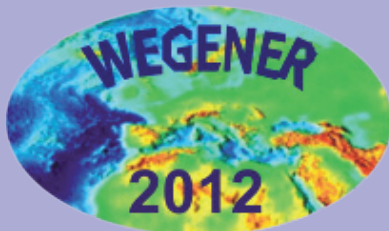




Earthquake Geodesy and Geodynamics

Monitoring and modelling
earth deformation from
giant to small scale events



Volume of Abstracts

University of Strasbourg
Collège Doctoral Européen
17 - 20 September 2012

<http://wegener2012.sciencesconf.org/>

16th General Assembly of

W E G E N E R



UNIVERSITÉ DE STRASBOURG





**WEGENER
XVI GENERAL ASSEMBLY**

Earthquake Geodesy and Geodynamics

**Monitoring and modelling earth deformation from
giant to small scale events**

Abstract volume

**University of Strasbourg - Collège Doctoral Européen
17 - 20 September 2012**



Earthquake Geodesy and Geodynamics

Monitoring and modelling earth deformation from giant to small scale events

Strasbourg, 17 - 20 September 2012

Dear participants,

The Institut de Physique du Globe of Strasbourg (IPGS), Ecole et Observatoire des Sciences de la Terre (EOST) and University of Strasbourg (UdS) welcome all participants to the XVI General Assembly of WEGENER. The World Earthquake GEodesy Network for Environmental Hazard Research (WEGENER) addresses a broad range of questions related to tectonic, atmospheric, oceanic, and climatic issues of interest to the earth science community. WEGENER is now a sub-commission 3.5 (Tectonics and Earthquake Geodesy) of the International Association of Geodesy (IAG).

Every two years the WEGENER General Assemblies are organized to serve as a high-level international forum, in which scientists from all over the world can discuss multidisciplinary interpretation of geodynamics, and strengthen the collaboration between countries.

WEGENER 2012 meeting selected this time the stimulating topic of Earthquake Geodesy and Geodynamics with a focus on the *"Monitoring and modelling earth deformation: From giant to small scale events"*. Diverse and timely contributions (92 abstracts) constitute a rich programme organized around 6 scientific sessions (see next pages). The meeting organisation also benefited from the support of the Région Alsace, CNRS-INSU, CNES, and IAG.

On behalf of the Local Organizing Committee (LOC) of WEGENER 2012, and WEGENER Board we wish you a fruitful and productive meeting, and an agreeable stay in Alsace and Strasbourg region.

Mustapha Meghraoui (chair of LOC)
Haluk Özener (president of WEGENER)

Earthquake Geodesy and Geodynamics

Monitoring and modelling earth deformation from giant to small scale events

Strasbourg, 17 - 20 September 2012

Organizing committee (EOST - IPG Strasbourg):

Mustapha Meghraoui
Frédéric Masson
Jacques Hinderer
Cecile Doubre
Noel Gourmelen

Scientific committee :

S. Zerbini (*University of Bologna, Italy*),
R. Reilinger (*MIT, Boston, USA*),
R. Gross (*JPL, NASA, USA*),
J. Hinderer (*IPG Strasbourg, France*),
M. Becker (*University of Darmstadt, Germany*),
H. Ozener (*Kandilli Observatory, Istanbul, Turkey*),
L. Bastos (*University of Porto, Portugal*),
M. Meghraoui (*IPG Strasbourg, France*),
F. Masson (*IPG Strasbourg, France*),
N. Gourmelen (*IPG Strasbourg, France*),
J.M. Nocquet (*Geosciences Azur, Nice, France*),
A. Hooper (*Delft University, Netherland*)
C. Doubre (*IPG Strasbourg, France*),
T. Wright (*Leeds University, United Kingdom*),
J. Biggs (*University of Bristol, United Kingdom*),
S. Jonsson (*KAUST, Saudi-Arabia*),
S. Stein (*Northwestern University, Illinois, USA*),
Y. Klinger (*IPG Paris, France*),
T. Dixon (*University of Miami, USA*),
C. Vigny (*ENS Paris, France*),
M. Simons (*CalTech, Pasadena, USA*),
F. Amelung (*University of Miami, USA*).

Meeting sessions:

1. Subduction zones and giant earthquakes (C. Vigny, M. Simons, L. Rivera)

The study of large and great subduction zone earthquakes is benefitting from important advances in observational methods and instrumental deployments, new analysis and modeling techniques, and a rapid increase in available computational power, all applied to a flurry of seismic events starting in the early 1990's. We invite contributions from all aspects of geology and geophysics, observational or theoretical that help further our understanding of these phenomena. Contributions may include detailed studies of individual events, contextual studies of the seismogenic character of a given region, broad scale regional intercomparisons, or more fundamental mechanical models and discussions.

