s: eutrophication $\rightarrow$ enhanced sediment burial favors a slight decrease of surface sediment concentrations in some subbasins
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- Highest $Hg_T$ and $MeHg_T$ sediment concentrations at the end of the 1970s in the central box 6 which receives industrial dumping → 10 times higher than southern lagoon

- 1980s: eutrophication → enhanced sediment burial favors a slight decrease of surface sediment concentrations in some subbasins

- 1990s: high sediment resuspension → transport of Hg from the central to southern and northern boxes: concentrations peak at the end of 1990s
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Hg species budget (2019):

- **Sediment resuspension** is the main $\text{Hg}_T$ source to the water column (38 kg y$^{-1}$)
- **MeHg** mostly from watershed
- For both Hg and MeHg, estimated outputs slightly exceed estimated inputs $\rightarrow$ concentrations decrease
- Net Hg and MeHg export to the Mediterranean Sea
Atmospheric deposition in 2100:
- **Reference:** 9.3 kg y⁻¹
- **A1B1:** 22.8 kg y⁻¹
- **Const. Em:** 12.6 kg y⁻¹
- **Emissions Control:** 6.1 kg y⁻¹
- **Zero Emissions:** 2.7 kg y⁻¹

The modeled changes in water and sediment concentrations range:
- +7% | -12% for Hg_T and MeHg_T in water
- +6% | -8% for Hg_T in sediment
- +6% | -6% for MeHg_T in sediment
Conclusions

• By combining local data and global estimates we reconstructed the Hg emissions history for the Venice Lagoon

• The modeled maximum Hg accumulation in sediments occurs 10 years later than the maximum in Hg inputs, during eutrophication phase

• High resuspension rates favor Hg export from the lagoon, but they also cause a redistribution of Hg from the central area to the less contaminated areas
Thank you!
Any questions?
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