Integration of short- and long-term radionuclide transport models for freshwater bodies and coastal waters into JRODOS

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NERIS

NERIS Workshop 2015 – 27-29 April, Milan, Italy

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- Introduction to JRODOS – HDM
- Integration of models for radionuclide transport in coastal waters: THREETOX and POSEIDON
- Integration of models for long-term radionuclide transport in freshwater bodies and catchments: MOIRA
- Application to the water bodies in the fallout zone of the Fukushima Daiichi NPP and coastal areas

Rodos – real time online decision support system for nuclear emergency management developed under auspices of 3rd- 7th Euratom Framework Programmes 1992-2013.

w.rodos.fzk.de

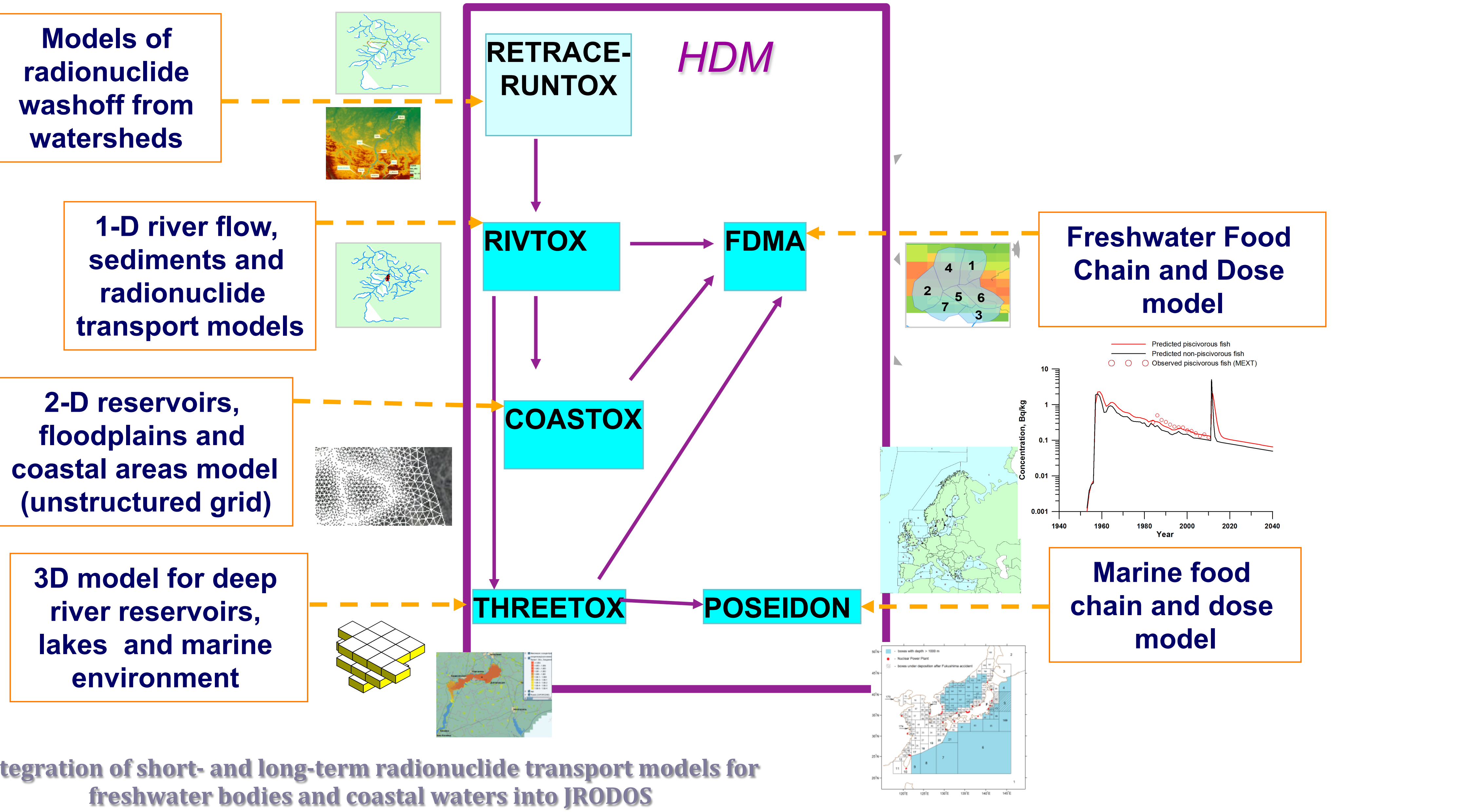
Re-engineered b
on the JAVA
technology and f
named **JRODOS**

A new version of
Hydrological
Dispersion Modu
(**JHDM**) was
introduced.

Within **PREPARE**
project → additio
developments to
increase its capa
with new functio

Hydrological Dispersion Models (HDM) of EC Decision Support System for Nuclear Emergency- RODOS

PREPAR



Integration of short- and long-term radionuclide transport models for freshwater bodies and coastal waters into JRODOS

PREPAR

EC Euratom for Nuclear Research and Training Activities:
Project Acronym: **PREPARE** **2013-2015**

Innovative integrated tools and platforms for radiological emergency preparedness and post-accident response in Europe

Work Package 5: Extension of aquatic dispersion and consequence modelling in Decision Support Systems, on the basis of recent experiences and technological advances

Work Package Coordinator: Mark Zhelezniak (UCEWP; IER)

Work Package participants: UCEWP; KIT; UPM; NRPA; CIEMAT; NRG; Liana Papush; IFIN; USEV; ENEA; IER

Integration of short- and long-term radionuclide transport models for freshwater bodies and coastal waters into JRODOS

Additional development of JRODOS-HDM in the frame of PREPARE project (WP5)

i. Modelling radionuclide transport in coastal waters driven by the atmospheric fallout from JRODOS ADM and/or by direct releases into marine environment.
   - for the post accidental real-time forecasting and for the analyses of long term contamination of the marine environment including marine biota;

ii. Modelling of long-term fate of radionuclides in freshwater system for predictions of the radiation doses via aquatic exposure pathways, by integrating the lake and river models from the MOIRA DSS;

iii. Analyses of the efficiency of countermeasures to diminish such doses after an accident, based on MOIRA DSS models

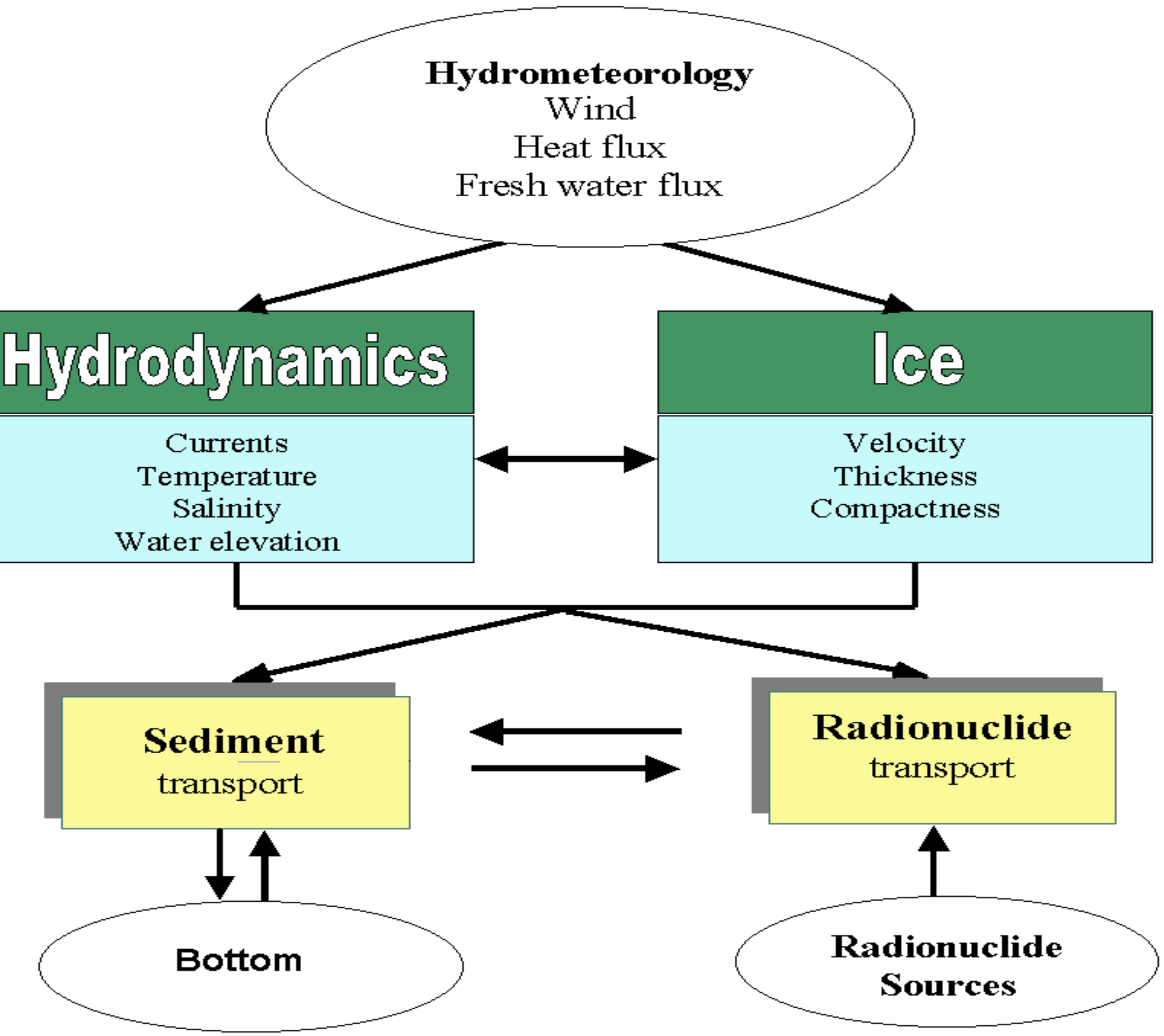
Aims of models for coastal areas in the JRODOS system

PREPAR

- **THREETOX** is 3D hydrodynamic modeling system for short- and medium term prediction of dispersion of radionuclides in surface water systems;
- **POSEIDON/RODOS** is 3D compartment model for long term prediction and assessment of radioactivity contamination of coastal seas
- Both models extensively validated with historical data (overall fallout and post-Chernobyl)

THREETOX modeling system

PREPAR

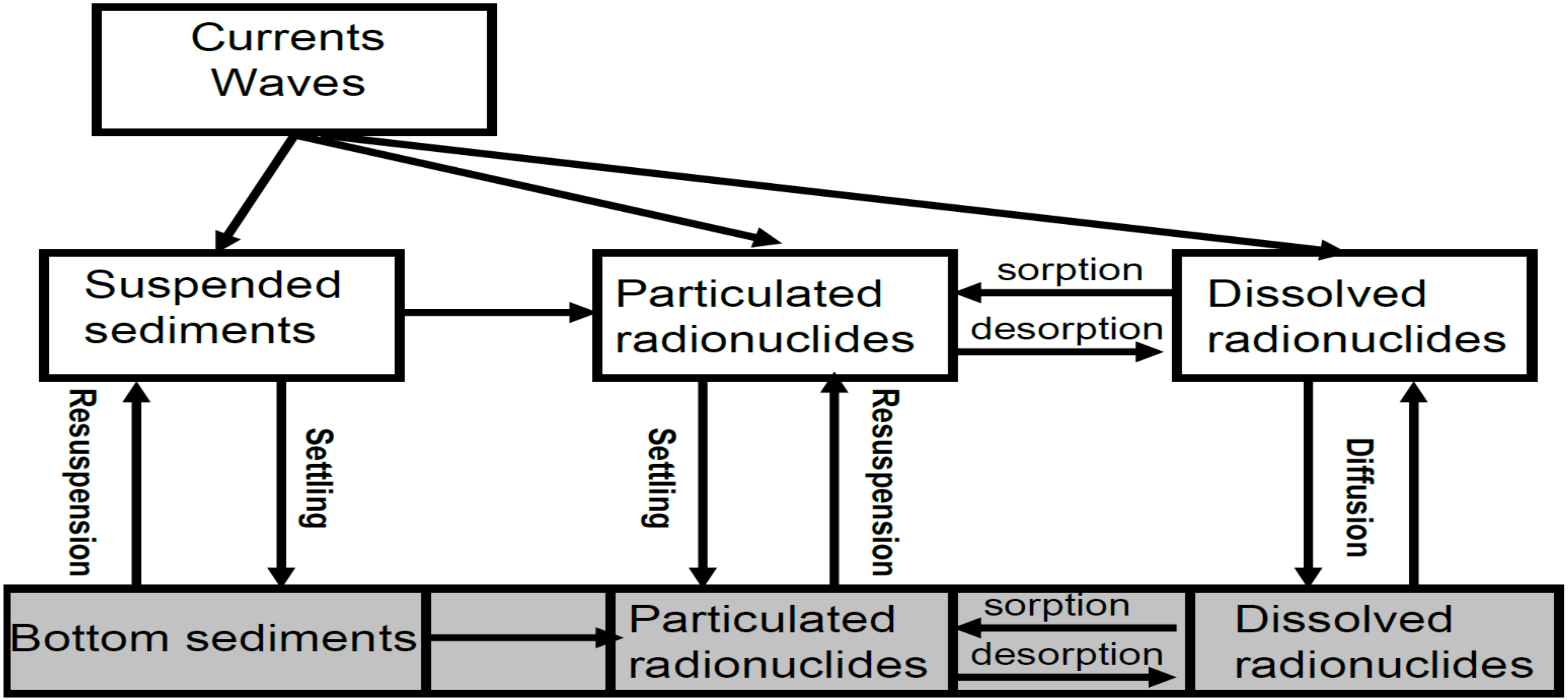


Main Characteristics

- Free-surface, primitive equation model;
- *k-epsilon* model of turbulence
- Ice dynamic-thermodynamic model
- Orthogonal curvilinear system coordinate
- Mixed vertical coordinates
- Wetting-and-drying algorithm
- Heat exchange with bottom
- Two-way nesting
- Near field sub-models
- Eulerian models of sediment transport
- Eulerian models of radionuclide transpor

