Dr. Olivier Evrard

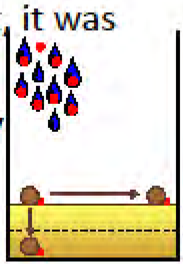
I think I will use your microphone in this. Thank you. Good evening, everyone. I will talk about the work we did with Russian colleagues from the University of Moscow. We worked actually on modeling runoff and erosion in one of the areas of Russia that were strongly contaminated by Chernobyl Accident fallout. Professor Onda asked me also to give an introduction of Chernobyl fallout and the consequences of this radioactive fallout in the environment.

Foreword

- I am not a nuclear engineer nor a Chernobyl accident specialist…
- I was 4 years old when the Chernobyl accident occurred…
- Polemic interpretations of authority management of the accident and its consequences

Playing in the familial garden in 1986…

- When we worked in an area of Russia contaminated by Chernobyl fallout, it was not to investigate the contamination issue
- We wanted instead to use the radioactive contaminants (and particularly caesium-137) to **trace soil particles** and sediment in catchments



Just I wanted to start with some remarks as a foreword. First is that I am not a nuclear engineer nor a Chernobyl accident specialist. I want just to give you a few elements, a brief overview of what happened there. It's also associated, perhaps, somehow with what I have heard about Chernobyl since I was a child. In fact, when the Chernobyl clouds flew over Belgium, where I was when I was a child, fortunately the weather was nice. As you can see on these pictures, my mom found back in the family albums, I was playing with my small brother in the garden.

In fact, there was a lot of polemics about Chernobyl because there was no precaution measurement taken when the clouds flew over most of Europe. In fact, when we worked in the area of Russia contaminated by Chernobyl fallout, our objective wasn't to work on the contamination itself but to use the radioactive fallout as a tracer of particles and sediments because with the fallout, most of it goes to the ground with rainfall and then absorbs onto particles and we use this caesium as a tracer of the particles.

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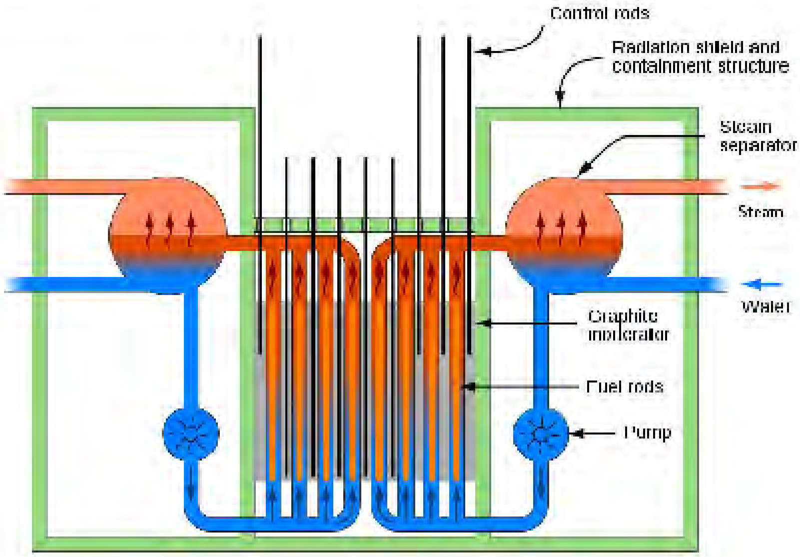
LSCE

- The Chernobyl nuclear power plant: RMBK (*High Power Channel-type Reactor*) reactors

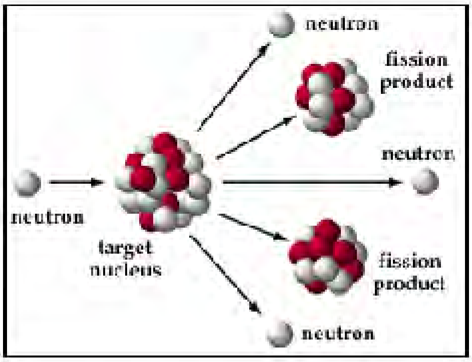


- Failures during a « safety test » started on 25 April 1986
- Core explosions that led to massive radionuclide emissions into the atmosphere
- Several fires were triggered and lasted ~ 10 days

As I said, I'm not a nuclear engineer nor a specialist, but that is to show you where Chernobyl is in Eastern Europe, at the border between Belarus, Ukraine, and Russia. It's what they call RMBK reactor, so a very old style reactor with only one water circuit. In fact, several failures occurred during safety tests that power plant engineers started on the 25th of April in 1986. It led to several core explosions that led to massive radioactive fallouts and emissions into the atmosphere. After those explosions, there were several fires triggered that lasted at least 10 days. The local firemen weren't equipped to extinguish the fire and they had many problems to stop it and they had to put a ● and several substances to try to keep it under control.

- An important remark regarding Chernobyl nuclear power plant:
  - Nuclear fuel was used >> it is changed every 3 years
  - At the time of accident, nuclear fuel had to be changed!
  - Consequence: fuel contained many radioactive fission products

  - **Nuclear fission products** are produced during uranium splitting



- Krypton-85 (gas)
- Strontium-90 (bêta emitter, calcium mimic)
- Iodine-131 (thyroid)
- Caesium-134
- Caesium-137
- ...

An important remark I wanted to make regarding Chernobyl accident was that the nuclear fuel they used in the power plant was actually old and at the point to be changed when the accident occurred. That means that at the time of the accident, the nuclear fuel contains many radioactive fission products. That's what is shown in the graph below, so you have your target nucleus, uranium, and then when it's hit by neutrons, there're fission products resulting from this reaction and all other neutrons emitted that can hit other target nucleus. All the fission products that are resulting from this are numerous. It's a bit complicated and have gas components just like krypton-85, you have strontium-90, you have iodine, different radioisotopes of caesium, so it's a bit complicated. At this time, there were many of those products in the fuel and it's made the situation a bit complicated.

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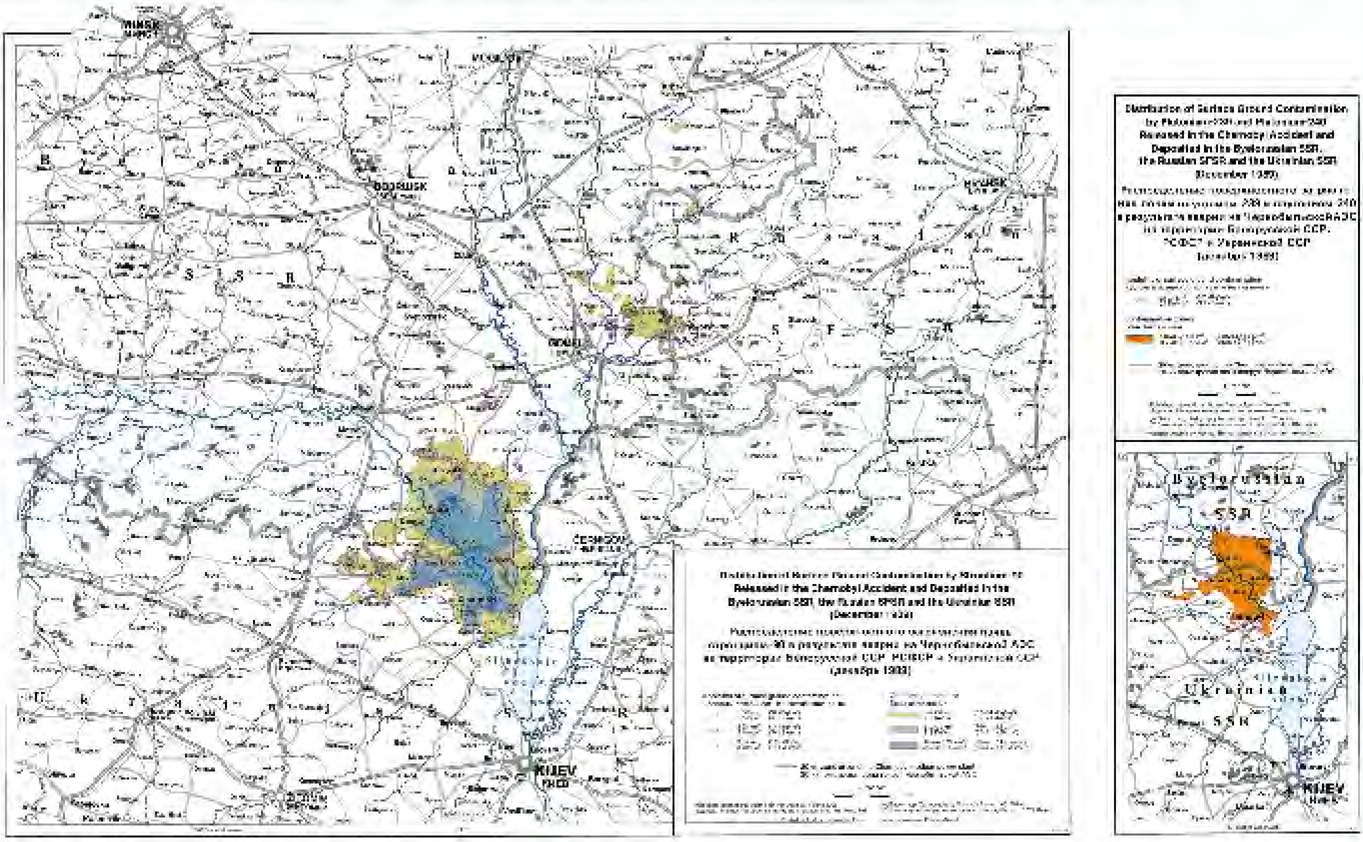
LSCE

Map of strontium-90 and plutonium-239 fallout in the Chernobyl region

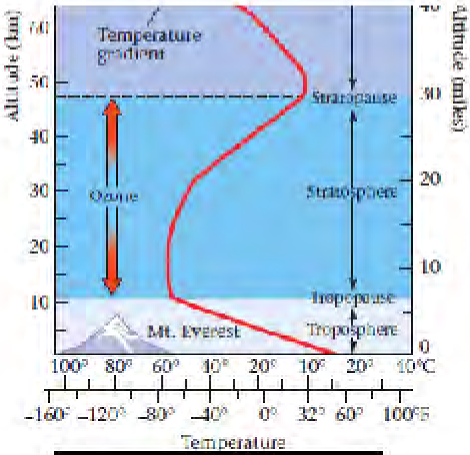


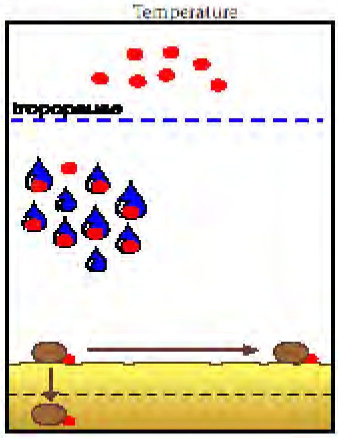
Source: IAEA website

You can find most of the data we have on this accident are related to the caesium-137 emissions. But if it's not clear, if you are at the back of the room, but you can find, for example, the IAEA website, you can find information and maps, for example, in this case of strontium-90 and plutonium-239 fallout presenting from the Chernobyl accident. In fact, the Chernobyl ● is fear and they match strontium-90 concentrations around the power plant and on this smaller map, they mapped the area where they found plutonium. You can find few information that's not so easy to find data related to other fission products. Most of them are related to the caesium fallout.

LSCE

- Different types of radionuclide inputs into the atmosphere:
  - Bombs (8 – 30 km altitude)
  - Chernobyl (1.5 – 10 km altitude)
  - Fukushima (2–3 km altitude)
  - Radionuclide dispersion was therefore very different
    - more homogeneous in case of bombs;
    - driven by rainfall (snowfall) after Chernobyl and Fukushima accidents
  - Polemics regarding weather forecasts on TV





Another remark was that the different radionuclide inputs that were introduced into the atmosphere originate from three main sources in Europe. The first one is the one associated with the bomb test and fallout started from 8 to 30 kilometers altitude, so quite high. At this altitude, you can have just like homogenization of fallout. Then, you can find it back in an homogenous way all across Europe because this fallout was observed during the long periods from a high altitude, and so you can say that rainfall was homogenous during this period and so that this fallout is homogenous across Europe.

Then, you have the Chernobyl fallout that came from a lower altitude, maximum 10 kilometers. Fukushima was even lower from 2 or 3 kilometers altitude according to what I found. The radionuclide dispersion was very different for those different types of radionuclide inputs. It was more homogenous in the case of the bombs and really strongly driven by rainfall or snowfall after Chernobyl and Fukushima accidents. As it is driven by rainfall, there were many polemics, mainly in the case of Chernobyl fallout, regarding the orientation of the weather forecast that was given on TV. In France, for example, there was 'so Chernobyl is fear' and there was a big polemics because people told that the radioactive cloud was stopped at the German border and that it didn't cross the border and didn't affected France. There were many polemics regarding it and it's not easy to find relevant information on this fallout for all the different countries.

- Several contamination plumes were blown out from the power plant

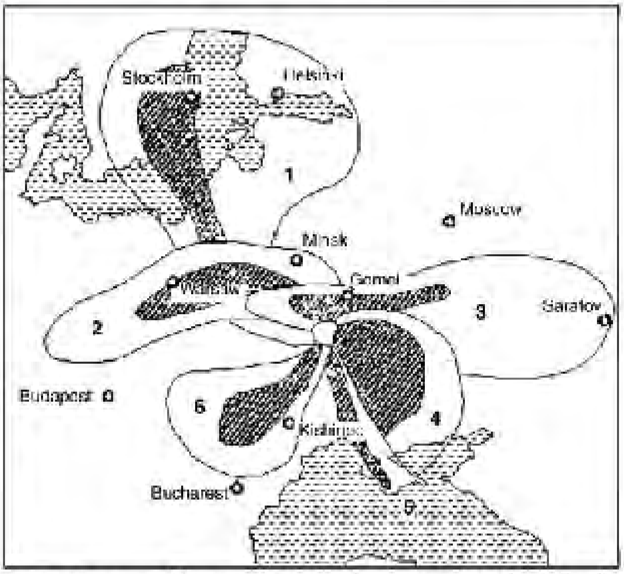


Figure 1.4. Six stages of formation of radioactive gaseous aerosol emissions from Chernobyl from April 26 to May 4, 1986: (1) April 26, 0 hours (Greenwich time); (2) April 27, 0 hours; (3) April 27, 12.00 hours; (4) April 29, 0 hours; (5) May 2, 0 hours; (6) May 4, 12.00 hours (Borzylov, 1991). Shading indicates the main areas of the radionuclide fallout.

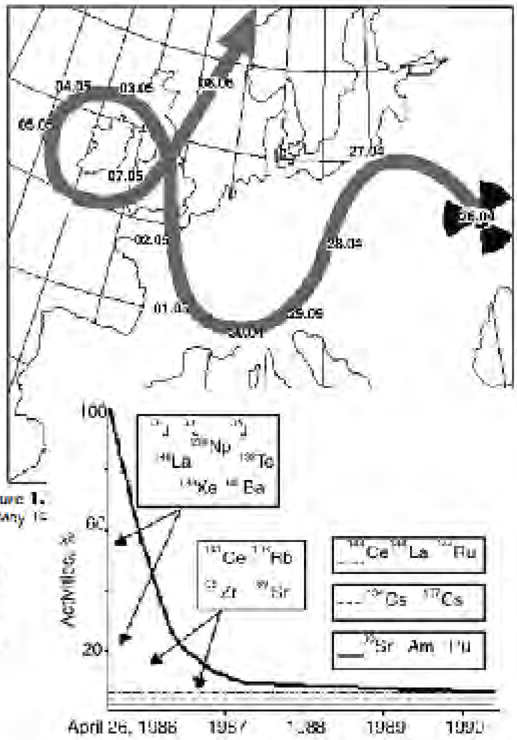


Figure 1.17. Dynamics of radioisotope structure of Chernobyl's contamination, percentage of total activity (Yablokov, 2002, from Sokolov and Krivolutsky, 1998).

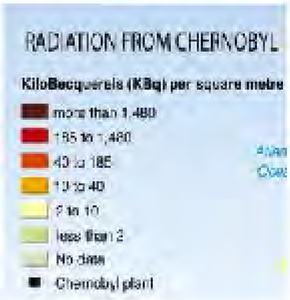
Source: Yablokov et al. (2010)

In fact, there were fires at the Chernobyl power plant and there were several plumes with radioactive contaminants that were emitted during the 5 to 10 days during which fires were very important from the power plants. You can see on this map that was reconstructed by Byelorussian scientist that it flew over another European countries, just like Sweden and Finland. Then, you have the second plume towards Poland, another one towards Russia, and then additional plumes towards the south. If you look at the path that was followed by the Western European clouds, it was quite complicated and you will find maximum fallout in the regions where there was rainfall.

LSCE

- Two major contamination plumes were blown out:
  - a western plume towards western Europe
  - an eastern plume towards Russia

Most contamination maps deal with ^{137}Cs



Gomel region (Belarus)

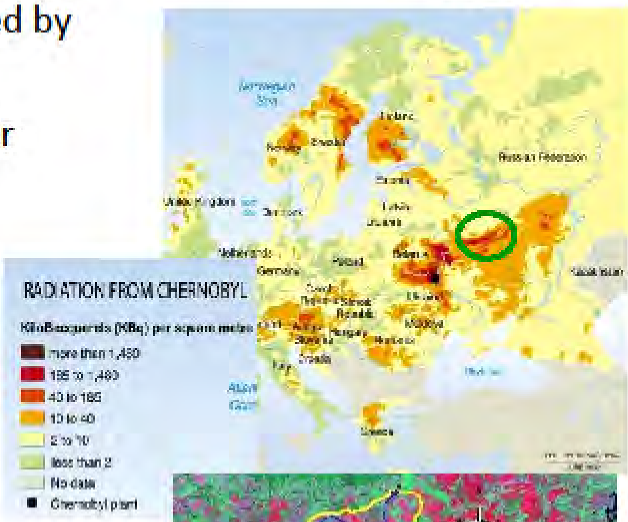
Plavsk hotspot (Russia)

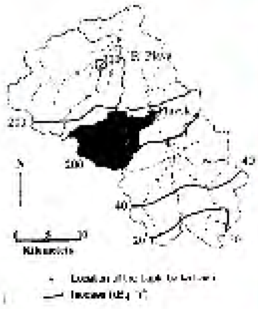
Three border region: Ukraine – Belarus - Russia

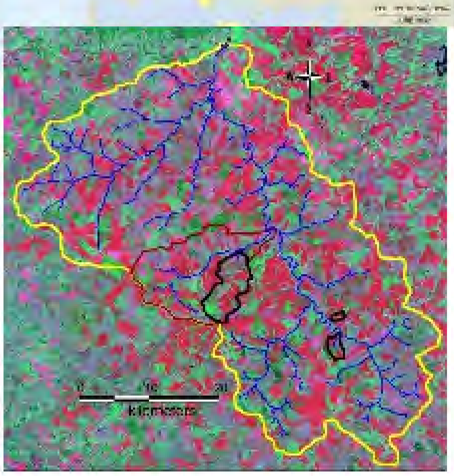
Important secondary contamination areas in Finland, Sweden, Norway and Austria

If we synthesize, there were two major contamination plumes one towards Western Europe and a second one towards Russia. The area where we worked – so the more red, the more contaminated by Chernobyl fallout. You have a very contaminated area around Chernobyl power plant in what I call the three border region, I mean, Ukraine, Belarus and Russia. Then you have a secondary contaminated area what they call the Plavsk hotspot in Russia, Plavsk hotspot because it's based around Plavsk town. We worked in this area.

