Vertical distribution of Chernobyl-derived ^{137}Cs in bottom sediments represents a long-term dynamics of water contamination

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Abstract

Today, 33 years after the Chernobyl accident, long-term dynamics of radio-cesium in the environment becomes the most relevant issue. Study of bottom sediments in lakes and reservoirs provide insight in understanding long-term dynamics of radionuclides strongly bound to sediment particles such as 137Cs. With this in mind, in 2018 a number of cores of bottom sediments were collected in the deep parts of Lake Glubokoe, Lake Azbuchin and Cooling Pond in the close vicinity of the Chernobyl NPP and in Schekino reservoir (Upa River) in Tula region of Russia. All these water bodies were contaminated as a result of the accident in 1986. The collected bottom sediment cores were sliced in 2-cm layers, dried and passed through 2-mm sieve, after which analyzed for 137Cs using γ-spectrometry. The obtained 137Cs vertical distributions in sediments accumulation zones of the water bodies suggest that almost no vertical mixing of sediments has occurred, and the 137Cs peaks are well-defined and not diffuse ones. Assuming that sediment accumulation rates after the accident were more or less uniform, layers of bottom sediments can be attributed to certain time of sedimentation. With 137Cs activity concentration in a given layer of bottom sediments corresponding to 137Cs concentration on suspended matter at that point in time, we were able to obtain the dynamics of particulate 137Cs activity concentrations from 1986 to 2018. Using the experimental values of the distribution coefficient Kd, changes in the dissolved 137Cs activity concentrations in the above water bodies have been estimated for the period of 32 years after the accident. The estimates of dissolved 137Cs concentrations seem to be in reasonable agreement with monitoring data. By and large, the general trend of the particulate and dissolved 137Cs and 241Am activity concentrations in all water bodies are consistent with the semi-empirical “diffusional” model. This research was supported by Science and Technology Research Partnership for Sustainable Development (SATREPS), Japan Science and Technology Agency (JST)/Japan International Cooperation Agency (JICA) (JPMJSA 1603) and by bilateral project No. 18-55-50002 of Russian Foundation for Basic Research (RFBR) and Japan Society for the Promotion of Science (JSPS).

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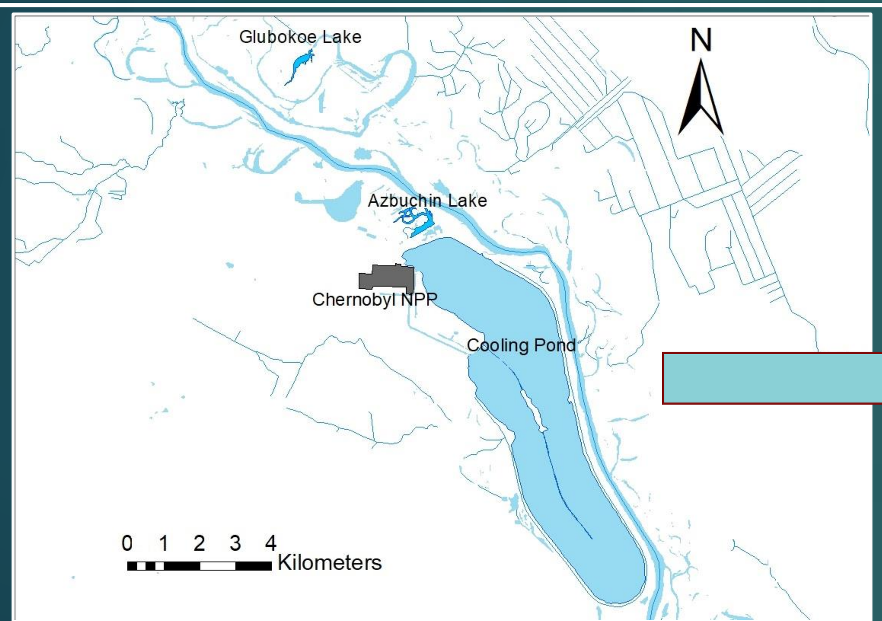
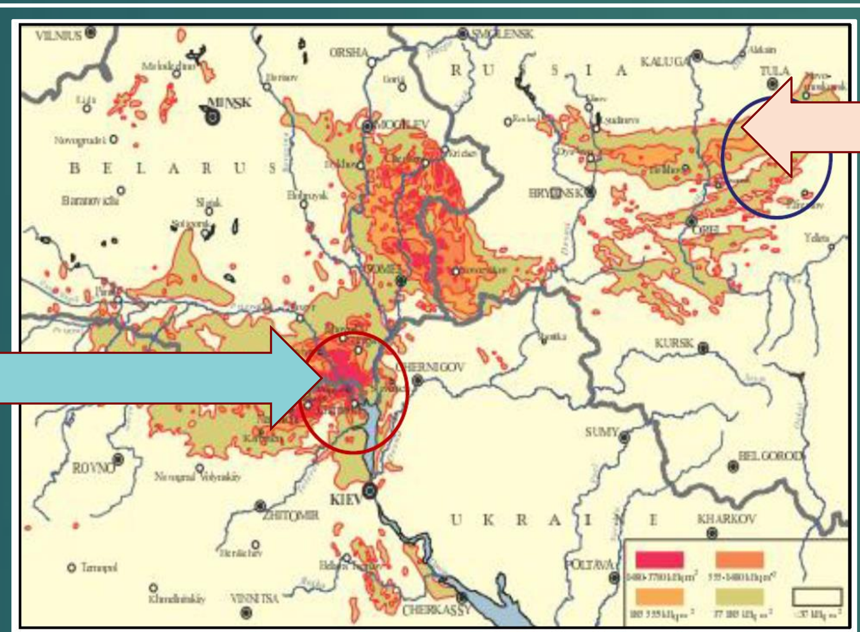
Long-term dynamics of radionuclides in the environment has become particularly relevant today, 33 years after the Chernobyl accident. Bottom sediments of lakes and reservoirs provide insight in understanding time changes of radionuclides strongly bound to sediment particles such as ^{137}Cs. A number of cores of bottom sediments were collected in 2018 in deep parts of **Lake Glubokoe, Lake Azbuchin and Cooling Pond (CP) in close vicinity of the Chernobyl NPP** and in **Schekino reservoir (Upa River) in Tula region of Russia.**

