2nd Caesium Workshop: meeting challenges for Fukushima recovery, at Fukushima (2014.10.7)

NIES Modelling of Cs transport in terrestrial area around Fukushima

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Purpose of this study

- Background
  - It is necessary to know the long-term fate of ^{137}Cs
  - Understanding and forecasting of fate processes such as accumulation, runoff and flow-down through river system needs to be known, to consider the future actions to the residual terrestrial contamination
- Purpose of the study
  - To establish simulation model for multimedia fate processes of ^{137}Cs in Fukushima and surrounding region
  - Simulation has been performed by combining atmospheric transport model (CMAQ) outputs and a multimedia fate model G-CIEMS (Grid-Catchment Integrated Modeling System) which has been developed for Japan

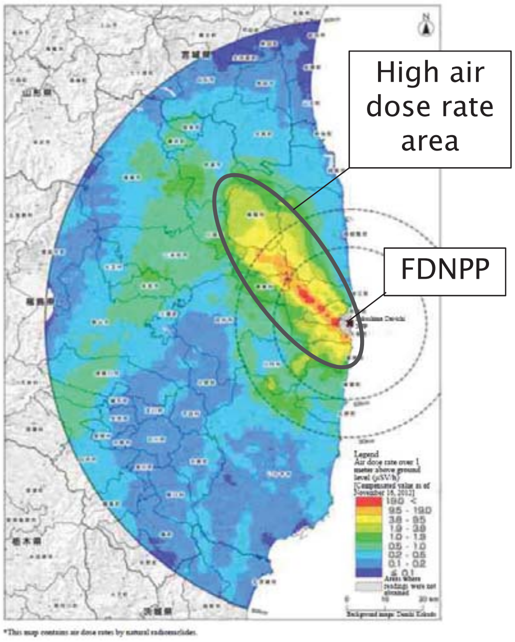
Today's topics

1. Overview of Fukushima
2. Introduction of multimedia fate model
3. Model conditions and results
4. Model improvement
5. Future tasks

1. Overview of Fukushima

Radioactive Cs in Fukushima

- Main nuclear species: ^{137}Cs(half-life of 30 yrs) and ^{134}Cs (half-life of 2 yrs)
- Frequently investigated area: within 80km from the Fukushima Dai-ichi Nuclear Power Plant (FDNPP)
- High air dose rate area spreads in a north-westerly direction (ellipsoidal area in the right map)

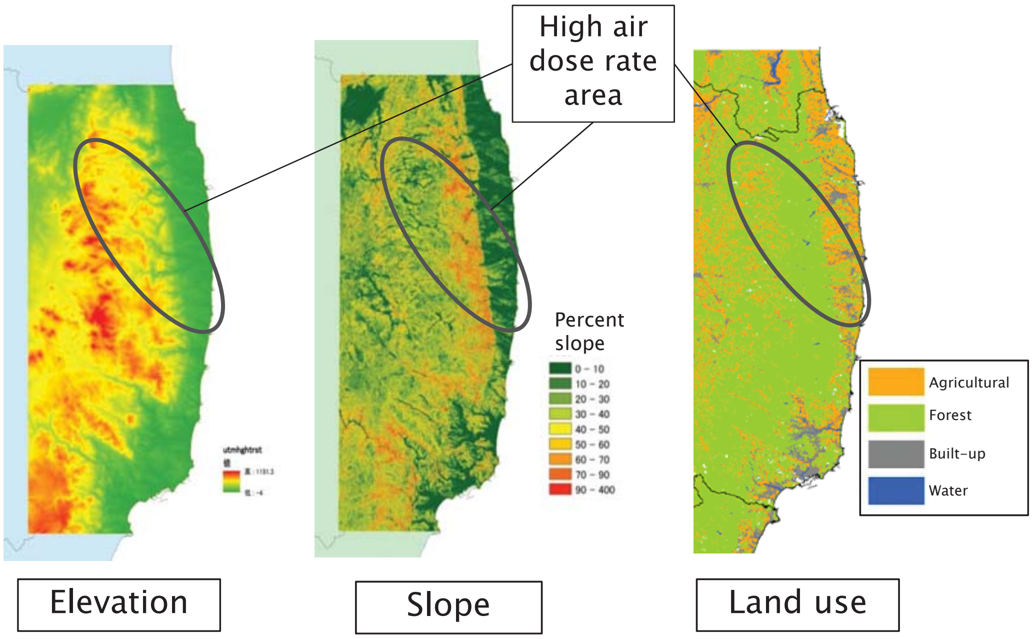


Air dose rate over 1m above ground level in the 6th airborne monitoring

From Nuclear Regulation Authority
http://radioactivity.nsr.go.jp

Land form, land use in high conc. area

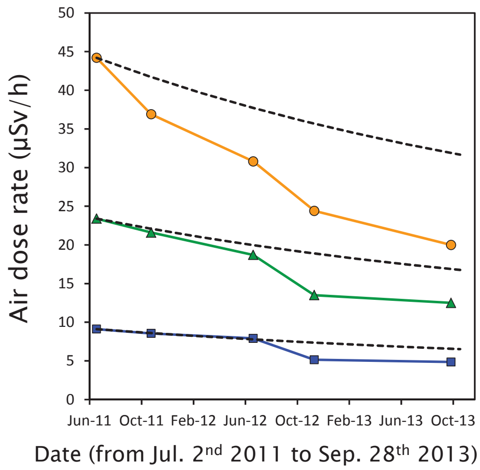
- Mainly east side of Abukuma mountains (=Hamadori region)
  - Top area of mountains: forest + agriculture, low slope
  - Half level of mountains: forest, steep
  - Bottom area: agricultural land + built-up area, flat



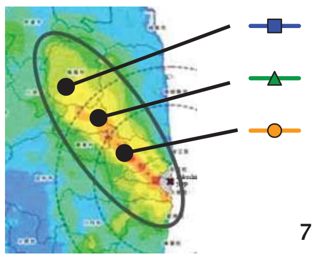
Time trend of air dose rate

- Air dose rate over 1m above the ground level from the 3rd – 7th airborne monitoring
- 3 meshes (1km x 1km mesh) picked up from high concentration area
- Dotted lines indicate theoretical radioactive decay of ^{134}Cs + ^{137}Cs