- Plavsk hotspot (Russia) severely contaminated by Chernobyl fallout in 1986
- Cultivated region draining into the Plava River
- Total catchment area of ~ 2000 km²
- Important social and economical problems
  - Small river disappearance
  - Concentration of contaminants in dry valley systems (locally called 'balkas')
- No continuous river monitoring scheme
- Focus on a subcatchment (i.e., Lokna River) with an area of 160 km²







This area was severely contaminated by Chernobyl fallout in 1986. This fallout corresponds to more than 90%–95% of the total fallout. It means that the fallout due to the bomb test is very low in this area. It's a cultivated region draining into the Plava River and the total catchment area amounts to 2000 square kilometers. This is the Plava catchment and we worked in a small subcatchment about 200 kilometers draining into the Plava River, where the contamination was particularly high.

In this region of Russia, we had additional problems. There are rivers. There are croplands. The main concern is that the contaminated particles drain into the valleys and contaminates them, which could be a problem for food chain contamination, for example. Unfortunately, there is no continuous river or rainfall monitoring scheme, which makes it very difficult to model erosion during the last decades in the area. We wanted to find a way to obtain quantification of erosion and accumulation of contaminated sediment in the river valleys by using a model.

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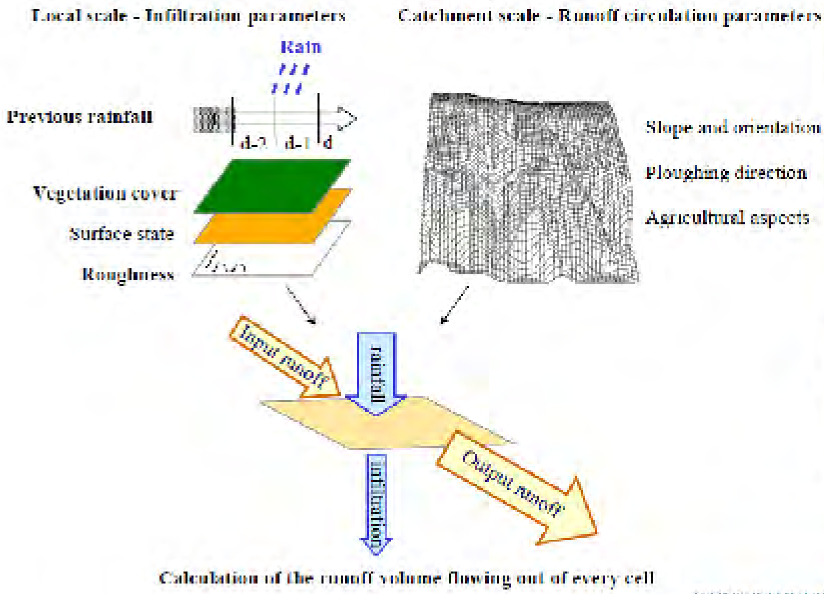
LSCE

- Test of a runoff/erosion expert-based model
- Challenge for several reasons
    - Lack of input data
    - Suspected dominance of tillage erosion



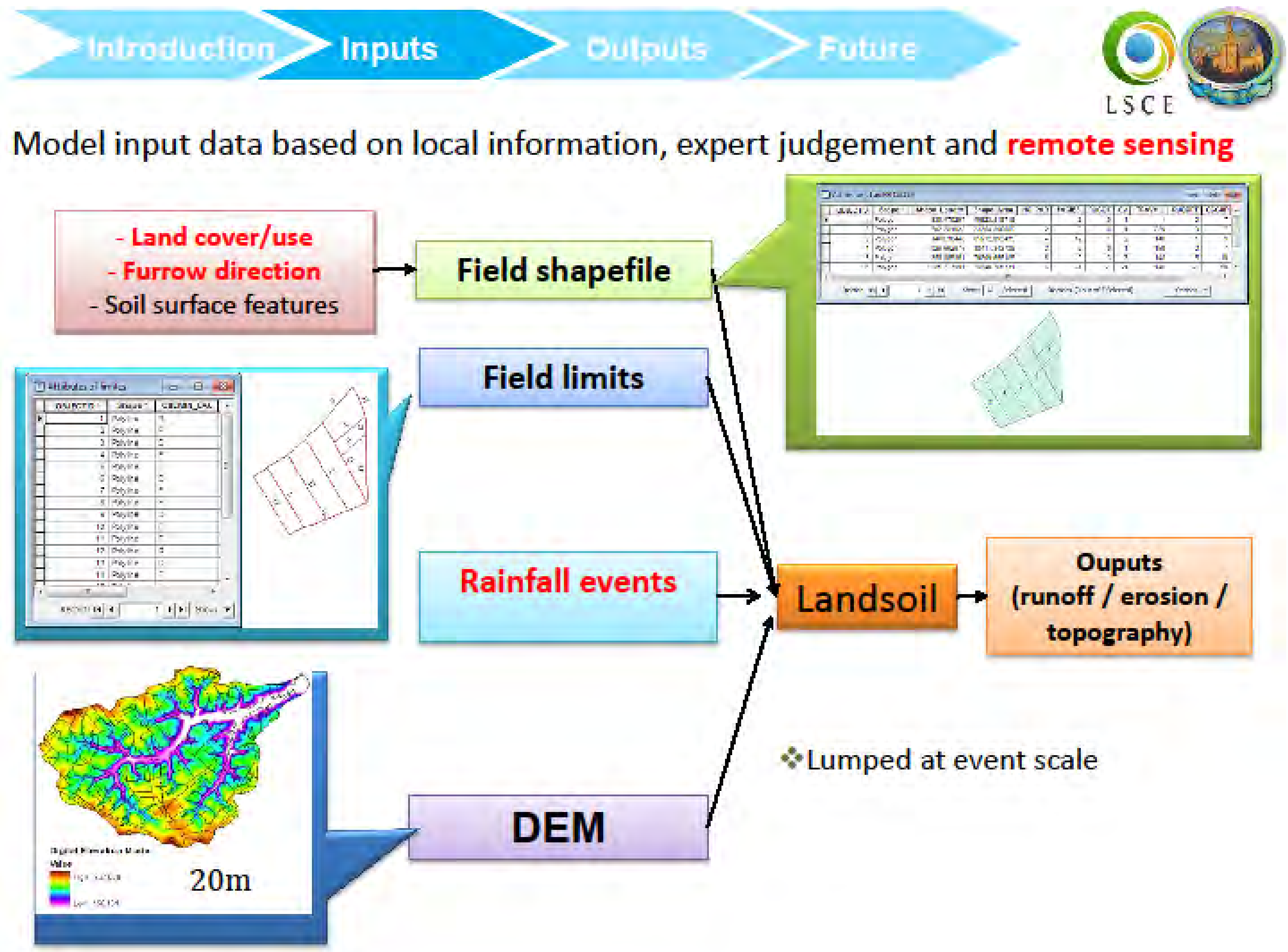
Cerdan et al. (2001); Evrard et al. (2009)

ANR

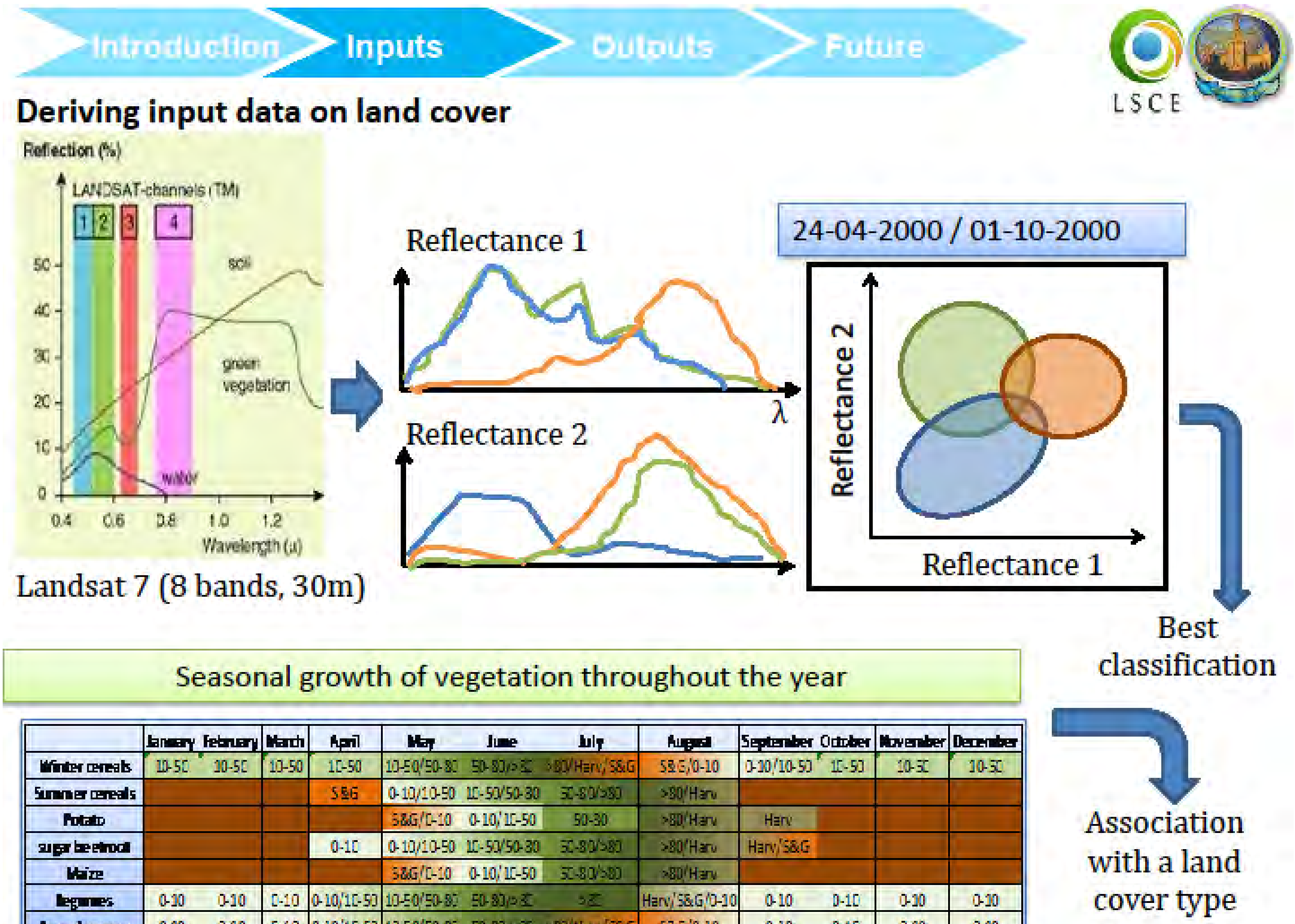
LANDSOIL

Lanscape and soil conservation

This model is in fact what they call an expert-based model. Why an expert-based model? Because it focuses on the main processes occurring in the area, so it's not an empirical model nor a completely physically based model, but it's based on two types of information. The first one you have, of course, the topography given by the digital elevation model. You add to this topography information, also information on tillage, so the farming practices conducted in this catchment. That's one part of the information. Based on this information, you can derive the drainage network. But what is also very important in agricultural and cultivated areas is all the surface states. I mean the vegetation cover, the soil roughness, the presence of a crust on the soil surface. For example, in this case, when you have a crust on the soil surface, when there is rainfall, you see that there is runoff very rapidly. Afterwards, this runoff can concentrate on roads or in gullies, for example.



The idea of this model is to combine all of this information to obtain data on runoff and erosion at any point of the catchment. But the problem is that we have not many information, not many data in this catchment. What we need is this information. Topography, that was not so difficult because in Russia they have very detailed topographic maps and we could – just like digitizing all the control ● and obtain a rather precise DEM. Information on the different fields which you have in the area, but after you need information on what there is in this field, I mean, the cropland, grassland, what kind of crop, and so on. Information on rainfall events and based on this, you can run the model and obtain a runoff and erosion outputs.



	January	February	March	April	May	June	July	August	September	October	November	December
Winter cereals	10-50	10-50	10-50	10-50	10-50/50-80	50-80/>80	>80/Harv/S&G	S&G/0-10	0-10/10-50	10-50	10-50	10-50
Summer cereals				S&G	0-10/10-50	10-50/50-80	50-80/>80	>80/Harv				
Potato					S&G/0-10	0-10/10-50	50-80	>80/Harv	Harv			
sugar beetroot				0-10	0-10/10-50	10-50/50-80	50-80/>80	>80/Harv	Harv/S&G			
Maize					S&G/0-10	0-10/10-50	50-80/>80	>80/Harv				
legumes	0-10	0-10	0-10	0-10/10-50	10-50/50-80	50-80/>80	>80	Harv/S&G/0-10	0-10	0-10	0-10	0-10
Annual grasses	0-10	0-10	0-10	0-10/10-50	10-50/50-80	50-80/>80	>80/Harv/S&G	S&G/0-10	0-10	0-10	0-10	0-10

S&G=Semi and Germination, Harv=Harvest

The problem was to obtain – I will focus on land cover of the different fields, have information on the furrow direction, and information on rainfall. We wanted to simulate erosion between 1986, so between the Chernobyl accident and, let's say, 2005. We have information on land cover because there was no local database. We have Felix ● working on remote sensing and they obtained information, satellite images at two periods during the year 2000 in April and in October. We know what are all the different crop types grown in this catchment. We know that the vegetation during the different months of the year, it evolves so the crop grows and the soil characteristics change throughout the year. Based on this information and based on the difference on the reflectance observed and retrieved from the satellite images, we could associate each fields with a given crop type.

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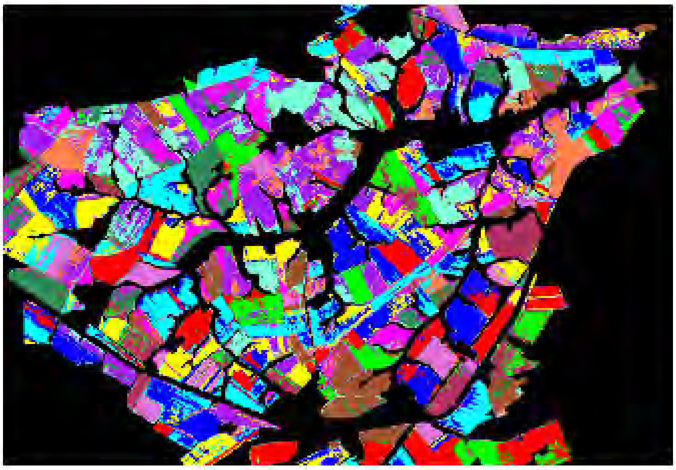
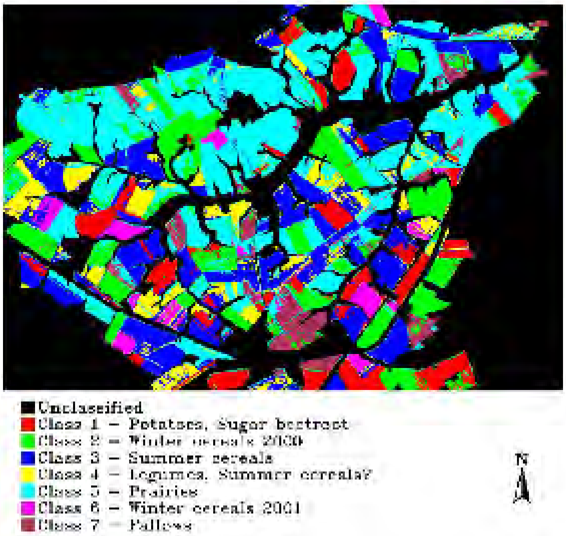
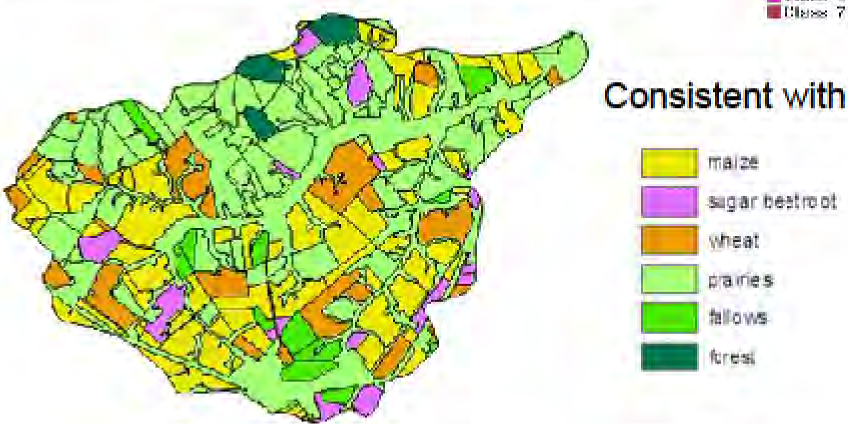
LSCE

K-means classification (13 classes)

