Overview of IMMSP team's research activities

Ivan Kovalets, Igor Brovchenko, Roman Bezhenar

IMMSP and Environmental Modeling

Institute of Mathematical Machines and Systems Problems (IMMSP) National Academy of Sciences of Ukraine:

- formerly part of Institute of Cybernetics as Design Bureau where IC's systems where implemented
- separated in 1992

IC1986:

7000 staff members,

Hardware, algorithmic and software development for Soviet military and industrial applications

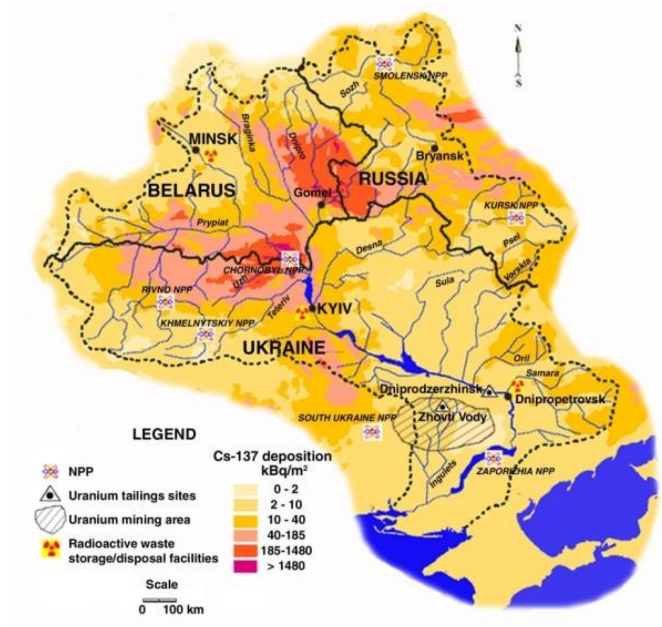
Prof, Victor Glushkov has headed former Lebedev's Lab in 1958, than transformed into the **Institute of Cybernetics (IC)** of Academy of Sciences

Control Center of Soviet Space Programme, Developed by IMMSP

Operational headquarters for forecasting of radionuclide water contamination following Chernobyl accident – predecessor of todays Division of Environmental Modeling

Division of Environmental Modelling (DEM) - IMMSP

has been established in May, 1986, following Chornobyl Accident.



First team lead – Dr Mark Zheleznyak, since Nov 2013 – Professor of Institute of Environmental Radioactivity Fukushima University

Present Head: Dr. Igor Brovchenko, Corresponding Member of NASU

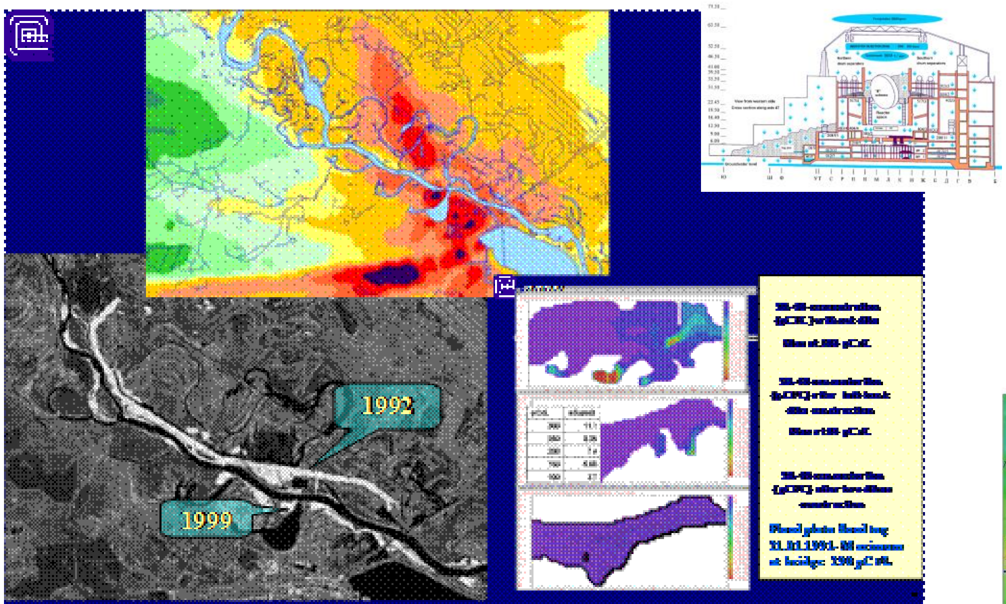
Research provided by **two** Departments headed by

Dr. Ivan Kovalets (*Dep. of Environmental Informatics and Atmospheric Modeling*),

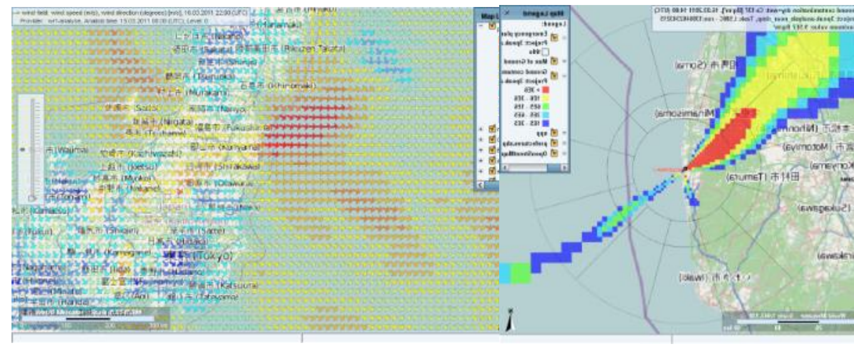
Prof. **Vladimir Maderich** (*Dep. of Marine and River Systems Modeling*)

as also by the spinoff company of IMMSP- Ukrainian Center of Environmental and Water Projects (**UCEWP**) www.ucewp.kiev.ua