2. The role of continental faults in the Mediterranean, Africa and Middle-East (M. Meghraoui, T. Wright, J-M. Nocquet)

Over the last years, significant [advances](#) have been made [in](#) characterizing active deformation in the plate boundary zone separating Africa, Arabia and Eurasia. Recent tectonic, geodetic and seismological studies along large continental faults systems in the eastern Mediterranean region, Middle East and Africa (African Rift system, the Red Sea and Dead Sea Fault (DSF), the East Anatolian Fault (EAF) and the North Anatolian Fault (NAF)) are providing a new wealth of data and results demonstrating the complex nature of continental tectonic structures, helping to better understand the role of faults in regional deformation. The well known history of earthquake ruptures in the Eastern Mediterranean and Middle East also offers a unique opportunity to develop integrated approaches [that include studies of](#) active tectonics, paleoseismology, [and](#) geodesy together with advanced modelling of seismic ruptures and the earthquake cycle. The aim of this session is to present updated [results](#) on the active deformation [of seismogenic continental](#) faults and [to](#) discuss integrated methods and results. We [particularly](#) encourage submission of abstracts on [the relationship of](#) fault complexity to the occurrence of large earthquake ruptures, the measurements and modelling of the active deformation at regional or fault scales, and on crust/lithosphere deformation processes along plate boundary zones, [in relation to](#) present-day observed deformation.

3. Seismotectonics and the Earthquake Cycle (S. Stein, Y. Klinger, N. Gournelen)

Although earthquake seismology provides considerable detail about what occurs during the climactic phase of the seismic cycle, what occurs in space and time during the preseismic, post-seismic and interseismic phases are less well understood. Geodetic, geologic, modeling and laboratory studies provide valuable but sometimes difficult-to-interpret and apparently inconsistent inferences. This situation poses challenges for both understanding fundamental processes on the fault and regional scales, and assessing earthquake hazards. We invite papers addressing aspects of these issues.

4. Earth Observation Systems and Reference Frames, Observation Techniques, Methods and Data Analysis (M. Becker, H. Ozener, Z. Altamimi)

This session is devoted to all contributions that deal with the basic techniques and strategies for earthquake geodesy and natural hazard research. It covers the theoretical and practical aspects of reference systems and applications for their realizations. The role of Earth observation systems in establishing the monitoring of global change as well as selected applications and results relevant to our understanding of the changing Earth are solicited. Contributions on new and results of new and old observation techniques, new analysis methods and tools that allow a more precise or higher resolution detection of deformation, station motion and surface changes are of interest. Novel applications of GNSS, InSAR and conventional geodetic techniques and integrated multi sensor approaches are welcome. Contributions to GGOS, EPOS, ECGN or other programs will be appreciated.

5. Solid Earth dynamics from surface and satellite gravity observations (J. Hinderer, S. Zerbini, R. Biancale)

This session is open to all studies relating geodesy (GPS, VLBI, SLR, DORIS) and gravimetry (GRACE satellite, absolute, superconducting, spring gravimeters) observations to a large variety of signals. On one hand, new results on seismic and post-seismic deformation, aseismic fault slip, volcanic deformation are welcome, including especially the GRACE signature of recent large earthquakes. On the other hand, we also seek for investigations on the solid Earth response to surface loads of atmospheric, oceanic, hydrologic and glaciological origins. We invite papers on the separation of signals due to tectonics and large-scale surface loading which is crucial in geodetic observations, especially in regions submitted simultaneously to plate tectonics, post-glacial rebound, present-day ice melting and water storage change in large river basins. We also encourage abstracts on the potentiality of combining gravity and surface vertical deformations studies to have more insight on the geodynamical processes going on.

6. Magmatic processes and crustal deformation (C. Doubre, S. Jonsson, J. Biggs)

Many recent studies have demonstrated the usefulness of geodetic techniques to monitor volcanic unrest. The large spatial coverage of satellite-based methods has a unique ability to detect unrest on a regional scale, while ground-based geodetic techniques such as cGPS and strainmeters provide high temporal resolution information at frequently erupting volcanoes. The use of these techniques has brought significant advances to the understanding of intrusion and magma reservoir dynamics. We encourage participants to present original studies focusing on these aspects, in particular on new insights on intrusion and eruption dynamics and the mechanical behavior of the crust, and in linking geodesy to observations/models from other fields such as seismology, petrology, geochemistry, hydrology etc .

Meeting Programme

Monday 17 September

12:30 - 13:30 - Welcome of participants and registration

13:30 - 14:00 - Opening of the meeting: Mustapha Meghraoui (LOC), Presidency of UdS
Haluk Ozener (President of Wegener Group), Frederic Masson (Head of EOST)

14:00 - 18:30 - Session 2

The role of continental faults in the Mediterranean, Africa and Middle-East

Chair: **M. Meghraoui, T. Wright, J-M. Nocquet**

ORAL		
Invited: Present-day kinematics of the Mediterranean: a comprehensive overview of GPS results	J-M Nocquet	14:00 - 14:30
Broad-scale NE-SW compressional strain within the Arabian plate	A. Arrajehi, K. Al-damegh, T. Al-Otaibi, A. Al-humaizi, M. Floyd, R. King, R. Reilinger, S. McClusky, M. Daoud, J. Sholan, F. Bou-Rabee	14:30 - 14:50
Thermal and Compositional Controls on African Seismicity	T. Craig & J. Jackson	14:50 - 15:10
Seismic and aseismic deformation along the East African Rift System from a reanalysis of the GPS velocity field of Africa	A. Deprez, C. Doubre, F. Masson	15:10 - 15:30
Recent Creep Rate of Ismetpasa Segment of North Anatolian Fault (Turkey) inferred from 7-years GPS Observations	H. Ozener, S. Ergintav, U. Dogan, Z. Cakir, A. Dogru, B. Turgut, O. Yilmaz, K. Halicioglu, A. Sabuncu, E. Havazli	15:30 - 15:50
Kinematics of the eastern Caucasus near Baku, Azerbaijan	F. Kadirov, M. Floyd, A. Alizada, I. Guliev, R. Reilinger, R. King	15:50 - 16:10

