headline

Natural hazards: how can research help?

The impact of natural hazards, though unavoidable, can be limited through dedicated research, such as that done in Toulouse laboratories and institutes.

>>> Daniel GUEDALIA, CNRS senior scientist at the Laboratoire d'Aérologie (joint UPS/CNRS laboratory)

In 2008, worldwide natural hazards caused around 220 000 human deaths and 140 billion euros of damage. Many hazards occur in densely populated areas and subsequently destroy basic vital infrastructures. Major natural hazards are geophysical (earthquakes, tsunamis, volcanoes) or meteorological/climatological (storms and lightning, tropical cyclones, droughts and floods).

A first step in research on natural hazards is to improve our knowledge of the processes and mechanisms that cause them. Such studies lead to numerical forecasting models to warn populations in due time or to define norms (for example, for paraseismic regulation).

Several research teams at Paul Sabatier University are taking part in this general research endeavor. Among them:

- Laboratoire d'Aérologie (LA), involved in mesoscale meteorological research. LA has made significant advances in studying the impact of extreme events, such as intense rainfall and associated damaging floods, on people and property. It also studies atmospheric electricity activities in thunderstorms and severe tropical meteorology events (such as squall lines and tropical cyclones). Most of this research has been done in close collaboration with Toulouse research teams at Meteo-France.

- A group at the laboratoire DTP (Dynamique Terrestre et Planétaire) specialized in seismic studies. This group, in charge of the Pyrenean seismic survey network, is well known for research that links earthquakes and terrestrial internal geophysics. An accelerometer network has been implemented in the Pyrénees so as to better define "hot spot" areas.

- A group in LMTG (Laboratoire d'étude des mécanismes de transferts en géologie) that has identified the origins of some landslides through clay morphology structures.

The results, of paramount importance for natural hazards prediction, are described in this issue of the magazine.

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LMTG : Laboratoire des Mécanismes et Transferts en Géologie/Laboratory for Mechanisms and Transfer in Geology
LA : Laboratoire d'Aérologie/Laboratory of Aerology
DTP : Laboratoire Dynamique Terrestre et Planétaire/ Laboratory for Terrestrial and Planetary Dynamics

Towards a better evaluation of the seismic risk in the French Pyrenees

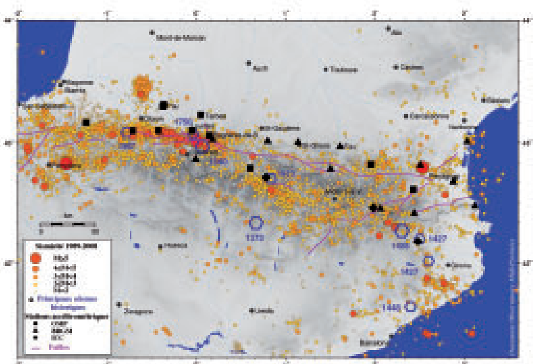
In addition to the seismic network devoted to surveying seismic activity in the Pyrenees, an accelerometric network has been set up to identify risk zones in the major cities of the region. The network will help to develop paraseismic engineering techniques to protect buildings.

>>> Annie SOURIAU, CNRS senior scientist and Marie CALVET, physicist at the Dynamique Terrestre et Planétaire laboratory (joint UPS/CNRS laboratory) of the Observatoire Midi-Pyrénées.

The Pyrenees are the most active seismic region in metropolitan France. Although the seismicity here is moderate compared to that of other countries in the Mediterranean basin, such as Greece or Italy, it is strong enough to warrant a permanent survey. About forty seismic stations are distributed on both sides of the range and they allow to detect more than 800 earthquakes each year in the Pyrenees. Seismic maps are a major tool for identifying active faults in the region and in France, the RSSP (Réseau de Surveillance Sismique des Pyrénées) is in charge of 20 stations and informs the public authorities in case of a felt event. The main event recorded during the last 40 years was near Saint-Paul-de-Fenouillet in the Eastern Pyrenees in 1996, with magnitude of 5.3.