◆ Attenuation occurs by other reason than radioactive decay (e.g. weathering)



Time trend of air dose rate over 1m

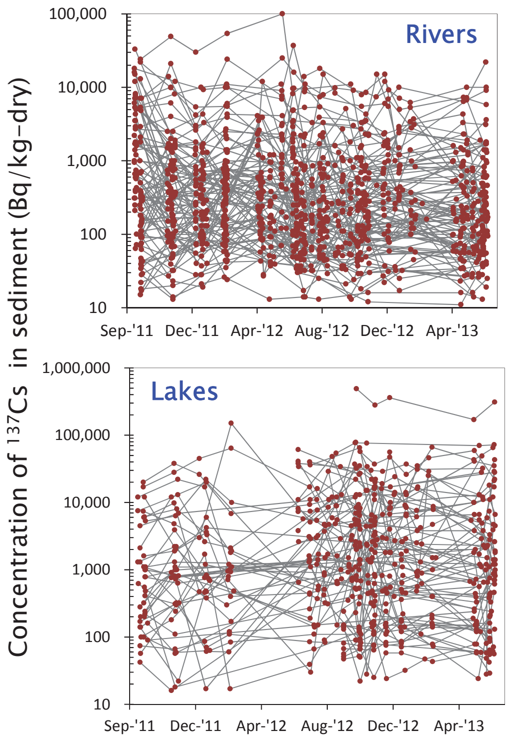


From Nuclear Regulation Authority
http://radioactivity.nsr.go.jp

Concentration of ^{137}Cs in sediment

- Pick up the sites where ^{137}Cs was detected in all samples in Fukushima prefecture.
- Same site's results are connected.

◆ Concentration in each site widely varied.
◆ Whole trend is not clear



Concentration of ^{137}Cs in sediment in Fukushima prefecture.

From the Ministry of the environment
http:// www.env.go.jp/en/water/rmms/surveys.html

Meteorological properties of Fukushima

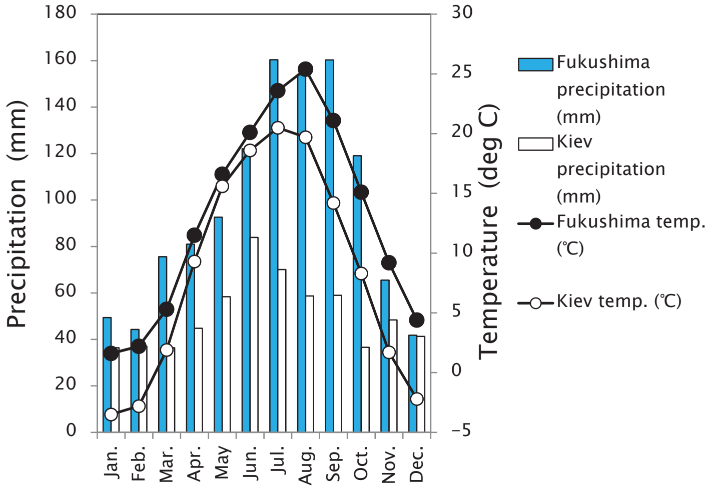
Comparison with Kiev city located near Chernobyl

- Mean monthly temperature and precipitation in average year, Fukushima city and Kiev city

Fukushima's

- Temperature is about 5 degrees C higher
- Precipitation is two times higher

◆ **Influence of rainfall is important**



From Japan Meteorological Agency
http://www.data.jma.go.jp

Key processes in each "place"

- Forest area
  - Vertical transport: intake into trees, litterfall, from litter layer to soil (include decomposition of litter), vertical distribution in soil layer
  - Characteristics: tree species (evergreen/conifer, or more detail), slope, management condition
  - Soil runoff: soil erosion, gully erosion, landslide
- Surface water and sediments (rivers and lakes, dams)
  - Initial deposition: surface water area, structural river width
  - Temporal change: flow rate, river width, hotspots in river bed
  - Suspended solids: bed load transport, suspended sediment transport, wash load, sedimentation and resuspension
- Urban area
  - Artificial material: sorption of Cs, penetration of Cs
  - Artificial transport: decontamination, waste transportation (e.g. dead leaves, weeds)
  - Water network: river water, sewage water, irrigation (seasonal event)

Key points related to environmental fate of radioactive Cs

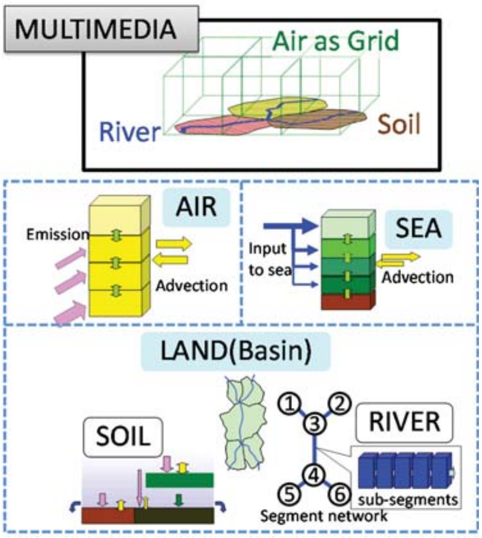
Especially for the Fukushima accident

- Forest is main "high polluted area"
- Radioactive Cs transports from "high polluted" mountainous area to lower-level, flat, inhabited area
- Air dose rate at the surface (1m above) obtained by airborne monitoring is gradually decreasing, but concentration of ^{137}Cs in sediment might not.
- Influence of heavy rainfall event is important

2. Introduction of multimedia fate model

Multimedia fate model（G-CIEMS）

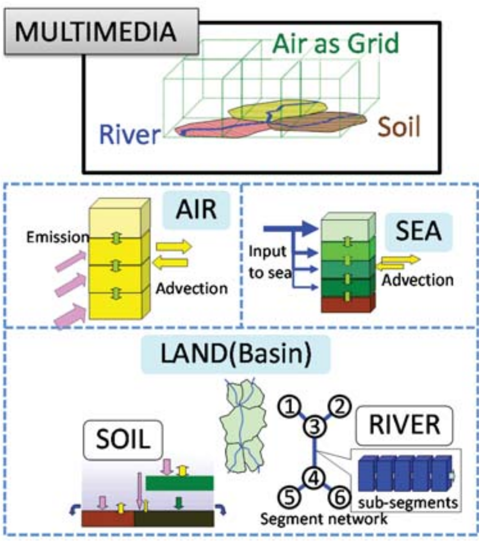
- Calculating fate of organic chemicals in multimedia (atmosphere, surface soil, surface water, etc) for whole Japan
- Spatial resolution for all media based on actual geological formation
- Connection between Soil runoff, river, and rivers network