16:10 - 16:30 - Coffee Break

ORAL		
Seven years of postseismic deformation following the 2003 Mw=6.8 Zemmouri earthquake (Algeria) from InSAR Time Series	E. Cetin, M. Meghraoui, Z. Cakir, A. Akoglu, O. Mimouni & M. Chebbah	16:30 - 16:50
The Mw 5.1 Lorca (Spain) Earthquake Successfully Recorded by GPS	L. Mendoza, J. M. D'Avila Jose, J. Garate, M. Becker	16:50 - 17:10
Remote sensing for moderate earthquake deformations in the Eastern Mediterranean	M. Ilieva, P. Briole, P. Elias, D. Dimitrov	17:10 - 17:30
Deformation Field and Velocity Vectors for the Egyptian Territory Deduced from Permanent GPS Data	M. Saleh, M. Becker, A-M. S. Mohamed, N. Abou-Aly, M. Salah, K. Hassan	17:30 - 17:50
Spatio-temporal distribution of tectonic strain accumulation and release in the Apennines from decadal geodetic rates and 400 years of historical seismicity	N. D'Agostino	17:50 - 18:10
Reassessment of the source of the 1976 Friuli, NE Italy, earthquake sequence from the joint inversion of high-precision levelling and triangulation data	D. Cheloni, N. D'Agostino, E. D'Anastasio, G. Selvaggi	18:10 - 18:30

19:30 - 21:30 – Gala dinner

Tuesday 18 September

08:30 - 12:30 - Session 1 Subduction zones and giant earthquakes

Chair: **C. Vigny, M. Simons, L. Rivera**

ORAL		
Invited : Short to long-term segmentation of the subduction seismogenic zone: what interpretations?	A. Socquet	08:30 - 09:00
Invited : Imaging coseismic slip along subduction megathrusts: recent progress and future challenges	A. Sladen	09:00 - 09:30
Invited : Controlled source seismic imaging of subduction zones; what can we learn from the down-going plate	M. Delescluse, M. Nedimovic , D. Shillington, S. Carbotte, A. Becel, J-P. Canales, H. Carton, S. Webb, H. Kuehn	09:30 - 10:00

10:00 - 10:30 - Coffee Break

ORAL		
The coastline as a dynamic marker of forearc deformation and Megathrust segmentation along the Andean subduction Margin	L. Audin, M. Saillard, J-P Avouac	10:30 - 10:50
Constraint of the interseismic deformation in the Mw 9.0 Tohoku-oki earthquake area: Insights from paleogeodesy and paleoseismology	M. Meghraoui, S. Toda, M. Ferry, S. Schmidt, H. Tsutsumi, K. Okumura, T. Haraguchi	10:50 - 11:10
Vertical deformation of northeastern Honshu coastline: from minutes to thousands of years and “Implications on the earthquake cycle along the Japan trench	S. Schmidt, M. Meghraoui , E. Cetin, K. Okumura, S. Toda	11:10 - 11:30
On the occurrence of the 2011 Tohoku earthquake: role of preseismic stress accumulation and coseismic absolute stress release on a weak fault	Y. Mitsui, Y. Iio, Y. Fukahata	11:30 - 11:50
Strain accumulation in the Southern Andes (25°-35°S) observed by ERS and Envisat SAR data	G. Ducret, M-P. Doin, R. Grandin, A. Socquet, C. Vigny, M. Métis, M. Bejar-Pizarro	11:50 - 12:10
Episodic slow slips and synchronous with seismic swarms in the northern Andes subduction zone	J-M. Nocquet, J. C. Villegas Lanza, M. Vallée, P. Mothes, F. Rolandone, P. Jarrin, M. Chlieh, H. Tavera, M. Regnier, Y. Font, M. Segovia	12:10 - 12:30

12:30 - 14:00 – Lunch

Lunch-Meeting discussion on Supersites initiatives and perspectives

14:00 - 16:00 - Poster session

POSTER (Session 1)	
W phase source inversion using the high-rate regional GPS data of the 2011 Tohoku-oki earthquake	L. Rivera, H. Kanamori, Z. Duputel
Crustal deformation prior to the 2011 Tohoku earthquake, Japan, from the continuous GPS data of the dense GEONET network.	E. Klein, J-M. Nocquet, L. Rolland, P. Bosser, T. Dinh Trong, T. Yahagi, M. Vergnolle, A. Sladen
Strategies to develop early warning tsunami-induced tilt for the 2007, M=7.6, Tocopilla and the 2010, M=8.8 Maule earthquakes, Chile, from long base tiltmeter and broad-band seismometer records.	F. Boudin, S. Allgeyer, P. Bernard, H. Hebert , M. Olcay, M. El-Madani, B. Schurr, M-F. Esnault, R. Madariaga, G. Asch, I. Nunez, M. Kammenthaler

