Overview of the F-TRACE Project

- **Objectives**
  1. Elucidate behavior of transport of radioisotopes (Cs at first) from contaminated forest to biosphere and sea.
  2. Develop dose evaluation system and methodology to constrain Cs transport, leading to decrease of dose.
  3. Construct comprehensive system to predict transport of radioisotopes combining with methods for dose reduction.

1) Transport modelling

2) Comprehensive system

2a) Evaluation of radiation dose

- Inhalation
- External exposure
- Ingestion

3) Constraint of Cs transport

- Soil particles, organics, soluble Cs
- Forest, soil, artificial materials (roof, asphalt, concrete, etc.), water, rubble, etc.
Key phenomena in the Cs transport

[Mountain forests]
Canopy → Soil surface
- stemflow, litter fall
Soil surface → subsurface
- advection, dispersion
Soil surface → River
- erosion, dissolution, debris flow etc.

[Rivers & reservoirs]
Transport by flowing water
- with mineral particles
- deposition under the settling velocity
- trapping by plants on the flood channel

[Estuaries]
- Transport by tides, waves, and coastal currents
- Desorption of Cs from soil particles
- Aggregation and deposition of soil particles

Investigation & Simulation Area

Modelling of transport by flowing water:
5 rivers in Pacific coastal region

- **Forests investigation**
  - Kawamata (deciduous forest)
  - Kawauchi (ever-green / deciduous forest)
  - Namie (ever-green / deciduous forest)
  - Okuma (ever-green forest)

- **Rivers & Estuaries investigation**
  - Ukedo river (highest Cs inventory)
  - Tomioka & Ogi-no-sawa rivers (flow through decontaminated area)
  - Odaka river (high salinity at estuary)
  - Kuma river (no dam deposit)
  - Maeda rivers (flow through the highest dose rate area)

- **Dam reservoirs investigation**
  - Ogi dam (Ogi-no-sawa river basin)
  - Ohgaki dam (Ukedo river basin)
  - Takigawa dam (Tomioka river basin)
  - Ponds in Okuma and Futaba town

- Flowing from relatively high to low dose rate areas → **easy to detect Cs transport**
- Small scale → less difficulty with the modelling & its validation
From field investigation to the modelling & simulation

(i) Forest to river
  → Soil loss model
  USLE etc.
  OUTPUT: Inflow of Cs to the rivers

(ii) River to estuaries & coastal region
  → 1D transport model
  TODAM etc.
  → 2D transport model
  iRIC etc.
  OUTPUT: Inflow of Cs to the sea

(iii) Estuaries & coastal region to sea
  → 3D transport & reworking model in estuaries and sea
  FLESCOT, ROMS etc.
  OUTPUT: Transport and reworking behavior within the coastal region

Field investigation
Example of research area: Ogi-no-sawa basin

- River investigation
  - Continuous river observation (water level, turbidity, sampling)
  - Periodic monitoring and sampling

- Monitoring of dose rate and meteorological conditions

- Dam investigation
  - Sampling water and deposits

- Forest investigation
  - Sampling soils
  - Continuous observation of stemflow and surface flow etc.

Example of research area: Ogi-no-sawa basin

- Monitoring of dose rate (decontaminated area)


Forest investigation

- Forest investigation
  - Sampling soils
  - Continuous observation of stemflow and surface flow etc.

Monitoring of surface runoff and soil loss in the forest

- Stemflow and rain fall in and out of forest; source of surface runoff in the forest
- Soil wetness; parameter related to an infiltration of surface water into the soil
- Turbidity of surface water; concentration of suspended solid in the surface water
- Triangular weir; measurement of water level, turbidity, and water sampling
- Tank for soil catchment; measurement of soil yield in the observation plot, soil sampling

Depth profile of radiocaesium in topsoil of the forest

- More than 90% of Cs was still left within 5 cm depth of topsoil (~2 y after the accident).
Dose rate across the edge of the forest

