Important
Ce document, hors annexes, ne doit pas dépasser 40 pages, corps de texte en police de taille 11. Ce point constitue un critère de recevabilité de la proposition de projet. Les propositions de projets ne satisfaisant pas aux critères de recevabilité ne seront pas évaluées.

Nom et prénom du coordinateur / coordinator's name	**VIGNY CHRISTOPHE**		
Acronyme / Acronym	**MEGA-Chile**		
Titre de la proposition de projet	Mega-séismes au Chili: Exemple de Maule en 2010 (Mw 8.8) et implications sismo-tectoniques		
Proposal title	Megathrust earthquakes in Chile: 2010 Maule Earthquake (Mw 8.8) and sismo-tectonic implications		
Comité d'évaluation / Evaluation committee	SIMI 5-6		
Projet multidisciplinaire / multidisciplinary proposal	☐ OUI ☒ NON Si oui, indiquer un comité secondaire :		
Type de recherche / Type of research	☒ Recherche Fondamentale / Basic Research ☐ Recherche Industrielle / Industrial Research ☐ Développement Expérimental / Experimental Development		
Coopération internationale / International cooperation	☒ OUI ☐ NON		
Aide totale demandée / Grant requested	449 019 €	**Durée de la proposition de projet / Proposal duration**	36 mois

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1. RESUME DE LA PROPOSITION DE PROJET / PROPOSAL ABSTRACT

We propose to study the Mw 8.8 Maule mega earthquake of February 2010 in every possible detail and to put it into the perspective of the geodynamics of the Andean margin. The Chilean subduction is one of the most active in the world, with 4 mega earthquakes in the last 120 years (1906, 1922, 1960 & 2010). The occurrence of these earthquakes poses a number of problems that will be addressed by a group of researchers that has been working in Chile for more than 20 years, doing research that helped to set the frame for a successful study the 2010 event. The study of this event will be used as a starting point to improve our approach of active subduction: as we conduct our study of the Maule earthquake in south-central Chile, we will be increasingly focusing our attention to the regions to the North of Santiago that are now approaching the end of their respective seismic "cycles". Foremost of them are the Northern Chile gap and the Coquimbo region that seems to be in earlier stage in the preparation of an earthquake. These observations will be translated into models of the deformation of the active margin in order to understand a long standing problem in subduction zones, why in spite of frequent earthquakes the margin does not seem to accumulate finite deformation.

For the specific study of the Maule earthquake we have acquired a substantial co-seismic data set that includes campaign GPS, high dynamic range accelerograms and classical strong motion instruments. In addition to these we dispose of a set of 1 Hz continuously recording GPS antennas. This unique data set will be used to study the rupture process of the earthquake and we hope to explain why such a large event produced moderate strong motion. Is this a unique feature of this event, or is it typical of most large subduction zone mega-earthquakes? In order to answer this question we need to study the slip distribution of the main event and understand why the aftershocks stretched over an area that seems to be substantially longer than the rupture of the main event. The aftershock series did not contain any events larger than Mw 7.1, a puzzling feature indeed. We dispose of several months of aftershock recordings obtained by the CNRS-INSU researchers and our foreign and Chilean colleagues. Are these aftershock uniformly distributed or highly concentrated in a few "asperities" as preliminary results seem to suggest?

Maule 2010 is the first mega earthquake that occurs in a closely surveyed area. Studies published in the last 10 years pointed out that the interplate zone was completely locked not just inside in the so-called "Darwin gap" but well outside it, suggesting that historical earthquakes can serve to identify gaps, but not to determine their actual size. Of equal interest is the problem of after slip that will be studied with the instruments deployed before the event and by a much richer set of cGPS instruments deployed after it. We anticipate new observations that may help resolve the big questions of after slip: where does it occur and what are the properties of faults and bulk

rheology that produce long episodes of silent deformation around earthquakes. This problem is closely related to that of segmentation; there is indeed substantial evidence that the Chilean margin has long standing segments associated both with features of the oceanic plate (sea mounts, transform faults and others) and of the over riding plate (faults, uplifted terraces, etc). Do they actually play a role in stopping earthquakes or at least in fragmenting them? The Mejillones, Arauco and Talinay peninsulas are long standing features where earthquakes seem to stop or perhaps slow down as they reach them. We plan to explore their role using tectonic, geological and geodetic methods. The Maule earthquake is a rare event; the lessons to be learned from the study of this rare earthquake will most certainly have a lasting influence in the way geoscientists and earthquake engineers approach the problem of the occurrence of these events.

2. CONTEXTE, POSITIONNEMENT ET OBJECTIFS DE LA PROPOSITION / CONTEXT, POSITIONNING AND OBJECTIVES OF THE PROPOSAL

2.1. CONTEXTE DE LA PROPOSITION DE PROJET / CONTEXT OF THE PROPOSAL

Since the end of the 1980s we have been working actively on the Chilean subduction zone. Over the last decade we have been developing a monitoring infrastructure based on arrays of many continuous GPS stations (60), seismological stations (broad band, accelerometers), tilt meters, and repeated measurements on numerous geodetic benchmarks (> 300). Thanks to all these studies, we had identified two seismic gaps with an extremely high seismic hazard and a third region of interest where "strange" things occurred in terms of upper plate deformation and seismicity. One of the identified seismic gaps – the Maule area – ruptured in 2010 with the 5th largest subduction earthquake in the instrumental era, just one year after we announced its potential for an imminent magnitude 8+ earthquake (fig 1). The second one – The North Chile area – has experienced large earthquakes (Mw 8.1 Antofagasta 1995, Mw 7.7 Tocopilla 2007, Tarapaca intraslab event 2005) and all calculations show that it is very mature.

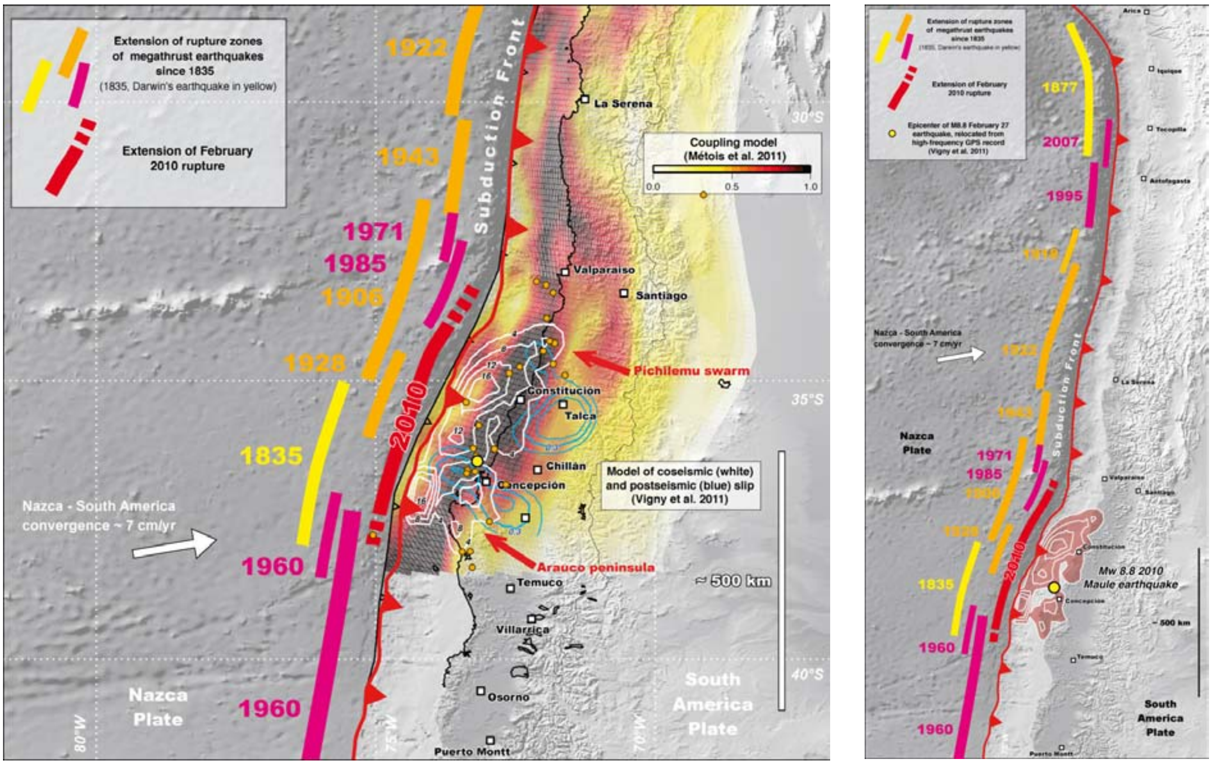


Figure 1. :Left box: The Maule earthquake of 27 february 2010. Coupling inverted from pre-seismic GPS data (Métois et al. 2011), slip distribution inverted from co-seismic geodetic (GPS+INSAR) data (Socquet et al. 2011). Historical earthquake segmentation compiled by R.Lacassin. Right box: the localization of the earthquake on the larger Chilean subduction trench.

One of the very important findings made immediately after the 27 February 2010 Maule event is that although its magnitude was 8.8 (which makes it the 5th larger earthquake of the instrumental era), the destructions caused by the earthquake itself were moderate. This might be related to the relatively low level of accelerations produced (significantly less than 1g everywhere). In addition, hardly any large aftershocks were recorded in the weeks and months following the main shock. Those a-priori surprising facts are related to the complex source (bi-lateral, slow initiation, etc…) of this event. Understanding the source of the Maule event will enhance our capacity of forecasting what might occur not only in other areas of Chile (i.e. the North Chile gap) but also on other subduction zones where major earthquakes are expected.

A second important finding about the Maule earthquake is that it occurred precisely in the area where the coupling determined by our earlier GPS measurements was maximum. In particular, at the northern termination of the rupture, co-seismic slip stops or decreases sharply where the rupture reaches a narrow area of low coupling (the San Antonio bay). Nevertheless, The determination of the northern termination of the

rupture being itself a difficult task: geodesy indicates no significant slip occurred north of 34°S, while aftershocks extend up to at least 33°S.
Going back to the correlation between coupling and co-seismic slip: does this observation mean that we should not expect a major earthquake north of the Maule event, since the coupling is lower (and seismicity is higher) in this area than it was in the Maule area prior to the earthquake? Does this mean we should expect a large earthquake north of 28°S, where sparse existing GPS measurements tend to indicate a higher coupling? Or on the contrary, was the 1835 gap the last highly coupled segment, inside this 1000 km long segment between 38°s and 28°S, ready now for one major mega-thrust event of magnitude significantly larger than 9 – a repeat of the 1730 megathrust event ?

Immediately after the Maule event of 27 February 2010, we installed both a seismological network and an array of cGPS stations in the epicentre area. Data have been – and will continue – to be collected with the support of CNRS-INSU.
This project takes place in the specific National and International context :

- The whole Franco-Chilean cooperation is operated under a specific umbrella, the International Associate Laboratory (LIA) "Montessus de Ballore", MOU signed between French CNRS and Chilean University of Chile at Santiago.
- A post-seismic intervention funded by CNRS / French Ministry of foreign affairs was conducted in central Chile after the Maule earthquake of February 2010. Seismological and cGPS networks were installed. They are maintained by specific grants from INSU, IPGP and ENS.
- Other teams conducted post-seismic interventions and installed networks of instruments: CAP (Bevis et al.) installed ~20 cGPS, University of Liverpool (Rietbrock et al.) installed seismographs and cGPS; IRIS (Beck et al.) installed ~60 seismographs. We cooperate and share data with them.

We request here specific funding to analyse those data. This unique event casts a new light on what was and is presently occurring on other segments of the subduction. The aim of this project - studying this event and what is taking place nearby - will give unprecedented information on how megathrust fault segments rupture and interact with each other.

2.2. ÉTAT DE L'ART ET POSITION DE LA PROPOSITION DE PROJET / STATE OF THE ART AND POSITIONNING OF THE PROPOSAL

Despite little paleo-seismological information, the seismicity in Chile is relatively well-known, based on historical data gathered by historians and seismologists (Montessus de Ballore, 1911-1916, Lomnitz, 1972, Comte and Pardo, 1991). From these works, the

Chilean subduction appears as fragmented in a number of segments (~ 100-200 km long and 50-100 km wide) which can host repeated great earthquakes and occasionally produce megathrust earthquakes when the rupture manages to propagate between different segments. The segments along the subduction zone in Chile are at different stages of their seismic cycle along the coast and have their own geometrical and mechanical characteristics. In the early 1970s and 1980s, several authors (Kelleher et al., 1973; McCann et al., 1979) divided the subduction zone into regions where great earthquakes of very long lengths occur and regions where only moderate large earthquakes occur. Seismic gaps were defined as regions that had not experienced a large earthquake for the last 30 years. In hindsight this period of time is too short to characterize the seismic activity produced by the Chilean subduction (Cisternas, 2005). The seismic gap concept was originally proposed as a long-term forecast of major earthquakes (see, e.g. McNally 1983; Nishinko, 1985). A long-standing discussion ensued as to whether those gaps are semi-permanent features of the subduction limited by barriers well attested in the surface geology, or simply reflect the largest events in recent history (Comte et al., 1986; Madariaga, 1998): An important issue with regard to seismic hazard assessment in Chile.

Three segments in Chile, e.g. Central Chile (Constitución and Concepción 35°S-37°S and Coquimpo-Illapel 30°S-32°S) and Northern Chile (Antogasta and Arica 18°S-27°S), were identified and instrumented in collaboration between the Chilean and the French teams, e.g. with the support of French ANR-CATT projects, Chilean CONYCIT projects, and the CNRS/U-Chile association through the international associated laboratory (LIA) "Montessus de ballore". In previous proposals, two of these segments were identified as major and mature gaps: Constitución-Concepción and Antogasta-Arica.

- The first one ruptured on 27 February 2010 with a Mw 8.8 earthquake, 175 years after the 1835 earthquake described by Darwin and Fitzroy in the area, and several decades after it had been surrounded by subduction and intraplate earthquakes (1960, 1985, 1937). It is now experiencing after-slip and post-seismic relaxation.
- The second one did not experience any large earthquake since 1877, but has been surrounded again by subduction and intraplate events over the last decade (1995, 2001, 2007, 2005). It is still going under inter-seismic accumulation, but for how long ?

A third segment (Illapel) was identified in a slightly different situation: the last subduction earthquake there was in 1943 ("only" 65 years ago), but it had been the locus of an increasing seismicity (with a dozen of significant earthquakes of magnitude between 6 and 7), over the last decade, again after an intraplate earthquake (Punitaqui, 1997, Mw 7.3).

The fact that the three segments are at different stages of their evolution (post-seismic for Maule, pre-seismic for Iquique, and probably in-between for Illapel) should allow us to calibrate the visco-elastic models of the subduction taking into account the full earthquake cycle with all its components and spatio-temporal interactions.

In this proposal, we propose to focus our studies in these regions where a huge amount of high quality observations have been and are continuously recorded allowing us to improve our physical understanding of the spatio-temporal seismic activity and deformation of subduction segments, in relation with their geometry and structure, as well as their stability.

We build upon the post-seismic intervention that was conducted in March 2010 (sponsored by French foreign affairs ministry and CNRS-INSU) and during which we accumulated a very significant amount of data. Very rapidly after the earthquake (we were in Chile as soon as March 3rd, with 1 1/2 ton of equipment) we installed a network of seismographs, accelerometers and cGPS stations to monitor the aftershock activity and post-seismic deformations. In the following weeks, different international groups (GFZ-Potsdam, Caltech, Ohio state University, IRIS, University of Liverpool, …) also deployed networks of instruments (cGPS and seismographs). This rare event - a Mw 8.8 earthquake- will be the best monitored ever.