POSTER (Session 2)	
Monitoring and modeling of interseismic creep of the North Anatolian Fault at Ismetpasa using Persistent Scatterer InSAR	E. Cetin, Z. Cakir, U. Dogan, A. Akoglu, H. Ozener, S. Ergintav, M. Meghraoui
Using seismic and GPS data for hazard estimation in some active regions in Egypt	A-M. Mohamed
Seismicity and 10-years recent crustal deformation studies at Aswan region, Egypt	M. Abdel-Monem, M. Haggag, M. Saleh, N. Abou-Aly
ALERT-ES project: Development of an Earthquake Early Warning System (EEWS) for SW Iberian Peninsula	J. Martin Davila, E. Buforn, X. Goula, A. Pazos, M. Carranza, Y. Colom, M. Lopez Mesa, J. Garate, A. Udias, A. Roca, C. Rioja, A. Jimenez Jose, L. Lozano, A. Zollo, W. Hanka, R. Madariaga, M. Harnafi
A general overview of changes of the earth crust due to earthquakes, land slide and other geological phenomena in the territory of Albania; Monitoring of these changes	B. Nurce, I. Milushi, G. Gjata, S. Allaraj
Slip rate and locking depth of the southern Dead Sea fault revisited from new GPS measurements	F. Masson, Y. Hamiel, A. Deprez, Y. Klinger, A. Agnon
Determination of Strain Accumulation along Tuzla Fault and its Vicinity, Western Turkey	E. Havazli, H. Ozener
GPS constrains on modern geodynamical motion in the Ossetia region of the Great Caucasus: preliminary results	V. Milyukov, A. Mironov, G. Steblov, V. Drobishev, H. Hubaev, A. Kusraev, K. M. Torchinov, V. Shevchenko
Block model at the Hatay Triple junction in N-W Syria and S-E Turkey from GPS data inversion	Y. Mahmoud, Z. Cakir, F. Masson, M. Meghraoui
Main features of the deep structure by earthquake tomography and GPS active tectonics: Case of Rif Mountain (Morocco) and Betic Cordillera (Spain)	Y. Timoulali

Levy characteristics for the creep velocity distribution of the faults of the Afar region: Consequences for the extreme events scaling as function of duration and size	R. Toussaint, C. Doubre, D. Léobal, G. Peltzer, K.T. Tallakstad, K.J. Maloy, S. Santucci
---	--

POSTER (Session 4)	
Facilitating Geodesy Data Sharing: UNAVCO Participation in the Joint European Union - United States COOPEUS Project	F. Boler, C. Meertens, S. Wier, M. Miller
Fast error analysis of continuous GPS position time series	M. Bos, R-M . Fernandes, S. Williams, L. Bastos
Immersed tube tunnels and survey works	E. Yavuz, F. Köse
High rate, high accuracy Earth deformation monitoring using GPS – Application to the Japanese 2011 earthquake	F. Fund, F. Perosanz, F. Mercier, S. Loyer
Towards a fusion of GNSS, SAR-Interferometry and Precise Levelling Data in the Upper Rhine Graben Area	T. Fuhrmann, A. Knopfler, M. Mayer, M. Westerhaus, K. Zippelt, B. Heck

16:00 - 16:30 - Coffee Break

16:30 - 18:30 - Session 4 Earth Observation Systems and Reference Frames

Chair: M. Becker, H. Ozener, Z. Altamimi

ORAL		
A geodetic component to GONAF borehole observatory (NW Turkey)	D. Mencin, M. Floyd, R. Reilinger, M. Bohnhoff, G. Dresen, F. Bulut, S. Ergintav	16:30 - 16:45
Monitoring methods of tunnels deformations	E. Yavuz, F. Köse, N. Ersoy	16:45 - 17:00
A new class of tiltmeters and seismometers based on optic fiber Fabry-Pérot interferometry: Results and use for active tectonics	J. Chery, F. Boudin, M. Cattoen, H-C Seat, P. Chawah, G. Plantier, A. Sourice, P. Bernard, C. Brunet, S. Gaffet, D. Boyer	17:00 - 17:15
Regularized estimation of Euler Pole parameters	B. Aktug, O. Yildirim	17:15 - 17:30
Automatic analyses of GPS time series for tectonics	D. Tran Trong, J-M. Nocquet	17:30 - 17:45
On the determination of highly precise coordinate time series using GURN (GNSS Upper Rhine Graben Network) data	A. Knopfler, M. Mayer, F. Masson, P. Ulrich, B. Heck	17:45 - 18:00
Blending of reprocessed GNSS coordinate time series parameters with geological data	S. Leinen, M. Becker, G. Läufer, R. Lehné	18:00 - 18:15
High resolution loading estimates for precise geodetic observations	J-P. Boy	18:15 - 18:30

19h – 20h Visit to the Museum of Seismology (by Prof. Michel Cara)

Wednesday 19 September

08:30 - 12:30 - Session 5 Solid Earth dynamics from surface and satellite gravity observations