THREETOX Radionuclide transfer processes in water and sediments

PREPARE



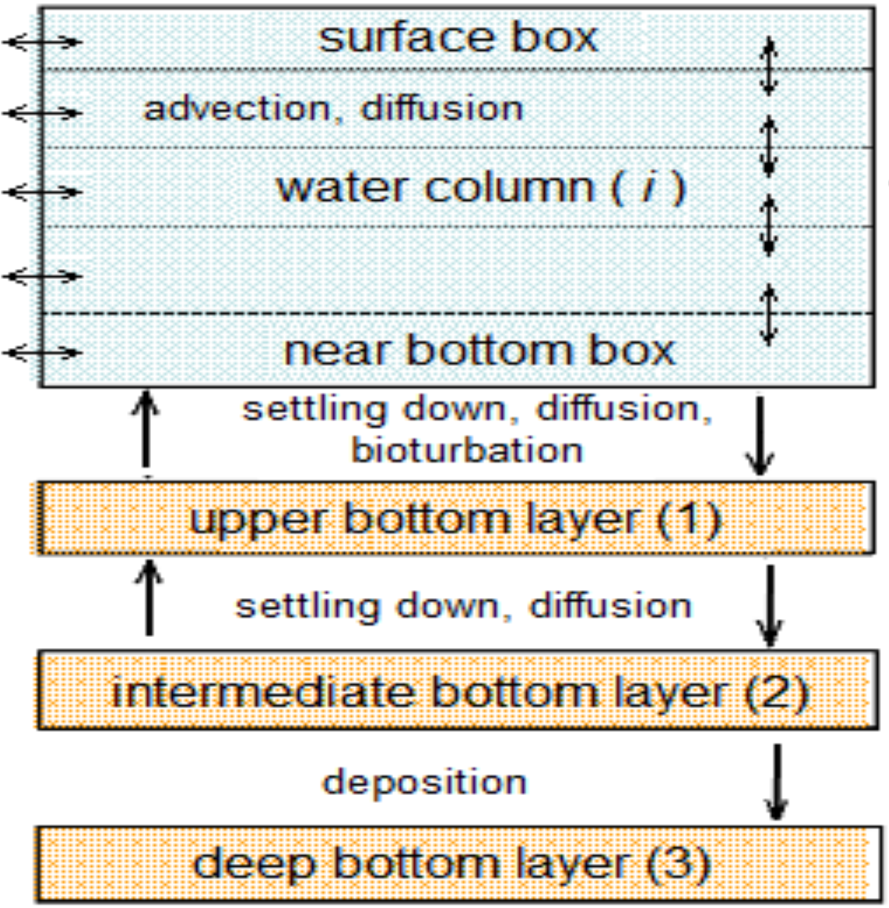
Integration of short- and long-term radionuclide transport models for freshwater bodies and coastal waters into JRODOS

Two modes of use of THREETOX

- Prediction of thermohydrodynamics of water bodies and transport of radionuclides
- Prediction of transport of radionuclides using available hydrodynamics fields from ocean forecast models (MyOcean e.g.)

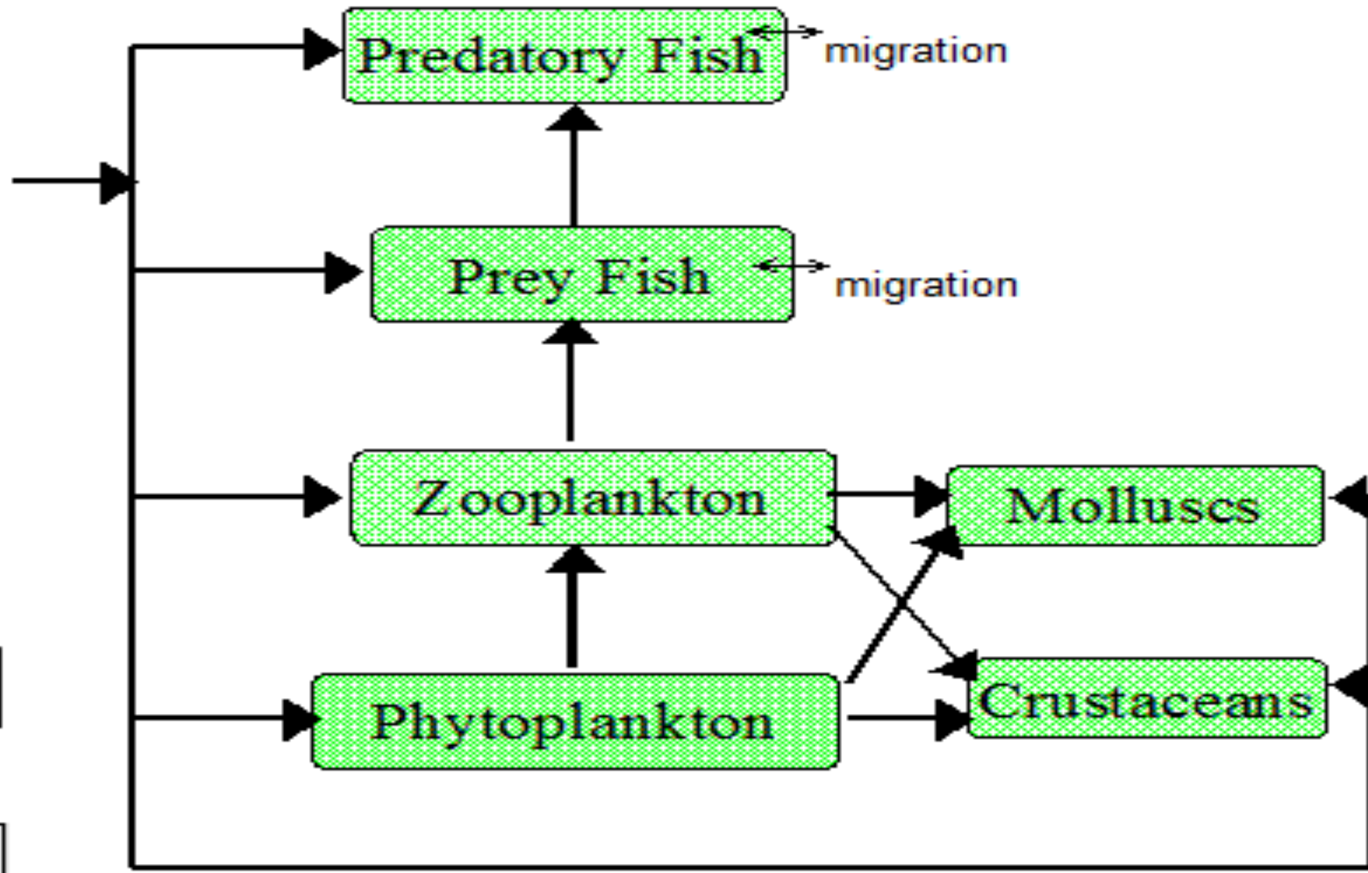
PREPAR

Compartment structure of POSEIDON-R boxes



Lepicard, Raffestin, 1998
Lepicard, Heling, Maderich, 2004

Structure of BURN-POSEIDON



Heling et al., 2002
Maderich et al., 2014

BURN-POSEIDON dynamic food chain model

PREPAR

hytoplankton receives radionuclides via adsorption and
bsorption of radionuclides (equilibrium approach).

$$C_{phpl}(t) = C_w(t)\ CF_{phpl}$$

or other organisms dynamical approach is used.

$$\underbrace{\frac{dC_{(pred)}}{dt}}_{\text{ccumulation}} = \underbrace{a\,K_{1,prey}C_{f,prey}}_{\text{Uptake from food}} + \underbrace{b\,K_w C_w(t)}_{\text{Uptake from water}} - \underbrace{K_{0.5,zpl}C_{(pred)}}_{\text{Losses}}$$

, *b* – extraction coefficients, $K_{0.5}$ – biological half life

eling R., Koziy L., Bulgakov V. (2002) On the dynamical uptake model
eveloped for the uptake of radionuclides in marine organisms for the
OSEIDON-R model system. Radioprotection 37 (C1), 833-838.

**Simplification in the BURN
model**

- Grouping the marine organisms in a limited num of classes based on the tro level and types of species
- Grouping the radionuclides into a limited number of classes associated for fish the dominating (target) tiss in which a radionuclide accumulates preferably

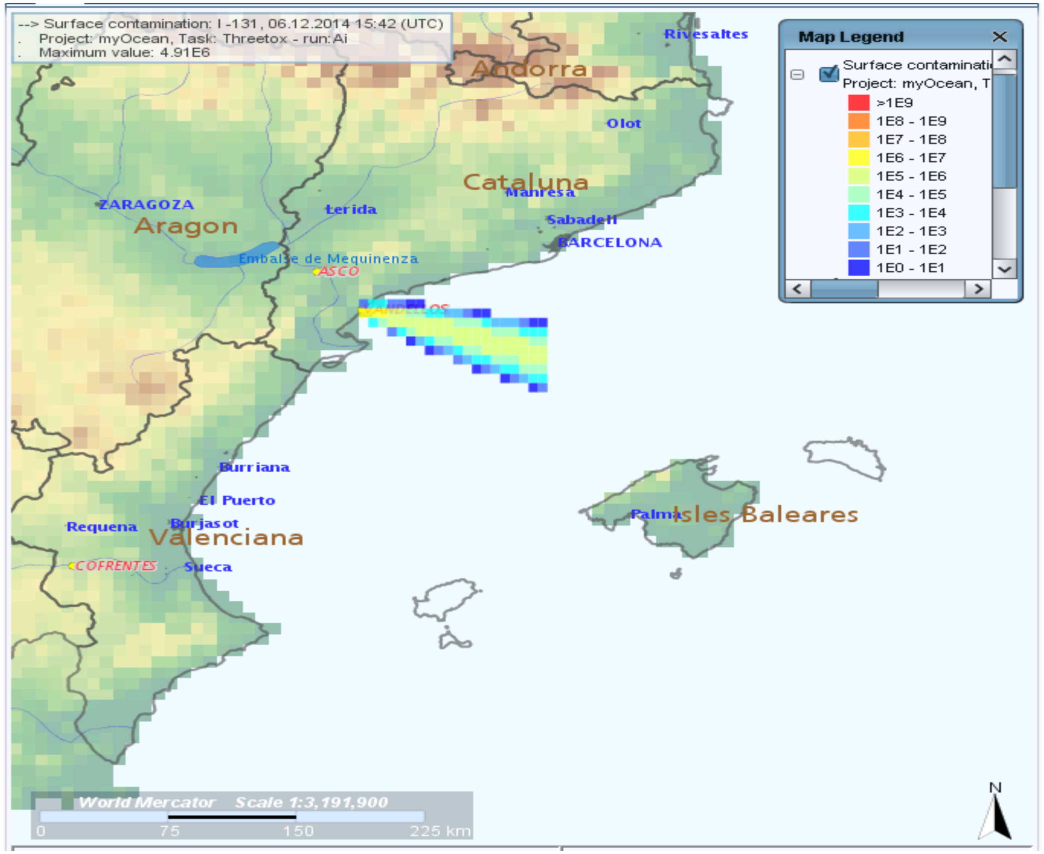
Radionuclide release assignment in POSEIDON-R

PREPAR

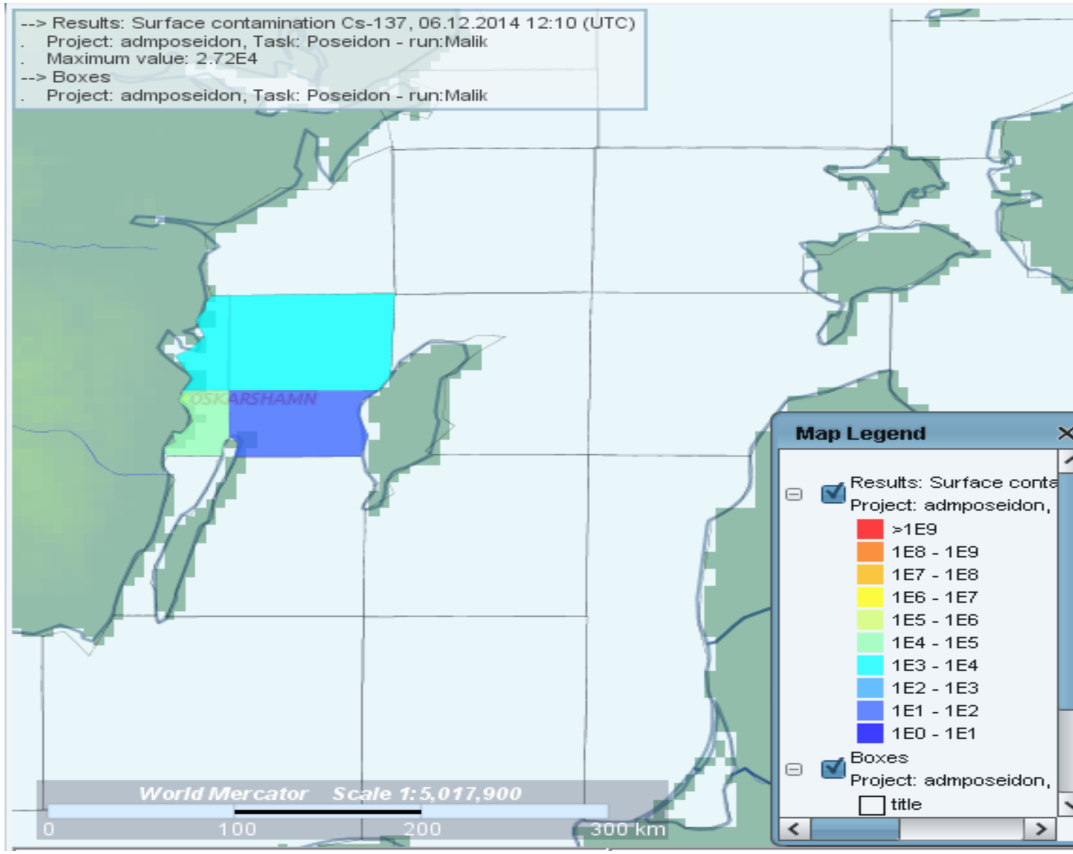
- Point sources associated with routine releases of nuclear facilities
- Point sources associated with **accidental releases**
- **Atmospheric fallout** → New software interfaces for the transfer of atmospheric fallout on marine surface simulated by JRODOS ADM into THREETOX and into POSEIDON have been developed

Surface contamination of radionuclides interpolated from JRODOS-ADM

PREPAR



Surface contamination of I-129 interpolated on THREETOX grid



Surface contamination of Cs-137 interpolated on POSEIDON box system

TRHEETOX new software tool for the retrieval of the marine and weather forecast data for coastal areas

PREPAR

Since autumn 2011, regularly updated results of the U.S. NOAA, National Weather Service, Ocean Prediction Center, global oceanographic modelling are available in ope source mode (for Europe in www.myocean.eu.org).