2.3. OBJECTIFS ET CARACTERE AMBITIEUX ET/OU NOVATEUR DE LA PROPOSITION DE PROJET / OBJECTIVES, ORIGINALITY AND/OR NOVELTY OF THE PROPOSAL

The Mw8.8 Maule earthquake of 27 February 2010 raises new and challenging questions related to the understanding of the nucleation and the propagation of a megathrust earthquake rupture, the frequency contents associated to such large subduction earthquake, the segments of the subduction zone in Chile and the way large seismic gap eventually rupture. This project aims at providing new answers and perspectives to these questions, all in the light of the Maule Earthquake.

The first Challenge is to understand the Maule earthquake (a rare Mw 8.8 event) itself:

Why did it generate only moderate accelerations ?
Why aftershocks apparently extend significantly longer than the rupture? Is that true?
Why no large aftershock occurred until now? Will there be any?
Is it the repeat of the 1835 Earthquake described by Darwin and Fitzroy?
Did the rupture brake the entire width of the subduction plane from trench to transition zone?

A second related challenging scientific objective of this project is to improve our understanding of the complex patterns of earthquakes on the Chilean trench. The asperity model proposed by Kanamori and McNally (1982) and Ruff (1992) is probably the simplest self-consistent paradigm to start with. Small or moderate earthquakes represent failure of individual asperity while great earthquake represent the collective failure of several asperities depending on the asperity interactions and the seismic history. The Valparaiso (1985) or Tocopilla (2007) earthquakes suggest that the asperity sizes may be smaller than the inter-plate width implying along-dip and along-strike asperity interactions. The Maule earthquake of 2010 is an example of a great earthquake which ruptured the entire width of the subduction plane and a possible association of several asperities with a complex source initiation and bi-lateral propagation. Additionally, geodetic evidences of after-slip and postseismic deformations in Chile, as well as non-volcanic tremors (Roggers and Dragert, 2003; Obara et al., 2004; Shelly et al., 2006), observed in Japan, Cascadia and Mexico, often in conjunction with slow slip events, strongly suggest the importance of seismic/aseismic interactions between asperities in a segment.

Scientific issues are to identify the seismogenic asperities, and their distribution; to understand the asperity origin in relation with the deep structures and variations of the plates coupling; to understand the seismic and aseismic asperity interactions over various time and space scales; to understand the implications for earthquake dynamics and radiation and for earthquake and deformation activity patterns. All these studies require dense high-quality observations data sets integrating cGPS, broadband, seismographs, strong motion, as well as spatial radar interferometry (InSAR). Such observations will be available for our project, thanks to the rapid deployment of hundreds of instruments (to which we already significantly contributed) in the rupture area of the Maule earthquake and around. For geodesy, if GPS methods are well known, well mastered and state-of-the art, to extract the best inter-seismic information from available SAR images, new methodologies will have to be developed. We will face difficult issues like correction of topographic or tropospheric effects and the flattening of large images in the context of large-scale deformation. We are confident that recent developments to which we contributed significantly, will allow us to overcome these difficult technical and methodological issues.

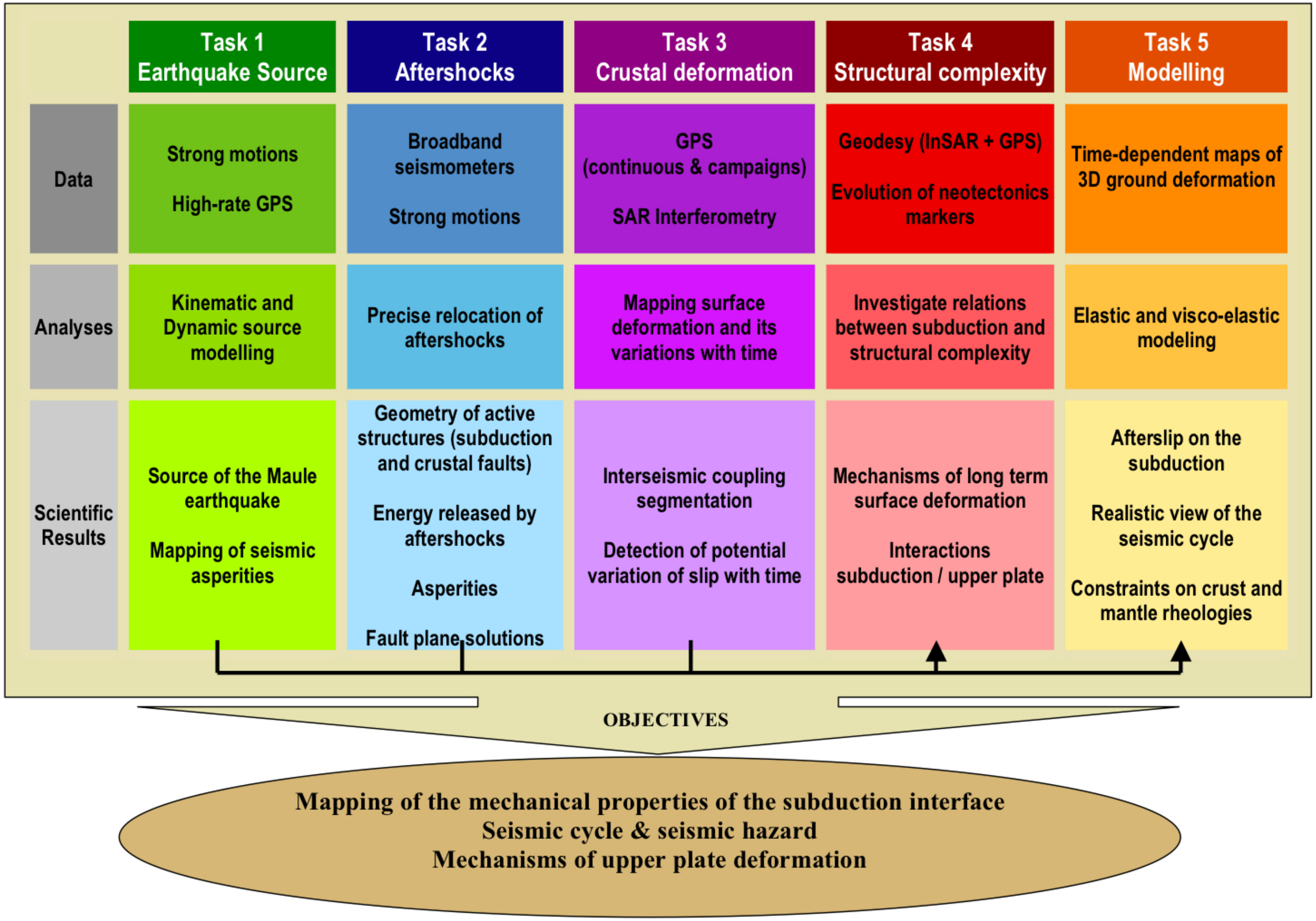
A third challenging objective of this project is to improve our understanding of the segmentation of the subduction zone in Chile. Understanding barriers between segments and their relative stability in space and time is a challenging issue for mega-thrust earthquake seismic hazard assessment. Ruptures of both the 1995 Antofagasta earthquake (Mw 8.1) and the 2007 Tocopilla earthquake (Mw 7.8) have probably been arrested by structural complexity under the Mejillones peninsula. The same is possible for the rupture of the larger 1877 Iquique (M~8.5) earthquake. The Arauco peninsula south of Concepción acted as a barrier for the 1835 (M~8.5), 1960 (Mw ~9.5) and 2010 (Mw 8.8) earthquakes. Like Mejillones, Arauco is marked with evidences of both quaternary and contemporary uplift. This is also the case for smaller structures like the Tallinay peninsula which acted as a barrier for the 1943 (Mw 7.9) and 1922 (Mw 8.4) earthquakes near Coquimbo. However, paleo-seismological information along the coast of Chile is still relatively scant, and most of our knowledge of the seismic activity is based on historical data gathered by Chilean historians and seismologists. With probably the exception of Central Chile, this information is biased by the scarcity of early settlements, the difficulty to interpret old documents and, most important and by the relative shortness of this record versus a seismic cycle of possibly many centuries. In order to tackle this problem one must integrate geology and geomorphology observations, geodetic informations and seismic profiles together with paleo-seismologic informations. All these informations are now available, and in particular in central Chile.

An important scientific outcome of this project will be a better understanding of the seismic hazard along the Chilean subduction zone and its consequences.

3. PROGRAMME SCIENTIFIQUE ET TECHNIQUE, ORGANISATION DE LA PROPOSITION DE PROJET / SCIENTIFIC AND TECHNICAL PROGRAMME, PROPOSAL ORGANISATION

3.1. PROGRAMME SCIENTIFIQUE, STRUCTURATION DE LA PROPOSITION DE PROJET/ SCIENTIFIC PROGRAMME, PROPOSAL STRUCTURE

The project is subdivided into 5 Tasks which will make progress at their own pace. However we plan to share and discuss the results obtained in each task, in order to reach an integrated view of the subduction mechanical behaviour, seismic cycle, seismic hazard as well as the mechanisms of upper plate deformation.
Task 1 is dedicated to the modelling of the earthquake source, on a kinematic and dynamic point of view. Task 2 aims at building a data base of precisely located aftershocks. Task 3 aims at quantifying upper plate deformation north of the Maule area, before major earthquakes occur there, using InSAR and GPS. Task 4 will investigate the mechanical relations between subducting and overlying plates, and tackle the problem of segmentation and topography generation. Finally, Task5 will develop both elastic and visco-elastic modelling approaches to investigate the different phases of the seismic cycle, as well as the whole seismic cycle.


Task 1
Earthquake Source
Task 2
Aftershocks
Task 3
Crustal deformation
Task 4
Structural complexity
Task 5
Modelling
Data
Strong motions
High-rate GPS
Broadband seismometers
Strong motions
GPS (continuous & campaigns)
SAR Interferometry
Geodesy (InSAR + GPS)
Evolution of neotectonics markers
Time-dependent maps of 3D ground deformation
Analyses
Kinematic and Dynamic source modelling
Precise relocation of aftershocks
Mapping surface deformation and its variations with time
Investigate relations between subduction and structural complexity
Elastic and visco-elastic modeling
Scientific Results
Source of the Maule earthquake
Mapping of seismic asperities
Geometry of active structures (subduction and crustal faults)
Energy released by aftershocks
Asperities
Fault plane solutions
Interseismic coupling segmentation
Detection of potential variation of slip with time
Mechanisms of long term surface deformation
Interactions subduction / upper plate
Afterslip on the subduction
Realistic view of the seismic cycle
Constraints on crust and mantle rheologies
OBJECTIVES
Mapping of the mechanical properties of the subduction interface
Seismic cycle & seismic hazard
Mechanisms of upper plate deformation

3.2. DESCRIPTION DES TRAVAUX PAR TACHE / DESCRIPTION BY TASK

3.2.1 TÂCHE 1 / TASK 1 LOW AND HIGH FREQUENCY CHARACTERISTICS OF THE MAULE EARTHQUAKE AND SOME OF ITS MAJOR AFTERSHOCKS

Coordinator: R. Madariaga
Participants: R. Madariaga, professeur ENS, M. Lancieri, chercheur IRSN; S. Ruiz PhD student U. Chile-ENS-IPGP; A. Fuenzalida, PhD student AXA
Collaborations : J. Campos, Prof U. de Chile; M. Astroza Prof U. de Chile, S. Peyrat Prof. Assit. U. de Chile

The 27 February 2010 Maule mega-earthquake was the fifth largest earthquake recorded since the beginning of the 20th century, yet it produced limited damage. One of the foremost questions in applied seismology (see "Grand Challenges in Seismology") : does damage in large subduction zone earthquakes scale with the Moment (or equivalently Mw), or is it due to some other characteristic of earthquakes that moment release does not account for ? The Maule earthquake was a major event with a large rupture zone of about 450-500 km length by roughly 140 km width; it produced a significant tsunami and large geodetic deformations in the near and intermediate field. Yet, from the point of view of damage in Central Chile it was an earthquake barely more destructive than the big Mw 7.8 event that hit Valparaiso on 3 March 1985. The zone of damage in 2010 is much longer than that of 1985 extending well below the Arauco peninsula, some 600 km south of Valparaiso. A possible explanation, advanced by some engineers is that the Maule event was smoother than what was expected, producing a low level of acceleration (less than 60 % of g); another is that Chilean construction practices have significantly improved in the last 20 years. Either way, and there may be other explanations not envisioned yet, we need to understand damage during large earthquakes better. This is important not just for Chile, but for all other areas of the world where mega earthquakes are expected, like the NW United States, Alaska, Kamchatka in Russia, Central Japan, Taiwan, Peru, Colombia, etc.

We propose to study the Maule event comparing high and low frequencies in a systematic manner. For that purpose we have three types of data: static deformation as observed by interferometry, GPS, and tsunami excitation (Delouis et al, 2010; Vigny et al, 2010; Lorito et al, 2010, Tong et al, 2010, etc). We also dispose of data on low to intermediate frequency radiation in the near and far field from continuous GPS motograms and high frequency signals from some 15 high dynamic range accelerometers and some 30 more conventional engineering accelerograms.

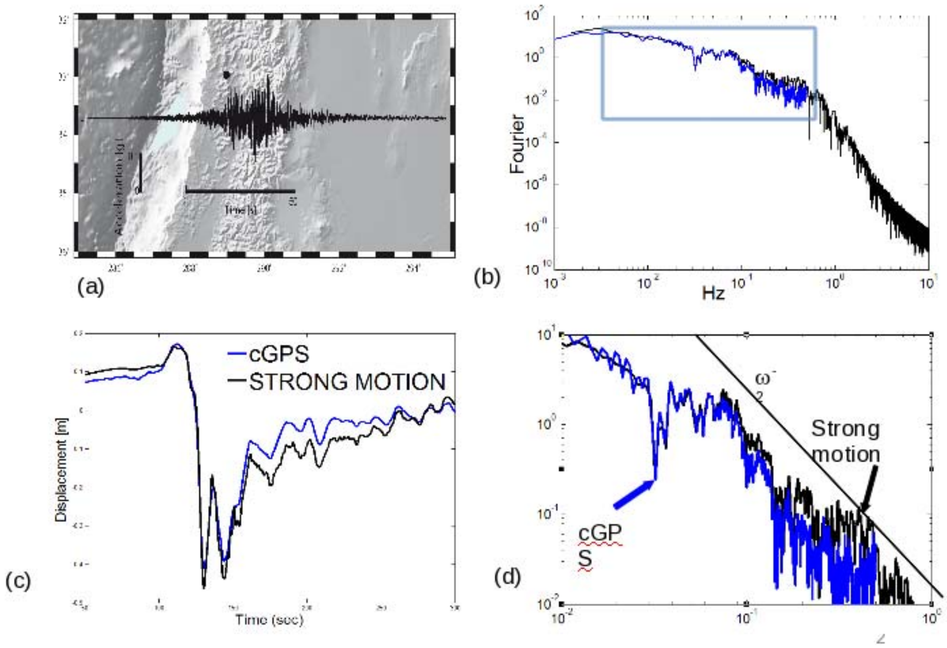
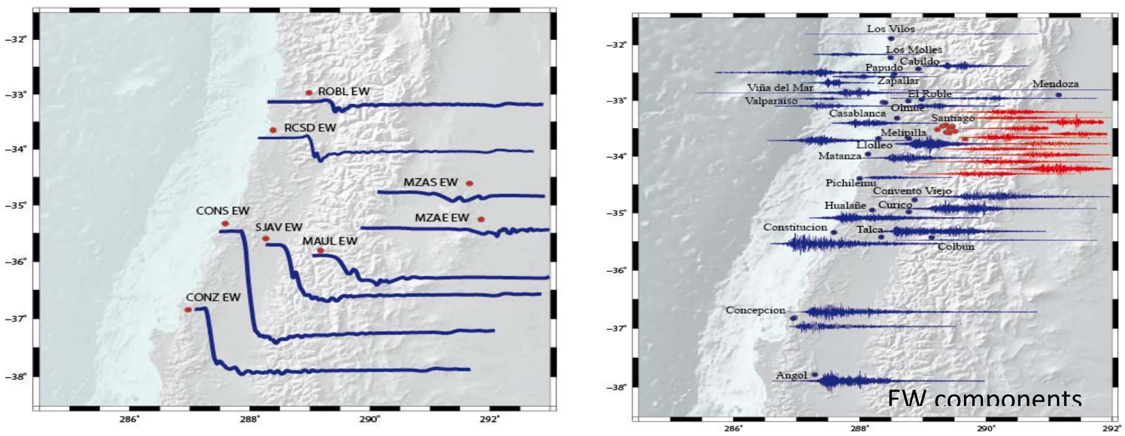


Figure 2.. Study of the accelerogram and cGPS record at the El Roble station between Santiago and Valparaiso. This station recorded the 24 bit accelerogram shown in (a) together with the cGPS plotted in blue in fig (c). In (c) we also show the displacement record integrated from the accelerograms using matched filters with zero phase shift. In (b) we show the spectra of the cGPS and accelerogram that nicely overlap in the and from 0.005 to 0.16 Hz. Figure (d) shows a blow up of the spectra showing that at El Roble far field effects control the frequency contents for frequency higher than 0.07 Hz.