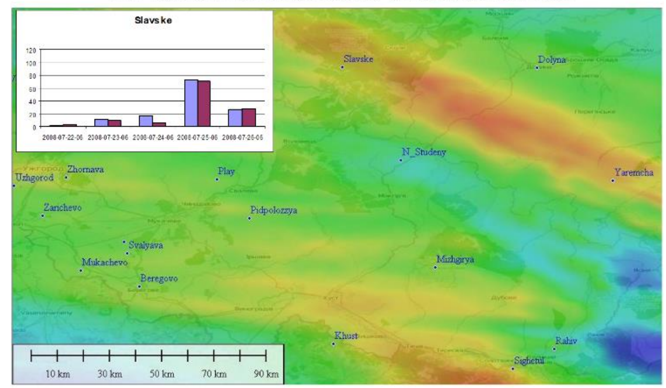
Research fields and some applications



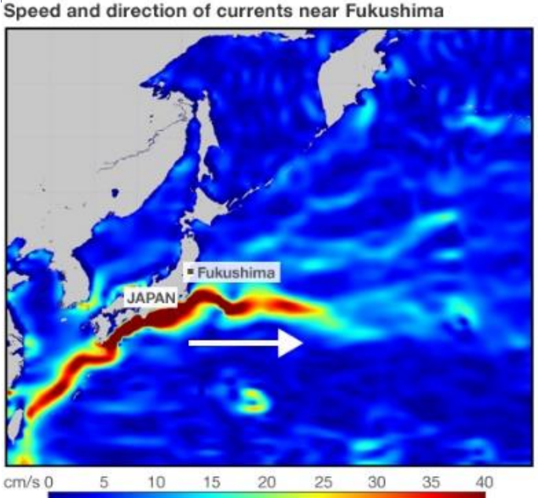
Pripyat River upstream Chernobyl NPP – flood protection dikes constructed after the monitoring & modeling justifications



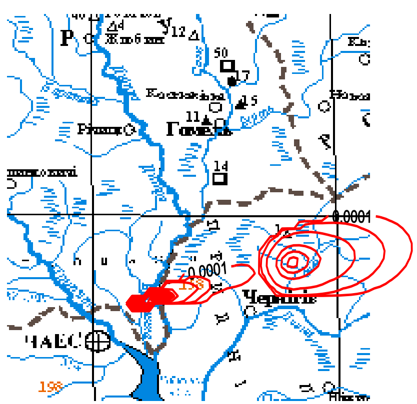
WRF-simulated extreme precipitation during flood of July, 2008



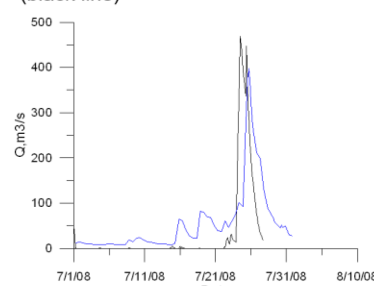
Speed and direction of currents near Fukushima



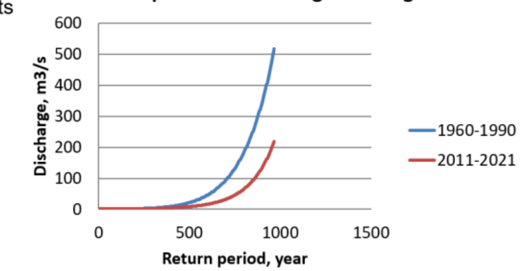
Source: R.BINGHAM ET AL



Forecasted with DHSVM-Ukraine water discharge in Uzhgorod (flood of July, 2008) as compared with measurements (black line)

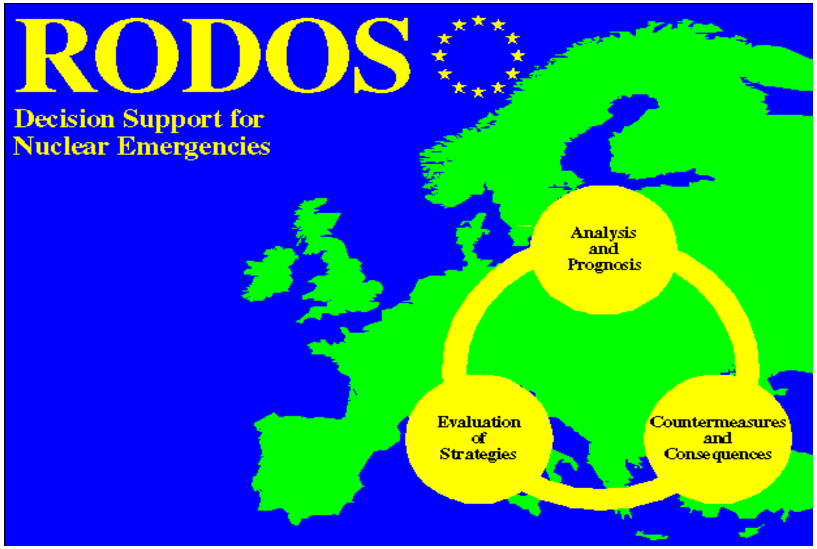


Return periods of discharges in Uzhgorod



Involvement of DEM in the development of the EU nuclear emergency response system RODOS (since 1994)

- Lead on the development of Hydrological Dispersion Module (HDM):
  1D river transport model RIVTOX, 2D transport model COASTOX, 3D transport model THREETOX
- Participation in the development of Atmospheric Dispersion Module (ADM): data assimilation and inverse source term estimation
- Co-developer of the software kernel of RODOS system
- Responsible for RODOS implementation in Ukraine



Key Recent and ongoing research projects

(2021-2023) Direct and inverse problems of pollution distribution in the atmospheric and marine environment and their use to identify sources of pollution (National Research Fund of Ukraine – project to support young and experienced researchers)