A software tool has been developed for the retrieval of the global marine current operational model data to be used by THREETOX as the outer boundary conditions for the currents downscaling in any specified coastal area and for the retrieving the operational meteorological fields

- In the same manner as the regional Numerical Weather Prediction model WRF can use the NOAA/ NCEP global weather forecast results for downscaling the meteorological fields for JRODOS-ADM modelling.

Software tool for processing boundary conditions data consists of two independent branches

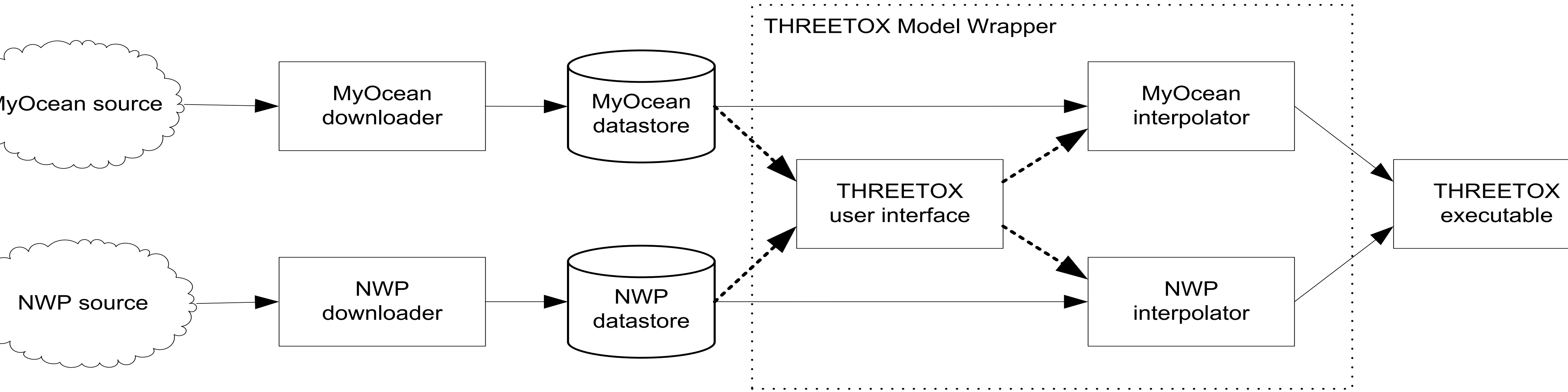
- numerical weather prediction (NWP)
- marine model data branch

Each branch includes downloader, data storage, storage access block and interpolato

TRHEETOX new software tool for the retrieval of the marine and weather forecast data for coastal areas

PREPAR

Data retrieval flow…



Dotted arrows transfer only meta information, solid arrows – meta data and fields

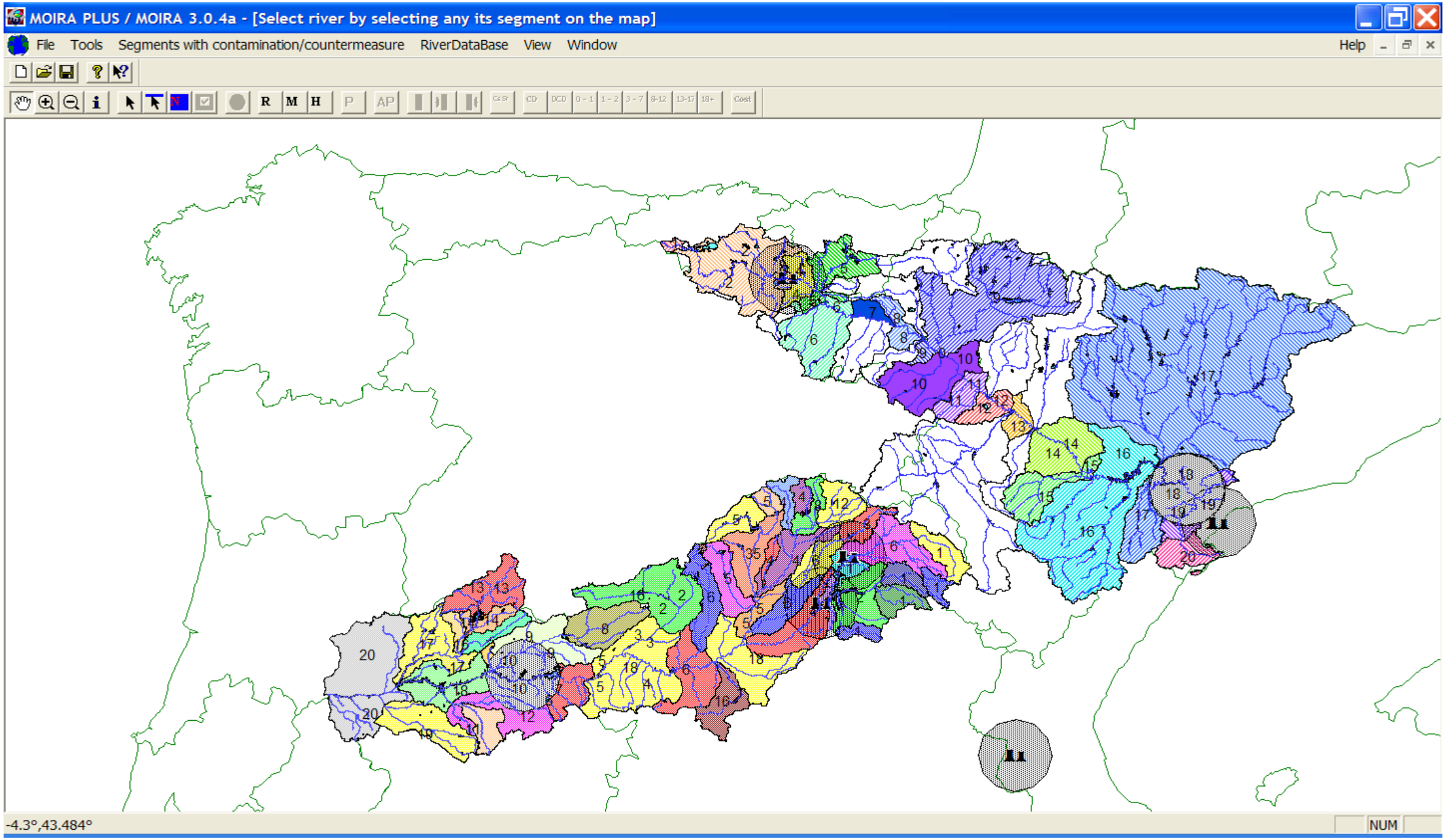
MOIRA Decision Suport System

PREPAR

- MOIRA is a computerized Decision Support System (DSS) to help selecting optimal management strategies for different aquatic ecosystems contaminate by radionuclides.
- MOIRA is NOT aimed at emergency situations, but rather at management strategies for the long-term. It complements JRODOS-HDM. Some users suggested integration of both systems.
- MOIRA is designed to allow for a realistic assessment of the radiological, ecological, economic and social impacts of management alternatives, in a wa as rational and complete as possible.
- The system incorporates a decision analysis module based on Multi-Attribute Analysis (level 4)

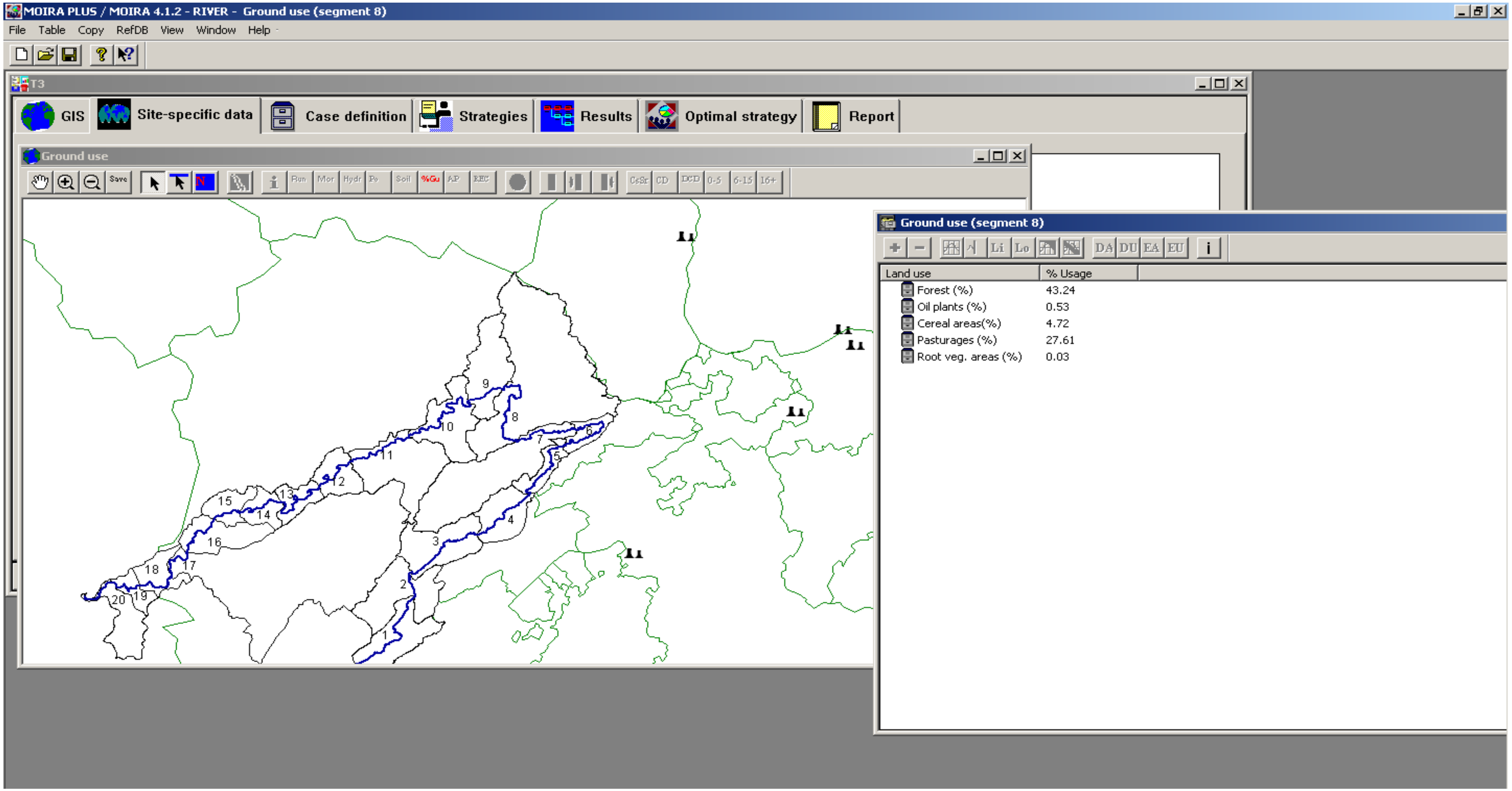
MOIRA

PREPAR



MOIRA-PLUS customisation: the Tagus and Ebro rivers in Spain

PREPAR



MOIRA-PLUS customisation: the Doubs river in France (Biguenet et al., 2011)

Elements of MOIRA software (1) PREPAR

- Validated models for predicting time behaviour of contaminants (^{137}Cs ar ^{90}Sr) in **lakes, rivers and drainage areas** and well as the effect of selected countermeasures to reduce the contamination levels.
  - To analyse complex rivers systems and catchments it is limited to the definition of not more than 20 river branches and reaches.
  - The models have been validated against several lake and rivers historical data.
- Models to assess doses to man and biota (fish) and to evaluate dose resulting after implementing countermeasures affecting the direct human exposure to contaminated elements
- A conceptually simple micro-economic approach to assess the economic cost of the different kind of countermeasures implemented

Elements of MOIRA software (2) PREPAR

- In lakes, a **Lake Ecosystem Index (LEI)** to assess the impact of physical ar chemical countermeasures on the lake ecological quality (Håkanson et al., 2000).
- Methodologies based on multi-attribute analysis (MAA) techniques for rankin the different feasible interventions accounting for the above-mentioned impacts (Ríos-Insúa et al., 2006).
- Software components implementing the above models and methodologies
- Data storage and analysis tools (Geographical Information System, GIS, anc data bases) (Hofman, 2004)

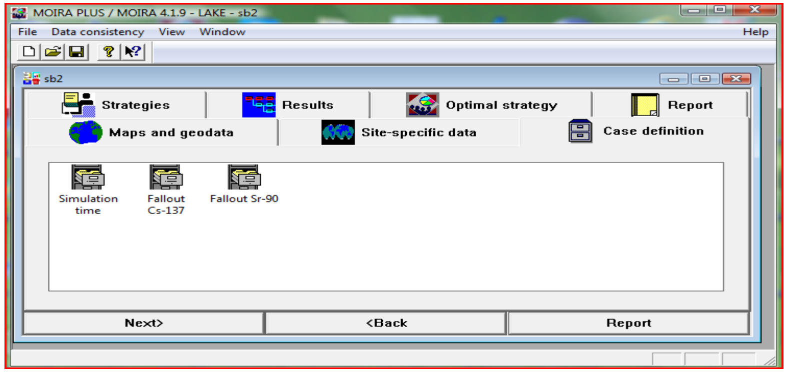
- MOIRA runs in a simple Windows PC (with MapInfo® GIS and PowerSim®)

Countermeasures available for simulation in the MOIRA system

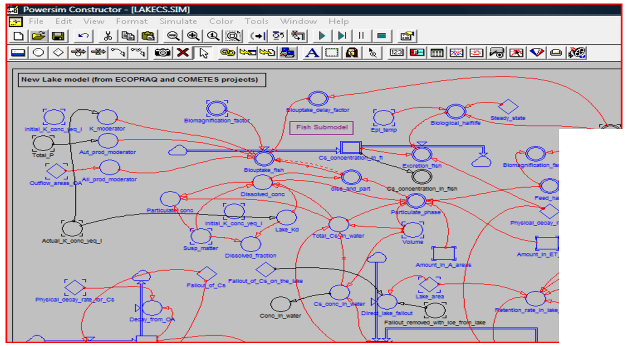
pplication of chemical agents (Time dependent)	Application of physical measures (Time dependent)	Application of social restrictions (in user defined periods or based on contamination and dose limits)
Potash reatment **Direct liming** **Wetland liming** **Fertilisation**	• **Removal of sediments** • **Removal of snow and ice** • Building flood dykes • Water flow diversion between segments in rivers	• Bans on fish consumption • Bans on water ingestion (with alternative sources of clean water) • Bans on irrigation • Restricted access to contaminat areas