In order to use these data we have to demonstrate that the different recordings are compatible and determine the exact range over which they overlap. This is shown in Fig. 2 where the strong motion record and the cGPS recording at the Cerro Robles site near Santiago were simultaneously recorded. The spectral analysis of these records show that motograms contain information from static to about 0.15 Hz, while high dynamic range accelerograms are useful in the range from 0.005 to 10 Hz. A similar comparison of high dynamic range accelerograms and conventional engineering instruments show that the latter can be used in the range from 0.03 to 10 Hz. Thus we can use the bumper crop of accelerograms in order to study the origin of high frequency waves from this earthquake as suggested by (Ruiz et al, and Lancieri et al, 2010).

Acelerograms of the Maule earthquake written in the Santiago metropolitan area all have durations of about 60 s and two strong pulses of acceleration with peaks of about 20-30 % g. This is strong motion, but much less than what was expected for such a large event (see the film by National geographic and $$$$$, 2010). A straightforward comparison of the accelerograms recorded in the Maipo valley (Melipilla, Santiago, Llolleo) shows that records of the Mw 8.8 event of 27 February 2010 look almost identical to those of the 1985 Valparaiso event (Ruiz et al, 2010a, 2010b).

A careful study of the intensity distribution by Astroza et al reveals that the maximum recorded intensity of ground motion reach only 8 in the Mercalli scale, meaning that the 2010 event was a mild earthquake.



cGPS: Vigny et al. (2010) Strong Motion Data: Barrientos (2010), Boroschek

3

Figure 3. Available data for the study of the 27 February 2010 Maule earthquake. On the left we show the EW components of available motograms showing the clear crack-like slip at the very near field stations. At longer distance wave propagation phenomena requires corrections for the seismic structure of the upper mantle in Chile. On the right, we present a subset of all available EW accelerograms; they cover the area from Angol in the South to Los Vilos North of Valparaiso. There may be additional accelerograms owned by private companies that we are eagerly looking for. This is a unique collection of strong motion data, only available to us through agreements with the Chilean participants in this project.

Work program

We propose to study the source of the 27 February Maule earthquake at the broadest possible frequency band using all available data. We distinguish three steps in this work:

Subtask 1.1 Full kinematic inversion. We intend to carry out a full inversion that includes all the kinematic data of the Chilean earthquake already available. The main question is how far did the earthquake rupture extend in the trench direction. Studies presented at the fall AGU meeting in San Francisco using ALOS interferometry, tsunami and a few intermediate and far field GPS data seem to favour a rather narrow rupture zone. The inversion of the campaign GPS data acquired along the coast from Arauco to Llico by Vigny et al, (2010) indicates that the rupture extended significantly close to the trench. Inversion of static data is very accurate near the source but its accuracy decreases with distance from the observers. For this reason we would like to invert the static data together with the intermediate field as recorded by continuous GPS instruments in the near and intermediate field. Inversion of this data can not be done without processing because the static field is overwhelmingly dominant at the stations in Concepcion, Constitucion, San Javier and Maule. A possibility is either selectively filtering this data, but this introduces very serious time delays. Another possibility is using the ground velocity obtained by numerical derivation of the motograms. Comparison of the motograms with high rate accelerograms will be used a guide for data processing.

Subtask 1.2 High and intermediate frequency inversion. We dispose of close to 30 recordings of either acceleration from 16 bits accelerograms, high dynamic range 24 bit accelerograms and the motograms already mentioned earlier. From spectral analysis we know that this data has a common frequency band 0.02 to 0.16 Hz. Once inversion is done in this band we can extend the source to higher frequencies using the low dynamic range accelerometers. The goal will be not to determine a precise distribution of intermediate frequency sources, but to identify their approximate location. Identifying these sources from the high frequency data will be done only statistically using methods proposed by Ide and Aochi in recent publications.

Subtask 1.3 High and low frequency characteristics of the Maule earthquake. The ultimate goal of our project is to explain how a magnitude 8.8 earthquake produced accelerations that are similar to those produced by a Mw 8 event. This is a crucial question for future studies of seismic risk in those regions of the world where mega earthquakes are expected. Foremost, the Northern Chile gap from the Mejillones Peninsula to Southern Peru.

3.2.2 TÂCHE 2 / TASK 2 AFTERSHOCKS OF THE MAULE EARTHQUAKE

Coordinator : H. Lyon-Caen
Participants : H. Lyon-Caen, DR CNRS-ENS, P. Bernard, Physicien IPGP, J.P. Vilotte, Physicien IPGP, A. Fuenzalida, PhD student ENS, 1 post doc
Collaborations : A. Rietbrock (U. of Liverpool), J. Campos, D. Comte, M. Pardo, P. Toledo (U. de Chile)

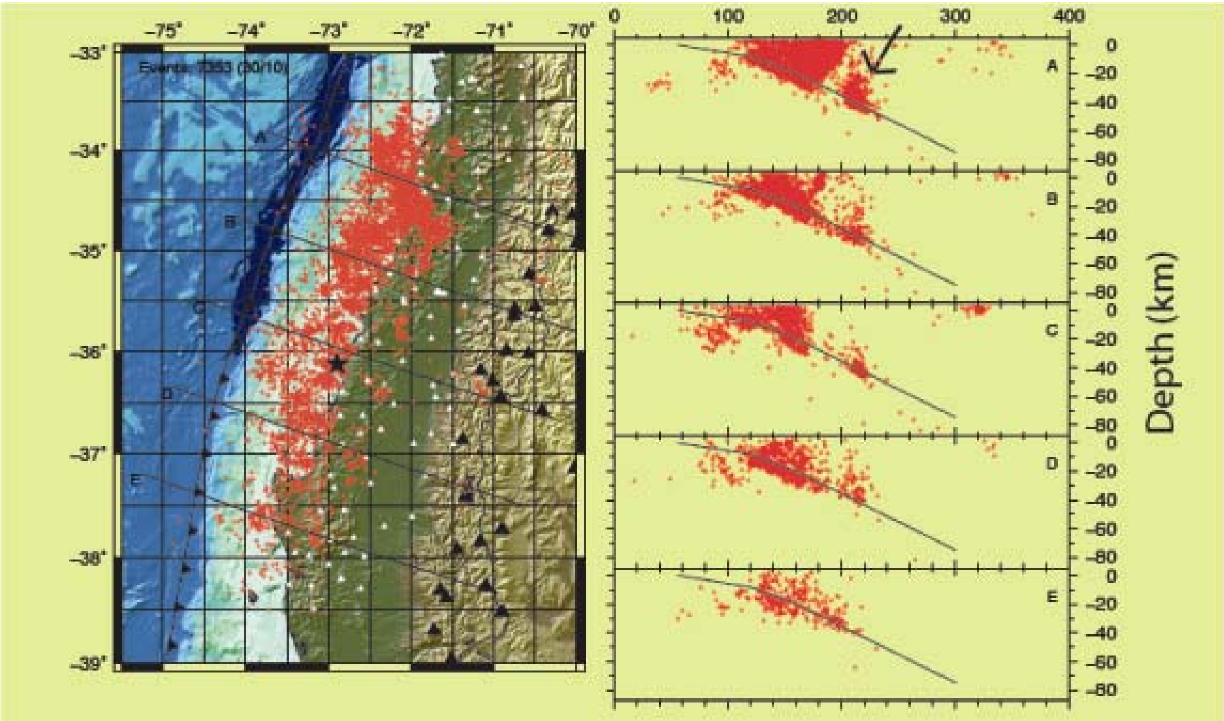


Figure 4: preliminary aftershocks catalog (7300 events – red dots) and localization from A. Rietbrook et al.(2010). The white triangles depict seismological stations (142 stations).

Immediately after the earthquake of 27 February 2010, a coordinated multinational effort took place to record the aftershock activity. In total 142 seismic stations were deployed by Chilean, French, USA, UK and German institutions, making this one of the best-observed aftershock sequences of a megathrust earthquake to date (fig. ?). Preliminary results based on automatic detection and location of ~7300 events covering the period of 21/03 to 01/06 (over ~100 000 recorded events) show the great amount of good data that can be looked at to learn about the rupture process of this event (Rietbrock et al., AGU 2010; http://pcwww.liverpool.ac.uk/~ariet/Maule_AGU2010_Rietbrock.pdf). In this work package we propose to focus our efforts on the detailed study of aftershocks in three areas with a specific goal in each of them. This work will be done in close collaboration with Andreas Rietbrock (University of Liverpool) who will focus on the tomography of these areas. Of course these studies will have to be combined at some point but in a first step we focus on double difference relocation in a 1D velocity model. A double difference algorithm developed by Andreas Rietbrock, taking into account a 3D structure could be used as well.

Sub task 2.1 The northern end of the rupture: Although the northern end of the rupture is located about 34°N, the aftershocks extend further north and into the rupture area of the March 5 1985, Mw=8.0 event. However the rupture area of the 1985 is poorly documented, due in particular to fairly poor location accuracy of the aftershocks (both in depth and EW direction). We propose to revisit the 1985 event to better understand its relationship with that of 2010, one key question being whether slip deficit remains in this area or not. In particular, we will take advantage of the fact that some aftershocks of 2010 occur in the 1985 aftershock area to relocate 1985 aftershocks with respect to the better located 2010 events. Seismic stations from the Servicio Sismologico in operation in 1985 are still in operation and will be used for double difference locations. Kinematic models of the 1985 event will also be reviewed. Combining information, a revised rupture area for 1985 will be proposed.

Sub task 2.2 The southern end of the rupture and the Arauco peninsula: This area has been the site of one of the largest aftershock on January 2 2011 (Mw=7.1), when the french network (including strong motion and broad band stations) which is quite dense in this area, was still in operation, contrary to US and German ones. We thus have the opportunity to make a detailed study of the seismic activity around the Arauco peninsula and south of it, in order to better image the plate there and understand the link with the 1960 northern limit of rupture. The 2011 event is located in the same area as the 1974 (Ms=7.1) and 1975 (Ms=7.7) that were located right at the place the 1960 event was loaded. One interesting point is that these events are located close to transverse faults identified by Melnick et al. (2009, AGU 2010). In addition, preliminary look at the data, shows that shallow crustal seismicity is present around the peninsula. Detailed study of this seismicity could be important to understand the mechanical role of the peninsula which represents a structural complexity. The interpretation will be done in conjunction with WP5 (task 5.2).

Sub task 2.3 The two large crustal normal faulting events of 11/03: The Pichilemu events of 11/03 consisted of a doublet of large normal faults, M=6.9 and 7.0, 15 minutes apart, followed by their own sequence of aftershocks. They were well recorded by the Maule postseismic seismological array, and both shocks produced a clear surface deformation well-recorded by continuous GPS and InSAR. No clear surface rupture was identified, although tectonic studies provide evidence for clear trace at the surface, with the relevant azimuth. These two events are striking for two reasons: first, they seem to have occurred at two different depths in the crust, possibly breaking through it down to the plate interface; second, their tension axis is parallel to the compression axis of the subduction, thus providing evidence for the inversion of the stress direction in a few tens of kilometers only, certainly helped by the coseismic strain of the Maule earthquake. The detailed analysis of the aftershocks (double difference relocation with identification of multiplets, fault plane solutions) should help to better define the geometry of the activated fault(s), and, combining with GPS, INSAR and tectonic observations (see WP5 task 5.1) to understand its mechanics in relationship with Maule earthquake. Preliminary results have been obtained by Comte et al. (AGU 2010) but a comprehensive study of these events remains to be done, in collaboration with D. Comte and M. Pardo of U. de Chile.

3.2.3 TÂCHE 3 / TASK 3 DETERMINATION OF THE INTER-SEISMIC COUPLING

Coordinator : Christophe Vigny
Participants : C. Vigny, DR CNRS-ENS, A. Socquet, physicien adj. IPGP, M.P. Doin, CR CNRS-ENS, M. Métois, PhD student ENS-IPGP, R. Grandin, PostDoc, Ducret G., PhD student, S.Morvan, field engineer ENS, A. Delorme, GIS engineer IPGP
Collaborations : J. Campos, D. Carrizo (U de Chile), M. Bejar-Pizzaro (IGM-Madrid)

The Maule Earthquake showed that there was a strong correlation between inter-seismic coupling that prevailed prior to the earthquake and co-seismic slip (fig 1). Roughly speaking and on average, the slip is maximum where the coupling was maximum and the rupture is stopped by areas where coupling is low. Additionally, the coupling pattern seems to correlate well with past ruptures and therefore the segmentation. Thus, although the physical mechanism for such correlation is not completely understood, quantifying inter-seismic coupling along the subduction, on segments which did not break yet, is of primary importance to quantify seismic hazard along the trench.

For this task, we will continue to determine the coupling on the trench using simple elastic models based on Okada's equations and the back-slip assumption. Although physically limited, these models proved efficient in determining a simple quantity (the "coupling" or "slip deficit") which revealed a good proxy for the determination of the presence of velocity weakening asperities capable of producing a seismic rupture.

Models need data. Large portions of the Chilean trench remain where the amount of upper plate deformation is still poorly known. Additionally, we cannot push aside the fact that coupling may change with time, over long time scales. Therefore, the object of this task is to acquire those much needed data by:

a) performing yearly GPS campaigns on a dense but large network covering the entire area of interest
b) systematically processing SAR images over long period of times in specific areas

Those two processes are complementary: GPS gives the ultimate precisions, InSAR (when available and coherent) gives the spatial resolution. Both will take advantage of the existence of a large scale cGPS network, which will provide an accurate reference frame for GPS campaign measurements and reference points -possibly ionospheric and tropospheric corrections- for InSAR.