Some destructive events in the past

Historical seismicity in the region has been well documented since the Middle Ages and reveals strong destructive events along the entire range, with estimated magnitudes up to 6.4 (an event more than 30 times stronger than the Saint-Paul, 1996 event). The main events were in Ribagorza in the South Central Pyrenees (1373), in Catalonia in the Eastern Pyrenees (1427-28), in Bigorre in the North Central Pyrenees (1660 and 1750), in the Central Pyrenees beneath the highest summit Maladeta (1923), and in Bearn in the Western Pyrenees (Arette event, 1967). Strong ground accelerations caused severe destruction with important loss to human life (for example, 700 deaths in 1428 and 30 in 1660). Being better able to determine potential accelerations and how buildings will react to these accelerations is thus of great importance for better evaluating seismic risk.



>>> Accelerometric network of the Pyrenees, superimposed on the instrumental seismicity since 1989, and to main historical events.

An accelerometric network for better evaluating seismic hazard

The French government has deployed an accelerometric network in the most seismic active regions since 1996. This network, called “RAP”, for “Réseau Accélérométrique Permanent”, includes 20 stations in the French Pyrenees, 11 of them being managed by the Observatoire Midi-Pyrénées (OMP). While the survey stations are set up in quiet zones, in order to detect very small seismic signals, the accelerometers are devoted to measuring strong motion and are generally set up in cities with maximal risk. The accelerometric records allow to accurately determine magnitudes and attenuation models for seismic waves, and to establish shake maps related to felt events. Numerical modeling also allows to simulate large historical events based on moderate events that occurred in the same places. Accelerometric data are thus an important tool for seismic prevention, they contribute to a better definition of the rules for paraseismic calculations.

From hazard to risk: how do buildings behave during earthquakes?

Inside a city, different places may experience very different accelerations (that vary by up to a factor of 10) during an earthquake, depending on the nature of the ground. This is called the site effect. Sediments and topography may also enhance the seismic signal at particular frequencies. These effects have been analyzed by the OMP team inside the city of Lourdes, and are at the origin of a Prevention Seismic Plan set up by the city council. Another study of topographic effects has been performed in the Bagnères-de-Bigorre valley, close to the 1660 event epicenter. The response of buildings is another important piece in evaluating the risk. A high building in Lourdes has been equipped with accelerometers at different levels, from underground to top, for modeling its resonance frequencies. This project from the Seismological laboratory in Grenoble is supported by the Direction Départementale de l'Equipement and it brings together the OMP in Toulouse and an engineering school (ENIT) in Tarbes. Since 2005, the French government has promoted an “Earthquake Plan” in which the Central Pyrenees are a pilot site, offering the possibility of a fruitful cooperation between scientists and government for better preventing seismic risk and better informing the public.

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Book: Souriau, A. and Sylvander, M., 2004.
Les séismes dans les Pyrénées, Ed. Loubatières, Toulouse, 192 pp.

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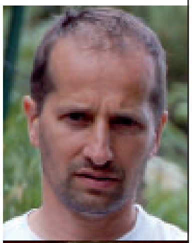
Why is there less lightning at the weekend?

What conditions lead to lightning? Why are cities more at risk of being struck? Where are the risks stronger? Answering these questions requires a thorough analysis of the electrical processes that exist in thunderclouds.

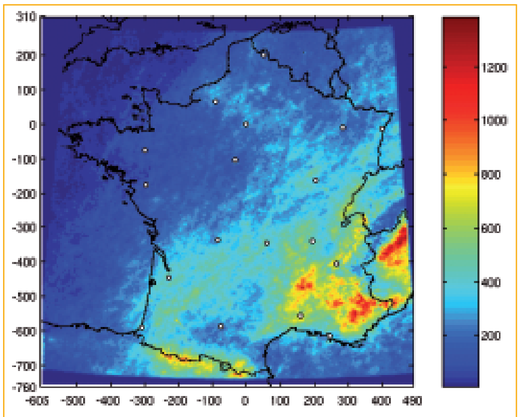


>>> Serge SOULA, Physicist and Sylvain COQUILLAT, Professor at UPS, are researcher at the Laboratoire d'Aérologie (joint CNRS/UPS laboratory)

