Modelling of Cesium Transfer and γ Radiation in Forest Ecosystems: Current IRSN Approach, Projects

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Hello. Good evening everybody. I'm very pleased to give this evening a talk about the modeling of radionuclides and especially cesium transfer and gamma ray propagation in forest ecosystems. I will basically focus on a detailed presentation of the currently used forest model at IRSN. IRSN is the Institute of Radiological Protection and Nuclear Safety in France. After that, I will present also some preliminary case studies for Japanese forests based on published data we found in the literature. I will end this talk by presenting basically two modeling projects we launched at IRSN focusing on the forest modeling.

My name is Marc-Andre Gonze. I'm a senior scientist at IRSN. Basically, I've been involved for many years in the European research project dealing with the radionuclides dynamics in soil-vegetation and atmospheric boundary layer. After that, about 10 years ago, I promoted and managed a project called SYMBIOSE, which aims at developing for the IRSN and the French electricity company called Electricite de France developing a radiological risk assessment tool or code. After that since the occurrence of the Fukushima accident, I've also been involved in the study of environmental consequence of the radioactive deposition on to the terrestrial landscape. We at IRSN have the opportunity to study all the contamination disseminated or propagated in the different ecosystems, Japanese ecosystems.

To my talk, I associate two of my colleagues, Philippe Calmon and Christophe Mourlon because they were completely involved many years ago after the Chernobyl accident in the specification, testing, and implementation of the forest model. Finally, I also associate Marie Simon-Cornu, which is the head of my laboratory and because she is also managing the continental research work package in the AMORAD project.

Outline

I. Radiological risk assessment tools
II. Forest modelling : TRANSFER (Caesium)
III. Forest modelling : AMBIENT DOSE RATE (Caesium)
IV. IRSN's modelling projects

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I will basically put my focus on the detailed presentation of first the transfer process of cesium in forest ecosystems. I will also give a detailed presentation of the way we calculate the ambient dose rate or the gamma rate in forest ecosystems. This is for the two basic aspects; the first will be the transfer and the ambient dose rates.

To begin with, I will tell you a few words about the radiological risk assessment tools we developed or we currently use at IRSN. I will end this presentation by telling you a few words about the two research projects about forest.

I. Radiological Risk Assessment Tools

ASTRAL

SYMBIOSE

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The radiological risk assessment tools

Forest modeling projects

European **RODOS** (1995-1999) – Calmon P
- Development of the Real-time On-line DecisiOn support System for off-site emergency management in Europe, in case of a nuclear accident
- Co-development with the Finish TNO (STUK) of a forest model, for predicting internal and external doses to humans interacting with forest ecosystems contaminated by an accidental atmospheric deposition

IAEA **BIOMASS** (1997-2001) & **EMRAS** (2003-2007) - Calmon P
- Forest model inter-comparison (BIOMASS)
- Review of forest model parameters (EMRAS)

IRSN & Electricité de France **ASTRAL** (1997-2007) - Calmon P, Mourlon C *et al.*

Forest model implementation in the ASTRAL Radiological Risk Assessment tool
- ASTRAL Available on the Intranet and Extranet

IRSN & Electricité de France **SYMBIOSE** (2005-) - Gonze MA, Mourlon C *et al.*
- Forest model currently being updated and implemented in SYMBIOSE

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You have to know that IRSN has been involved for many years in various national or international research projects dealing with forest. The first project was the European RODOS project, which started in '95, which aimed at developing the Decision Support System or the Real On-line Decision Support System in case of nuclear accident in Europe. IRSN was most specifically involved with the Finnish Technical Nuclear Organization in the development of a forest model that has been implemented in this Decision Support System. Basically, this forest model was expected to predict both internal and external doses to humans, which interact with forest ecosystems and in case of a nuclear accident, that is accidental atmospheric deposition. After that my colleague, Philippe Calmon, has also been involved in two IAEA programs, let's say, BIOMASS and EMRAS programs from '97 to 2007, aiming first at inter-comparing the various European forest models that were developed after the Chernobyl accident and he also participates to a work package which aims at reviewing some forest model parameters like aggregated transfer factors and so on. After that in '97, the IRSN and Electricite de France, which is the biggest nuclear operator in Europe, decided to launch the ASTRAL project, which aimed at developing the first IRSN Radiological Risk

Assessment Tool, which was called ASTRAL and which included both forest model and agricultural models and which calculated or computed the dosimetric impact to man. At the moment, the ASTRAL code is available for anybody who is demanding on the internet and extranet. More recently that is, let's say, 8 years ago, I promoted a new program, which is called SYMBIOSE, which aimed at developing a multimedia and quite complex radiological risk assessment tools to deal with a wide range of nuclear situations. The forest model that has been developed in the ASTRAL project is currently being updated and implemented in our radiological risk assessment tool, SYMBIOSE.

SYMBIOSE

A Platform for:

- Assessing the fate, transport & dosimetric impact of radionuclides in Biosphere
- Managing related environmental data and scientific knowledge
- Developing modules and fit-for-purpose simulators

Dealing with:

- Normal, incidental or accidental functionning of nuclear installations
- Radioactive releases : atmospheric, aquatic and/or marine
- Multiple interacting media: atmosphere, marine system, river, cropland, anthropic, feedstuff/foodstuff chain, forest (currently being implemented) and processes at their interfaces (*ex.:* atmospheric deposition, watershed erosion)
- Dosimetric impacts : external, inhalation & ingestion

Based on advanced modelling approaches:

- Specific to H-3, C-14 et Cl-36
- Dynamic (temporal variability)
- Spatially-distributed (spatial variability)
- Deterministic or probabilistic (uncertainties)

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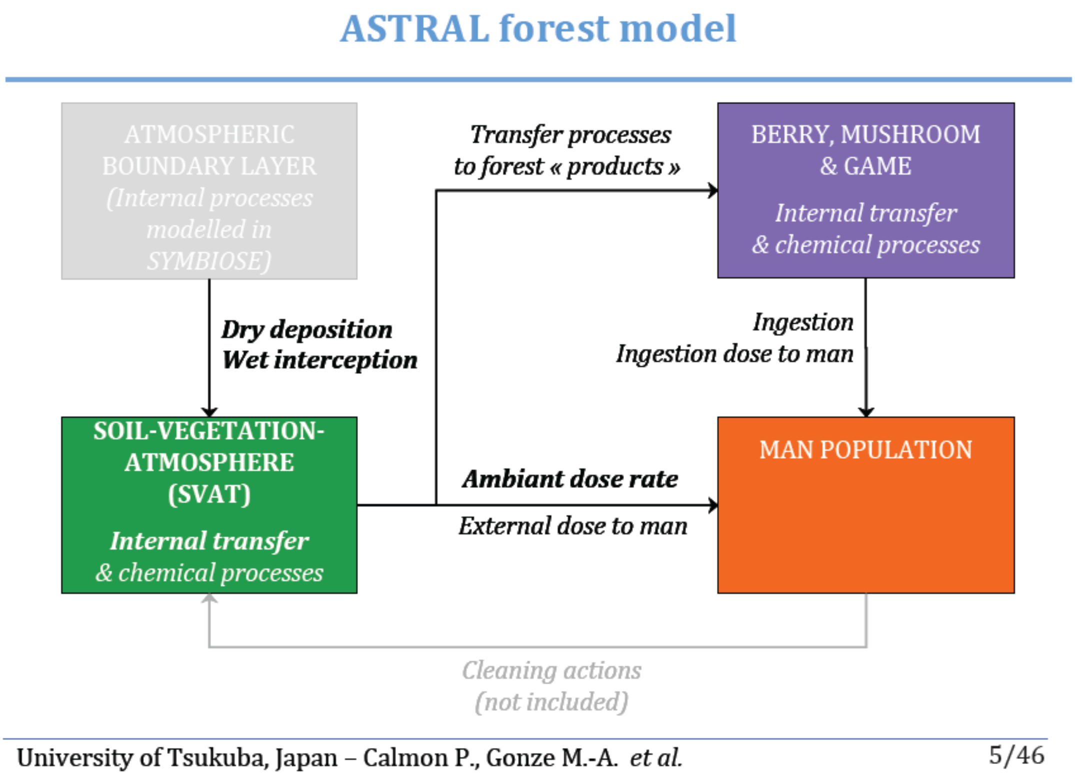
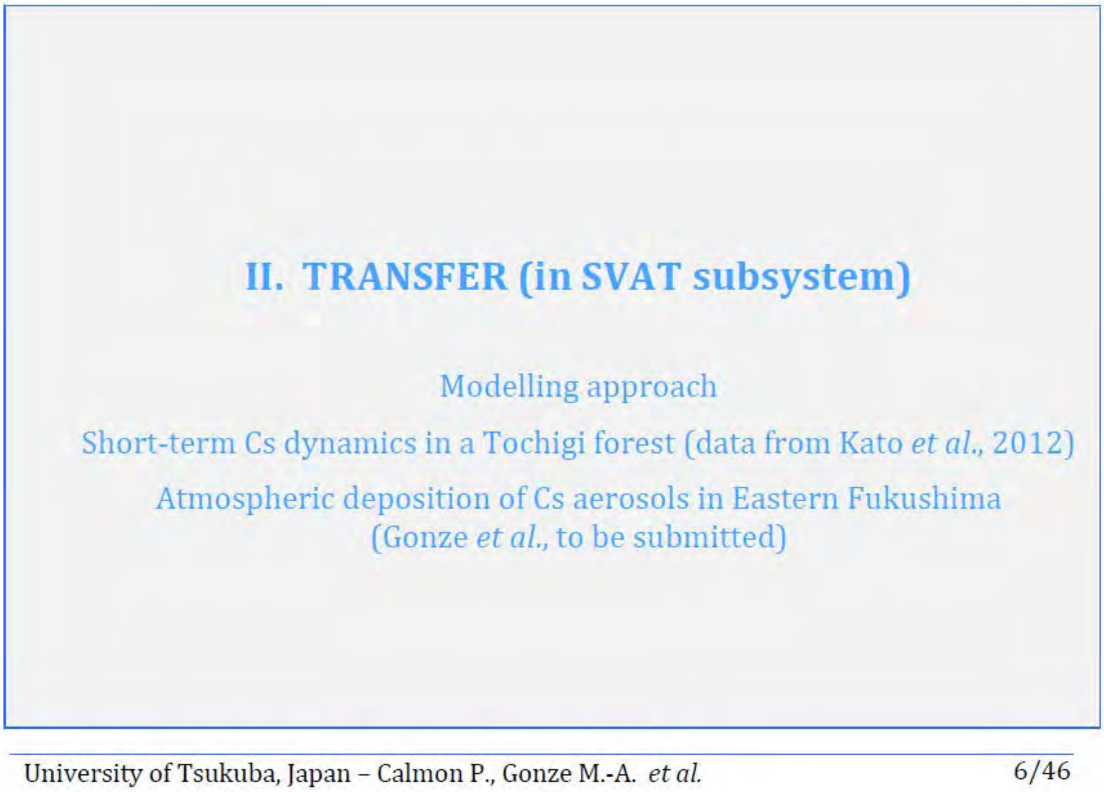
Let me tell you a few words about SYMBIOSE. SYMBIOSE is now a quite operational platform dedicated to the assessment of the fate, transport, and dosimetric impact of radionuclides in biosphere, basically impact to man, not impact to environment at the moment. But this is also a platform for managing whole data and knowledge that are required to perform radiological risk assessment studies. Due to its highly modular architecture, this platform enables us also to develop modules, transfer all dosimetric dedicated modules and develop from these modules fit-for-purpose simulators just by interfacing or assembling calculation models. This platform is capable to deal with both normal incidental or accidental functioning of nuclear installations. It takes account of the various radioactive releases that is atmospheric, aquatic one or marine releases. It accounts for multiple media which are preserved at the landscape level like atmosphere, marine system, river, cropland and so on and forests. Also, it takes accounts for the various processes or interaction at their interfaces like atmospheric deposition for sure and like watershed erosion, which is a major transfer process, which is able to transport contamination from the landscape to aquatic systems or even to marine systems. Finally, this platform is able to compute dosimetric impacts, external inhalation or ingestion.

All the physical models, which have been implemented in the SYMBIOSE platforms are advanced models, let's say, up-to-date models, for example we implemented specific models for tritium, carbon 14, chlorine 36. Whole equations are dynamic. This means that we're able to predict time series of inventories, activities and threats in the biosphere. The specificity of this platform with respect to many, many other platforms in Europe is that this platform is able to account for the specificity of the landscape that is the calculation how intrinsically spatially-distributed. This is the way to account for the spatial variability of the contamination in the environment. Finally, you have the possibility to perform probabilistic calculations, basically parametric uncertainties just to account for the uncertainty in the environment.



Now, let's step to the ASTRAL forest model. Basically, this forest model consists in three different modules. The first one is called Soil-Vegetation-Atmosphere module, which is responsible for calculating or computing the activity and the threats within the Soil-Vegetation and Atmosphere System potentially contaminated from the atmospheric boundary layer through both dry deposition and wet deposition. The second module is dedicated to the prediction of activity in forest products. To call forest products are basically berries, mushrooms and forest games. All these components, forest components are potentially contaminated through processes like root uptake, like direct interceptions of atmospheric depositions through translocation, for example from the trunk to the canopy and food through ingestion of contaminated forest products. The third module in ASTRAL is dedicated to the calculation of external and internal dose to man through ingestion of forest products. The computation of the external dose to man requires as a preliminary step to model of predict the ambient dose rate within the forest system. Finally, at the moment, we do not explicitly account for the cleaning actions that is reduction from man population onto the soil-vegetation-atmosphere, which aims at lowering the radioactivity levels in the forest. But I must say that it would not be or it would be quite

simple to implement simple cleaning actions in forest systems like tree cuttings or litter collecting and so on.
Okay, so as the time is limited tonight, I propose to focus first on the detailed presentation of the processes within the soil-vegetation-atmosphere including atmospheric depositions. In the second part, I will deal or describe the way we compute ambient dose rates in the forest models. But I'm open to answer your questions about all the modules.



The first part dealing with the transfer in the soil-vegetation-atmosphere subsystem: I propose here to first describe basically the conceptual assumptions and the mathematical parameterizations we adopt for the various transfer processes within the system. After that, I will show you forest case studies on the Japanese forests where we test these forest models against some recent data published by Kato in a Tochigi forest and dealing with the short-term Cs dynamics that is, let's say, the few first ones after the Fukushima accident. After that, I will present seven [ph] case studies where we tried to study the available data of contamination in soil and available contamination data and we succeeded in estimating through the various dry-wet deposition parameterizations. We tried to estimate the dry and wet contribution of deposition in the Fukushima Prefecture. We compared our results through the JAEA numerical simulations, so two parts. Modeling, four case studies in Japanese forests and seven case studies about atmospheric deposition of Cs aerosols.