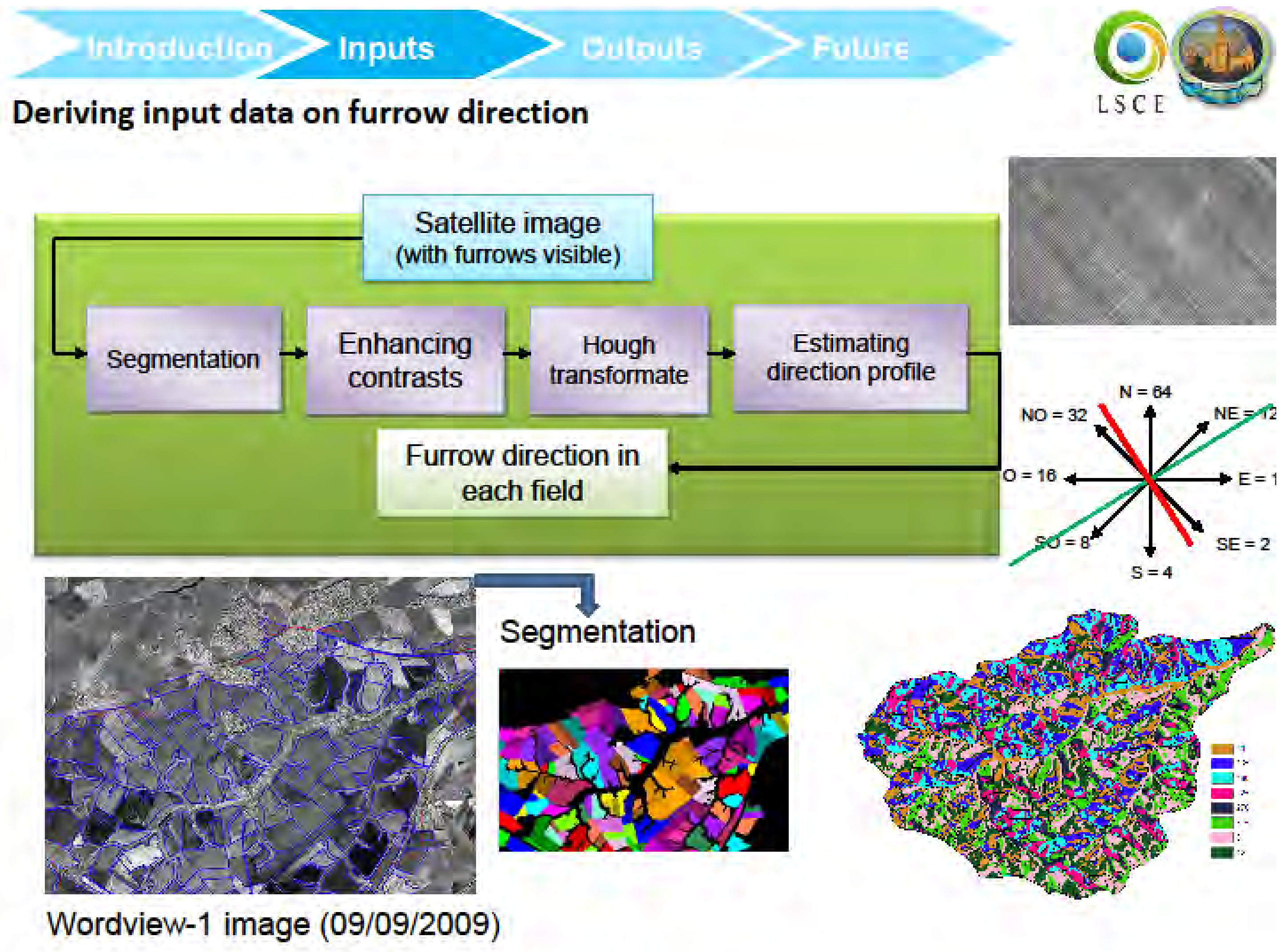






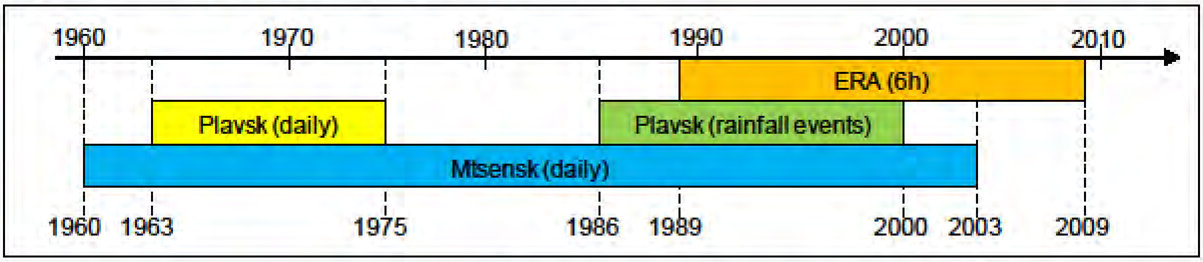
Consistent with the available field data

They worked on satellite image classification and could obtain a land cover map for the entire catchment. Then, they used another type of satellite images, QuickBird images, more precise, where you can detect the furrow directions. They used a type of treatment that they made automatic so that you don't have to start from each field manually to derive the furrow direction.



They made an image segmentation to retrieve different fields and then expected the furrow direction for different fields, which is very important to derive the flow network in the catchment. We have this information too.

Deriving rainfall input data (1986 – present)



- *Required data:* rainfall depth, duration, max. intensity, antecedent rainfall (48h)
- A 6-h time step is insufficient for erosion modelling studies!
- Need to construct realistic rainfall scenarios

Type	# days	RA (mm)	D (h)	I-max (mm h^{-1})
Heavy storm	1	≥ 15	1	41
Storm	1	< 15	1	20
Heavy night storm	2	≥ 15	2	41
Night storm	2	< 15	6	20
Continuous rain	≥ 3	n/r	6 d^{-1}	9

The last big problem was to have rainfall information for the entire period between 1986 and present. This is the kind of rainfall data that were available in this area. There was a rain gauge in Plavsk City with the information, but only between 1963 and 1973. Then, we also had another database detailed for different rainfall events but only between 1955 and 2000. Well, in fact it was very complicated because we had no homogenous database. We worked on different, more or less, detailed database on rainfall events. Also, European scale data to reconstruct realistic rainfall scenarios, I mean to make a classification of different rainfall events that occurs in this area: storms or low intensity continuous rainfall and so on, because the main problem when you model erosion is that you need very detailed information in time. If you have only total rainfall amount of 1 day, it's not enough to see much erosion because if you have, for example, 15 millimeters rainfall in 1 hour, it will be very different than 15 millimeters in 1 day in terms of erosion. We wanted to reconstruct realistic scenarios to take this into account.

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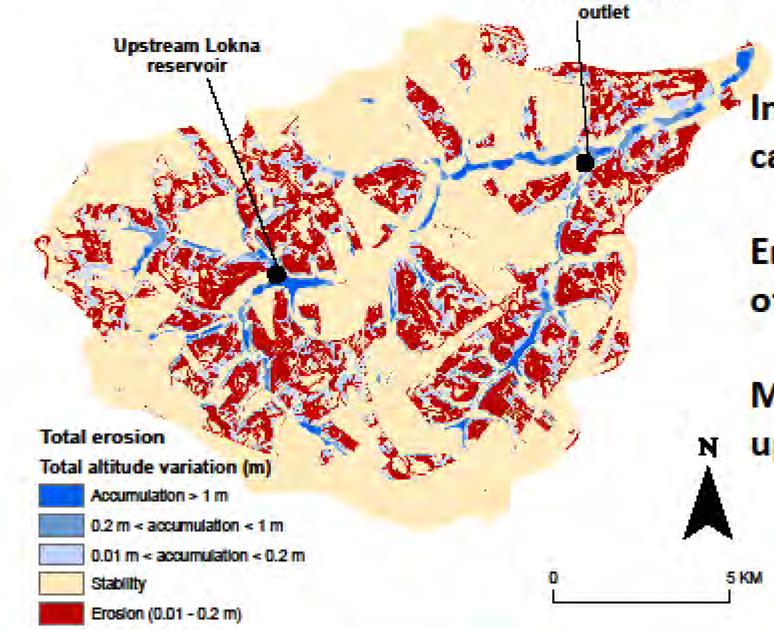
LSCE

Simulated erosion patterns (1986 – 2003)



Important soil movement within the catchment (20 t ha^{-1} yr^{-1})

Erosion concentrated on cropland (mean of 14.3 t ha^{-1} yr^{-1})

Major sediment accumulation in the upstream Lokna reservoir

The results. This is the total erosion pattern simulated for the 1986-2003 period. In red, erosion areas; in blue accumulation areas, so it's logical. What you see in yellow, it's the areas of forest or grassland and there was almost no movement, soil movement in those areas. In contrast, in red you have the erosion areas, mostly concentrated in croplands. In the valleys, you have the blue areas that represent accumulation. In fact, we modeled a very important soil movement within the catchment. On average, 20 tons per hectare and per year, with erosion concentrated on cropland. Then, for example in this area, a very important accumulation and it corresponds to reservoir.

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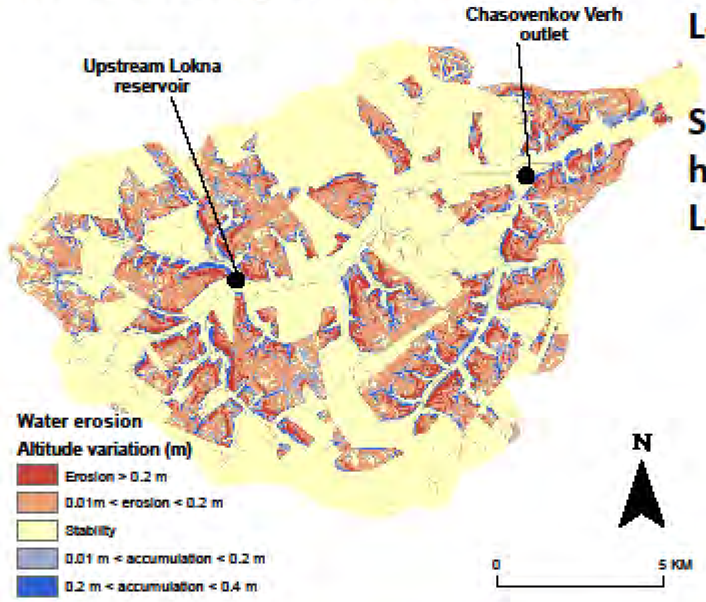
Water erosion (1986 – 2003)

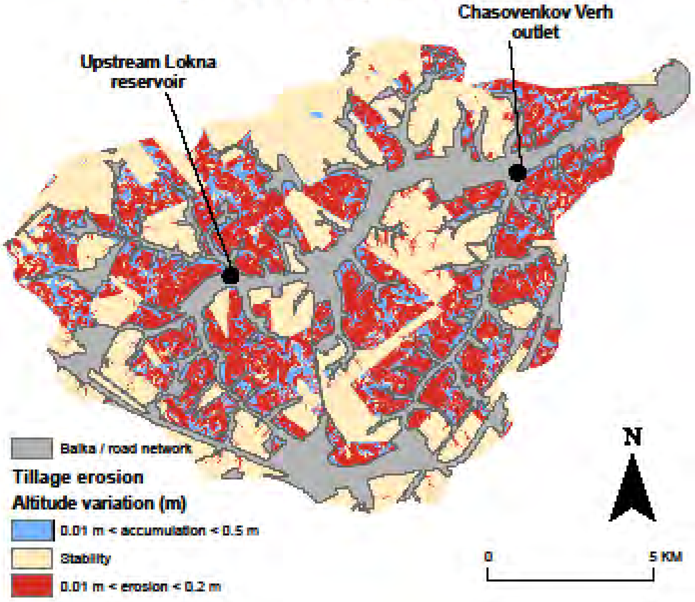


Low to moderate water erosion (3 t ha^{-1} yr^{-1})

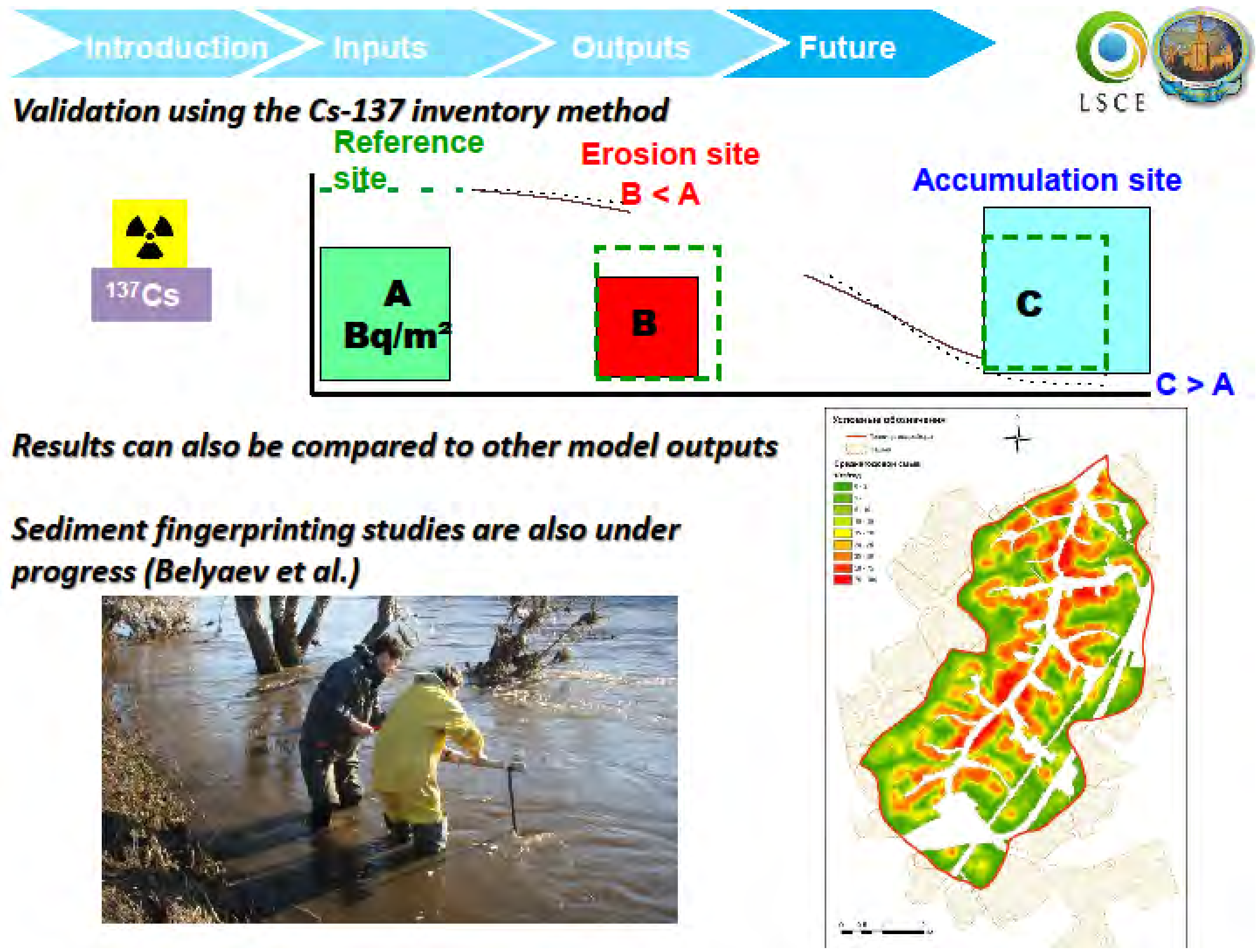
Sediment connectivity only achieved during heaviest storms

Low sediment delivery ratio (8 – 11%)

Tillage erosion (1986 – 2003)



That was the map for total erosion, but if we separate total erosion into water erosion – this is the first map – and tillage erosion, so due to the farming practices, you see that in fact we have a very low to moderate water erosion only 3 tons per hectare and per year, but a much more important tillage erosion. You have sediment connectivity within the catchment only during the heaviest storms. That means only 10 important events during the entire period. This leads to a very low sediment delivery ratio. It means that you have important soil movements but only 8% to 11% of the sediment exported from the catchment. You have important redistribution within the catchment but low export from the catchment.



Now, what we wanted to do with our Russian colleagues is to validate those model outputs with the caesium-137 inventory method. Not only with this inventory method, but also with sediment fingerprinting studies and all other model outputs. This model is a Russian model based on the Universal Soil Loss Equation, developed from the United States. For the points where we started validation, it was relevant. I mean it was consistent. The different outputs obtained with different methods were consistent.

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LSCE

- Landsoil erosion models provided satisfactory results
- Remote sensing provided most of required model input data
- Soil movement is important in this region of Western Russia
- Nowadays, tillage erosion is dominant
- Storms can lead to concentrated erosion
- areas
- Important sediment accumulation is modelled/ observed along the dry valley systems and in an upstream reservoir
- Potential implications for human health ??

We're happy because based on satellite images-derived information we could obtain satisfactory results based on this model; that we could obtain all input data with satellite images in this area, where there weren't many inputs data available databases; that soil movement is very important in this west is region of Russia, mostly driven by tillage erosion, but during heavy storms, there is sediment exports concentrated erosion, gully erosion and export from the catchment. We also have very important sediment accumulation in the dry valley system and in upstream reservoir, and this could have potential implications for human health because this is contaminated sediment. But, in fact, this was a test that we made 3 years ago. This is the cattle output but we didn't detect caesium-137 in it. That was a good point but it was also taken more than 20 years after the accident.

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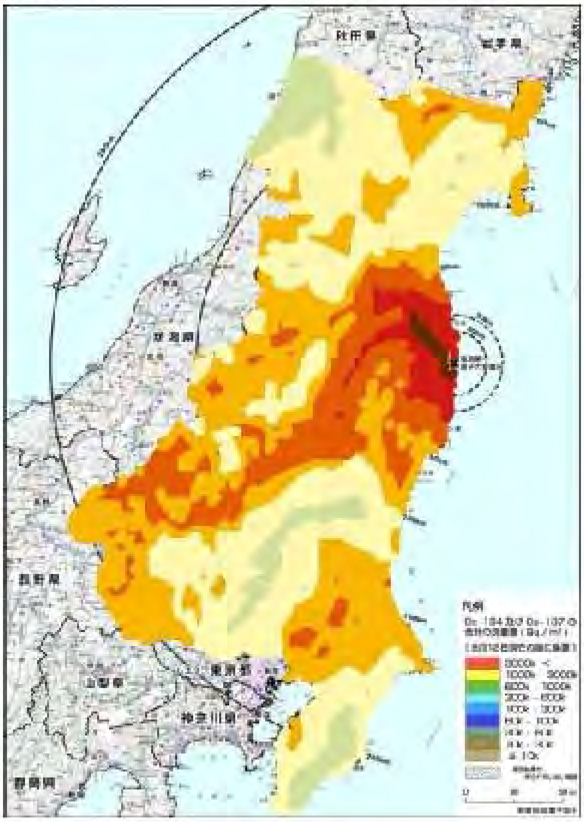
LSCE

- Lessons to be learnt for studying the impacts of Fukushima accident
  - Are both contamination patterns comparable??