Integration of MOIRA Lake and River models into JRODOS

MOIRA DSS (standalone)



Powersim®



Lake Model

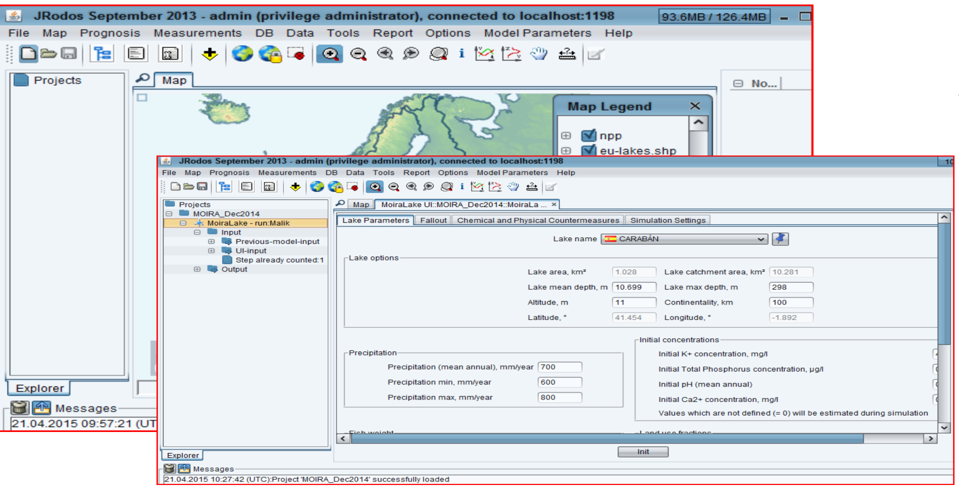
River Model

Dose Model

Economic Model

MMA

JRODOS DSS



MOIRA Lake and River Models are developed as FORTRAN codes and compiled into .dll

Models are integrated as plug-ins

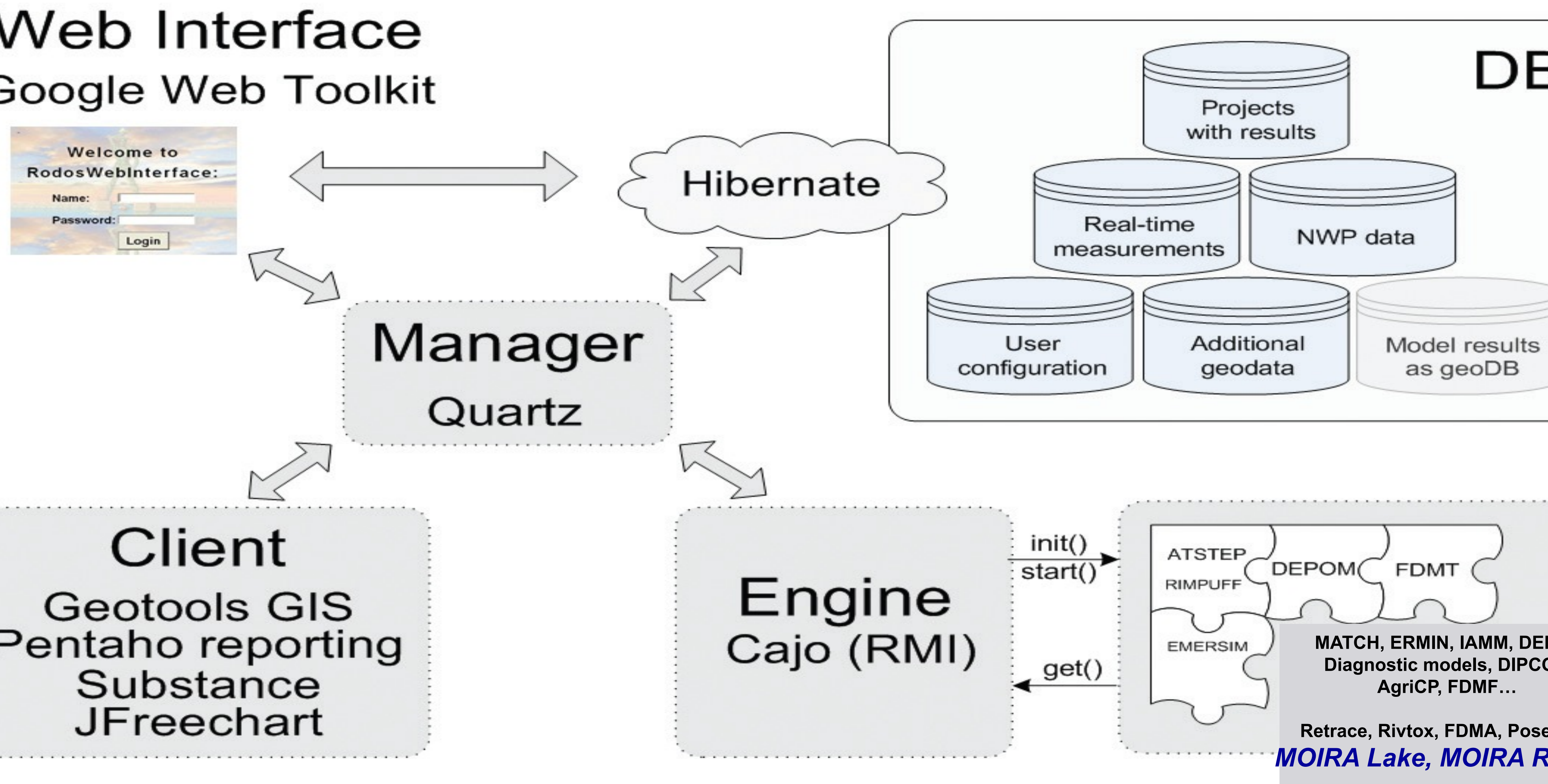
Integration of short- and long-term radionuclide transport models for freshwater bodies and coastal waters into JRODOS

Integration of MOIRA Lake and River Models into JRodos

- Development of the MOIRA Models as Fortran modules (based on their Powersim® implementations in the MOIRA DSS)
- Development of the model-specific JRODOS User Interface Java modules
- Establishment of the data exchange between models and user interface
- Transfer of the GIS data available in the MOIRA DSS into the JRODOS GIS

JRodos Software structure

PREPAR



Implementation and testing of the extended HDM-JRODOS for the coastal areas, rivers, reservoirs and lakes affected by the Fukushima Daiichi NPP fallout

PREPAR

Integration of short- and long-term radionuclide transport models for freshwater bodies and coastal waters into JRODOS

Modelling of Fukushima releases with JRODOS

PREPAR

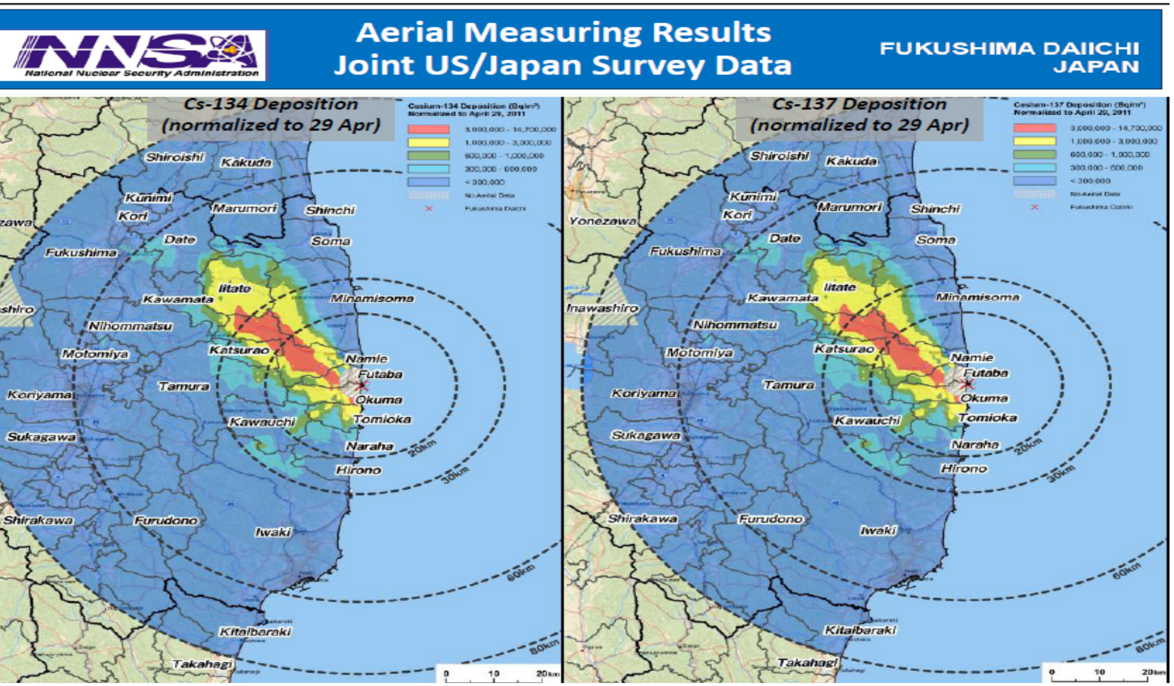
Steps done to model atmospheric dispersion and deposits with ADM:

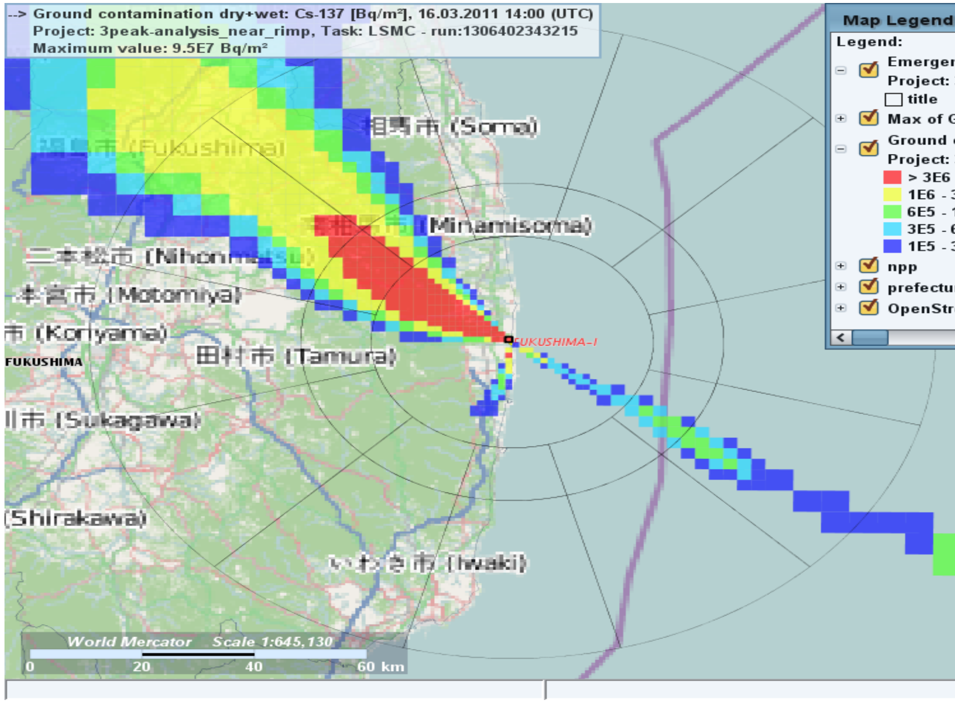
- Adaptation of JRODOS to Japan (topography, land use, from open sources
- The Meteorological Institute of KIT and IMMSP/UCEWP have provided meteorological forecast data based on the American global model GFS (50-100 km) adapted with the model WRF for local applications (10-20 km)
- The GRS (Gesellchaft für Anlagen und Reaktorsicherheit) has provided potential source terms for the calculations