ASTRAL model features

Source term

- Up to 40 chemical elements, including Cs, I, Sr and Te (no H, C and Cl !)
- Particulate & gazeous forms

Time domain

- Up to about 3 years
- 1-day time step

Modelling assumptions

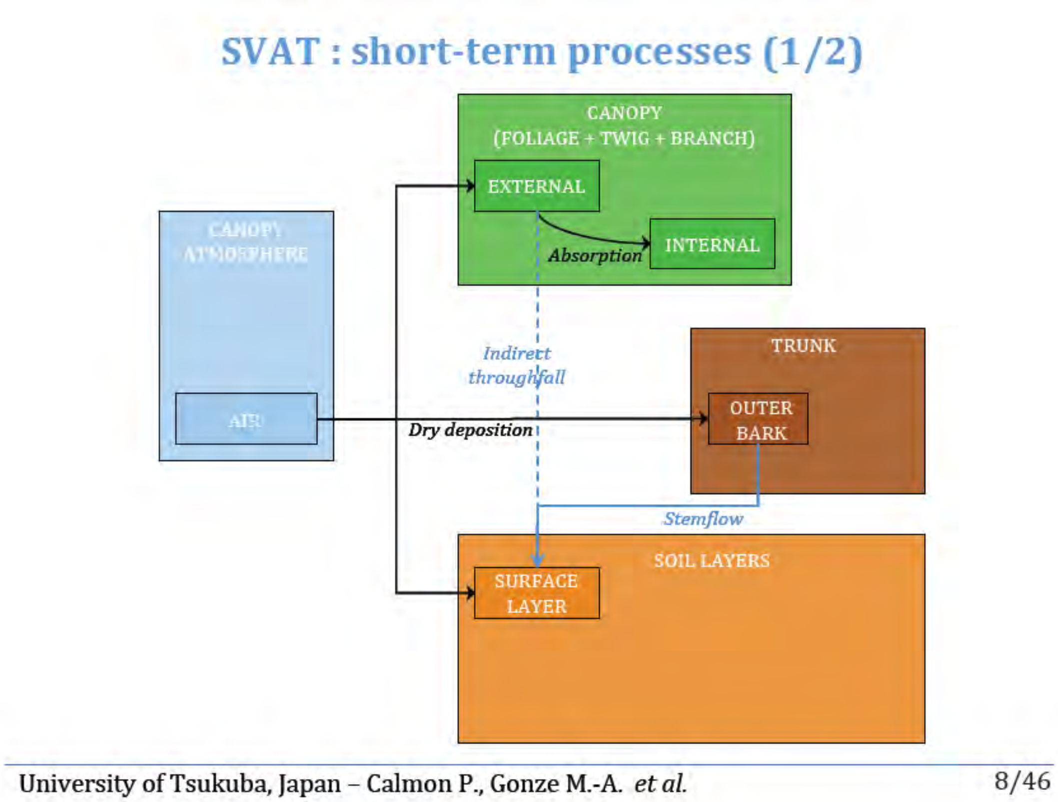
- Deciduous (broadleaf), evergreen (coniferous) or mixed forests
- Dynamic model: non stationary mass balance equations
- First order kinetics rate (in day^{-1}) for transfer processes
- No mean growth of biomass/Leaf Area index (LAI), but seasonal variations
- Only γ emitters for external dosimetry

Outputs

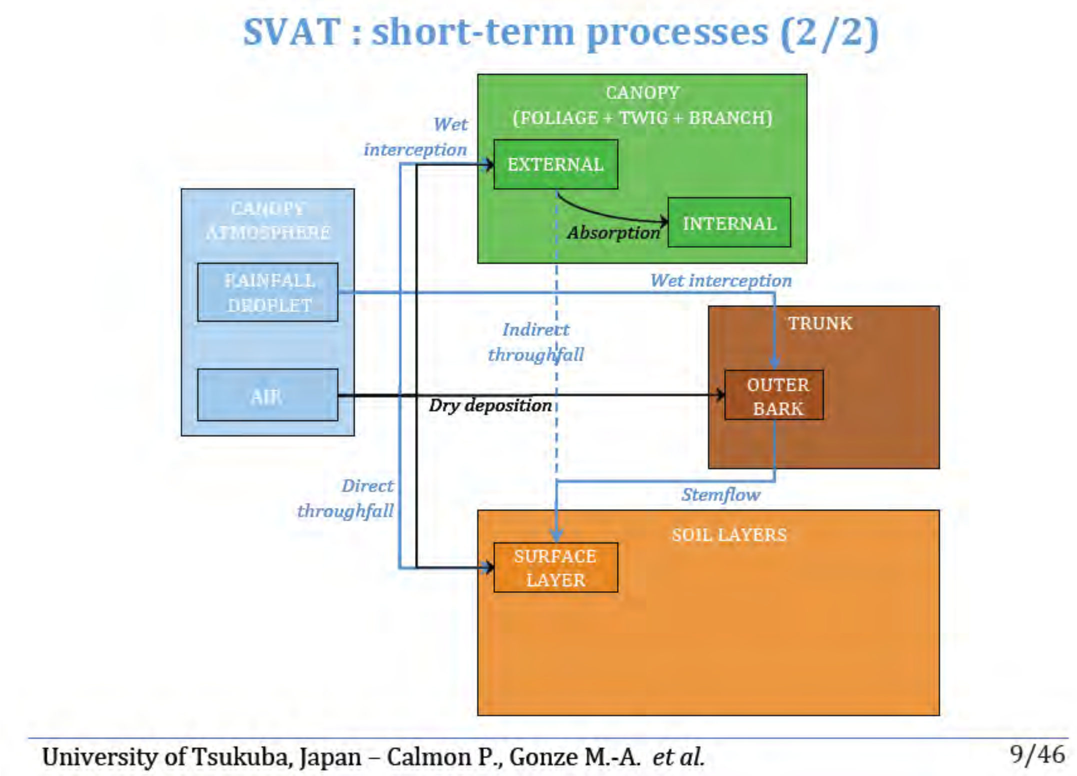
- Inventories (in $Bq.m^{-2}$) and/or activities ($Bq.kg^{-1}$)
- Kerma rates at 1m height above ground ($nGy.h^{-1}$)
- Internal & external dose rates to man ($\mu Sv.h^{-1}$)

Some features of this ASTRAL model. At the moment, this model accounts for nearly 40 chemical elements including cesium, iodine, strontium, technetium isotopes, but no models or parameterizations for specific radionuclides or chemical elements like tritium, carbon, and chloride. Radionuclides can be considered under particulate or gaseous forms, especially important for iodine. This model is a short-term model, let's say, it means that the predictions are given up to nearly 3 years. But after that, we do not guarantee results. The computation is based on a day time step.

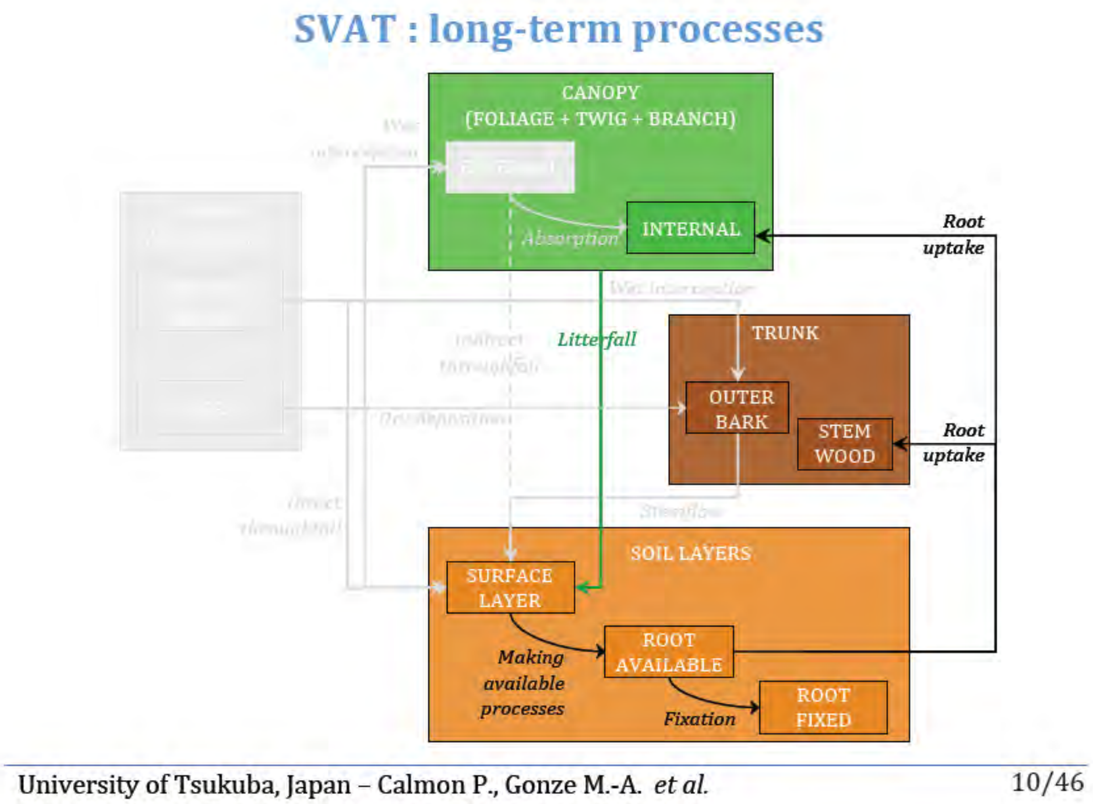
A few modeling assumptions now, so we basically model deciduous that is broadleaf or evergreen coniferous forests or mixed forests. The model is dynamic. It means that basically it stays on the resolution of non-stationary mass balance equations. Generally speaking, most of the transfer processes are mathematically parameterized through the use of first order kinetics rate in per day or per second. The physical problem is to estimate this first order kinetics rate. One important assumption is that we do not take account at the moment for the long-term growth of biomass or leaf area index, but we just account for the seasonal variations of the leaf area index. For the dosimetry calculations, we only account for gamma emitters. The various outputs are spatially distributed as time-varying. We basically output inventories in Becquerel per square meter in the soil-tree-atmosphere system and all massive activities in Becquerel per kilogram in the various tree organs. We also compute kerma rates at 1 meter height above ground in nano-Grays per hour. Through the use of some coefficient, we step further to the internal or external dose rate calculation to man. All these outputs have spatial dependence and time-varying.



Basically, I present here some conceptual modeling of the forest system. So, we basically distinguished two groups of transfer process in the forest, let's say, short-term process or the process of interaction between the canopy atmosphere and the soil-tree system and another group, which is called long-term process like root uptake, translocation within the tree, and over time of in-soil process. This is the description of the short-term process. Basically, we model the forest system through four basic compartments, let's say, the canopy atmosphere in blue, the blue box. The canopy compartments without any distinction between the foliage, the twig, or the branch at the moment. This is the green box. Then the trunk, the brown box and the various soil layers in orange box. The first family of short-term process we account for is the dry deposition process, let's say, this is the transfer of contamination present in airborne contamination, the transfer of deposition on to the external surface of canopy trunk and the surface layer. In case of non-contaminating precipitation, you have to know that this precipitation or rainfall is able to remobilize contaminational radionuclides that were intercepted by the canopy or trunk. This is called the indirect throughfall flux or the stemflow flux. That is the transfer from the external canopy or outer bark that is the external trunk on to the surface layer. We'll see later how we parameterized this short-term process.



Another family of short-term process is the wet deposition. The wet deposition is just the deposition of contaminated rainfall droplets, but direct deposition on to the soil surface, this process is called the direct throughfall or some interception by the canopy of this incoming rainfall droplet, this is the wet interception process. For water droplets that have not been intercepted by canopy, the trunk may intercept some fraction of these water droplets. You also have to account for wet interception by chance of the contaminated rainfall droplets. I forgot one important process. We call the absorption. That is the transfer of external contaminants or radionuclides, the transfer to internal diffuse [ph] through cuticule or stomata absorption. This basically corresponds to the incorporation by the vegetation into its living biomass of aerosols or gaseous radionuclides. Basically you have competition, we can see that you have competition between this absorption process and the wet rainfall, the throughfall process. Basically, this two key plain process explains a great part of the dynamics, the short-term dynamics you observe after an accidental deposition, two [Unclear].



Now, let's step to the long-term process. As I told you, the first family is all processes that occur once the radionuclide deposited on to the soil layer. That is basically what we call the making available processes. That is all kind of biophysical-chemical processes that potentially transfer the radionuclides from the surface layer to the root layer. That is [Unclear], and with the distinction made between an available pool, that is available for the root uptake and the non-available pool. For the cesium for example, we know that if you follow the contamination in croplands for example from year to year after the Chernobyl accident, you observe that the contamination in the leafy vegetables decreased slowly from year to year. This corresponds basically to the fact that from year to year, you have an increased fraction of the initial cesium that was irreversibly fixed into the soil and got non-available for the vegetation or for the root uptake process. The second family of the long-term process, this is the root uptake. That is the transfer from contamination presenting the root available pool to internal biomass, basically the stem wood or internal biomass of the canopy in foliage internal needles, internal leaves, twigs, and branch. One of the weaknesses of this model is that we do not account explicitly for translocation process that is the [Unclear] process of redistribution within the tree. This is a possible line for improving this model. This is typically one simple way to improve in the context of the AMORAD project.

Dry deposition

Dry deposition flux of airborne radionuclide C onto a vegetation cover *i* (Bq.m^{-2}.s^{-1}) is calculated from activity in air $[C]_a(zr,t)$ (in Bq.m^{-3}) at a reference altitude *zr*, using a dry deposition velocity Vd_i (in m.s^{-1}):

$$TC_i^{dry} = Vd_i \times [C]_a$$

Deposition velocity Vd_i dependents on:

- physico-chemical form of C
- canopy Leaf Area Index or fresh biomass
- aerodynamical characteristics

Some references: Slinn, 1982 ; Zhang, 2001 ; Baklanov and Sørensen, 2001 ; IAEA, 2009 ; Pröhl G., 2009 ; Petroff *et al.*, 2008, 2009, 2010 ; Andersson, 2011

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Now, I propose to briefly present you some mathematical parameterization of short-term process. Basically, dry deposition is model as follows, the flux in Becquerel per square meter and per second of a radionuclide C onto a vegetation cover i is calculated from activity in air at a reference level zr and time T just by multiplying this activity by a fundamental parameter, which is called dry deposition velocity. This parameter is known to depend on the physico-chemical form of the radionuclides that is basically particulate form or gaseous form. It also depends on particulate form on the aerosol diameter of the density of this aerosol. It also strongly depends on the canopy leaf area index or the fresh biomass. Finally, this dry deposition velocity is known to strongly depend on aerodynamical characteristics like mean wind velocity or the friction velocity or even the atmospheric stability. I gave you here some important reference. Well, you will be able to find very interesting results or mechanistic considerations about the way you can estimate this dry deposition velocity.

