QSHA - Activity REPORT - Semester S3
(global report at half-way of the project)

WP1 – Construction of reliable and relevant models for wave propagation simulation purposes

WP 1-1 METHODOLOGICAL IMPROVEMENTS FOR 3D RECONSTRUCTIONS (P.I. C. CORNOU)

Participants: Pierre Gouedard, Philippe Roux, Marc Wathelet, Seiji Tsuno, Cécile Cornou, B. Guillier (LGIT)

Activity summary

Several scientific issues have been addressed from 01/2006:

- Within the framework of the last symposium on the Effects of Surface Geology on seismic motion (ESG2006, Grenoble, august 30th – September 1st 2006), an international noise blind test was proposed in order to compare surface waves dispersion characteristics derived from competing analysis approaches and to make a clear assessment regarding the potential of microtremor array studies for site condition estimation. This experiment outlines that the following critical issues need to be improved in the future if one wants to use ambient vibration recordings for estimating site conditions: 1) accurate identification and interpretation of surface wave modes; 2) introduction of prior information or combined/joint inversion with other reconnaissance data; 3) quantitative and meaningful evaluation of confidence intervals on shear-wave profiles. (Cornou et al., 2006)
- Performance of the newly proposed cross-correlated technique in retrieving subsurface structure has been tested against classical ambient noise array analysis (FK, SPAC). Noise synthetics have been simulated in a complex shallow structure at a given array for both isotropic and directional spatial distribution of sources seismic ambient noise at a given array layout. Noise synthetics were then analysed by using High Resolution frequency-wavenumber technique (HRFK), Spatial autocorrelation (SPAC) technique and the proposed noise correlation technique. Results outline that noise correlation enables to provide phase velocity estimates of both Rayleigh and Love waves within a wider frequency band than classical techniques (Figure 1). (Gouedard et al., 2007)
- First analysis of the earthquakes data from the last temporary seismological experiment in Grenoble (july-october 2005; 19 broad-band stations deployed within the Grenoble basin; experiment funded by the European SISMOVALP project) has outlined the variability in some area of the site response at high frequency (between 2 and 5 Hz) and the importance of the shallowest layers on the ground motion amplification (Chaljub et al., 2006). Active surface waves measurement (MASW) campaign has been conducted in January 2006 in the Grenoble city in order to better constrain velocity structure within the shallowest layers (< 50 m). Methodological developments related to this experiment are detailed in WP1.3 section.
- Finally, we have pursued the work initiated within the EU-SESAME project on the potentiality of ambient noise based technique to retrieve reliable information on site conditions in 2D and 3D structures. This work was performed by using ambient noise synthetics computed within the SESAME project and was focused on the noise H/V technique. Results show that H/V noise technique can be used as an alternative tool to classical geophysical exploration only if wave propagation is 1D and should be disregarded in case of 2D/3D structures, characterized by H/V curves exhibiting broad or plateau-like shapes (Guillier et al., 2006; Cornou et al., 2007).

