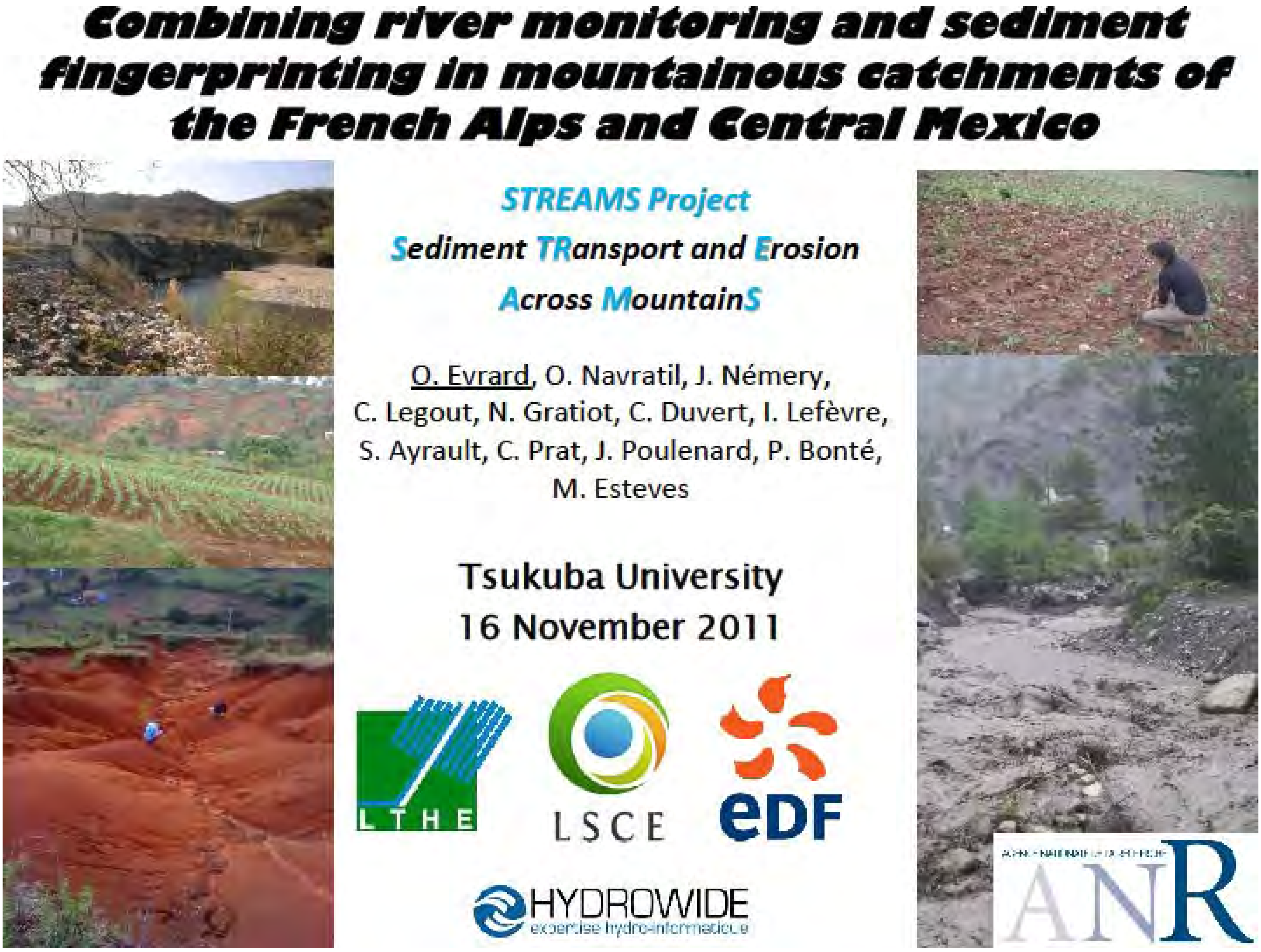


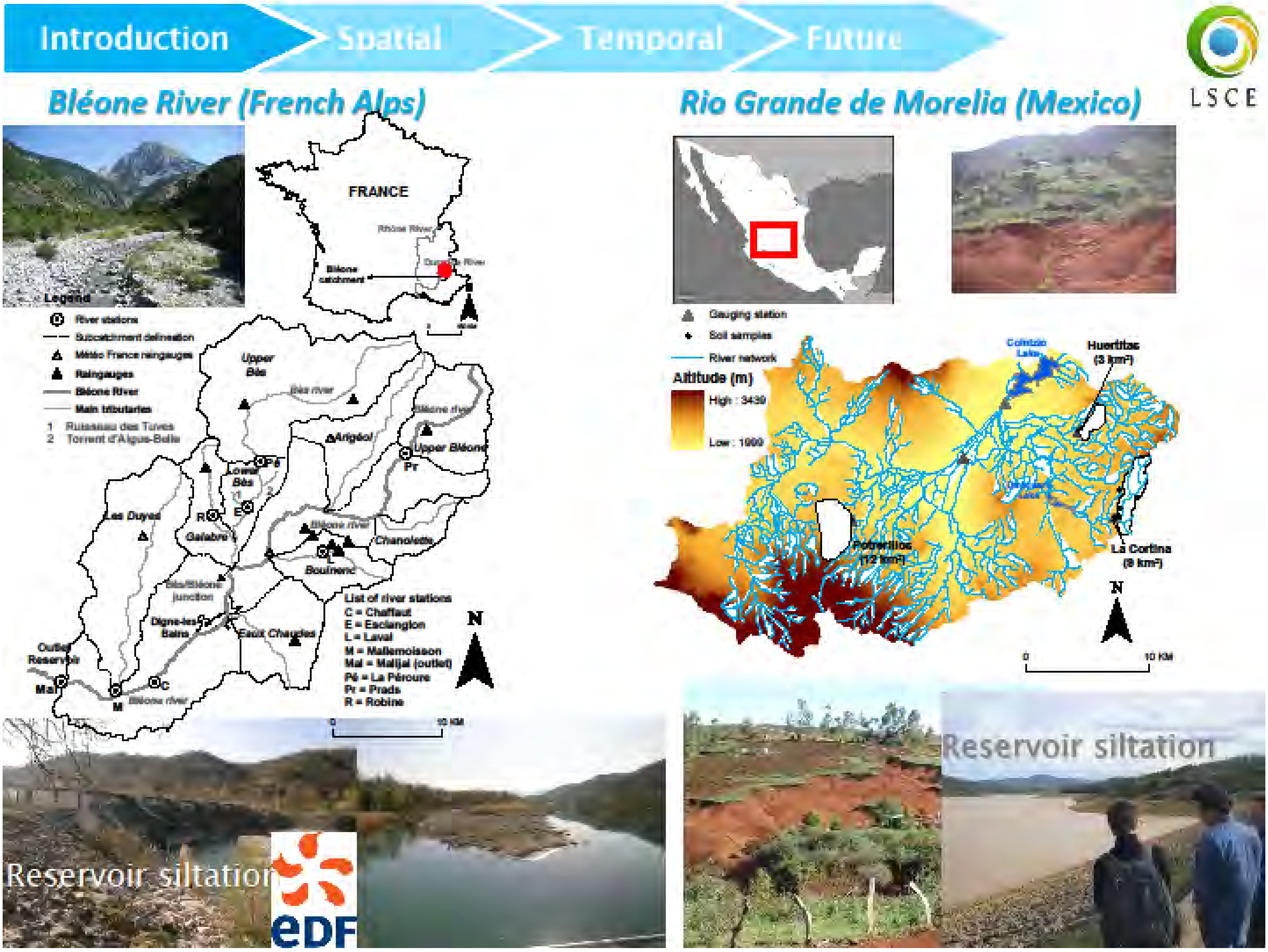
Dr. Olivier Evrard

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.