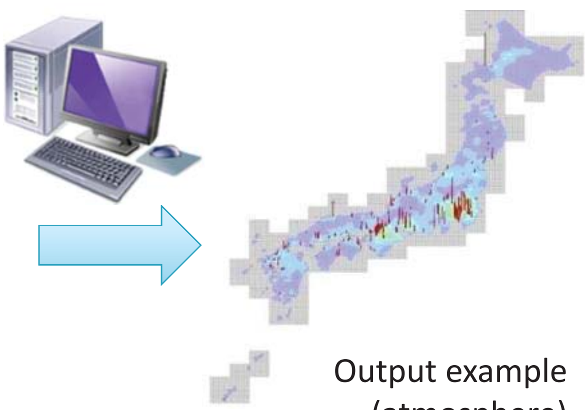


media	Average size	No of segments
Atmosphere	5km x 5 km (or 1km x 1km)	About 38 thousands (above the terrestrial land)
Surface water	5.6 km (length)	About 38 thousands
Surface soils	9.3 km^2	About 38 thousands
sediment	under the all surface water segments	

Multimedia fate model（G-CIEMS）

- For exposure assessment of organic pollutant, based on spatial distribution of concentration in each media
- Mainly for annual average situation



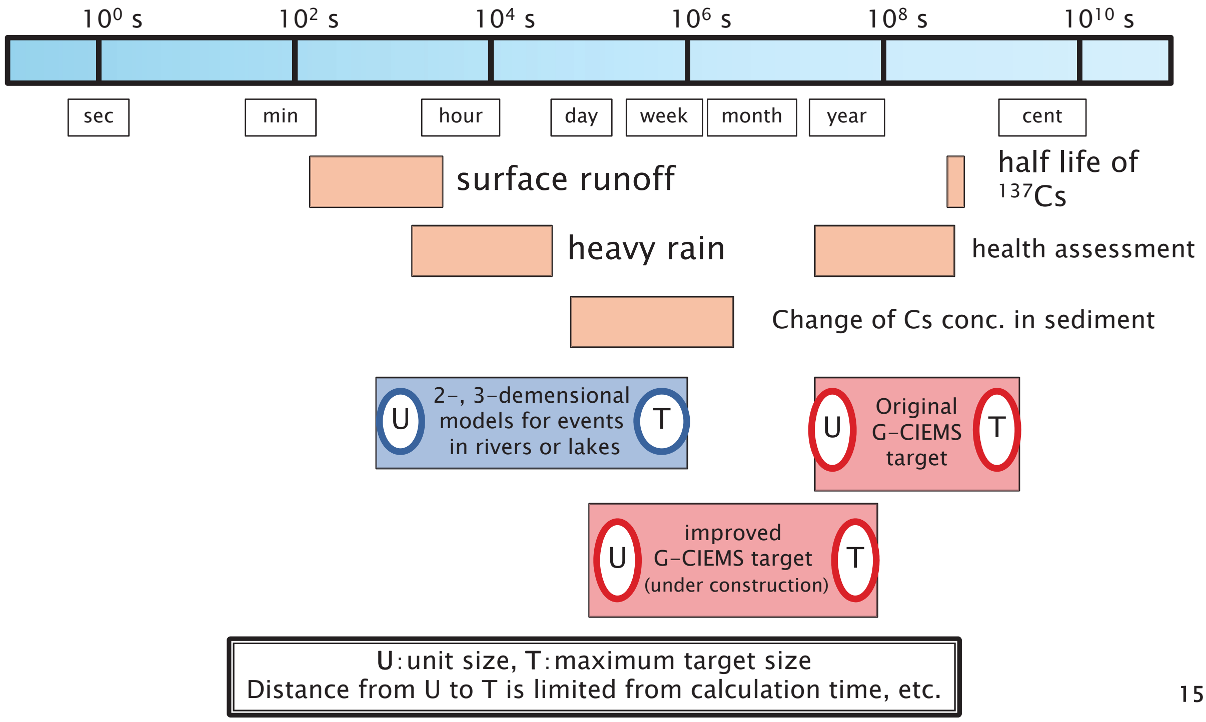


Output example (atmosphere)