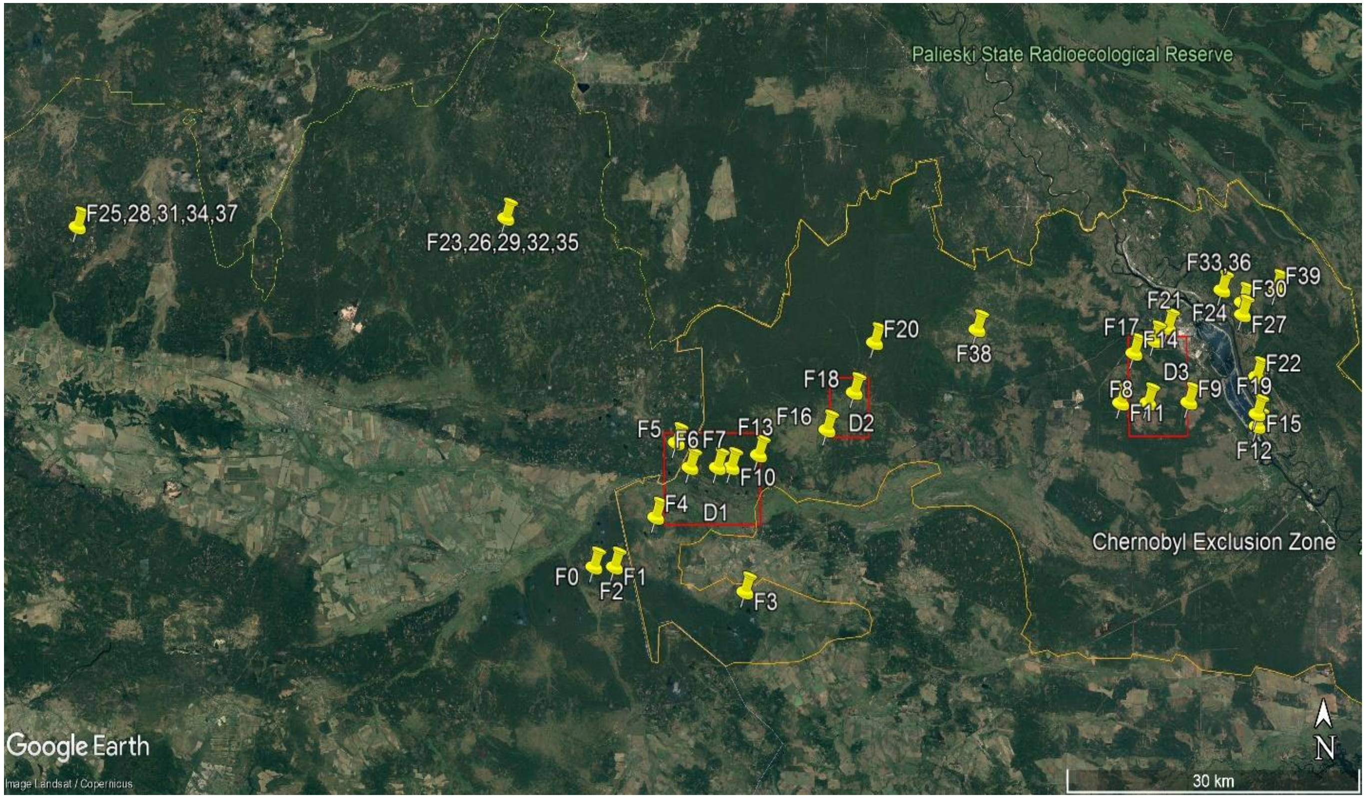
(Present) PolarRES – Polar regions in Earth System (Horizon 2020)

Collaboration with Korean Institute of Ocean Science and Technology in a project funded by the Ministry of Oceans and Fisheries, Development of a global marine radioactive contamination effect prediction system

Collaboration with Odesa State Ecological University on the Development of Automated system of forecasting of oceanographic parameters in the Urainian part of the Black Sea (responsibility on meteorological forecasting subsystem)

The most powerful in history wildfires in Chernobyl Exclusion Zone (ChEZ)

3-20 April, 2020, covered 30,000 ha in ChEZ , including the most contaminated parts of ChEZ like “Red Forest”



On 16-17 April wildfires were accompanied by **dust storm that covered Northern Ukraine**

- the first dust storm in this region in a few last decades according to State Emergency Service of Ukraine

The dust storm on 16 April 2020
Image source:
https://www.pravda.com.ua/news/2020/04/17/7248378/

Combined inverse modeling of wildfires and dust storm

- to evaluate emission inventories during wildfires in ChEZ together with their confidence limits

- to evaluate of contribution of the dust storm in radioactive air pollution during this event

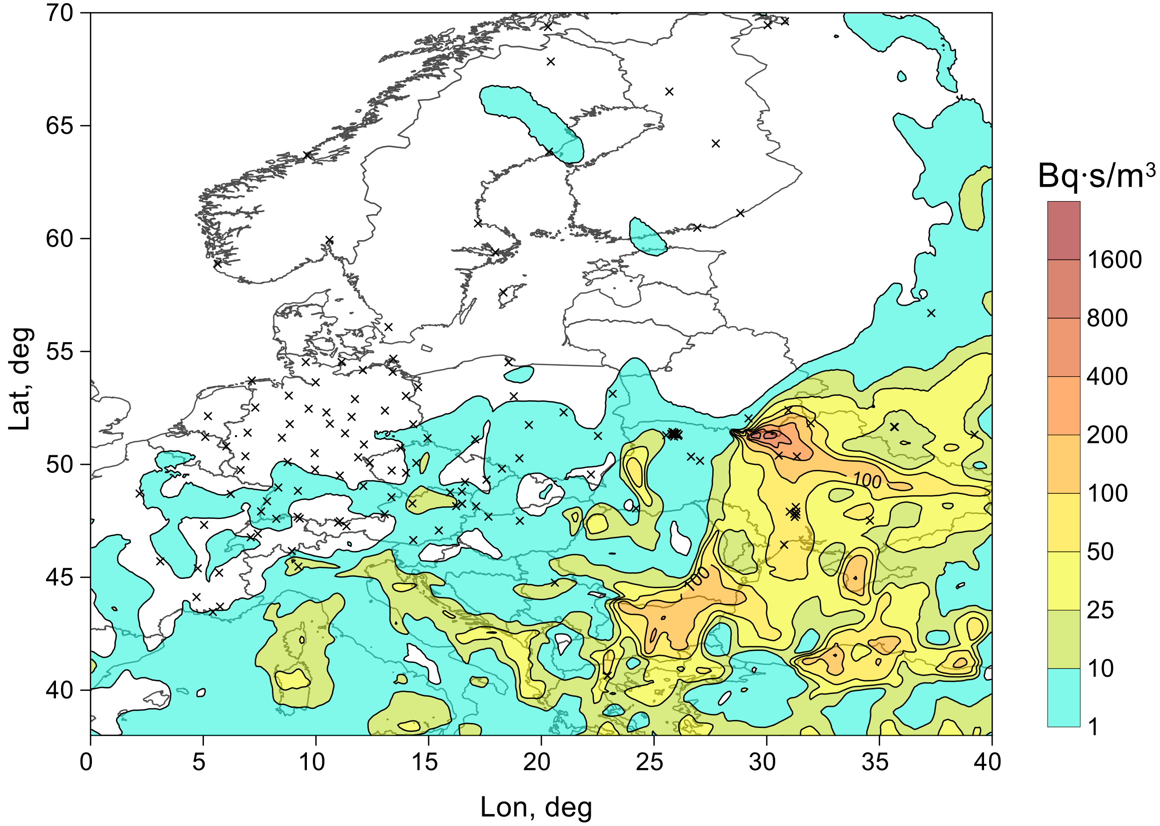
Kovalets et al. (2020)
Atmos. Env., doi: 10.1016/j.atmosenv.2022.119305

Ensemble Source Inversion Method, input data:

