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Tallinn University of Technology

HAZARDOUS CHEMICALS IN THE EASTERN GULF OF FINLAND - CONCENTRATIONS AND IMPACT ASSESSMENT

Modelling and pressure maps

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Project reference:	ER90
Funding organizations:	European Neighborhood Instrument, European Union, SA Environmental Investment Centre

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Model setup

GETM (General Estuarine Transport Model; Burchard & Bolding, 2002) has been applied in the present study to analyze the pathways of hazardous substances in the Baltic Sea and, more particularly, in the Gulf of Finland.

GETM is a 3-dimensional primitive equation model with a free-surface and Boussinesq approximation that uses coupling with GOTM (General Ocean Turbulence Model, Umlauf et al., 2005) model to calculate the vertical mixing from two equation k-epsilon model.

The Baltic Sea in this study is resolved with a 1 nautical mile grid spacing horizontally and with 50 vertically adaptive coordinates (Gräwe et al., 2015; Klingbeil et al., 2018). The initial T/S field is based on Copernicus re-analysis for the 2009-04-01 interpolated to the model grid. An open boundary is located in the westernmost part of the Baltic Sea, Kattegat, and climatological T/S profiles and sea surface height from the Gothenburg tide gauge have been utilized for the open boundary conditions. River discharge is taken from the forcing compiled for the BMIP (Baltic Model Intercomparison Project) by Väli et al. (2019). For the atmospheric forcing, momentum and heat flux through the sea surface, ERA-5 re-analysis is being used.

Scenarios

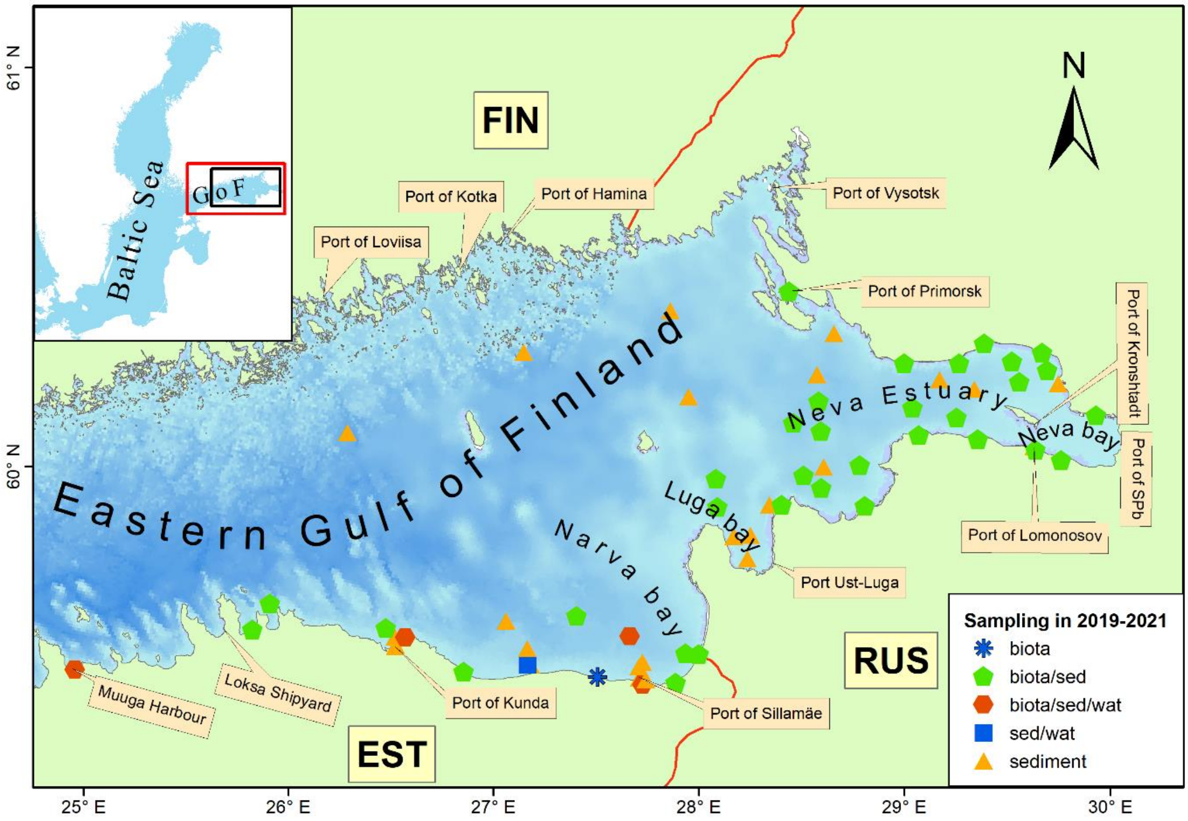

Figure 1. In situ sampling sites.

Realistic climatological loads of cadmium, lead and mercury to the Baltic Sea reported in the HELCOM PLC5 have been used in the present study. The total annual loads to the different basins in the Baltic Sea are presented in Table 1. The possible input of heavy metals is the largest at the river mouth areas of River Narva, River Luga and River Neva. The load from other rivers is much smaller. Based on the final model simulation results, we define the most likely accumulation areas of hazardous substances in the GoF.

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Table 1: The mean annual load of heavy metals to the different basins of the Baltic Sea (in tons per year) as used in the simulations – an average riverine load for 2012-2014 (HELCOM, 2018) and long-term average atmospheric deposition (HELCOM, 2020) were used.

Source	Riverine load			Atmospheric deposition		
Basin/metal	Cd	Hg	Pb	Cd	Hg	Pb
BP	2.71	1.02	58.3	4.5	2.1	171.3
GOF	24.80	0.08	279.7	0.8	0.3	27.4
GOR	0.29	0.16	8.9	0.4	0.2	17.6
BOS	1.61	0.25	22.3	0.7	0.6	26.1
BOB	2.05	0.46	30.3	0.4	0.4	14.0
BS	31.45	1.96	399.5	8.2	4.3	307.2

Results

The sedimentation of the heavy metals in different years is presented in figures 2 to 11. The largest accumulation zones are in the vicinity of the Neva river and Narva river, where the riverine input of heavy metals is the largest. Some accumulation is also visible near the northern coast in the vicinity of Kotka and Hamina due to the Kymijoki river. The simulated accumulation is largest at the shallower areas, i.e. close to the coast, compared to the deep areas of the GoF for all the studied metals. The extension from the coast is larger at the northern coast due to the effects of the bathymetry – the southern coast is approximately two times steeper and the depths are larger.