Suzuki, N. *et al.* (2004) *Environ. Sci. Tech.*

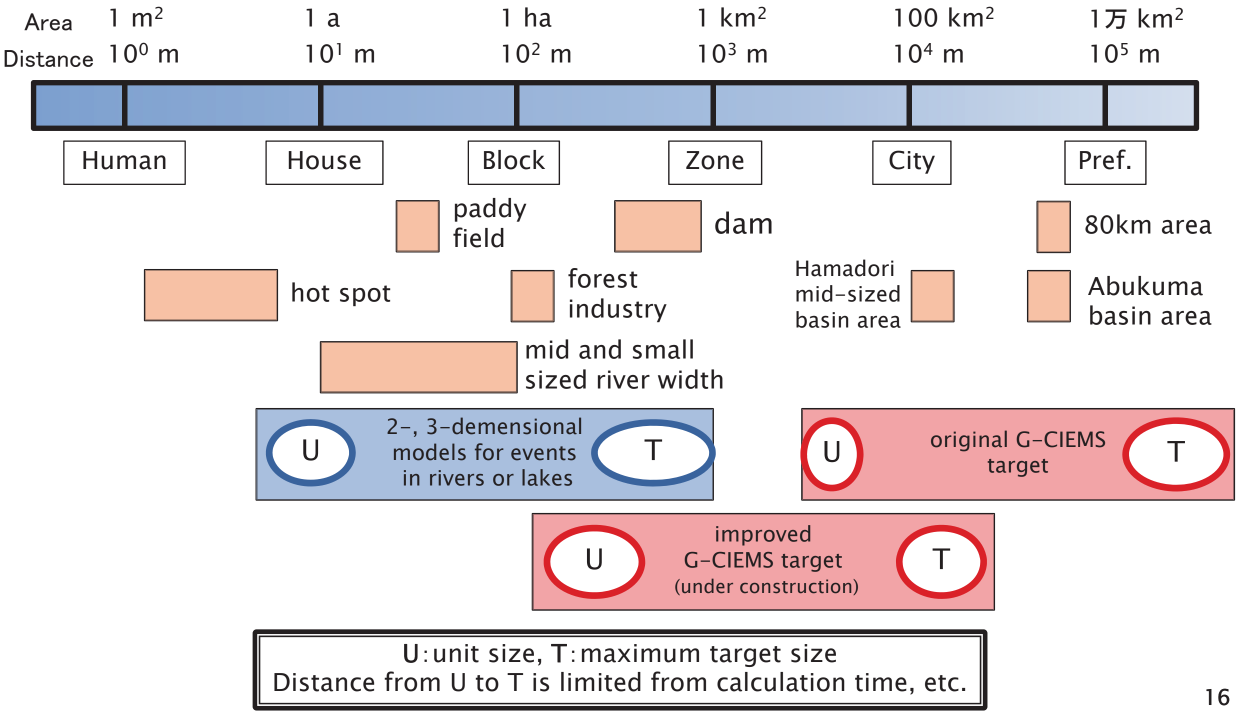
Target temporal scale

Temporal resolution of each event



Target spatial scale

Spatial resolution of each event



Summary about model scale

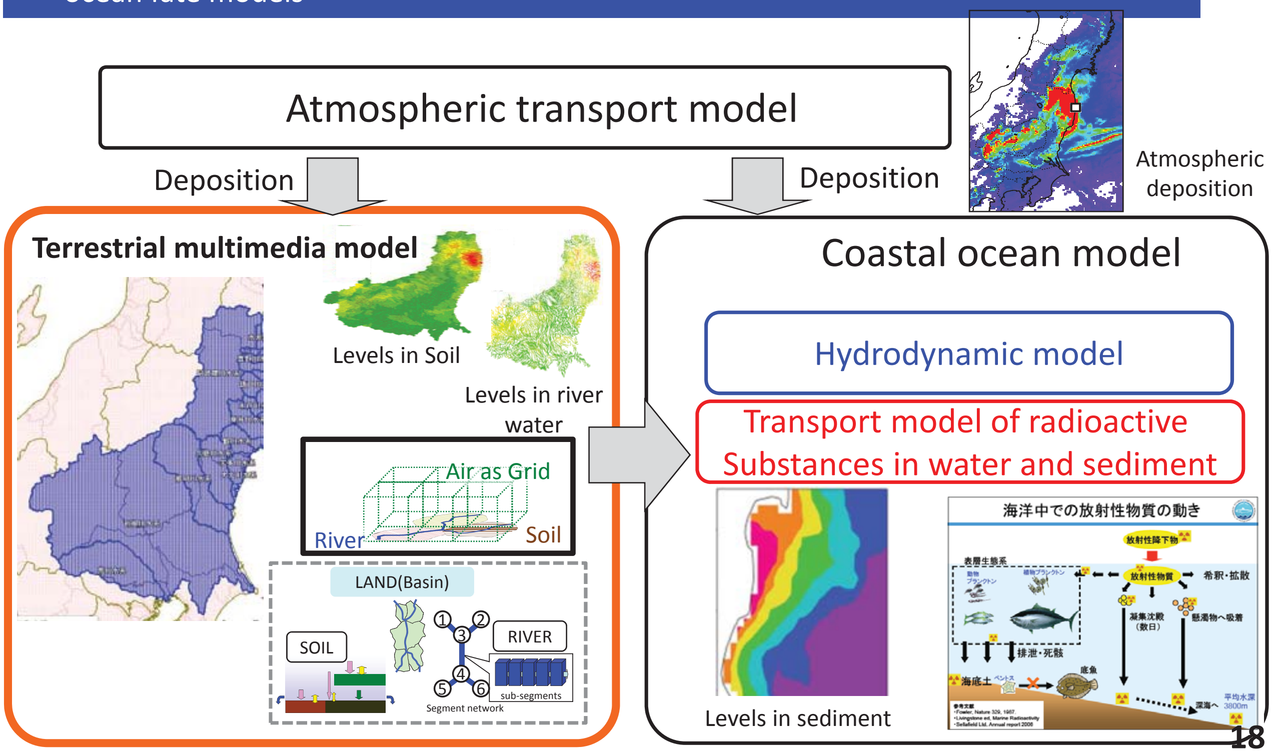
About developing a model for Cs fate in the environment

- First step
  - To roughly grasp the whole situation (e.g. flow and stock)
  - Spatial scale: Fukushima + north Kanto region
  - Temporal scale: annual, decade