Subtask 3.1 : GPS measurements

We will use the existing network (~150 markers) made of the original networks installed in northern Chile in the early 1990's (~40 markers) complemented by new markers we installed/measured in June 2010 (~30 markers), the network installed in the 4th region of

Chile (Coquimbo) in the years 2004-2009 (~60 markers), and the newest markers we installed/measured in June 2010 between 23°S and 28°S where almost no measurements had ever been done (20 markers). These numerous markers design a small scale network over most of the northern part of the Chilean trench that has not ruptured yet: from Santiago to Arica (figure 4). All new markers since 2000 are special bolts, sealed in the bedrock, on which the GPS antenna is directly screwed. This ensures precise measurements, both for the centering of the antenna and vertical measurements, guarantying quality results after a few years of repeated campaigns only.

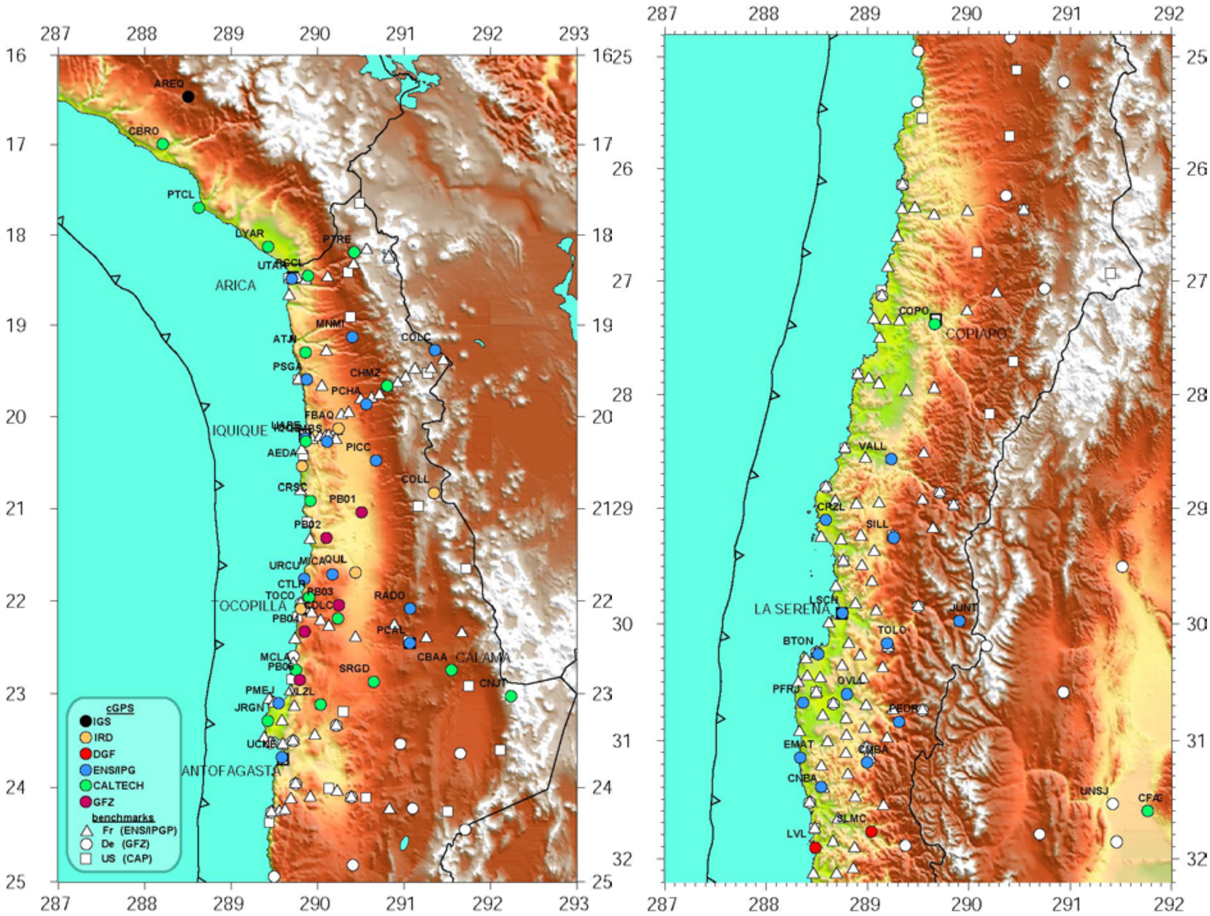


Figure 5: cGPS and GPS campaign networks

We will resurvey the entire network every year, including large scale markers from other networks (CAP, SAGA). The GPS surveys will be performed at the same period of the year, each year in order to reduce seasonal artifacts. Each point is measured at least during two or three 24-hour sessions, with a 30 seconds sampling, using dual-frequency receivers and geodetic antennas ensuring high quality measurements. The survey will be conducted with a maximum number of receivers provided (at free cost) by the French INSU instrumental pool and by the LIA-MdB pool in Chile (~30 to 40 instruments in total) in order to directly measure a maximum of baselines between stations. This should guarantee a good consistency of the geodetic network. In addition, the numerous permanent GPS stations in the area will ensure a stable reference frame and help tying sites that could not be measured in a common time window.

Subtask 3.2 : InSAR time series

The recent InSAR studies which have evidenced interseismic deformation across strike-slip faults are restricted to a stack of interferograms giving access only to the average interseismic signal (in time but also in space, along the fault), interpreted by means of simple elastic models. One obtains an average slip-rate on a fault below a locking depth the physical meaning of which remains badly understood (Wright et al., 2001, 2004, Taylor et al., 2006, Jolivet et al., 2008, Cavalié et al., 2008). The current challenge consists in trying to detect and model possible spatial (along-strike) variations to precisely map the coupling and the segmentation along the trench, using Envisat and ERS archives. In a second step, and using a denser data set (that should be acquired by the pair of Sentinel satellites to be launched in 2012 and 2013), we will try to assess temporal variations of the interseismic deformation (episodes of creep for example, as observed on certain normal faults in Afar, thanks to long time series of radar data, Doubre et Peltzer, 2007).

In Chile, to constrain small interseismic deformation, we face various methodological problems. First, the interseismic deformation pattern is parallel to the trench and correlated with an important topography (the Andean flexure) that ranges from 0 m along the coast to 5000 m on the Altiplano. InSAR measurements are prone to large errors associated with the radar phase propagation delays, that are most of the time correlated with the topography. In addition, because of the N-S configuration of the Chilean subduction, InSAR data are very sensitive to deformation, but a trade-off exists between large wave-length deformation field and orbital errors that generate track-parallel fringes on interferograms. Therefore, if we want to measure precisely long wavelength interseismic deformation, it is necessary to increase the sensitivity of InSAR measurements. To achieve this, we plan to process a large number of interferograms and try to correct the interferometric phase from atmospheric effects. These effects are mainly due to the combination of strong topographic variations in the chosen zones of study and temporal variations of the vertical stratification of water vapor, pressure and temperature in the troposphere. The research tracks to investigate include the systematic analysis of the correlation between the interferometric phase and the topography (Cavalié et al., 2007, 2008), the use of additional atmospheric models (Puyssegur and al., 2007, Doin et al. 2009), and satellite data of water vapor (from MERIS images, and/or cGPS continuous data). In particular, we will test the possibility of establishing, at the moment of each acquisition of radar image, profiles of stratification of water vapor perpendicular to the targeted faults using the cGPS data available, to correct the interferograms from atmospheric delays. To flatten our interferograms, we will use independent geodetic data (provided in Chile by the existent cGPS network). The efficiency of this methodology has already been tested in the framework of the PhD of Marta Béjar-Pizarro, who successfully retrieved the interseismic deformation field using the available

Envisat data on one descending long-strip in North Chile (Fig 5). We plan to extend (and improve) this type of analysis for various parallel tracks along the Chilean coast, from 35°S to 18°S.

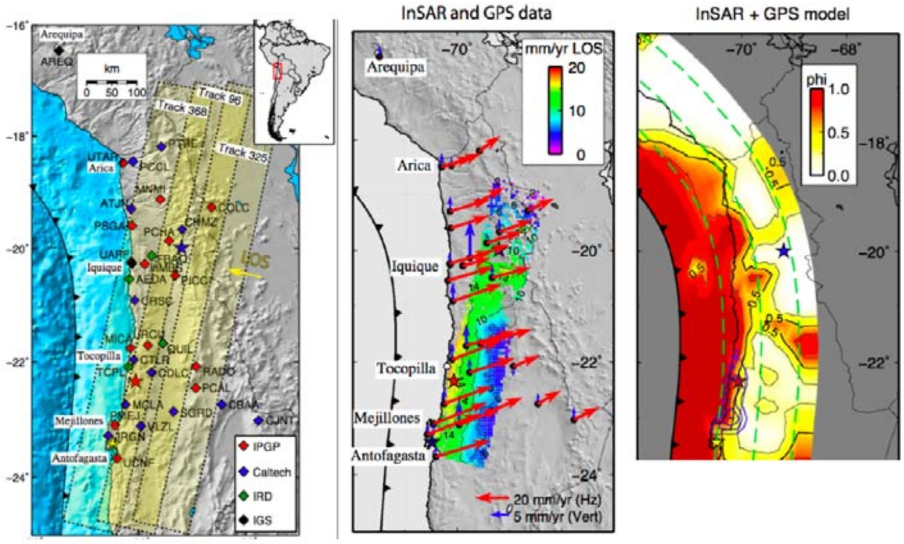


Fig 6: Left: Geodetic data available in North Chile. cGPS stations are plotted as coloured diamonds. SAR tracks are depicted in light brown. Center: Interseimic deformation field. Red arrows show horizontal component, blue arrows is vertical component and color map is the stacked interferogram (deformation is in the line of sight of the satellite and converted in mm/yr. Right: Interseismic loading in North Chile, inverted using cGPS and InSAR data. Stars represent the epicenters of 2005 Tarapacà (blue) and 2007 Tocopilla (red) earthquakes. Blue iso-contour lines of the 2007 Tocopilla earthquake (Bejar-Pizarro et al. 2010) are superimposed on the coupling distribution (PhD thesis of Marta Bejar-Pizarro).

In a first step we will exploit the Envisat and ERS archives, and complete the available ERS2 data by programming new acquisitions. Data are distributed at no cost by ESA through the ESA project AOE720 (PIs : A. Socquet, MP. Doin & JB de Chabalier). This will provide us with a complete data set: for ERS and Envisat data on 3 decending tracks (325, 53, 282) in central Chile (25-33°S) and three descending tracks (368, 96, 325) in North Chile (18°-25°S) (fig. 5). We might be able to perform interferograms with 10 to 15 years intervals, because of the high coherence of the area.

In a second step, we will use the data acquired by the future Sentinel-1 pair of satellites (Sentinel-1A to be launched in 2012 and Sentinel-1B in 2013). Both satellites will acquire continuous SAR data with a TopSAR ScanSAR acquisition mode that guaranties a very stable acquisition pattern, with a swath of 250km and a repeat pass of 12 days, allowing for image acquisition as often as every 6 days when both satellites will be on orbit. It will be a challenge to integrate this huge data set along the whole Chilean coast, and we will need to automatize the processing routines for interferogram generation, time-series analysis, flattening and tropospheric corrections. When this automatization becomes operational, Sentinel InSAR time-series together with continuous GPS data in the area will offer a unique opportunity to detect small, transient deformations, and should therefore shed a new light on the time-dependent behaviour of the subduction mega-thrust.

3.2.4 TÂCHE 4 / TASK 4 COMPLEXITY AT THE PLATE INTERFACE VS. COUPLING & SEGMENTATION

Coordinator : R. Lacassin
Participants: R. Lacassin, DR CNRS-IPGP, R. Armijo, Physicien, A. Socquet, Physycien adj., M. Simoes, CR CRNS-IPGP, R. Grandin PostDoc CEA-ENS, A. Coudurier-Curveur, PhD student, A. Delorme, GIS engineer IPGP.
Collaborations: G. Vargas and D. Carrizo (U. Chile), N. Cubas (Caltech)

The subduction zone at the western margin of South America is the living paradigm for the A-type (or Chilean-type) of subduction, which is the geodynamic system that has generated the largest earthquakes (e.g. 1960 Valdivia Mw 9.5, 2010 Maule Mw 8.8 earthquakes), as well as the Andes, one of the largest mountain belt - and high-plateau- systems of our planet. At the subduction interface, there is a fundamental interaction between mechanisms leading to these two processes. However, it is now clear (contrary to expectations ascribed to C. Darwin) that crustal deformation associated with any large subduction earthquake leaves no significant contribution to mountain building. It is also clear that crustal deformation and uplift involve the whole forearc region from the continental margin, just above the seismogenic subduction interface, to the volcanic arc at more than 4000m of elevation. How those two fundamental processes interact is unknown and no current geodynamic model appears to explain satisfactorily both, the generation of the large earthquakes and the topographic relief being generated by some combination of accretion and tectonic shortening, thus necessarily by structural complexity at the subduction interface. We note that current models of the subduction interface based solely on seismologic or geodetic data do not resolve that complexity.

Here we make the hypothesis that crustal deformation in the Chilean forearc (and more specifically the deformation identified from observation of geology and morphology in some spots along the Chilean coastline) is associated with specific geometric/mechanical complexities at the subduction interface, which appear persistent over the geological time scale (~10^5-10^6 yrs) and can thus be defined from the geology. Examples are the peninsular regions of Arauco - Isla Santa María (characterized by secondary splay thrusts, e.g. Melnick et al. 2006, 2009) and of Mejillones (characterized by secondary normal faulting, e.g. Armijo and Thiele 1990, Allmendinger and Gonzalez 2009). As a consequence, variations of the mode and degree of complexity at the subduction interface should govern along-strike variations of mechanical parameters (i.e., friction, coupling), location of persistent asperities and barriers, and ultimately segmentation. We will focus on 4 sub-tasks (see Fig.1 and Fig. 4.1 for geographical location): the first 3 sub-tasks are targeted at features of the 2010 Mw 8.8 Maule earthquake rupture zone in Central Chile; the 4th Sub-Task is aimed at the understanding of features of complexity variation in the rupture area of the 1995 Mw 8.1 Antofagasta (e.g. Ruegg et al. 1996, Delouis et al. 1997, Chlieh et al. 2004) and the 2007 Mw 7.7 Tocopilla earthquakes in North Chile (Delouis et al. 2009, Peyrat et al. 2010, Béjar-Pizarro et al. 2010).

Sub-Task 4.1 Study of the March 11, 2010 Mw 6.9 Pichilemu earthquake that is considered as an aftershock of the February 27, 2010 Mw 8.8 mainshock. The source location and mechanism of this event clearly indicates extension of the upper plate just above the subduction interface, in the N end region of the 2010 rupture. This is the first time the occurrence of a relatively large event of this type (comparable to faulting in Mejillones) can be precisely documented. Using the available seismologic (see Task 2) and geodetic (GPS and InSAR) data combined with our geological evidence collected in the field, we will explore how the extensional strain field is activated.

Sub-Task 4.2 Study of the secondary deformation associated with the 2010 Mw 8.8 rupture in the region of the Arauco peninsula, in the S end region of the 2010 rupture. We will use The GPS and InSAR data to characterize the residual deformation, possibly accommodated by thrust splaying, once the first-order model of the earthquake (main subduction interface rupture) has been removed. We will also use results of Task 2 on the localisation of aftershocks. We also plan to assess whether the Mw 7.1 Araucanía of January 2, 2011 has occurred on the subduction interface or on a splay fault.

Sub-Task 4.3 Evaluation of geological constraints (active structures in the upper plate, uplift deduced from geomorphology) in the region between the Gulfs of San Antonio and La Serena, north of the 2010 Mw 8.8 rupture. The coupling in this region is well constrained by GPS data (Fig. 1). Our aim is to determine if the observed low coupling in the smaller regions beneath the Gulfs of San Antonio and La Serena are persistent features.