The accumulation strongly depends also on the particle size. The light particles travel further from the source, and therefore, are more dispersed. Heavy particles tend to settle in the vicinity of the input source and therefore their concentrations at the shore are much larger compared to the light or medium size particles.

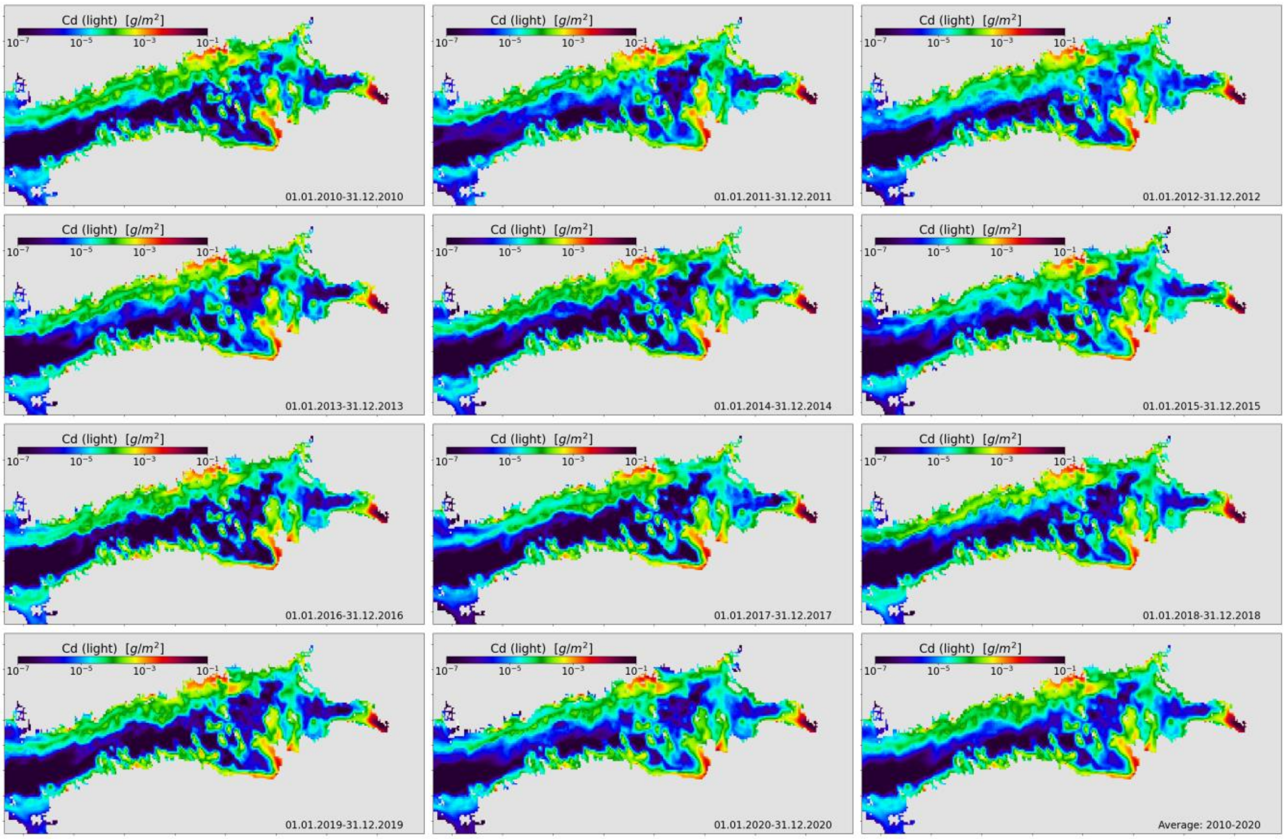

Figure 2: Sedimentation of Cd attached to the light particles in the Gulf of Finland during 2010-2020.

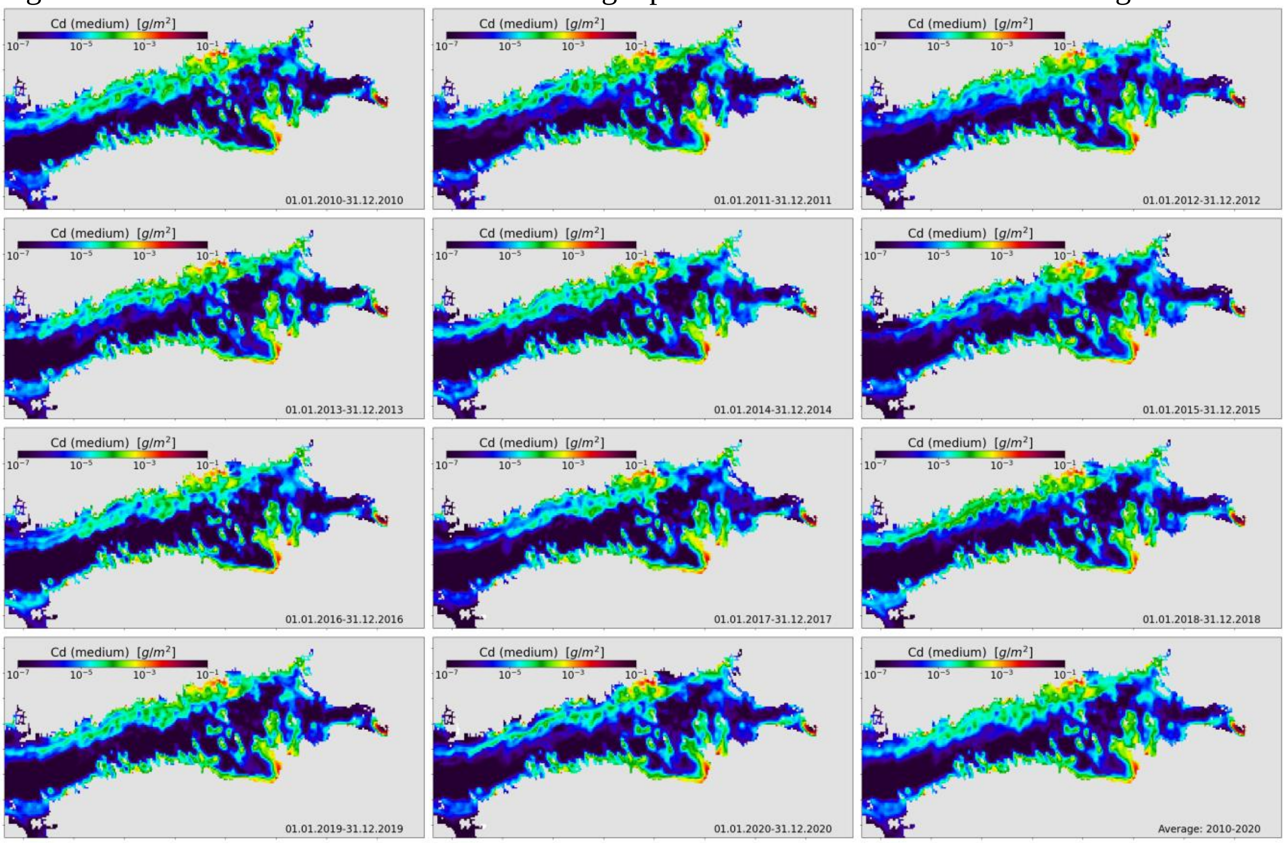

Figure 3: Sedimentation of Cd attached to the medium particles in the Gulf of Finland during 2010-2020.