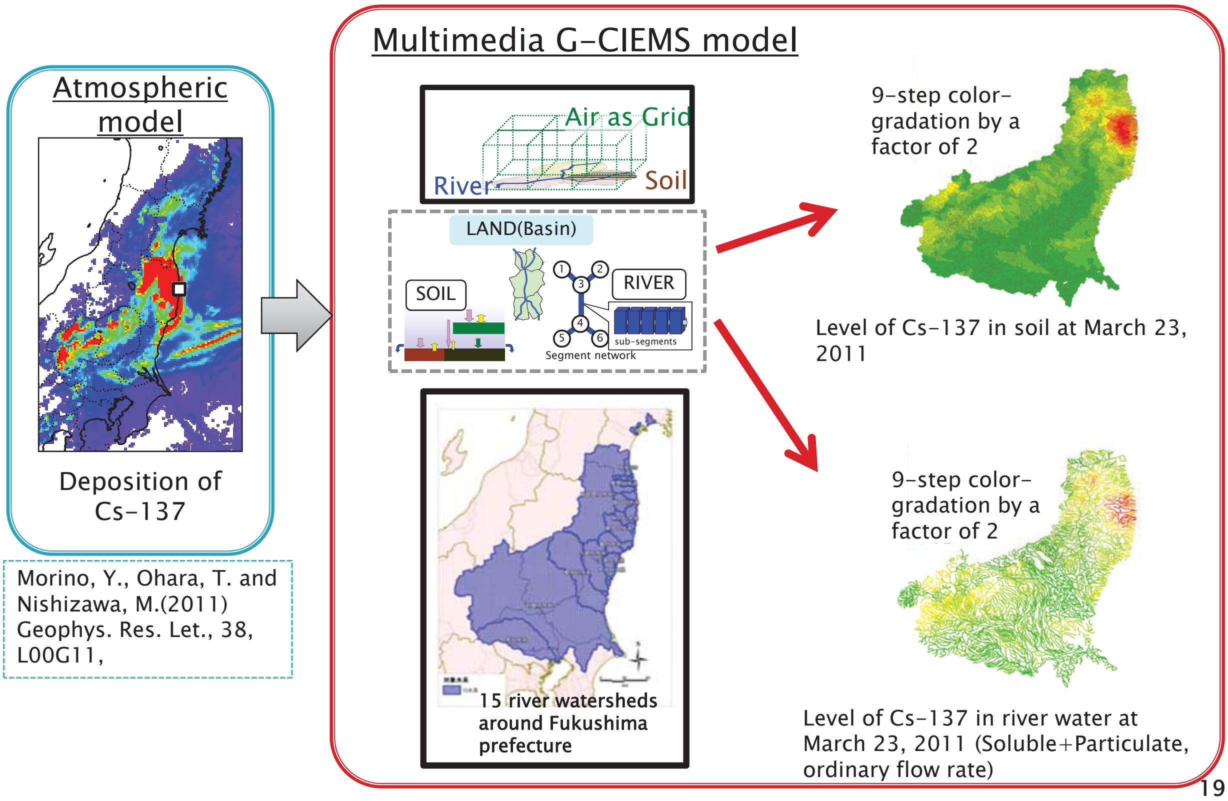
- Next step
  - To represent key processes (e.g. Surface runoff caused by heavy rain)
  - Focus on limited area such as high concentration area, interesting place
  - Spatial scale: Abukuma river basin, hamadori region.
  - Temporal scale: annual

Project in NIES : multimedia fate modeling study

- To establish simulation model to estimate the long-term (up to several tenth years) fate of radioactive substances, combining existing atmospheric, multimedia and ocean fate models

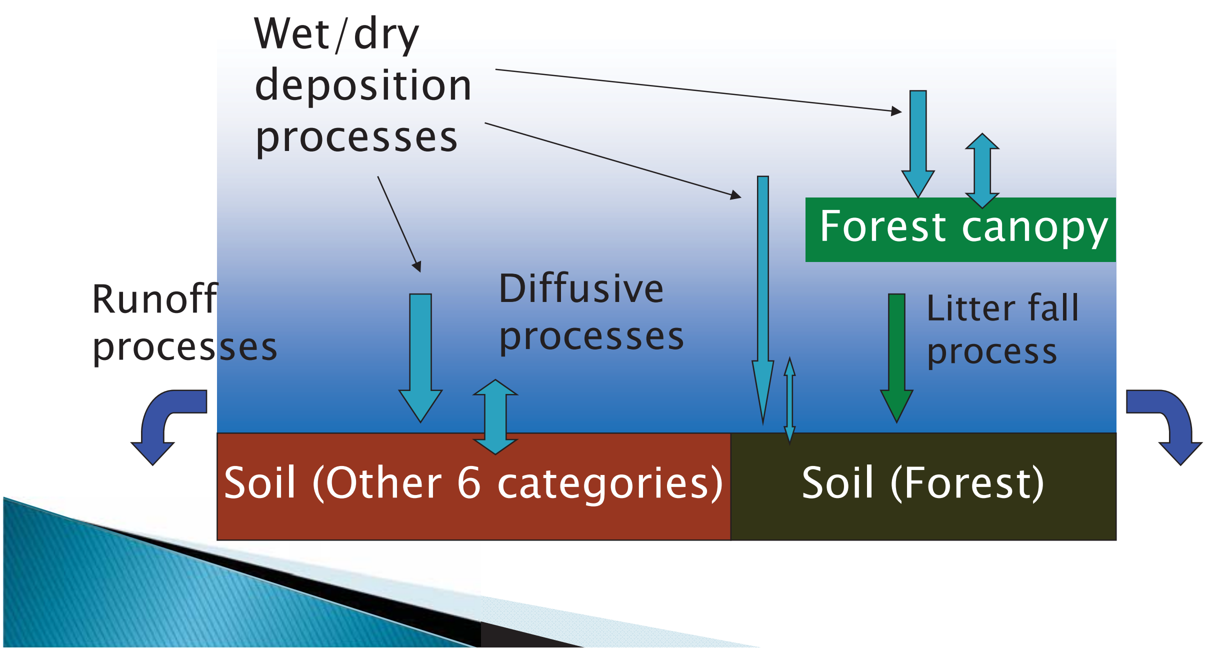


Model domain setup



Transport processes in soil compartment

- Each soil segment have 7 categorized zones (land-use area), which have independent properties and concentration

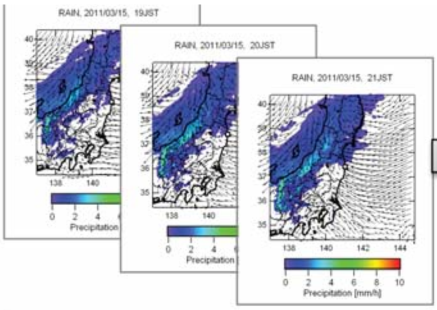


Atmospheric transport model (ATM)

Application of pollutant-transport model to radioactive substance

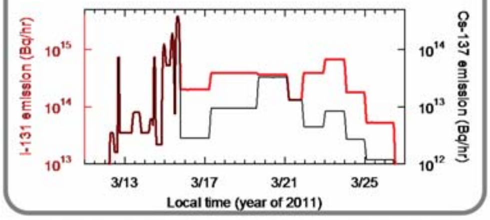
Meteorology model (WRF)

Numerical weather prediction system to produce 4-dimetional wind/precipitation data-field for model calculation



Source data (JAEA)

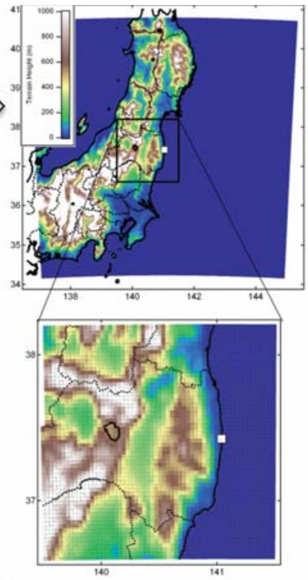
Hourly emission estimates of I-131 and Cs-137 from damaged plant