Coupling of JRODOS-ADM results with JRODOS-HDM modules

Comparison of monitoring and simulation with JRODOS-ADM

PREPAR



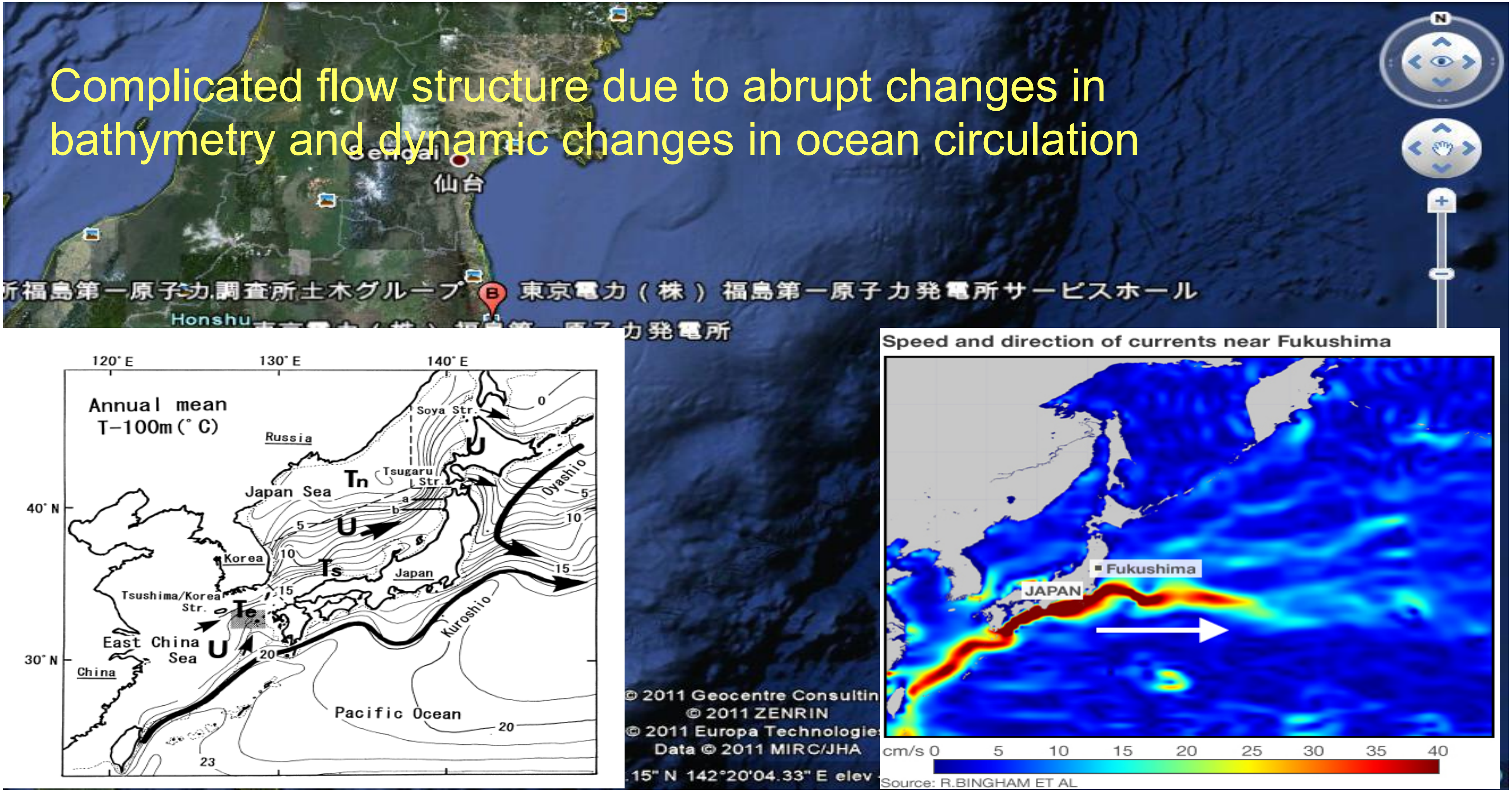


tp://energy.gov/news/10194.htm

Integration of short- and long-term radionuclide transport models for freshwater bodies and coastal waters into JRODOS

Adaptation of the RODOS-HDM to Japan coastal zones

PREPAR



Boundary conditions for the release scenarios

rect water release
m NPP

ater 4.3 m³/h.

oncentration ^{137}Cs

3 GBq/L

6 April 2011

tal 0.95 PBq

95 x 10^{15} Bq)

SA estimate based
TEPCO data (
esented on IAEA
eb Site)

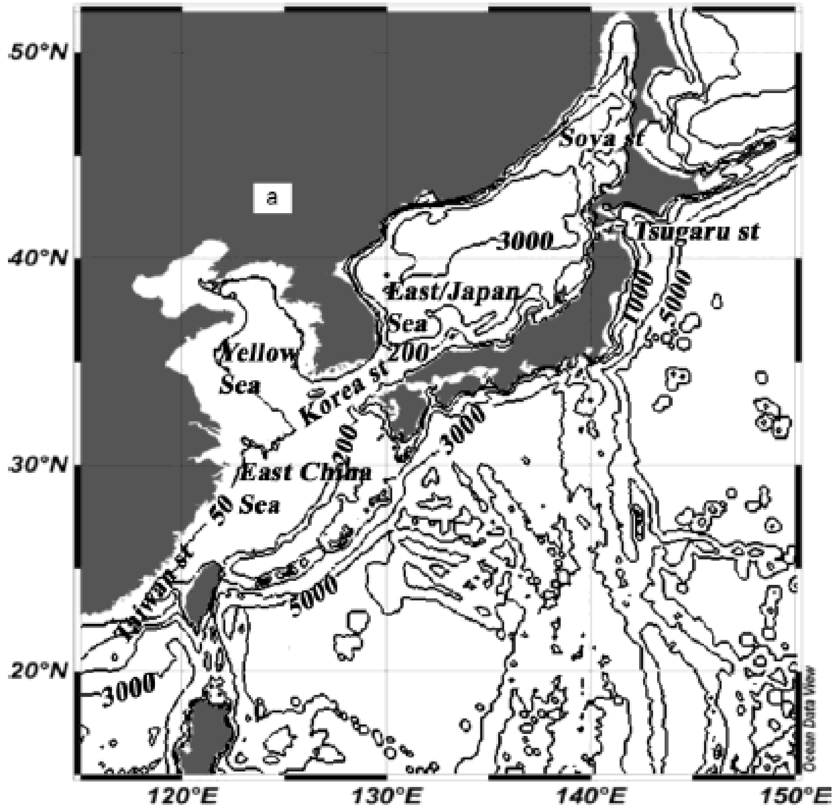
Atmospheric Fallout from RODOS ADM

Meteorological Data from US Final Reanalysi

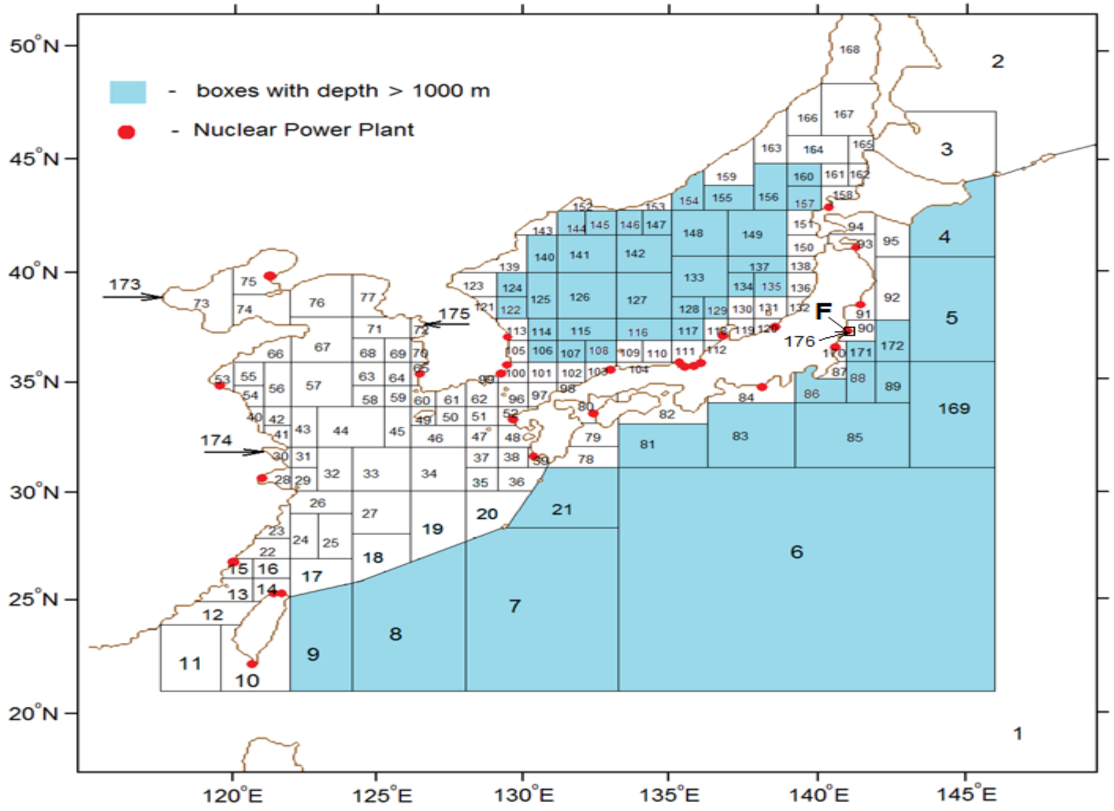
Oceanographical

Boundary Conditions from Korean KORDI Pacific Ocean Model MOM

Application of compartment model POSEIDON-R to the Northwestern Pacific and adjacent seas



Bathymetry map of Northwestern Pacific with adjacent seas



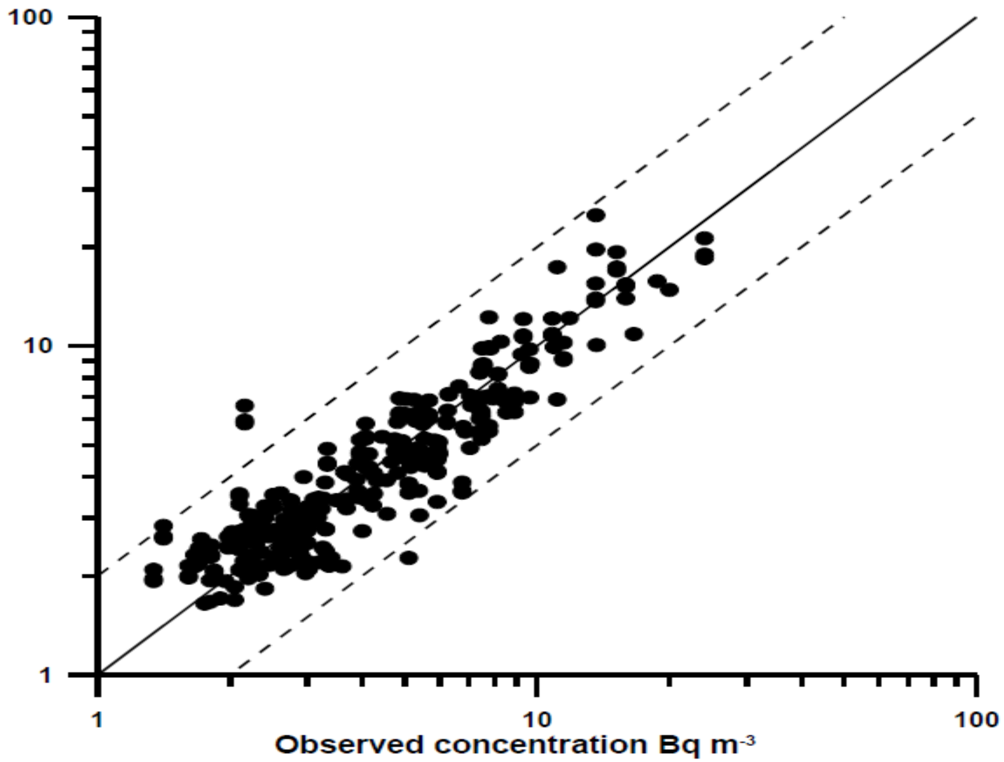
Compartment system for Northwestern Pacific with adjacent seas

Integration of short- and long-term radionuclide transport models for freshwater bodies and coastal waters into JRODOS

Application of compartment model POSEIDON-R to the Northwestern Pacific and adjacent seas

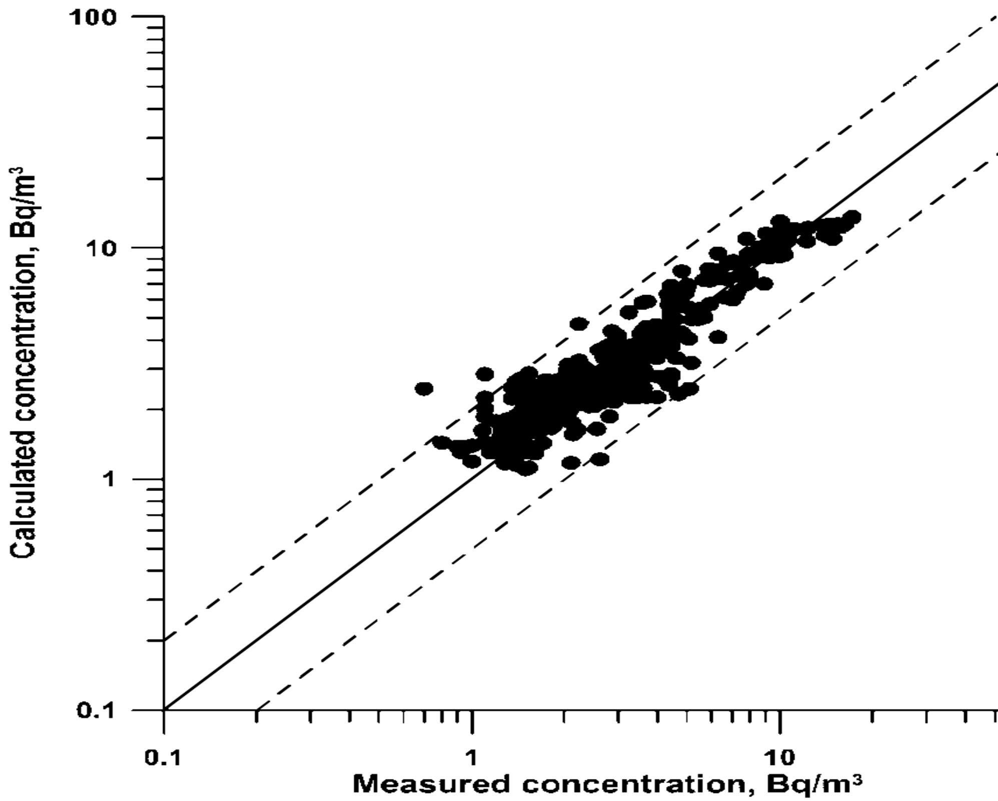
PREPAR

^{137}Cs



Correlation coefficient is 0.925

^{90}Sr



Correlation coefficient is 0.958

Correlations between predicted and measured concentration in the surface water in all modelled region for the period 1960-2005

Application of compartment model POSEIDON-R to the Northwestern Pacific and adjacent seas

PREPAR

urces of contamination due to Fukushima Dai-ichi accident

rce	^{137}Cs, PBq (10^{15}Bq)	^{90}Sr, PBq (10^{15}Bq)
tly to the n	4.0	0.08-0.64
spheric t	8.2	0.0

Damaged reactor an turbine buildings

Temporar storage ta

Continuing leakage of ^{137}Cs was estimated (Kanda, 2013) as:

3.6 TBq/yr – from NPP area

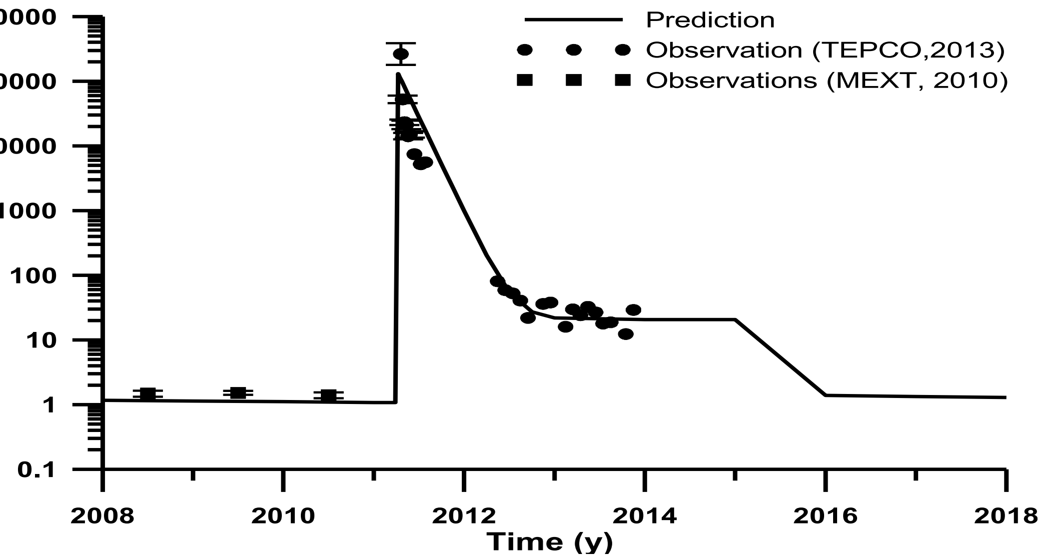
1.56 TBq/yr – from rivers

da J. (2013) Continuing ^{137}Cs release to the sea from the Fukushima Dai-ichi nuclear power plant through 2. Biogeosci. Discuss. 10, 3577-3595.