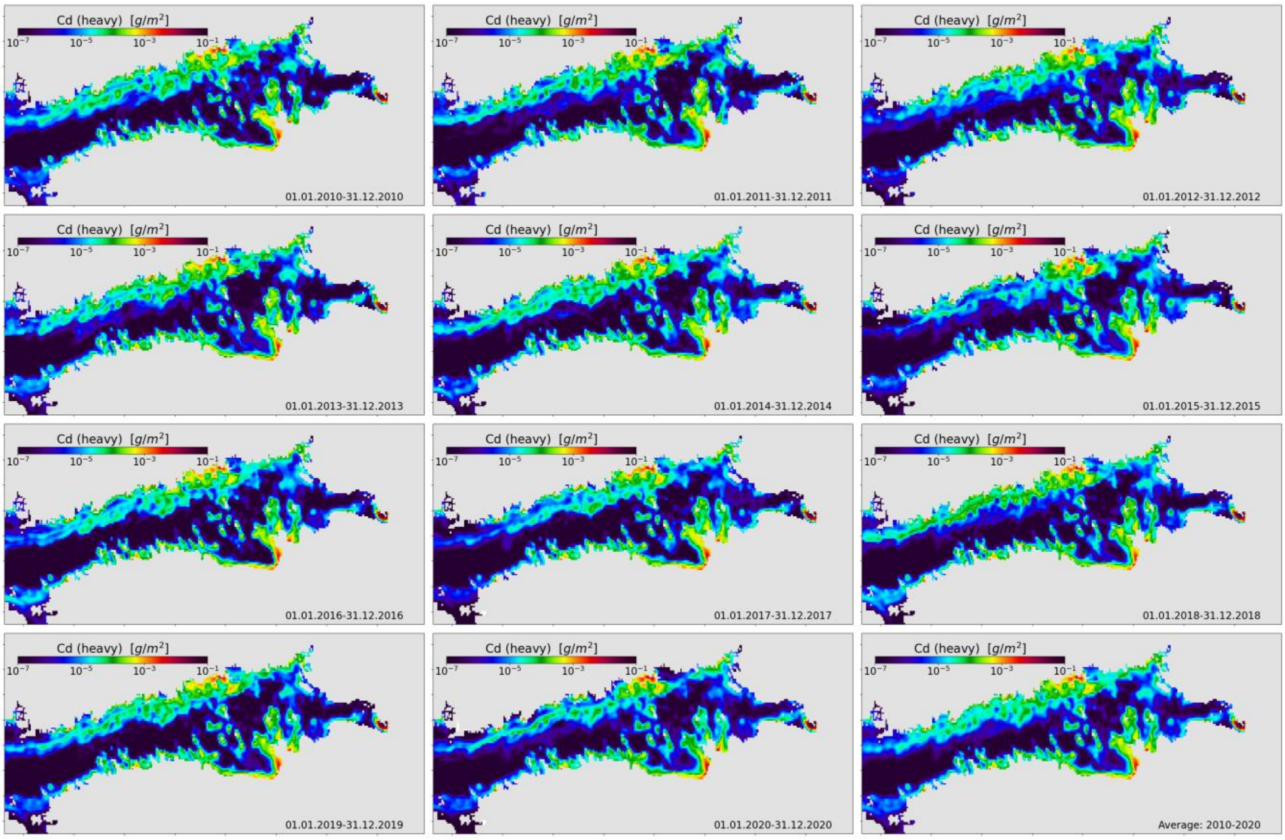

Figure 4: Sedimentation of Cd attached to the heavy particles in the Gulf of Finland during 2010-2020.

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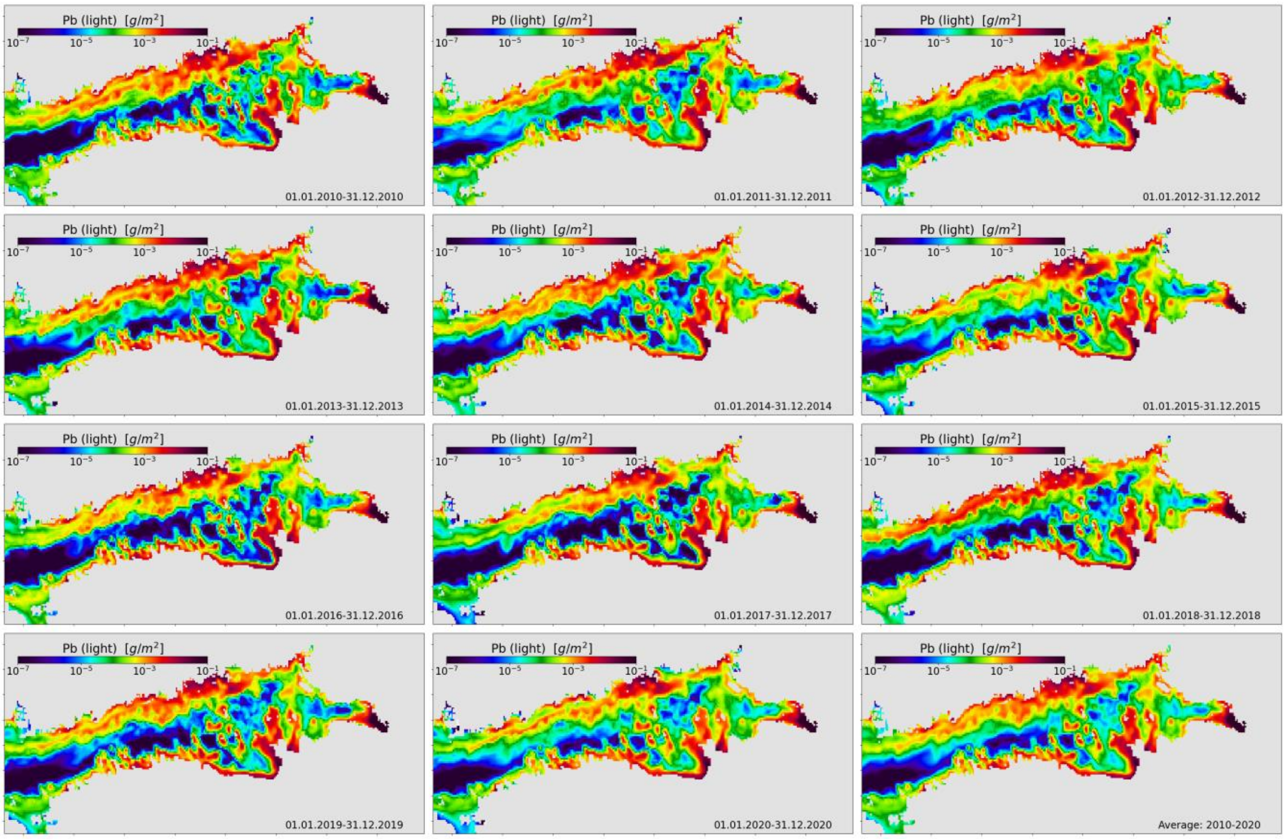