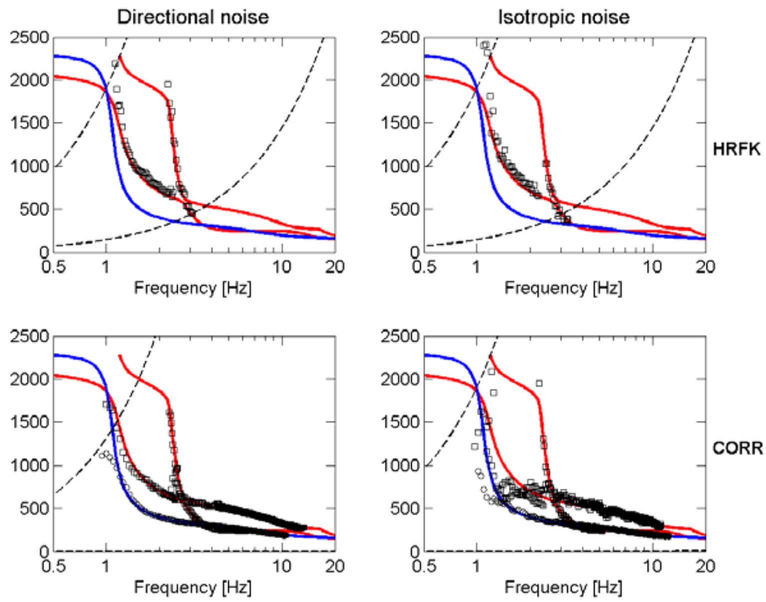


Figure 1: (Top) Phase velocity estimates of fundamental and higher modes of Rayleigh waves (black squares) derived from frequency-velocity normalized histograms obtained by using HRFK analysis. (Bottom) Phase velocity estimates of fundamental and higher modes of Rayleigh and Love waves (black squares) derived from frequency-velocity diagrams obtained by using correlation technique. Limits of array response given the following wavelength limits [□$_{min}$□2d$_{min}$□$_{max}$ = 3d$_{max}$]are indicated by dashed lines. Theoretical dispersion curves of fundamental and higher modes of Rayleigh and Love waves are indicated by red and blue lines, respectively.

Scientific issues and perspectives

The very good performance of the cross-correlation technique compared to classical ambient noise array studies for retrieving subsurface structure makes this technique very attractive. However, before any routine application of this technique, further efforts are needed to better estimate the capabilities and limits of this technique, and to determine whether this technique is also suitable or not for retrieving the ellipticity of Rayleigh waves, quantity which will greatly improve estimation of velocity structure through joint ellipticity-phase velocity inversion.

Estimation of dispersion curve over a wide band of frequencies requires to recover both the short and long wavelengths of the wavefield. Recovering the shortest wavelengths of the wavefield by using ambient noise technique is especially difficult because of significant contribution of higher modes to the wavefield, as outlined by the ESG2006 Noise Blind Test. An alternative consists then in combining phase velocities obtained with active and passive measurements (i.e. ambient array noise and MASW measures).

In connection with the EU-NERIES project, ambient noise array and MASW experiments are planned in autumn 2007 at several accelerometric sites in Europe. At those sites, we plan to compare results obtained from correlation technique with the ones obtained through combination of active and passive measurements. This study will allow to better assess the potentiality of correlation technique for real world experiments.

<u>Planning</u>:

- autumn 2007: field measurements at several sites in Europe (NERIES project) and tentative extraction of ellipticity of Rayleigh waves by using correlation technique;
- spring 2008: study of the potentiality and limits of the correlation technique on the acquired field data by comparing results from correlation technique with those obtained by combining active and passive surface waves measurements;

Scientific productions

Chaljub, E., C. Cornou, J. Verbeke, J. Converset, C. Voisin, L. Stehly, J.-R. Grasso, P. Guéguen, S. Roussel, P. Roux, S. Hatton and M. Campillo. 2006. Measurement and variability study of site effects in the 3D glacial valley of Grenoble, French Alps, in Proc. 3nd Int. Symp. on the Effects of Surface Geology on Seismic Motion, Grenoble, 29 August - 01 September, 2006, Bard, P.Y., Chaljub, E., Cornou, C., Cotton, F. and Guéguen, P. Editors, LCPC Editions, paper# 154

Cornou, C., B. Guillier, K. Boussoura, K. Selmi, F. Renalier. Limite de la technique H/V comme outil d'exploration géophysique pour les structures 2D et 3D, colloque AFPS, 4-8 Juillet 2007.

Cornou, C., Ohrnberger, M., Boore, D. M., Kudo, K., Bard P.-Y., 2006.Using ambient noise array techniques for site characterisation: results from an international benchmark, in Proc. 3nd Int. Symp. on the Effects of Surface Geology on Seismic Motion, Grenoble, 29 August - 01 September, 2006, Bard, P.Y., Chaljub, E., Cornou, C., Cotton, F. and Guéguen, P. Editors, LCPC Editions, paper NBT.

Cornou, C., Ohrnberger, M., Boore, D. M., Kudo, K., Bard P.-Y., 2006.Using ambient noise array techniques for site characterisation: results from an international benchmark, First European Conference on Earthquake Engineering and Seismology (a joint event of the 13th ECEE & 30th General Assembly of the ESC) Geneva, Switzerland, 3-8 September 2006

Guillier, B, C. Cornou, J. Kristek, P. Moczo, S. Bonnefoy-Claudet, P.-Y. Bard, D. Faeh, 2006. Simulation of seismic ambient vibrations: does the H/V provide quantitative information in 2D-3D structures ?, *Third International Symposium on the Effects of Surface Geology on Seismic Motion, P.-Y. Bard, E. Chaljub, C. Cornou, F. Cotton, P. Guéguen Eds, Grenoble, France, 30 August - 1 September 2006, paper 185.*

Roux, P., P. Gouedard, C. Cornou, 2007. Dispersion curves and small scale geophysics using noise cross-correlation techniques, 153rd Meeting of the Acoustical Society of America, Salt lake city, 4-8th June 2007.