- **Organic horizon**: 10 cm
- **Surface condition**: Trace of surface runoff
- **Decontaminated area**: Whole view of the survey line
- **Trace of surface runoff**: To the South
- **Cider forest**: Broadleaf deciduous trees (mantle community of the cider forest)
- **Ground surface**: Deposition of litter

Rivers and estuaries investigation

- **River investigation**
  - Continuous river observation (water level, turbidity, sampling)
  - Periodic monitoring and sampling

- **Continuous river observation**
- **Measurement of velocity and turbidity**
- **Sampling (water, sediment)**
- **Measurement of river cross section shape**

![Topographic map](http://watchizu.gsi.go.jp/watchizu.html?meshcode=56400655)
### Distribution of dose rate across the river

**Odaka River, middle stream (ODAR-5)**

- **High dose rate area:** Flood channel
- **Low dose rate area:** Side bar

**Dose rate** ($\mu$Sv/h)
- $0.4-0.7$
- $0.7-1.0$
- $1.0-1.3$
- $1.3-1.6$
- $1.6-1.9$
- $1.9-2.2$
- $2.2-2.5$
- $2.5-2.8$
- $2.8-3.1$
- $\geq 3.1$

**△:** $1$ m height
**○:** $1$ cm height

1 m

https://maps.google.co.jp/maps?hl=ja

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### Depositional process of soil particles in the river

**Odaka River, middle stream** (ODAR-5)

- **Flood channel**
- **River channel**

**Flowing water only in the high water level** → Transport of Cs with soil particles

**Trapping of fine soil particles by the plants on the flood channel**

**No deposition** of fine soil particles → relatively low dose rate
Cs concentration in the river sediments

- Cs concentration of sediment in flood channel is higher than that of river channel, but the difference is within one order of magnitude.
- Cs is strongly adsorbed onto mineral particles in the sediments.
- Cs concentration drastically decreased at the closest point to estuary in Odaka River, where:
  - no coastal sandbar was formed at estuary,
  - salinity near estuary was similar to seawater.
- Cs was possibly desorbed from soil particles near estuary due to high salinity.

Salinity of river water

<table>
<thead>
<tr>
<th>River</th>
<th>Location</th>
<th>Surface Salinity</th>
<th>0.5m Salinity</th>
<th>1m Salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odaka River</td>
<td>at low tide</td>
<td>left bank 0.3%</td>
<td>right bank 0.3%</td>
<td>left bank 0.5%</td>
</tr>
<tr>
<td></td>
<td>at high tide</td>
<td>left bank 1.2%</td>
<td>right bank 1.3%</td>
<td>left bank 1.3%</td>
</tr>
<tr>
<td>Ukedo River</td>
<td>at low tide</td>
<td>left bank 0%</td>
<td>right bank 0%</td>
<td>left bank 0%</td>
</tr>
<tr>
<td></td>
<td>at high tide</td>
<td>left bank 0%</td>
<td>right bank 0%</td>
<td>left bank 0%</td>
</tr>
</tbody>
</table>

Data from various sampling locations and depths.
Dam reservoir investigation

- Sampling water and deposits

Sampling of sediments and water in the reservoir

- Water sampling (Heyroth sampling bottle)
- Sampling of bottom sediments (Smith-Mcintyre Bottom sampler)
- Core logging (undisturbed sampling)
- Core logging (Gravity core sampler)
Depth profile of radiocaesium in the bottom sediments

1: Undisturbed
Core length: 6.5 cm

2-2: Undisturbed
Core length: 6.8 cm

3-2: Undisturbed
Core length: 16.0 cm

4-1: Gravity
Core length: 16.0 cm

4-2: Undisturbed
Core length: 11.7 cm

- Thick fine-grained sediment at deeper part of the dam
  - 22 cm in thickness,
  - constant Cs conc.

- Thin fine-grained sediment at shallow part of the dam
  - ca. 7 cm in thickness
  - comparable Cs conc.