Figure 5: Sedimentation of Pb attached to the light particles in the Gulf of Finland during 2010-2020.

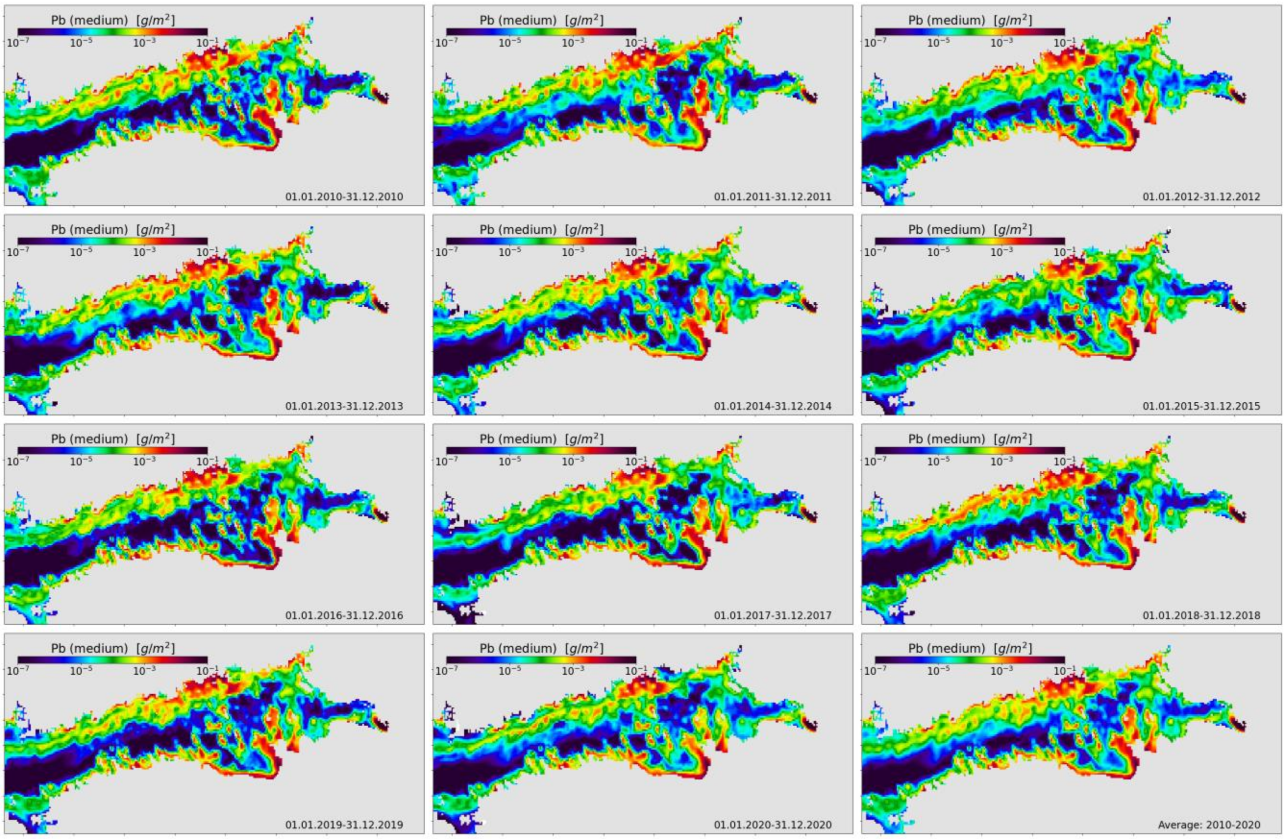

Figure 6: Sedimentation of Pb attached to the medium particles in the Gulf of Finland during 2010-2020.

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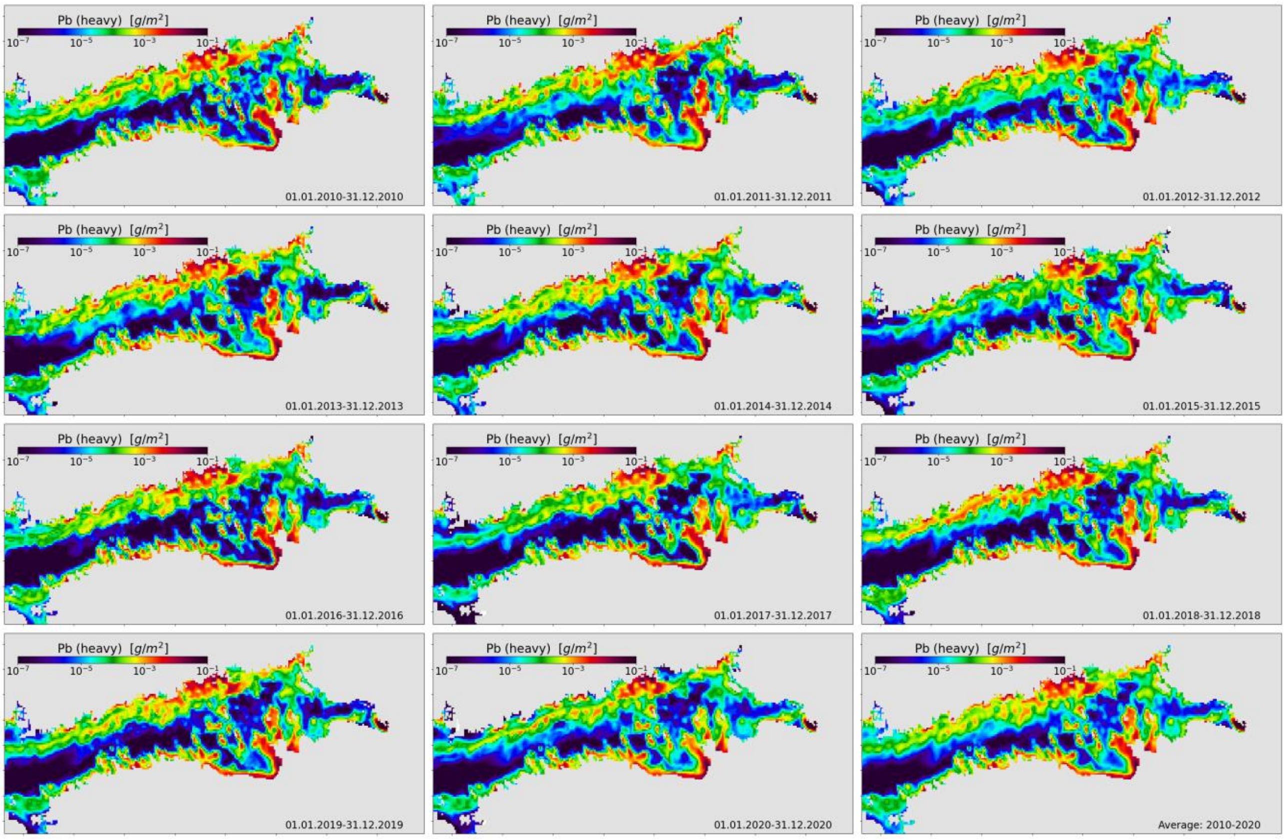