Using Chernobyl impact map scale

Source: http://maps.grida.no/go/graphic/radiation-from-chernobyl



What are the lessons that could be learned for studying the impacts of Fukushima accident? The first point is that we can compare both contamination maps. On the left side, you have the contamination map in Europe after Chernobyl. On the right side, if you use a similar radioisotope activity scale, this is what you will obtain in the Fukushima region. That means that in total, the Chernobyl radioactive emissions were 10 times more important than from Fukushima. But it was spread on much more important area, a much more important surface. In Fukushima, it was spread over a much less important surface, which means that you have a very important contamination around the power plant.

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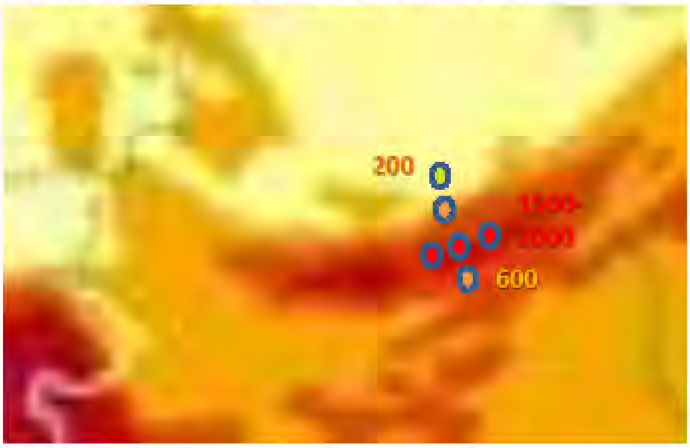
LSCE

- Summer 2011: Fieldwork in the Plavsk contamination hotspot (Russia)

Counts / min (^{137}Cs)
5-min countings

- Overall, initial airborne contamination map is correct (1993 survey).
- ^{137}Cs inventories at reference sites are stable all around the contamination hotspot



- We still have to calibrate with the core inventories measured by our colleagues

Then, second point is that this year we went to the field to check the initial airborne contamination map. This is a zoom on this map. We wanted to check that the initial contamination map was correct. The *initial contamination map was done in 1993. We could check. This is only* the counts per minute of caesium-137. We made 5-minute countings in the field using a portable detector and it was very consistent. We'll have to calibrate this with the core inventories measured by our colleagues in Russia, but we have actually low count numbers in the less initially contaminated area and a much larger counts per minute figures in the most contaminated area.

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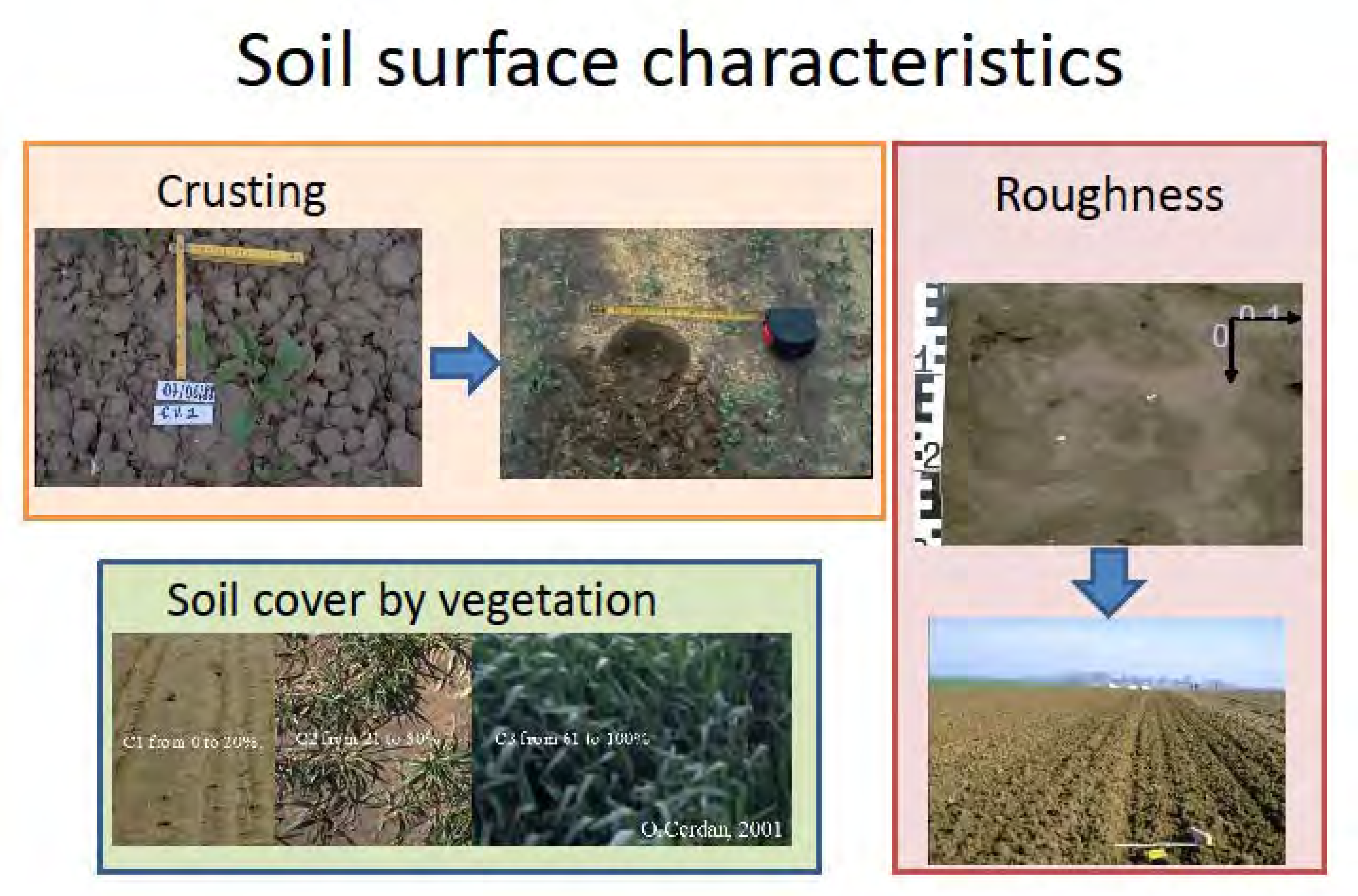
- Summer 2011: Fieldwork in the Plavsk contamination hotspot (Russia)

- Contamination is much higher in valleys where sediment accumulates (typically 2000 Bq kg^{-1}, 25 years after the accident)
- At reference sites, there is still ^{137}Cs detectable in edible parts of plants (2 Bq kg^{-1}, 25 years after the accident)
- Hotspots were locally found in villages (up to 10,000 Bq kg^{-1} of ^{137}Cs)

Another point is that contamination is much higher in valleys where sediments accumulate. We still have, even 25 years after the accident, around 2000 Becquerels per kilogram of caesium-137 in sediment. Also, at reference sites, we still measured caesium-137 in the part of the plants that you can eat just like in wheat, in maize, in potatoes. We still found 2 Becquerels per kilo of caesium-137, 25 years after the accident. We also found contamination of hotspots in the villages, so you have just a school next to this car park and we still found in this soil up to 10,000 Becquerel per kilogram of caesium-137, 25 years after the accident.

Thank you for your attention.



This was just to show the soil surface characteristics, but basically, it was what I want to tell about our work in the Chernobyl region.

- Environmental consequences
  - Local contamination of lakes, soils and vegetation
  - Forest fires; contamination of forest fauna

- Consequences on human health
  - There is a large debate… For non-specialists, it is difficult to find relevant data
  - Example of recent article:

British Journal of Cancer (2011) **104**, 181–187. doi:10.1038/sj.bjc.6605967
www.bjcancer.com
Published online 23 November 2010

Thyroid cancer risk in Belarus among children and adolescents exposed to radioiodine after the Chernobyl accident

10–15 years after the Chernobyl accident, thyroid cancer risk was significantly increased among individuals exposed to fallout as children or adolescents, but the risk appeared to be lower than in other Chernobyl studies and studies of childhood external irradiation

  - Official UN/IAEA reports: 50 dead and 4000 people suffering from radiation consequences
  - Yablokov et al.: ca. 1,000,000 victims…

Male1
We have questions. Thank you, Mr. Olivier. [Japanese]. Any questions or comments?

Male2
Let me start. Thank you very much for your nice presentation. I have two questions. Maybe, I'm not clear about these two points. The first one is you used expert model to estimate soil erosion. The parameter that you have used in this model is almost similar Universal Soil Loss Equation. What is the difference between these two models? Maybe if we finish one, and the other one after you gave the total soil erosion using this model, you divide the erosion rate into two, the water and the tillage erosion. But, what about wind erosion?

Dr. Olivier Evrard
Okay. I will start with second question because it's easier. There is not a lot of wind erosion in this area. It's negligible according to our colleagues, so we didn't really work on this. It's not really a driving parameter of soil movement in this area.

Regarding expert-based models, in fact, it's not really based on the same parameters and as the USLE model because the USLE model is really based on local, empirically-obtained data and on Plavsk. You have Plavsk and you derive statistical relationships valid for a given region. In this case, what we do is that it was based on rainfall simulation experiments, on soil surface states, representative of the different situations you can observe all throughout the year for different crops. It gives you an idea of the infiltration rates for the different situations. When you have rainfall on this kind of surface states, you have more or less a balance of what infiltrates and what runs off.

But then, I think that in fact this model was developed in France, in Normandy, where you have fixed deposits of loose silty soils and those silty soils are very sensitive to crusting. It means that when you have not a dense crop cover of the soil, when you have rainfall, you have very [Technical Difficulty] a crust, just like on these areas, and then you have very rapidly a runoff. I think that when you understand in which actual situations you have a potential important runoff and erosion, which is taken into account in this model by combining and associating the characteristics related to crop cover, roughness, and crusting, and that you combine it with a relevant flow network by combining the topography and all the other features that you have in the landscape and then you can drive the flow, just like the ditches, the roads, the furrow directions. I think that you obtain something that lead to relevant results. I don't know if I answered your question.

Male1
Maybe ask detailed – you have a question? I just want to question. In your experimental catchment, how much for that inventory of caesium-137 in the catchment that…?

Dr. Olivier Evrard
How much in the inventories you mean?

Male1
Yeah.

Dr. Olivier Evrard
Today or when contamination occurred?

Male1
Yes, today.

Dr. Olivier Evrard
Today? In this area, in the red area for reference sites, you have inventories of about 200,000 Becquerel per square meter, 200K Becquerel per square meter.

Male1
But that means 2000 – not 2000 Becquerel per…

Dr. Olivier Evrard
No, no. In this map, it was preliminary results. It just comes for a minute for caesium-137 with this effect because we just received the – because it's a problem to take back sediments and soil samples from Russia. The analysis must be done in Moscow. Since we did it in August and September of this year, I just received the results yesterday or within the first – but I can tell you today that this number of counts corresponds to 200,000 Becquerel per meter, more or less.

Male1
Okay.

Male3
Thank you for the pleasant talk. I would like to ask more kind of just curiosity but did Fukushima accident influenced your research activity…?

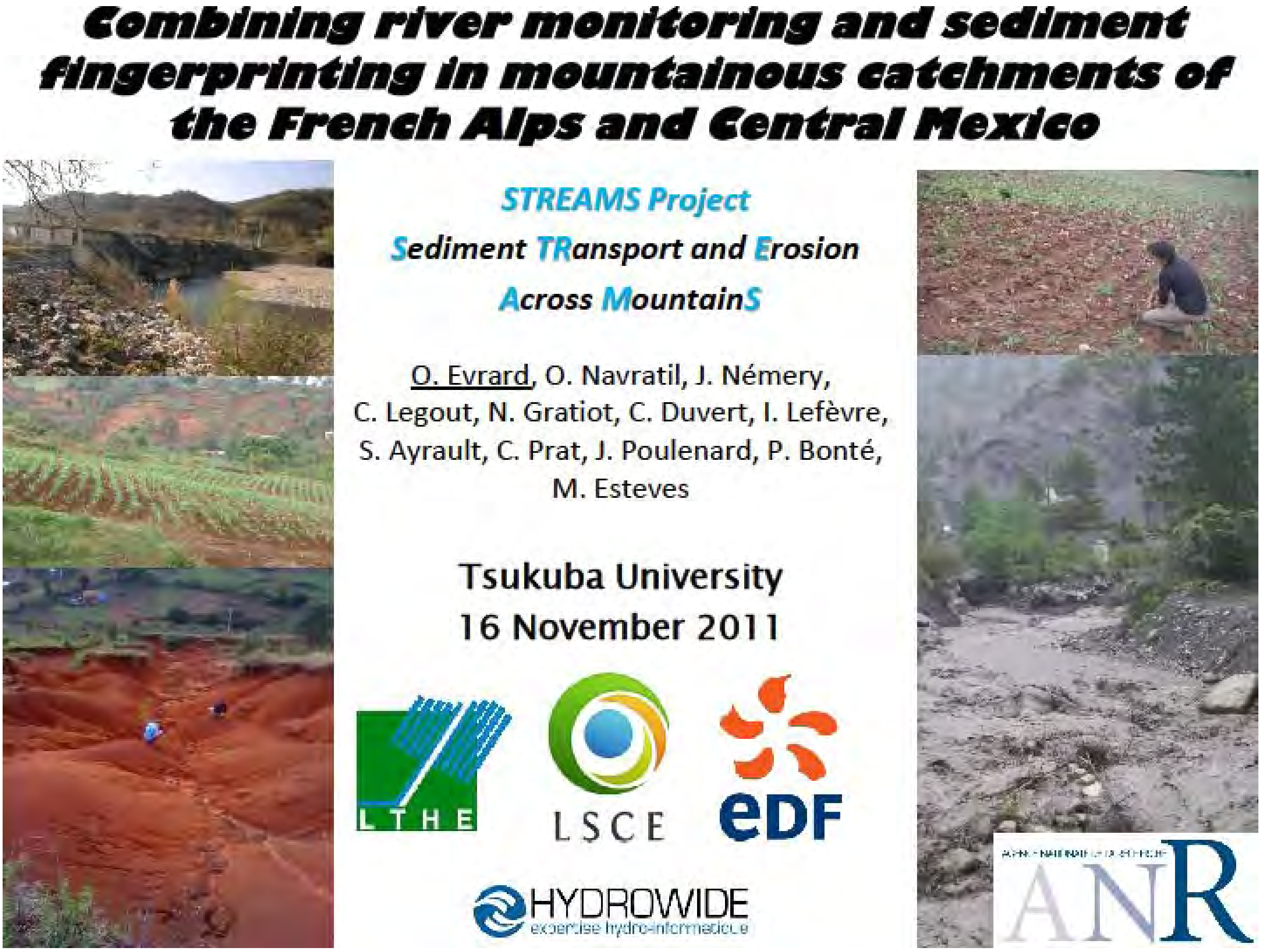
Dr. Olivier Evrard
Not at all. Not in Russia. In France, in Paris on the Seine River, we have a Ph.D. students working on something else on the movement of contaminants in the Seine River and we detected iodine and caesium from Fukushima. But it wasn't – we didn't know that we would detect it but it was really, really low levels but we could detect it anyway.

Male3
Are this campaign for Summer 2011 is just done before…?

Dr. Olivier Evrard
Yeah, it was done before in this area. It was just to check that the initial contamination map was correct and to have a look on what we observe 25 years after – before that after the accident.

Male1
Maybe, we went to the next topic of the…

Thank you.



Dr. Olivier Evrard

The next topic was really to show you what we did in the French Alps and in Mexico. It was in a project funded by the French National Research Agency, the same as the one that funds our common TOFU project. In fact, we wanted to combine river monitoring with ● and sediment fingerprinting in mountainous catchments. I thought it could be interesting to show what we did in not contaminated areas but with sediment fingerprinting to understand where sediment comes from and at which speed it moves throughout the catchment.