Sub-Task 4.4 Kinematic and mechanical modelling of the structural complexity variation associated with the southern end of the seismic gap in North Chile (mega-earthquake pending since the 1877 Mw 8.5 earthquake). The region is well documented by data of the 1995 Mw 8.1 Antofagasta and the 2007 Mw 7.7 Tocopilla earthquakes (M. Béjar-Pizarro, thesis 2011, Béjar-Pizarro et al. 2010, fig. 7). In addition, using very constraining geological/morphological data collected in the Atacama desert (A. Coudurier-Curveur, thesis 2011), we plan to produce a series of generic models of mechanical complexities and complexity variation consistent with the earthquake data and explaining explicitly the development of the main geological features, such as the normal faulting, the Coastal Scarp, the wholesale uplift of the forearc region and the Mejillones peninsula. Using this test of N Chile, where we have enough data of excellent quality to build such models, we will be able to derive implications for the other part of the Chilean subduction, and specifically the Maule area.

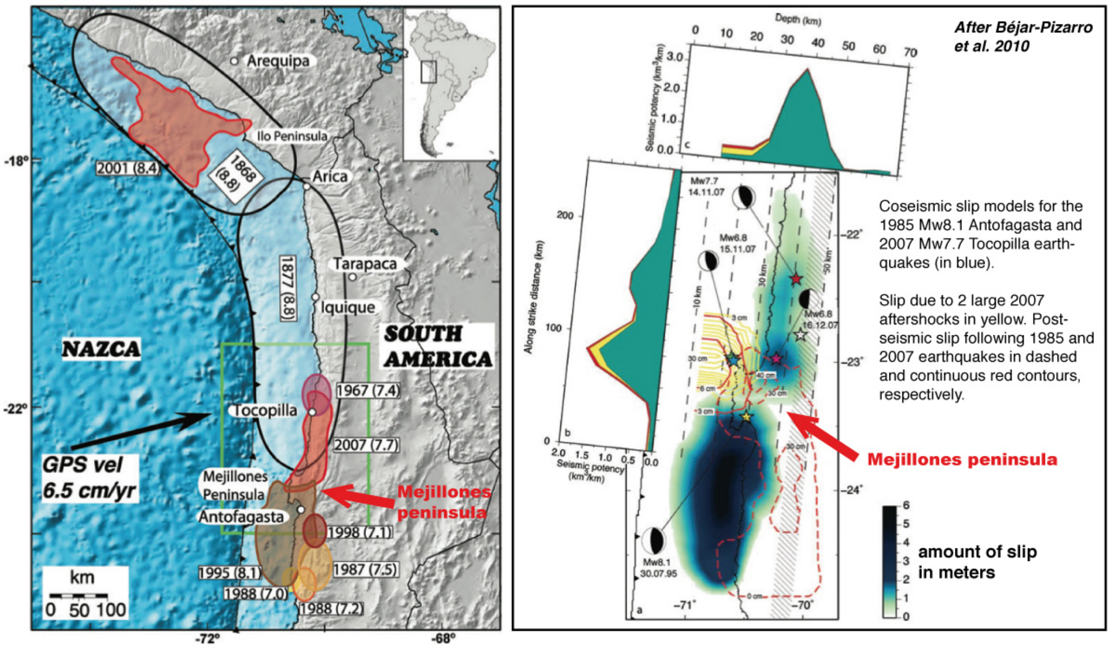


Figure 7 - Past earthquakes in N Chile. Detail of slip models for the 1985 and 2007 events and post-seismic deformation. After Bejar et al. 2010. The Mejillones peninsula marks an intersegment stable at geological time scales (at least several hundreds of years). Figure 1, in the introduction of the project, illustrates the case of South-central Chile.

3.2.5 TACHE 5 / TASK 5 POSTSEISMIC DEFORMATION

Coordinator : L. Fleitout
Participants: L. Fleitout, DR CNRS-ENS, A. Socquet, Physicien adj. IPGP, O. Trubienko, PhD Student ENS.
Collaborations: JD Garaud, chercheur ONERA, G. Cailletaud, professeur Mines-Paris-Tech

Post-seismic deformation is often observed but its causes are still not well understood. Either viscoelastic relaxation in the mantle, aseismic afterslip on the subduction fault or poroelastic rebound are invoked to explain geodetic and seismologic observations. The physics of such phenomena which involve several time scales that typically range from minutes to months and years are still debated. Viscoelastic relaxation is most likely the dominant mechanism over large time (years to tens of years) and space scales. It gives insights about the rheologies of the asthenosphere, of the mantle wedge and perhaps of the lower crust. Poroelastic phenomena constrain fluid circulation in the area of the fault zone. Afterslip is thought to relax the accumulated stresses in zones of the fault characterized by small or moderate co-seismic slip.
In this task we propose to tackle the problem of post-seismic deformation using two complementary approaches to assess the mechanisms responsible for post-seismic deformation at two different scales (in both time and space). At the local scale and during

the first months & years following the earthquake we will try to detect afterslip phenomena on the subduction interface using simple elastic modeling. At a larger scale we will investigate the different components of post-seismic deformation using more sophisticated visco-elastic modeling.

Sub Task 5.1: Detection and elastic modeling of afterslip on the subduction interface

Afterslip is a particular class of slow slip event. It is important to document and understand it because it often accounts for as much slip as occurs in the main shock. This large amount of afterslip may contribute to explain the observation that seismic moment released at plate boundaries is less than the total moment expected if all plate motion is accommodated seismically. Afterslip appears to relax zones of low co-seismic slip on the rupture itself (WP 1), updip or downdip the rupture as predicted by state- and rate-dependent frictional models [e.g. Marone et al., 1991 ; Heki et al., 1997; Yagi et al., 2003 ; Bürgmann et al., 2001 ; Burgmann, et al., 2002; Chlieh et al., 2004; Pritchard and Simons, 2006; Schwartz and Rokosky, 2007; Bejar-Pizarro et al., 2010; Perfettini et al. 2010; Vigny et al 2011; fig 1]. Therefore studies of afterslip are important to test rate- and state-dependent friction laws. Accurate estimation of the decay time of afterslip as well as rigorous numerical tests of whether the observed decay is, in fact, logarithmic and remains so over the entire observing period should allow rate- and state-friction laws to be rigorously tested with geodetic and seismic field observations (task 3).

Monitoring post-seismic deformation with high spatial and temporal resolution should inform us about the location of afterslip processes on the subduction interface, but also about migration of deformation at both ends of earthquake rupture. At the time of the earthquake, our team was running continuous GPS stations (dark blue hexagons on fig. 8) that brought critical observations to the community for the understanding of the seismic rupture. As soon as one week after the main shock, we started to install 10 additional cGPS stations in near field (light blue hexagons on fig. 8), that were completed several weeks after by additional dense cGPS stations installed by other international teams (orange hexagons). If we want to detect post-seismic afterslip and constrain rate- and state-friction laws, early observations are critical. First results show that afterslip inverted from the first 12 days following the earthquake has a complementary pattern to co-seismic slip (fig. 1). We propose here to refine and extend this type of analysis, in order to obtain an integrated view of the time and space evolution of afterslip on the subduction interface.

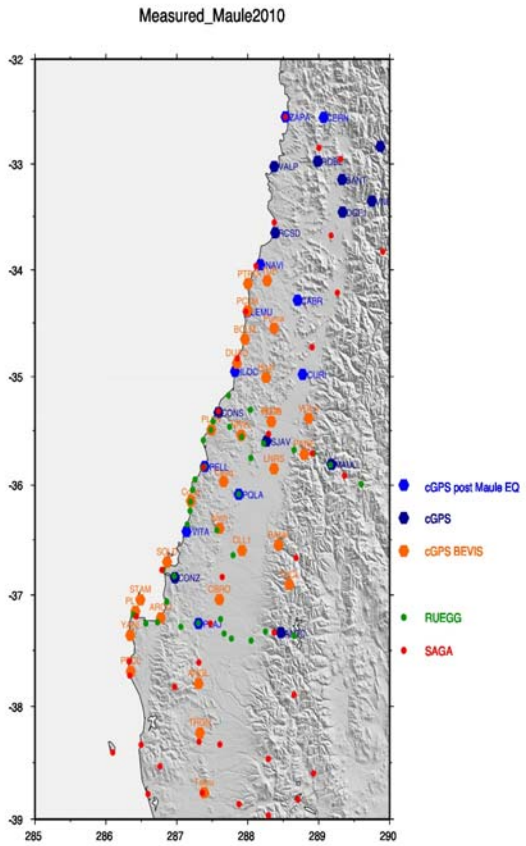


Fig 8: Map of GPS data available for the study of post-seismic deformation. In dark blue cGPS that were running during the earthquake. In light blue, Franco-Chilean cGPS installed one week after the earthquake. In orange, additional cGPS installed later after the earthquake.

First of all, an important work of analysis of GPS data is necessary. In order to detect small, transient motions, the automated GPS processing should be refined and farther analyzed. In particular, the combination of the data and the way they are projected into a global reference frame should be improved. In addition, time series should be filtered from non-tectonic periodical signals, such as seasonal tropospheric variability, water table loading, geodetic monuments stability, errors due to the reference frame, the satellites orbits, or the earth orientation/rotation parameters. Spectral analysis also permits detailed error quantification by characterizing the noise associated with the measurements.

Then, this geodetic data set will be inverted to obtain the slip events over time on the subduction interface. For this purpose, the time-dependent modeling should allow us to retrieve patches of slip at depth by performing a series of elastic models covering different time periods spanned by our data set. This method was successfully used by Pritchard and Simons [2006] for monitoring afterslip that followed the 1995 Antofagasta earthquake in North Chile or by Grandin et al. [2010] to retrieve transient rift opening in Ethiopian Afar. Recently published complementary methods will be explored to perform integrated modeling of transient slip [eg. Radiguet et al., 2010; Kositsky & Avouac, 2010; Perfettini et al., 2010]

Sub Task 5.2. Viscoelastic modeling using a 3D spherical finite element code

The viscoelastic modeling will be complementary of the elastic modeling proposed in the subtask 6.1. Its purpose will be to separate the amplitude as a function of time of slip on the fault plane, relaxation in the asthenosphere and, possibly, relaxation in the low viscosity wedge. We have already performed such a viscoelastic modeling for the deformations in South-East Asia following the Aceh, Nias and Benkulu earthquakes. We have shown that the deformation related to relaxation in the asthenosphere can be separated from slip on the fault plane because it is characterized by far-field post-seismic subsidence and also by a relatively large amplitude of far-field over near-field horizontal motions. However, for South-East Asia earthquakes, except perhaps for Benkulu, there were very few permanent stations registering the deformation in the first days after the earthquake. Morover, a large part of the deformed area over the Sunda plate is covered by the sea so that the spatial coverage with GPS data is there rather partial. We expect that the dense network of stations in Chile will help us to answer several questions still open after the study in South-East Asia.

The procedure applied for modelling post-seismic rebound in South-East Asia after the 2004 Sumatra earthquake and that we plan to apply to Chile is the following: we use the finite element code Zebulon (Ecole des Mines, ONERA, Northwest numerics). We perform a 3D mesh modeling a region around the subduction zone corresponding to a portion of spherical shell extending over more than 30° in latitude and longitude and from the core-mantle boundary to the Earth's surface. The mesh is refined close to the subduction zone and includes a plane of subduction with a realistic geometry (fig. 9). It is possible to choose the mechanical properties of each region of the mesh as well as the sliding properties over the subduction plane (with flat elements named 'éléments de zone cohésive'). We introduce elastic properties varying as a function of depth and regionally (oceans, continents, accretionary prism). We include a viscoelastic mantle (Maxwell or Burger models), a viscoelastic low viscosity wedge. We also test viscoelastic properties in a low viscosity channel in the lower part of the subduction fault. In Chile, it might be important to consider lower continental crusts with a low viscosity but a far-field cratonic lithosphere with disappearance of the low viscosity asthenosphere. First, using the coseismic deformation registered by GPS and INSAR, we invert for the coseismic sliding on the fault plane using the elastic response of our finite element model. We noticed that it was important for this coseismic slip determination to use an accurate 3D elastic structure. Then, we compute the surface deformation induced by the viscoelastic relaxation in the low viscosity regions of our model. The observed GPS horizontal and vertical postseismic displacements are then interpreted as a consequence of sliding on the subduction plane and relaxation in the asthenosphere and low viscosity wedge. In South-East Asia, we have been able to show that it was not possible to explain simultaneously the near-field and the far-field data with either one or the other source of deformation: a combination of the two mechanisms is required. Asthenospheric relaxation is more important for far-field deformation and it induces far-field subsidence. Sliding on the fault plane or relaxation in the low viscosity wedge is more important for near-field deformation.

There are three points that we will address more specifically using the dense GPS data in Chile:

- 1) It is rather difficult to distinguish relaxation in a low viscosity wedge from sliding in the deep part of the subduction fault plane using surface deformation data. However, the pattern of far-field subsidence associated with the asthenospheric relaxation is affected by the mechanical structure (low viscosity channel versus low viscosity wedge) in the bottom part of the subduction plane. We are confident that the dense network of permanent stations registering the deformations after the Maule earthquake will permit to clarify this point.

- 2) Over a short time-scale (a few months), there is a very rapid deformation registered both by near-field and far-field stations investigated in detail through Task 6-1. The short-term near-field signal is relatively large compared to the short-term far-field signal. Therefore, as mentioned in SubTask 5-1, it seems mainly due to sliding on the fault plane. However, it has been suggested that a short term relaxation phase associated with an asthenosphere with a burger viscoelastic rheology could also explain this signal (Pollitz et al. 2006). Using the same approach as for the longer term signal, we should be able to separate, for the short-term signal also, the two mechanisms and to correct the estimate of the sliding on the fault plane from a potential polluting signal coming from asthenospheric viscous relaxation.
- 3) Understanding the whole seismic cycle and in particular deciphering the meaning of the interseismic deformations is important for evaluating the seismic risk. As shown by the far-field data in South-East Asia and also by the large post-seismic deformations still persisting 50 years after the 1960 Valvidia earthquake (Hu et al. 2004), the post-seismic deformation is very large and most of it is associated with asthenospheric relaxation. This means that the interseismic phase cannot be considered as the complementary of the coseismic phase and of post-sismic sliding on the fault plane. We plan to use our knowledge of the mechanical properties of the asthenosphere and of the lower part of the subduction plane gained through the study of postseismic deformations to improve the interpretation of the interseismic phase in coordination with WP4. We have shown that this could be done using either 'realistic models' with applied far field plate velocities and earthquakes occurring periodically over the shallow part of the subduction plane or 'viscoelastic back-slip models' (which is somewhat simpler technically but yields exactly the same results).

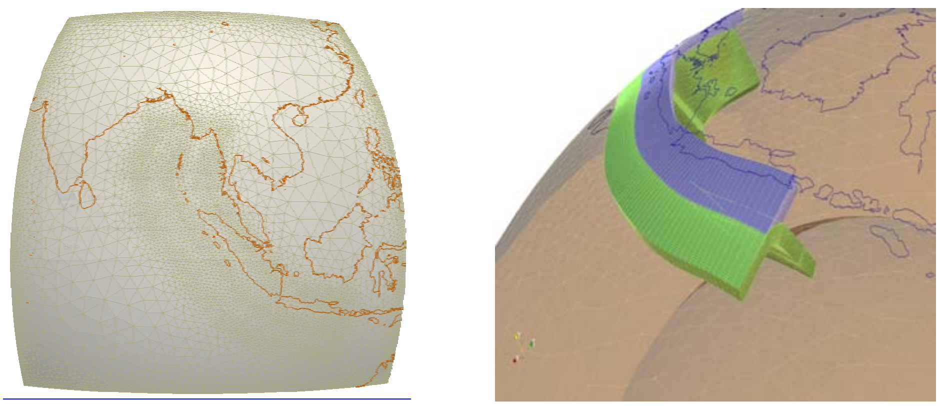


Figure9: Example of mesh used for modelling the postseismic deformations in Asia. We plan to build a similar mesh for the Chile.