Chemical transport model (CMAQ)

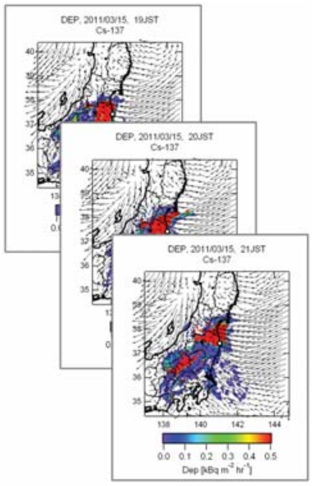
Simulation of advection/diffusion from sources and wet/dry depositions

Simulation domain



Simulation results

Levels and depositions of Cs-137



3. Model conditions and results

- Setup model conditions
- Results of calculation

Parameter setup (1)

- Fixed assumption
  - Chemical species of Cs is not considered
    - No enough information
  - Soil depth
    - Farm land: 30 cm, built-up area: 3.5 cm, other areas : 5 cm
    - Tentative setup considering the area characteristics of the land use
  - River flow rate
    - Constant flow rates based on ordinary water discharges
  - River and lake sediment
    - Constant depth as 2 cm
    - Constant re-suspension at a rate of complete turnover in 3 years
- Values for considering sensitivity to results
  - K_d: Distribution coefficient of Cs between solid and liquid
  - Soil Runoff rates in each land-use areas

Parameter setup(2)

– ranges of sensitivity analysis for K_d and runoff rates

Distribution Coefficient (K_d):
- Central value: Geometric mean in IAEA report*
- High-K_d : 5-times higher than the central
- Low-K_d : 5-time lower than the central

Soil Runoff rates
- Forest and Shrub: Based on field observation of ^{137}Cs runoff in Tsukuba Mt. (0.3%/year)
- Paddy/Farm land: Based on agricultural land guidance (Case1, 3), or 5 times lower than that (Case2, 4)
- Built-up area: Based on airborne monitoring analysis (Case 1, 2), or same as nonvegetated area (Case 3, 4)
- Nonvegetated/Other areas: 20 times lower than the farm land value (Based on plant coefficients in USLE cited in agricultural land guidance

Kd (L/kg)	High Kd	Cent Kd	Low Kd
In Soil	6.0 x 10^3	1.2 x 10^3	2.4 x 10^2
In surface water and sediment	1.45 x 10^5	2.9 x 10^4	5.8 x 10^3

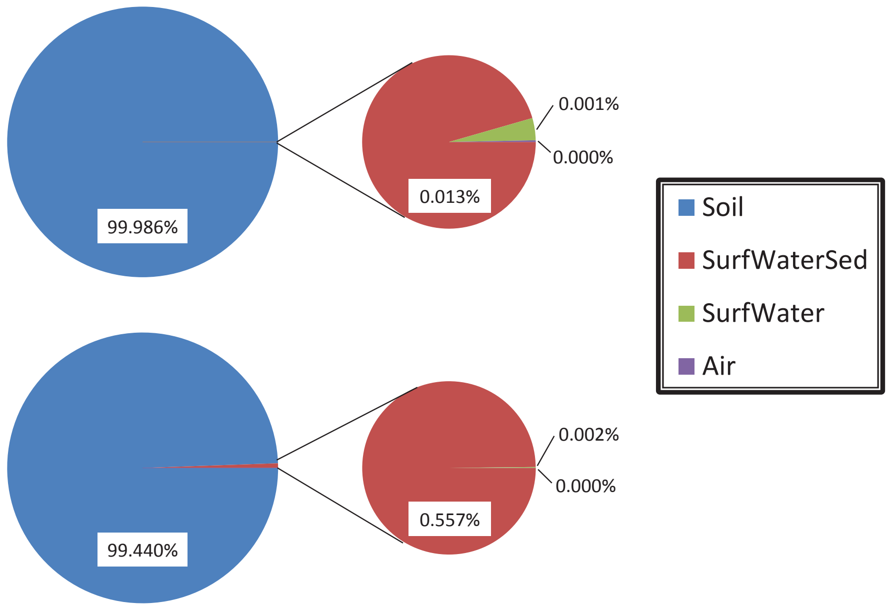
	Soil depth (cm)	Soil runoff rate as bulk (mm/y)			
		Case 1	Case 2	Case 3	Case 4
Forest and shrub	5	0.17	0.17	0.17	0.17
Paddy and other farmland	30	1	0.2	1	0.2
Built-up	3.5	4.6	4.6	0.05	0.05
Nonvegetated and Others	5	0.05	0.01	0.05	0.01

Central condition used in following results.

*IAEA (2010), Technical Reports Series no. 472.

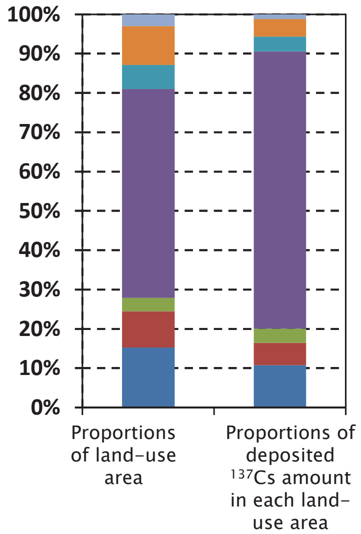
Media distribution of ^{137}Cs in the simulation domain