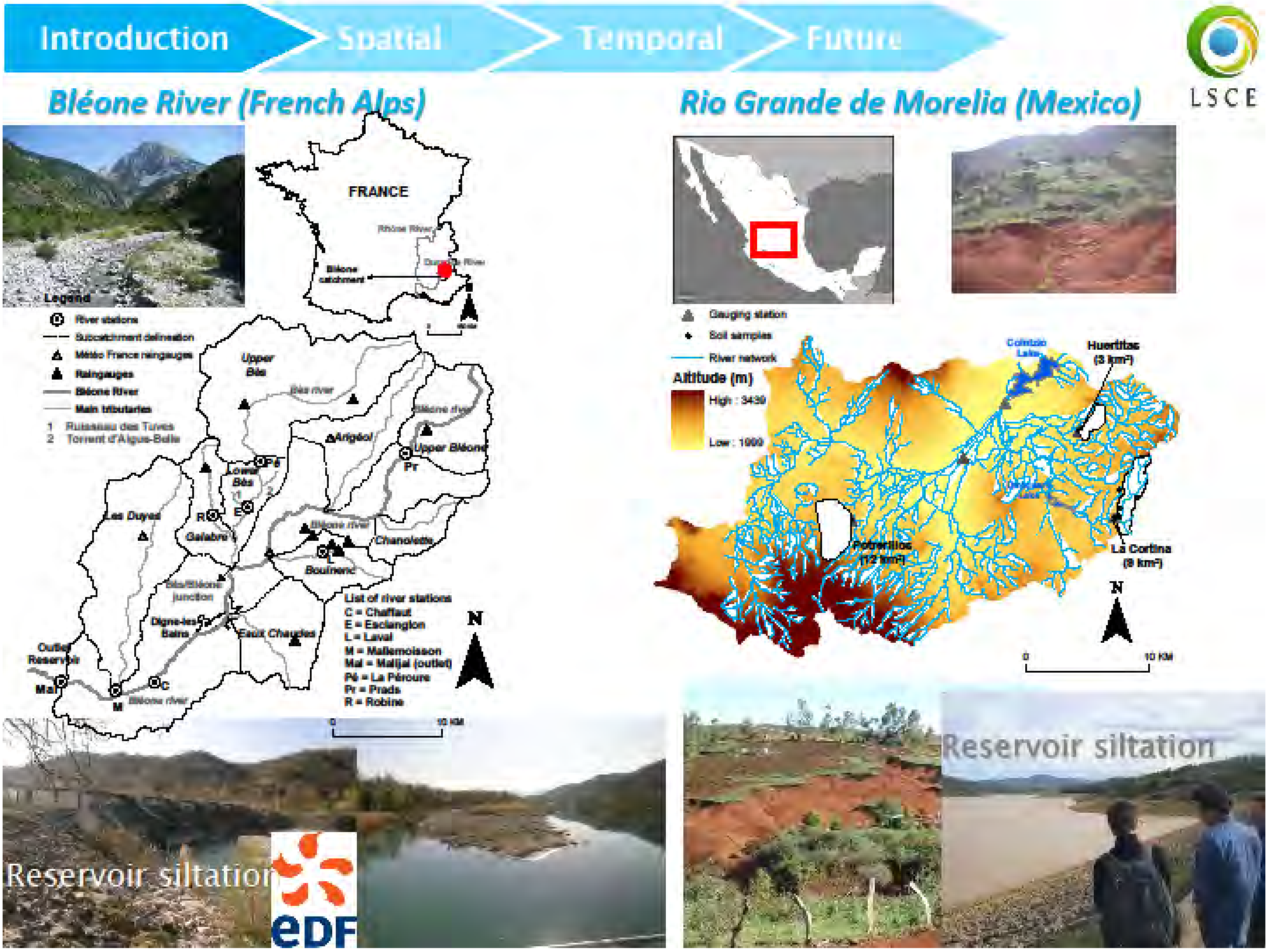
Introduction > Spatial > Temporal > Future

LSCE

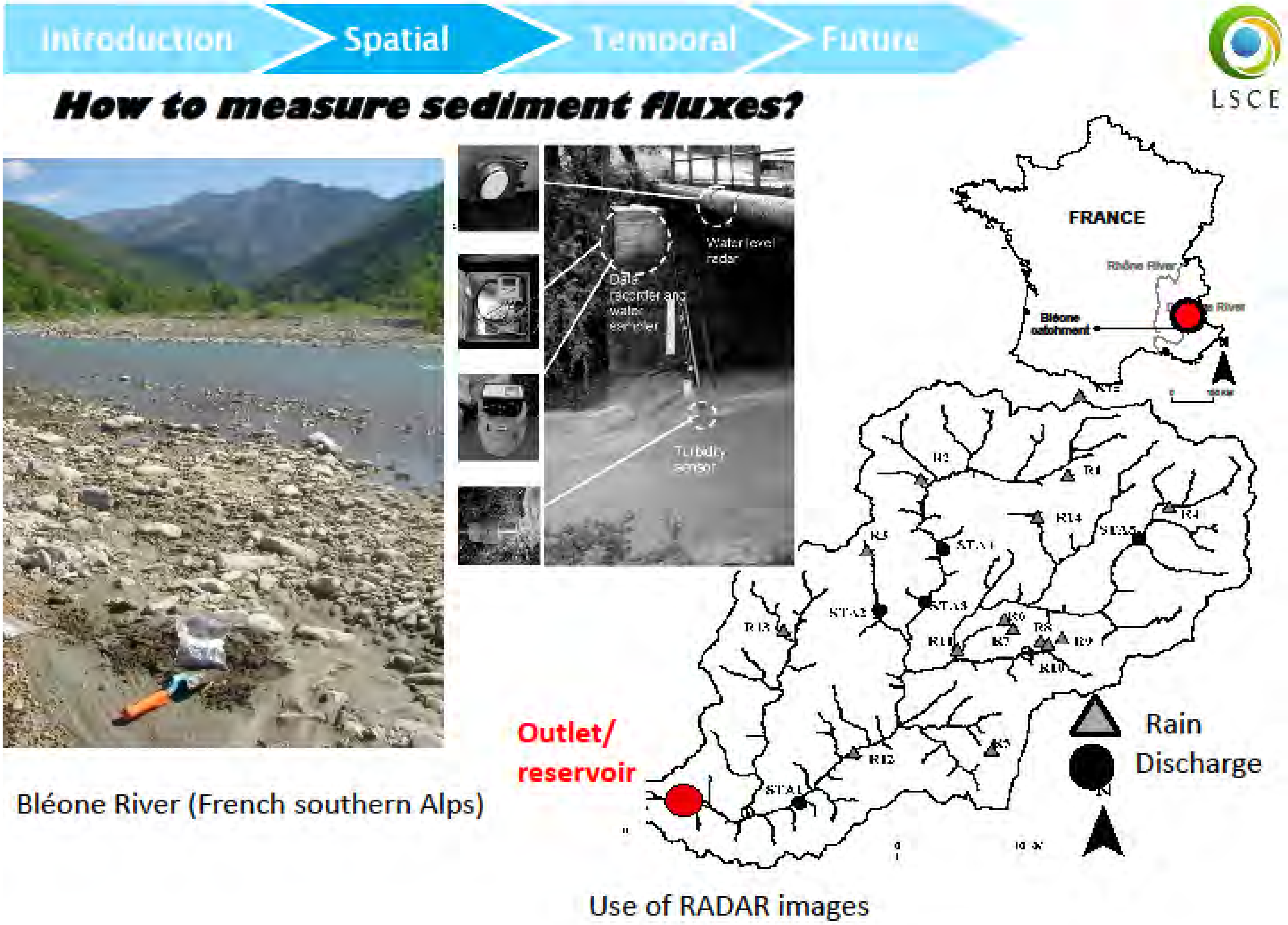
- Severe soil erosion in mountainous catchments
- Strong spatial and temporal variations
- Insufficient monitoring network
- Catchments with area between 500-1000 km²
- Important social and economical problems
    - Soil loss from the fields
    - Transport of contaminants
    - Modifies channel morphology
    - Increased risk of flooding
    - Reservoir siltation

Why did we want to do this? Just because in mountainous catchments, soil erosion is very important and very variable in space and in time. Most of the time, mainly in Russia for example, there is insufficient or inexistent monitoring network and in, I would say, intermediate catchments, that means with a surface between 500 and 1000 square kilometers, you can observe very important social and economic problems. For example, and this was in Mexico, you have evident programs for cultivation when you have this type of gullies. You have programs for navigation. In Southern France, they built several dams to produce hydroelectric power. If you have a lot of sediments accumulating, there is a rise to all these problems to provide clear water to those power plants. We wanted to work on the soil erosion in those catchments for those reasons.

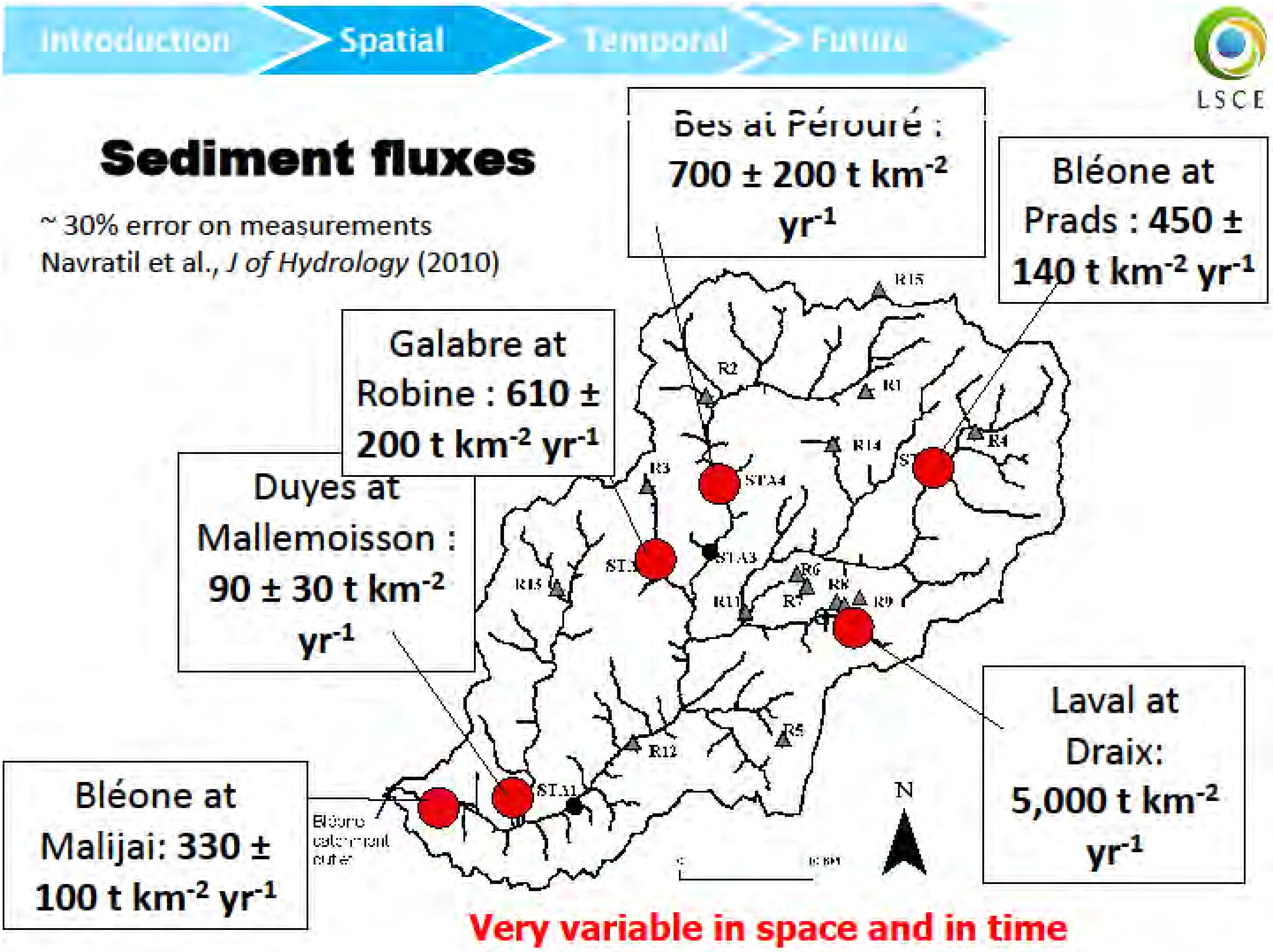
Two very different catchments were selected. One is in this region of France, in Southeastern France. It's a maritime catchment with a surface of 1000 square kilometers. You have a permanent river network. This is the Bléone River with several tributaries. The main problem associated with erosion is a reservoir situation and the electricity producer is not happy because he wants clear water to supply to the hydroelectric power plants. We have mostly sedimentary rocks.



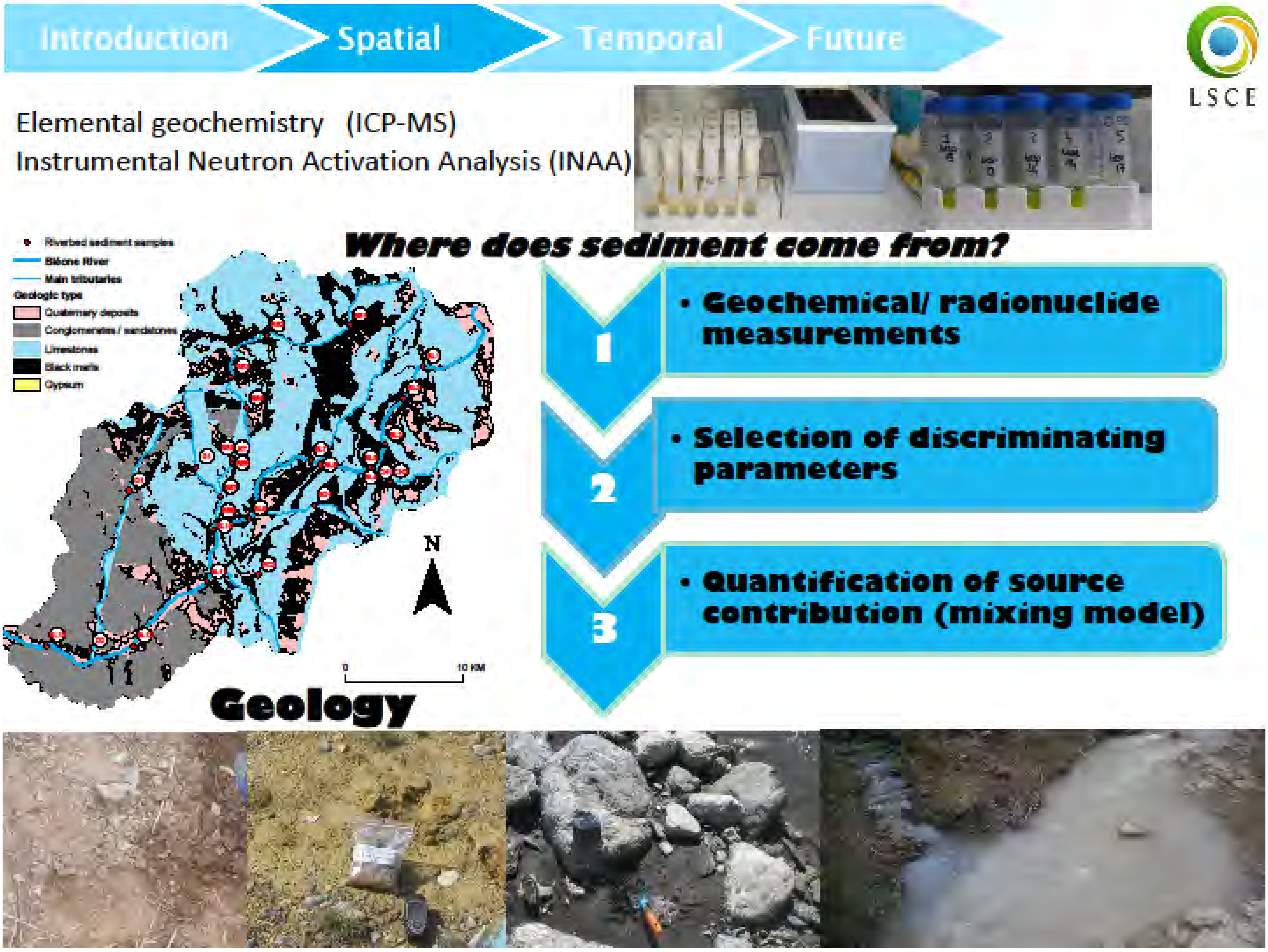
In Mexico, it's completely different. We don't have permanent river network because you have succession of dry season and wet season. You have volcanic rocks. There is also a reservoir at the catchment outlet but used for very different reasons. In fact, it's used to provide drinking water to 1 million inhabitants. If water is not clean, it also leads to evident problems. The idea was to work in two different catchments on a methodology to understand where sediment comes from and at what speed it moves?



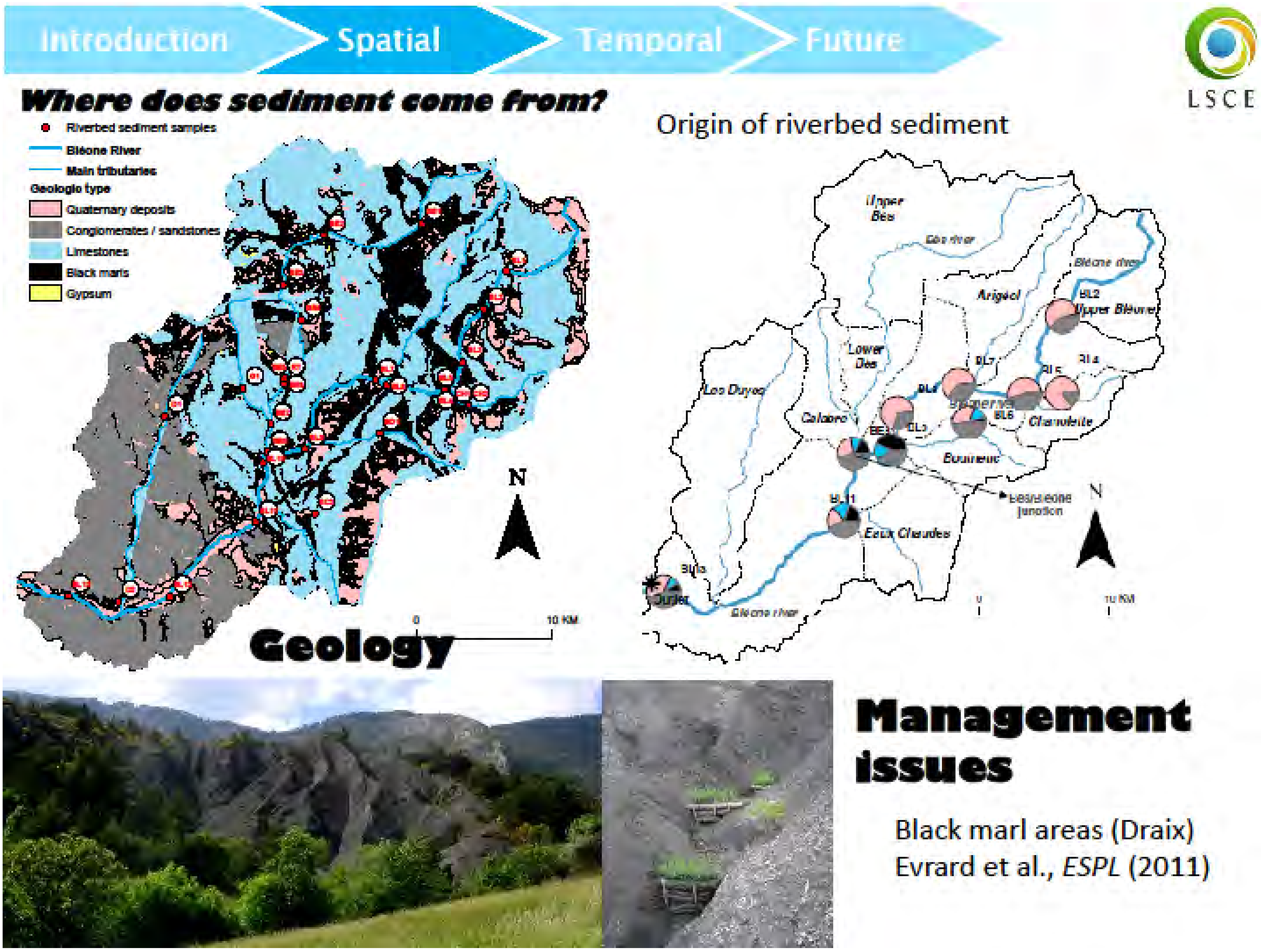
How to measure sediment fluxes? We worked with our hydrologists colleagues and they installed several river monitoring stations at several points. This is the example of the Alpine in the French catchment. Many were engaged, many rivers stations with sediment samplers, turbidity meters, water-level recorders of course. They also obtained information on rainfall based on radar images.