Results

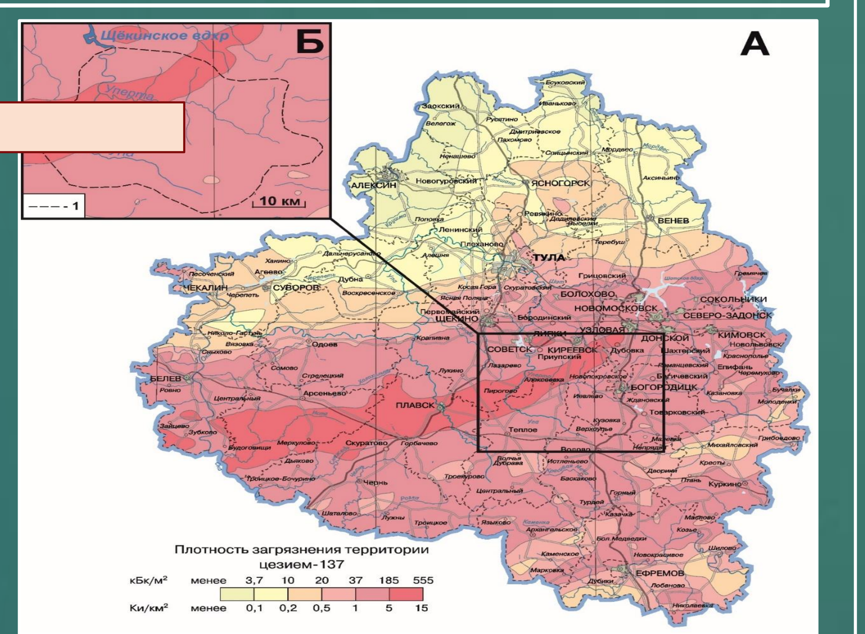
The obtained ^{137}Cs vertical distributions in sediments suggest that no vertical mixing of sediments has occurred, and the ^{137}Cs peaks are well-defined and not diffuse ones. Assuming that sedimentation rates after the accident were more or less uniform, layers of bottom sediments can be attributed to certain time. We obtained the dynamics of particulate ^{137}Cs activity concentrations from 1986 to 2018. Using experimental values of the distribution coefficient K_d, changes in the dissolved ^{137}Cs activity concentrations in the above water bodies have been estimated for the period of 32 years after the accident. The estimates of dissolved ^{137}Cs concentrations are in reasonable agreement with monitoring data. The general trend of the particulate and dissolved ^{137}Cs and ^{241}Am activity concentrations in all water bodies apparently can be described by the semi-empirical "diffusional" model.