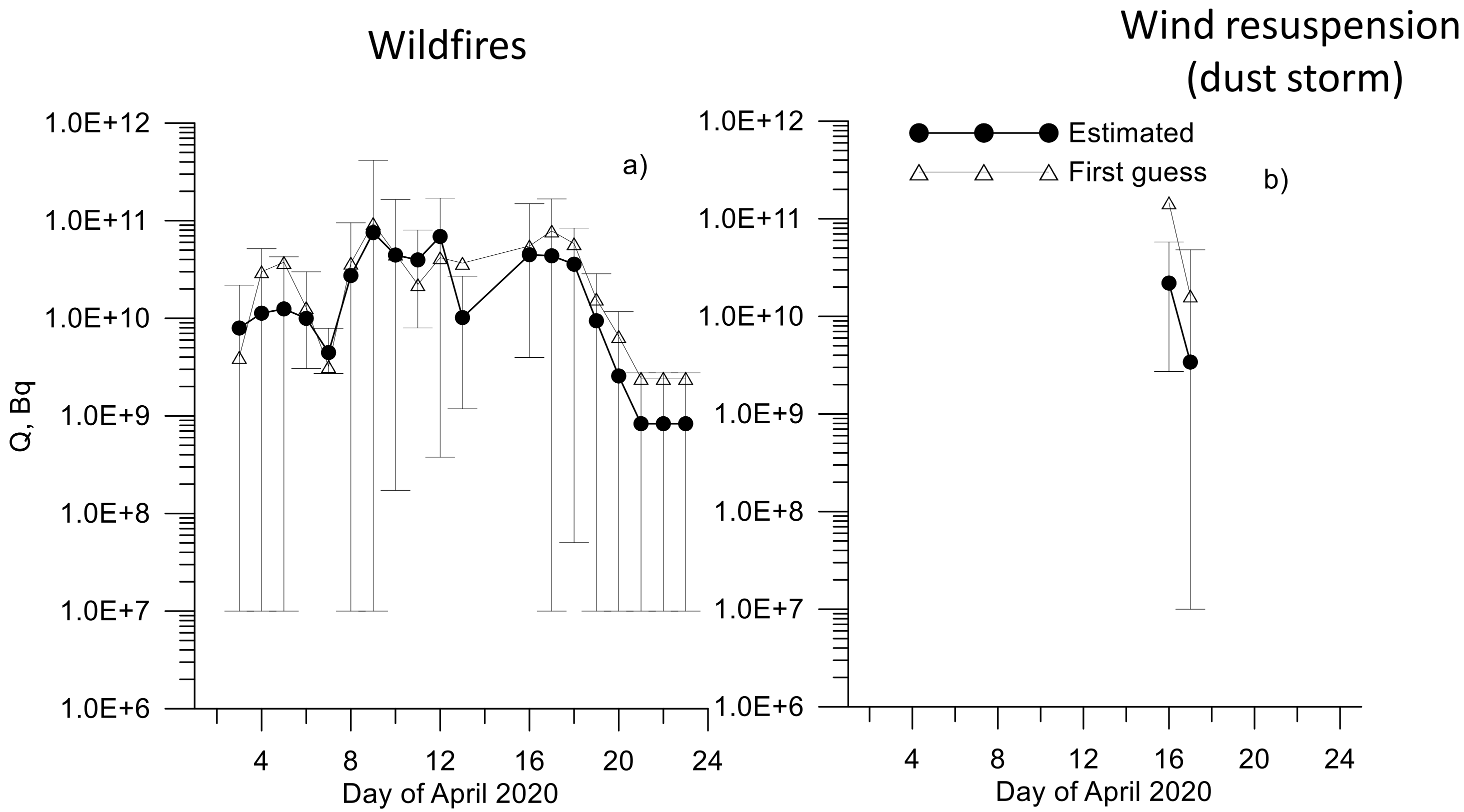
- Meteorological fields – 22 realizations in GEFS forecasts by NCEP were input to FLEXPART Lagrangian transport model
- varying *fraction emitted between 0 and* z_{bot}
- varying *fraction emitted between* z_{bot} *and* z_{top}
- Varying *fractions of the size 1, 8 and 16 µm*

In total – 792 ensemble members

Measurement stations used for inverse modeling and time integrated concentration of Cs-137 for the whole simulation period (3-27.04.2020)