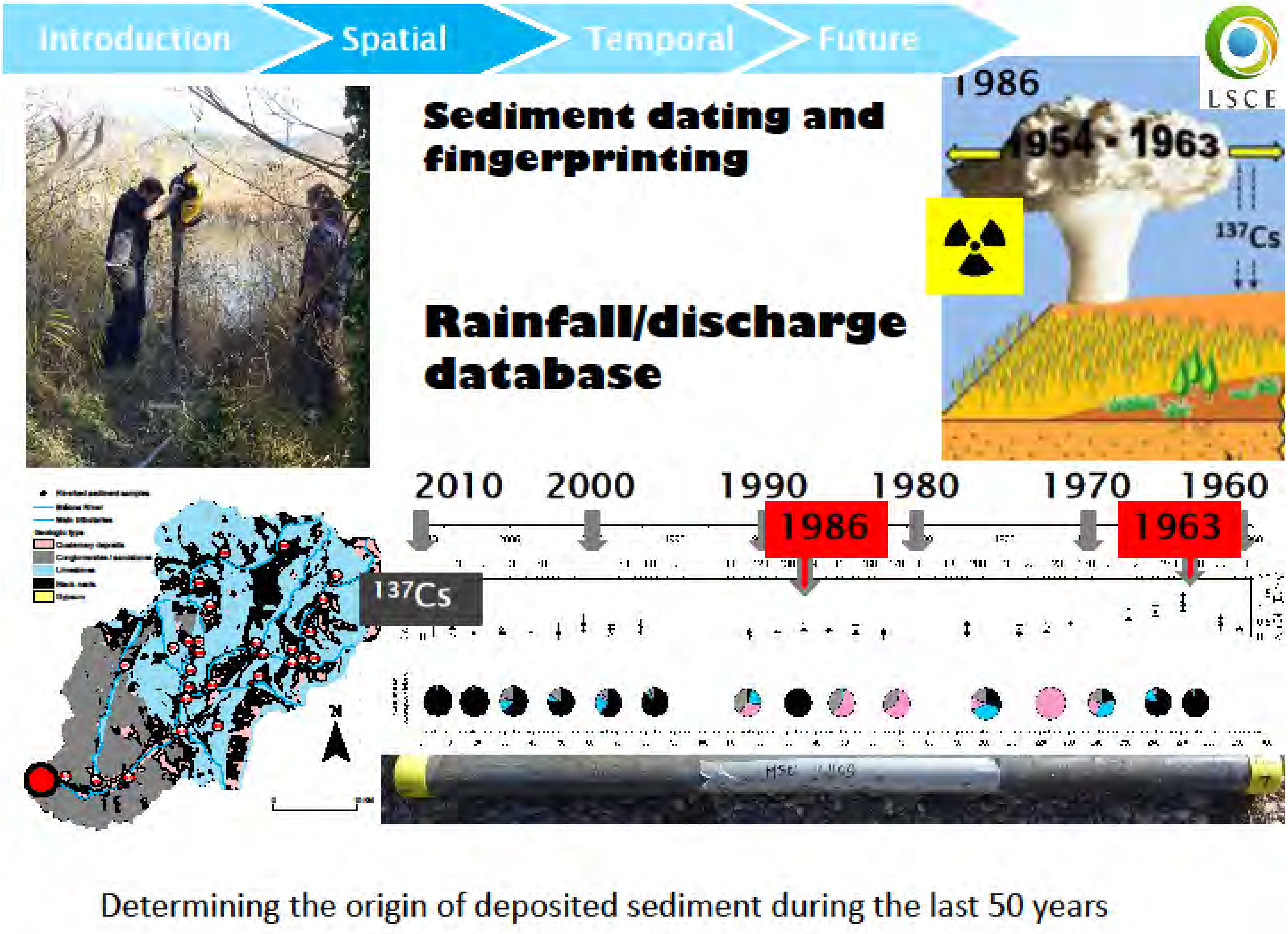
Then, you obtain this kind of information, not only information on sediment fluxes at the outlets as it occurs most of the time, but you have information at different points within the catchment and you see that sediment fluxes are very variable in space and time because it ranges between 90 tons per squared kilometers and per year at this point, and more than 5000 ton per square meter and per year at this point, so very variable in space.



To understand where it comes from we worked – we used sediment fingerprinting method. This map, you cannot read it, but it's not important, just to explain how it works. The different colors correspond to different lithologies, to different geological substrates that this is to say that the different geological types are associated with different geochemical elements with different signature. We use geochemical techniques to measure different panel of geochemical and radionuclide properties and the different potential sources. In this catchment, it's very evident to see that – we see the color of the different soil types, their difference, and the whole idea was to say that different types were also characterized by different geochemical and radionuclide properties. We measured the properties. We select, among all the properties, the ones that can discriminate the different sources. Then, using statistical mixing models, we can quantify where the sediment comes from. You take a sediment sample in the river, you can tell based on this mixing model, where the sediment comes from.



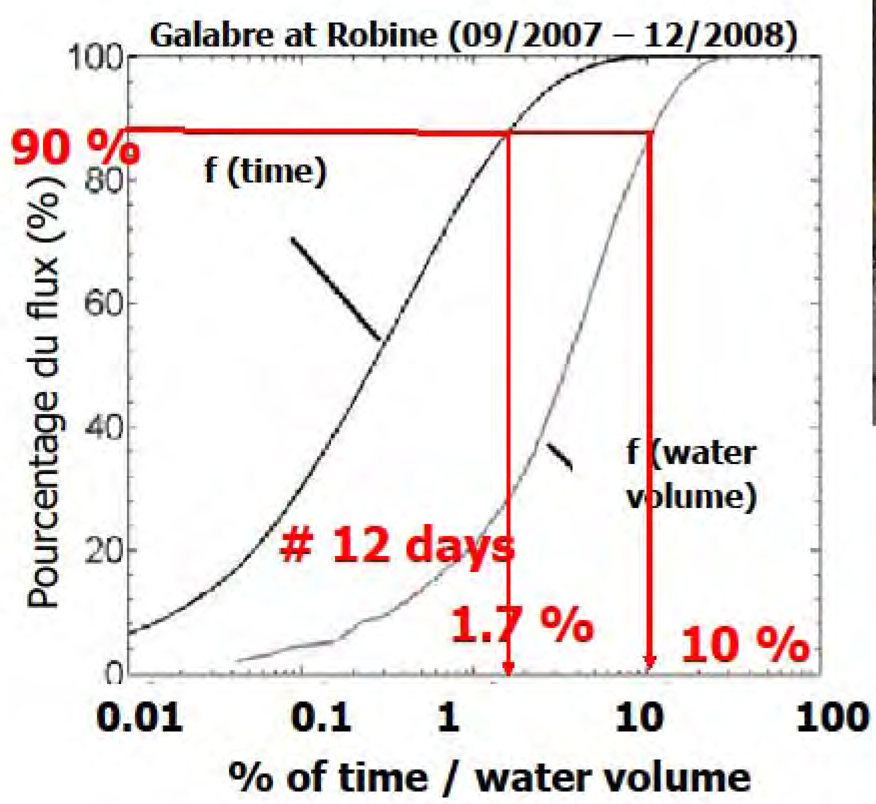
For example, on the left side you have once again this geological map. On the right side, you have the location of different sediment samples collected along the river network. You see that for a given flood, we could quantify the sources of supplying sediments at the different places. In fact, it has very important management implications because all the areas in this geological map that are in black correspond to black marl areas that are characterized by very important erosion you see about land morphology. They started to install this kind of small dams and what they call bioengineering measures, whether they plant trees, and build dams, and so on, and they say that the electricity producer won't have problems anymore with sedimentation and the outlet. But if you look at those by slide shots showing the origin of sediment, you see that if you stop erosion here, okay you will stop a part of the sediment, but you will still have many sediments coming from other areas in the catchment. This kind of method can provide important information on the management you have to work in your catchment.



Then, we also sample the sediment core just behind the reservoir. We catch the core in different sections, and we analyze them in gamma spectrometry and we could date it. In fact, the dam was built in 1960 and we could detect the caesium peaks in 1963, 1986, we could date it. Then, we applied the fingerprinting methods on the different sediment sections and we could determine the origin of sediments during the last 50 years to give more ● for conclusions and to check the validity through time.

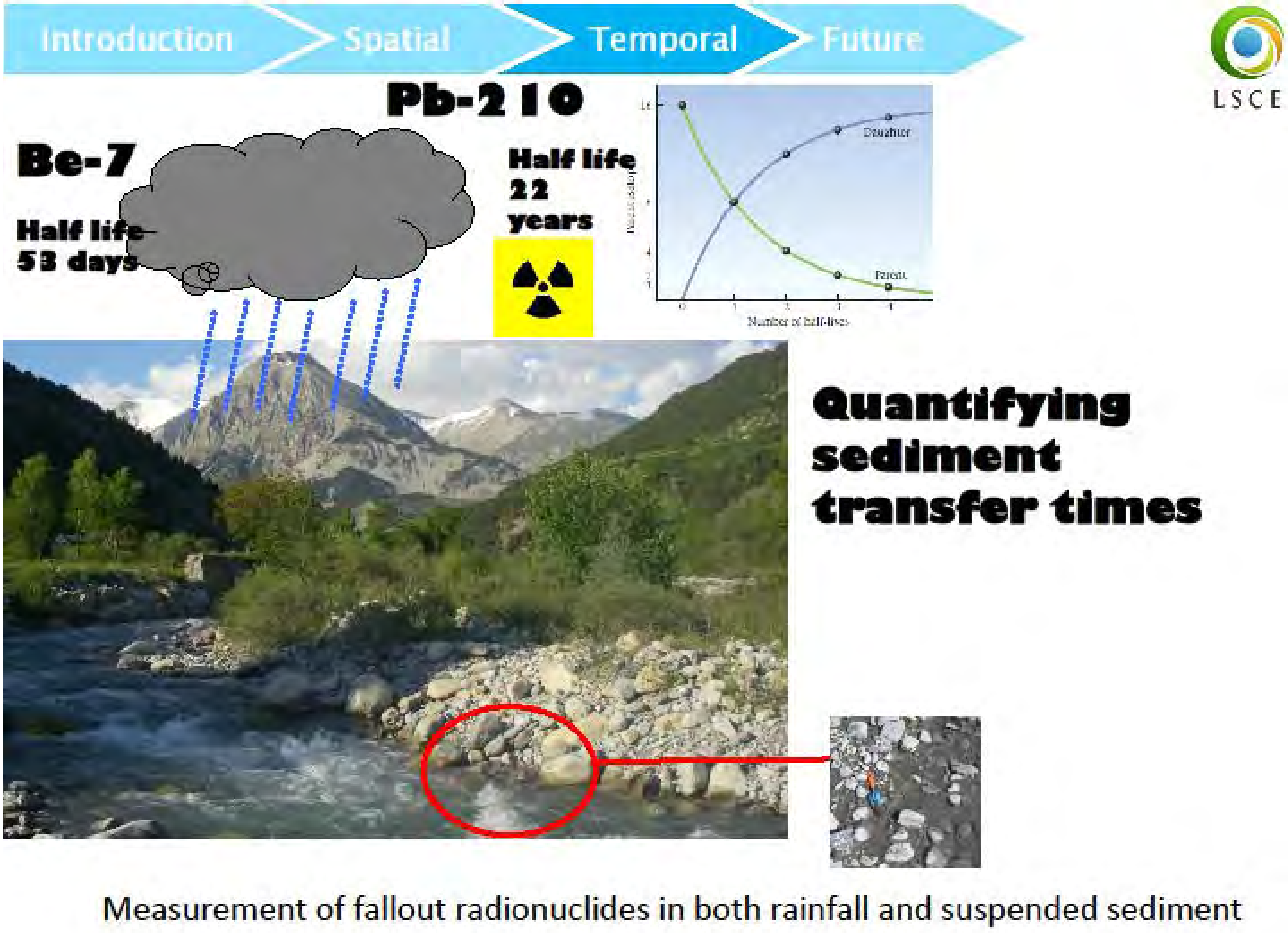
Introduction > Spatial > Temporal > Future

➢ Massive and episodic suspended sediment fluxes

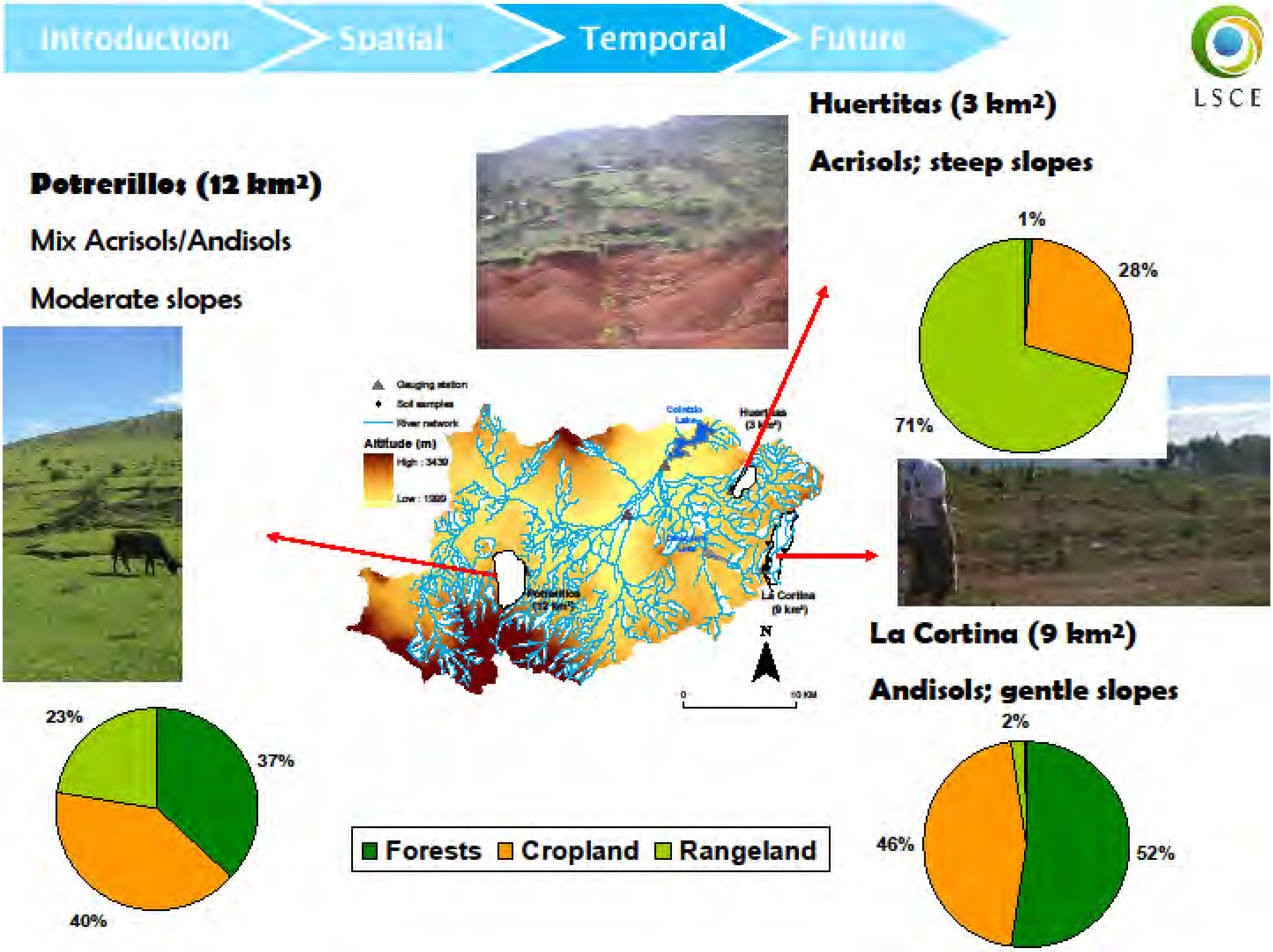


Navratil et al. (2010)

