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Modelling of the seasonal dynamics of the water masses, ice and radionuclide transport in the large Siberian river estuaries

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1 Introduction

The activities of several nuclear reprocessing plants (Siberian Chemical Combine (SCC), Mining, Chemical Combine (MCC) and Mayak Production Association (Mayak)) that are placed on the watersheds of large Siberian rivers Ob' and Yenisey may potentially cause contamination of the Arctic Ocean. Therefore, use of the models is necessary to assess the influence on potential radioactivity spreading location of these sources and impact of global warming on dispersion processes in the system river-estuary.

In frame of EU INCO-COPERNICUS project RADARC (*Johannesen et al.* [2002]) a linked chain of 1D river model RIVTOX and 3D model THREETOX was used to simulate impact of the previous and potential releases from the nuclear installations in the basins of Ob' and Yenisey rivers on the radioactive contamination of the Kara Sea and Arctic Ocean.

2 Model Chain

The model chain includes 1D river net model RIVTOX and 3D estuary model THREETOX. The THREETOX code (*Margvelashvili et al.* [1997] is intended for simulation of the transport and fate of the radionuclides and other contaminants in the stratified waterbodies. THREETOX includes a set of submodels: a hydrodynamics submodel, ice dynamics-thermodynamics submodel, suspended sediment transport and radionuclide transport submodels. The hydrodynamics is simulated on the basis of the three-dimensional, time-dependent, free surface, primitive equation model. The modified $k-\varepsilon$ model (*Burchard and Pettersen* [1999]) is used. The dynamic-thermodynamic ice and snow model is based on the Hamburg Sea-Ice Model (*Stössel and Owens* [1992] that was modified by implementation of elastic-viscous-plastic rheology. Suspended sediment transport is described by the advection-diffusion equations, taking into account fall velocities of the sediment grains. The bottom boundary condition describes sediment resuspension or settling down depending on the ratio between the equilibrium and actual near bottom suspended sediment concentration. The thickness of the upper layer of the bottom deposition is governed by the equation of the bottom deformation. The equations of the radionuclide transport describe the concentration of the radionuclide in solute, the concentration in the suspended sediments and the concentration in the bottom deposition. The exchanges between these forms have been described as adsorption-desorption and sedimentation-resuspension processes. Adsorption and desorption of radionuclide between liquid and solid phases are described by the radionuclide exchange rates, and by the distribution coefficients.

The one-dimensional river model RIVTOX was developed at the IPMMS (*Zheleznyak et al*. 1992). It simulates the radionuclide and chemical pollution transport in networks of river channels. Sources can be a direct release into the river or the runoff from the catchment.The hydraulics part of the RIVTOX is based on the of Saint-Venant equations. The governing equations of the sub-model of suspended sediment and radionuclide transport model are derived from the 3-d model equations. They describe advection-diffusion transport of the cross-sectional averaged concentrations of suspended sediments, toxins in solution, toxins in suspended sediments and in bottom depositions. The adsorption-desorption and diffusion contamination transfer in the systems "solution - suspended sediments" and "solution - bottom deposition" are treated also via the distribution coefficient approach.

3 Study area

The 1D model RIVTOX of river dynamics and radionuclide transport was adapted to the Ob' river path from Mayak and SCC and to the Yenisey River from MCC (see Figure 1). The river network was subdivided into a set of branches in compliance with the location of observation points and the main tributaries. The parameters of water cross-sections for observation points were used. The monthly tributary discharges values for 1949-1995 were used to simulate river hydraulics. The data on release from the radionuclide sources were collected in frame of RADARC project (*Johannessen et al.* [2002]). The THREETOX was customised for the Ob' and Yenisey estuaries using digitised navigational maps of estuaries. The horizontal grid resolution is 8x6 km in the Ob' and 3 km in the Yenisey. The 6hr fields of wind, air temperature, precipitation, humidity and cloudiness were used from NCEP reanalysis for the period 1949-1995. Daily mean discharges of rivers, suspended sediment and radionuclide concentrations were calculated by the RIVTOX model. In the estuary mouth, the temperature, salinity and velocity distributions and sea level computed by the Kara Sea model (*Johannessen et al*. [2002]) were used in the estuary model as outer boundary conditions. The simulations of the period 1949-1994 were carried out for the Ob' and period 1974-1994 for the Yenisey.