Coniferous forest

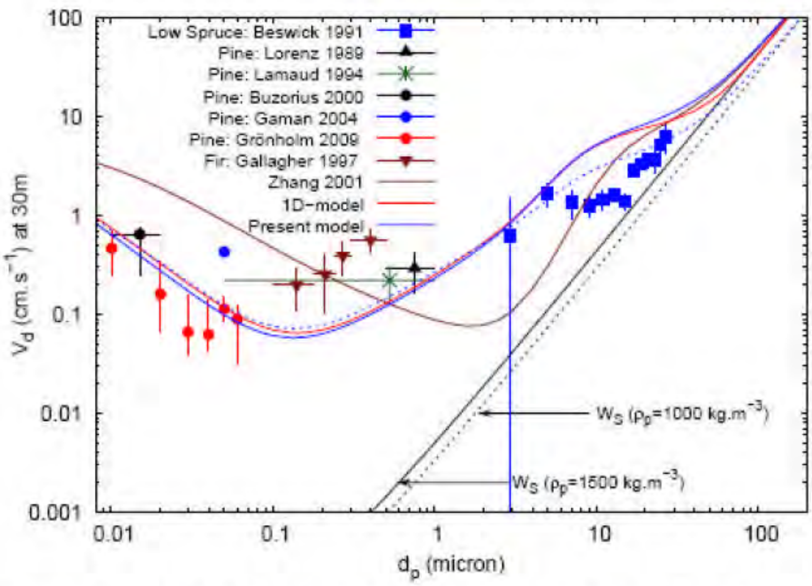

Fig. : Dry deposition velocity as a function of aerosol diameter d_p (in μm); field measuremetns *vs* physically based model predictions (from Petroff and Zhang, 2010)

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As an illustration here, I'll give you a graph where on the Y-axis, we have the dry deposition velocity in the coniferous forest in centimeter per second for aerosol, as a function of the diameter of the aerosol, the micron and log-log plot. All the field measurements, I mean the variable and the credible field data are represented here on this graph and corresponds to varying tree-species, aerodynamical characteristics, and these field measurements have to be compared to the predictions of a purely mechanistic deposition model predictions, we have been developing at IRSN a few years ago by one of our Ph.D. students, Alexandre Petroff, this graph shows you that at the moment we're more or less able to predict the dry deposition velocity on to a forest canopy as a function of aerosol characteristics as a function of leaf area index and as a function of turbulence. This model tells you that typically the dry deposition velocity on the coniferous evergreen forests is about 10 times greater than the dry deposition velocity onto the forest soil. This typical ratio has been adopted in the ASTRAL model, for example if you have dry deposition velocity of 0.1 centimeter per second for a pine of 20 meters height, then you will have 0.01 for dry deposition velocity onto the soil, what order of magnitude of difference.

Wet interception

Wet deposition flux of airborne radionuclide C onto vegetation cover i (in $Bq.m^{-2}.s^{-1}$) is calculated from the vertically integrated activity in air (from zr to cloud altitude zc) using a scavenging rate $\Lambda(t)$ (in s^{-1}) and a wet interception factor $IF_i(t)$ (n.d.):

$$TC_i^{wet} = IF_i \times TC^{wet} \quad \text{with} \quad TC^{wet} = \Lambda \times \int_{z_r}^{z_c} [\mathrm{C}]_a \, dz$$

Interception factor IF_i depends on :

- physico-chemical form of C (*e.g.* chemical affinity for cuticule or stomata)
- precipitation characteristics
- canopy Leaf Area Index or fresh biomass (seasonal variation)

Example of empirical regression model :

$$IF_i = Biomass_i^{\beta} \times RainfallHeight^{\alpha} \times RainfallIntensity^{\gamma}$$

Where α, β and γ basically depend on the radionuclide valence

Some references : Hoffman 89, 95 ; Muller H. & Pröhl G., 1993 ; Sportisse, 2007 ; Pröhl G., 2009

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Now, another important process is the wet interception process. The wet interception or the wet deposition flux of the radionuclide C onto the same vegetation cover i in Becquerel per square meter and per second is basically calculated from first the vertically-integrated activity in air from the reference level just above ground up to the cloud altitude multiplied by what is called the scavenging rate in per second. This flux predicts the total deposited flux when it's raining. Then you compute the fraction of this deposition, which is intercepted by the canopy or by the trunk. Then you have to multiply this total throughfall flux by what is called the interception factor, which is specific to the vegetation, specific to the radionuclides, and also specific to the precipitation characteristics. Many, many field measurements or measurements in control laboratory have been produced and published after the Chernobyl accident basically for many kinds of crops, grasses or herbs, and for all these data, some empirical regression model was proposed. This I gave you an example of formulation empirical regression model, we typically use in ASTRAL which relates this interception factor to the biomass of the vegetation cover to the rainfall height and also to the rainfall intensity, so basically here you have a lot of linear relationship. The coefficients here, alpha, beta, and gamma are basically dependent on the radionuclide valence. These coefficients are different from iodine and then from cesium for example. Another empirical formulation was proposed typically by Muller and Prohl. This is a well-known researcher on deposition and wet deposition. Another formulation was proposed, which did not account for rainfall intensity, but basically we checked that both formulations were equivalent.

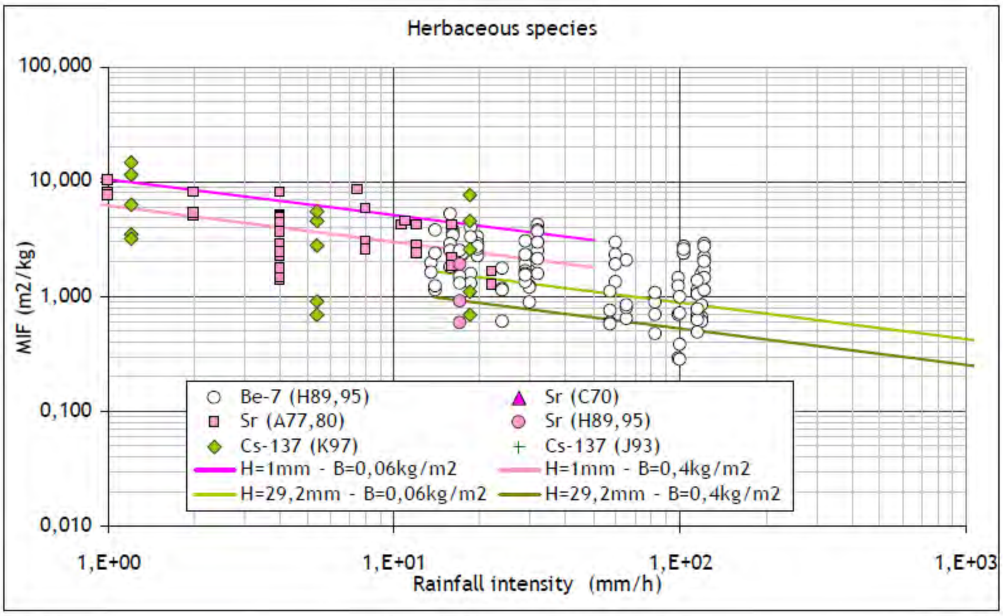

Fig. : Mass Interception Factor (in $m^2.kg^{-1}$) of monovalent/divalent solute cations (Cs, Sr & Be) by herbaceous vegetation as a function of rainfall intensity ; measurements *vs* empirical regression relationship (Gonze & Sy, to be submitted)

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On this slide, to illustrate I gave you here on the Y-axis for herbaceous species, but you can find herbaceous species on the forest floor, so this is interesting. On the Y axis, you have what we call the Mass Interception Factor. That is the interception factor normalized by the biomass of the vegetation in square meter per kilogram as a function against the rainfall intensity in millimeter per hour and all boxes here represents field data or laboratory data for monovalent and divalent solute cations that is cesium, strontium, and beryllium. This graph shows you that basically this Mass Interception Factor is strongly or significantly decreasing for example with the rainfall intensity. The regression model is displayed as lines for different rainfall height and different biomass. This formulation is used in ASTRAL. I must say that we do not have enough data on forests to change this relationship and to extrapolate this relationship to forest canopy. We basically assume that the forest canopy is just like herbaceous canopy, so we use the same formulation. The same assumption was made in the ECOSYS model, which was developed by our German colleagues from ESF.

Throughfall & Stemflow fluxes

Indirect throughfall flux of radionuclide C from vegetation cover i (in Bq.m^{-2}.s^{-1}) is calculated from external surface activity in canopy $[C]_{c.ext}(t)$ (in Bq.m^{-2} leaf) and Canopy Leaf Area Index LAI_i (in m^2 leaf.m^{-2}) using an effective weathering rate λ_i^{wea} (in s^{-1}):

$$TC_i^{throughfall} = \lambda_i^{wea} \times LAI_i \times [C]_{c.ext}$$

Weathering rate λ_i^{wea} should dependent on:

- physico-chemical form of C (*e.g.* retention by wax, cuticule and micro-rugosities)
- climatic & canopy characteristics (*e.g.* water droplet / foliage interactions)

But to few post-Chernobyl data to explore into details its variability !

Similar approach for stemflow flux, introducing a bark-specific weathering rate

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Now, the throughfall and stemflow fluxes, basically in ASTRAL the indirect throughfall flux of radionuclide C from the vegetation cover i is calculated from the external surface activity in canopy in Becquerel per square meter of leaf surface. This quantity multiplies by the leaf area index and introducing here weathering rate in per second. This weathering rate should theoretically depend on the physico-chemical form of the radionuclide and especially on the affinity of the radionuclides for the cuticule or the stomata, also the rugosities of the leaves or needles and also should depend on the climatic and canopy characteristics as it directly depends on the interaction between water droplet and foliage. But unfortunately, we do not have data enough from post-Chernobyl experiment to explore the variability of this weathering rate as a function of the physico-chemical form and the climatic and canopy characteristics. We basically assume a constant value for this weathering rate, but dependent on the radionuclides and a similar approach is adopted for the stemflow flux by introducing a bark-specific weathering rate.

Litterfall flux

Litterfall flux of radionuclide C from vegetation cover i (Bq.m^{-2}.s^{-1}) is calculated, during litterfall perdiod, from an estimated activity in senescing foliage (in Bq.kg^{-1}) and a senescing biomass flux λ_i^{lf} (in kg.m^{-2}.s^{-1}):

$$TC_i^{throughfall} = \lambda_i^{lf} \times FT^{sen} \times \frac{[C]_c}{M_i}$$

Where:

- M_i : canopy biomass (kg.m^{-2})
- FT^{sen} : senescing-to-living foliage concentration

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The litterfall flux is quite simple. You just say that the litterfall flux is basically the activity in the senescing path, the senescing needle or senescing leaf multiplied by biomass flux, that is the flux of dead biomass onto the soil. This formulation introduced what we call senescing-to-living foliage concentration, which can be significantly different from one as was for example shown by my colleagues, Goor and Thiry in their experiments in [Unclear].

Post-Chernobyl measurements

Radioactivity measurements (Bunzl *et al.*, 1989 ; Hötzl, 1987)

- One stand of evergreen coniferous forests to the South of Munchen (85-year old Norway spruce)
- Cumulated deposited activity onto forest floor (Bq.m^{-2}) from April 86 to Nov 1987
- Hourly air concentration and deposition of airborne Cs-134/7 in Apr & May 1986 in Neuerberg (GSF centrum in the vicinity of Munchen, Germany)
- Main deposition events on Apr 30 (~ 16 kBq.m^{-2} ~ 80%) and May 1 to 8, with a decreasing activity level (~ 4 kBq.m^{-2} ~ 20%)

Weather measurements

- Hourly precipitation measurements in Neuerberg: heavy rain storm ~4mm on Apr 30 afternoon, then dry weather till May 8
- Can be slightly different on the forest site

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I propose now to illustrate the use of this short-term process model on basically two cases to this, one dealing with the humans, Bunzl and his colleagues met in South of Germany after the Chernobyl accident and the second case dealing with the Tochigi forest. Bunzl and his colleagues worked on one stand of evergreen forests to the South of Munchen. The trees were more or less 85-year old. This was Norway spruce, which is very common species in Europe. That measured to the cumulated deposited activity onto the forest floor from April '86 to November '87, let's say, nearly 2 years. They also measured the hourly concentration in the air and the deposition of cesium in April and May '86, not on the coniferous or the forest stand but near in location, which is near the experimental field. The main deposition was basically assumed to occur on April 30, let's say, 16 kilo-Becquerel per square meter and 4 kilo-Becquerel per square meter from May 1 to May 8 with a continuously decreasing activity level. As we know from other publications that a time of depositions on April 30 in the afternoon, they had heavy rain storm. We know that the major depositions on April 30 occurred during heavy rain storm and after it was basically dry deposition. This is basically the data, which are available to perform calculations.

Modelling scenario

- Short-term processes modelling only !
- 2-day deposition event
- Rainfall : 4 mm (Apr 30)
- Evergreen category

- Transfer parameter values : about default ones
- Elicitated parameter uncertainties (pdfs) and correlations in-between
- Probabilistic simulations (#1000 runs)

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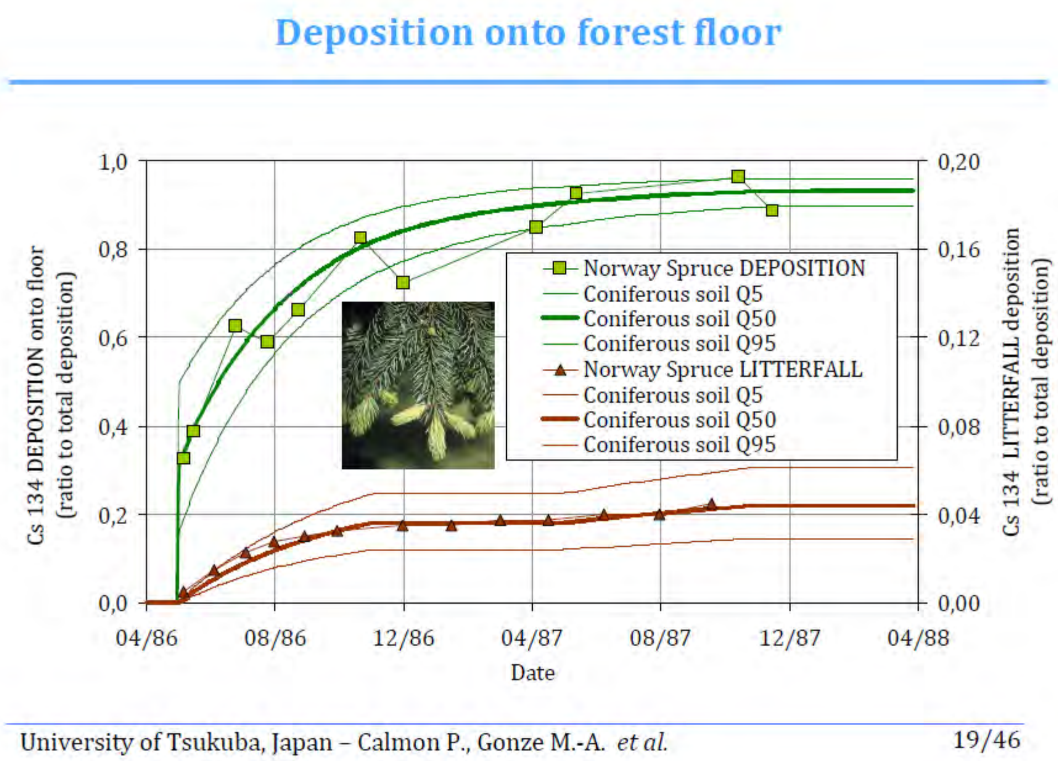
The modeling scenario now, what kind of assumption be made? First, we just account for the short-term processes. We neglected the root uptake and translocation long-term process. We considered in the scenario a 2-day deposition event on April 30 and May 1. We considered a rainfall of 4 millimeter. We chose the evergreen category in the model. We used default or more or less default parameter values that are proposed in the forest models. We also accounted for parameter uncertainties in the transfer of parameters. We elicitated with one of my expert colleagues, Philippe Calmon in the forest. We tried to elicitate the uncertainties on the key parameters. Also, we tried to account for the correlations between some uncertain parameters, and then we performed the probabilistic calculations more than 1000 runs basically.