WP 1-2 CONSTRUCTION OF A CRUSTAL STRUCTURE FOR COSTAL AREAS (P.I.: A. DESCHAMPS, GA)

WP 1-3 RECONSTITUTION OF SURFACE STRUCTURES FOR A FEW AREAS (PI : AM DUVAL, CETE M)

Participants : Etienne Bertrand, Anne-Marie Duval (CETE Méditerranée), Cécile Cornou, Seiji Tsuno, Emmanuel Chaljub (LGIT), Gabriel Courrioux (BRGM)

Nice model :

WP1-3-a: A first 3D model was established from data compiled by CETE Méditerranée over one decade thanks to GEM-GEP project: borehole data (around 450) were homogeneized, formatted and interpolated over the territory thanks to GDM geomodeler. A precise geological map (1/5000) and a MNT (50 m) were also used to constrain the surface limits. Local experts controlled the resulting 3D model. The same data were used with the BRGM Geomodeler to produce another model (which is now distributed among French scientific partner).

1) These two models (GDM/Geomodeler) were compared. Each one reveals to be far from realistic expected model in some part of the territory: in the northern downtown for the Geomodeler one, in the Var valley for the GDM one. These differences are due both to the interpolation and to the control points.

2) From this first stage, new data have been collected: 30 borehole data and bedrock depth resulting from a microtremor dense array in the center (RAP site: NALS). The GDM model has been improved taking into account these new data. Another geological profil interpretation is taken into account in the Var valley. The surface model is based on a 10 m step MNT. The resulting model is called CETE10.

3) The next step is linked to the ingoing microtremor measurements. The resulting H/V curves will produce resonance frequency (Fo). Assuming Vs, the total alluvial depth will be derived from Fo measurements. These data are planed to be incorporated in the CETE10 model during the year 2007.

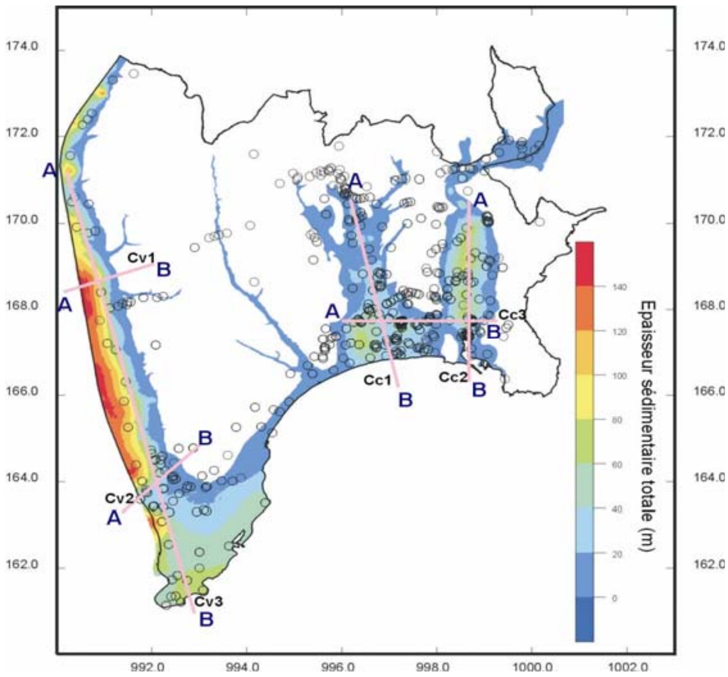


Figure 2 : Bore-holes and cross-section in Nice model

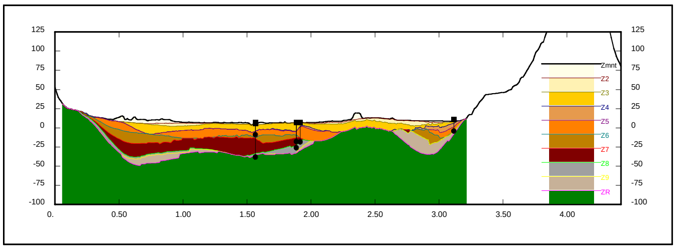


Figure 3 : East-West central cross section – Modèle CETE10

Grenoble model :