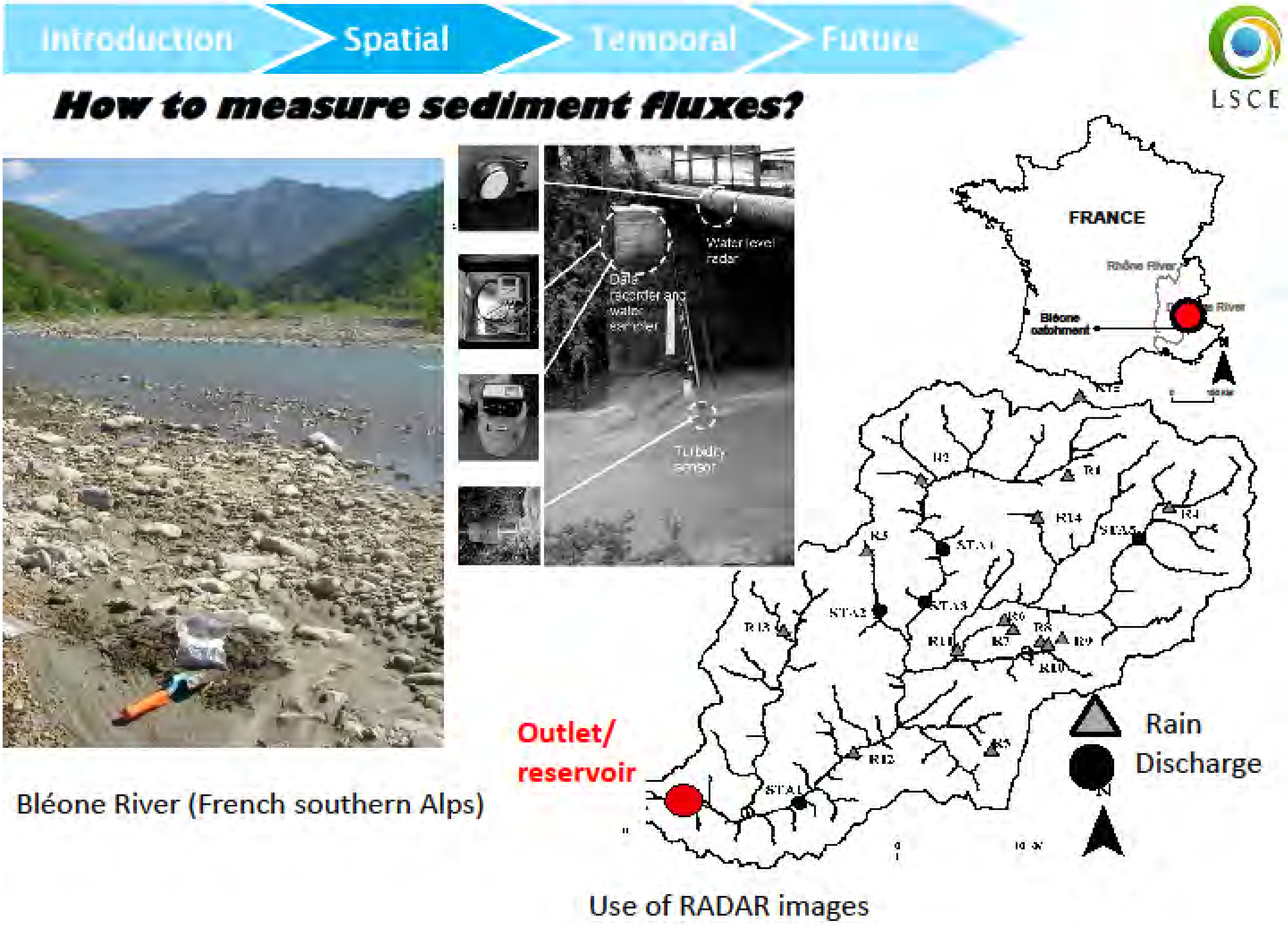
- Severe soil erosion in mountainous catchments
- Strong spatial and temporal variations
- Insufficient monitoring network
- Catchments with area between 500-1000 km^2
- Important social and economical problems
  - Soil loss from the fields
  - Transport of contaminants
  - Modifies channel morphology
  - 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.

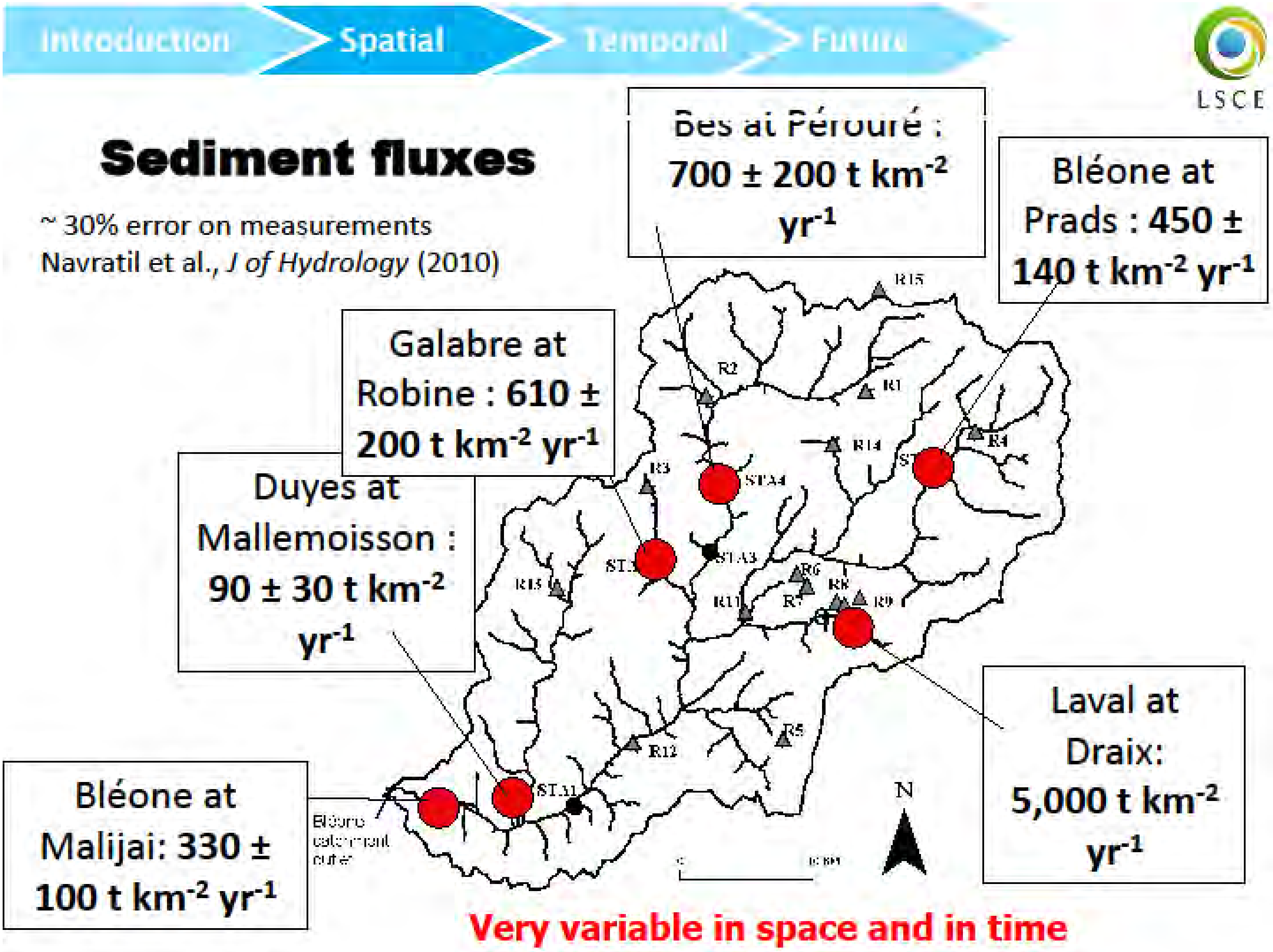
Two very different catchments were selected. One is in this region of France, in Southeastern France. It's a maritime catchment with a surface of 1000 square kilometers. You have a permanent river network. This is the Bléone River with several tributaries. The main problem associated with erosion is 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.