Estimated emissions



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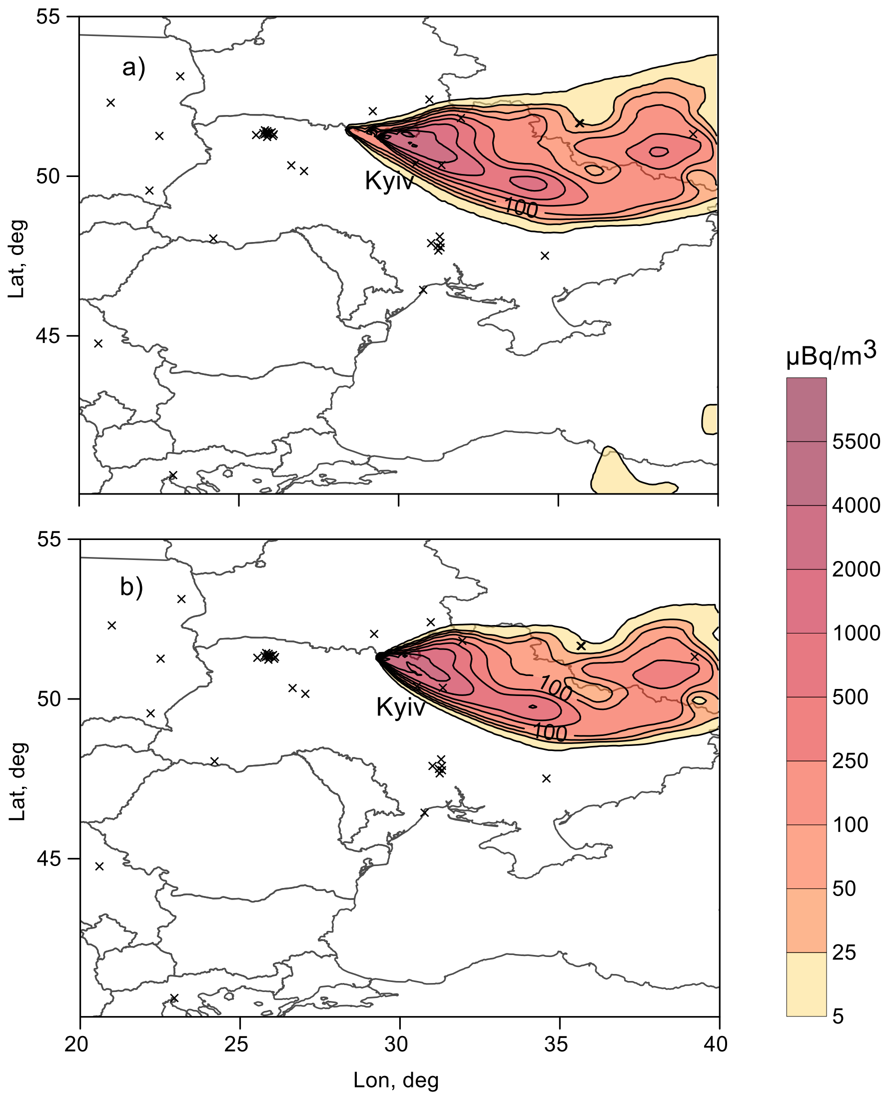
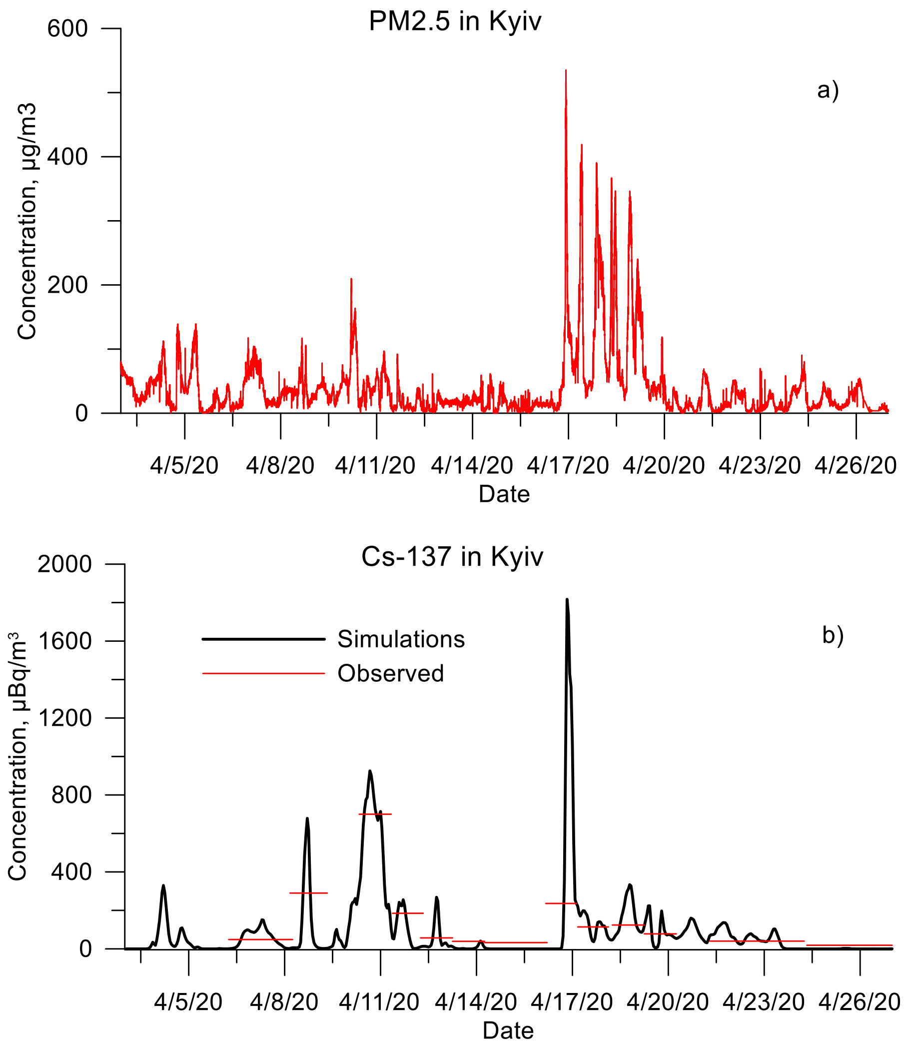


The simulated ground-level distribution of concentration of ^{137}Cs averaged for the 24 hr period (16.04.2022, 06 UTC -17.04.2022, 06 UTC);

a) concentration created by all sources;

b) concentration created only by wind resuspension during the dust storm;

Isolines: 1, 25, 50, 100, 250, 500, 1500, 2500 $\mu Bq \cdot m^{-3}$.



a) Time series of PM2.5 concentrations in Kyiv according to measurement data from www.saveecobot.com;

b) time series of observed (Masson et al., 2021) and simulated concentrations of ^{137}Cs in Kyiv.

In summary:

- Ensemble iterative source inversion method (EISIM) was developed to properly take into account uncertainties in input data and model parameters in process of source term estimation
- About 500 (up to 1300) GBq came from wildfires
- About 25 (up to 100) GBq came from dust storm
- Re-emission of contaminated ash by dust storm, happening along with wildfire is a kind of ‘compound extreme’

3D modeling of heat transfer processes

THREETOX is the 3-dimensional model of thermo-hydrodynamics developed in IMMSP. It includes

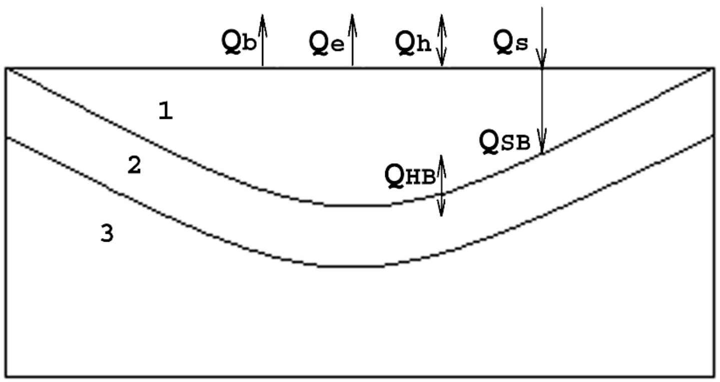
•Reynolds-averaged equations in Boussinesq and hydrostatic approximations