3.3. Calendrier des taches, livrables et jalons / Tasks schedule, deliverables and milestones

All tasks will be moving forward simultaneously. No task depends on a particular achievement of another tasks. Regular monthly meeting will be scheduled

4. Strategie de valorisation, de protection et d'exploitation des resultats / Dissemination and exploitation of results, intellectual property

A - Scientific Dissemination

- The results of this project will be published in peer-Review International journals in seismology, geophysics, tectonics and earthquake engineering. These papers will foster the international visibility of the French and Chilean teams as well as their collaborative efforts.
- The results of this project will also be regularly presented in International meetings in Geophysics like the EGU and the AGU meetings, as well as in Latin American meetings. Attention will be paid to send Chilean and French young researchers and students participating to this project at those meetings.
- The project will also foster special sessions, co-chaired by Chilean and French scientists at these international meetings.

B – Scientific training and teaching

- This project will lead to a number of Chilean and French Ph.D. Theses, co-supervised by a Chilean and a French supervisor. The Ph.D positions allow students to be trained in state-of-the-art data analysis technologies and modelling. Students will spend time both in Chile and French research laboratories.

C – International collaborations

- This project is supported by the existing Associated International Laboratory "Montessus de Ballore" between the CNRS/INSU and the Universidad de Chile.
- Beside these existing collaborations, the project will allow to reinforce or foster new collaborations with other international partners, e.g. in the United States (Caltech, Ohio State University), in UK (University of Liverpool) and in Germany (GFZ-Potsdam).
- These International collaborations will also benefit to the Master, PhD and young researchers involved in this project.

D – Data distribution and availability

This project will produce new integrated data bases in France and Chile (GPS, InSAR, and seismological) that will be made available to the national and international scientific community

5. DESCRIPTION DU PARTENARIAT / CONSORTIUM DESCRIPTION

5.1. DESCRIPTION, ADEQUATION ET COMPLEMENTARITE DES PARTENAIRES / PARTNERS DESCRIPTION AND RELEVANCE, COMPLEMENTARITY

ENS
Monitoring crustal deformation along subductions (using GPS and seismology) is an identified project of the "laboratoire de Géologie de l'ENS" research plan.

Over the last 10 years, **C. Vigny** (coordinator of the project and coordinator of task 3), with collaborations with DGF at U-Chile, Santiago has been developing GPS activities (cGPS networks, benchmarks installation, measurement campaigns, data processing, teaching) in Chile.

Raul Madariaga (coordinator of task 1), is a renown seismologist (award of the Stephan Muller medal of the European geophysical Society – 1999 and the Harry F. Reid medal of the Seismological Society of America – 2004). His specific knowledge of subduction earthquakes and his joined theoretical and data approach of source mechanisms, his long time involvement with research projects in Chile, and his network of past and present students in Chile are extremely valuable to the project.

Hélène Lyon-Caen (coordinator of task 2 – Aftershocks of the Maule earthquake), has been involved in many large earthquakes studies. As an active participant to the Corinth Rift Laboratory European project since 2000, she is responsible for the data analysis of the seismological network CRLNET. She thus has a good experience of managing large amount of data and is familiar with up to date processing techniques.

Luce Fleitout (coordinator of task 5 – Modelling of the Post-seismic deformation of the Maule earthquake), has worked on the mechanical and thermomechanical modelling of the solid Earth (tectonic deformation, forces exerted on plates, geoid and mantle convection, convection and plate thicknesses...). In recent years, she has been interested in the viscoelastic response of the Earth due to loads (post-glacial rebond) or to large earthquakes.

Through a collaboration with ONERA and Mines-Paritech, she has implemented a 3D finite element code able to tackle viscoelastic or non-linear responses with strong lateral mechanical heterogeneities

IPGP

The IPGP department of Research is a single CNRS research unit, UMR "IPGP", made of thirteen scientific teams all been ranked A+ by AERES. This project involves two of these teams:

- the "Tectonics and Mechanics of the Lithosphere" team works on transient and finite strain of the lithosphere, from the earthquake cycle to mountain-building time-scales. The team maps, describes 3D geometry (4D including time) and measures rates of deformation using geology, marine geophysics, remote sensing, neotectonics, paleoseismology and space-geodesy. Numerical modeling allows to integrate these observations into mechanical models of deformation at different scales.
- the "Seismology" team pursues research in the areas of seismology, such as imaging and tomography of the Earth's interior, studies of earthquakes and of seismic cycle, developing theoretical and numerical approaches for modeling seismic rupture and seismic wave propagation, and mitigation of seismic and other natural hazards. Members of the team are actively involved in operation of permanent seismic networks (GEOSCOPE, volcanological observatories run by IPGP), in temporal seismological deployments, and in the development of new types of seismic instrumentation.

Robin Lacassin (coordinator of task 5, and responsible of partner IPGP), is a geologist, specialist of large-scale tectonics, mountain building processes, fault and shear zone evolution. He works on large-earthquakes in relation with fault mechanics, geomorphic and geological evolutions at different time and space scales. He is leading the Tectonics and Mechanics of the Lithosphere team of IPGP.

Rolando Armijo is one the few french geoscientists listed in ISI highly-cited scientists. He is a world-leader in seismotectonics. He developed pioneering interpretation methods in geomorphology and active tectonics, and produced comprehensive studies in regions as the Himalaya and Tibet, the Andes and the Mediterranean region. He studied the deformation associated to recent and past earthquakes; contributes to leading-edge current studies of deformation transients related to the seismic cycle using space geodesy (GPS and SAR interferometry), seismology and mechanical modelling.

Anne Socquet is a specialist of geodesy applied to seismo-tectonic problems. She is skilled in both GPS and InSAR processing. She is also involved in plate tectonics modelling, as well as elastic modelling of earthquake signals and interseismic loading. Since a few years, she took the responsibility of a cGPS network, and a series of campaign points, within the North Chile seismic gap in collaboration with Chilean colleagues.

Martine Simoes is a specialist of tectonic geomorphology and more specifically of studies of erosion, rock exhumation, and fluvial incision above active thrusts. She has also produced kinematic and thermo-kinematic modelling of accretion on active thrust systems and on the Sumatran subduction zone.

Jean-Pierre Vilotte, seismologist, has been extremely active over the last 5 years for the development of the Chilean-French cooperation, and with the international ties and collaboration of this structure with other groups. Vilotte is the director of the LIA "Montessus de Ballore" and as such he organized the French post-seismic intervention after the Maule earthquake of February 2010. He also fostered and organized the relations between the LIA and other groups working in Chile, before and after the Maule event, namely Caltech, GFZ-Potsdam, IRIS, Univ. of Liverpool.

The two partners (ENS and IPGP) have a long history of collaboration in general and in particular in Chile. Those joined efforts leaded to the creation in 2007 of the international laboratory (LIA) "Montessus de Ballore" by CNRS and U-chile, where the French side is represented by ENS and IPGP.

5.2. QUALIFICATION DU COORDINATEUR DE LA PROPOSITION DE PROJET/ QUALIFICATION OF THE PROPOSAL COORDINATOR

Christophe Vigny at ENS has a long experience of GPS data acquisition (both survey and cGPS) in many areas of the world. Over the last 20 years he designed, installed and measured networks in Indonesia, Thailand, Myanmar, Nepal, Iran, Afar, Antarctica, the Alps, Greece and Chile. His work has been subject to ~40 publications in peer reviewed international newspaper, and high visibility journals like Nature for the case of Sumatra since the Earthquake and Tsunami of 2004.

Since 2000, Vigny has been one of the key actors of GPS geodesy in Chile: he is one of the co-author of the GPS article in PEPI, 1999 which declared the Maule gap mature with a high probability of an imminent 8 to 8.5 earthquake. He was also responsible for the installation of 3 cGPS stations in the epicentral area as early as 2003 (CONS, SJAV, MAUL), which produced critical data.

Vigny is also one of the key actors in the "GPS applied to geodynamics" French community, having signed or co-signed a very significant part of the publications of this group.

Finally, Vigny also as had some experience in managing projects or subprojects aimed at acquiring, processing and modelling GPS data (both survey and cGPS) funded by EC and ANR.

- GEODYSSEA (EC) 1994-1997: GPS measurements all over SE-Asia (Indonesia, Malaysia, Thailand, Vietnam, Philippines, Singapore, Brunei)
- SUB-CHILI (ANR) 2005-2008: GPS measurements in Chile
- OPOSSUM (ANR) 2006-2009: deformation in Sumatra

Those projects included all aspects of this current proposal, including 3D-finite element modelling.

5.3. QUALIFICATION, ROLE ET IMPLICATION DES PARTICIPANTS / QUALIFICATION AND CONTRIBUTION OF EACH PARTNER

Partenaire / partner	Nom / Name	Prénom / First name	Emploi actuel / Position	Discipline / Field of research	Personne.mois* / Person.month	Rôle/Responsabilité dans la proposition de projet/ Contribution to the proposal 4 lignes max
ENS						
Coordinateur/responsable	VIGNY	Christophe	DR CNRS	Geodesy	24	Direction & coordination Coordinator of task 3 "coupling" network design, GPS data acquisition, processing, modelling & publication
Autres membres	MADARIAGA	Raul	Prof. ENS	Seismology	15	Coordinator of task 1 "source of Maule" Kinematic inversion mixing strong motion and cGPS data. Frequency spectrum analysis of the Source. Seismic hazard.
	LYON-CAEN	Hélène	DR CNRS	Seismology	9	Coordinator of task 2 "aftershocks" Implement precise re-localisation methods, revisit 1985 Valparaiso earthquake
	FLEITOUT	Luce	DR CNRS	Modelling	15	Coordinator of task 5 "post-seismic def." 3D finite element modelling of visco elastic post-seismic relaxation
	DOIN	Mari-Pierre	CR CNRS	Geodesy	6	INSAR methodology
	LANCIERI	Maria	Chercheur IRSN	Seismology	9	Analyse strong motion data

	MORVAN	Sylvain	Ingénieur	Geodesy	18	Participate to field work, GPS data base, automatic data processing
	GRANDIN	Raphael	PostDoc CNES	Geodesy	6	INSAR data analysis and modelling
	xxx	xxx	PostDoc ANR	Sismology	18	Aftershocks relocation & data base
	DUCRET	Gabriel	PhD student	Geodesy	18	INSAR methodology
	FUENZALIDA	Amaya	PhD student	Seismology	15	Aftershocks & source studies
	METOIS	Marianne	PhD student	Geodesy	15	GPS: data acquisition, processing, modelling.
	RUIZ	Sergio	PhD student	Seismology	18	Source studies, analyses of strong motion data
	TRUBIENKO	Olga	PhD student	Modelling	18	3D finite element modelling of visco elastic post-seismic relaxation

IPGP						
Coordinateur/responsable	LACASSIN	Robin	DR CNRS	Tectonics	15	Direction & coordination Coordinator of task 4 "complexity" Forearc long term tectonics mechanical modelling supervisation
Autres membres	ARMIJO	Rolando	Physicien	Tectonics	15	Link between short-term and long-term geological and geomorphic observations
	SIMOES	Martine	CR CNRS	Geomorphology	12	Fluvial incisions and relation with coastal uplift.
	SOCQUET	Anne	Phys. Adj.	Geodesy	18	GPS data acquisition. INSAR data analysis. Modelling of geodetic data. Link between geodetic and geological data
	VILOTTE	Jean-Pierre	Physicien	Seismology	3	Coordination within the national/international framework (French post-seismic intervention, Caltech, GFZ-Potsdam, IRIS, ….)
	DELORME	Arthur	Ingénieur	Geodesy	3	Field work – data acquisition – INSAR processing
	COUDURIER	Aurélie	PhD student	Tectonics	10	
	XXX	XXX	PhD student	Tectonics	24	New PhD to be hired. Acquisition of geological field data and Mechanical modelling.
	BERNARD	Pascal	Physicien	Seismology	3	Expert

Collaborations extérieures						

	ASTROZA	Manuel	Prof U-Chile	Seismolgy		Source
	CAILLETAUD	Georges	Prof. Mines	Numerical methods		3D finite element
	CAMPOS	Jaime	Prof U-Chile	Seismolgy		Source
	COMTE	Diana	Prof U-Chile	Seismolgy		Aftershocks
	GARAUD	Jean-Didier	Chercheur ONERA	Numerical methods		3D finite element
	PARDO	Mario	Prof U-Chile	Seismolgy		Aftershocks
	PEYRAT	Sophie	Prof U-Chile	Seismolgy		Source
	RIETBOCK	Andreas	Prof U-Liverpool	Seismolgy		Aftershocks
	BEJAR-PIZARO	Marta	Chercheur IGM-Madrid	Geodesy		INSAR
	CARRIZO	Daniel	Chercheur U-Chile	Geodesy		GPS
	VARGAS	Gabriel	Chercheur U-Chile	tectonics		Neotectonics
	TOLEDO	Patrizio	PhD student	Seismolgy		Aftershocks

* à renseigner par rapport à la durée totale du projet

6. JUSTIFICATION SCIENTIFIQUE DES MOYENS DEMANDES / SCIENTIFIC JUSTIFICATION OF REQUESTED RESSOURCES

Actions/Budget per task

Task 1 : Source of Maule Eq

• Visits by our Chilean partners	21 000
a. Sophie Peyrat (1 to 2 months per year @ 3000 Euro per visit)	
b. Sergio Ruiz (4 months for 2012 and 2013 @6000 per visit)	
• Missions to Chile	7 500
a. Raul Madariaga (1 month per year @ 2500 Euro per visit)	
• Computers and other small furnitures	10 000
• Several publications in JGR, GRL or Nature geosciences, GJI is free	5 000
• Participation at AGU and EGU meetings	10 000
TOTAL for 3 years	53 500 Euros

Task 2 : Aftershocks

• 18 month post-doc (4083€/month TTC)	73 494
• 1 computer and disks for data storage and saving	3 000
• 4 visits to Liverpool, 2 persons for 3 days	4 400
Flight = 250x8= 2000€ +Per diem (100€/day, 2x3x4)=24x100	
• Participation to 2 EGU and 1 AGU meetings for 1 person	5 000
• Publications	3 000
• 2 trips to Chile	3 720
Flight : 2x1300€= 2600€+Per diem: 70€/day x 2 x 8	
TOTAL for 3 years	92 614 Euros

Task 3 : Coupling

1. 1 yearly GPS campaign (4 teams x 2 persons – 15 days) **x3** 18 800
   a. 4 Plane ticket (France – Chile) = 1300x4 = 5200E
   b. 4 car rentals (4x4 camionettas) = 1000x4 = 4000E
   c: gas (400l x 4 x 1E) = 1600E
   d: per diem (50E/day x 2 x 4 x 15) = 6000 E
   e: small consumables (batteries, tools, markers, glue, ...) = 1000E
   f: equipment transportation (freight, customs carnet ATA, taxi, etc…) = 1000E
2. InSAR & GPS processing / Elastic modelling

InSAR images will be provided at no cost by ESA through project AOE720, but our participation to the Fringe meeting organized by ESA is required.
To process the InSAR and GPS data sets, we will need dedicated servers at both ENS and IPGP with high processing and storage capacities. We also request here funding for acquisition of SARScape and ENVI/IDL softwares, that will be necessary for TopSAR ScanSAR Sentinel data processing. One SARScape licence is already at ENS and we only ask for annual renewal of the licence. We ask for another one to be installed at

IPGP. We also need funding for post-processing and modelling softwares (IDL/ENVI & Matlab) that will be used for both GPS and InSAR time-series analysis, as well as for elastic modelling proposed in Tasks 4.1, 4.2 and 5.1.