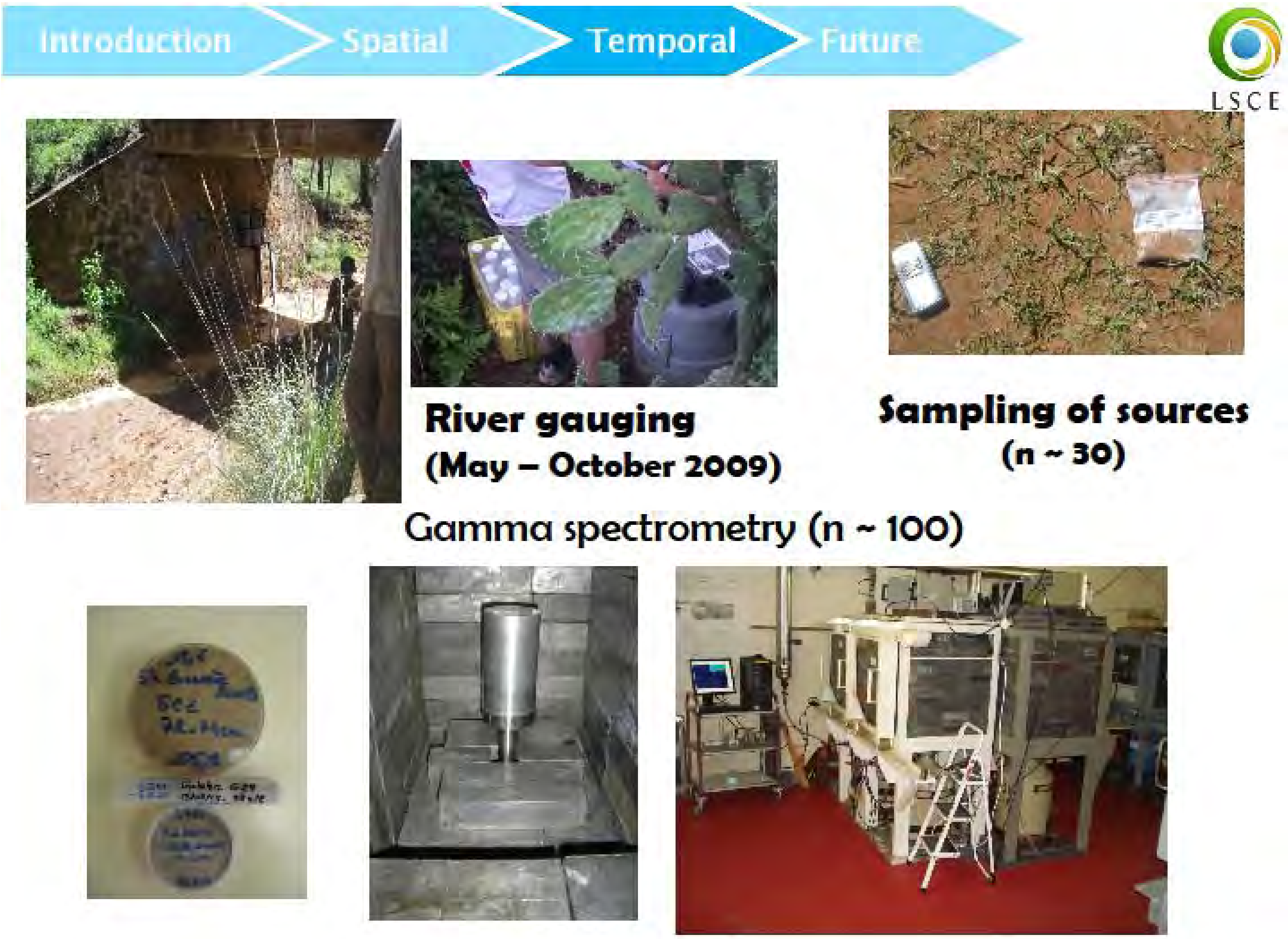
This was to show you what we did to understand where the sediment comes from. Then, the second question was to quantify the time at which they move throughout the catchment. In this Alpine catchment, we have in fact a very massive and episodic suspended sediment flux as you see during the floods that sediment loss is very, very high in the river. In certain areas, it's up to 200, 300 grams per liter. In fact, you have 90% of sediment is exported from the catchment in 1.7% of the total observation time are exported by 10% of the total water volume. It's very massive, very episodic.



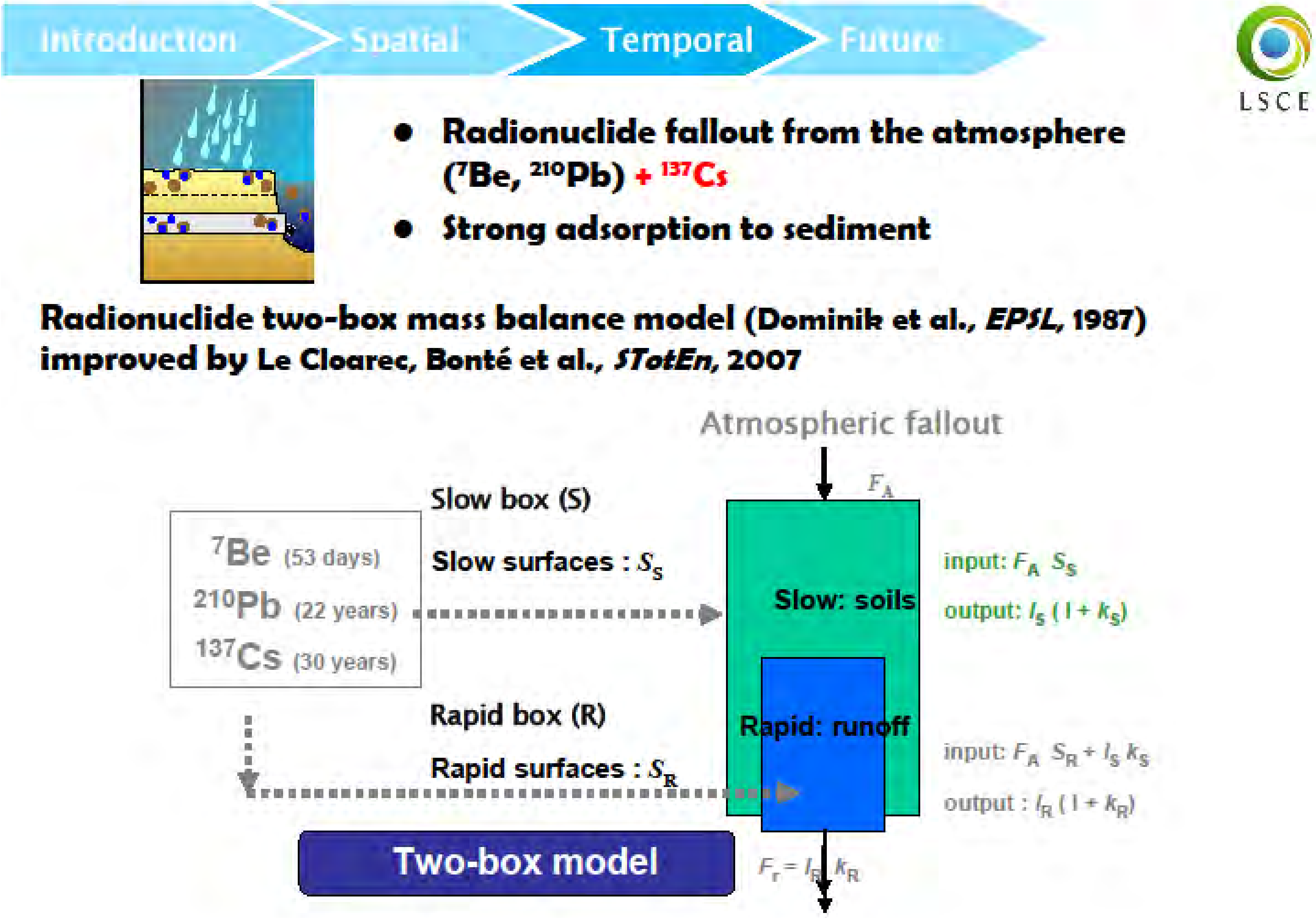
To help quantify the sediment transit times, we use radioactive isotopes that are naturally present in the environment. We use two isotopes characterized by very different half lives. The first one is beryllium-7 with a half life of 53 days. The second one is lead-210 with a half life of 22 years.



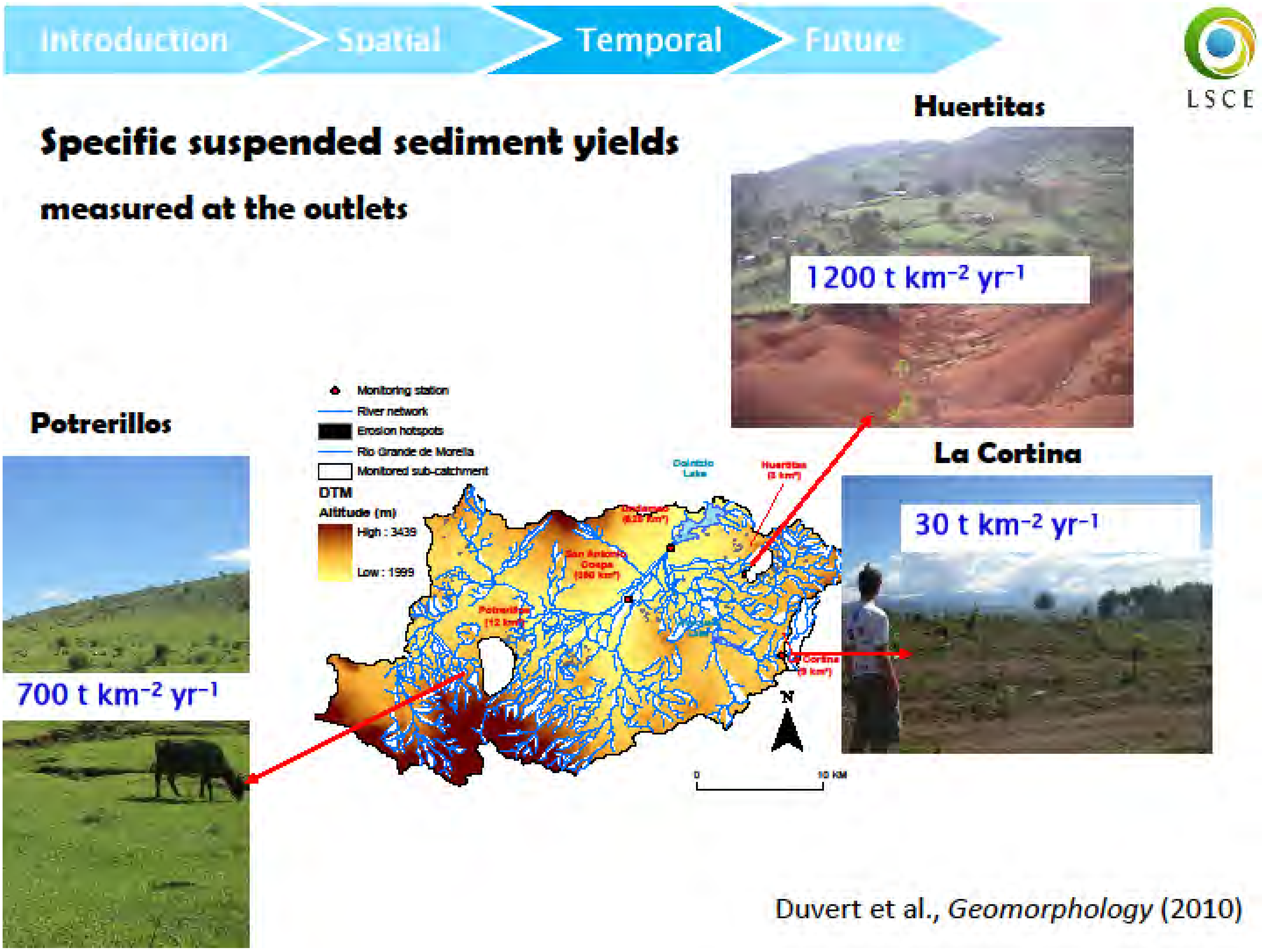
The idea is to measure the fallout of those radioisotopes in rainfall, and to measure the activities of those radioisotopes on the river sediment. Measuring the activities in both rainfall and suspended sediment can provide you, in certain conditions, an idea of the sediment transfer times.



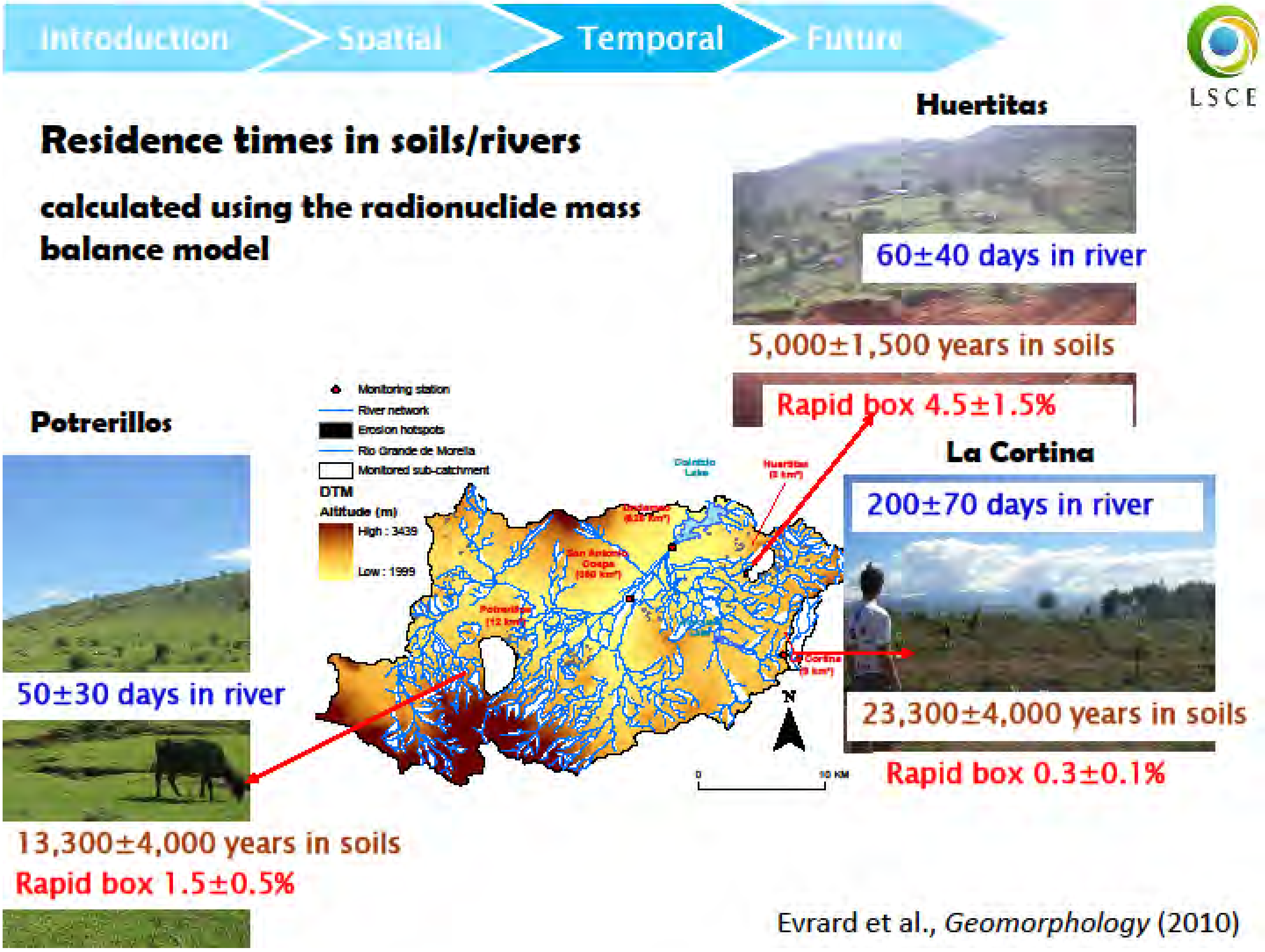
We applied this method in, the other one, the Mexican catchment. This is the entire catchment. We worked on three subcatchments, representative of the different land use and slope conditions you have in the entire catchment. You have, for example, Huertitas with Acrisol types, very steep slopes. In contrast, you have this catchment, La Cortina with another soil types, more gentle slopes, a lot of forests. In this one, you have a mix of forests, grasslands, and croplands. We worked in three subcatchments with different characteristics. At the outlet of each subcatchment, we had a river monitoring station, sediment sampler. During the wet season in 2009, between May-October, we had sediment samples for each floods of the wet season. We also sampled sediment sources in the catchment. We had information on the radionuclide activities in rainfall all throughout the season.



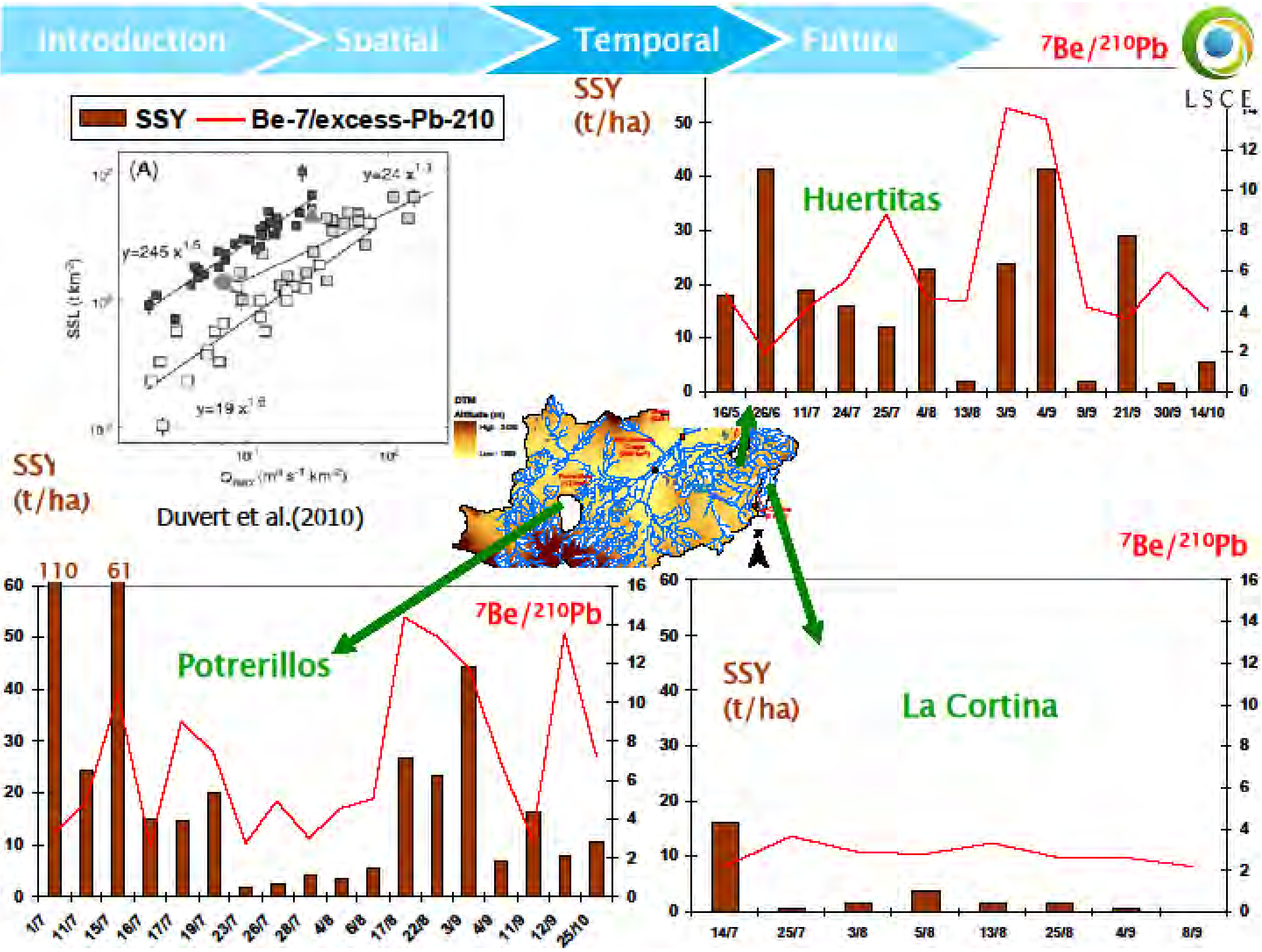
We measured all the samples in gamma spectrometry at all laboratory in France. Then, we calculated the transfer times by using this two-box mass balance model. How does it work? We measure atmospheric fallout, so the activity in beryllium and lead-210 in rainfall because there was no caesium fallout at that time during which we worked in the catchment. You have the input and you also have the output because those radionuclides strongly adsorp onto particles. We measured the activities in sediments exported by the catchment. Based on the inputs and the outputs, drawing and calculated mass balances you can subdivide the catchment in two boxes; a as slow box, which corresponds to the soils; and the rapid box, which corresponds to the river. By calculating the inputs, outputs, and the mass balances, you can obtain information on the residence times in each box.