Then we got this kind of results. On the Y-axis, for example, you have here the deposition of cesium 134 onto the floor forest for this Norway spruce here normalized by the total deposition that is that this ratio varies from 0 to 1 as a function of time from April ’86 to April ’88. In the green color, this is the deposition ratio. In the brown color, this is the right axis. This is the litterfall deposition that is just a contribution of the litterfall in the deposition onto the soil. The field data are displayed in green squares and brown triangles. The predictions, the probabilistic predictions are given at the 5, 50, and 95 coniferous level. You can say that the predictions are in quite good agreement with the field measurements and especially you can see that the initial interception is quite well predicted here by accounting for both dry deposition and wet interceptions by canopy and that the short-term or 2-year dynamics is quite well reproduced. In this scenario, we consider for example that the litterfall typically for the Norway spruce, the needle fall occurred from April to October and then it stops and then starts again the year after.

Short term dynamics of Cs in a Tochigi forest

Radioactivity measurements (Kato *et al.*, 2012)

- Wet deposition of airborne Cs-134/7 and I-131 from Mar to Aug 2011
- Two stands of evergreen coniferous forests in Tochigi Prefecture (cedar, cypress)
- Deposited activity onto forest floor ($Bq.m^{-2}$) through precipitation for each of the 12 consecutive sampling periods : total wet deposition, throughfall & stemflow
- Dry contribution not measured, although present in throughfall & stemflow
- Deposited activities : ~ 80% (Mar), ~ 10% (Apr), ~ 10% (May-June)

Additional knowledge (from atmospheric simulations by JAEA, 2012)

- Two main deposition events on Mar 21 and 30, with precipitation supposedly
- Some uncertainty on the wet contribution; a plausible range: 0.5 to 0.95 (?)
- Some uncertainty on rainfall heights; a plausible range: 3 to 10mm

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The second case study is we worked on the data produced and published by Kato from Tsukuba University where they measured the wet deposition of airborne cesium and also iodine from March to August 2011. They worked on two stands of evergreen coniferous forests in the Tochigi Prefecture; cedar and cypress. I don't remember the Latin name. They measured the deposited activity onto the forest floor through precipitation only for each of the 12 consecutive sampling periods. They also measured the throughfall and the stemflow contribution. One important point is that when you measure the activity in this throughfall and stemflow flux, you also measure the contribution of the dry deposition, because if dry deposition occurred at that time, then the radionuclides you recover them in this throughfall and the stemflow flux. As dry contribution was not measured in this experiment, we were obliged to neglect this contribution. Unfortunately in this experiment, we did not have detailed information on the time series of both rainfall height and the wet and dry contribution of atmospheric depositions. But we know that when looking at atmospheric numerical simulations as published by the Japanese Atomic Energy Agency, we are able to propose some plausible range for the wet contributions varying from 0.5 to 0.95 and also plausible range for rainfall height varying from 3 millimeters to 10 millimeters. I hope that we'll be able to discuss these kinds of uncertainties with our colleagues from University of Tsukuba.

Modelling scenario

- Short-term processes only !
- 4-month deposition kinetics
- **Every day** rainfall : from 3 to 10 mm
- Dry deposition neglected
- Evergreen category

- **If default parameter values**, than model overestimates depositon onto the floor !
- **Much more realistic results** if default parameter values and pdfs same as before, except for :
  - o Canopy coverage ratio = slightly increased
  - o Foliage absorption rate = significantly increased
  - ~ calibration exercise
- Probabilistic simulations (#1000 runs)

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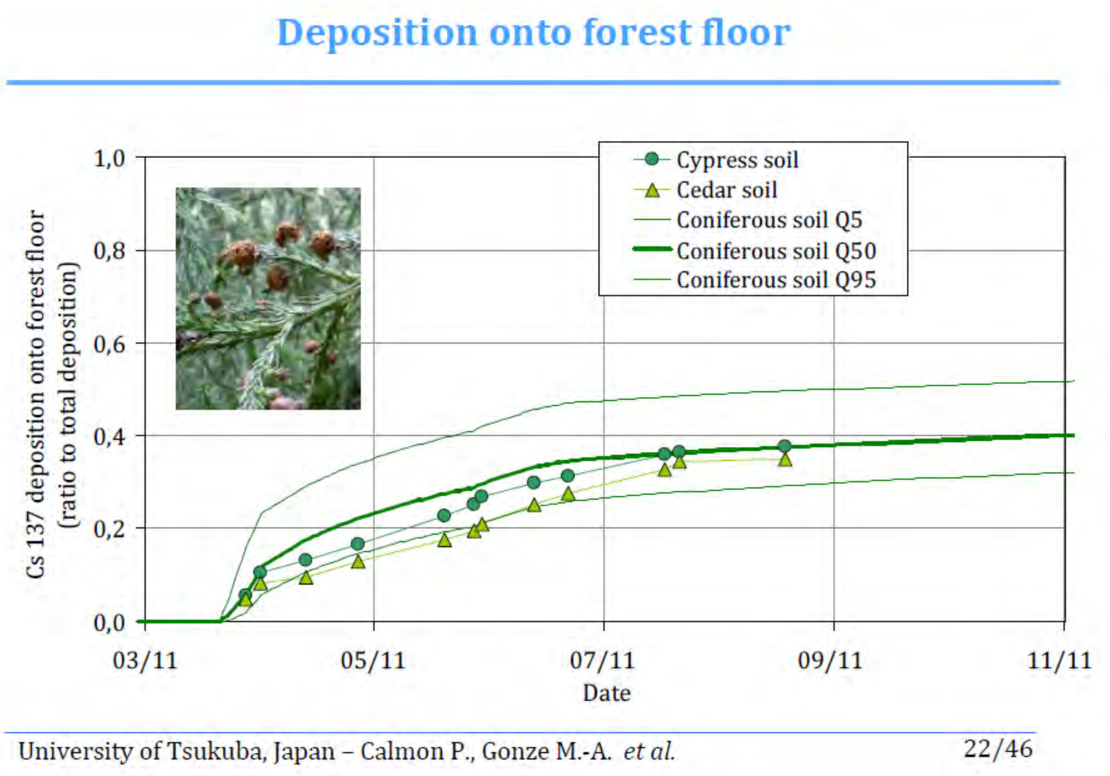
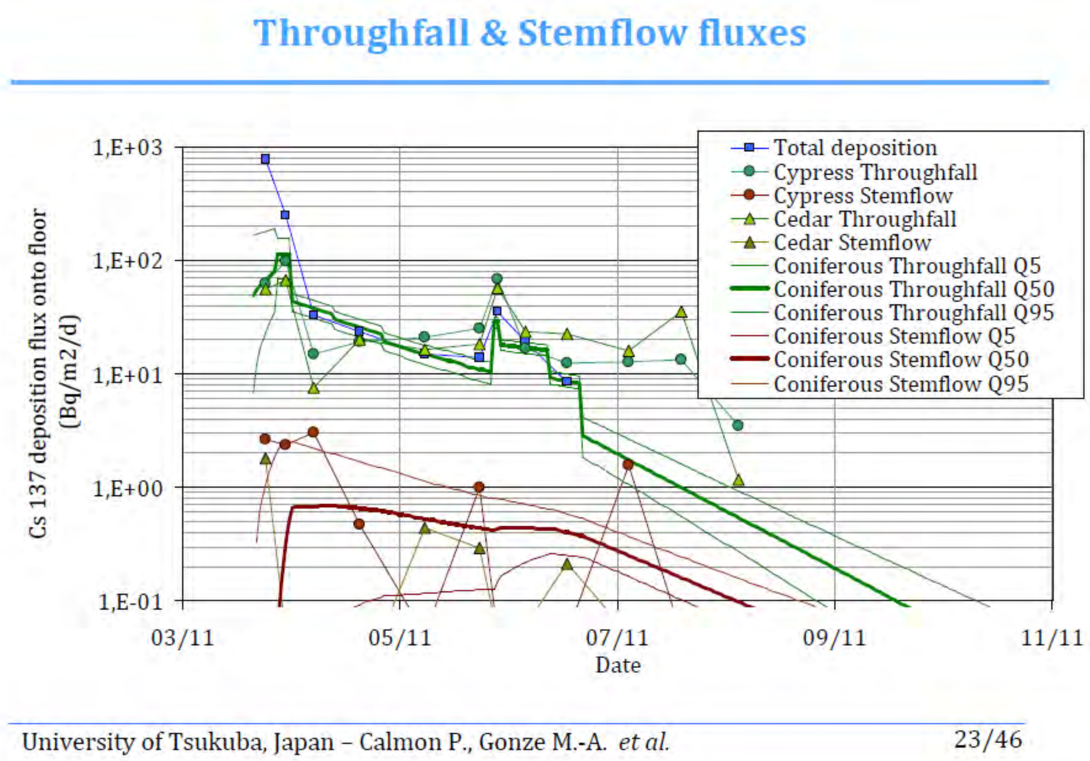
In this case, the modeling scenario, so we accounted for the short-term processes only. We considered a 4-month deposition kinetics because they measured continuous depositions during the first 4 months after the Fukushima accident. As we didn't have any information about daily precipitation, we assumed that it rained every day with a typical rainfall rate from 3 millimeter to 10 millimeter. Dry deposition was neglected. Evergreen category was chosen. Now, the important thing is that if we use the default parameter values just like those that were used in the German scenario, then we clearly observe that the model significantly overestimated the deposition onto the floor and many attempts were made to just try to understand why the Tochigi situations were so different from the German situations. We were obliged to perform some kind of calibration exercises. We tried to modify some key controlling parameters in order to recover or to reproduce more realistic results. Quite good results were obtained. If we increased slightly what we call the canopy coverage ratio that is the fraction of the surface, which is covered by the canopy, the remaining fraction being the soil, occupied by the soil. We were obliged to significantly increase the absorption rates through the cuticule or the foliage.



By increasing these two parameters, we obtained this kind of results here, where here again on the Y-axis, you have the cesium deposition normalized by the total depositions from March to November. As we can see the fraction of the deposition onto the floor is much more lower 0.5 than in the German scenario, but this is normal because in modeling scenario, we increased the capacity of the canopy to intercept the airborne radioactivity. So, we do not say here that ASTRAL provides good results, but we just say that we think that some key parameters that would explain for a part the significant difference between both scenarios would come from this process of interaction between atmosphere, airborne radionuclides, and the foliage that is the foliage absorption and the weathering properties.



Another important result, we looked at the throughfall and stemflow flux in this scenario. We have reproduced here the deposition first onto the floor. In green, this is the throughfall flux. In brown, this is the stemflow flux from March to November. Basically, we were quite satisfied because we reproduced here the order of magnitudes of difference between the throughfall flux or the contribution of the throughfall and the stemflow. Also, the temporal variability was not so much captured or predicted. We have observed also quite strong strengths here where the field measurement tells you that you still have here an important throughfall flux from the end of June, but no depositions were measured. This is quite questionable because if no deposition occurred, then for example the model tells you that the throughfall flux is going to decrease strongly. These are some of the questions we'd like to discuss with all Japanese colleagues.

Modelling of Cs aerosols deposition in Fukushima

Context

- Atmospheric deposition: a crucial process
  - Major input to forest ecosystems
  - Dry *vs* wet contribution is a sensitive information
- Complex dispersion/deposition patterns due to complex source terms, meteorological conditions, orographic & coastal effects
- Much uncertainty remains (*cf.* numerical studies by JAEA, NIES, IRSN)

Objective

- Computing dry *vs* wet contribution, by exploiting:
  - Available measurements of radioactivity concentrations
  - Landscape characteristics
  - Dry deposition velocity assumptions

See Gonze *et al.*, 2013 for a detailed description of methodology

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Another case study is the modeling of cesium aerosol deposition in the Fukushima prefecture. The context is the following one: You know that the atmospheric deposition is a crucial process and especially the major input to forest ecosystems. An important parameter is the dry or wet contribution of the deposition because it's greatly influenced the fraction of the contamination that will be intercepted by canopies. You know that the Fukushima Daiichi nuclear term source was complex and led to a very complex dispersion and deposition patterns, especially in the Fukushima Prefecture due to the source terms, but also due to complex meteorological conditions, orographic and coastal effects and so on. We must say today that some uncertainty or even much uncertainty remains once the wet and dry contribution of the deposition for each location in Japan. The objective of this study was to use the dry and wet deposition parameterizations to process or to explore the radioactive measurements as provided by Japanese organizations and also to use the landscape characteristics to estimate through some kind of spatial methods, the dry and wet contribution. This is going to be published next year.

Data sets

1. Airborne surveys (groundsurface activity)
   - By MEXT, Fukushima Prefecture & US-DOE
   - From Apr. 2011 (survey 1) ...
   - Airborne measurements of γ radiations due to Cs-134/137
   - Emitted by a collection of contaminated bodies : soil, vegetation covers, ...
   - Results sensitive to calibration factors, spatial interpolation, ...
2. *In-situ* surveys (bareland soil activity)
   - By Japanese Universities & IRSN under JAEA coordination
   - In summer 2011 (survey 1), winter 2011 (survey 2) , ...
   - Soil monitoring of Cs-134/137 activities in inhabited areas; gardens, schoolyards, ...
   - 2200 stations: samplings of the top soil layer + γ measurements at ground
   - Important samll scale spatial variability