Water bodies under study in Chernobyl Exclusion Zone (Ukraine)

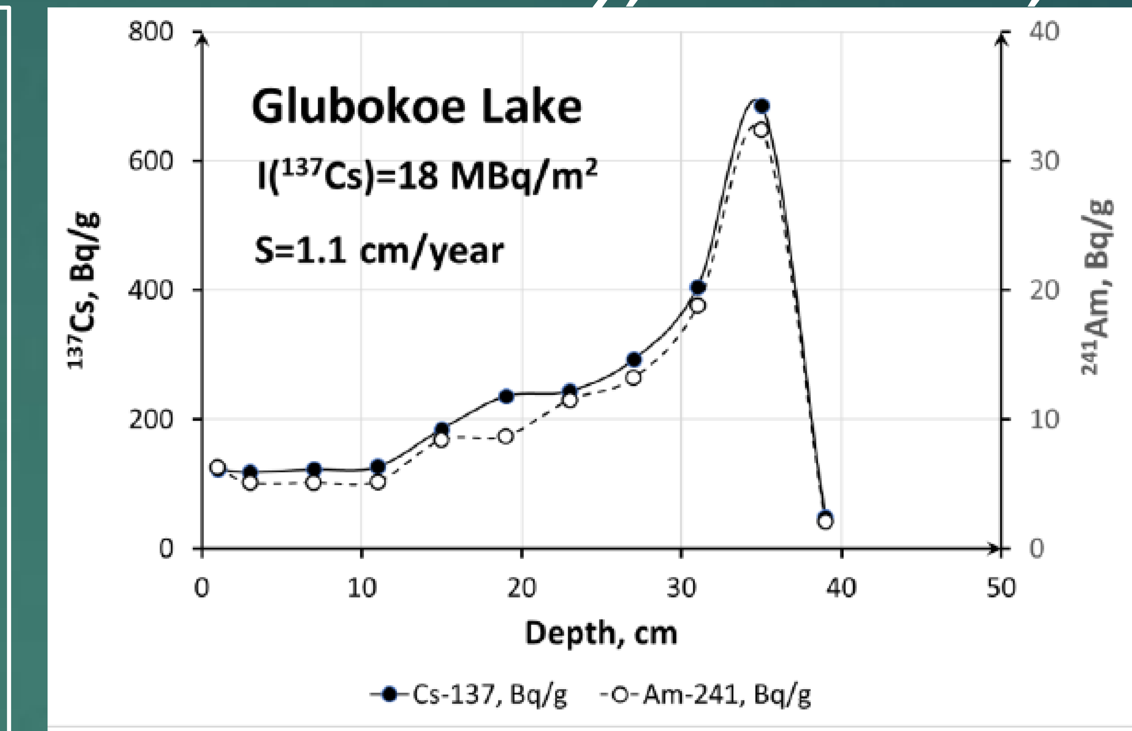


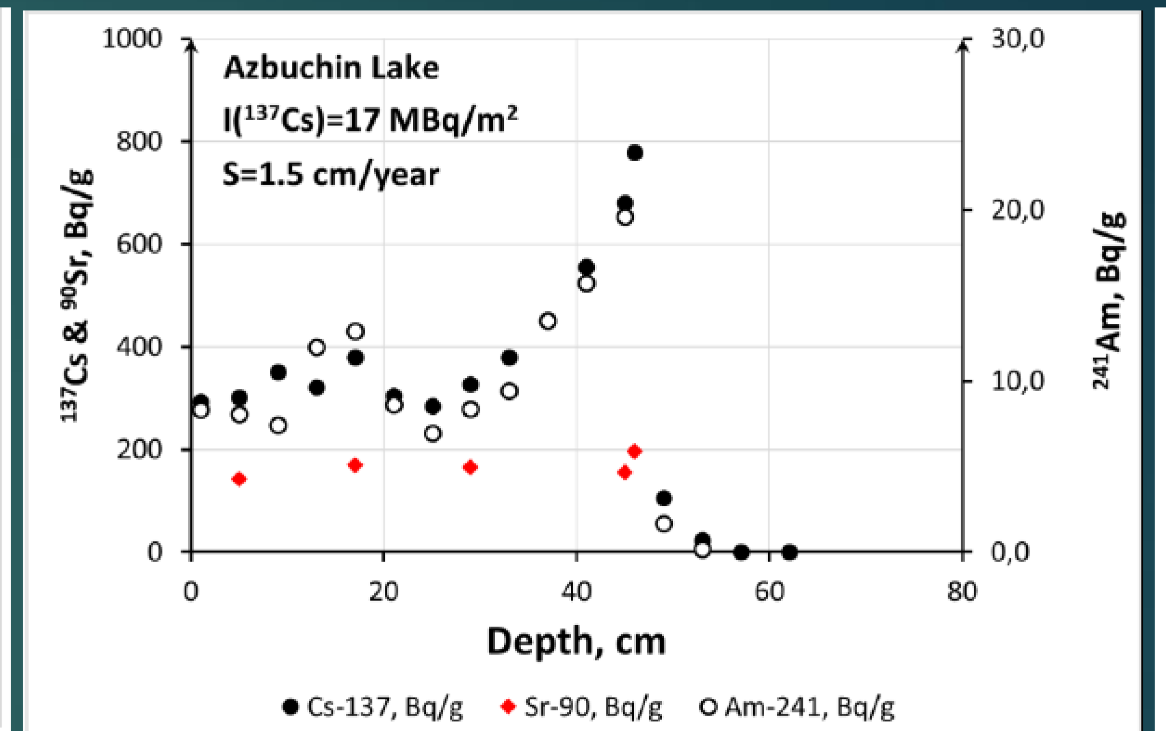
^{137}Cs deposition in Belarus, Russia and Ukraine

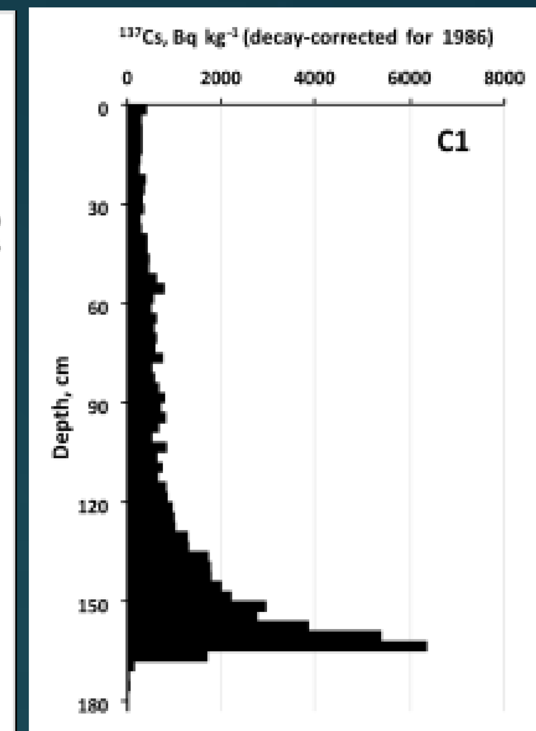


Upa River Catchment in Tula region (Russia)

Bottom sediments core sampling at Glubokoe, Azbuchi lakes, Cooling Pond and Schekino Dam reservoir







Vertical distributions of radionuclides in Glubokoe, Azbuchi lakes and Schekino Dam reservoir

Semiempirical "diffusional" model of radionuclide long-term dynamics in lakes and rivers

- In case of closed lake (Bulgakov et al., 2002):

$$C_p^{bottom}(t) \sim \frac{\sigma}{\rho\sqrt{\pi D_{eff}^{bottom} t}} e^{-\lambda t} = C_b^0 \frac{e^{-\lambda t}}{\sqrt{t}}$$

- In case of surface runoff (Konoplev et al., 2018):