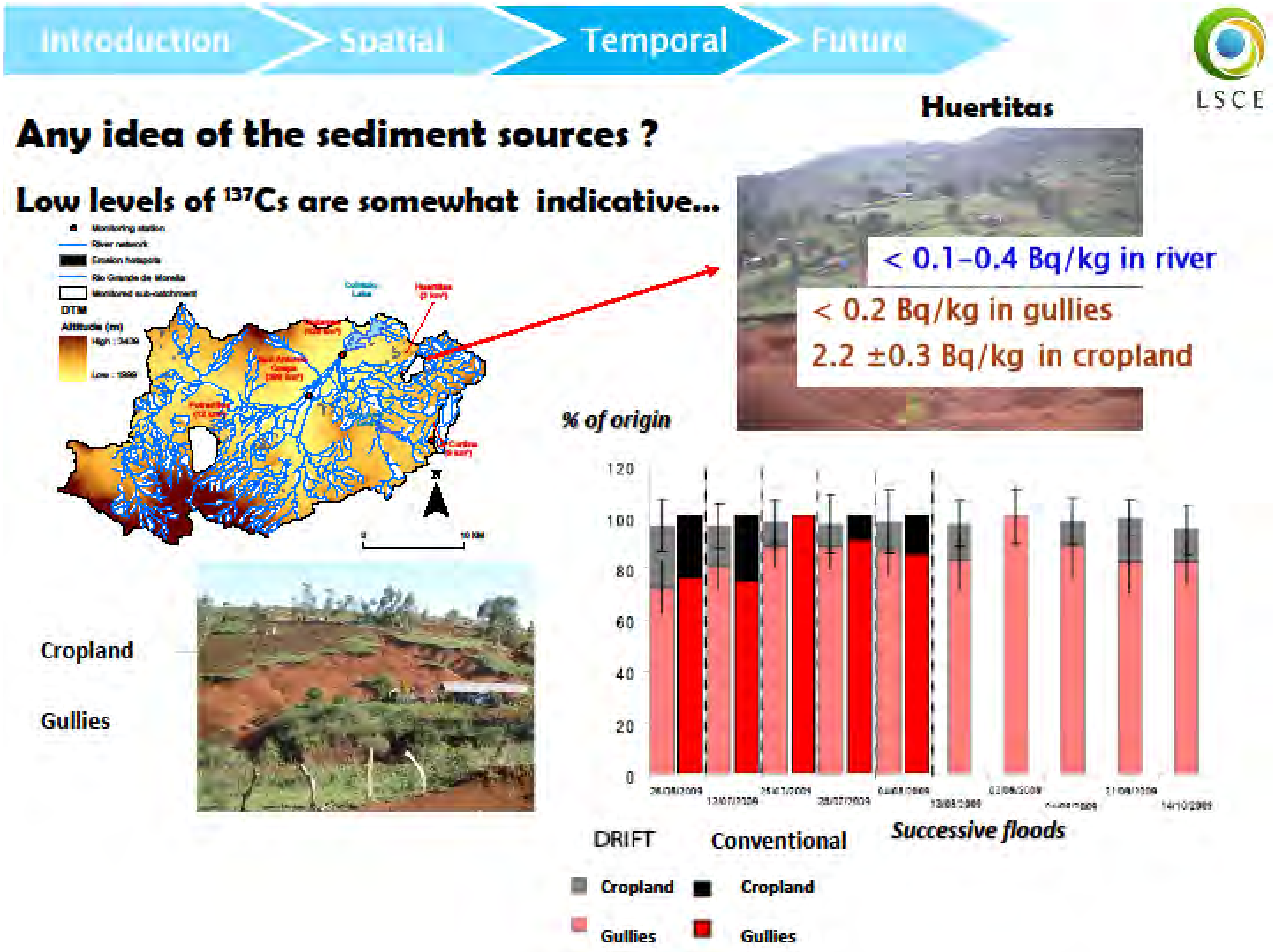
For the three subcatchments, we had in fact very different sediment outputs. In this one, it was very important, more than 1000 tons per squared kilometer and per year.



In this one, it was very low, about 30 tons per squared kilometer and per year. For the residence times calculated using this method, we had about a residence time of sediment of about 50 days in river in this catchment, a similar time in this catchment, but a much longer residence times of sediment in this catchment. Also, different mean residence times of particles in soils in the different catchments.

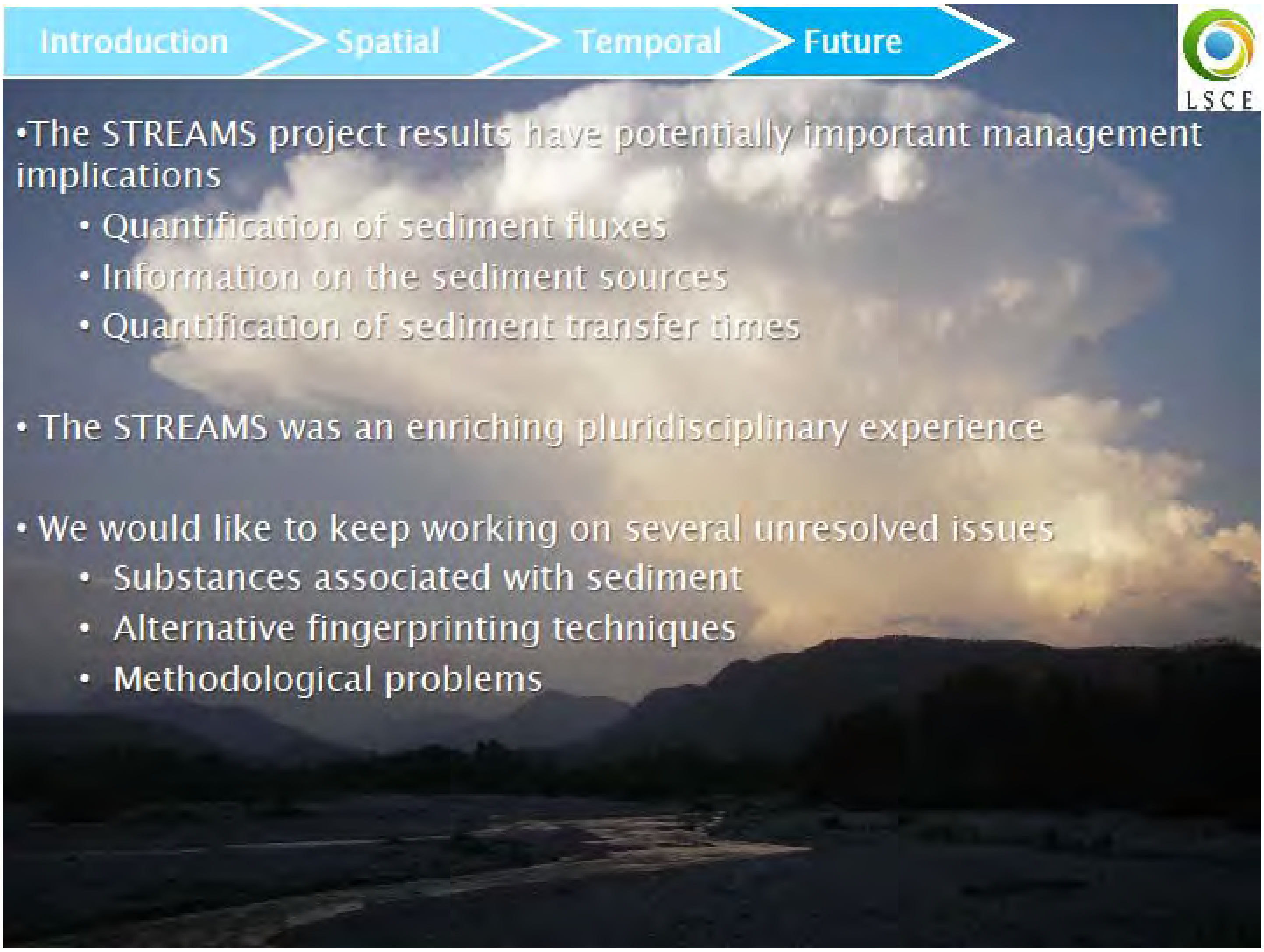


This is a mean residence time in each box, but we can also look at what it gives during the wet season for the different floods. This is the graph for each subcatchment. For the different floods, in brown, you have the bars corresponding to the sediment export from the catchment. The curve in reds indicates the ratio between beryllium and lead. You see that you have a very sawtooth behavior in this catchment and in this catchment. Here it's much smoother.



In fact, in this catchment, in the first catchment, you have an important sediment export at the beginning of the wet season and then just like a dormant behavior. In contrast, in the two other catchments with a larger surface of cropland, we have a very reactive behavior with after heavy storms, you have exports and total sediment fluxes from the catchment. Based on these types of methods, we can really have an information on the residence time of sediment in the catchment.

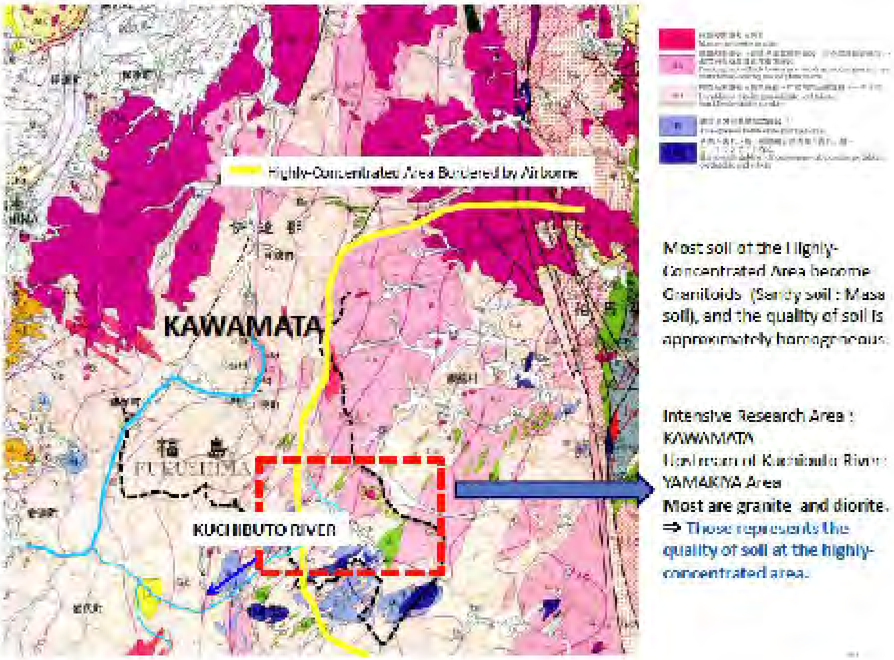
Another question was to quantify the supply of sediment by the different sources. For example is this, Huertitas catchment, you have just like the bets ● between the local managers and the farmers because the local managers tell that the farmers are responsible for the soil erosion, and that sediment causing problems comes from the croplands, and the farmers tell that it's not true, and that sediments comes from the gullies and that to stop erosion you should stabilize the gullies. In fact, what we could show is that most sediment indeed come from the gullies, so the bars in red correspond to sediments coming from gullies, and the part of the bars in black correspond to the sediment coming from cropland. From the results, it was really evidence that it came mostly from the gully systems.



To sum up the main points; during this project, we could provide answers to important management questions by quantifying sediment residence times by giving information on sediment sources, and we still want to work on those topics. Also, by working on tracing other substances, just like carbon associated with sediment, and also to develop alternative fingerprinting techniques, just like the ones based not on geochemical measurements or radionuclide measurements, but based on the color of sediment; although, infrared spectra of soils that you can recommend that are very easy and cheap to measure, and also, to answer to different methodological problems raised during the study.

Open questions for the Fukushima study

- Feasibility of ^{7}Be and ^{210}Pb measurements in rainfall and sediment?
- Existence of potentially discriminant lithologies?



Source: http://fmwse.suiri.tsukuba.ac.jp/

The open questions for Fukushima study would be, is it possible to measure beryllium-7 and lead-210 in rainfall and sediment? Also, I found this on one of your websites, does it exist potentially discriminant lithologies in the catchment. Apparently in the Kuchibuto River, you have different lithology than in other parts and, probably, it would be possible but it's still an open question.

Thank you very much. I hope you are not asleep.

Male1
Thank you very much.

[Japanese]

[Male]
Well, it is very interesting that you compared the residence time of the particles in the river in three subwatersheds ●. Is the difference of the residence times of the particles in the river depending on the difference of runoff rate or ● runoff source?

Dr. Olivier Evrard
That's a very good question. In fact, we looked at different possible potential explanations and it didn't work with all rainfall and discharge parameters. There was no statistically significant relationship. The most evident explanation would be that the land use is very important. This is one of the most important parameters. Then, one thing that's complicated to take into account in this type of model is sediment connectivity within the catchment that can be different for the three sites and which is not evident to take into account with those simple box models, where you just subdivide your catchment in two boxes, the river box and the soil box. But it should be something we can look at.

Male1
When you look at the field, the channel shape or the structure itself is very much different among the three subwatersheds. Such kind of difference might affect on the difference of the residence times.

Dr. Olivier Evrard
Yeah. There're different potential explanations. In fact, the objective was really, first, to try to apply the methods at the catchment scale and also to be in a very remote place because it was in Mexico and there was no gamma spectrometry device available in the area, so we had to send everything back to France and measure it rapidly because beryllium-7 decays quite rapidly. We wanted to try the method. We were happy because it provided at least relevant results. It was more a test but we were happy about the results of the test. Thank you.

[Multiple Speakers]

Male2
A simple question. In your model or in your layout you assumed that the sediment is coming either from the slopes, from agriculture, or from the gullies, right, these are the main two sources for Mexico.

Dr. Olivier Evrard
You mean in this…

Male2
Yeah. What about other sources like river sediment or riverbed sort or something? Is it the only source you have in your catchment?

Dr. Olivier Evrard
Well, in this catchment, those were the most evident sources because – and in fact, another interesting result of – I didn't talk about it but – the model calculates also the surface percentage covered by your rapid box within the catchment but just to respect the mass balance thing. For this specific catchment, it calculated the surface of the rapid box as being around 5% of the catchment total surface. If you calculate the surface covered by the river plus the gully, obviously, in those gully systems, it covers about 5% of the total catchment surface, which would mean that in this gully

system sediment moves very rapidly. In fact, riverbanks in this case would be the gully systems which makes it, probably, an easy catchment site, an easy test site. Thank you.

Male1
I have a question. You have lead-210. You showed the caesium – next slide or before that – about the same resources using caesium-137.

Dr. Olivier Evrard
Same resource?

Male1
Yeah.

Dr. Olivier Evrard
Now, you mean in Mexico or in...?

Male1
In Mexico. This type based on the caesium-137 database, so you have most of the source should be from the gully instead of not from the box. What about the lead-210? Did you also measure the lead-210 and also derive the same conclusion?

Dr. Olivier Evrard
In fact for the residence times, we used lead-210 but for the spatial study, the sediment fingerprinting study, we didn't use lead-210 because it was not evident that it could discriminate between the different sources. But caesium could in fact because in croplands, you have about around two Becquerels per kilo of caesium and in the gully system, you have almost no more caesium. It was almost evident that – because in river sediment, we didn't measure caesium. We didn't detect caesium either, so it was just like an evident case study of giving a very evident answer for sediment resource question.

Male1
Okay.

[Male]
Okay. Thank you very much for the interesting talk. Now, I understand that radionuclide is a powerful tracer of the particles. I have a general question of the tracer, the particle for the distinguished sources. What is a prospective tracer rather than radionuclides? Is there other tracers? Do you have any idea on the other prospective tracers for particles?

Dr. Olivier Evrard
How's the prospective – what?

[Male]
Other tracers.

Dr. Olivier Evrard
Okay. Your question about the tracers, you mean the geochemical tracers or the...?

[Male]
Geochemical or even in tracers.

Dr. Olivier Evrard
You mean for Japan?

[Male]
Basically in Japan or in your field in the forest or in the mountainside.

Dr. Olivier Evrard
In fact, it really depends on the sites. In Mexico, it was really complicated because it was covered by volcanic terrains but very eroded and very old terrains so there weren't so many evident geochemical differences. In the Alps, overall it was rather homogenous, but we could detect in the traced elements evident discriminating tracers. But, probably, apparently, if you look at this map, it should clearly be easier to apply in Japan than in Mexico, but we should try and test it. I don't know if have completely answered your question.

Male1
In the Alps study, did you distinguish the sediment sources by geochemical tracer and...?

Dr. Olivier Evrard
Also combination with certain radionuclides.

Male1
Okay. Great. Yeah, nobody, so thank you very much.

Dr. Olivier Evrard
Thank you.

END