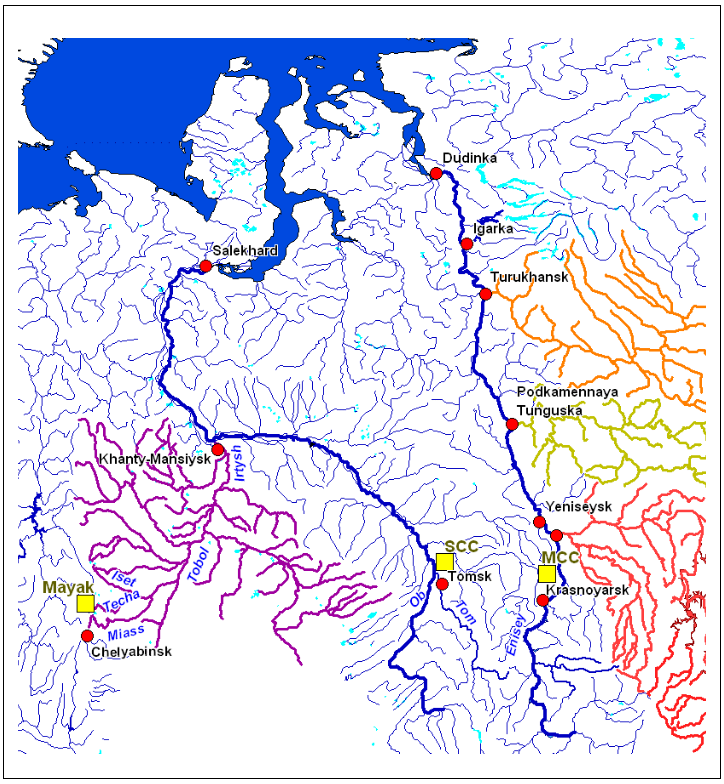

Figure 1: Ob' and Yenisey river system. The boxes correspond to the Mayak Production Association (Mayak), Siberian Chemical Combine (SCC) and Mining, Chemical Combine (MCC).

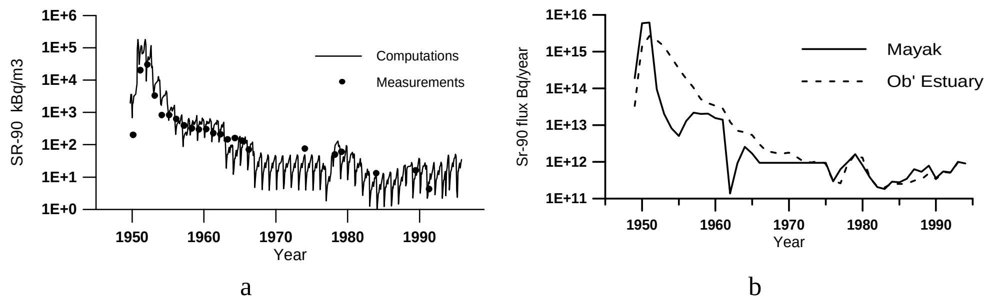

Figure 2: The computed and observed concentration of ^{90}Sr in the Musliumovo (Techa River) (a) and measured yearly mean release of ^{90}Sr from Mayak vs. computed flux from Ob' estuary to the Kara Sea.