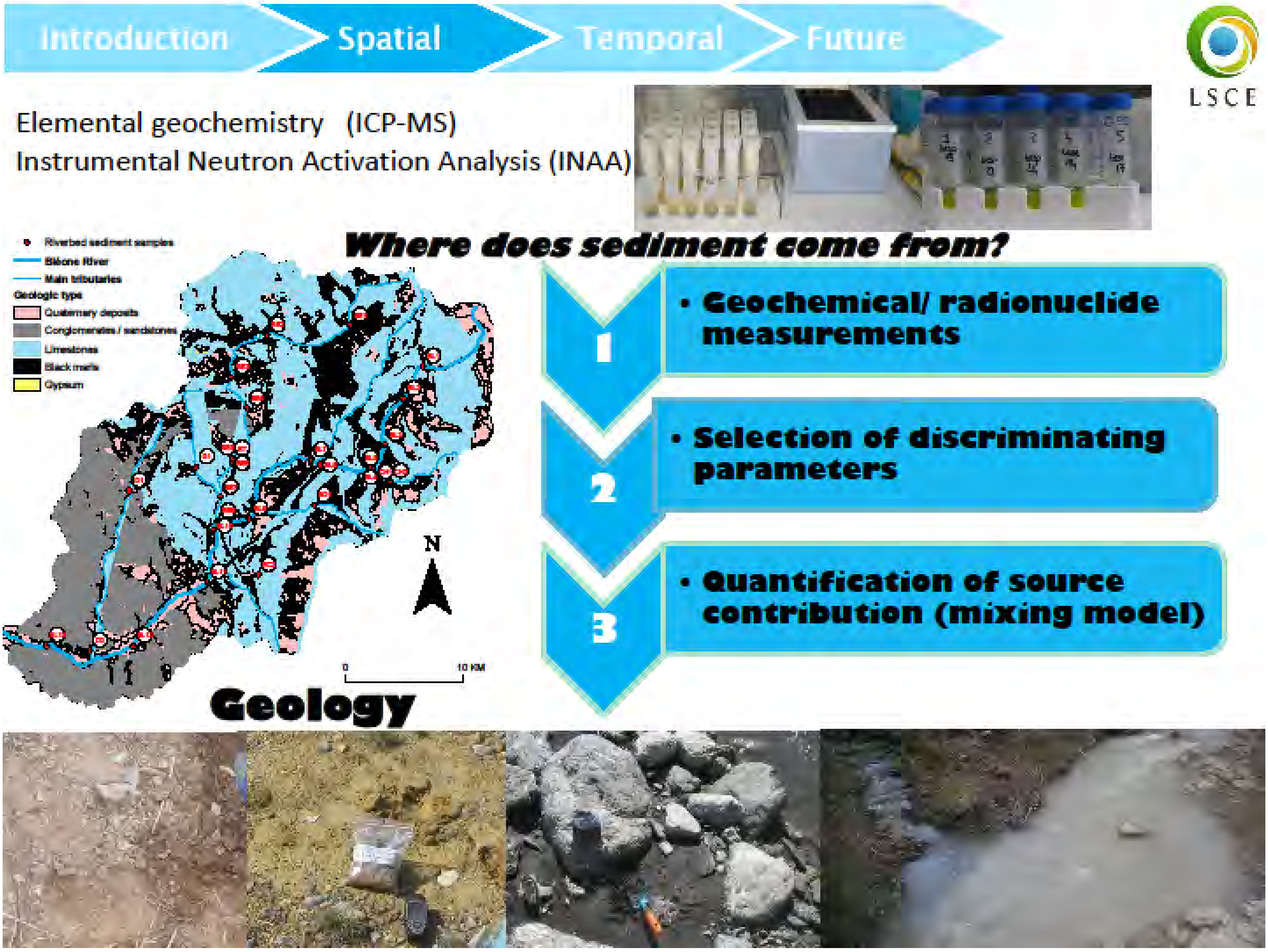
In Mexico, it's completely different. We don't have permanent river network because you have succession of dry season and wet season. You have volcanic rocks. There is also a reservoir at the catchment outlet but used for very different reasons. In fact, it's used to provide drinking water to 1 million 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?



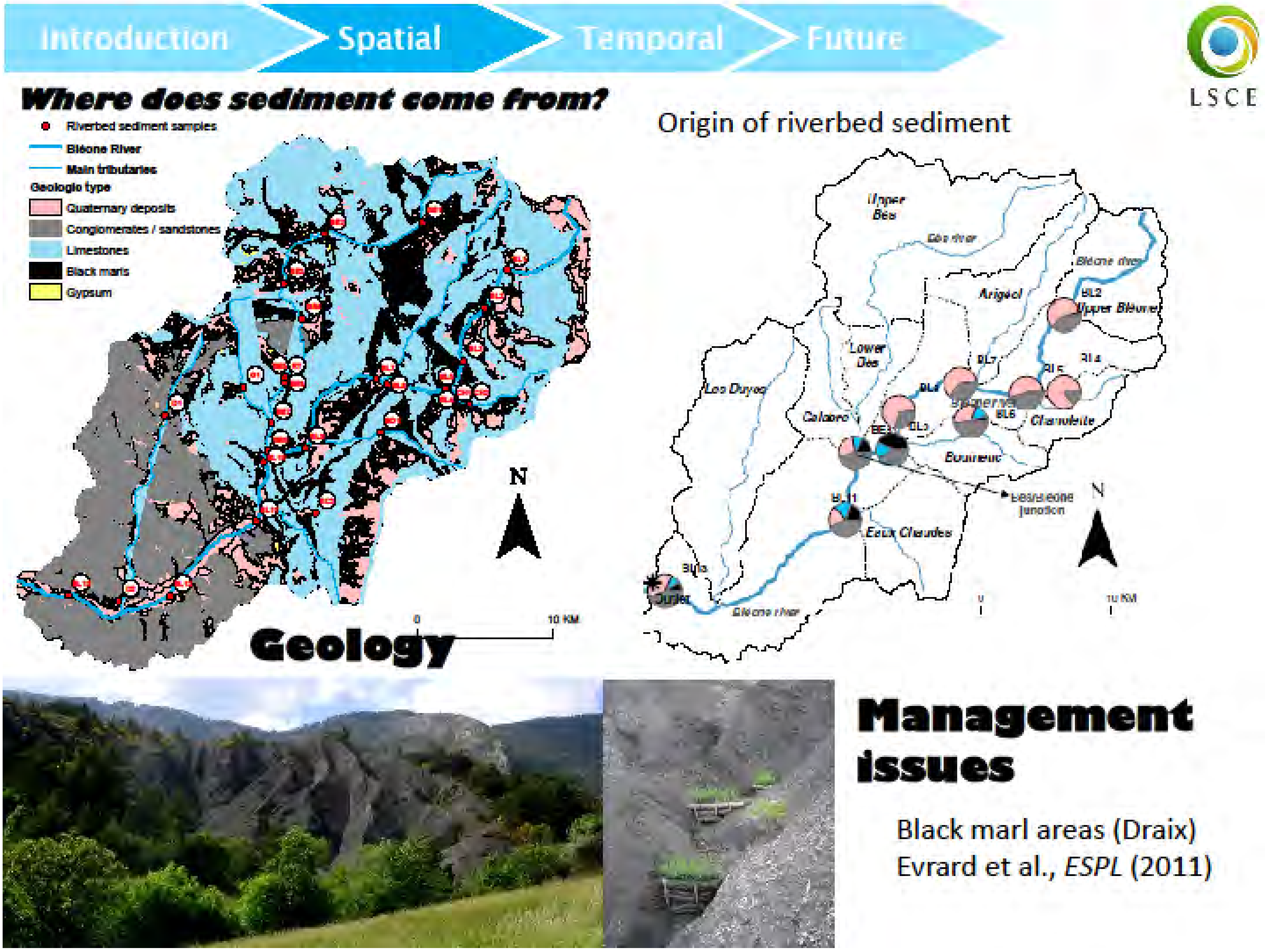
How to measure sediment fluxes? We worked with our hydrologists colleagues and they installed several river monitoring stations at several points. This is the example of the Alpine in the French catchment. Many were engaged, many rivers stations with sediment samplers, turbidity meters, water-level recorders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