Figure 7: Sedimentation of Pb attached to the heavy particles in the Gulf of Finland during 2010-2020.

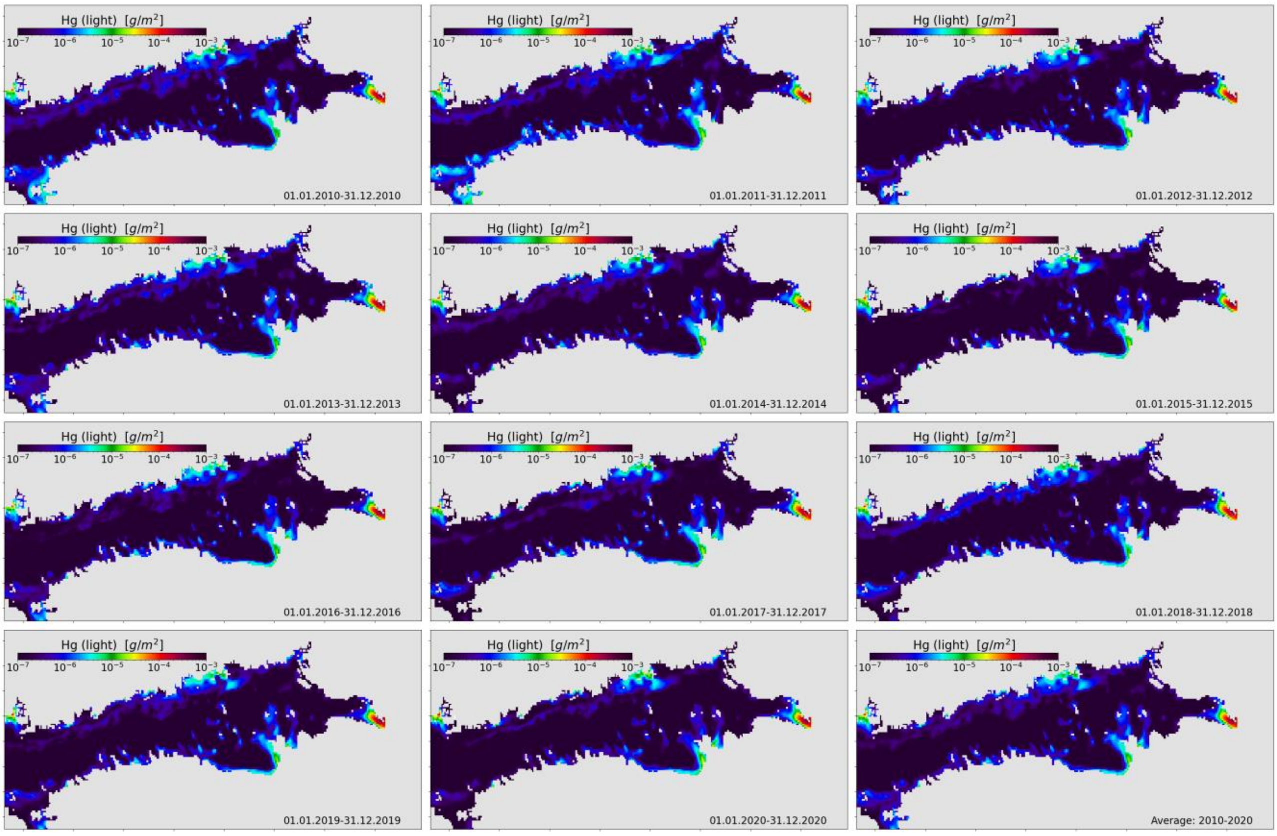

Figure 8: Sedimentation of Hg attached to the light particles in the Gulf of Finland during 2010-2020.