DETERMINATION OF SUPERFICIAL STRUCTURES IN THE GRENOBLE BASIN
Seiji TSUNO, Cecile CORNOU, Pierre-Yves BARD (LGIT)

In order to achieve a reliable broad-band nmerical simulation of earthquake ground motions, it is necessary to evaluate the site conditions including superficial structural models. In the Grenoble Basin, several geophysical and geotechnical surveys have been already carried out for understanding the deep velocity structures (Bettig et al., 2001; Nicoud et al., 2002; Vallon, 1999). However, only very few shallow velocity profiles are available with the required precision, especially for depths smaller than 30 to 50 m. As the superficial shear-wave velocity structures is critically affecting the response of common buildings, we applied the MASW measurement in the Grenoble sedimentary basin.

The MASW measurements (e.g. Park et al., 1999) were performed in the Grenoble Basin during January, 2007 to determine the superficial basin structures. We selected 19 measurement sites especially in the north, the south and the west sides of the Grenoble Basin : some previous MASW measurements had been already performed by Bitri et al., 2003 (BRGM) in the east side. It also includes 3 rock sites in Chartreuse, Vercors and Belledonne mountains. We generally recorded vertical components of surface waves (Rayleigh waves) excited by a hammer shot of different off-set distances in a linear array deploying 24 sensors (4.5 Hz geophone) with an interval pitch of 2 m or 3 m. We applied the High-Resolution method (Capon, 1969) to the stacked data of the MASW records. We finally obtained the F-K power spectra and the dispersion curves from a superposition of the results calculated by each off-set distance.

The (high frequency) phase velocities obtained with the MASW measurements exhibit a significant variability throughout the Grenoble Basin, as shown in Figure 4. In the east and west sides of the Grenoble Basin, very shallow phase velocity values are found to be very low (down to about 100 m/s for frequencies higher than 30 Hz). On the opposite, measurements in the northern, southern and central parts of the Grenoble Basin, lead to minimum (high frequency) phase velocities larger than 250 m/s. Shallow deposits are thus shown to be highly heterogeneous in the Grenoble Basin. The wave-length of Rayleigh waves in the Grenoble Basin is shown as a function of phase velocity in Figure 5. The wave-lengths obtained by the MASW measurement for the western and eastern parts of the Grenoble Basin are in good agreement with those derived from array microtremors techniques (e.g. Bettig et al., 2001). On the other hand, the superficial wave-length of Rayleigh waves in the NS zone located along the Drac river does not match well with the obtained by the array techniques. Figure 5 also includes for comparison purposes the "ESG model" which was adopted for the numerical benchmark test (Chaljub et al., 2006) on third international ESG symposium held in Grenoble in 2006. The now very clear heterogeneity of superficial structures in the Grenoble Basin will lead us to revisit the shallow part of this "ESG" velocity structural model (i.e., for wave-length smaller than 150 m).
A few additional measurements are still needed, however, for a better coverage of the northern and eastern areas. And the observed heterogeneities still need to be compared with the actual amplifications derived from the analysis of the earthquake recordings obtained with the various temporary array surveys in the Grenoble Basin.

A few MASW measurements were also carried out at rock sites surrounding the Grenoble Basin (Chartreuse, Vercors, Belledonne). They confirmed the high values already derived from deep refraction surveys and borehole logging: up to 1.5 to 2 km/s for S wave velocities at depths smaller than 10 m.