• 2 Data servers (Storage bay + applicative servers) 2 x 4000 €	8 000
• 2 x 20To of storage capacity (eg. 8 x 5To storage bricks) 2 x 4000 €	8 000
• 4 Laptops / desktops x 1500 €	6 000
• 1 SARScape licence for ENVI (Focussing, Interferometry and ScanSAR Interferometry Modules)	9 400
• Renewal SARScape licence 2 + 3 years = 5 x 2175 €	10 875
• 2 ENVI / IDL licences x 2800 €	5 600
• ENVI / IDL yearly licences renewal 4 x 510 €	2 040
• 2 Matlab licences x 2300 €	4 600
• Publication fees	5 000
• Participation at AGU, EGU and Fringe meetings	10 000
• Visits by our Spanish partner (M. Béjar-Pizarro) twice a year = 6 x 750€	4 500
Total for 3 years	130 415 Euros

Task 4 : Structural complexity

• 1 geological campaign each year (4 persons, 20 days) - plane tickets (including international + domestic flights) 1500€ x 4 = 6000€ - car rental (1 large 4x4 vehicle) 2400€ = 2400€ - field expanses (gas, per diem, etc, 70€ x 4 x 20) = 5600€	**x3**	14 000
• Visits by our Chilean partners (D. Carrizo, G. Vargas)		2 500
• Sampling and analytical costs for dating of geomorphic markers - small sampling material = 1 000€ - transport of samples from Chile to France = 1500€ - analytical costs (14C or OSL) : 30 samples x 600€ = 18 000€		20 500
• Participation to publication fees		5 000
• Participation to AGU/EGU		10 000
Total for 3 years		80 000 Euros

Task 5 : Post-seismic modelling

• Computers and other small furnitures	5 000
• Several publications in JGR, GRL or Nature geosciences, GJI is free	3 000
• Participation at AGU and EGU meetings	12 000
Total for 3 years	20 000 Euros

6.1. PARTENAIRE 1 / PARTNER 1 : ENS — 267 734 €

- *Équipement / Equipment*

No equipment (unit cost > 4000 Euros) is requested for this project

- *Personnel / Staff* — ***73 494 €***

We request a 18 month post doc, attributed to Task 2 « aftershocks ».
Under the supervision of Hélène Lyon-caen (coordinator of the task) and Andreas Rietbrock at Univ. of Liverpool, the post-doc will manage the whole data base for relocation, providing the general framework for focussed studies in which he will participate. He will also work on the relocation in the 3D model developed in Liverpool.

- *Prestation de service externe / Subcontracting*

No subcontracting

- *Missions / Travel* — ***154 240 €***

Field work	54 000
Trips/visits to/of collegues in Europe & Chili	36 620
Congress (EGU/AGU)	27 000

- *Dépenses justifiées sur une procédure de facturation interne / Costs justified by internal invoicies*

None

- *Autres dépenses de fonctionnement / Other expenses* — ***40 000 €***

Computer consumables	18 000
Publication fees	11 000
Laboratory overhead (4%)	11 000

6.2. PARTENAIRE 2 / PARTNER 2 : IPGP — 164 015 €

- *Équipement / Equipment*

No equipment (unit cost > 4000 Euros) is requested for this project

- *Personnel / Staff*

No personnel is requested by this partner

- *Prestation de service externe / Subcontracting*

No subcontracting

- *Missions / Travel* — ***69 000 €***

Field work	42 000
Trips/visits to/of collegues in Europe & Chili	7 000
Congress (EGU/AGU)	20 000

- *Dépenses justifiées sur une procédure de facturation interne / Costs justified by internal invoices*

None

- *Autres dépenses de fonctionnement / Other expenses* — ***95 015 €***

Sample analysis	20 500
Computers consumable	22 000
Licences	32 515
Publication fees	10 000
Laboratory overhead (4%)	10 000

7. ANNEXES / ANNEXES

Les annexes ne sont pas comptabilisées dans la limite des 40 pages à respecter.

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Perfettini, et al. Seismic and aseismic slip on the Central Peru megathrust. Nature, 465(7294):78–81, 2010. ISSN 0028-0836.

Peyrat, S., Madariaga, R., Buforn, E., Campos, J., Asch, G. & Vilotte, J.P., 2010. Kinematic rupture process of the 2007 Tocopilla earthquake and its main aftershocks from teleseismic and strong motion data, Geophys. J. Int., 182, 1411–1430.

Pollitz, F., R. Burgmann and P. Banerjee (2006), Post-seismic relaxation following the great 2004 Sumatra-Andaman earthquake on a compressible self-gravitating Earth, GJI, 167, 397-42

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Puysségur, B., R. Michel, and J.-P. Avouac (2007), Tropospheric phase delay in interferometric synthetic aperture radar estimated from meteorological model and multispectral imagery, J. Geophys. Res., 112, B05419, doi:10.1029/2006JB004352.

Radiguet, M., F. Cotton, M. Vergnolle, M. Campillo, B. Valette, V. Kostoglodov and N. Cotte (2010), Spatial and temporal evolution of a long term slow slip event: the 2006 Guerrero Slow Slip Event, Geophys. J. Int., doi: 10.1111/j.1365-246X.2010.04866.x.

Rietbrock et al., Aftershock seismicity of the Mw 8.8 Maule earthquake of 27 February 2010 using a 2D velocity model, AGU Fall meeting 2010

Rogers and Draggert, 2003, Episodic tremor and slip on the Cascadia subduction zone: The chatter of silent slip, Science, Vol. 300, n° 5627, pp 1942-1943, DOI 10.1126/Science.108478

Ruegg, J.C. et al., 1996. The Mw = 8.1 Antofagasta (North Chile) earth- quake of July 30, 1995: first results from teleseismic and geodetic data, Geophys. Res. Lett., 23, 917–920.

Ruegg J.C., et al., 2002, Interseismic strain accumulation in south central Chile from GPS measurements, 1996-1999, *Geophys. Res. Lett., 29, no 11*, 10.1029/2001GL013438.

Ruegg, J.C., et al., 2009, Interseismic strain accumulation measured by GPS in the seismic gap between Constitucion and Concepcion in Chile, *PEPI,* 10.1016/j.pepi.2008.02.015.

Ruff L. (1992). Asperity distributions and large earthquake occurrence in subduction zones, *Tectonophysics*, Vol. 211, Pages 61-83

Schwartz, S. Y., and J. M. Rokosky (2007), Slow slip events and seismic tremor at circum-pacific subduction zones, Rev. Geophys., 45, RG3004, doi:10.1029/2006RG000208.

Shelly D., G. Beroza, S. Ide and S. Nakamula (2006, Low-frequency earthquakes in Shikoku, Japan, and their relationship to episodic tremor and slip, *Nature* **442**, 188-191, doi:10.1038/nature04931

Taylor, M., Peltzer, G. Current slip rates on conjugate strike-slip faults in central Tibet using synthetic aperture radar interferometry. J. Geophys. Res. 111 (B12402), 2006

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Wright, T., Parsons, B. and E. Fielding, Measurement of interseismic strain accumulation across the North Anatolian fault by satellite radar interferometry, Geophysical Research Letters, 28, pp 2117-2120, 2001.

Wright, T., et al. (2004), InSAR Observations of Low Slip Rates on the Major Faults of Western Tibet, Science, 305, 236-239.

Yagi, Y., M. Kikuchi, and T. Nishimura (2003), Co-seismic slip, post-seismic slip, and largest aftershock associated with the 1994 Sanriku-haruka-oki, Japan, earthquake, Geophys. Res. Lett., 30(22), 2177, doi:10.1029/2003GL018189.

7.2. BIOGRAPHIES / CV, RESUME

Rolando ARMIJO

BORN : December 14, 1950 at Santiago, Chile; Male.

EDUCATION :

Doctorat d'Etat ès Sciences, University of Paris (1986).
Doctorat de 3ème cycle, Structural Geology, University of Paris (1977).
B.Sc. in Earth Sciences, University of Paris (1975).

POSITIONS HELD :

Professor of Geophysics (Physicien), Institut de Physique du Globe de Paris (IPGP), 1988-present.
Head of Tectonics Laboratory, IPGP, 1997-2001.
Associate Professor, Institut de Physique du Globe de Paris, 1980-1988.
Research Fellow, CICESE, Mexico, 1978-1980.
Assistant, University of Paris, 1977-1978.

HONORS :

"1994 Best Paper Award", Structural Geology and Tectonics Division, Geological Society of America.
Prize "Eugénie de Rosemont" (Sciences), Chancellerie des Universités de Paris, 1997.
Prize "Constantinos Ktena" (Geology), Academy of Athens, 1997.

SCIENTIFIC CONTRIBUTIONS :

(1) Pioneered interpretation methods in geomorphology and active continental tectonics, produced comprehensive studies in different regions as the Himalaya and Tibet, the Andes and the Perú-Chilean subduction zone, the East-African Rift, the Mediterranean region. Contributed to studies of submarine deformation in the East-Pacific Rise and in Turkey.

(2) Mapped many major active faults using fieldwork, geophysical data and various remote-sensing techniques; studied the deformation associated to recent and past earthquakes; contributes to leading-edge current studies of deformation transients related to the seismic cycle using space geodesy (GPS and SAR interferometry), seismology and mechanical modelling.

(3) Leaded an important international multi-disciplinary project on the seismic hazard in Turkey and the North Anatolian Fault, including studies on land and oceanographic cruises to study the Sea of Marmara pull-apart.

Recognised among the 349 ISI Highly Cited Researchers in Geosciences, worldwide, or among the 166 Highly Cited Researchers in France, for all ISI disciplines taken together (*http://isihighlycited.com/*).
Published ISI international journals: 67; Total citations: more than 4700; Citations in 2010: 387; H-index: 33.

CHOICE OF RECENT PUBLICATIONS :

Armijo, R., et al., Submarine fault scarps in the Sea of Marmara pull-apart (North Anatolian Fault): Implications for seismic hazard in Istanbul, Geochem. Geophys. Geosyst., 6, Q06009, doi:10.1029/2004GC000896, 2005.

Pondard, N., Armijo, R. et al., Fault interactions in the Sea of Marmara pull-apart (North Anatolian Fault): earthquake clustering and propagating earthquake sequences, Geophys. J. Int., 171, 1185-1197, doi:10.1111/j.1365-246X.2007.03580.x*,* 2007.

Hubert-Ferrari, A., G. King, J. van der Woerd, I. Villa, E. Altunel & R. Armijo, Long-term evolution of the North Anatolian Fault: new constraints from its eastern termination, *Geological Society, London, Special Publications*, **311**, 133-154, DOI: 10.1144/SP311.5, 2009.

Armijo R., Rauld R., Thiele R., Vargas G., Campos J., Lacassin R., Kausel E., The West Andean Thrust (WAT), the San Ramón Fault and the seismic hazard for Santiago (Chile), Tectonics, vol.29, TC2007, doi:10.1029/2008TC002428, 2010.

Béjar-Pizarro M., Carrizo D., Socquet A., Armijo R. et al., Asperities and barriers on the seismogenic zone in North Chile: state-of-the-art after the 2007 Mw 7.7 Tocopilla earthquake inferred by GPS and InSAR data. Geophys. J. Int., 183, 390-406, doi: 10.1111/j.1365-246X.2010.04748.x, 2010.

Luce Fleitout born march 7th 1955

Studies: Ecole Normale supérieure from 1974 to 1978

Positions: Chagé de recherche CNRS, then Directeur de recherche CNRS
(in Orsay university from 1978 to 1989, in Ecole Normale Supérieure since 1989)

Fields of research:
Modeling and data treatment concerning:
Lithospheric stress field and forces moving the plates
Geoid and gravity anomalies
Mantle dynamics (convection at the base of the plates, phase transitions)
Post-glacial rebond
Post-sismic rebond

International collaborations
USA (UCLA, Arizona University, Stony Brook, MIT)
Tchek Republik (Prague)
Germany (Gottingen)

Administration of science
Chargé de mission CNRS from 1991 to 1996 (work at the Earth science direction of CNRS dealing with promotions of scientists, research grants etc...)
Member of Comité national from 1996 to 2000
Member of comités de spécialiste (Montpellier, Paris)
Member of numerous INSU grant commitees

Teaching administration
responsable de DEA de 2002 à 2007

Honors
Prix de l'académie des Sciences (cartographie) in 1997 (Science academy price)
AGU member

5 Publications récentes
1. Garaud, J.D., L. Fleitout and G. Cailletaud Simulation parallèle de la relaxation post-sismique dans la région de Sumatra, 9eme colloque en calcul de structures, Giens 2009, hal00399738, juin 2009
2. Cattin et al. Stress change and effective friction coefficient along the Sumatra-Andaman sagaing fault system, G3, march 2009
3. Krien, Y., and L. Fleitout, gravity above subduction zones and the forces controlling plate motions, JGR, doi101029, 2007JB005279, 2008
4. Krien Y, Fleitout L , Accommodation of volume changes in phase transition zones: Macroscopic scale JGR, Volume: 115 Article Number: B03403 Published: MAR 2 2010
5. Cadek, O, Fleitout L, Effect of lateral viscosity variations in the core-mantle boundary region on predictions of the long-wavelength geoid, STUDIA GEOPHYSICA ET GEODAETICA Volume: 50 Issue: 2 Pages: 217-232 PUBLISHED: APR 2006

Robin LACASSIN

http://www.ipgp.fr/~lacassin

Born May, 19th, 1959

Directeur de recherche CNRS DR2 - Director of IPGP Tectonics Lab. since 2007.

PhD Thesis 1984 Université de Montpellier, supervisor Maurice Mattauer.
HDR 1992. CR CNRS 1985. DR since 2001.

Geologist, specialist of large-scale tectonics, mountain building processes, fault and shear zone evolution. Works on large-earhquakes in relation with fault mechanics, geomorphic and geological evolutions at different time and space scales.

48 published papers in international journals, cited 1700 times (140-180 citations/year during past 4 years), H-factor 21.

<u>Choice of recent Publications</u> :

Lacassin, R., F. Valli, N. Arnaud; P.H. Leloup, J.-L. Paquette, L. Haibing. P. Tapponnier, M.L. Chevalier, S. Guillot, G. Maheo-G, Z.Q. Xu, Large-scale geometry, offset and kinematic evolution of the Karakorum fault, Tibet. Earth Planet. Sci. Lett., 219 (3-4), 255-269, 2004.

King, G., A. Mignan, D. Bowman, R. Lacassin, R. Dmowska, Seismic activity in the Sumatra-Java region prior to the December 26, 2004 (Mw=9.0-9.3) and March 28, 2005 (Mw=8.7) earthquakes, Earth Planet. Sci. Lett., 244, 639-654, 2006.

Leloup, P.H., N. Arnaud, E.R. Sobel, R. Lacassin, Alpine thermal and structural evolution of the highest external crystalline massif: the Mont Blanc, Tectonics, 24, TC2402, 2006.