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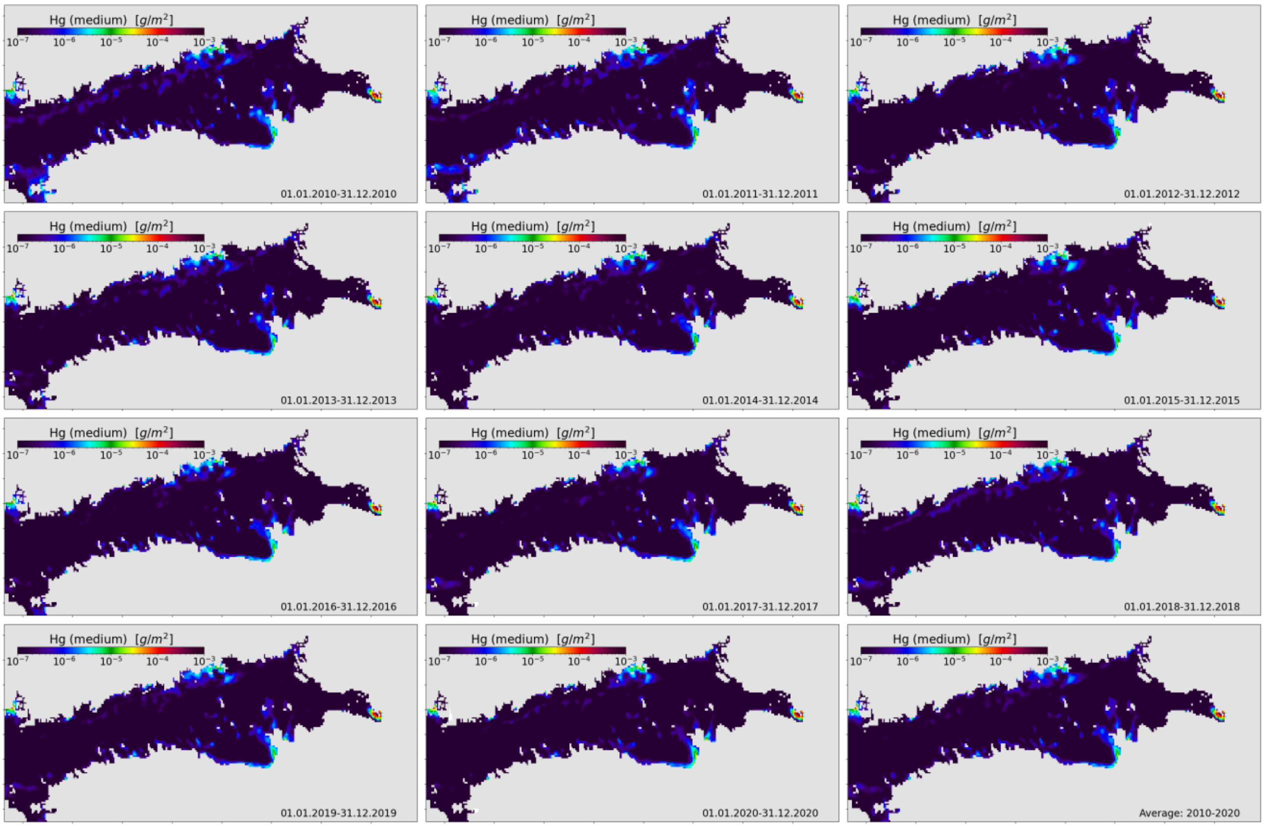

Figure 9: Sedimentation of Hg attached to the medium particles in the Gulf of Finland during 2010-2020.

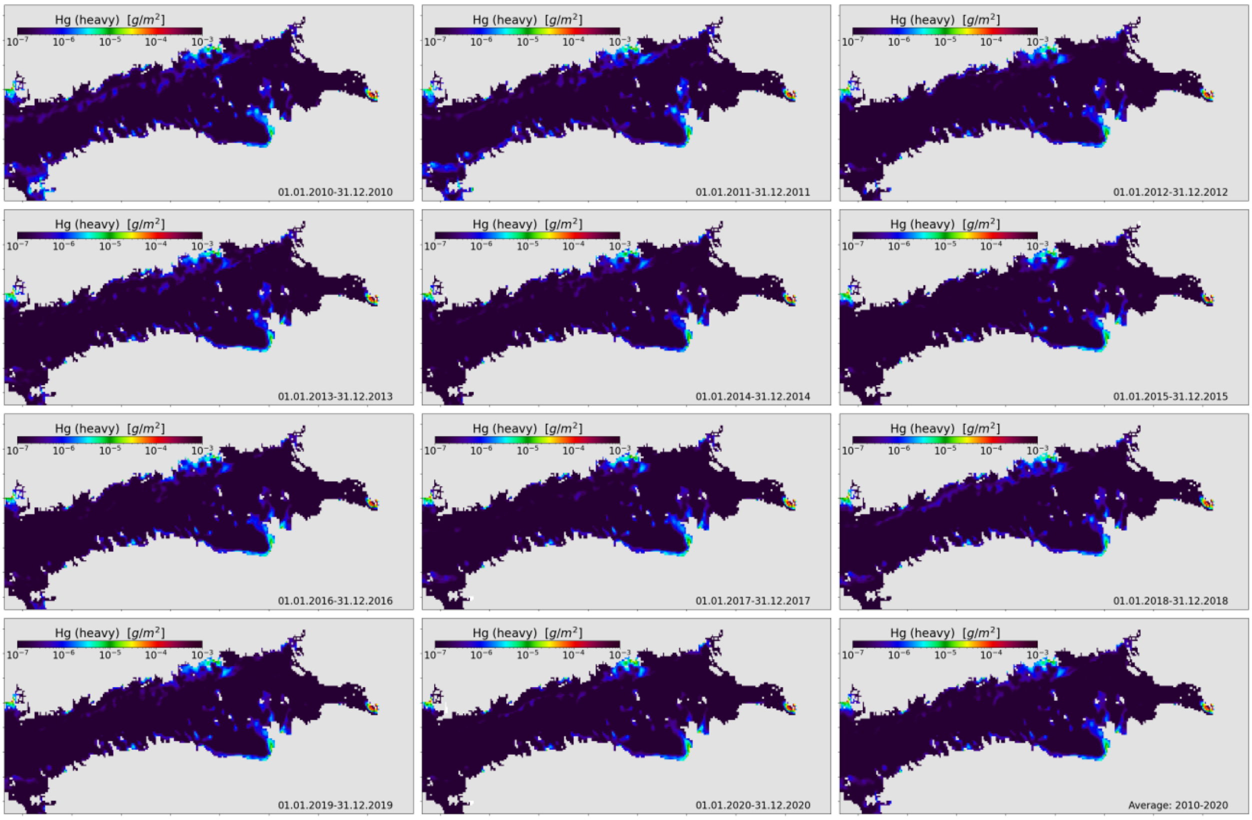

Figure 10: Sedimentation of Hg attached to the heavy particles in the Gulf of Finland during 2010-2020.

The sedimentation load to the Gulf of Finland is summarized on Figure 10.