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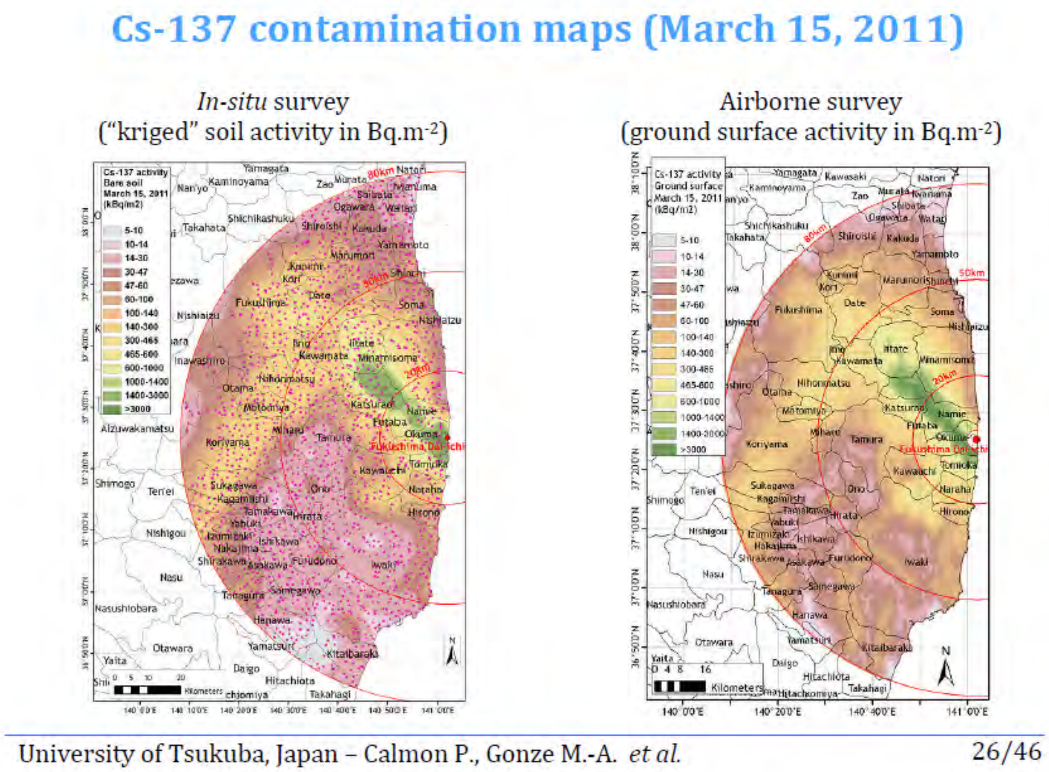
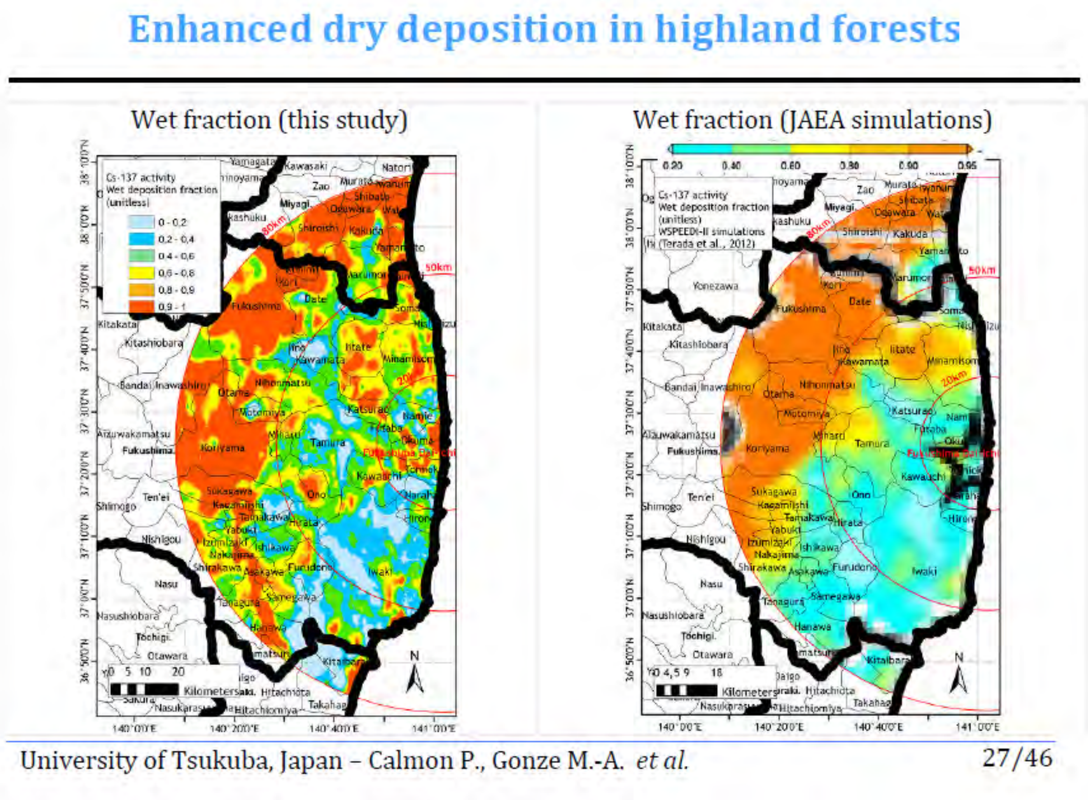
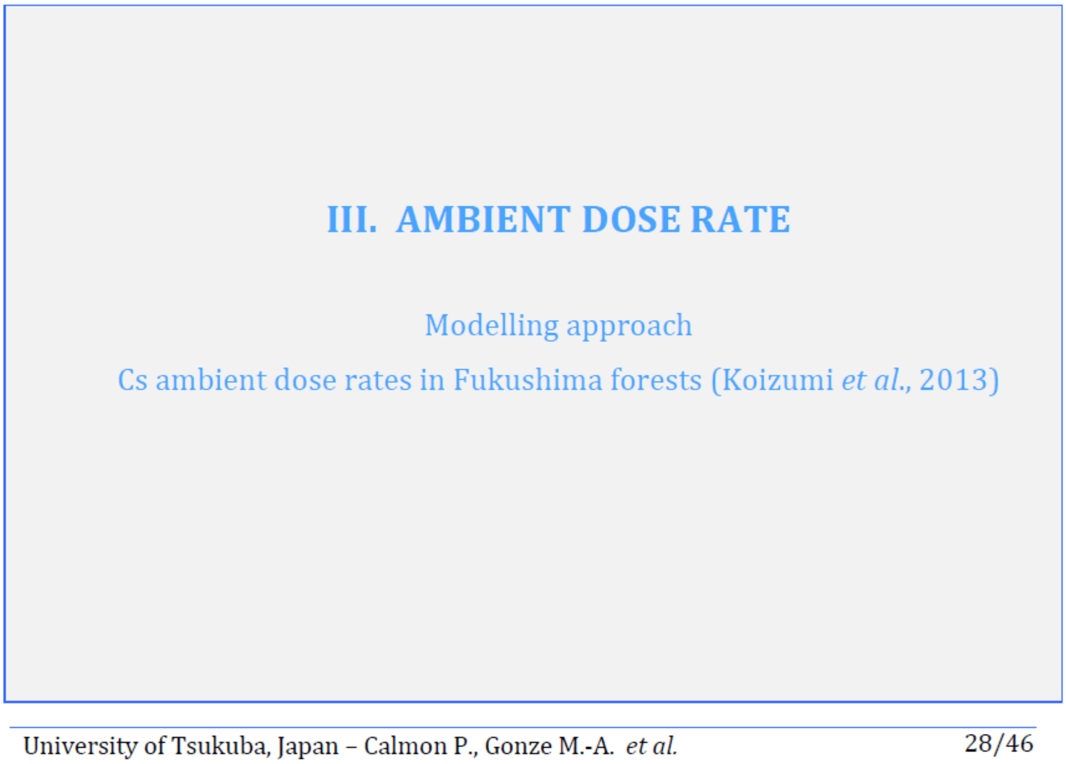
Basically, this model was based on two kinds of data sets. The first one was the ground surface activity as measured by airborne devices from April. The second data sets were the radioactive measurements in bare land soils, different campaigns where the activity in soil was monitored basically in inhabited regions like public gardens, schoolyards, roadsides and so on. Basically, this data set concerns specifically the inhabited areas. To the contrary, this data set gives you a measure of the spatial average contamination at the ground surface.



For example, we looked at IRSN more specifically into details to the difference between both these contamination surveys. On the left side here, you have the map of the soil activity in Becquerel per square meter extrapolated to March 15. As a result of the kriging, the geostatistical interpolation of the measurements that were made at all these peak points. On the right side, you have the results of the airborne survey. You can see that on large spatial scales, both data sets are coherent. But when you're looking at details, you can see some differences, let's say, for example to the Southwest of the Fukushima Daiichi Nuclear Power Plant, you observed here with an airborne device much more contamination in some located forests, then the contamination that was measured in inhabited areas. You can also observe some difference of contamination here in the Northwest place as the contamination level here as measured from airplane or helicopter is significantly greater than the one that was measured in situ. If you compute some kind of spatial indicator, which quantifies the difference between both contamination maps, you use the landscape characteristics and you introduce the dry and wet deposition parameterizations for different land-use categories,



then you end up with this map. On this map, this is the result of our study, we estimated here in the Fukushima Prefecture, the map of the wet contribution, the wet deposited fraction of cesium activity in the Fukushima Prefecture to be compared, so varying from zero in the blue region up to one in the red region. The red region corresponds to basically wet deposition. The blue region basically corresponds to the dry deposition. I personally find very interesting numerical simulation as performed by JAEA that was published by Terada and Katata. These atmospheric simulations give you some kind of also estimation of the wet deposition fractions. What you can see is that both figures have more or less coherence, even also at small spatial scales, we have some discrepancies in between. You can look over here some kind of wet deposition patterns or spots like in Iitate City or Katsurao and also to the south. We observed that this dry deposition occurred mainly here in high-land evergreen forest. This means that many of the forests, evergreen coniferous forests that are at relatively high altitude above 500 meters above the precipitation curve at time of contamination were mainly contaminated by dry deposition. This was confirmed by the JAEA simulations. This work is going to be published.



Second part, the way we compute the ambient dose rate. First, detailed description of the modeling approach and another interesting case study about measurement of dose rates in Fukushima forests as published this year.

Forest Equivalent Medium (FEM)

ASTRAL approach

- Semi-infinite multi-layered medium: Soil-Understorey (S), Trunk (T), Canopy (C) and Atmospheric Boundary Layer (ABL) (although neglected in ASTRAL)
- Each layer with a homogeneous apparent density ρ, chemical composition & radionuclide concentration
- Except for S where an in-depth concentration profile ([^{137}Cs] (z<0) in Bq.m^{-2}) is considered, through the so-called time-varying relaxation mass per unit area: $1/\beta\,(t)$ (kg.m^{-2})

$$[^{137}Cs]_S(z) = [^{137}Cs]_S(z=0) \times \beta \times \exp(\beta \times \rho_S \times z)$$

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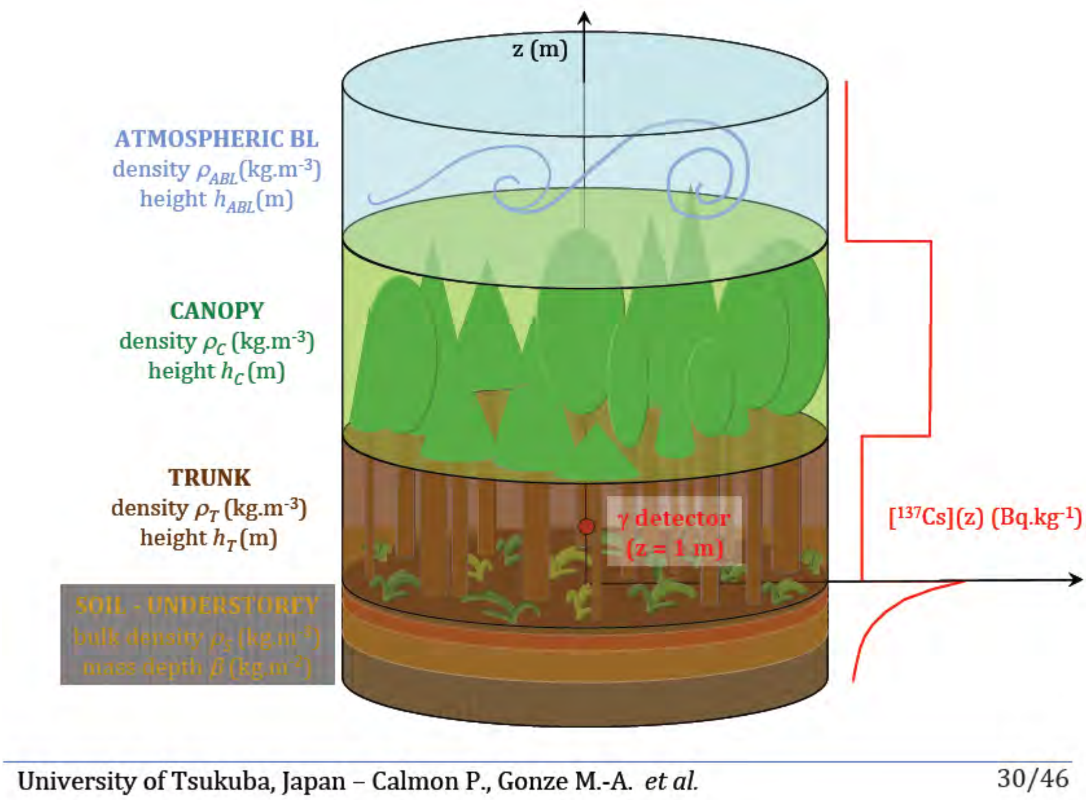
So, basically, to compute the ambient dose rate in a forest system, we made the approximation, which is called the Forest Equivalent Medium. Following these assumptions, you consider that your forest medium can be discretized as a superior position of layer, different layer, horizontally semi-infinite and we basically distinguish four different layers, the soil-understorey layers called S, the trunk layers below the canopy, capital T, above this the canopy including branch, twigs, needles, leaves, capital C, and above this, the truly speaking atmospheric boundary layer, although neglected in ASTRAL. Each of these four layers is considered to be homogeneous that is that you assume that this layer as a homogeneous apparent density in kilogram per cubic meter as homogeneous chemical compositions, as homogenous radionuclide concentration,



and each layer is given by typical heads except for the soil layer where you consider vertically decreasing contamination profile like here. Basically, this is what we called the Forest Equivalent Medium. This is used for computing the ambient dose rates.

You recover here the four layers. Each layer is given by its density and its characteristic heights. You've got here vertical profile of contamination in the forests, which can vary with time, but which is assumed to be homogeneous vertically within each layer except in soil where we consider a typical exponentially decreasing profile.

Basic equations

Kerma rate KR ($nGy.h^{-1}$)

- Calculated at 1m height above soil
- Results from the contribution of semi-infinite plane sources :
  - at depth $z \leq 0$ (in Soil layer)

$$KR_S(z, \rho_T) = S1 \times \exp(S2 \times \rho_S \times z) + S3 \times \exp(S4 \times \rho_S \times z)$$

  - at height $0 < z \leq h_T$ (in Trunk layer)

$$KR_T(z, \rho_T) = T1 + T2 \times z - T3 \times \ln(z)$$

  - at height $h_T < z \leq h_T + h_C$ (in Canopy layer)

$$KR_C(z, \rho_T, h_T, \rho_C) = C1 + C2 \times z - C3 \times \ln(z)$$

Ambiant dose rate ADR ($\mu Sv.h^{-1}$)

- Calculated from conversion coefficients (in $Sv.Gy^{-1}$), specific to Soil Layer and Trunk or Canopy layer

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Then from this, we used some kind of equation, empirical equations to compute the kerma rate, we compute the various contribution of semi-infinite plane sources at various depths in the soil layer, in the trunk layer, and in the canopy layer with empirical relationship. This relationship involves some kind of coefficients that were calculated or adjusted against physically based dosimetric calculations. All these coefficients here are calculated in the whole forest models for each radionuclide. That's all. They're calculated for each radionuclide. To obtain the total kerma rate, you just have to integrate all this contribution along the vertical from the soil layer to the atmospheric boundary layer and then you get the kerma rate at 1 meter above soil. To step to the ambient dose rate in microsievert per hour, we just used some kind of conversion coefficient.

Ambiant dose rates in Fukushima forests

Radioactivity measurements (Koizumi *et al.*, 2013)

- Survey in Jul & Sep 2011
- 9 forest sites in the "emergency evacuation preparation zone" , including:
  - 33 deciduous tree species: Acer, Castanea, Morus, Quercus, Prunus,...
  - 11 evergreen tree species: Chamaecyparis, Cryptomeria, Pinus,...
- 147 measurements of:
  - dose rate at z=1m (in $\mu Sv.h^{-1}$)
  - Cs-134/7 activity in soil down to h=5cm (in $Bq.m^{-2}$)
  - activities in branch & foliage (in $Bq.kg^{-1}$)

Additional knowledge

- Dry *vs* wet deposition relying on estimations by Gonze *et al.*, 2013
- No information on effective rainfall charcateristics at time(s) of deposition !