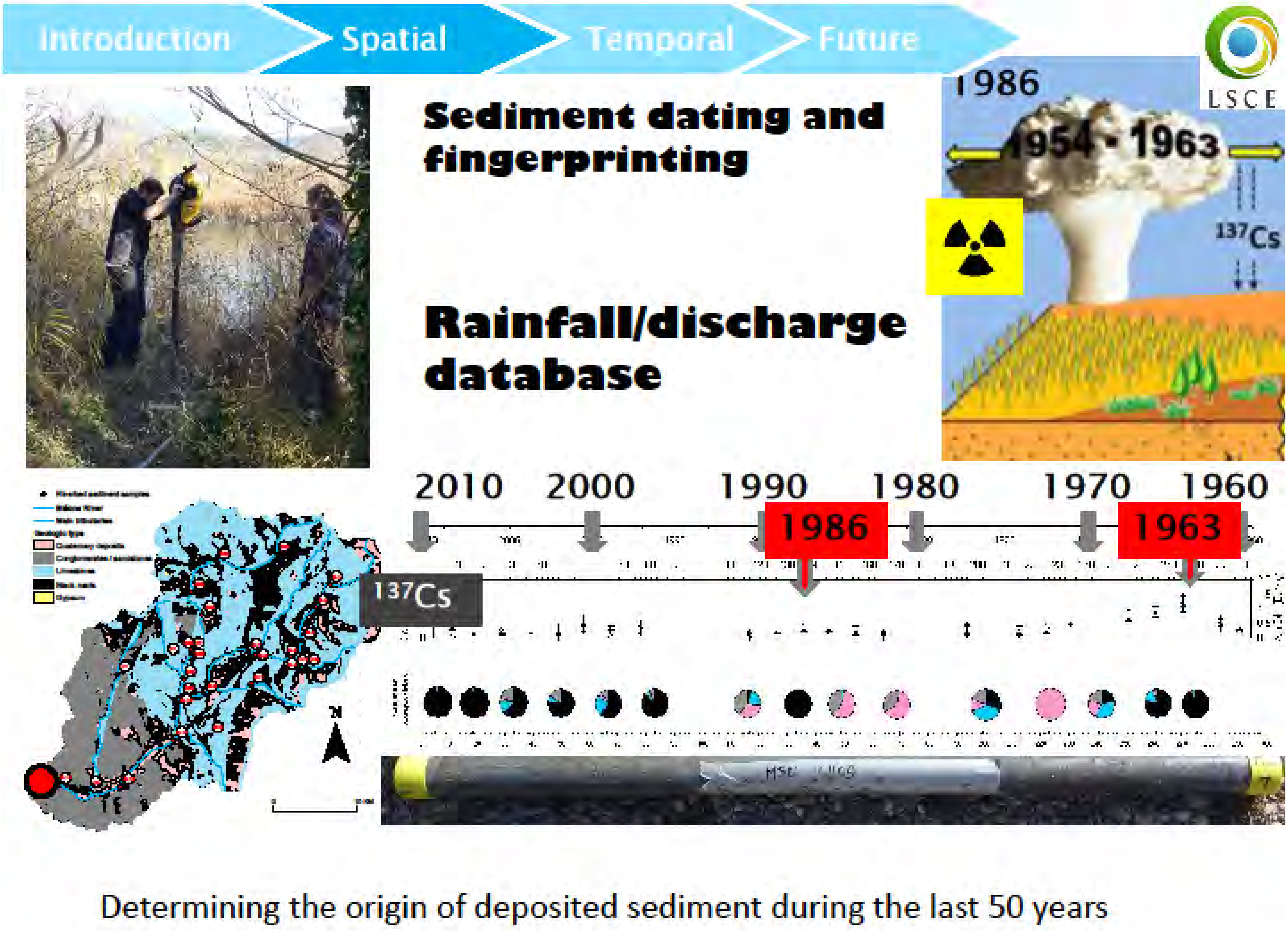
Then, you obtain this kind of information, not only information on sediment fluxes at the outlets as it occurs most of the time, but you have information at different points within the catchment and you see that sediment fluxes are very variable in space and time because it ranges between 90 tons per 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.

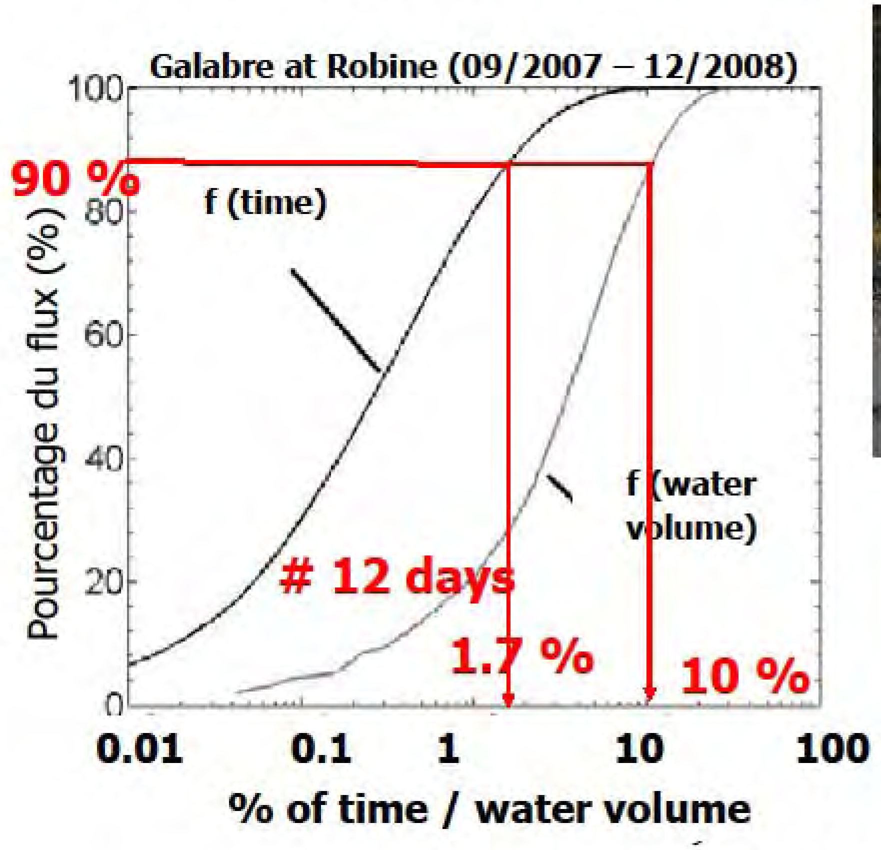


For example, on the left side you have once again this geological map. On the right side, you have the location of different sediment samples collected along the river network. You see that for a given flood, we could quantify the sources of supplying sediments at the different places. In fact, it has 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.



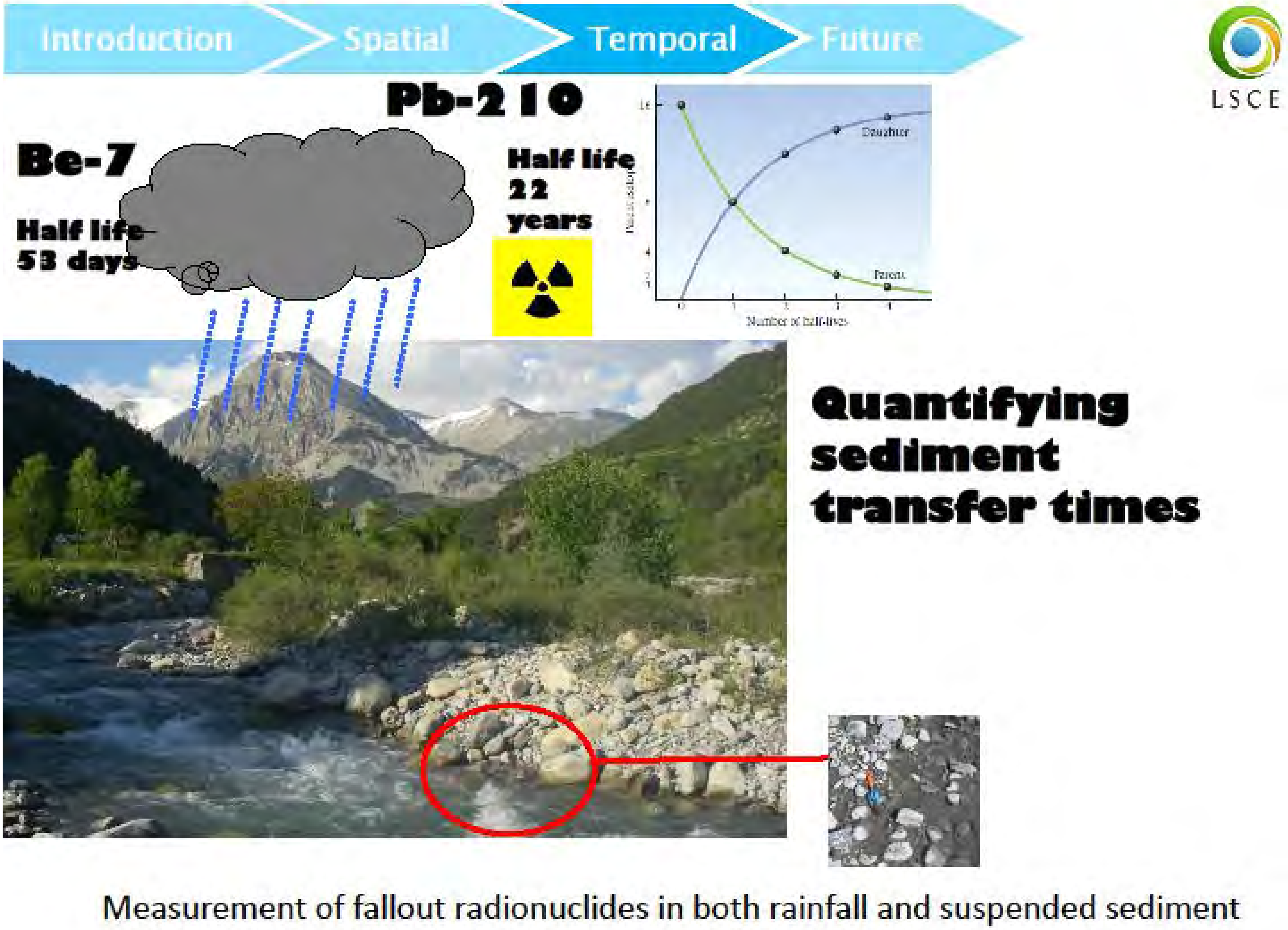
Then, we also sample the sediment core just behind the reservoir. We catch the core in different sections, and we analyze them in gamma spectrometry and we could date it. In fact, the dam was built in 1960 and we could detect the caesium peaks in 1963, 1986, we could date it. Then, we applied the fingerprinting 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.