Chair: J. Hinderer, S. Zerbini, R. Biancale

ORAL		
Invited: Combining absolute gravity, GPS and GRACE to better constrain continental dynamics from GIA to great subduction earthquakes	S. Mazzotti, J. Henton, T. Lambert, N. Courtier, H. Dragert	08:30 - 09:00
Fourteen years of GPS and gravity measurements in and around Bologna, Italy	S. Zerbini, M. Errico, R. Falk, E. Santi, H. Wziontek, G. Cappello	09:00 - 09:20
Taiwan Continuous GPS Geodetic Array: The deformation rate and apparent seasonal variation from 1994-2010	K-C Lin, J-M Nocquet, J-C Hu, B. Delouis	09:20 - 09:40
Towards a global strain map from InSAR and GPS	T. Wright, M. Garthwaite, H. Wang, A. Shepherd, H-S Jung, A. Hooper	09:40 - 10:00

10:00 - 10:30 - Coffee Break

ORAL		
Monitoring of Ground Deformation in the Haoud Berkaoui Oil Field (Sahara, Algeria) Using Time Series Analysis of SAR Images	S. Bouraoui, M. Meghraoui, R. Bougdal, Z. Cakir	10:30 - 10:50
Mexico City, a sinking city	D. Poreh, T. Van Dam, E. Cabral-Cano	10:50 - 11:10
Visco-elastic deformation of the lithosphere around the lake Siling Co in Tibet	M-P. Doin, C. Twardzik, G. Ducret, C. Lasserre, S. Guillaso, S. Jianbao	11:10 - 11:30
Along strike variations of crustal geometry in the Himalayas from new gravity anomalies data and numerical modelling	T. Berthet, R. Cattin, G. Hetenyi, C. Champollion, J. Chopel, E. Doerflinger, D. Drukpa, P. Hammer, S. Lechmann, N. Lemoigne, S. Sapkota	11:30 - 11:50
Earth's free oscillation following the 2011 Tohoku earthquake detected by dense GPS array in Japan	Y. Mitsui, K. Heki	11:50 - 12:10
Superconducting gravimeter measurements for land surface model assessment	L. Longuevergne, S. Gascoin, J-P. Boy, S. Rinaldi, A. Ducharne, N. Florsch, J. Hinderer	12:10 - 12:30

12:30 - 14:00 – Lunch

14:00 - 16:00 - Poster session

POSTER (Session 5)	
The Geoid and the stress state in the Lithosphere of Western Europe	T. Camelbeeck, O. De Viron, M. Van Camp, D. Kusters
PBO and next generation high-rate real-time geodetic networks for active earthquake processes	D. Mencin, D. Melgar, Y. Bock, C. Meertens
New insights on coseismic ionospheric disturbances induced by a well observed intra-continental earthquake, the 2011 Van earthquake in Eastern Turkey	L. Rolland, M. Vergnolle, J-M. Nocquet, J-X. Dessa, F. Tavakoli, A. Sladen, F. Cappa
Time Series Cycle Effect on the Homogeneity and Accuracy of the Egyptian Permanent GPS Network (EPGN)	K. Zahran, N. Abou-Aly, M. Saleh, S. M. Abd el-Monem
Geophysical signals in the occasion of recent large earthquakes in the recording of the interferometric water tube tilt meter, Lohja, Finland	H. Ruotsalainen
Characterization of the dynamics of slope movements with image correlation techniques	J-P. Malet, J. Travelletti, J. Gance, A. Stumpf, G. Skupinski, C. Delacourt
Rapid Ice loss at Vatnajökull, Iceland, since the late 1990s constrained from InSAR.	W. Zhao, F. Amelung
Observation of strain rate variations by a quartz-tube extensometer in the Sopronbányfalva Geodynamic Observatory, Hungary	G. Mentés

POSTER (Session 6)	
Fault activity in the Manda Hararo rift in Afar (Ethiopia) using Interferometric Synthetic Aperture Radar.	S. Dumont, A. Socquet, R. Grandin, C. Doubre, Y. Klinger, E. Jacques

POSTER (Session 3)	
Slip rate of the Chaman fault, Pakistan, from InSAR	H. Fattahi, F. Amelung
Post-seismic deformation in Central Nevada from 19 years of InSAR observations.	F. Greene, F. Amelung
Tectonic geomorphology and active megathrust traces in the East-Himalayan Syntaxis	E. Kali, P. Tapponnier, J. van der Woerd, S. Choudhury, S. Baruah, K. Alam, A. Ahsan, C. Dorbath, P. Banerjee

The Pingding segment of the Altyn Tagh Fault (91°E): Slip rate determination from cosmogenic radionuclide dating of offset fluvial terraces.	A-S. Mériaux, J. Van der Woerd, P. Tapponnier, F.J. Ryerson, R. C. Finkel, C. Lasserre, X. Xu
Long-term growth of the Himalaya inferred from interseismic InSAR measurement	R. Grandin, M-P Doin, L. Bollinger, B. Pinel-Puysségur, G. Ducret, R. Jolivet, S-N. Sapkota
Seismic cycle stress change along the Himalayas over the last 900 years	R. Cattin, R. Hoste-Colomer, T. Berthet, G. Hetenyi
Fault kinematics and mechanics at the seismic cycle time-scale from experimental approach.	Y. Caniven, S.Dominguez, R.Soliva, R.Cattin, M.Peyret, C.Romano
Fault bends : behavior during the interseismic period constrained by SAR interferometry	S. Daout, G. Ducret, C. Lasserre, M-P. Doin, R. Jolivet, R. Grandin, S. Jianbao, Z-K. Shen, J-M. Nocquet, Y. Klinger
Constraints on the Centroid Moment Tensors from Radial Modes	E. Zabránova