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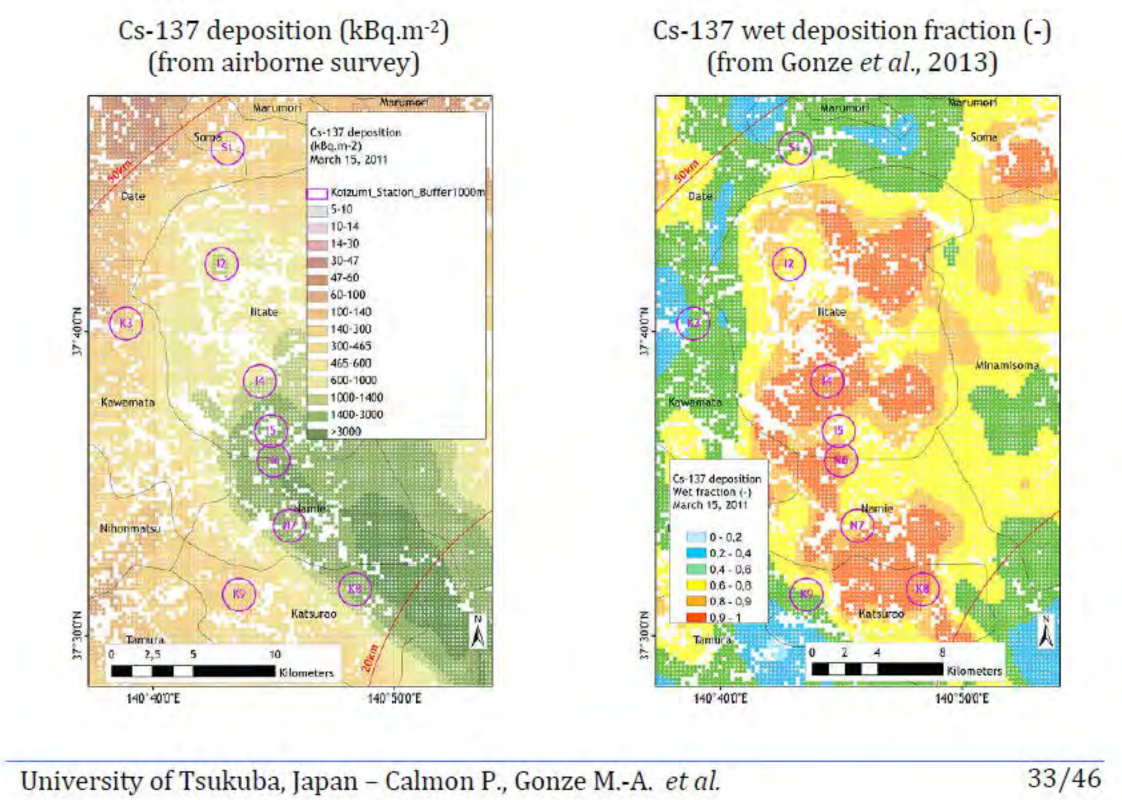
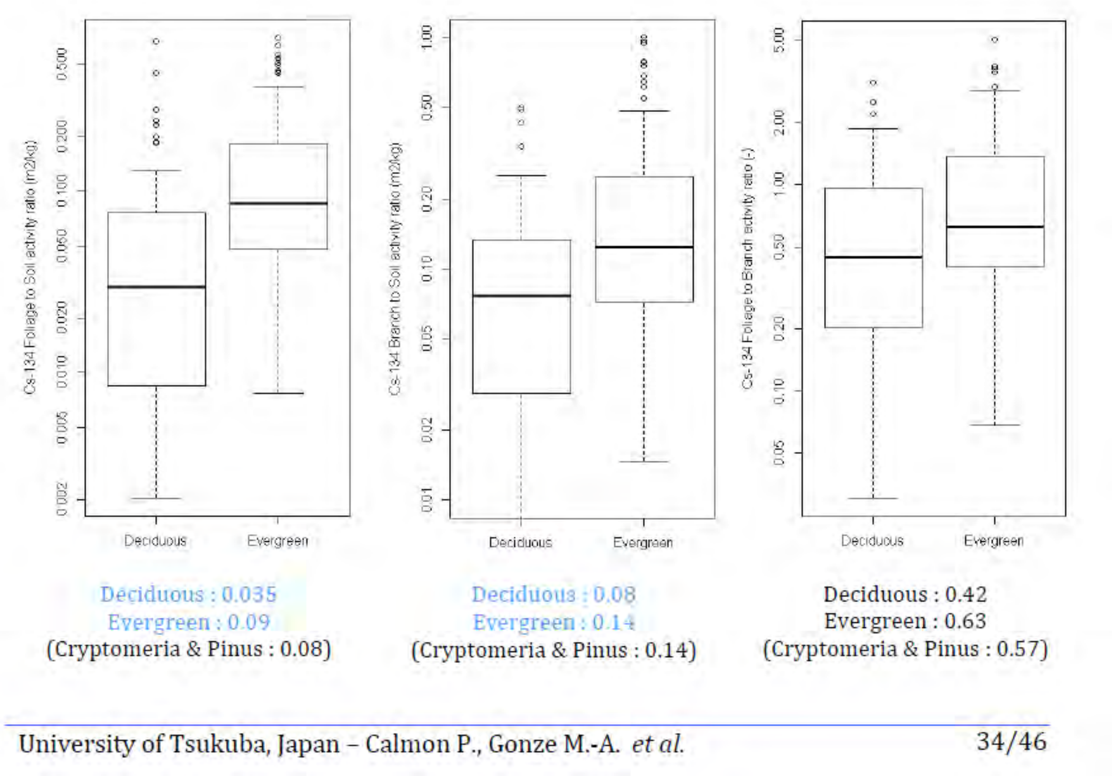
Okay. Now, application of these ambient dose rate modules to the Fukushima forests. Koizumi and his colleagues have been monitoring the ambient dose rates in July and September in some forest sites that were located in the emergency evacuation preparation zone. They sampled a great number of different tree species, let's say, 33 deciduous tree species and 11 evergreen tree species. They published 147 measurements for each species. Dose rate at 1 meter above branch, activity in soil down to 5 centimeter depth in Becquerel per square meter for both cesium 134 and 137 and they also measured activities in branch and foliage. But the problem in this scenario is that we do not have here again a precise information on the deposition characteristics or the rainfall characteristics on each of these nine forest sites. In this case study, we assumed that the dry and wet depositions could be predicted based on the estimations I just presented before.



As displayed here, on the left side here, map of the cesium-137 deposition in kilo Becquerel per square meter as measured by the airborne survey in the forest areas only. The nine monitoring sites are displayed here as local cycle of radius 1 kilometer. On the right side here, we have displayed or we have zoomed on the wet deposition map varying from 0.2 in blue regions to 1 in the red regions. As you can see from this slide, you can see that the monitoring survey covers a wide range of radioactivity levels from the lowest to the highest ones and also a wide range of dry versus wet deposition contributions, from dry deposition basically here comparing wet deposition here in the middle of Iitate City.



One interesting measurement here was provided by Koizumi and his colleagues. It gave the measure here the activity ratio for cesium-134 between the foliage and the soil, between the branch and the soil and between the foliage and the branch for both tree categories that is deciduous and evergreen. They typically observed that for deciduous trees, the ratio of the foliage activity to the soil activity was about 0.035. For evergreen species, it changes to 0.1. It's a little bit the same for the branch to soil activity ratio, but it's less obvious. If you assume now that the biomass, the foliage biomass is more or less similar to the branch biomass and this is more or less true, then you can estimate from this the typical ratio between the activity in overall canopy including both foliage and branch and the soil, and this typical ratio can be estimated to 0.06 for deciduous and 0.12 for evergreen. This is an interesting ratio that we will check in our simulations.

Modelling scenario

- 1-day deposition on March 15, 2011
- Coupling of transfer & dosimetry models
- Specific pdfs for wet fraction & total deposition (positive correlated), computed from maps and site locations
- Rainfall pdfs (unknown !) : 2-5 mm (assuming a positive correlation with wet fraction)
- Evergreen category
- Sampling simulated from Jul to Sep 2011

- Transfer parameter values: same as in Bunzl *et al.* scenario
- Dosimetric parameter values : default values
- Elicitation of dosimetry related parameter uncertainties(pdfs), and correlation in-between
- Probabilistic simulations (#1000 runs)

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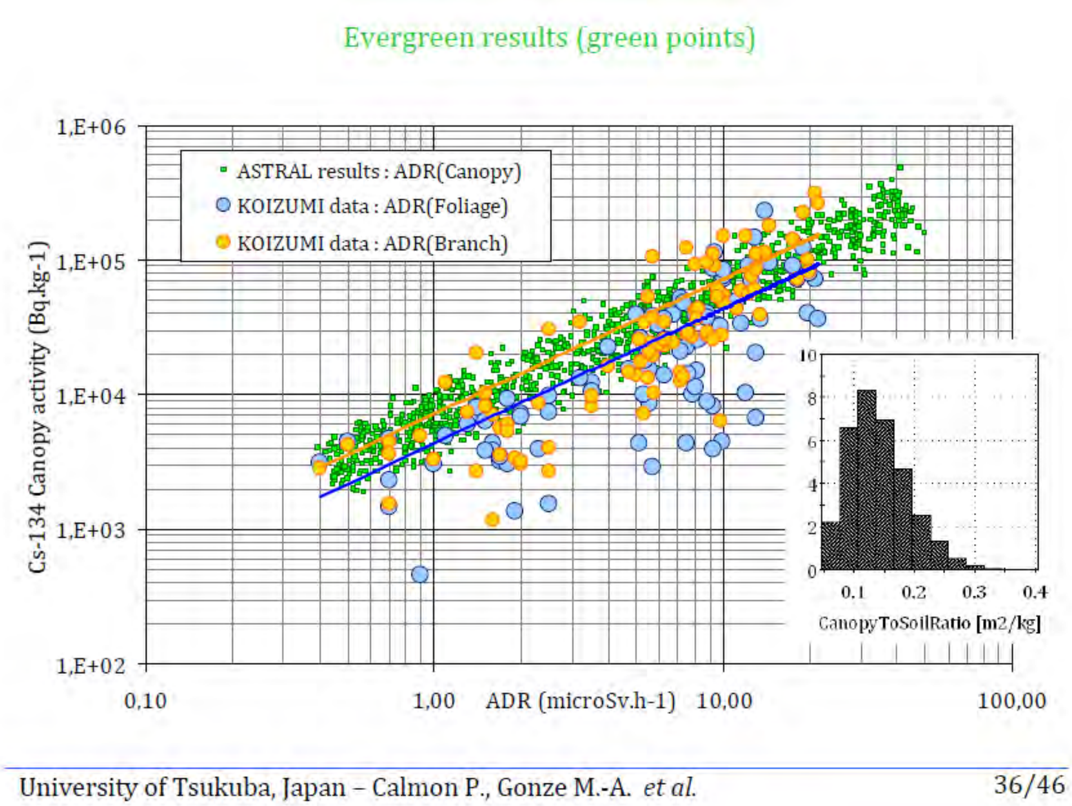
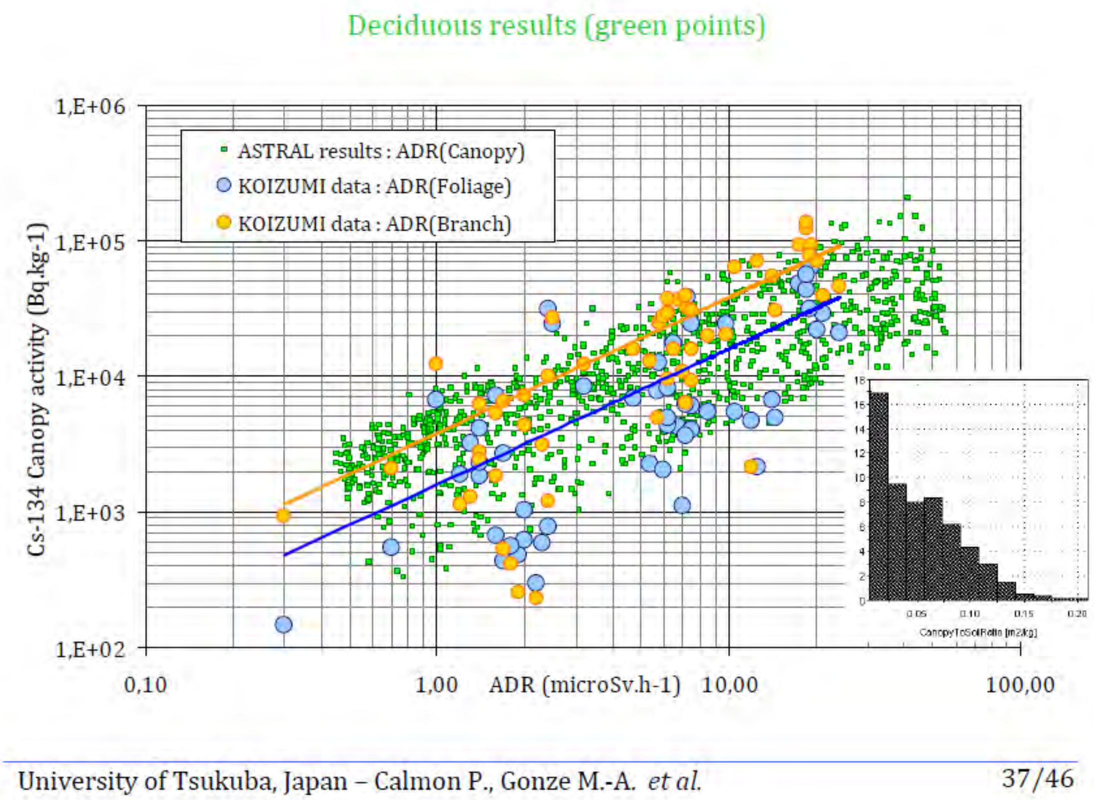
The modeling scenario here using the forest model, we just assumed 1-day deposition on March 15. We coupled both transfer and dosimetric models here. We applied specific probability density functions for the wet fraction and the total deposition as it could be computed from the maps and site locations I just showed before. We also input some kind of probability density functions for the rainfall assuming that rainfall should have varied between 2 millimeters and 5 millimeters. The calculations were performed for both evergreen and deciduous categories. Sampling was simulated to be realistic from July to September 2011.

We introduced the same parameter values, transfer parameter values as chosen in the Bunzl scenario, default values for the dosimetric parameter values, and we also here elicitated the parameter uncertainties.