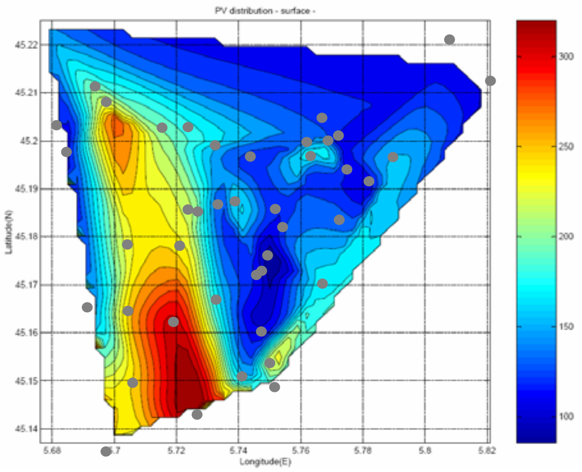


Figure 4: Distribution map of phase velocities of Rayleigh waves on surface ; Right column represents the phase velocity of Rayleigh waves in unit of m/s. White circles denote the locations of the MASW measurement including the performed by BRGM. The higher phase velocities than 250m/s appear in the belt between the north and the south of the Grenoble Basin. On the other hand, we can see the lower phase velocities than 150m/s in the east and west of the basin.

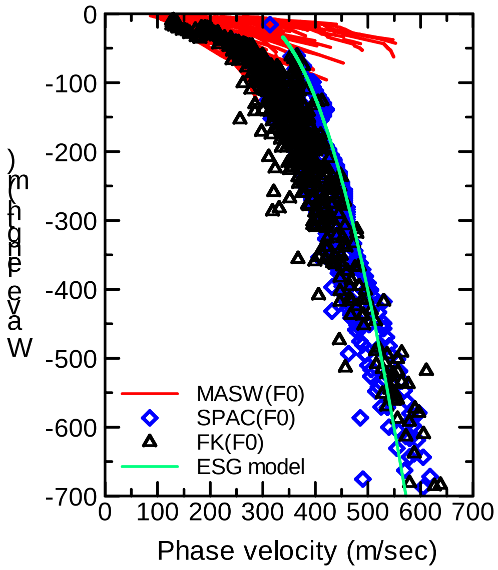


Figure 5 : Wave-lengths of Rayleigh waves as a function of phase velocity in Grenoble. Red lines denote the wave-length obtained by the MASW measurement. Diamond and triangle marks denote the wave-length obtained by the SPAC method and the F-K method respectively. The empirical model based on the result of reflection survey (green line) is the one that has been adopted in the numerical benchmark test (Chaljub et al, 2006). The heterogeneity of surface structures in the Grenoble Basin is appearing very clearly at short wave-length (<150 m).

QSHA WP1-4 Report : Ligure Geomodels (P.I.: Gabriel Courrioux)

Participants: Marie-Odile Beslier, Françoise Sage, Dimitri Schreiber, Sebastien Garziglia (GéoAzur), Olivier Sardou (Gis Curare),
Anne-Marie Duval, Etienne Bertand (CETE Nice)
Isabelle Thinon, Gabriel Courrioux (BRGM).

a) Work description
The general objective of WP1-4 is to provide realistic solid geological models which can be used for wave propagation simulation (WP3). One aspect is to make fluent the process which goes from geological modelling to simulation, so that it is possible to make the models alive and evolving when geological models and/or velocity distributions can be better defined with new data. This process has been tested and is considered as effective to day on the basis of voxet exportation.
Depending on the scale of modelling, different geological objects are considered.
Three scales have been chosen, all are focused around Nice area including ocean–continent transition.
The first major boundary is the topography level. An accurate knowledge of the ocean-continent transition is critical for wave propagation simulation. Therefore a regional DTM has been made homogeneous all over the area, regrouping data from different sources (O. Sardou).
The Regional model (from 0 to 50 km depth) called Ligure includes main relevant surfaces at crustal scale. These are: the moho, the intermediate velocity layer at base of crust, and the basement/cover boundary. These have been modelled using a bibliographic synthesis (M.O. Beslier, D. Schreiber, G. Courrioux).
Subdivisions based on velocity contrasts within these main units will still be investigated.
The intermediate model (from 0 to 5 km depth) called Baie des Anges includes messinian erosion surface, salt basis, oligo-miocene sediments, and top of basement. In 2006 and 2007 about 280 Geoscience Azur seismic lines acquired during teaching cruises on the N.O. Le Thethys have been incorporated in Kingdom Suite software and are nearly interpreted. These will be used for building the model. (F. Sage, S. Garziglia, .I.Thinon).
The local model (0 to 500m) called Nice includes the messinian erosion surface, the base of quaternary, and nine levels within the Paillon and Var valley alluvions. Up to now the BRGM-CETE

previously built model is available. Some modifications based on more recent data are scheduled during 2nd semester 2007 (A.M. Duval, E. Bertrand).