- No radioactive Cs was significantly detected in any lake water samples.

Other investigation and observation around the Ogi dam

- Other investigation and observation around the Ogi dam:
  - ca. 100 m
  - Aerial photograph

- Continuous river observation

- SS trap

- Monitoring of air dose rate and meteorological conditions

- Forest investigation (●; observation plot)
Modeling and simulation

**Land erosion estimation by USLE**

**USLE (Universal Soil Loss Equation)**
- Developed by the US Department of Agriculture
- Applied to many agricultural fields in Japan

\[ A = R \times K \times LS \times C \times P \]

- \( A \): the potential annual soil loss (ton/ha/y)
- \( R \): the rainfall and runoff factor
- \( K \): the soil erodibility factor
- \( LS \): the slope length-gradient factor
- \( C \): the crop / vegetation and management factor
- \( P \): the support practice factor

- < precipitation data (from Japan Meteorological Agency)
- < Soil distribution (from the Cabinet)
- < Geometry (from Ministry of Land, Infrastructure, Transport and Tourism (MLIT))
- < Land use (from MLIT)
- < Land use (from MLIT)

Potential annual soil loss

Estimation of annual inflow of soil and Caesium along the Ukedo River by USLE
Cs transport in river networks

TODAM model
- Developed by Pacific Northwest National Laboratory (PNNL)
- Finite element method
- Transport of sediment, dissolved cesium and sediment-sorbed cesium in rivers and estuaries with multiple-channel network (sand, silt and clay are considered)

Main input data
- Geometry of rivers
- River flux
- Physical properties of sediments (e.g. d50, porosity)
- Adsorption/desorption properties
- Critical shear stress
- Dispersion coefficient for suspended sediment and dissolved cesium
- Boundary and initial conditions

Main output data
- Spatial distribution and time history of sediment conditions
- Spatial distribution and time history of concentration of dissolved and sediment-sorbed cesium

Examples of model calculation of river

Location of Ukedo river for model calculation by TODAM
Cs transport in estuaries

Numerical model (under consideration)
- FLESCOT
- ROMS
- Nays2D

Main input data
- Geometry of rivers and estuaries
- River flux
- Wind velocity and direction
- Temperature
- Velocity and direction of an ocean current
- Wave height and period
- Salinity concentration
- Physical properties of sediments (e.g. d50, porosity)
- Adsorption/desorption properties
- Critical share stress
- Dispersion coefficient for suspended sediment and dissolved cesium
- Boundary and initial conditions

Main output data
- Spatial distribution and time history of sediment conditions
- Spatial distribution and time history of concentration of dissolved and sediment-sorbed cesium

Data integration into ONE MAP (under construction)

<table>
<thead>
<tr>
<th>data_of_measurement</th>
<th>measurer</th>
<th>soil_sampling_5cm_depth</th>
<th>soil_sampling_10cm_depth</th>
<th>litter_sampling</th>
<th>soil_jaives</th>
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<tbody>
<tr>
<td>7 11 Dec-2012</td>
<td>Niizato, JAEA</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>7 11 Dec-2012</td>
<td>Niizato, JAEA</td>
<td>O (Dec-2012) by JAEA</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>7 1 Jan-2013</td>
<td>Niizato, JAEA</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>7 1 Jan-2013</td>
<td>Niizato, JAEA</td>
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<td>Niizato, JAEA</td>
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<tr>
<td>4 11 Dec-2012</td>
<td>Niizato, JAEA</td>
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<td>X</td>
</tr>
<tr>
<td>4 11 Dec-2012</td>
<td>Niizato, JAEA</td>
<td>O (Dec-2012) by JAEA</td>
<td>X</td>
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</tr>
<tr>
<td>4 11 Dec-2012</td>
<td>Niizato, JAEA</td>
<td>O (Dec-2012) by JAEA</td>
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<tr>
<td>5 15 Feb-2013</td>
<td>Niizato, JAEA</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>5 15 Feb-2013</td>
<td>Niizato, JAEA</td>
<td>O (Dec-2012) by JAEA</td>
<td>X</td>
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<td>Niizato, JAEA</td>
<td>O (Dec-2012) by JAEA</td>
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<td>X</td>
</tr>
<tr>
<td>3 7 Feb-2013</td>
<td>Ondo, JAEA</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Data with geographic coordinate (topographic survey on the field investigation)
Overlying the all of data into ONE MAP, then we can analysis the spatial relationship among physical geographic information, radioactivity of soil and surface water, etc.
Summary