16:00 - 16:30 - Coffee Break

16:30 - 18:30 - Session 6 **Magmatic processes and crustal deformation**

Chair: **Cecile Doubre, Juliet Biggs, Sigurjon Jonsson**

ORAL		
Invited: Shallow evolution of Santorini volcano constrained by InSAR and GPS measurements	M. Parks, J. Biggs, S. Ebmeier, P. England, T. Mather, P. Nomikou, K. Palamartchouk, X. Papanikolaou, D. Paradissis, B. Parsons, D. Pyle, C. Raptakis, V. Zacharis	16:30 - 16:50
Invited: The two magma chambers problem in volcano deformation	E. Rivalta	16:50 - 17:10
Invited: Space-geodetic evidence for multiple magma reservoirs and subvolcanic lateral intrusions at Fernandina Volcano, Galápagos Islands	M. Bagnardi, F. Amelung	17:10 - 17:30
Multiscale deformation monitoring at Colima Volcano using TerraSAR-X interferometry and camera observations	J. Salzer, T. Walter, D. Legrand, M. Breton, G. Reyes	17:30 - 17:45
The Magmatic system beneath Torfajökull volcano: A combination of radar and seismic interferometric observations	J. Martins, A. Hooper, D. Draganov, E. Ruigrok, B. White	17:45 - 18:00
Application of bistatic TanDEM-X SAR-interferometry to observe topographic changes at the summits of Merapi, Indonesia and Colima Volcano, Mexico	J. Kubanek, M. Westerhaus, B. Heck	18:00 - 18:15
Magmatic injection and recharge in the Asal Rift, Republic of Djibouti	G. Peltzer, J. Harrington, C. Doubre, J. Tomic Jelena	18:15 - 18:30

18:30 – 20:00 WEGENER Board meeting

Thursday 20 September

08:30 - 12:30 - Session 3 Seismotectonics and the Earthquake Cycle

Chair: Y. Klinger, A. Hooper, F. Amelung, N. Gournelen

ORAL		
Invited: The long and slow nucleation of most interplate earthquakes	M. Bouchon, J. Schmittbuhl, V. Durand, D. Marsan, H. Karabulut	08:30 - 08:50
Interplay of seismic and aseismic deformations along faults: An experimental approach	J. Schmittbuhl, O. Lengliné, J.P. Ampuero, M. Bouchon	08:50 - 09:10
Earthquake Cycle Research in North Iceland	S. Jonsson, S. Metzger	09:10 - 09:30
The 2004 Parkfield earthquake (Mw 6) post-seismic surface displacement observed by coupling ERS and ENVISAT InSAR between 2005 and 2010.	G. Bacques, D. Raucoules, M. De Michele, H. Aochi	09:30 - 09:50
Coseismic displacements and Holocene slip rates for two thrust faults at the mountain front of the Andean Precordillera (~33°S)	S. Schmidt, R. Hetzel, E. Salomon, F. Mingorance, A. Hampel	09:50 - 10:10

10:10 - 10:30 - Coffee Break

ORAL		
Upper bound deformation in the Upper Rhine Graben from GPS data - First results from GURN (GNSS Upper Rhine Graben Network)	M. Lehoujeur, F. Masson, P. Ulrich, C. Doubre, A. Knoepfler, M. Mayer, B. Heck	10:30 - 10:50
Vertical Displacements in the Upper Rhine Graben Area Derived from Precise Levelling Data	T. Fuhrmann, M. Westerhaus, K. Zippelt, B. Heck	10:50 - 11:10
An added-value source model of the Haiti earthquake - model robustness estimates from a fully joint optimization of seismic and geodetic data	H. Sudhaus, S. Heimann	11:10 - 11:30
Spatial and temporal variations of the shallow creep along the Haiyuan fault (Gansu, China) revealed by InSAR	R. Jolivet, C. Lasserre, T. Candela, F. Renard, M-P. Doin, Y. Klinger, G. Peltzer, R. Dailu	11:30 - 11:50
GPS velocity field across the Western Altyn Tagh Fault (Tibet), implication on fault mechanics	P. Vernant, J. He, J. Chery, W. Wang, S. Lu, W. Kuo, W. Xia	11:50 - 12:10
Two successive slow slip events evidenced in 2009-2010 by a dense GPS network in Guerrero, Mexico	A. Walpersdorf, N. Cotte, V. Kostoglodov, M. Vergnolle, M. Radiguet, J-A. Santiago, M. Campillo	12:10 - 12:30

12:30 - 13:30 – Lunch

13:30 - 19:00 Field excursion to the Vosges Mountains
Conducted by Prof. Hubert Whitechurch

19:00 - 21:30 – Wine tasting and Dinner

REGULARIZED ESTIMATION OF EULER POLE PARAMETERS

Bahadır Aktug¹ and Omer Yildirim²

¹*Bogazici University, Kandilli Observatory and Earthquake Research Institute, Geodesy Department, Cengelkoy, İstanbul, Turkey*