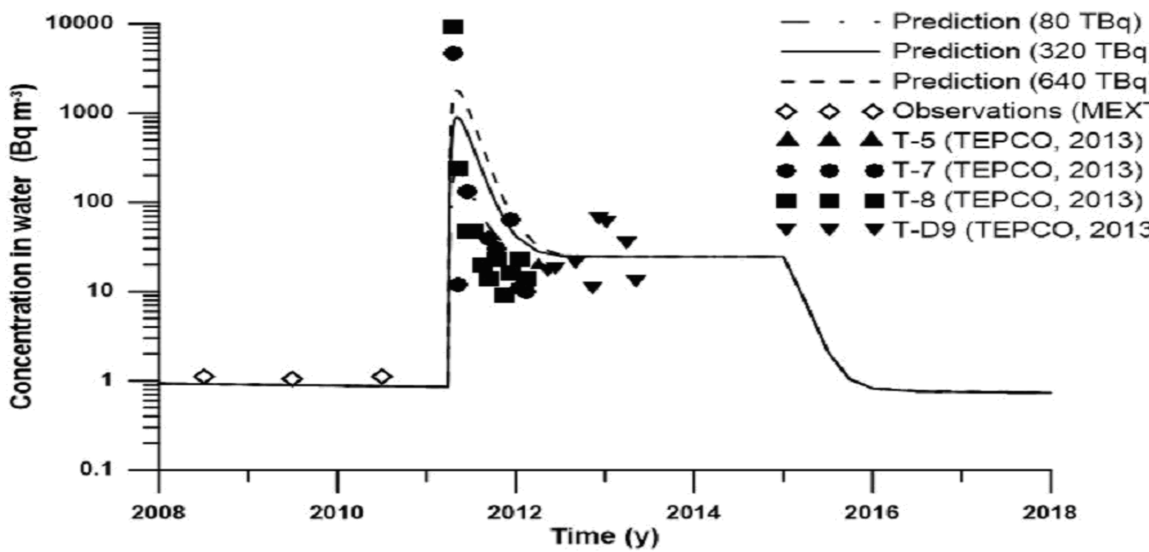
Application of compartment model POSEIDON-R to the Northwestern Pacific and adjacent seas

PREPAR

^{137}Cs



^{90}Sr

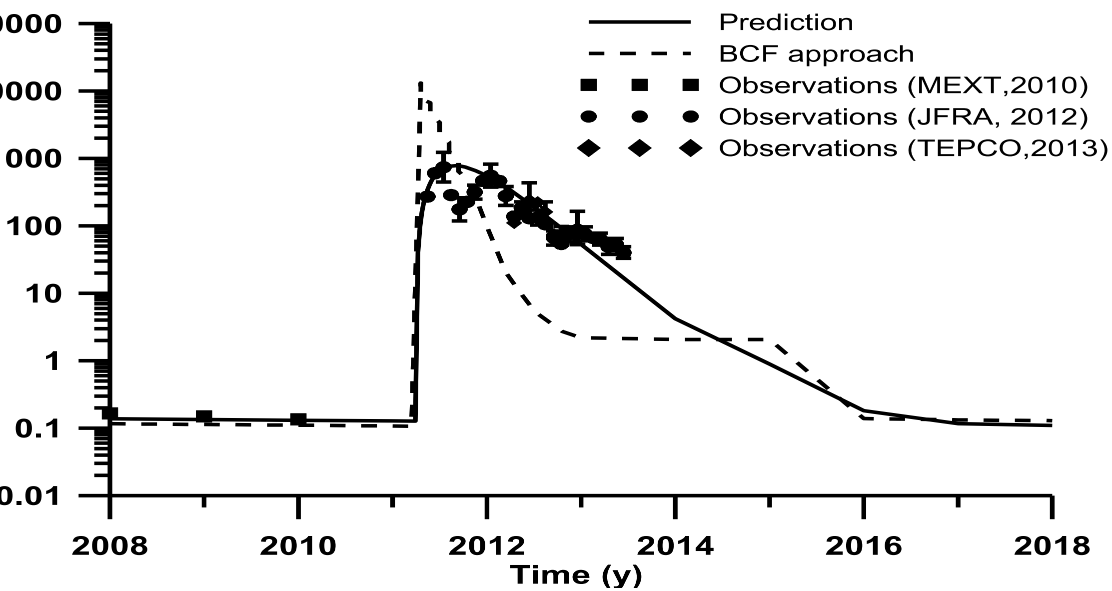


Comparison with measurements (TEPCO) for water in the coastal box

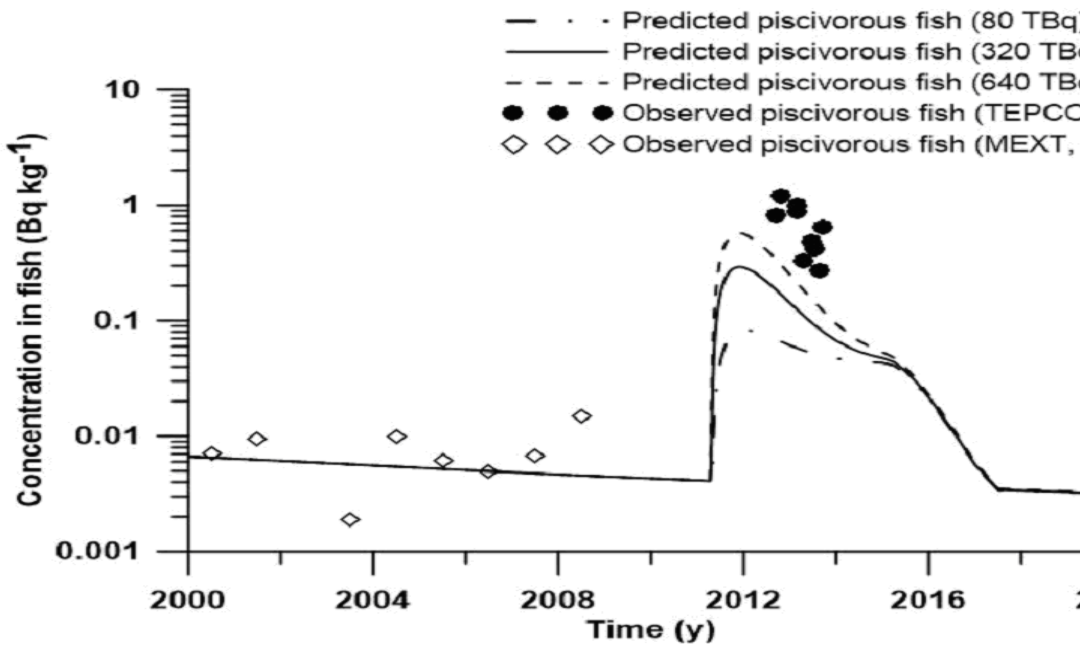
Application of compartment model POSEIDON-R to the Northwestern Pacific and adjacent seas

PREPAR

^{137}Cs



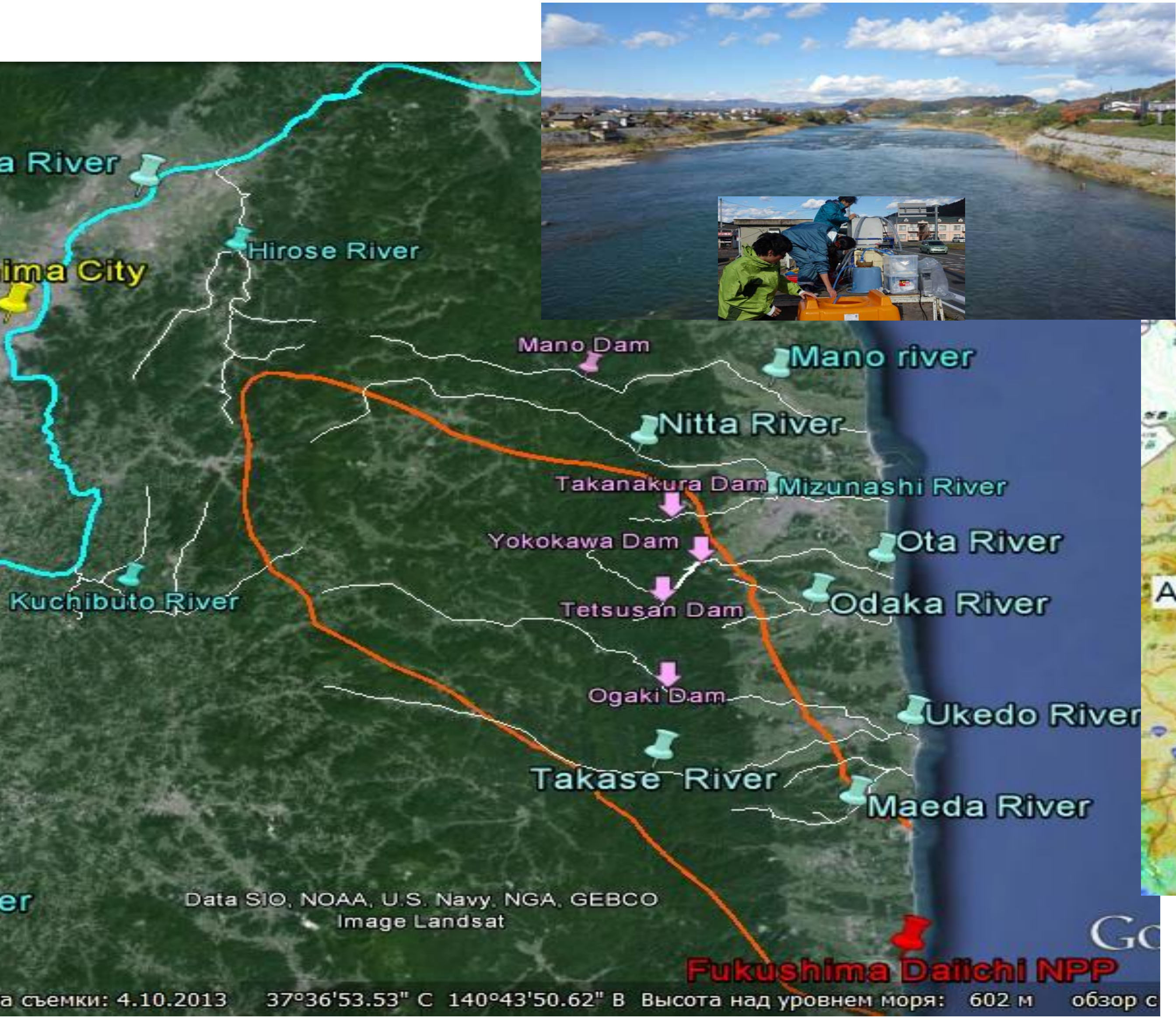
^{90}Sr

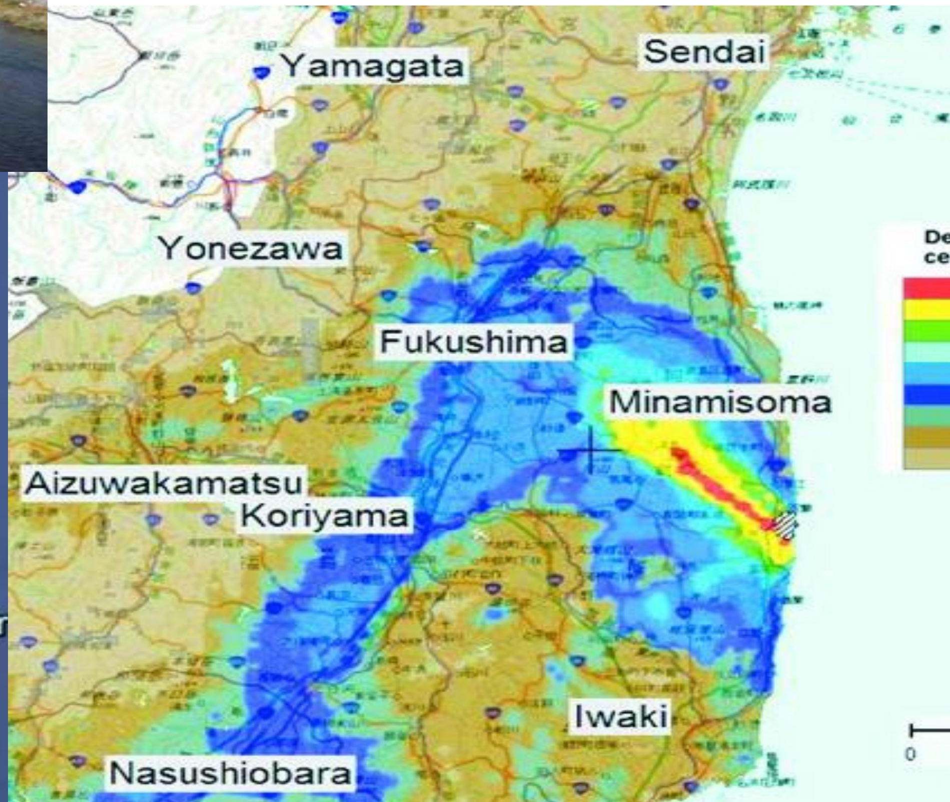


Comparison with measurements (TEPCO) for fish in coastal box

Water systems of Fukushima regions:

mon with Chernobyl problems = rivers/reservoirs as pathways of radionuclide transport fro
ost contaminated zones to the populated areas:





Falllout density December 2012

http://ramap.jmc.or.jp/map/eng/

Water systems of Chernobyl and Fukushima regions-: differences:

PREPAR

shima Region: Mountainous watersheds - steep
s, high erosion
amount of precipitations, rain seasons, typhoons
nic soils

Chernobyl Region:
Plain watersheds- mild slopes, small erosion
Mild amount of precipitations, no rain season

Water systems of Chernobyl and Fukushima regions-: differences:

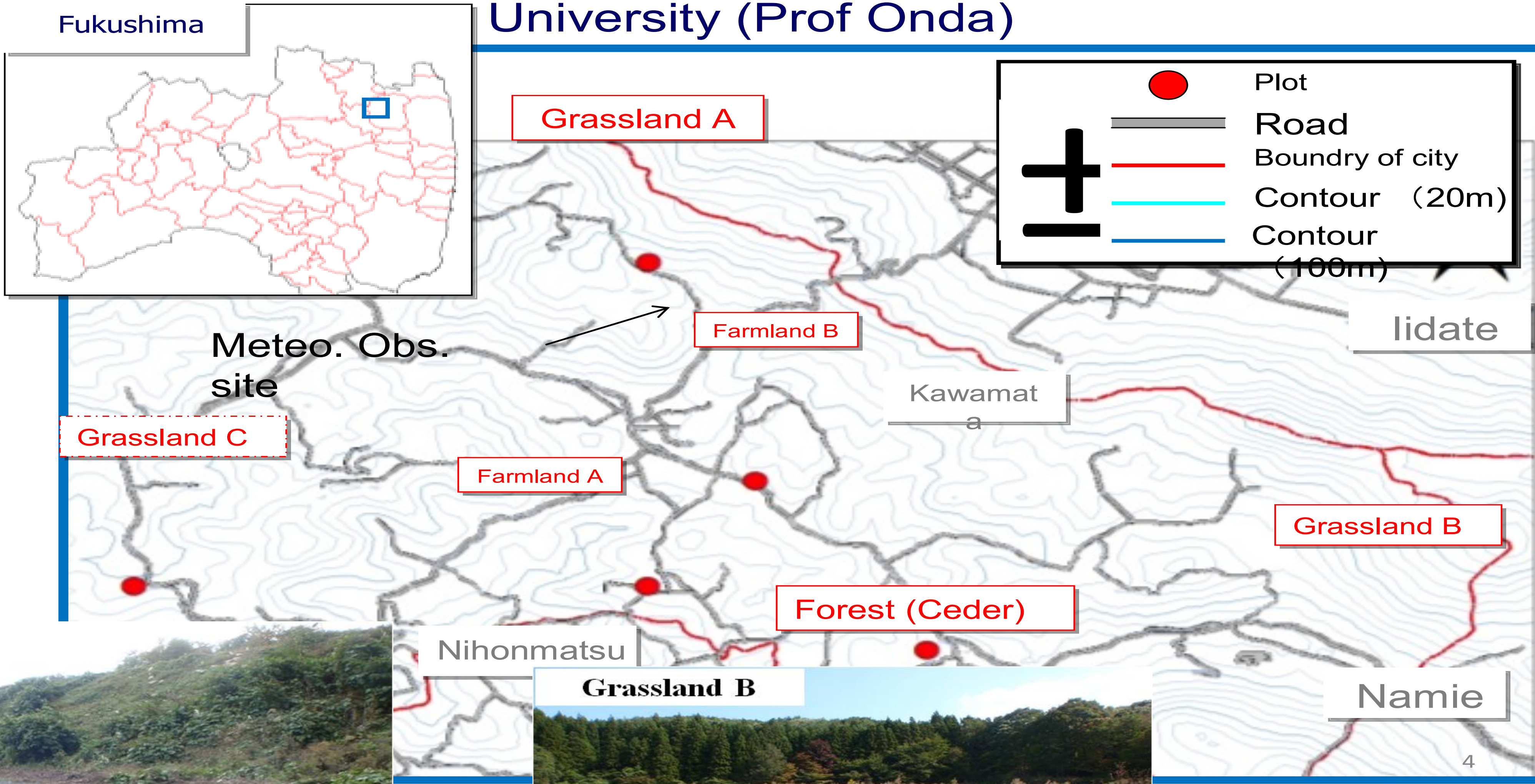
PREPAR

- 90%-95% of Cs-137 at Fukushima is transported by sediments in river water
- At Chernobyl – only up to 50% in initial period, then less, why??

- What are the reasons and with which weight for such difference??
  1) Steep mountain slopes vs mild or small plain slopes ??
  2) Volcanic Fukushima soils vs soils of the Ukrainian- Byelorussian Poles'ye, i.e difference in Kd?
  3) Typhoon generated higher amount of precipitations?

- Since November 2013 the model implementation for the water bodies of the Fukushima fallout zone has started in IER Fukushima university.
- Experimental plots to help interpretation.
  - For instance, for the same Kd the twice steeper slope provides 20 times higher amount of Cs-137 on sediments – only for highest amount of precipitation !

Experimental watershed plots of Tsukuba University (Prof Onda)



RODOS models implementation within PREPARE

PREPAR

1 RIVERS

Integration of short- and long-term radionuclide transport models for freshwater bodies and coastal waters into JRODOS

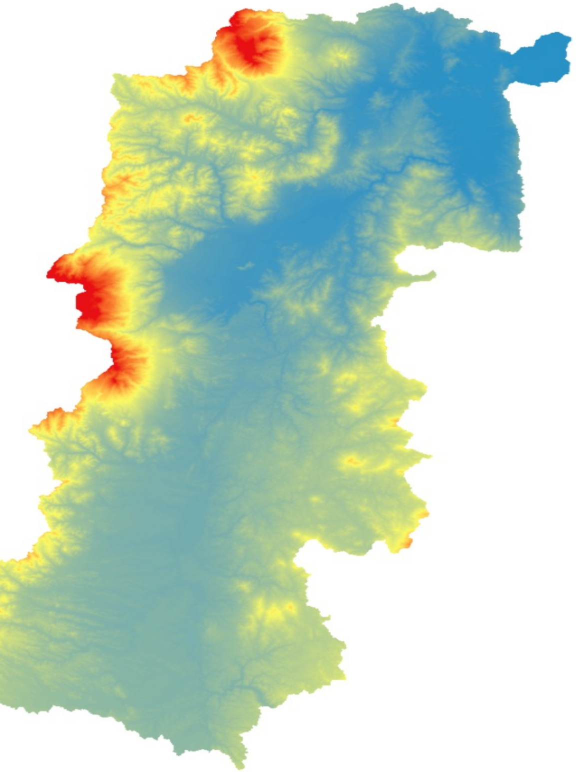
RODOS models implementation within PREPARE

PREPAR

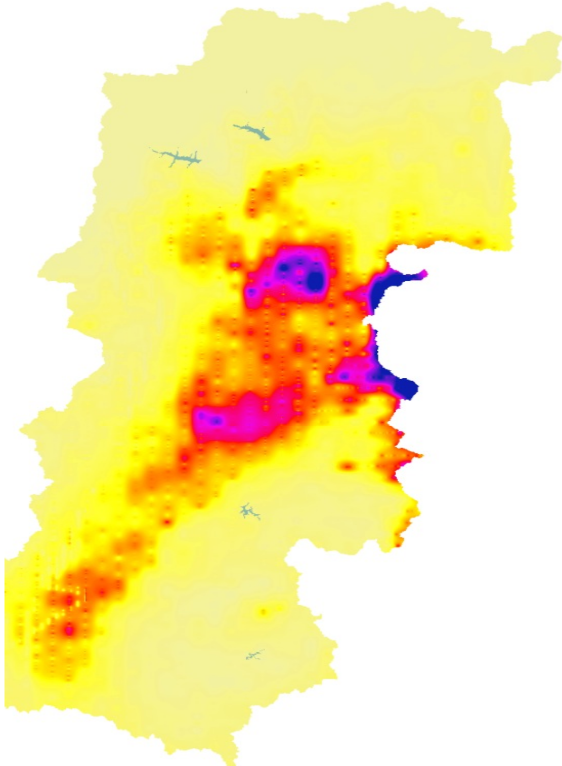
Fukushima
INSTITU
ENVIRO
RADIOA

Watersheds and Rivers

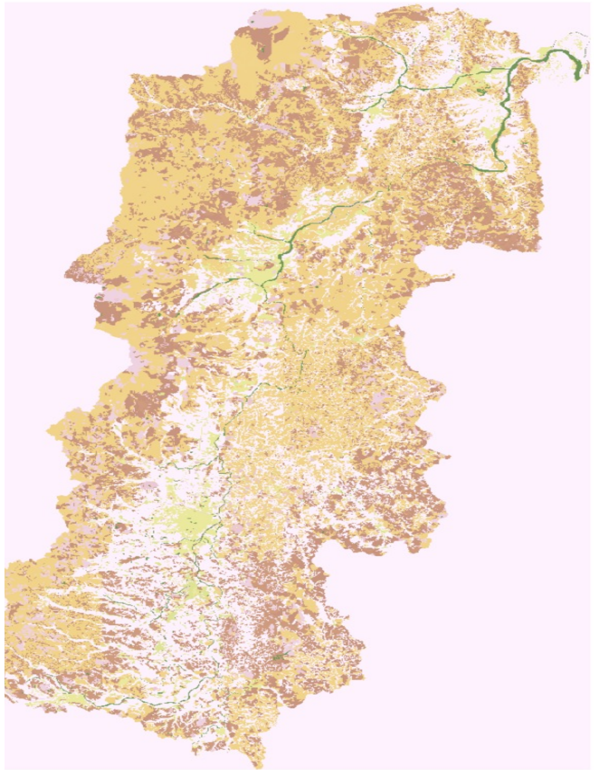
1 Abukuma River



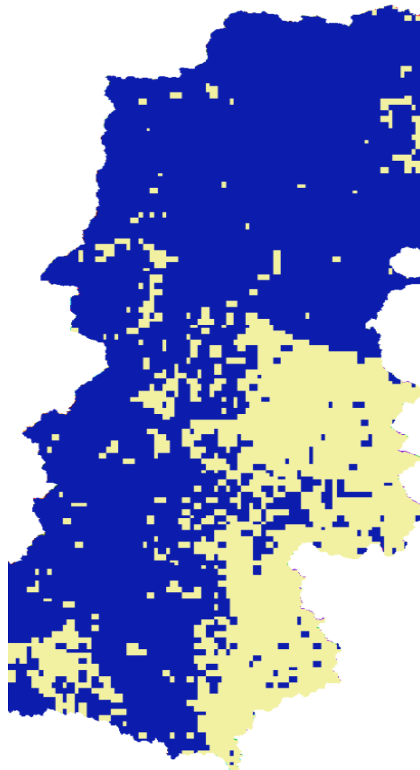
of Abukuma river



Cs-137 fallout density



Vegetation map



Soil map (loam, silt loam,

Integration of short- and long-term radionuclide transport models for freshwater bodies and coastal waters into JRODOS

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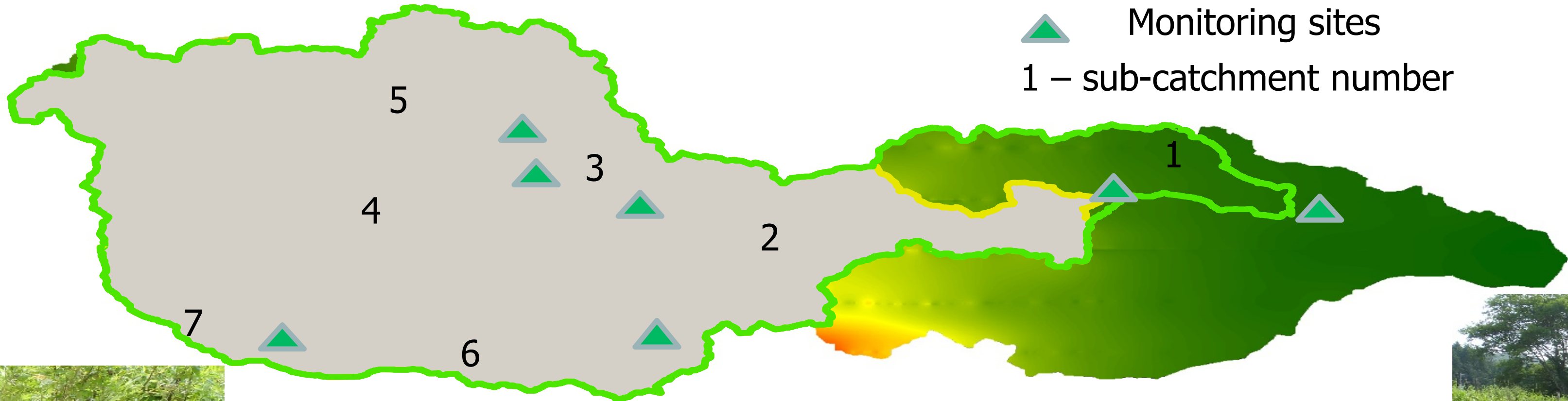
Map of radiocesium contamination of the Niida River catchment