•k-ε turbulence model

•Heat and salt transfer equations

•Improved formulas for heat exchange between air, water and bottom

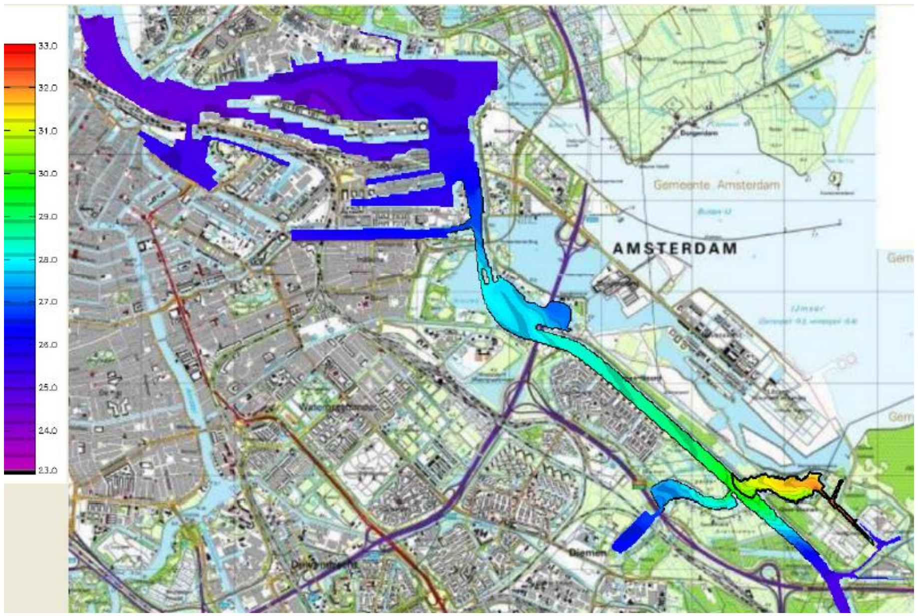
Heat exchange with atmosphere and bottom



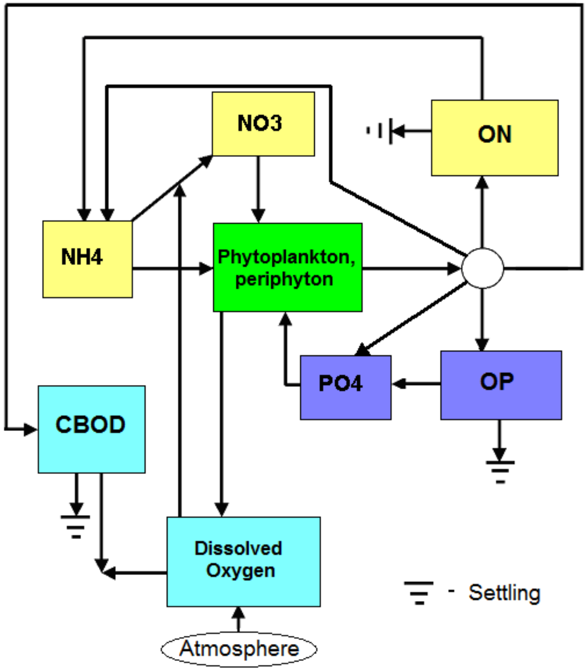
1 - water layer

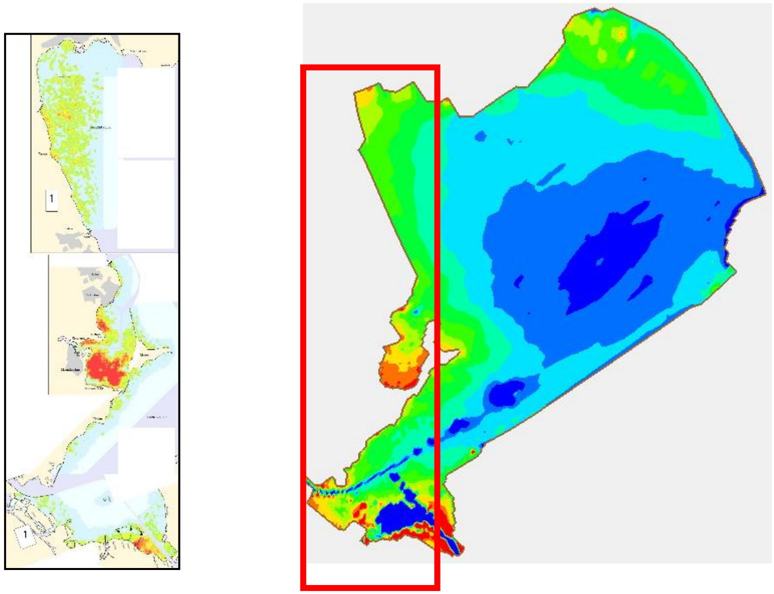
2 – active bottom layer

3 – deep bottom layer (T = const)



Water quality components in the THREETOX model





Calculated concentration of periphyton vs measured for lake Markermeer (Netherlands)

3D transport and chemical transformations

$$\frac{\partial C_i}{\partial t}+U\frac{\partial C_i}{\partial x}+V\frac{\partial C_i}{\partial y}+\left(W-W_{gi}\right)\frac{\partial C_i}{\partial z}=\frac{\partial}{\partial z}\left(\nu_t'\frac{\partial C_i}{\partial z}\right)+\frac{\partial}{\partial x}\left(A_h\frac{\partial C_i}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_h\frac{\partial C_i}{\partial y}\right)+S_i$$

chemical transformations

Only growth-death processes for periphyton

$$\frac{\partial C_P}{\partial t}=S_P$$

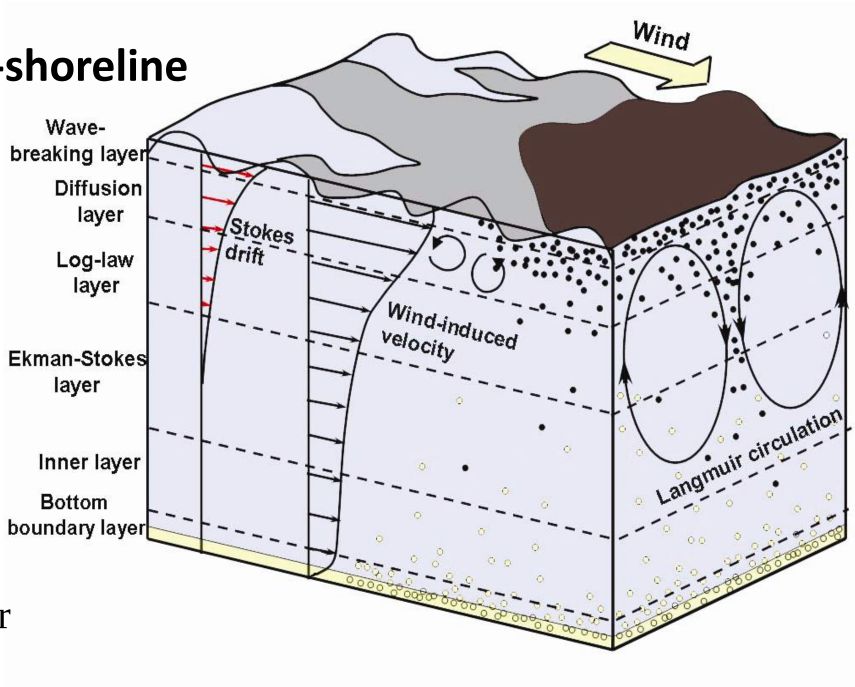
Roman Bezhenar; et al. 3D numerical model of ecohydrodynamics for shallow waters Journal of Coastal Research https://doi.org/10.2112/SI75-165.1