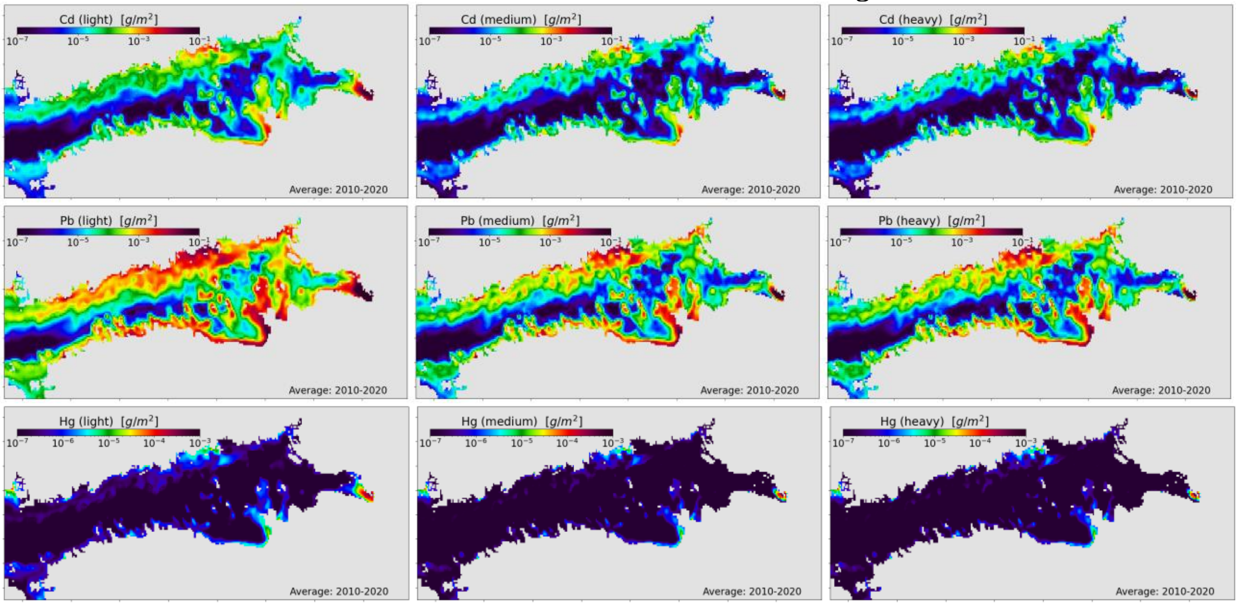

Figure 11: The mean sedimentation load of different heavy metals attached to light, medium or heavy particles to the Gulf of Finland during 2010-2020.

Comparison of modelled and field data

The comparison of simulated patterns of heavy metals with the observations is presented in figures 12 -15. In principle, the patterns match relatively well – the large accumulation of mercury in the Narva bay is captured with the long-term simulation, but the accumulation in the Neva bay is overestimated. Somehow, the largest values of mercury in the easternmost part of the Gulf are measured in the west from Kotlin island, at least 50 km from St. Petersburg.

In the case of cadmium and lead, the largest concentrations in the Neva bay are in the vicinity of St. Petersburg, although relatively large values are also measured more than 100 km from the Neva river. In Narva bay, the model is somehow overestimating the accumulation of the Pb and Cd concentrations, but there is also a lack of measurements to the north of the river along the actual pathway of river waters.

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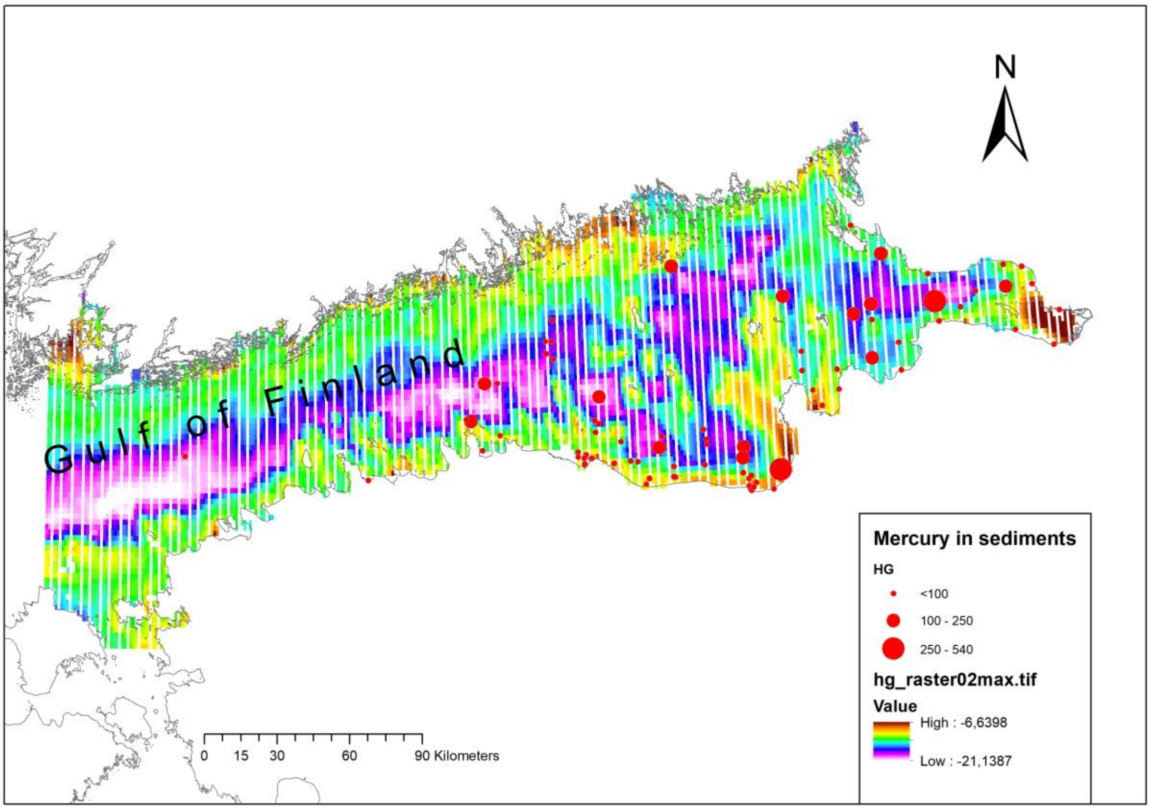

Figure 12: The mean sedimentation load of mercury attached to light, medium or heavy particles to the Gulf of Finland during 2010-2020 versus data from monitoring activities during 2010-2020.