b) Results

- DTM

A continuous DTM has been built all over the area in order to be integrated in different models. Original data show different resolutions depending on their source. The final compilation is built with a 100 m resolution.
On land sources are IGN BD ALTI®, SRTM (Shuttle Radar Topography Mission) distributed by CGIAR Consortium for Spatial Information on the french and italian territories respectively
At sea : Multibeam bathymetry acquired with Ifremer facilities, SHOM data (Service Hydrographique et Océanographique de la Marine National),
IBCM data *(Bathymetric Chart of the Mediterranean) of GEBCO (General Bathymetric Chart of the Oceans)*
Special care has been taken to properly fit DTM on junctions between all sources, especially at the sea-continent transition where interpolation has been made with a zero altitude constraint on the coastal line. The DTM is now available at a 100 m resolution.

The three deeper interfaces are deduced from the following bibliographic references:
Sea moho, Basement/cover, Intermediate velocity layer: Gravity inversion Chamot-Rooke et al (1999), Wide-angle seismics Contrucci et al. (2001), Rollet (1999), Lange (1997), Makris et al. (1999), multichannel seismics Rollet et al. (2002).
Littoral moho : Receiver functions : Bertrand et Deschamps (2000); Wide-angle seismics Fontaine (1996), GPS ; Calais et al, 1993;
Continental moho + Ivrea body : Wide-angle seismics : Waldauser 1998; Thouvenot et al. In press ; P wave trajectory inversion Tomography: Paul et al 2001 ; Gravity inversion: Schreiber et al. (in prep.).

- Moho

Putting all data together helps to compare , point out and discuss differences between data. It is not possible to mix all data sets for geometric modelling because of heterogeneous data sources and of some geometric conflicts.
Uncertities cannot be directly quantified from these dataset. Consequently, different models can be proposed. Model c (figure 1) has been finally retained for the benchmark simulations (all codes running on a same model) because the Moho depth is mainly constrained from wide-angle seismic data in both landward and seaward areas. The moho is however very poorly constrained at sea by a few set of velocity models. Models a and b will be equally used in order to assess the impact of uncertities on simulation results.