Mahéo, G., P.H. Leloup, F. Valli, R. Lacassin, N. Arnaud, J.-L. Paquette, A. fernandez, L. Haibing, K.A. Farley, P. Tapponnier, Post 4 Ma initiation of normal faulting in southern Tibet. Constraints from the Kung Co half graben, Earth Planetary Science Letters, 256, 233-243, 2007.

Valli, F., N. Arnaud, P. H. Leloup, E. R. Sobel, G. Mahéo, R. Lacassin, S. Guillot, H. Li, P. Tapponnier, and Z. Xu (2007), Twenty million years of continuous deformation along the Karakorum fault, western Tibet: A thermochronological analysis, Tectonics, 26, TC4004, doi:10.1029/2005TC001913.

Valli, F., P. H. Leloup, J. Paquette, N. Arnaud, H. Li, P. Tapponnier, R. Lacassin, S. Guillot, D. Liu, E. Deloule, Z. Xu, and G. Mahéo (2008), New U−Th/Pb constraints on timing of shearing and long−term slip−rate on the Karakorum fault, Tectonics, 27, TC5007, doi:10.1029/2007TC002184, 2008.

Armijo R., Rauld R., Thiele R., Vargas G., Campos J., Lacassin R., Kausel E. (2009), The West Andean Thrust (WAT), the San Ramón Fault and the seismic hazard for Santiago (Chile), Tectonics, doi:10.1029/2008TC002428, in press, 2010.

Hélène Lyon-Caen

born 11/03/1956
Directrice de Recherche, CNRS, Laboratoire de Géologie, Ecole Normale Supérieure
helene.lyon-caen@ens.fr

Education :
1976 : Ecole Normale Supérieure, Sèvres, mathématiques
1978 : DEA Géophysique interne
1980 : Thèse de 3ème cycle, Université Paris 7, sismologie
1985 : PhD thesis, Massachussets Institute of Technology, geophysics

Research interests:
seismotectonics, seismic sources, relationship active faults-seismicity-crustal deformation, seismic cycle, fault interactions

Responsabilities:

- Deputy director of the Laboratoire de Géologie, ENS since 2006-
- Head of the "Dynamique de la Terre" group at Laboratoire de Géologie, ENS: 2003-2006
- Workpackage leader in various EC projects related to Corinth Rift (EPOCH, SeisfaultGreece, Aegis, Corseis, 3HAZ) and ANR (Cattel@CRL, Siscor)

Awards: bronze medal of CNRS: 1993

Advisor of 7 Ph.D. thesis, 44 publications in international journals

5 Publications over the last 5 years:

Bernard P., **H. Lyon-Caen**, P. Briole, A. Deschamps, K. Pitilakis, M. Manakou, F. Boudin, C. Berge, K. Makropoulos, D. Diagourtas, P. Papadimitriou, F. Lemeille, G. Patau, H. Billiris, H. Castarede, O. Charade, A. Nercessian, A. Avallone, J. Zahradnik, S. Sack, A. Linde, F. Pacchiani, Seismicity, deformation and seismic hazard in the western rift of Corinth: new insights from the Corinth Rift Laboratory (CRL), *Tectonophysics, 426, doi:10.1016/j.tecto.2006.02.012,* 2006

Jansky, J., V. Plicka, **H. Lyon-Caen,** and O. Novotny (2007), Estimation of velocity in the uppermost crust in a part of the western Gulf of Corinth, Greece, from the inversion of P and S arrival times using the neighbourhood algorithm, *J. Seismol.*, v. 11(2), pp. 199-204

Lyon-Caen H., E. Barrier, C. Lasserre, A. Franco, I. Arzu, L. Chiquin, M. Chiquin, T. Duquesnoy, O. Flores, O. Galicia, J. Luna, E. Molina, O. Porras, J. Requena, V. Robles, J. Romero, R. Wolf, Kinematics of the north american – caribbean-cocos plates in Central America from new GPS measurements across the Polochic-Motagua fault system, *Geophys. Res. Lett.*, 33, L19309, doi:10.1029/2006GL027694, 2006

Pacchiani F. and **H. Lyon-Caen**, Geometry and spatio-temporal evolution of the 2001 Agios Ioanis earthquake swarm (Corinth Rift, Greece**)**, *Geophys. J. Int*., DOI: 10.1111/j.1365-246X.2009.04409.x., 2010.

Cociani L., C. Bean, **H. Lyon-Caen**, F. Pacchiani and A. Deschamps, Coseismic velocity variations caused by static stress changes associated with the 2001 Mw=4.3 Agios Ioannis earthquake in the Gulf of Corinth, Greece, *J. Geophys. Res*, v. 115, doi : B07313 10.1029/2009jb006859, 2010

MADARIAGA, Raul Ivan
Professeur Classe Exceptionnelle 2

Studies
Civil Engineer, Univeristy of Chile, 1967
Ph.D. in Geophysics from M. I. T., Juin 1971.

Cursus
- Assistant Professor, Dept. of Geophysics, University of Chile, Santiago, 1971-1973
- Research Associate, EAPS, Mass. Instituteof Technology, 1974-1976.
- Physicien Adjoint, IPGP, University of Paris VI, 1977-1979.
- Professeur Université Paris VII Denis Diderot, 1979-1998
- Membre Senior de l'Institut Universitaire de France, 1993-1998.
- Profeseur CE2, Ecole Normale Supérieure, depuis 1998.

Administration de la recherche
- Directeur UMR CNRS Laboratoire de Sismologie, IPGP – Univ. paris 7. 1985-1997.
- Membre du CNAP 1992-2000. Président du CNAP 1996-2000.
- Directeur de l'UMR 8538 Laboratoire de Géologie. ENS, 2000-2006.

Prix Distinctions
Felllow American geophysical Union
Senior Member of Institut Universitaire de France, 1993-1998.
Great Medal of the President of the University of Chile, 1998.
Stephan Mueller Medal of the European Geophysical Society, 1999.
Harry F. Reid Medal of the Seismological Society of America, 2004.

Published 123 papers in International journals

Advised 47 Ph.D. thesis

5 Main publications of last 5 years
Adda-Bedia, M. & Madariaga, R., Seismic radiation from a kink on an antiplane fault, *Bull. Seismol. Soc. Am.*, **98**, 2008.
Vigny, C., A. Rudloff, J.C. Ruegg, R. Madariaga, J. Campos, M. Alvarez. Upper plate deformation measured by GPS in the Coquimbo Gap, Chile. *Phys. Earth Planet. Int.* , **175**, 86-95, 2009.
Madariaga, R., Vigny, Ch., Métois, M., and Campos, J., Central Chile finally breaks *Science* **238**, 181-182, 2010.
Peyrat, S., Madariaga, R.,Buforn E., Campos, J., Asch, G. and Vilotte, J.P. Kinematic rupture process of the 2007 Tocopilla earthquake and its main aftershocks from teleseismic and strong-motion data. *Geophys. J. Int.* **182**, 1411-1430, 2010.
Di Carli, S., C. François-Holden, S. Peyrat, and R. Madariaga (2010), Dynamic inversion of the 2000 Tottori earthquake based on elliptical subfault approximations *J. Geophys. Res.*, 115, B12328, doi:10.1029/2009JB006358, 2010

SOCQUET Anne
Born 06/11/1976
Married, 2 children

EDUCATIONAL BACKGROUND

2003 – Ph.D. in Geophysics, Ecole Normale Supérieure / Université Paris XI, Paris, France
2000 – M.S. in Geophysics, Ecole Normale Supérieure / Université Paris XI , Paris, France
1999 – Magistere in Earth Sciences, Ecole Nationale Supérieure, Paris, France
1997 – Ba.Sc. in Mathematics, University Blaise Pascal, Clermont-Ferrand, France

PROFESSIONAL EXPERIENCE

2010 – Invited researcher at Departamento de Geofisica, Universidad de Chile, Santiago
since 2006 – Associate Physicist at Institut de Physique du Globe de Paris
2005-2006 – Postdoc at UCLA, Department of Earth and Space Sciences, Los Angeles, USA
2004 – Postdoc at Department of Earth Observation and Space Systems, Delft University of Technology, The Netherlands
2003-2004 – Assistant professor (ATER) at Versailles University

CURRENT RESEARCH ACTIVITY

Space geodesy (InSAR + GPS) applied to seismotectonics and faults behavior during the earthquake cycle (Myanmar, Indonesia, North Tibet, Chile or Ethiopia).

LIST OF 5 SELECTED PUBLICATIONS

14 + 4 articles in peer-review journals, h-index : 8, citation index : 287
(complete list on http://www.ipgp.fr/~socquet/publication)

Grandin, R., **A. Socquet**, E. Jacques, N. Mazzoni, J.-B. de Chabalier, and G. C. P. King, *Sequence of rifting in Afar (Manda-Hararo rift, Ethiopia, 2005-2009): time-space evolution and interactions between dikes from InSAR and static stress change modeling*, **J. Geophys. Res.**, doi:10.1029/2009JB000815 B09403, 2010.

Bejar-Pizzaro M., Carrizo D., **Socquet A.**, Armijo R. et al. *Asperities, barriers and transition zone in the North Chile seismic gap: State of the art after the 2007 Mw 7.7 Tocopilla earthquake inferred by GPS and InSAR data*, **Geoph. Journ. Int.**, GJI-S-09-0648, doi: 10.1111/j.1365-246X.2010.04748.x , 2010.

Grandin R., **Socquet A.**, Doin MP., de Chabalier JB., Jacques E, King G. *Transient rift opening in response to multiple dike injections at Manda Hararo (Afar, Ethiopia) imaged by time-dependent elastic inversion of InSAR data.* **J. Geophys. Res**, 115, B09403, doi:10.1029/2009JB006883, 2010.

Grandin R., **Socquet A.**, Binet R., Klinger Y., Jacques E., De Chabalier J.B., King G., Lasserre C., Tait S., Tapponnier P, Delorme A, Pinzuti P. *The September 2005 Wal'is-Dabbahu rifting event, Afar (Ethiopia): constraints provided by geodetic data*, **J. Geophys. Res** 114, B08404, doi:10.1029/2008JB005843, 2009.

Socquet, A., C. Vigny, N. Chamot-Rooke, W. Simons, C. Rangin, and B. Ambrosius (2006), *India and Sunda plates motion and deformation along their boundary in Myanmar determined by GPS*, **J. Geophys. Res.**, 111, B05406, doi:10.1029/2005JB003877.

VIGNY Christophe
Born 02 Mars 1964; Married, 3 children; now "Directeur de recherches" at CNRS

EDUCATION/DIPLOMAS

1987:	Master of physics – option astronomy and fluid mechanics
1989:	PhD in Earth Sciences entitled "Geoïd and internal dynamics of the Earth"
1990:	PostDoc at ONERA "modeling of space gravimetric measurements: ARISTOTELES/GRADIO satellite project"
1991:	PostDoc at MIT "Spatial Geodesy (GPS) and plate tectonics"
2006:	H.D.R. entitled "GPS: from plate tectonics to seismology"

PROFESSIONAL EXPERIENCE

1999-2004	Head of geophysics team of the "laboratoire de Géologie" (8 full-time researchers – 1 administrative staff).
1999-2003	"Chargé de mission" at INSU (l'Institut National des Sciences de l'Univers) - for satellite observation of the Earth.
2000-2004	Member of the scientific comitee of « Institut Geographique National » (IGN)
2002-2006	Director of GDR « Géodesie-Géophysique » a multi-institute cooperation implying CNRS, CNES, IGN, CEA, IRD, SHOM).
2007-2008	Co-Director of International Laboratory (LIA) "Montessus de Ballore" a joint-venture between French CNRS and Chilean U-Chile
2008	invited professor at DGF, U-Chile, Santiago, Chile (4 months)
2009-	Member of the Scientific Advisory Board of the Earth Observatory of Singapore

Since 1991, at "Laboratoire de Géologie" at ENS, Paris, France, working on the geodetic measurement (GPS) of the Earth crustal deformation associated to active faults with high seismic hazard.My last works were 1/ a comprehensive study of the sequence of earthquakes since 2004 on the Sumatran trench & 2/ a post-seismic intervention after the Mw8.8 Maule, Chile earthquake.

Advisor of 9 PhD thesis

PUBLICATIONS

Author of 41 publications in peer-reviewed int. journals [Citation Index 1207 – H-Index 19] 47 communications in congress, and 13 articles in broad audience journals and book chapters. (complete list on http://www.geologie.ens.fr/~vigny/biblio.html)

5 most recent and/or most significant publications:

1. Insight into the 2004 Sumatra-Andaman earthquake from GPS measurements in southeast Asia
   Vigny, C., W. Simons, S. Abu, R. Bamphenyu, et al.
   Nature, vol 436,14/07/05, pp201-206,doi:10.1038/nature03937, 2005
2. A decade of GPS in SE Asia: Resolving Sundaland motion and boundaries
   Simons, W., A. Socquet, **C. Vigny**, B. Ambrosius, et al.
   J. Geophys. Res., 112, B06420, doi:10.1029/2005JB003868*,* 2007.
3. Upper plate deformation measured by GPS in the Coquimbo gap, Chile
   Vigny, C., A. Rudloff, J.C. Ruegg, R. Madariaga, J. Campos, M. Alvarez
   PEPI, doi, 2009.
4. Interseismic strain accumulation measured by GPS in the seismic gap between Constitucion and Concepcion in Chile
   Ruegg, J.C., A. Rudloff, **C. Vigny**, et al., *PEPI,* Vol 175, issue 1-2, June, 10.1016/j.pepi.2008.02.015 , 2009.
5. Central Chile finally breaks
   Madariaga, R., M. Métois, **C. Vigny** and J. Campos
   Science; 2010.

7.3. Implication des personnes dans d'autres contrats / Staff involvment in other contracts

Part.	Nom de la personne participant au projet / name	Personne. Mois / PM	Intitulé de l'appel à projets, source de financement, montant attribué / Project name, financing institution, grant allocated	Titre du projet : Project title	Nom du coordinateur / coordinator name	Date début & Date fin / Start and end dates
N°1	Luce Fleitout	12	Action ALEA sur projet INSU	Déformation pré et post-sismique dans la région de Sumatra	Fleitout	2011
N°1	Hélene Lyon-Caen	18	ANR Blanc 247 kE	SISCOR	P. Bernard	2011-2014
N°1	Raul Madariaga					
N°1	Christophe Vigny	3	Action ALEA sur projet INSU	Déformation pré et post-sismique dans la région de Sumatra	Fleitout	2011
N°2	Robin Lacassin	4	Action SYSTER sur projet INSU	Diachronisme du west andean thrust		2011
N°2	Rolando Armijo	4	Action SYSTER sur projet INSU	Diachronisme du west andean thrust		2011
N°2	Robin Lacassin	3	Action ALEA sur projet INSU	Projet Aléa Sismique en Haiti		2011
N°2	Pascal Bernard	3	ANR CATELL	ASEISMIC	D.MARSAN	2008-2011
N°2	Pascal Bernard	3	ANR RISKNAT	LINES	J.CHERY	2009-2011
N°2	Pascal Bernard	20	ANR BLANC	SISCOR	P.BERNARD	2011-2014

N°2	Jean-Pierre Vilotte					
N°2	Anne Socquet	18	Programme Jeunes Chercheurs 2009 ANR 276 keuros	DORA (Dynamics of rifting in Afar)	C. Doubre	2009-2013
N°2	Anne Socquet	14.4	Programme Jeunes Chercheurs 2008 ANR 276 keuros	The Altyn Tagh fault slip rate paradox	P.Vernant	2008-2011
N°2	Anne Socquet	10	PNTS 2009 25 keuros	Déformations transitoires par InSAR, corrélation d'images et cGPS	A. Socquet	2009-2011