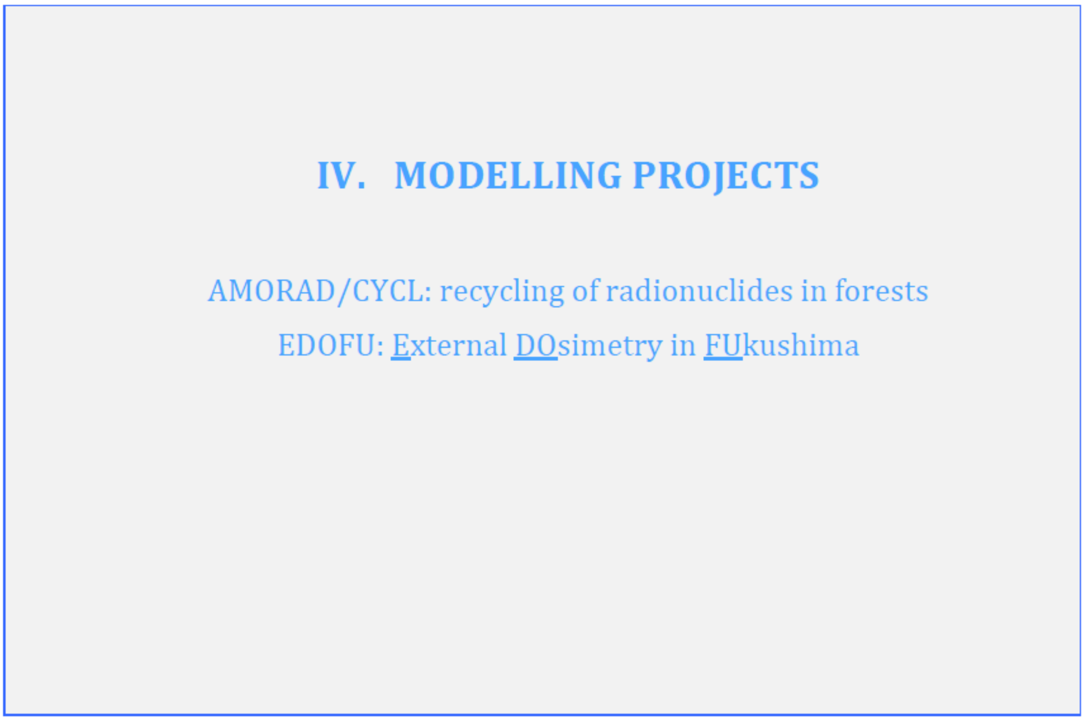


We obtained this kind of results.

I have reproduced here on the Y-axis, the activity in the canopy in Becquerel per kilogram against the ambient dose rates in microsievert per hour. Experimental points plotted here in orange circles for activity in the branch and for the blue circles activity in the foliage. This figure shows you that more or less the canopy activity can be linearly related to the ambient dose rates, but the regression coefficient is quite different for foliage and branch. We also plotted the results of our numerical simulations in green points here, the green points giving you the activity in overall canopy as a function of ambient dose rates. We were quite satisfied with our dosimetric models here. Typically, we more or less reproduced the linear relationship between activity and ambient dose rates, also a little bit overestimated, but the viability was underestimated with comparison with the field data. We also checked in our simulations that the typical canopy to soil ratio here for the evergreen forests was more or less equal to 0.12 and this is the case. In this case, we are quite confident in the transfer calculations and we are also quite confident in the dosimetric calculations,



and the same situation is now for the deciduous trees here. For the deciduous trees, you have to know that at time of deposition, the leaves were not developed. You had just branch. So, the interception was much or less important for deciduous than evergreen. This increased the fraction of the deposition, which was deposited onto the soil and decreased the fraction intercepted by the canopy because there was just branch. All the activity level in the canopy was lowered. But in this case, agreement is quite good and also the canopy to soil ratio here is about 0.06, which is quite good agreement with the Koizumi data. One of my conclusions is that my feeling is that on the dosimetric modules, we're quite confident. But we think that for the transfer modules, a lot of improvements are still to do in this model, especially on the long-term process.



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This is the reason for which I would like to have this presentation a little bit longer by presenting basically two projects, one some of you well know. This is the AMORAD research project, which focused on the study of the recycling process of radionuclides in forests. But I would like also to emphasize tonight a new project we launched at IRSN and I would like to promote this project tonight. This is called the EDOFU project for external dosimetry in Fukushima.

AMORAD : Forest WP (CYCL)

Thiry Y (ANDRA : coordinator)
Coppin F, Hurtevent P (IRSN/PRP-ENV/SERIS/L2BT)
Calmon P, Gonze MA, Mourlon C, Nicoulaud V, Simon-Cornu M (IRSN/PRP-ENV/SERIS/LM2E)
Kato H, Loffredo N, Onda Y (University of Tsukuba)

Model improvement focusing on long-term recycling processes

- Refinement of canopy description : branch *vs* foliage vs twig , needle cohorts ?, living *vs* senescing parts (dead branch, outer bark, oldest cohorts)
- Refinement of translocation, root uptake and litterfall fluxes (Goor & Thiry, 2004 ; ...)
- Refinement of in-soil/litter processes: litter degradation, layering of soil (?), available *vs* non available pool
- Explicit account for mean biomass/LAI dynamics (ecological modelling)
- (Species-dependent parametrizations ?)

Lot of interactions with CYCL fieldwork

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The first project, AMORAD, more specifically what we call the Forest Work Package, CYCL in English: CYCL work package actually is led by my colleague, Yves Thiry from France here, ANDRA, which is an expert in forest radioecology. This work package also involved my colleagues from experimental lab, Frédéric Coppin and Pierre Hurtevent and also Nicolas Loffredo and some people from our Environmental Modeling Laboratory are also involved here in the modeling development of the forest models. Also, we have an important partner, which is the University of Tsukuba on this project.

Concerning the model, we now have some quite clear ideas about the way we could improve this model, especially on the long-term recycling process. We basically identified four ways of improving this model. The first one is, in this model, the refinement of the canopy description just by distinguishing between the branch, the foliage, and the twig, because we know from Chernobyl experiment that the characteristic activity, especially in cesium, can be significantly different between branch and foliage and even twig. Further refinement would consist in distinguishing between the different needle cohorts. But we're not convinced this is quite important, because in the post-Chernobyl experiment, it was observed that very rapidly the contamination was translocated between the different needle cohorts as quite rapidly equilibrated. We would like also to distinguish between the living and the senescing parts by distinguishing explicitly modeling the dead branch, outer bark, and oldest cohorts, because activity is not the same in the senescing parts than in the living parts. This was clearly shown by the studies of Goor and Yves Thiry. We also would like to more explicitly account for long-term process like translocation within the tree, the root uptake and by discretizing the soil layer perhaps and also the litterfall fluxes and quite nice parameterizations are being proposed by Goor and Thiry.

Another way of improvement would consist in refining all in-soil and litter processes. This is a basic and important package in the CYCL research package. That is the litter degradation characterization of the litter degradation kinetic rates, possibly the layering of soil into different characteristic soil layers and more biophysicochemical characterization or distinction between the available and non-available pool. The final improvement way would be to explicitly account for this forest model for the long-term growth of biomass and leaf area index that is ecological modeling. There is a lot of interaction with experimental field, which has been planned in this project, a lot of work to do.

EDOFU : context

- Various gamma-ray monitoring surveys (fixed, carborne, airborne) confirm that, in contrast to what is observed in inhabited and cropland areas, ambient radiation levels remain significant in semi-natural terrestrial ecosystems, where remediation actions have not been undertaken yet (*ex.* mature evergreen forests)
- These measurements also reveal that the effective half-life of Cs 134/7 dose rate decrease is strongly dependent on the local environment, although highly variable in space for a given landscape unit, and significantl y smaller than the one expected from the physical half-lives (down to about 50%).
- The environmental processes responsible for such a decrease, their respective contributions and the factors responsible for this high spatial variability have not been clearly identified (climate, in-soil migration, cleaning actions, watershed erosion, measurement uncertainty, "canopy shielding effect" for airborn survey, ...)

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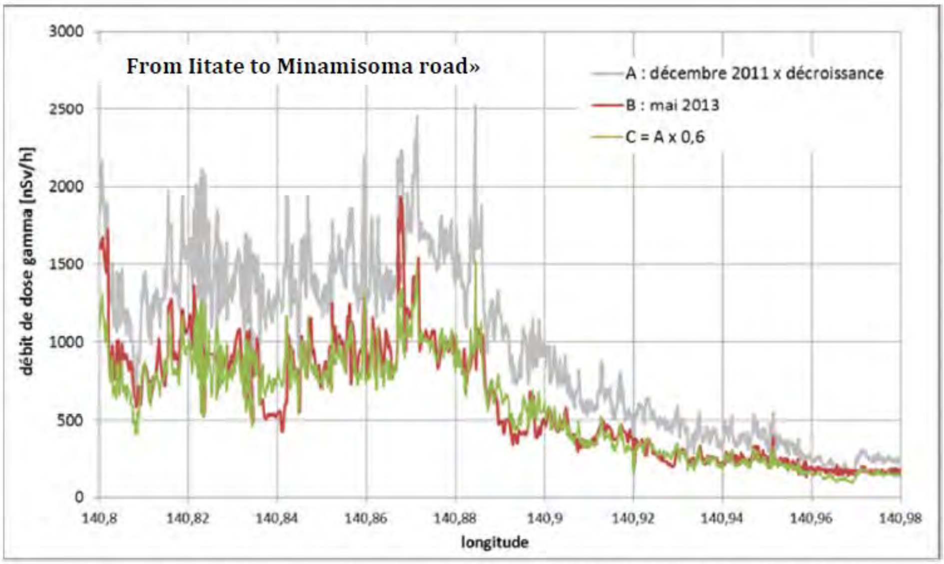
The new project has been launched this year at IRSN. The context is the following one. The various gamma-ray monitoring surveys as fixed, carborne or airborne in Japan confirm that in contrast to what is observed in inhabited and cropland areas, the ambient dose rate levels remain quite significant in semi-natural terrestrial ecosystems where typically remediation or cleaning actions have not been undertaken yet like forest and especially mature evergreen forests, so significant ambient dose rate in semi-natural terrestrial ecosystems.

Another part is that all these measurements reveal that the effective decrease or the time characteristic of decrease of the ambient dose rate induced by both cesium isotopes is strongly dependent on the local environment that is the half-life of ambient dose rate decreasing is depending on the local environment that is [ph], roadside, forest, restaurant, meadows, inhabited areas, paddy fields and so on. This was nicely observed and measured by the JAEA by carborne surveys. This half-life is also highly variable in space for given landscape unit, for example if you measure the decreasing time of its ambient dose rates on a football field, then you observe the high variability of this characteristic decreasing. One important thing is that this effective half-life of ambient dose rate decrease is significantly smaller than the one you can expect from the physical half-life. All this measurement tells you that the ambient dose rates decrease by more than 50% due to environmental processes other than the physical decay of radionuclides. At the moment, we must say that neither the environmental processes which are responsible for such a decrease nor their respective contributions or the factors that are responsible for this high spatial variability have been clearly identified. We could read some senescence on the internet about these things, for example we could read that watershed erosion and runoff could explain this strong decreasing of ambient dose rates. At IRSN, we're not convinced at all. We can think about many, many environmental processes for explaining this significant decrease of ambient dose rates in the Japanese landscape like in-soil migration, cleaning actions that is plowing of crop fields, and also cleaning action on houses, roads and inhabited areas, you can think about watershed erosion, but perhaps more contributions. You can think about one interesting thing. It's the canopy shielding effect. Because when you're measuring the ambient dose rates from an airplane flying at some altitude as the radioactivity is going down from the canopy to the soil, the distance is increasing and the gamma ray has shielded by the canopy and then the internal transfer process of radionuclides in the forest system, that is [Unclear] forest from canopy to soil has explained some decrease of the ambient dose rates as measured from airplanes, but you also have to account for uncertainty in measurement etcetera. So, this is a very, very challenging scientific question to solve. This is basically the objective of this project, EDOFU for external dosimetry in Fukushima.

Example: carborne measurements by IRSN



From Manach E & Debayle C, 2013 **(IRSN/PRP-ENV/SESURE)**

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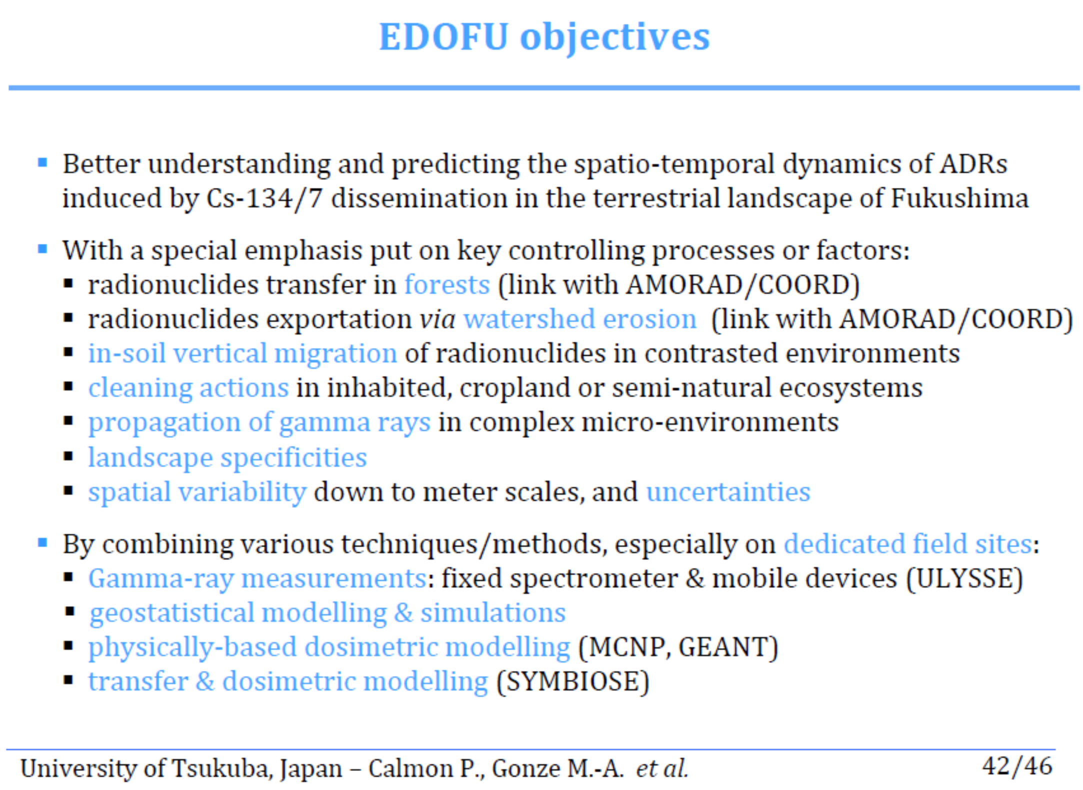
This is for example some measurements that were made by some of my colleagues from IRSN when they drove from the Iitate to Minamisoma road, and they made these measurements in December 2011 and in May 2013. That is nearly 1.5 years after. This is the spatial evaluation of the ambient dose rate in nanosievert per hour from Iitate to the seaside. The gray curve is the ambient dose rates in December 2011. The red curve is the ambient dose rates in May 2013. If you multiply - and this curve is physically decay corrected, and if you decrease the ambient dose rate, the gray curve by 40%, then you get the same level that was measured 1 year and after. This means typically that on the same road the ambient dose rates decreased, but also processed the physical decay by about 20% to 30% per year. Many, many monitoring surveys show you that the ambient dose rate in Japan, in Fukushima Prefecture is decreasing by about 20% to 25% per year. The underlying processes are quite unclear today.