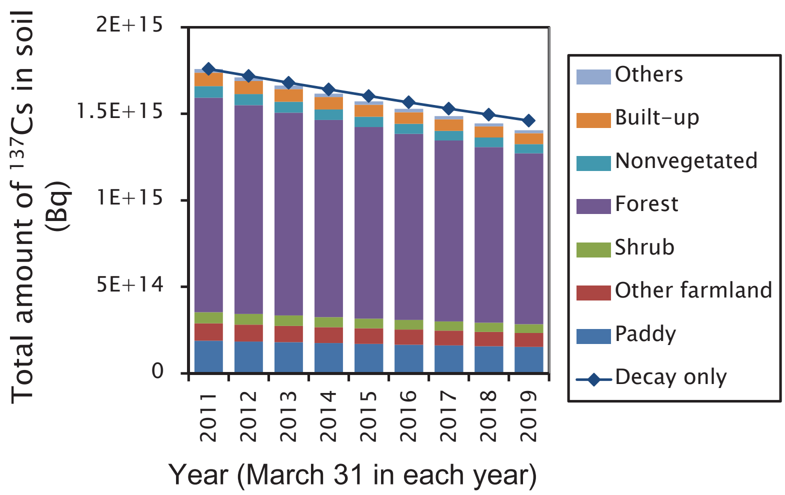
- Most part of ^{137}Cs exists in soil compartment
  - More than 99% in soil after 2 years
- Second largest part exists in surface water sediment



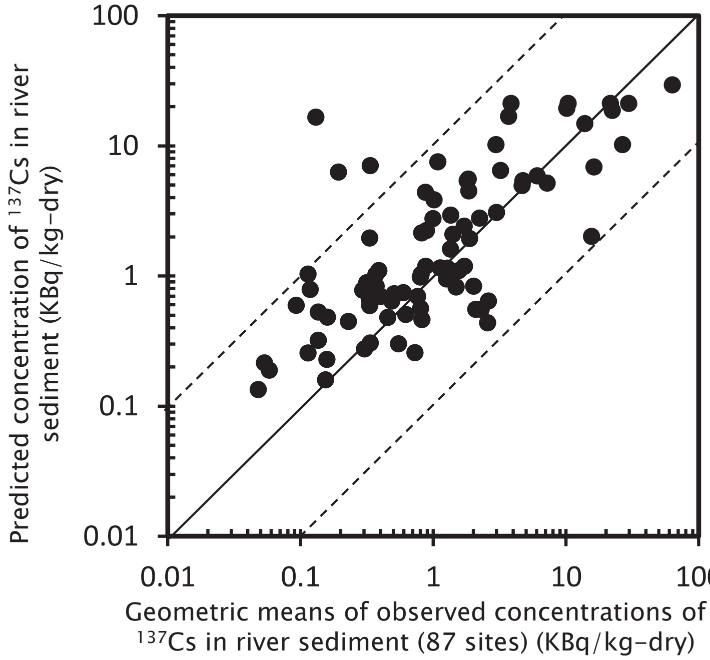
Simulated trend of ^{137}Cs in soil

- Most part of ^{137}Cs were mainly deposited to forest area
- Decreasing trend of ^{137}Cs in soil
  - Simulated to slightly faster than radioactive decay, by runoff processes





Comparison between observations and predictions of ^{137}Cs concentrations in river sediment

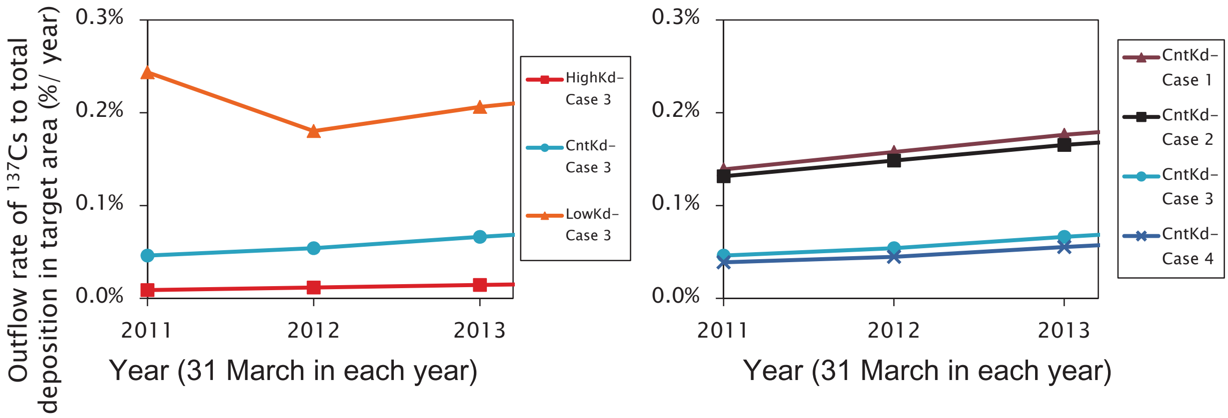


- Rough consistency between observations and predictions
- Further study need for more detailed analysis and other compartments

Comparison between geometric means of depth-corrected concentrations of ^{137}Cs in river sediment in Fukushima prf. where ^{137}Cs was detected in all four surveys performed in FY 2011, and predicted concentrations in related river sediment at March 31, 2012

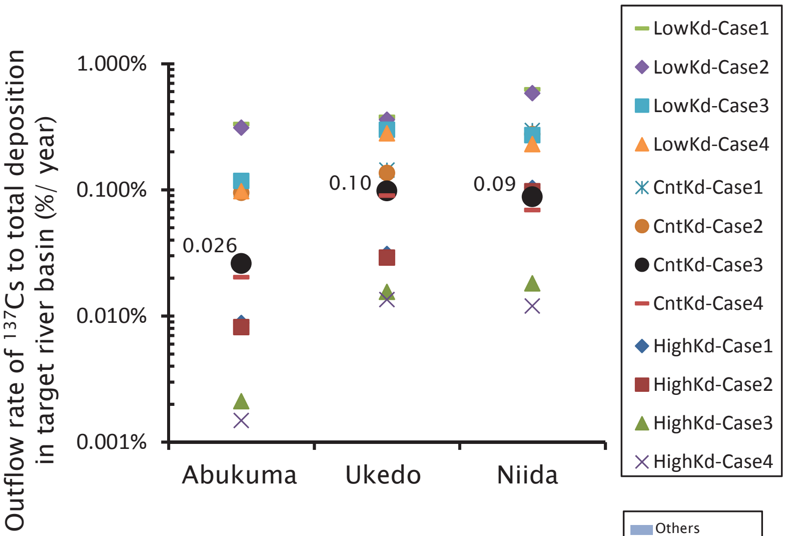
Discussion: Sensitivity analysis – ^{137}Cs Outflow from land to the sea