Lightning is an electric discharge phenomenon that occurs in certain clouds, known as cumulonimbus. It includes several types of flashes: cloud-to-ground flashes that strike the Earth's surface, within-cloud, cloud-to-air, and cloud-to-cloud flashes depending on whether the flashes stay in the cloud, if they go out of the cloud, and if they go out and return into the cloud, respectively. For about 20 years, electrical discharges have been observed well above thunderstorms, up to 90 km altitude. These are known as Transient Luminous Events (TLEs) and are classified into several types according to their shape. They include sprites, elves and jets. Research performed in the Atmospheric Electricity group at the Laboratoire d'Aérologie (LA) focuses on discharge triggering within thundercells and on the observation and analysis of how TLE conditions arise. The main risk associated with the storms, apart from the mechanical effects of strong winds and intense rainfall and hail, is related to the rate of lightning flashes - the peak current of which may exceed hundreds of kilo-amps and erratically strike surface structures, human beings or aircraft. Satellite observations allow to determine the flash rate on Earth at about 45 s^{-1}. In France, about 10 people die as a result of lightning strikes each year. To avoid being struck, it is recommended not to go out in stormy conditions and to stay away from high structures, such as trees and electric pylons. It is also better to stay away from open spaces, such as fields, to prevent becoming a lightning conductor oneself.

The South is more often struck

Lightning production depends on the presence of a large population of iced hydrometeors (such as ice crystals and graupel) that lead to the electrification of thunderclouds. It also depends on the intensity of convection and on the lifetime of cloud cells, which in turn depends on thermodynamical and dynamical conditions (such as temperature and water vapor near the ground, atmospheric vertical instability of the troposphere, wind shear at higher levels, or wind convergence near the ground). Archived data at the Météorage network (localization and characteristics of cloud-to-ground lightning) fromJune to October 1992 to 2007 show that the South of France is struck more often by lightning than the North because of more favorable thermodynamical conditions, and that higher altitude areas are among the most struck. Dynamical influences are also seen on the Vivarais mountains through increased lightning activity that occurs under the influence of maritime southern fluxes, or at large scales through general south-west to north-east directed influences, like dominating winds.



>>> Number of lightning strikes per 5 km x 5 km pixel from June to September (1992 to 2007).

Lightning density

Beyond the most conventional factors cited above, lightning production can also be influenced by anthropogenic emissions. Observations centered around Paris and the surrounding region show a higher lightning density above and around the city. By comparing weekday and weekend data over a long period, which allows to eliminate relief and urban heat island effects, our group has identified relatively weaker lightning activity during weekends above and around the city center. This is possibly due to weaker emissions of anthropogenic aerosols at the weekend.

Sprites

Sprites are produced above mesoscale convective storms (MCS) following a positive cloud-to-ground flash that neutralizes a large amount of charge from the cloud. Elves (luminous rings a few hundreds of km in diameter) are produced instantaneously after a positive or negative powerful flash (strong peak current). Observing such phenomena and characterizing these storms makes up a large part of the research activity of the European project CAL team.

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Swollen clay, moving soil and landslides

Swollen clays are responsible for numerous natural catastrophes, such as landslides, mud flows, and the development of cracks in buildings. Mapping swollen clays is therefore essential for assessing hazard and risk especially in populated areas where there is seismic activity.

>>> From left to right ; Jean-Claude SOULA, professor at UPS, Frédéric CHRISTOPHOUL and José DARROZES, assistant professors at UPS and Camille TRUCHE, post-doctorate, all members of the LMTG research team (joint UPS/CNRS/IRD laboratory).

Clay expands when it rains and shrinks and cracks during droughts. Swollen clays can lead to large landslides and mudflows even on low-angle slopes, and may provoke soil deformation when droughts are followed by rainy periods. Between 1989 and 2000, such "shrink-and-swell" phenomena caused more than 3 billion euros of damage in built-up areas in France. Although geological surveys of sites and clay analyses have been performed to include swollen clays in French hazard maps, this type of study is expensive and time-consuming on the local scale and is therefore rarely used for individual constructions. Moreover, the role of swollen clays in landslides is still poorly understood.

One of the goals of the Laboratoire des Mécanismes de Transfert en Géologie (LMTG) is to test new analytical techniques that are cheaper and more rapid to carry out than local studies based on analysing the infrared spectrum to assess the risk of shrink-and-swell events over various scales in the soils of our region. For this purpose, laboratory studies are performed along with spectrometric measurements (visible to infrared) using a ground radiometer, and regional mapping using multispectral imagery (SPOT HRS, ASTER). These studies are funded by the Région Midi Pyrénées. Our research is also focused on landslides and what triggers them. Although we understand how physical or geometrical parameters, such as water pressure, slope, and depth of the basal failure surface, affect landslides, we know less about how swollen clay destroys soils and how seismic activity influences slope stability. In the case of seismic shaking, we have developed a generalization of Newmark's popular 1965 model by taking into account the effect of the vertical component of ground shaking when calculating slope displacement. The analysis shows that this effect may be important, particularly for low-angle slopes with potential deep shear surfaces that are located close to the sources of large earthquakes. Here, the threshold shaking intensity required appears to cause catastrophic failure at much lower levels than calculated by the Newmark method. This method has been tested for the very large-scale (7 km^3) landslide in Tarapaca (Atacama Desert, Chile).