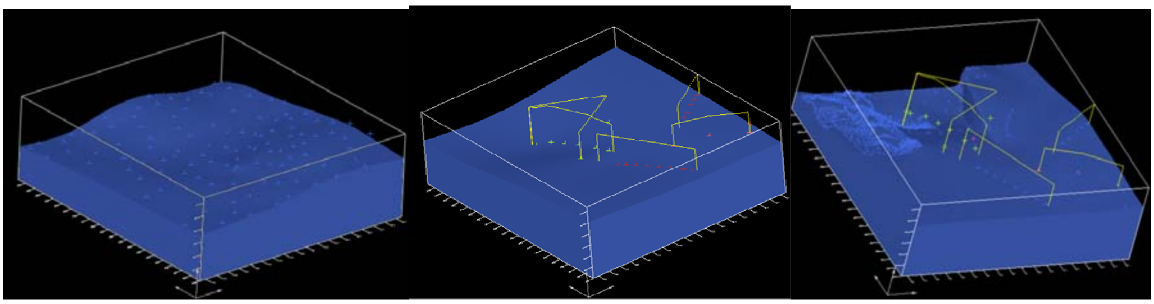


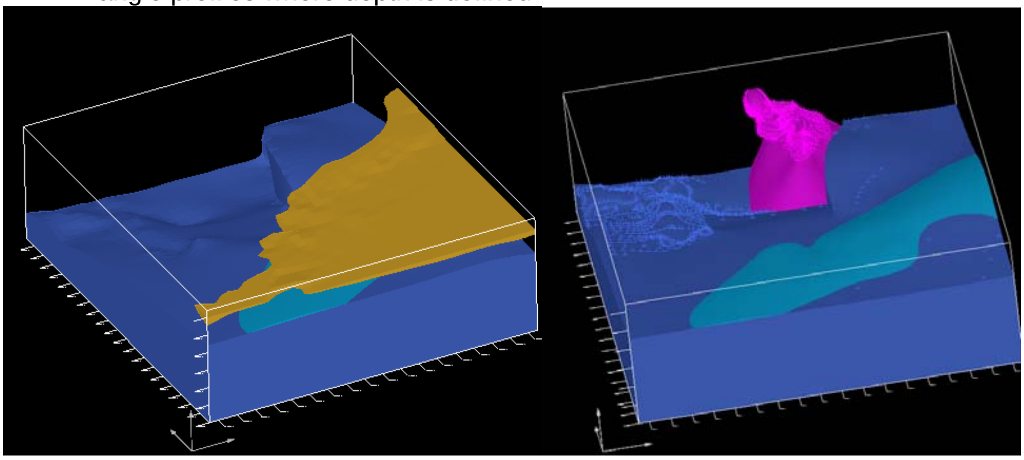
Figure 6: three different possible moho models.(Ivrea body not displayed). a) Moho from gravity inversion: Chamot-rooke et al (1999); b) Moho from wide-angle seismic data at sea: Contrucci et al 2001, Rollet,1999, Lange 1997, Makris et al 1999 ; at land from Bertrand and Deschamps (2000), Calais et al (1993) data; c) moho from wide-angle data at sea :Contrucci et al 2001, Rollet,1999, Lange 1997, Makris et al 1999; at land: composite moho (Schreiber et al. in prep.) from Waldhauser et al 1998 (Grand angle) , Thouvenot et al. in press. (seismic reflexion) Paul et Al. 2001 (seismic tomography).

- A 1 to 2 km thick intermediate velocity layer at Vp around 7.2 km/s is present in the deeper crust under the deep margin and in the ocean-continent transition.This leads to distinguish this layer as possibly relevant for simulations.

- The acoustic basement has been defined from distinction of different seismic facies on the multichannel seismic lines. It is badly constrained on the upper margin because of interferences with the multiple, and in the deep basin beneath the salt layer. So far, this acoustic basement has not been continued on land.

- Another interface also referred as top of acoustic basement can be defined on basis of velocities deduced from wide-angle seismic data. It corresponds to the velocity transition at about 5 or 6 km/s depending on the continental or oceanic nature of the basement.

Therefore, some interpretations and refinements have still to be done on land and sea to validate this interface. It is however possible to propose a preliminary model which uses Mercantour and Maures massif as 0 depth constraints and gently increases towards wide-angle profiles where depth is defined.



a) b)

Figure 7 : a) Model with moho, Intermediate velocity layer, and top of Rollet (1999) acoustic basement. b) moho, Ivrea body and intermediate velocity layer.

c) Perspectives

- Ligure Model :

On the moho one has to look more closely differences between all moho dataset and their quality, so that we are able to propose a more pertinent moho. This task can be scheduled during the 2nd semester 2007.

The Basement/Cover interface has to be more precisely defined at sea, by reconsidering some seismic profiles from Rollet (1999) and has to be modelled at land. Scheduled on 2007 (possibly 2008).

Some sub-domains within these units will have to be defined on the basis of velocity distributions. But one has to keep in mind that indications on velocity 3D distributions remain fuzzy. (2007).

- Baie des Anges model.

Seismic interpretations should be achieved in 2007. Taking into account the great quantity of profiles and complexity, the 3D modelling will propably continue until beginning of 2008.

- Nice Model :

Validating the model with recent data should be achieved by 2007.

d) Publications

- Schreiber et al. 3d Modelling of Alpine Moho in Southwestern Alps . In prep.
- On Ligure model, the main work is a synthesis of existing data. So it may be difficult for the moment to legitimate a real scientific publication unless we can find a walk-around.
- On Baie des Anges Model, it is likely that modelling work leads to a publication since they will be new original data.

ADDITIONAL COMMENTS

This work package has seen significant progress, with methodological developments systematically accompanied by their implementation within a user-friendly software (thanks to a complementary funding from the European project NERIES), field measurements and/or collection of new data for the shallow structures of the Grenoble and Nice areas, and data integration with a geomodeler software.

From a scientific viewpoint however, one challenge is to identify the possible biases associated with the non 1D character of underground structures : how to identify the existence of 2D or 3D lateral variations, what are these biases, and which processing should be used in such cases ? This goes well beyond the financial capabilities and the delays allowed by this 3-year project.

There exist some worries for the site of Algiers (local context + big delay in buying the new instruments for the RISC mobile accelerometric network: the old RAM is completely obsolete). The integration of all data and models within the BRGM geomodeler software also raises some issues because of the cost of the software for non-academic partners and questions about the future maintenance and updating of the models.