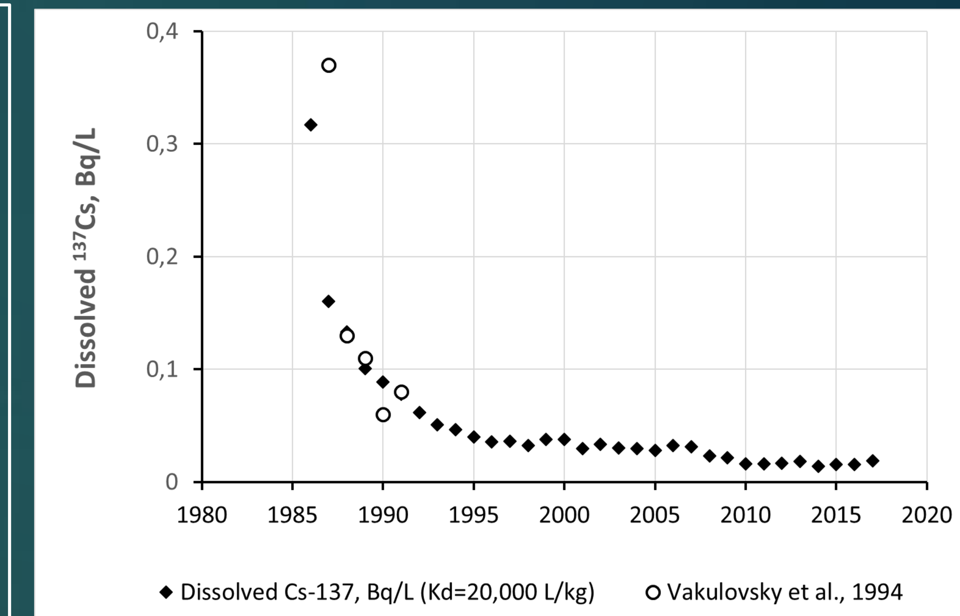
$$C_p^{soil}(t) \sim \frac{\sigma}{\rho\sqrt{\pi D_{eff}^{soil} t}} e^{-\lambda t} = C_s^0 \frac{e^{-\lambda t}}{\sqrt{t}}$$

- In lake for general case:

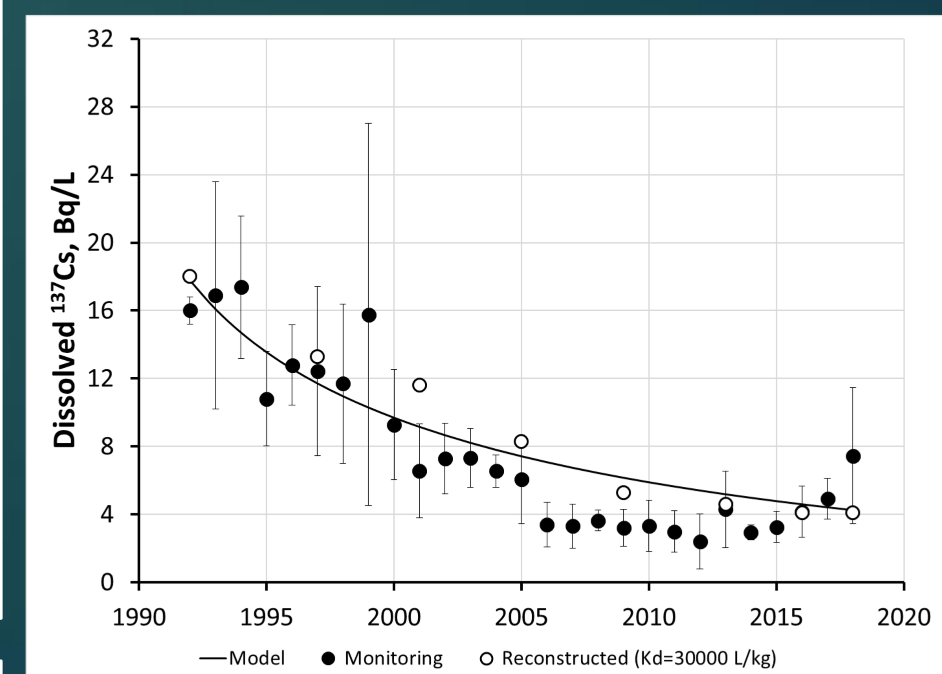
$$C_p^{lake}(t) = \alpha C_p^{bottom}(t) + (1-\alpha) C_p^{soil}(t) = C_p^0 \frac{e^{-\lambda t}}{\sqrt{t}}$$

- Time dependence of dissolved radionuclide in lake should follow equation:

$$C_w(t) \sim \frac{C_p^0}{K_d\sqrt{t}} e^{-\lambda t} = C_w^0 \frac{e^{-\lambda t}}{\sqrt{t}}$$



Reconstructed dissolved ^{137}Cs in Upa River against monitoring data



Reconstructed dynamics of dissolved ^{137}Cs in lake Glubokoe against data of monitoring and diffusional model

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