➢ Massive and episodic suspended sediment fluxes

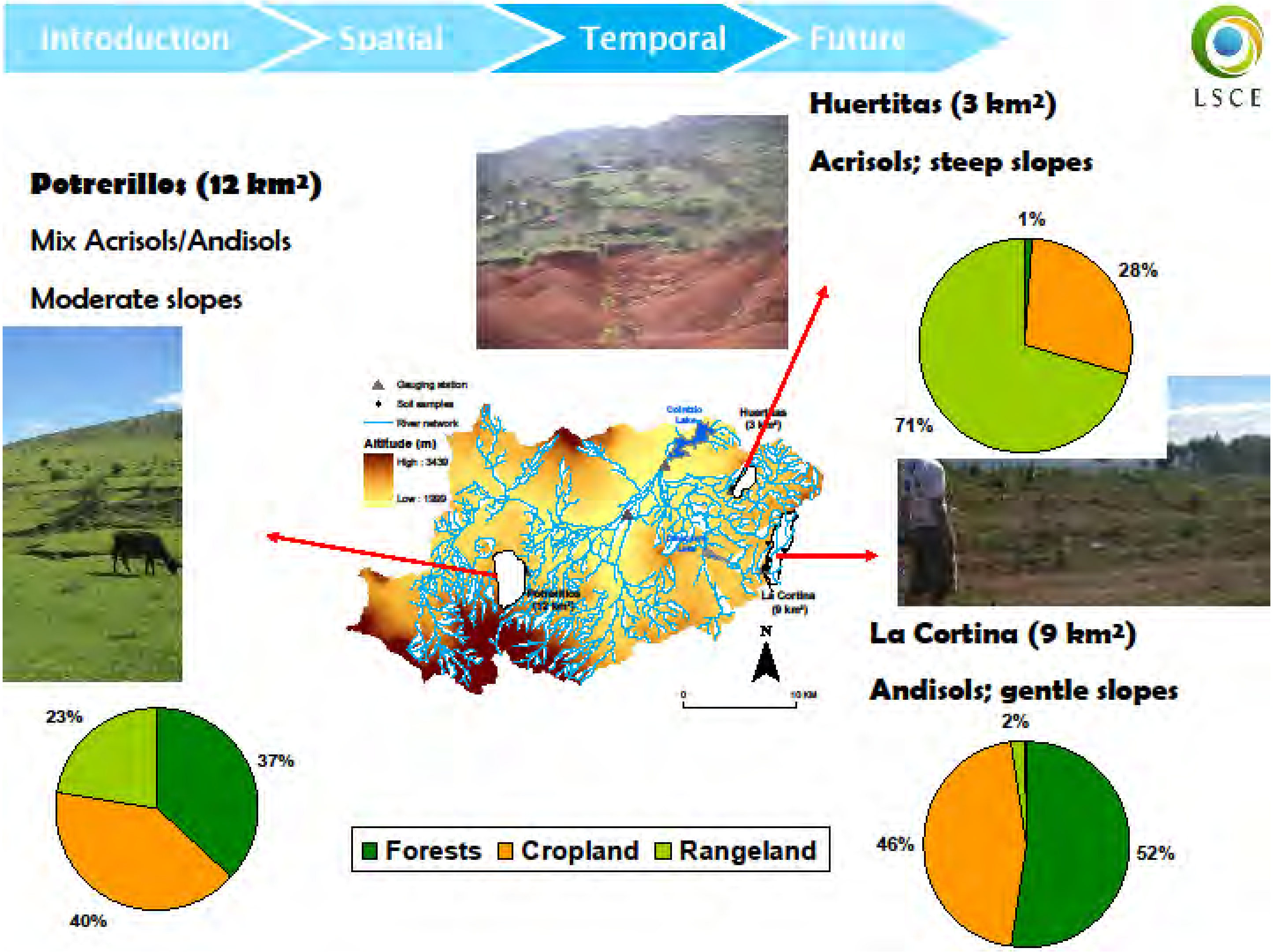


Navratil et al. (2010)

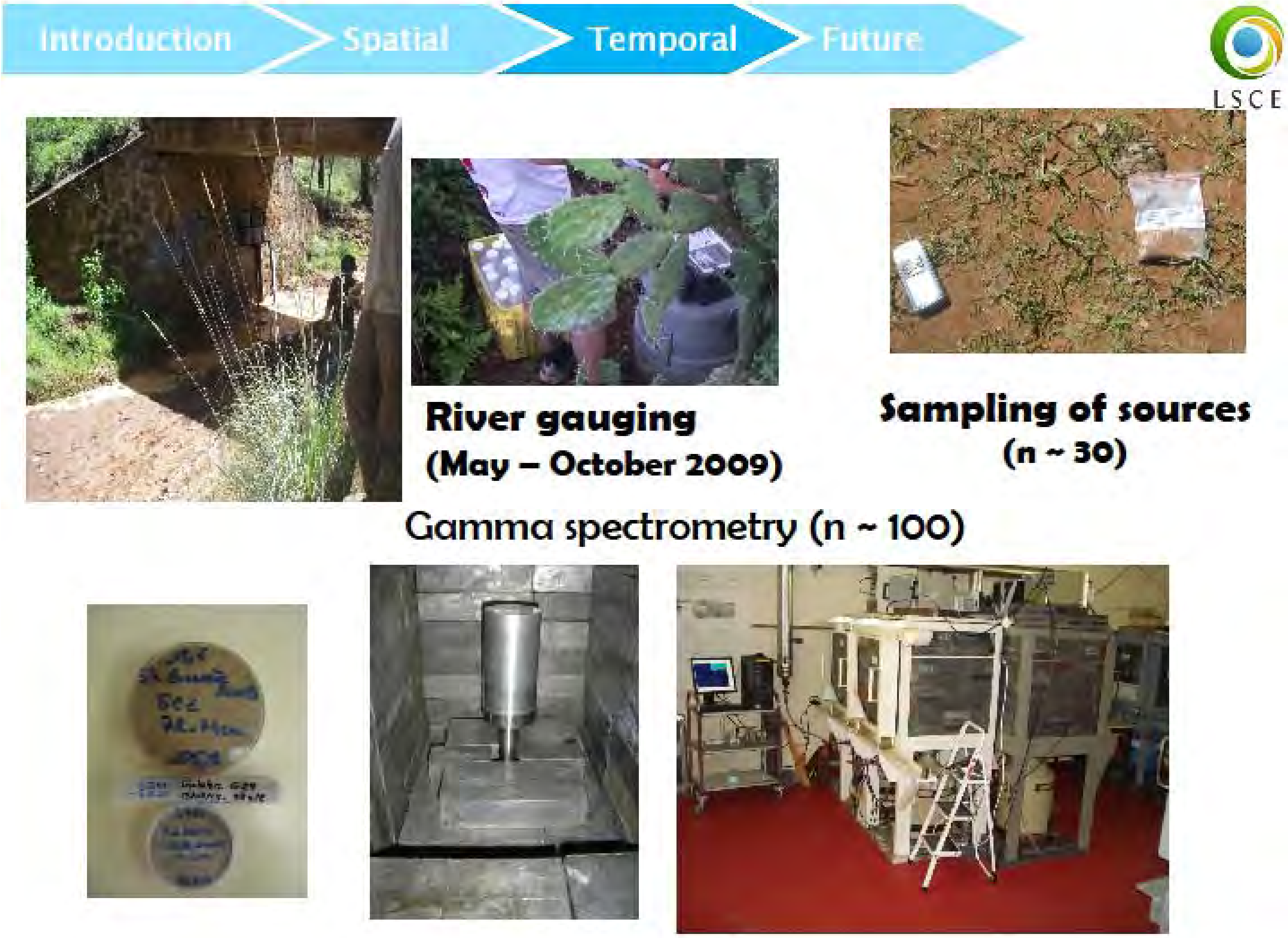
This was to show you what we did to understand where the sediment comes from. Then, the second question was to quantify the time at which they move throughout the catchment. In this Alpine catchment, we have in fact a very massive and episodic suspended sediment flux as you see during the floods that 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.