²*Gaziosmanpasa University, Department of Surveying Engineering, Tokat, Turkey*

Abstract

Euler vectors provide a unified framework to quantify the relative or absolute motions of tectonic plates through various geodetic and geophysical observations. With the advent of space geodesy, Euler parameters of many relatively small plates have been determined through the velocities derived from space-based geodetic observations. However, the available data is often insufficient both in number and in distribution to reliably estimate the Euler vector components, hence the Euler pole parameters. Since the Euler vectors are defined in an Earth-centered Cartesian frame, the geometrical coverage of observation points is limited and usually results in highly correlated vector components. For the case of estimating Euler pole parameters directly, the situation is even worse and either the latitude or the longitude of Euler pole is nearly collinear with the magnitude of the rotation rate. In this study, a new method is introduced which consists of analytical derivation of the covariance matrix of the Euler vector in an ideal network configuration and a regularized estimation method specifically tailored for estimating the Euler vector is presented. The results show that the proposed method outperforms the least squares estimation in terms of mean squared error, lowers the correlation between parameters and decreases the numerical instability.

Key words: Tectonics, Euler parameters, multicollinearity, GNSS velocities

Broad-scale NE-SW compressional strain within the Arabian plate

Abdullah ArRajehi¹, Khaled Al-Damegh¹, Thamer Al-Otaibi¹, Abdullah Al-Humaizi¹, Michael Floyd², Robert King², Robert Reilinger², Simon McClusky³, Mohamed Daoud⁴, Jamal Sholan⁵, Firyal Bou-Rabee⁶

1. King Abdulaziz City for Science and Technology, Riyadh, KSA

2. Dept. of Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, MA USA

3. Research School of Earth Sciences, ANU, Canberra, AUS

4. National Earthquake Center, Damascus, Syria

5. Seismological & Volcanological Observatory Center, Dhamar, Yemen

6. Geology Dept., Kuwait University, Kuwait City, Kuwait

Motion of the Arabian plate with respect to Eurasia has been remarkably steady over more than 25 Myr as revealed by comparison of geodetic and plate tectonic reconstructions (e.g., McQuarrie et al., 2003, GRL; ArRajehi et al., 2010, Tectonics). While internal plate deformation is small in comparison to the rate of Arabia-Eurasia convergence, the improved resolution of GPS observations indicate ~NE-SW compressional strain that appears to affect much of the plate south of latitude ~30°N. Seven ~ NE-SW oriented inter-station baselines all indicated shortening at rates in the range of 0.5 – 2 mm/yr, for the most part with 1-sigma velocity uncertainties <0.4 mm/yr. Plate-scale strain rates exceed 2×10^{-9} /yr. The spatial distribution of strain can not be resolved from the sparse available data, but strain appears to extend at least to Riyadh, KSA, ~600 km west of the Zagros Fold and Thrust Belt that forms the eastern, collisional boundary of the Arabian plate with Eurasia (Iran). Geodetic velocities in the plate tectonic reference frame for Arabia, derived from magnetic anomalies in the Red Sea (Chu and Gordon, 1998, GJI), show no significant E-W motion for GPS stations located along the Red Sea coast (i.e., geodetic and plate tectonic spreading rates across the Red Sea agree within their resolution), in contrast to sites in the plate interior and along the east side of the plate that indicate east-directed motions. In addition, NE-SW contraction is roughly normal to ~N-S striking major structural folds in the sedimentary rocks within the Arabian Platform. These relationships to longer-term plate motion and intra-plate deformation suggest that geodetically observed contraction has characterized the plate for at least the past ~3 Myr. Broad-scale contraction of the Arabian plate seems intuitively reasonable given that the east and north sides of the plate are dominated by active continental collision (Zagros, E Turkey/Caucasus) while the west and south sides are bordered by mid-ocean ridge spreading (Red Sea and Gulf of Aden). While the dynamic processes responsible for the observed strain remain speculative, we are investigating models involving long-range effects of the Arabia-Eurasia collision, ridge-push along the Red Sea and Gulf of Aden, and gravitational spreading of the higher elevation Arabian Shield towards the lower elevation platform. Further geodetic monitoring is planned to better resolve the spatial distribution of active strain and its implications for the dynamics of Arabian plate motion and deformation.

The coastline as a dynamic marker of forearc deformation and Megathrust segmentation along the Andean subduction margin

Audin, L.^a, Saillard, M., Avouac, J.-P.

^aInstitut des Sciences de la Terre – IRD : UR219- CNRS : UMR5275 – IFSTTAR – Université de Savoie – Université Joseph Fourier - Grenoble I – INSU – OSUG

* Corresponding author. E-mail address: laurence.audin@ird.fr.