The objective of this project is to better understand and predict the spatio-temporal dynamics of ambient dose rates induced by both cesium isotope dissemination in the terrestrial landscape of Fukushima with a special emphasis put on the key controlling processes or factors that are suspected or candidates that is the radionuclides transfer in forests and there is a strong link for sure with the AMORAD project. We would like also to, for in the whole modeling exercise, account for the watershed erosion and there is a strong link with another package in AMORAD, which is available. I made a mistake. This is the erosion work package in AMORAD. But we also would like to account for integrated assessment study of the in-soil vertical migration of radionuclides in very contrasted environments like hotels, forests, meadows, bare soils and so on. We would like also to account for the cleaning actions, especially in cropland regions and perhaps in the future in the semi-natural ecosystems like litterfall or tree cuttings. We are going to model explicitly the propagation of gamma rays in complex micro-environments like forests or inhabited zones and accounting for landscape specificities, spatial variability and uncertainties.

Basically, we're dealing with this big scientific topic by combining various techniques and methods on perhaps dedicated field sites. We would like to make some gamma-ray measurements with either fixed spectrometer or mobile device, either carborne or even airborne I don't know. We would like to make some geostatistical modeling of the data or ambient dose rate data in the environment and also to perform some geostatistical simulations just to produce some kind of plausible maps of contamination and ambient dose rates as an input calculation, some physically-based dosimetric modeling, and the final point perhaps the most important for us, that we would be very much interested in using or testing the SYMBIOSE platform to predict the dynamics of the cesium isotope in this very complex Fukushima landscape.

Just to add, I show you here some pictures given by one of my colleagues from the Environmental Division, who participated to two campaigns of radioactivity characterizations in inhabited areas to in-situ gamma-ray spectrometer. This is the kind of device we would like to use for this EDOFU project.

ULYSSE system

- NaI Scintillator de 2 litres
- GPS (precision = 60 cm)
- 1 measurement/second

from Debayle C, Manach E *et al.* (IRSN/PRP-ENV/SESURE)

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Another interesting system is what we developed at IRSN, the ULYSSE system where we have a large NaI scintillator that is embedded in a car or airborne and this kind of measurement was tested for more than 2 or 3 years in France just to characterize the natural land contamination in some specific areas in France. This is an interesting system.

EDOFU partners

- IRSN
  - Environmental Division : PRP-ENV/SERIS
  - Environmental Division : PRP-ENV/SESURE
  - Environmental Division : PRP-ENV/STEME
  - Nuclear Safety Research Division: PSN-RES/SEMIA
- Electricité de France (co-funding)
- **Japanese partners are welcome !**

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The partners in EDOFU, many people from the Environmental Division at IRSN, from the Environmental Division and also from the Nuclear Safety Research Division. As you may know at IRSN, we basically split into two big divisions, one dealing with radiological protection and one dealing with the nuclear safety of nuclear reactor. This project is co-funded by Electricite de France. We would very much appreciate if some Japanese partners could work with us on this topic.

THANK YOU

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I thank you very much for your attention. I apologize for this long talk, perhaps too much long talk. It's okay. Okay, it's still 7.

質　疑

Moderator

But we need time for questions.　Okay?

Dr. Marc-Andre Gonze

Yeah.

[Japanese]

Male Participant

I didn't understand the relationship between the map of airborne dose rate, soil measurement, and map of wet and dry deposition.　Could you please...?

Dr. Marc-Andre Gonze

Yeah.

Male Participant

...because in the south part of [Unclear] deposition, you talked about [Unclear] for which the main deposition was dry.

Dr. Marc-Andre Gonze

This one or...?

Male Participant

Before.

Dr. Marc-Andre Gonze

This...

Male Participant

Yes.　This slide okay.　In the south part, yes.

Dr. Marc-Andre Gonze

No, this is this.

Male Participant

Yes.　In the south part of [Unclear] deposition.　Yes, this map, you talked about if I understood that is wet deposition, dry deposition.

Dr. Marc-Andre Gonze

Dry deposition.

Male Participant

Dry...

Dr. Marc-Andre Gonze

In some locations.

Male Participant

Okay, in some locations, so why we didn't see the measurement in-soil activity, I mean – does it mean that the dry deposition is staying in the canopies or...?

Dr. Marc-Andre Gonze

This map is a fictive map because basically the measurements were made just in inhabited areas. All the monitoring locations here are located in around village in inhabited areas. From this data as provided by the Japanese researcher and universities, we performed some kriging interpolation, geostatistical interpolation to reproduce the kind of potential fictive map of contamination of the prefecture, the landscape just as if all the landscape was corresponding to inhabited areas. So, for example, here you predict the contamination level that you would have observed if this location was occupied by habitations. Okay?

Male Participant

Yeah.

Dr. Marc-Andre Gonze

This is the ground contamination. The average contamination in every kind of [Unclear] objects from trees, from soil, from road, from crops and so on. You are not measuring the same thing. It's normal. You can expect some difference in between because this is – you're not measuring the same thing in the same [Unclear] compound object and not at the same spatial space. You can by exploiting this difference between these two maps and using the deposition parameterizations, you can estimate the dry deposition fraction. Because for purely dry deposition, for the Becquerel per cubic meter in air if the contaminated [Unclear] is above the forest, the deposited flux will be much higher than if this [Unclear] was above the bare soil. Just by exploiting this difference, basically what we can see that if on the locations where there are differences, it means that dry deposition occurred. Typically, all these locations here correspond to high elevation in things I mean. This is the Ibuki mountain and all these are very forested areas, which are elevated. We think that at time of deposition, significant contribution of dry deposition occur in these areas here. It's normal that you do not observe this in inhabited area, because bare land soil is not so efficient for capturing airborne contamination than coniferous campaign. Is it clear now?

Male Participant

Yes, yes. It's clear. Thank you. This map was [Unclear] in March 2011?

Dr. Marc-Andre Gonze

Yes, all have been extrapolated to March 15 through the physical decay correction.

Male Participant

Okay.

Dr. Marc-Andre Gonze

Okay.

Male Participant

You extrapolated from March?

Dr. Marc-Andre Gonze

Yes, this is estimated on March 15, 2.5 years ago.

Male Participant

Okay.

Dr. Marc-Andre Gonze

Okay.

Male Participant

Okay. Thank you.

[Japanese]

Male Participant

Thank you very much. I'm very pleased to your open-minded presentation to discuss all the concept of new modeling or new approach. But it is so much condensed to understand within hours or 1 hour now. I would like to know about the very basic question. The first one is in the first part of your presentation, you showed tritium, carbon 14, chloride, using these three radionuclides to modeling, but I'm not familiar with three radionuclides. Usually, we think about cesium 134, but why do you use these three radionuclides to modeling? I don't understand why you mentioned about the tritium, carbon, and chloride.

Dr. Marc-Andre Gonze

You do not understand why we are interesting in modeling these three radionuclides?

Male Participant

Right.

Dr. Marc-Andre Gonze

Actually in France for example, all the nuclear industry, the release of radioactivity by the normal functioning of the nuclear industry decreased a lot. The only radionuclides that can be detected or measured in the environment are basically carbon 14 and tritium. This is the most significant release, radioactivity release in France at the moment. I guess that there is also some special nuclear industry, which is going to release tritium like for example you heard about a project in France, which is called ITER. This is for the nuclear fusion of the future. There is a big international project in France where they are going to study experimentally the nuclear fusion. This installation will produce a great amount of tritium in the environment. Also, the military nuclear industry produced tritium and so on. Both tritium and carbon 14 are very important radionuclides for us at the moment. Also, from scientifically point of view, they are very difficult models, because they are intrinsically linked to the living matter, I mean they are metabolized - they do not follow the same pathway as other radionuclides. For example at IRSN, I've some colleagues who are specialized in the modeling of tritium for many, many years - I mean I've a colleague who has been working for 10 years on the modeling of tritium for example, so it's very, very complex radionuclide and also chloride. I do not know – can you tell a few words?

Male Participant

For different reason because it's important radionuclide in certain nuclear waste, radioactive waste and because of dismantling of nuclear power plant and the possible release of such element, you know the graphite for example is the object of research on possible treatment. When you have an option, you have also a risk and I think I just consider truce [ph] element just to be well prepared in case of possible incident or just to demonstrate that there is no risk, to be well prepared.

Male Participant

Cesium 137 or 134, some relation to those major three radionuclides in the ambient environment. You use these three radionuclides to understand the behavior of cesium?

Dr. Marc-Andre Gonze

No.

Male Participant

No.

Dr. Marc-Andre Gonze

No.

Male Participant

The risk - the model is more generic than you maybe believe it is [Unclear].

Dr. Marc-Andre Gonze

No, the views of you are quite different. Basically, in the whole models, in every kind of ecosystems, marine, aquatic or terrestrial ecosystems, we basically have generic equations for all radionuclides apart from tritium, carbon 14, and chloride 36 to simplify. All these three radionuclides typically required specific scientific knowledge and development. Actually at the moment, there are some experimental or field and modeling projects at IRSN just dealing with carbon 14 in the cropland regions for the transfer to [Unclear] and so on.

Male Participant

Okay, probably I understand. The next basic question is about AMORAD. In the first three parts, you showed detail of your new modeling about accident in Fukushima, but the last part in AMORAD, what is the relationship between AMORAD and the first part of model described. I don't understand that the last one, AMORAD, why do you show the AMORAD in the last?

Dr. Marc-Andre Gonze

Because I wanted to tell you that at IRSN or generally in France and also in Japan, we're all interested in understanding more thoroughly the dynamics of radionuclides in forest ecosystems because this is a great challenge for you to manage this contaminated forest in Japan. There is a kind of revival of radioecological science, especially focusing on forest ecosystems. I'm not specialist in forest modeling or even in forest radioecology. But my feeling is that we do not much know about forest radionuclide dynamics in forest and many, many fundamental questions are still open and this was the reason for which some organization and research universities in France in collaboration with the University of Tsukuba wanted to promote a new research modeling program focusing on forest but also on watershed erosion and runoff, but in this big research program, there is also a big work package dealing with the marine ecosystems and predictions of radionuclide and cesium dynamics in the marine systems. For us, it's just a small piece of the puzzle. At AMORAD, the objective of the CYCL work package in AMORAD is just to improve the existing forest modeling approach and especially on the long-term transfer process because my feeling is that the ASTRAL model as I presented it, some of its weightiness concerned the way we model the long-term process.

Male Participant

So, it means the first part is more general description of your total model, four models.

Dr. Marc-Andre Gonze
Yeah.
Male Participant
I see.
Dr. Marc-Andre Gonze
Yeah.
Male Participant
Okay, thank you. The last one is just a comment. In your presentation, you mentioned about the importance of absorption in short-term modeling, short-term process.
Dr. Marc-Andre Gonze
A process through cuticule or...
Male Participant
Through cuticule, right, but you didn't describe the absorption for external bark. You didn't mention about the importance of absorption in the long-term process, but I think absorption is still important in the long-term process maybe. Professor Onda said you are staying in Japan next 1 month and [Unclear], so you have to feel free the process. Long-term process and the short-term process is very complicated and absorption will be improved [Unclear]. It's my opinion.
Dr. Marc-Andre Gonze
You're certainly right. I just discovered this morning that one of our colleagues still measured some kind of weathering or some kind of activity in the throughfall flux and stemflow flux, which means that significant fraction of the contamination is still available for weathering by rainfall and has not been incorporated. He also mentioned the existence of some kind of process which is the adverse of the absorption. But it's the remobilization of incorporated radionuclides through [Unclear] and so on. I completely agree with you on the fact that this is very complex process. There're possibly some improvements on these fine processes of interactions at the leaf or the needle surface.
Male Participant
Thank you.
Male Participant

Maybe just - for what concerns the possible absorptions to bark, we have also to admit that there is very few data and it still remains a question. Why the absorption through foliage is very well known, not maybe for foliage canopies, but it is very well known based on examples for [Unclear] for example, but you're true, the question remains open for absorption through bark but...

Male Participant

I think the bark is the crucial point on process of using a forest, we have very few data about bark, but absorption through the bark is larger than twig and the absorption very long remains and there is possibility to transfer from bark to foliage or bark to branches. We have to check if it is true or not.

Male Participant

Yeah. I think the best way to check that is to adopt an experimental approach with [Unclear] because you know the reality sometimes is very complex, especially in C2 monitoring.

[Japanese]

Female Participant

Thank you for your presentation. My question is about vertical deposit modeling from canopy to soil, your presentation in modeling deposit concentration in modeling, canopy and trunk content, and soil undersurface is exponential. Why is there such a modeling?

Dr. Marc-Andre Gonze

Can we go back to the slide?

Female Participant

Yes.

Dr. Marc-Andre Gonze

Soil concentration, vertical contamination profile in the soil.

Female Participant

Yes. Soil is exponential and canopy and trunk is flat, why I select such a model?

Dr. Marc-Andre Gonze

I don't understand the question.

Female Participant

Sorry. Concentration and soil surface is rather exponential supported many sampling or report [ph]. But I firstly see flat [ph] in canopy and trunk setting model. Why such modeling? Is there any report or paper for sampling?

Dr. Marc-Andre Gonze

I'm going to check the question with my colleague.

Male Participant

The question is, is there a report about the importance of the canopy in radiation?

Female Participant

Why this concentration flat in modeling?

Male Participant

It is exponential...

Dr. Marc-Andre Gonze

Is exponentially decreased, you mean?

Male Participant

[Unclear]

Dr. Marc-Andre Gonze

You'd like me to justify?

Female Participant

No. In soil, but it's...

Dr. Marc-Andre Gonze

Here.

Female Participant

Relatively on trunk...

Dr. Marc-Andre Gonze

Canopy and trunk, this is homogeneous.

Female Participant

Yes, homogeneous.

Dr. Marc-Andre Gonze

Homogeneous, so it doesn't vary with altitude or depth above the soil. But in soil, we consider vertical contaminant activity and your question is why...

Female Participant

Why canopy and soil in flat concentration?

Male Participant

[Unclear]

Dr. Marc-Andre Gonze

Okay. I agree with you. I mean from a theoretical point of view, it would be much more realistic to predict or to use a one-dimensional vertical model where we would be able to predict the evolution of the contamination within the canopy for example with depth, but this is very difficult task. I mean for example we have dry and wet deposition of radionuclides, which are able to predict the vertical profile of contamination within the canopy for example given the canopy characteristics and what we call the leaf area density. But after that, we do not have enough knowledge to model other processes than the dry deposition process. Basically in this ASTRAL model, we simplified the reality and we just assume that this is a compartmental assumption. But in soil, this is important because the soil, the mixing is not so much facilitated in the soil. For the dosimetric point of view, it's very important to properly model the decreasing of contamination in soil because the efficiency of soil to capture and absorb to gamma rays is much more efficient than canopy or even trunk layer which apparent density is much more lower, so gamma rays are not so much absorbed in canopy and trunk. From a dosimetric point of view, it's not so much important to account for the vertical heterogeneity of the activity except in soil.

Female Participant

Okay, thank you.

Dr. Marc-Andre Gonze

Okay.

Female Participant

I see. Thanks.

[Japanese]

Moderator

Thank you very much for your talk.

[Japanese]

END