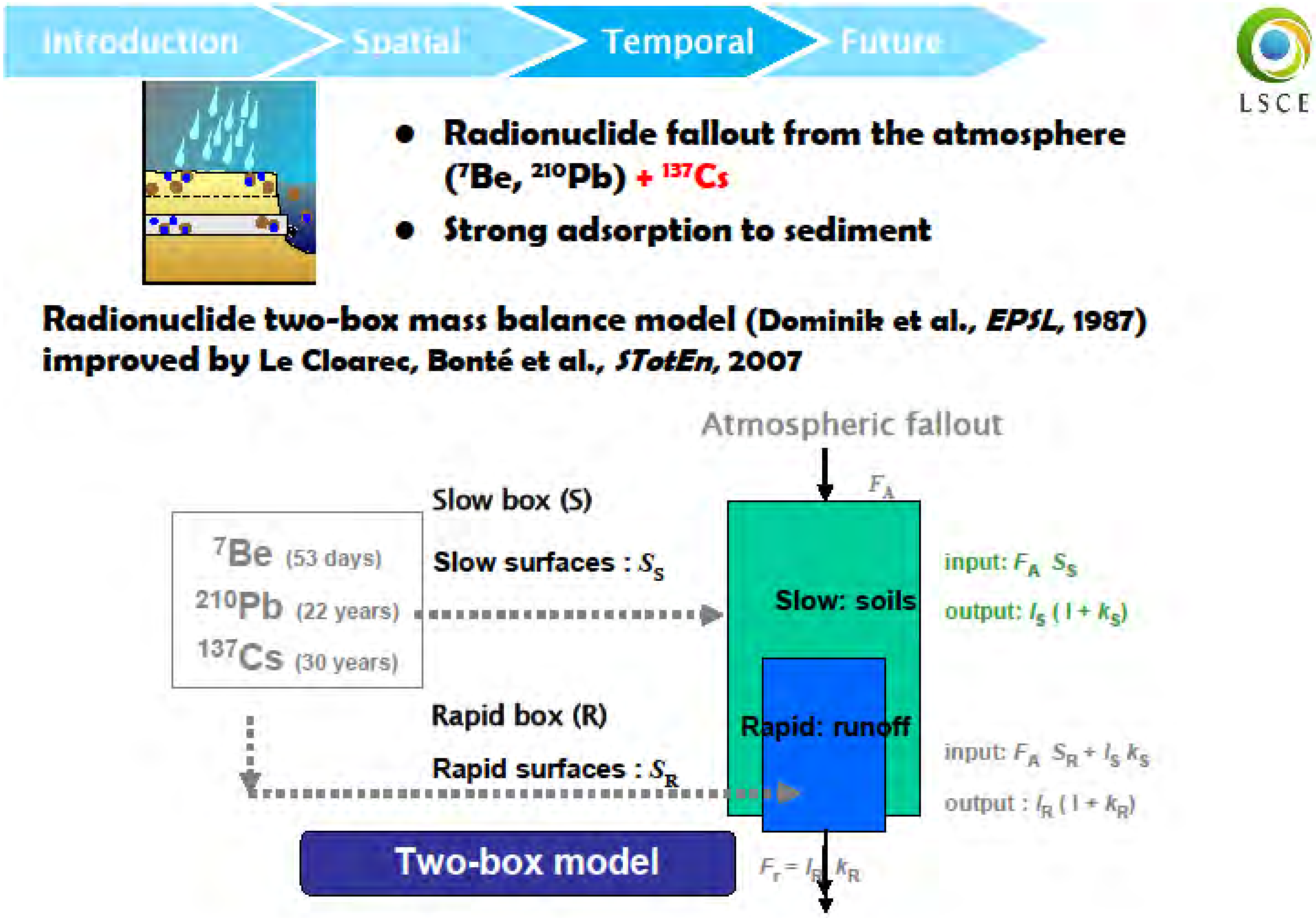
To help quantify the sediment transit times, we use radioactive isotopes that are naturally present in the environment. We use two isotopes characterized by very different half lives. The first one is beryllium-7 with a half life of 53 days. The second one is lead-210 with a half life of 22 years.



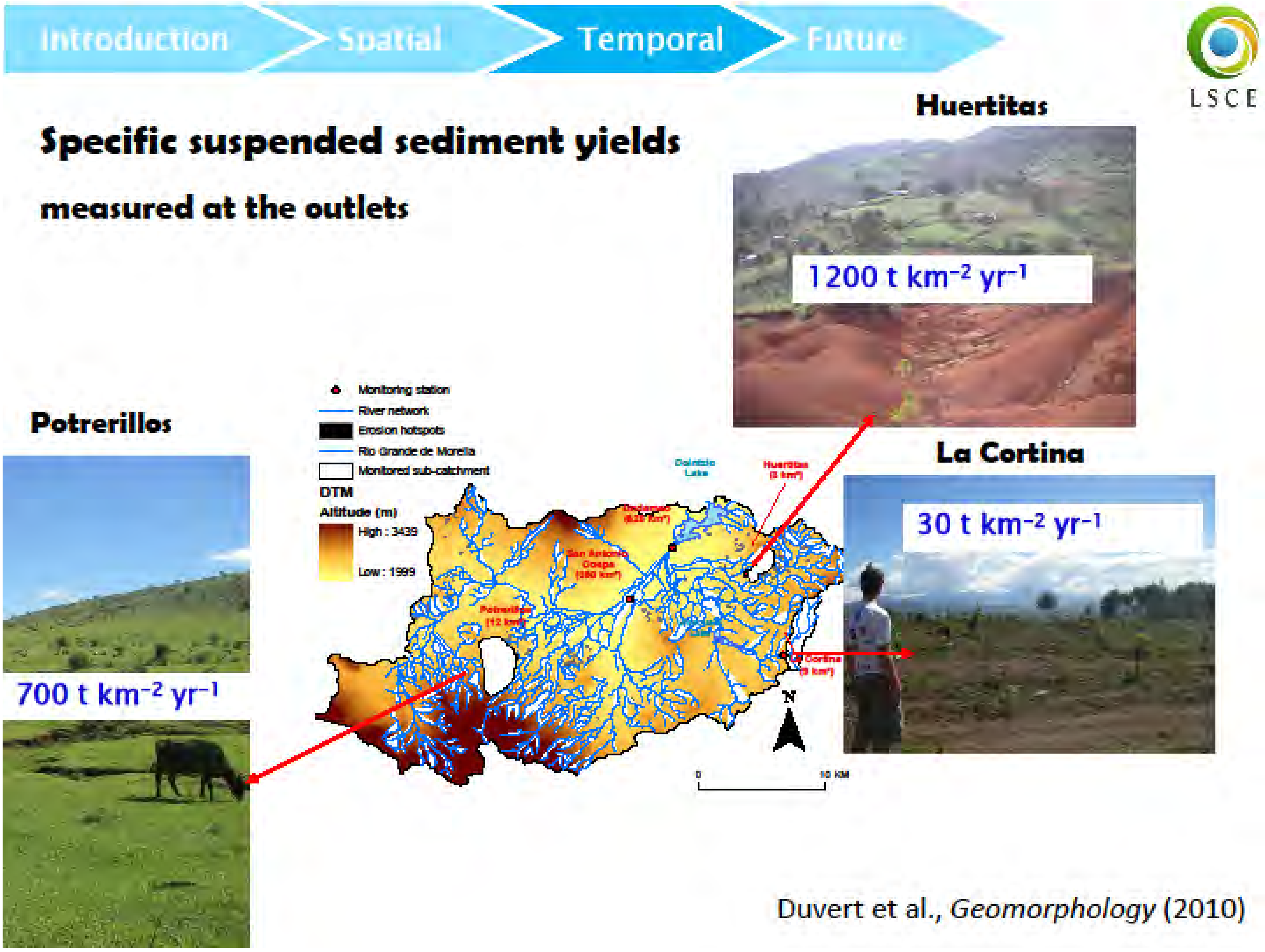
The idea is to measure the fallout of those radioisotopes in rainfall, and to measure the activities of those radioisotopes on the river sediment. Measuring the activities in both rainfall and suspended sediment can provide you, in certain conditions, an idea of the sediment transfer times.