Lagrangian methods for simulation in marine environment

- Particle tracking methods are conservative
- Powerful tool to analyze the output of ocean circulation models
- Random walk methods used for turbulent mixing
- Simple and effective parallelization
- A generalized probabilistic approach was developed to simulate transitions of particles between different states (e.g. radioactive decay, adsorption. Interaction with surface or bottom, droplets breakup)
- Lagrangian models of oil spill transport, sediments and radionuclide transport were developed verified and applied for a number of problems

Oil transport and fate model OILTOX

OILTOX is Lagrangian model to simulate oil transport and fate in four interacted phases:
oil-on-surface, oil-in-water, oil-on-bottom, oil-at-shoreline



Model numerical features

-Lagrangian algorithm for particle tracking
-3D Random Walk method for turbulent diffusion of oil droplets
-2D SPH method for solving shallow water equation for the gravitational spreading of surface oil slick
-Solves Kolmogorov equation for the probability of particle evaporation

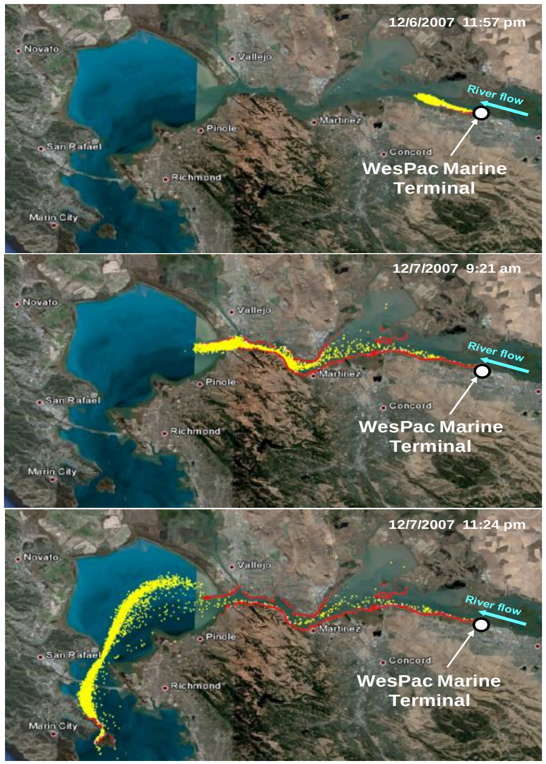
Transport processes

- Spreading
- Advection
- Horizontal and vertical turbulent dispersion
- Oil-shore interaction

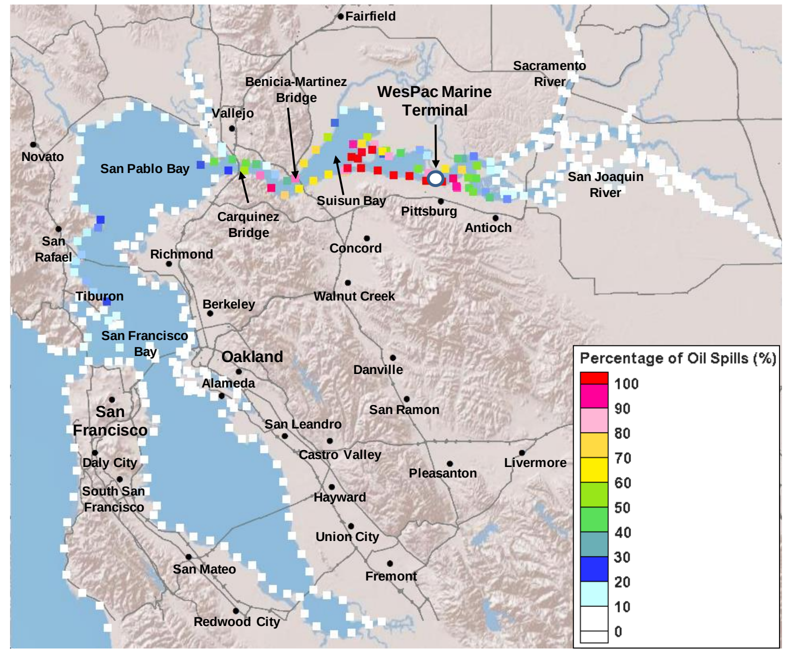
Weathering processes

- Evaporation
- Entrainment in water
- Emulsification
- Dissolution
- Sedimentation

Oil Spill Analysis WesPac Pittsburg Energy Infrastructure (San-Francisco bay)