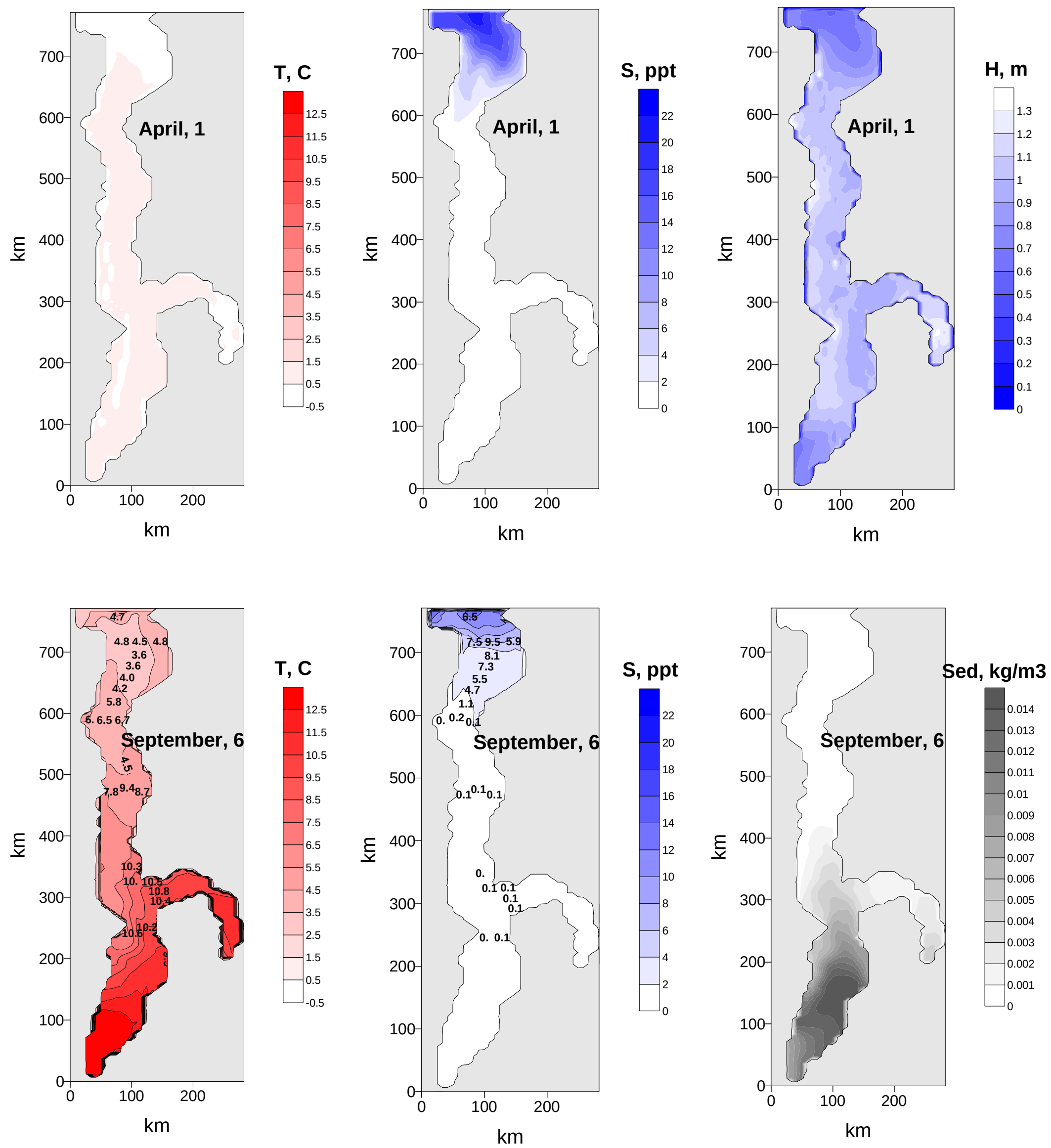

Figure 3: The computed surface fields of temperature, salinity and ice thickness in the Ob' Estuary in April 1994 and surface fields of temperature, salinity and near bottom distribution of suspended sediments in September 1994. The temperature and salinity are compared with KAREX-94 data.

3 Results and conclusions

The model chain was validated against the available data on river discharge, suspended sediment and radionuclide concentration, temperature, salinity and ice distribution in the estuaries. In Figure 2 the contribution of Mayak in ^{90}Sr contamination of the Ob' river system and the Kara Sea is presented. In Figure 2a the calculations are compared with ^{90}Sr measurements in Musliumovo (Techa River). As seen from figure the RIVTOX model reproduces transport of radionuclide quite well. In Figure 2b the fluxes of ^{90}Sr from Mayak and Ob' estuary mouth to the Kara Sea are given. This figure shows that after strong initial contamination in early 50th the sediments in the Ob' were sources for secondary contamination of river and estuary. Around 70% released in 1949-1994 ^{90}Sr reached the estuary mouth. The Yenisey River was contaminated the same way in 70th in result of washing up of contaminated sediments from the islands and flood plains. The numerical results agree quite well with the observations of the oceanographic fields. In Figure 3 the surface fields of temperature, salinity and ice thickness in the Ob' Estuary in April 1994 and surface fields of temperature, salinity and near bottom distribution of suspended sediments in September 1994 are presented. The computed temperature and salinity agree with the survey data from KAREX-94. The computed in other run the salt wedge in the relatively deep Yenisey Estuary is clearly visible.

The results of multi-year simulation of the water dynamics and radionuclide transport in the Ob' and Yenisey rivers and estuaries showed ability of the developed model chain to reproduce a seasonal dynamics of water mass. An important role of ice cover in the seasonal dynamics of the Ob' and Yenisey estuaries also was demonstrated. The developed model chain is used for assessment of the radionuclide spreading from inland sources.

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