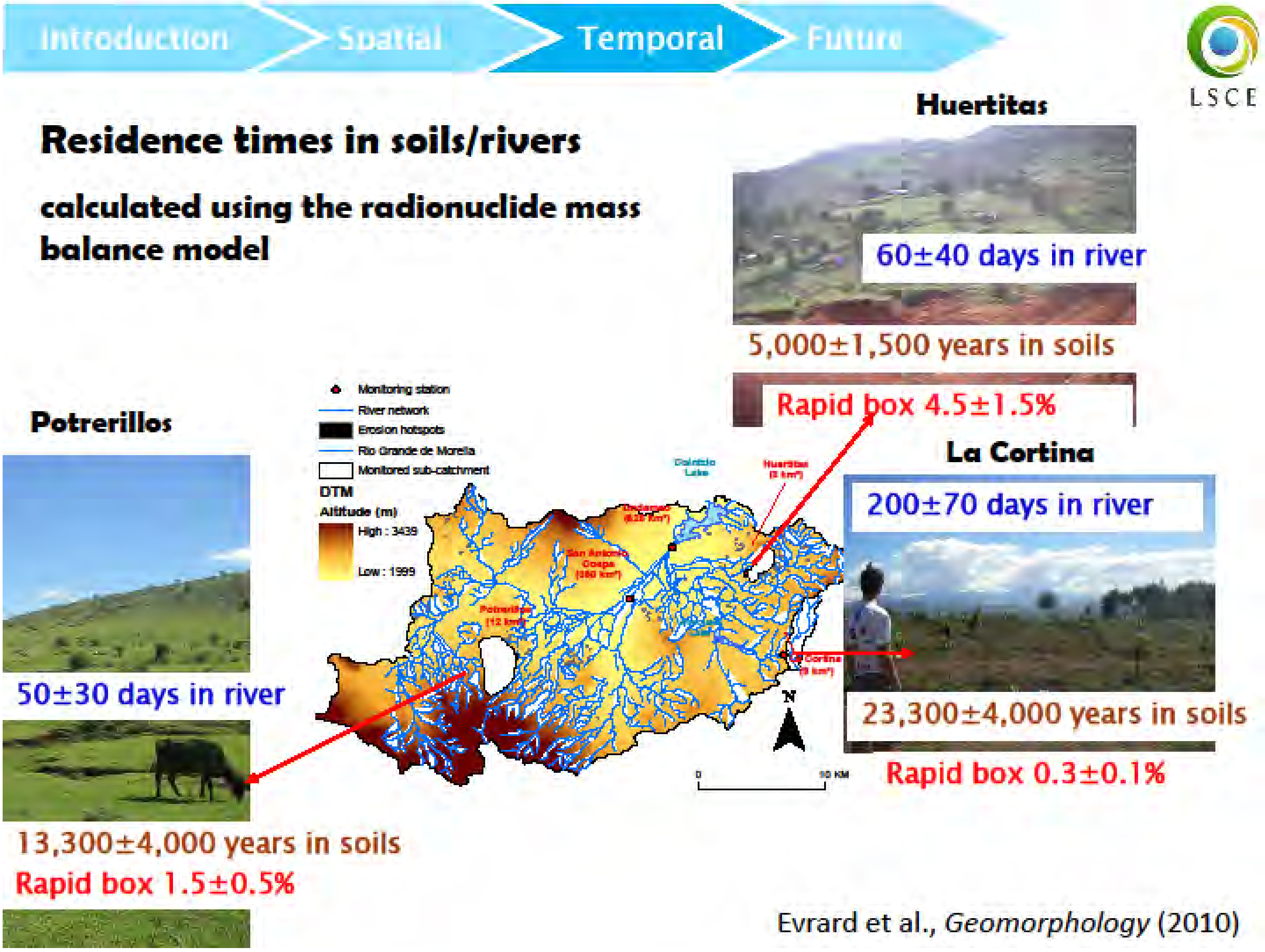
We applied this method in, the other one, the Mexican catchment. This is the entire catchment. We worked on three subcatchments, representative of the different land use and slope conditions you have in the entire catchment. You have, for example, Huertitas with Acrisol types, very steep slopes. In contrast, 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.



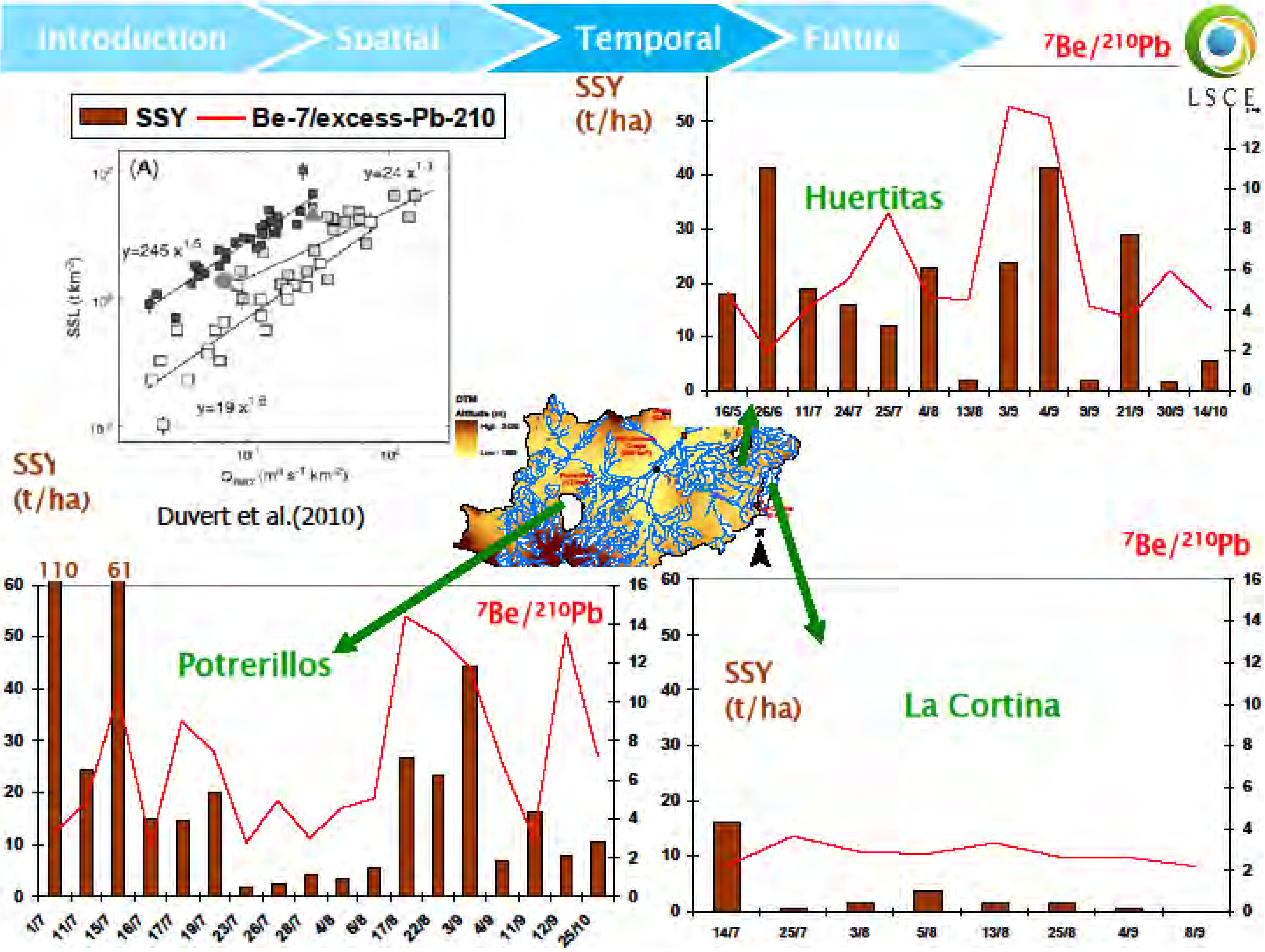
We measured all the samples in gamma spectrometry at all laboratory in France. Then, we calculated the transfer times by using this two-box mass balance model. How does it work? We measure atmospheric fallout, so the activity in beryllium and lead-210 in rainfall because there was no caesium fallout 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.