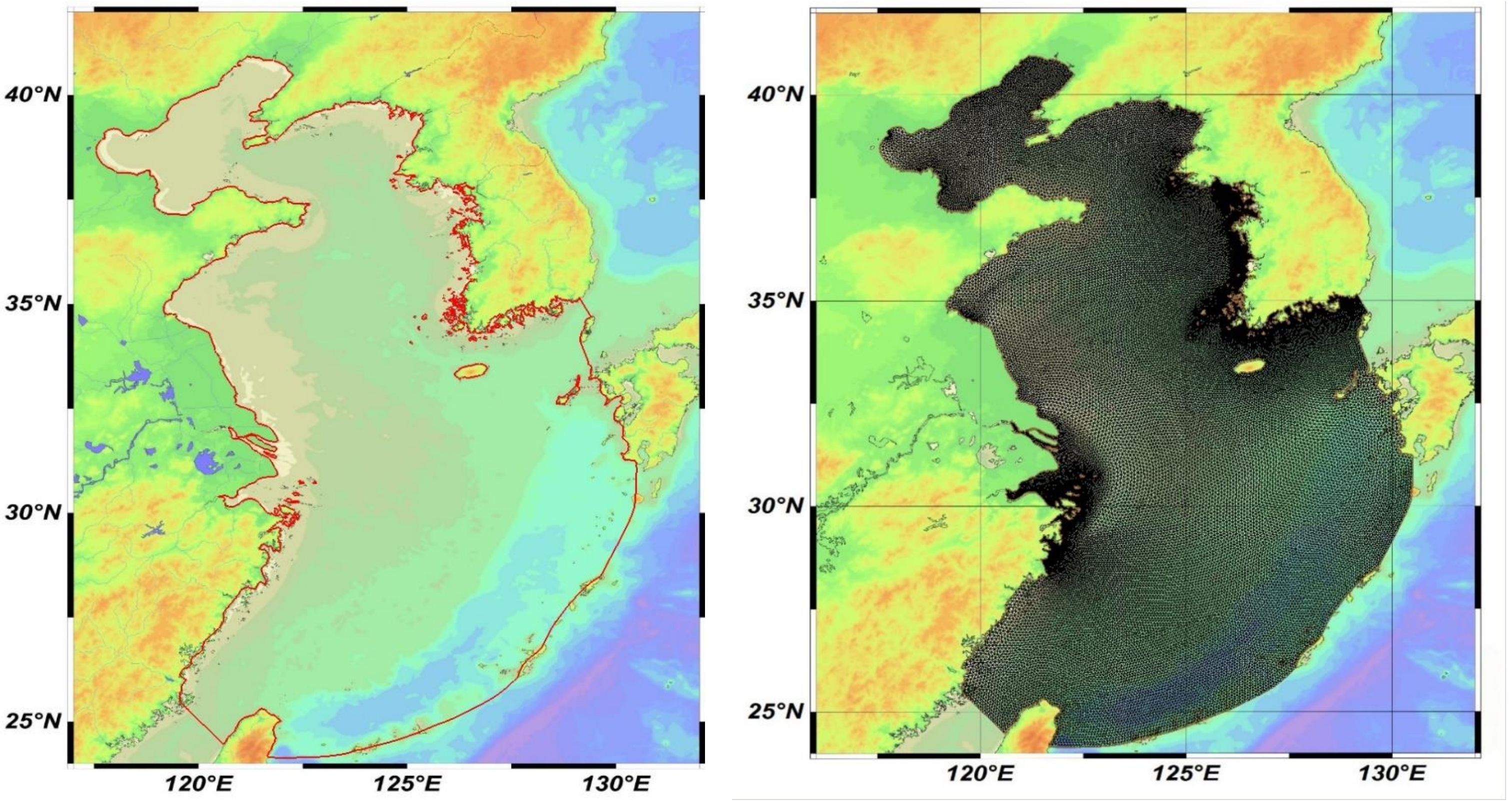


Example spill trajectory for a winter OILTOX simulation at three different times



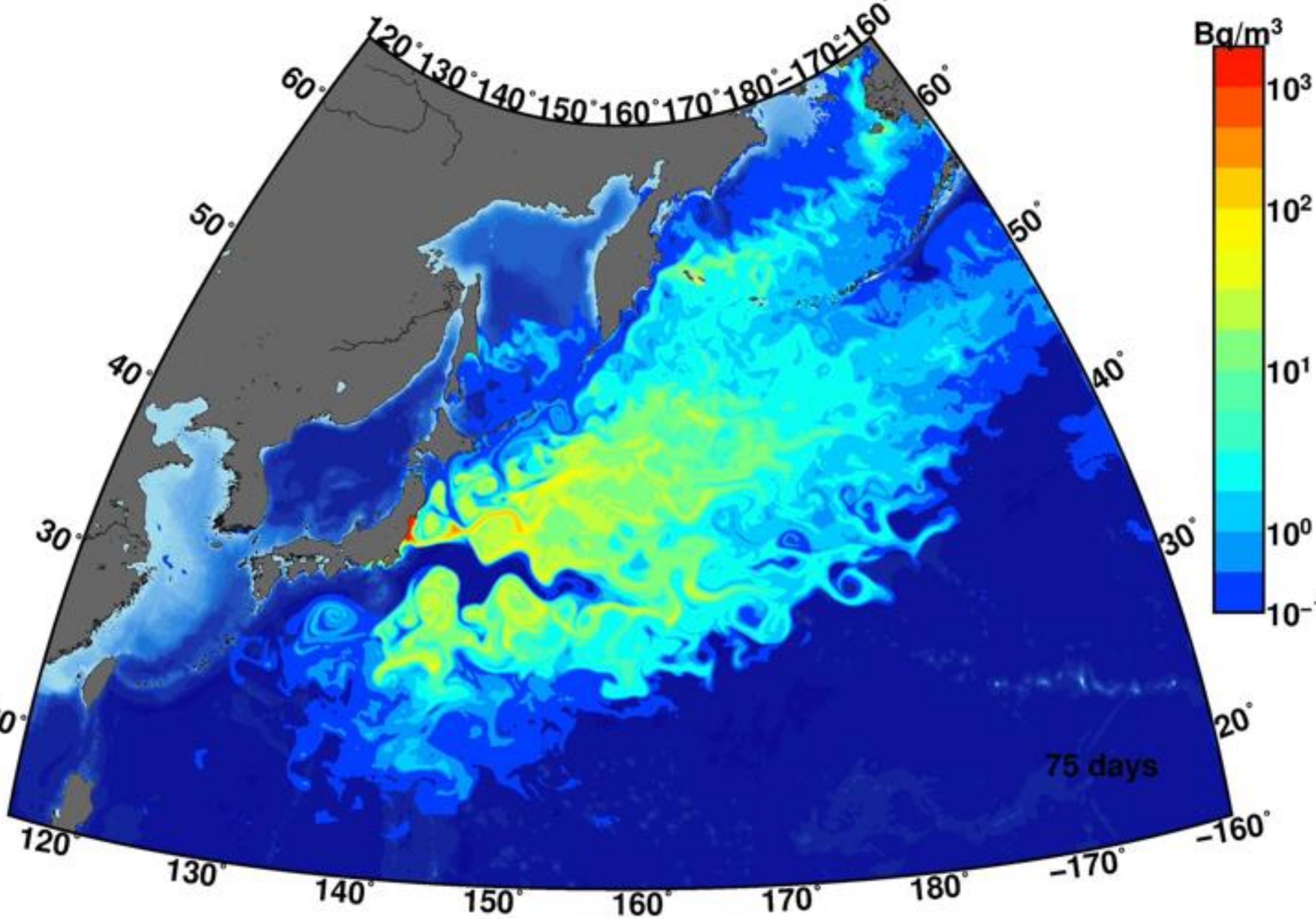
For each of the 12 modeling scenarios, 100 individual oil spills occurring during winter and 100 individual oil spills occurring during summer were simulated with the OILTOX model, for a total of 2,400 oil spill modeling runs

Sediment transport simulation. Application for the Yellow Sea



Unstructured model with mixed s-z vertical coordinate system,
resolution: from 400m to 8km
5 sediment sizes fractions
Tides, river inflow
Atmospheric forcing, heat fluxes

Large scale lagrangian modelling of ^{137}Cs concentration after the Fukushima accident



3D lagrangian random walk algorithm
Radioactive decay

- IMMSP team is ready for collaboration within the PEEX initiative in the fields of atmospheric and marine modeling

- Thank you for attention!