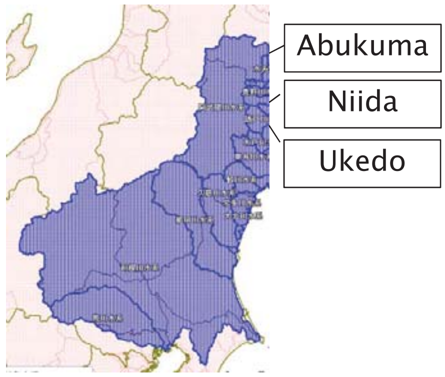
- Outflow flux of ^{137}Cs is simulated to keep steady trend
  - It may be strongly affected by distribution coefficients and soil runoff rates
- Since prediction still contains large uncertainty, further study is necessary before the results will be considered confidential

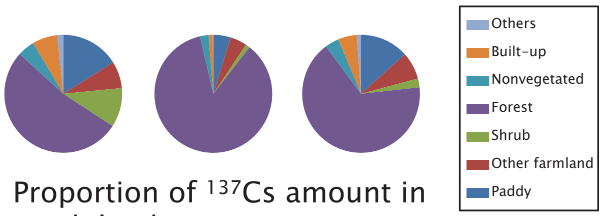


✓ Cnt K_d: 1.2×10³ L/kg, High-K_d : Cnt kd x 5, Low-K_d : Cnt Kd / 5
✓ Soil Runoff rates (default case is “Case 3”)
Case 1: High farm land, high built-up, Case 2: Low farm land, low built-up
Case 3: High farm land, low built-up, Case 4: Low farm land, low built-up

^{137}Cs outflow from 3 river basins







Proportion of ^{137}Cs amount in each land use area (2011.3.31)

- Almost 0.01 – 0.3 %/year
- Based on a "central" condition, 0.02 – 0.1 %/year

Summary of results

- First trial of multimedia fate model for ^{137}Cs around Fukushima region was developed
  - Media distribution
  - Long-term Temporal trend
  - Outflow simulation from river to ocean
- Preliminary study on major uncertainties from:
  - Runoff parameters
  - Solid-liquid partitioning

- Next tasks
  - Surface runoff processes
  - Transportation in surface water network

4. Model improvement

Focus on surface runoff caused by heavy rain

Outline of USLE

USLE (Universal Soil Loss Equation)

- To predict the average rate of soil erosion for agricultural fields. Kitahara *et. al* apply USLE to Japanese mountainous forest.

- A=R K L S C P
  - A: Soil loss per unit area
  - R: Rainfall and runoff factor
  - K: Soil erodibility factor, decided from soil condition
  - L: Slope-length factor
  - S: Slope-steepness factor
  - C: Cover and management factor, comparing to tilled fallow
  - P: Support practice factor, like strip-cropping or terracing

◆ Only R factor could change drastically.
◆ Several factors (C, P) could change seasonally or slowly.

USDA Agriculture handbook 537 (1978)
Kitahara, J. For. Res. 5 (2000)

Rainfall and runoff factor (R)

- R factor equals cumulative EI (Energy-times-Intensity) values, which indicate effects of each rain event.
- Modified method by Hosoyamada 1984 (1-hour rainfall intensity was used, though originally 30-min rainfall intensity was used,)

$$E = (916 + 331 log_{10} I) \times 0.753$$

$$R = \sum E \cdot I_{60}$$

E : Energy of unit rain (m･tonf/hectare/inch)

I : Intensity of rain (inch/hour)

I_{60}: Maximum 60-min intensity for each rain event

R : Runoff factor (m^2･tonf/hectare/hour)

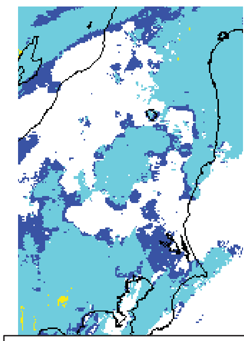
- rain event: divided by "no rain"(<1mm/hour), and total rainfall is more than 13 mm.

> - R factor include effect of "rainfall energy"
> - So, R factor is not proportional to amount of rainfall

Rainfall and R factor

Rainfall data

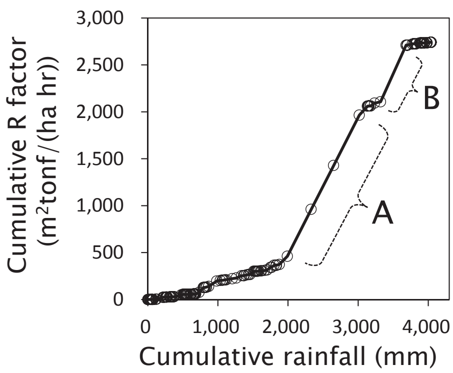
- Radar-AMeDAS Precipitation Analysis
  - Rain gauge observation at about 1,300 by Japan Meteorological Agency
  - Estimated precipitation based on Radar echo intensity data and AMeDAS observation data
  - rainfall data for each 3^{rd} mesh (≒$1km^2$), every 30 min.



Radar-AMeDAS Analysis

Daily rainfall vs daily R factor

- From March 1^{st} to December 31^{st} 2011
- In a mesh having the maximum value of total R factor
- Only two rainfall events ("A" and "B" in right fig.) contribute more than half of the total value of R factor



Discussion points about model improvement

- USLE would be useful in order to improve the model for having spatiotemporally higher resolution.
- It is important to evaluate influence of “higher resolution” in next viewpoints

- First (priority)
  - To accurately predict “total amount of outflow of ^{137}Cs from certain terrestrial region” (e.g. Annual flux)

- Second
  - To predict influence of a “big event” to the flux of Cs (but, to predict a big event itself is out of target)

5. Future tasks

Future tasks

- Discussion by monitoring data analysis
  - Both air dose rates and concentrations of ^{137}Cs and ^{134}Cs
  - Mass balance of ^{137}Cs in the environment
- Solid-liquid partitioning of ^{137}Cs
  - "Insoluble cesium ball"
  - Sorption onto organic matter
- Incorporation of detailed terrestrial/aquatic processes
  - Model improvement both terrestrial surface runoff and aquatic water/soil transportation
- Detailed consideration for built-up area
  - Artificial water network
  - Decontamination works

THANK YOU FOR YOUR ATTENTION!