- Radioactive Cs is strongly associated with mineral particles.
  - High concentration (10^4 - 10^5 Bq/kg) in river and reservoir sediments,
  - Low concentration (< 2 Bq/L) in river and reservoir water,
  - Indicate large distribution coefficient (> 5x(10^4 - 10^5) L/kg).

- Transport of radioactive Cs is dominated by litter and mineral particles.
  - Erosion, transport and sedimentation.
  - Dam reservoirs may be possibly used as reservoirs of mineral particles-borne radioactive Cs, leading to reduction of dose rate.
  - Velocity of Cs migrating in subsurface is low (>90% Cs in 5 cm depth).

- Modeling tools for Cs transportation is being developed.
  - Soil erosion => Water flow transportation => 3-D estuary flow
  - Data is obtained in-situ observation and lab-experiment, under QA.
  - Interaction of Cs to litter and mineral particles should be modeled.

Long-term schedule

<table>
<thead>
<tr>
<th>Research Programme</th>
<th>FY2012 to 2014</th>
<th>After FY2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigation Area</td>
<td>✓ Abukuma mountains&lt;br&gt;✓ Fluvial lowland/plain on the Pacific coastal region and along the main rivers&lt;br&gt;✓ Hills on the Pacific coastal region&lt;br&gt;✓ Dams and reservoirs in Abukuma mountains</td>
<td>✓ Abukuma mountains&lt;br&gt;✓ Fluvial lowland/plain on the Pacific coastal region and along the main rivers&lt;br&gt;✓ Abukuma River system&lt;br&gt;✓ Hills on the Pacific coastal region&lt;br&gt;✓ Dams and reservoirs in Abukuma mountains</td>
</tr>
<tr>
<td>✓ Elucidation of migration behavior of radiocaesium</td>
<td>✓ Development of model and simulation for Cs transport in the Fukushima environment&lt;br&gt;✓ Test application of the transport modelling of radiocaesium</td>
<td>✓ Monitoring of natural events and processes in the forests, rivers, dam deposits, estuaries, etc.&lt;br&gt;✓ Monitoring of Cs transport&lt;br&gt;✓ Model improvement and simulation</td>
</tr>
<tr>
<td>✓ Assessment of recontamination of the remediated area</td>
<td>✓ Post-remediation surveying&lt;br&gt;✓ Construction of transport scenario</td>
<td>✓ Model development and simulation of the recontamination, and its application</td>
</tr>
<tr>
<td>✓ Development of techniques for control of radiocaesium migration</td>
<td>i) Small-scale; Analysis of cost-effectiveness based on the practical field test</td>
<td>✓ Proposal and spreading of the techniques for the controlling of Cs migration to local governments and local residents</td>
</tr>
<tr>
<td></td>
<td>ii) Large-scale; availability of dams and reservoirs</td>
<td>✓ Proposal to the local and national governments</td>
</tr>
<tr>
<td>✓ Development of evaluation system for radiation exposure</td>
<td>i) Development of simplified and detailed evaluation system</td>
<td>✓ Improvement of the evaluation systems&lt;br&gt;✓ Long-term evaluation of radiation dose and application to the other province</td>
</tr>
<tr>
<td></td>
<td>ii) Test application of simplified evaluation system</td>
<td></td>
</tr>
</tbody>
</table>
Thank you for your attention!

“Witch’s eye” Goshiki-numa, located at the top of Mt. Azuma