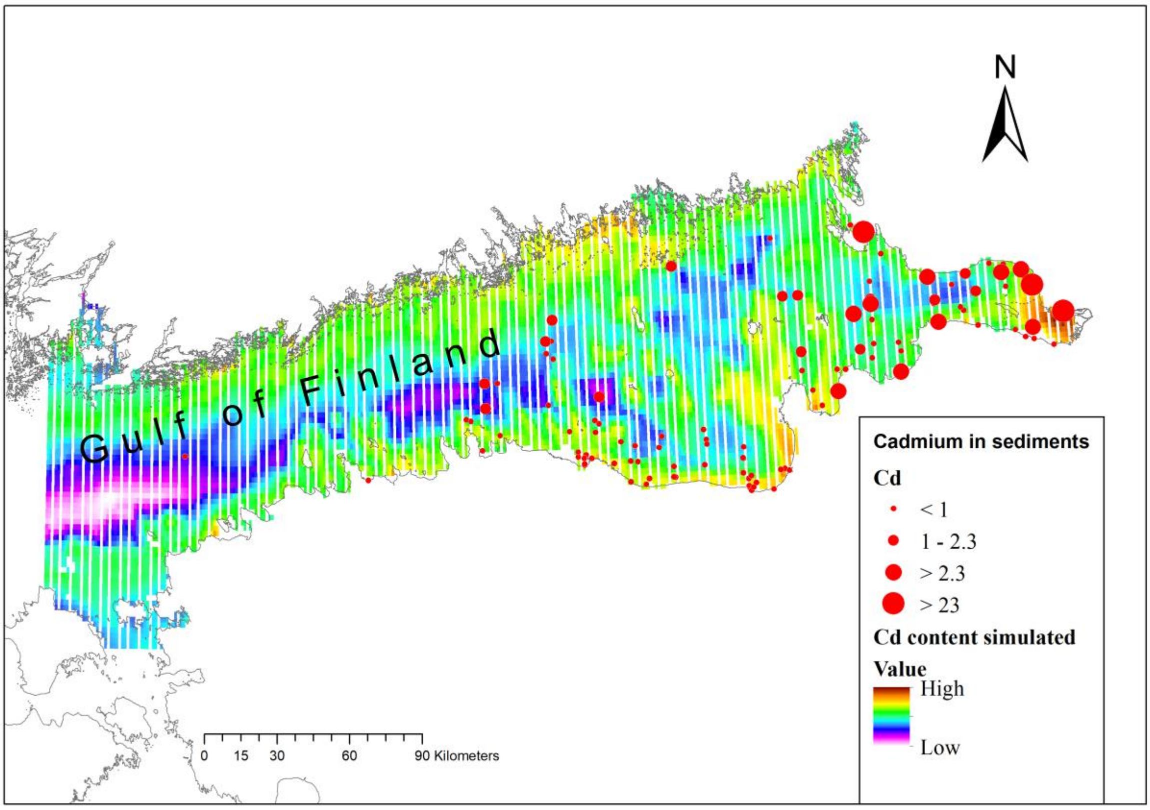

Figure 13: The mean sedimentation load of cadmium attached to light, medium or heavy particles to the Gulf of Finland during 2010-2020 versus data from monitoring activities during 2010-2020.

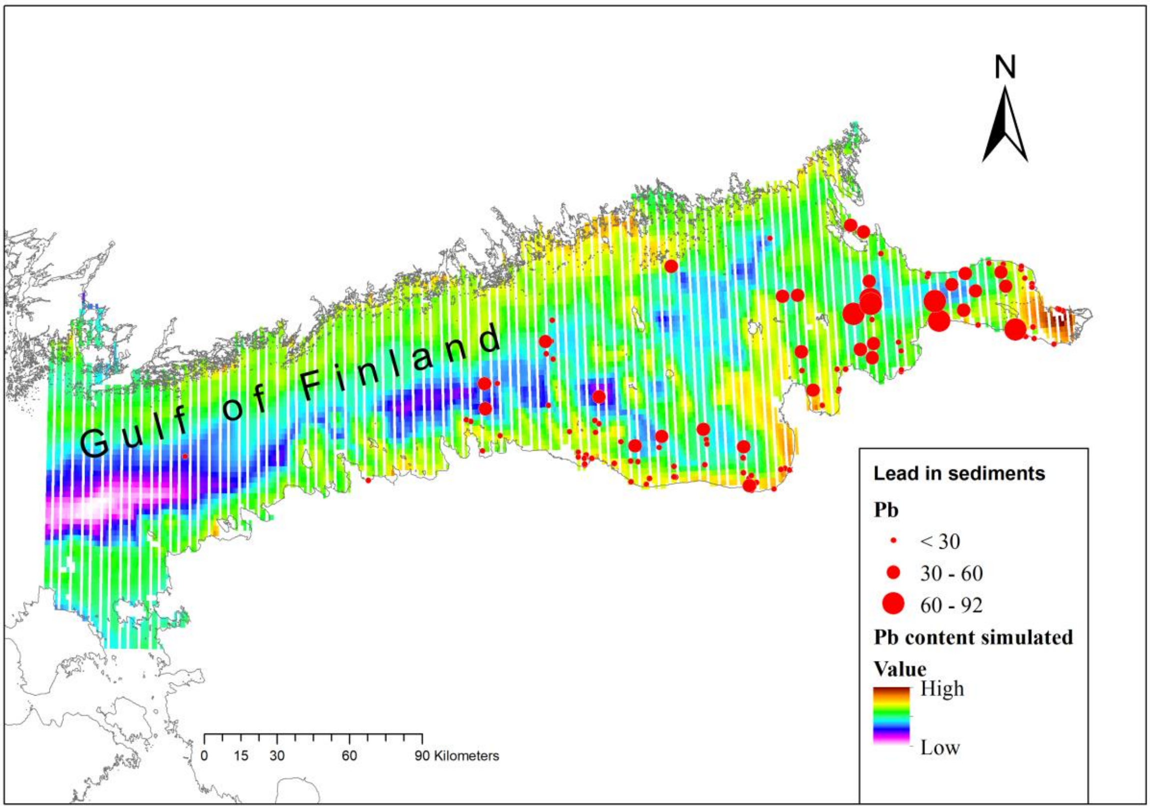

Figure 14: The mean sedimentation load of lead attached to light, medium or heavy particles to the Gulf of Finland during 2010-2020 versus data from monitoring activities during 2010-2020.

Discussion

The figures show that according to the model results, the highest concentrations of contaminants might be found around the sources of pollution (in our case - river estuaries and atmospheric loading), and from time to time during monitoring, the high levels of contaminants found in these areas as well. These are probably the areas where the sediment material that has been settled will remain for a more extended period. The field measurements do not show high concentrations when there is a stronger resuspension, and the sediment is transported further from the sources. The lack of resuspension in the model prevents the further spread, so when the particles get into the water, according to the simulation prerequisites, they remain there. However, different physical-chemical-biological processes should continue in nature and impact the spread and accumulation of chemical contaminants.

It is worth mentioning that according to the field data, the highest concentrations of mercury found in the Neva estuary and Narva bay did not comply with the load volumes, which are registered to be the lowest for the basin. However, probably the stability of this element or large historical loads (before the modelling period) into the environment might influence the distribution and availability of mercury in the study area.

Disclaimer

This publication has been produced with the financial assistance of the European Union. The content of this publication is the sole responsibility of TalTech and can under no circumstances be regarded as reflecting the position of the Programme or the European Union.

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