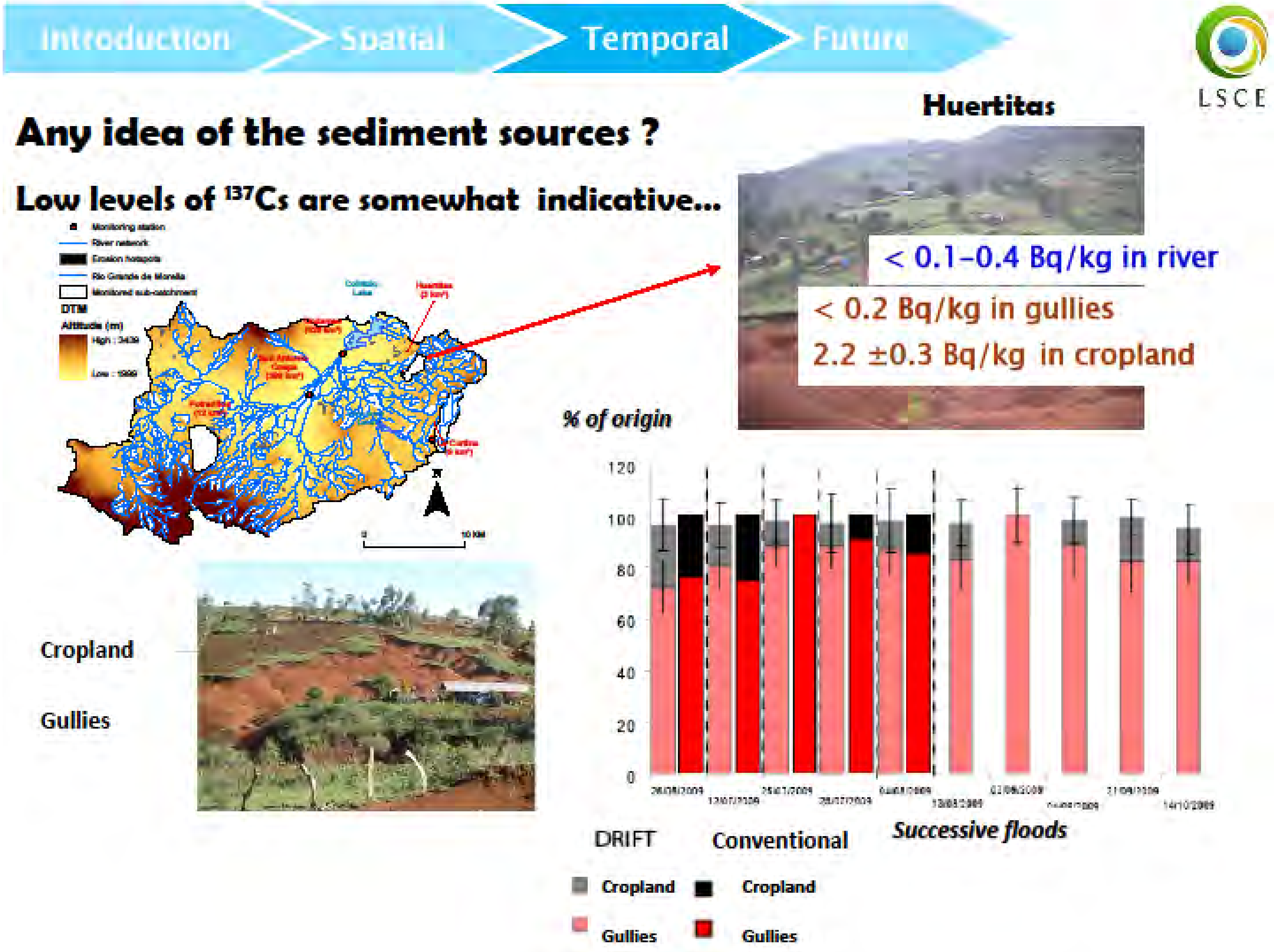
For the three subcatchments, we had in fact very different sediment outputs. In this one, it was very important, more than 1000 tons per squared kilometer and per year.



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.

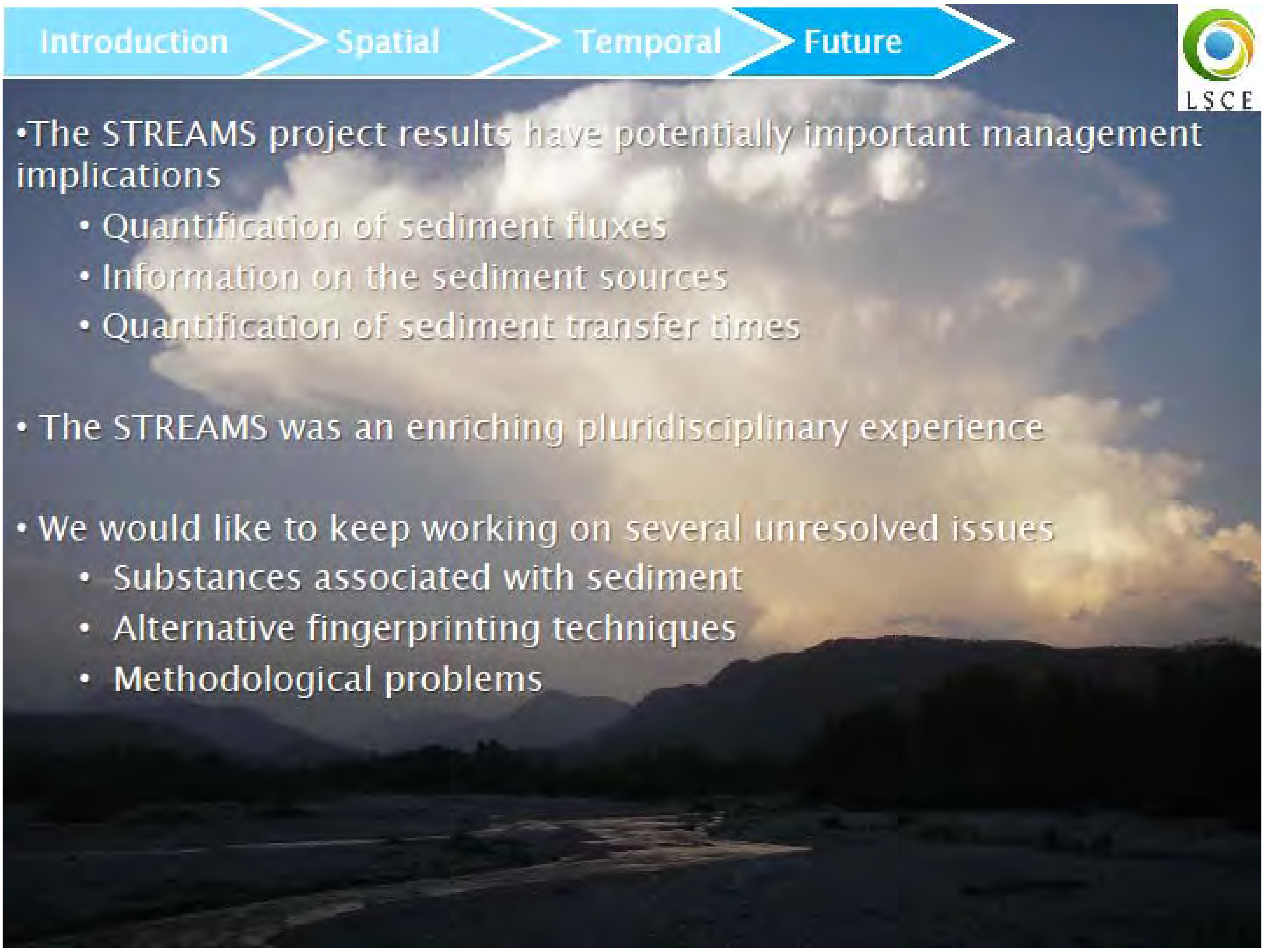


This is a mean residence time in each box, but we can also look at what it gives during the wet season for the different floods. This is the graph for each subcatchment. For the different floods, in brown, you have the bars corresponding to the sediment export from the catchment. The curve in reds indicates 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.

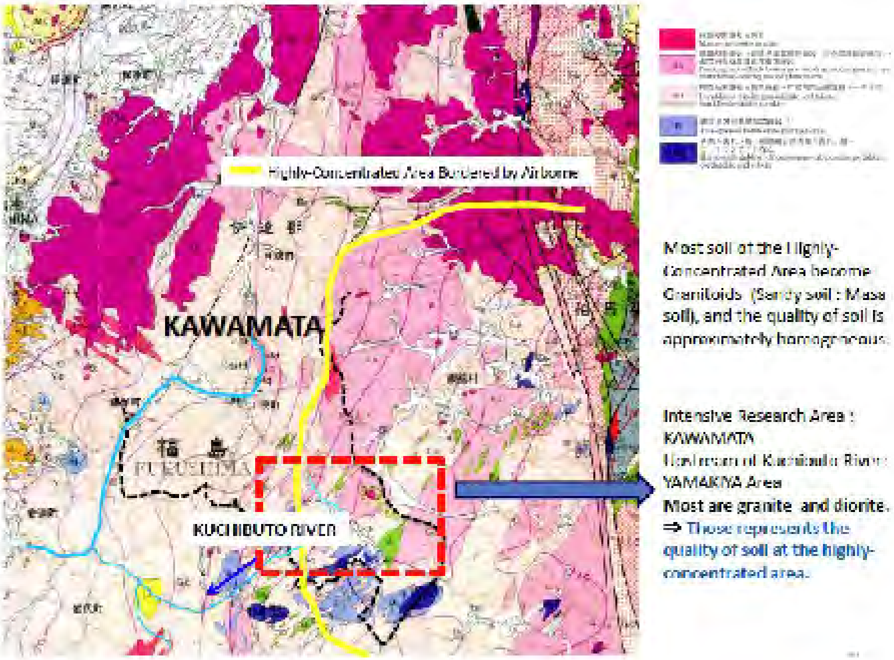


To sum up the main points; during this project, we could provide answers to important management questions by quantifying sediment residence times by giving information on sediment sources, and we still want to work on those topics. Also, by working on tracing other substances, just like carbon associated 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.

LSCE

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