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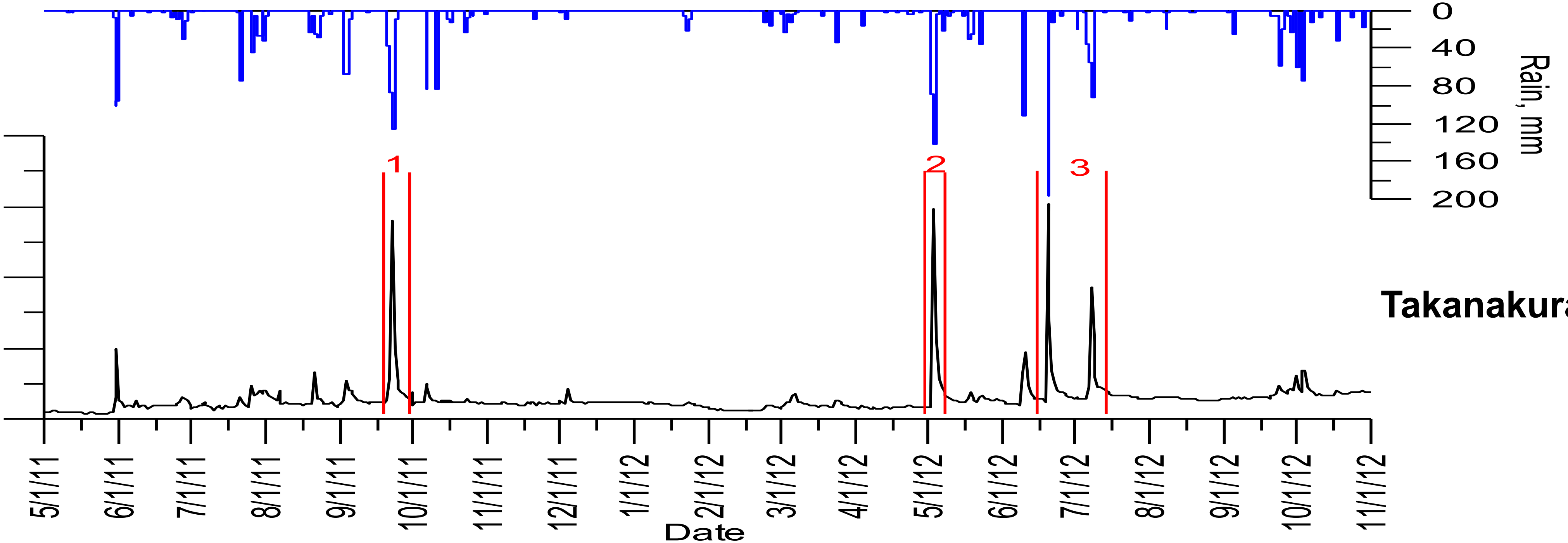
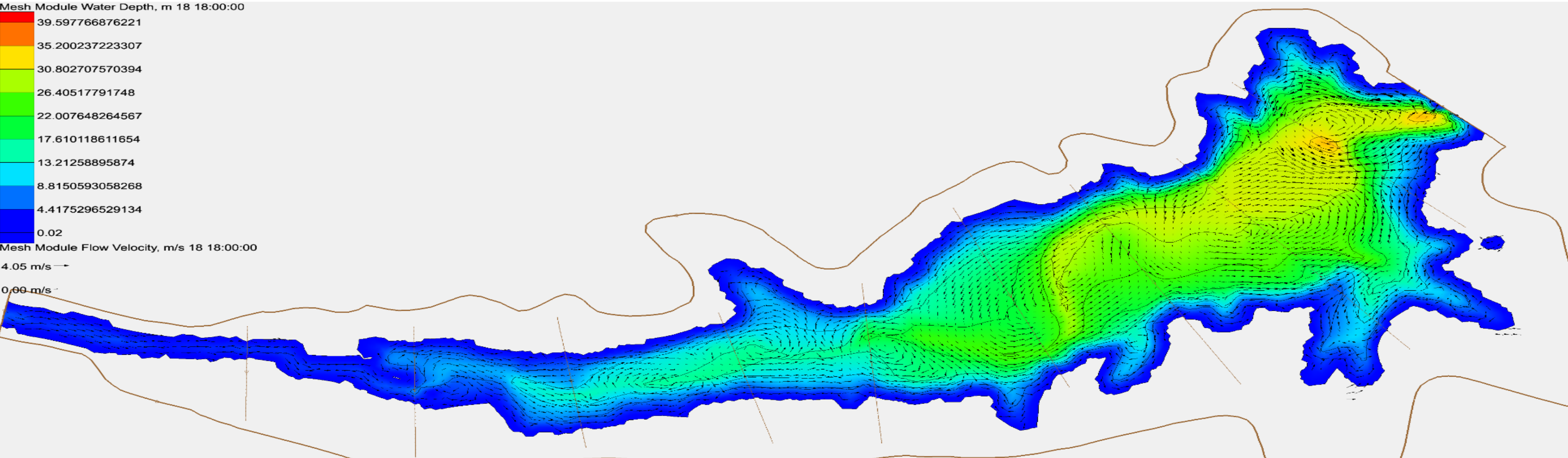
RADIOACTIVITY

2D COASTOX model implementation for simulation of Cs-137 transport in the reservoirs of Fukushima fallout Zone

Takanakura Dam



Water depth and water velocity field

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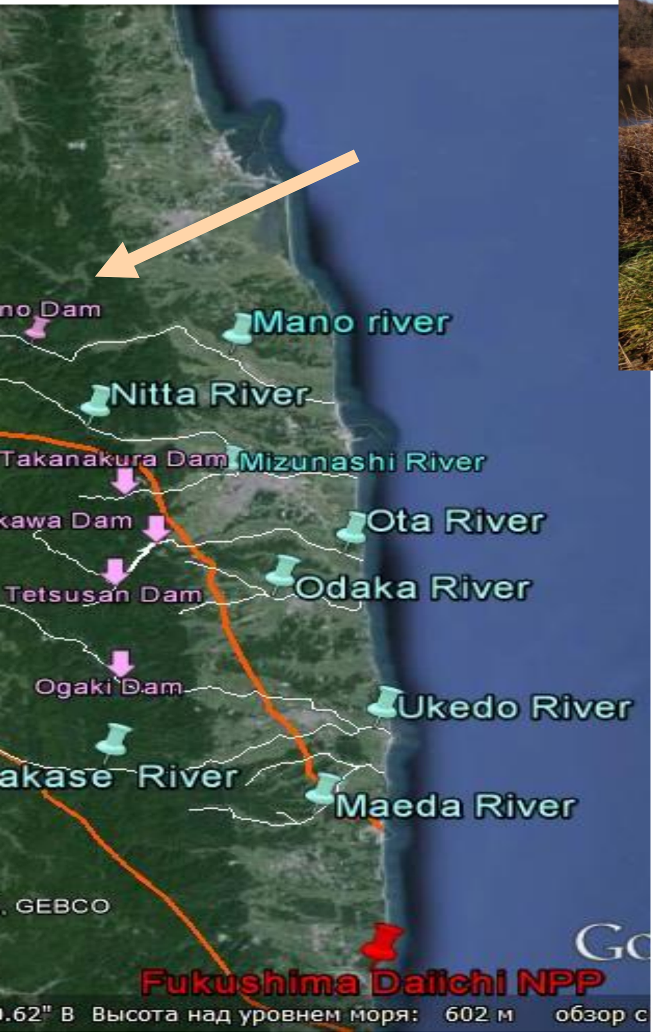
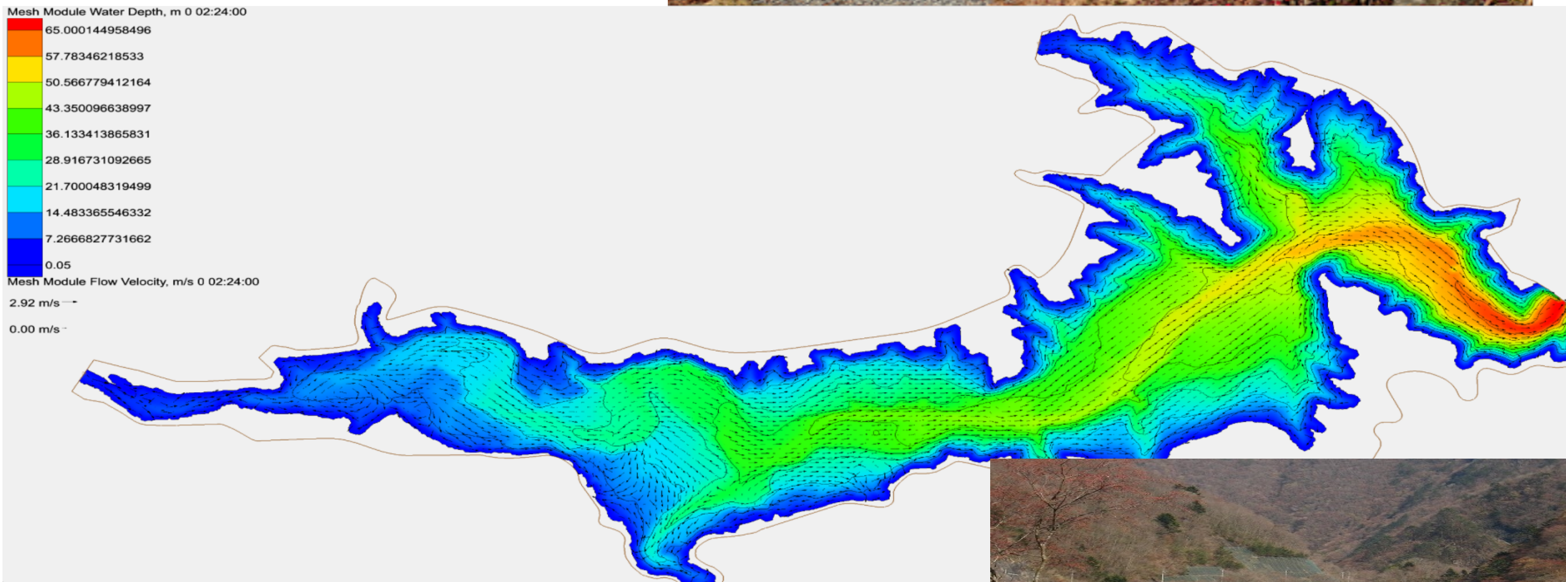
ADIOACTIVITY

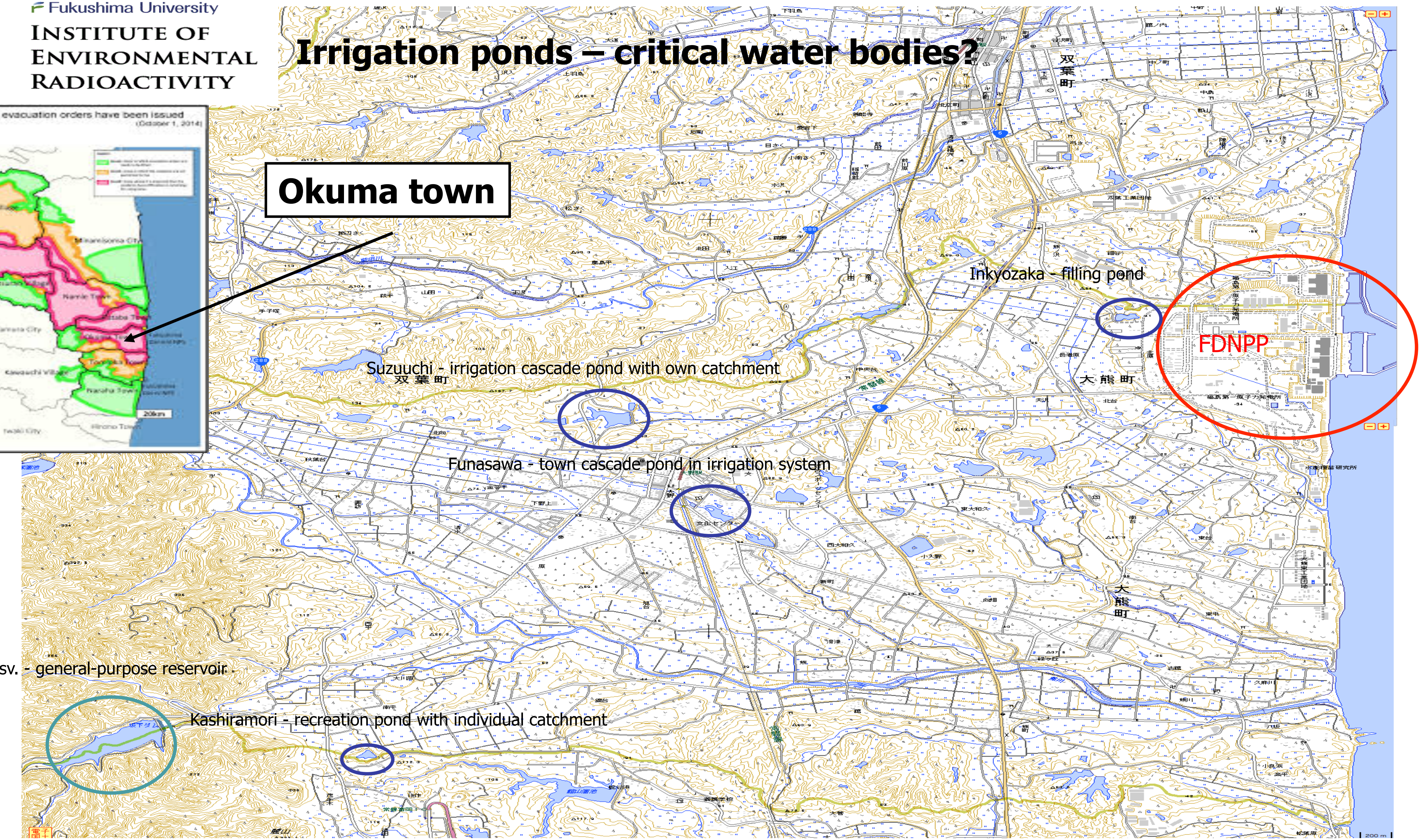
Mano Dam





Fukushima University
Institute of Environmental Radioactivity

Irrigation ponds – critical water bodies?



Status of THREETOX, POSEIDON & MOIRA in JRODOS within PREPARE

PREPAR

- Development of software interfaces for the transfer of atmospheric fallout simulated by JRODOS-ADM
- Comparison of THREETOX and POSEIDON with other models approaches of marine radionuclide transfer.
- Software tool for the retrieval of the global marine currents from operational model data
- THREETOX model improvements and testing of the updated model
- POSEIDON model improvements and testing of the updated model
- MOIRA Lake and River models translated and implemented in JRODOS. GUI developed. G adapted.
- Comparison of JRODOS-MOIRA Lake and River models against well-known test scenarios
- Application to Fukushima sites ongoing

PREPARE

Acknowledgement

- Partial funding received from the EC-Euratom FP7 (Nuclear Fission/Radiation Protection) **PREPARE project**: Innovative integrated tools and **p**latforms for **r**adiological **e**mergency **p**reparedness and post-**a**ccident **r**esponse in **E**urope (323287)