>>> a road blocked by a landslide

Finally, as part of the Research Programs on the South-West of Europe (SUDOE) project, we will now look at how to manage soil motion risk using physical and/or probabilistic approaches combined with socio-economic analyses. This project is being carried out in collaboration with several research teams from France (LMTG-UPS; GAME-Météo France; Laboratoire Régional des Ponts et Chaussées and BRGM), Spain (Universities of Oviedo, Cantabrie, and Zaragoza; Instituto Geologico y Minero de Espagna) and Portugal (Universities of Porto and Lisboa).

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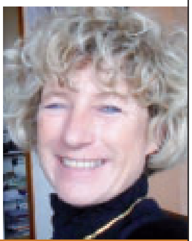
Better forecasting of flash floods



>>> Evelyne RICHARD, CNRS senior scientist at the Laboratoire d'Aérologie (Joint UPS/CNRS lab).

The south east of France regularly suffers from intense precipitation that results in major flooding in a few hours. In cooperation with Météo-France, the Laboratoire d'Aérologie is helping to improve forecasting of such events.

Hydro-meteorological events figure high on the list of natural disasters. Indeed, storms and floods alone make up about 60% of these catastrophes. For several years now, the Laboratoire d'Aérologie has been working closely with Météo-France research teams in an attempt to better understand these high-risk meteorological situations and so to better predict them.

Extremely heavy precipitation and the mechanisms generating flash floods are currently subjects of intense study. This flooding occurs very rapidly and water courses reach their danger levels within just a few hours of the rainfall peak. Because they happen so suddenly, it is impossible to set up effective protection against these floods unless they can be predicted well before the rainfall starts. Anticipating flash floods thus necessarily involves developing combined hydro-meteorological forecasting systems. At present, the greatest uncertainty in these systems originates from the rainfall forecast.

600 to 700 mm in a few days

The lands around the western Mediterranean basin, particularly mountainous areas, are regularly affected by flash floods in the autumn. Extreme episodes such as the catastrophic flooding in Algiers (in November 2001) that caused hundreds of casualties, or the recurring, devastating floods of the Ouvèze, Gardons and Vidourle rivers in south-east France are sadly notorious. Although the intensity of the rainfall is not the best indicator of the extent of damage, these episodes all have intense, very localized rainfall where the overall precipitation exceeds 200 mm, sometimes reaching exceptional levels of 600 to 700 mm in just a few days.

High-resolution forecasting

Forecasting such precipitation is based on complex, increasingly high-performance, numerical models on which the teams in Toulouse have worked long and hard. These models use state-of-the-art knowledge in physics of the atmosphere and have recently started operating at a spatial resolution close to a kilometre.

>>> South east France, a high-risk area frequently affected by devastating flash floods.

This resolution allows both the fine structure of the relief and the detailed features of the storms to be described. But, in spite of this recent progress, many difficulties remain. The chaotic nature of the atmosphere imposes an intrinsic limit on the predictability of events and our imperfect knowledge of the state of the atmosphere leads to errors in the initial conditions. Since it is impossible to completely eliminate these sources of error, it is essential to quantify the uncertainties associated with them. So, rather than providing a deterministic forecast that is uncertain by its very nature, the objective is to build up a system of forecasts that explores all the possible solutions and which can be analyzed in terms of probabilities.

This concept of ensemble forecasting has been widely used in global models that provide medium-term weather forecasts. But, transposing it to high-resolution, short-term forecasts is quite a challenge. This type of system will be developed under the HYMEX (HYdrological cycle in Mediterranean EXperiment, http://www.cnrm.meteo.fr/hymex/) project, which is devoted to studying the Mediterranean hydrological cycle. It is a French initiative mobilizing a vast national and international community, and our team in particular.

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