Mw9 earthquakes along active subduction zones are the source of some of the most deadly natural hazards on Earth. Furthermore, as observed by Darwin after the in 1835 Chile event¹, megathrust earthquakes also result in sudden geomorphic changes along coastline. However, how short-term elastic cycle events along subduction zones transfer into long-term permanent deformation generating coastal topographic relief is an outstanding problem in geomorphology. Determining Megathrust earthquakes recurrence and their location is limited by the short time period of observation of these events with respect to the geological time scale, and consequently impacts on the seismic hazard assessment along subduction zones. Based on recent observations along the coastline of Chile and Peru we suggest that forearc deformation and the coastline geometry, reflect lateral variation of "long-term" coupling along the Megathrust which can influence the lateral extent of interplate earthquakes. We suggest that promontories and peninsulas, where the coastline is closer than about 110 km from the trench, show systematic evidence for locally high uplift rates (> 0.4 m/ka). These peninsulas and promontories are dynamic features reflecting anelastic deformation of the forearc (rather than areas that are more resistant to coastal erosion). They correlate with aseismic slip on the Megathrust or aseismic deformation of the forearc and some clearly coincide with the end of the historic rupture zones on the Megathrust. This suggests that these areas prevent stress build up and inhibit lateral seismic rupture propagation. Correlation with aseismic deformation suggests that the barrier effect might be due to rheology and friction, although geometric effects might also play a role.

Session 1. Subduction zones and giant earthquakes

The 2004 Parkfield earthquake (Mw 6) post-seismic surface displacement observed by coupling ERS and ENVISAT InSAR between 2005 and 2010.

Session : Seismotectonics and the Earthquake Cycle

*Guillaume Bacques, Daniel Raucoules, Marcello De Michele, Hideo Aochi
BRGM, Bureau de Recherches Géologiques et Minières, Orléans*

We used the ability of InSAR technique to provide precise displacement map in line of sight to characterise the post-seismic deformation following the 28 September 2004 (Mw 6) Parkfield earthquake between 2005 and 2010 (San Andreas Fault, California). Measuring the post-seismic displacement distribution and its spatio-temporal evolution is one of the most important steps to constrain the slip budget upon the fault plain and consequently to improve our knowledge concerning the seismic cycle. The expected 2004 Parkfield event, by its time delay and its magnitude, has been classified as an outsider compare to the previous events and led researchers to reconsider the validity of the seismic cycle at Parkfield (e.g. W. H. Bakun et al, Nature, 2005). Up to now, the analysis of seismic and space-geodetic data covering all the seismic cycle around the 2004 event seconded with numerical models provided new elements such as the co-seismic and post-seismic slip distribution and its evolution upon the fault plain (e.g. S. Barbot et al, Science, 2012). Thanks to its high spatial resolution, the use of InSAR could provide complementary new insight on the shallower part of the fault slip behavior. In this study, we propose to use both ERS and ENVISAT interferograms to increase the temporal data sampling on the Parkfield section of the San Andreas Fault. Firstly, we combined 5 years of available SAR acquisitions including both ERS-2 and Envisat covering the post-seismic period from 2005 to 2010 to provide stacks of unwrapped interferograms that represent the estimation of the mean velocity per year. Secondly, we stacked selected interferogram (both from ERS2 and Envisat) in the attempt to measure the temporal evolution of the surface velocities associated with the post seismic surface displacement. Here we present the first result from our study. The measured detailed space distribution and the decay of the displacement velocity rate during the post-seismic period is used as input for slip budget assessment.

Space-geodetic evidence for multiple magma reservoirs and subvolcanic lateral intrusions at Fernandina Volcano, Galápagos Islands.

Marco Bagnardi and Falk Amelung

Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami,
USA, email: mbagnardi@rsmas.miami.edu

Using Interferometric Synthetic Aperture Radar (InSAR) measurements of the surface deformation at Fernandina Volcano, Galápagos (Ecuador), acquired between February 2003 and September 2010, we study the structure and the dynamics of the shallow magmatic system of the volcano. Through the analysis of spatial and temporal variations of the measured line-of-sight displacement we identify multiple sources of deformation beneath the summit and the southern flank. At least two sources are considered to represent permanent zones of magma storage given their persistent or recurrent activity. Elastic deformation models indicate the presence of a sill-like magma body at ~ 1.1 km below sea level and an oblate-spheroid cavity at ~ 4.9 km b.s.l. The two reservoirs are hydraulically connected. This inferred structure of the shallow storage system is in agreement with previous geodetic studies and previous petrological analysis of both subaerial and submarine lavas. The almost eight-year long observation interval provides for the first time geodetic evidence for two subvolcanic lateral intrusions from the central storage system (in December 2006 and August 2007). Subvolcanic lateral intrusions could provide the explanation for enigmatic volcanic events at Fernandina like the rapid uplift at Punta Espinoza in 1927 and the 1968 caldera collapse without significant eruption.

Along strike variations of crustal geometry in the Himalayas from new gravity anomalies data and numerical modelling

THÉO BERTHET¹, RODOLPHE CATTIN¹, GYÖRGY HETÉNYI², CÉDRIC CHAMPOLLION¹, JAMYANG CHOPHEL³, ERIK DOERFLINGER¹, DOWCHU DRUKPA³, PAUL HAMMER⁴, SARAH LECHMANN⁴, NICOLAS LEMOIGNE¹, SOM SARKOTA⁵

1 Géosciences Montpellier, UMR5243-CC60, Université Montpellier 2, Place E.Bataillon, 34095 Montpellier cedex 5, France

2 Swiss Seismological Service, ETH Zürich, Sonneggstrasse 5, 8092 Zürich, Switzerland, gyorgy.hetenyi@sed.ethz.ch

3 Seismology and Geophysics Division, Department of Geology and Mines, Post Box 173, Thimphu, Bhutan

4 Department of Earth Sciences, ETH Zürich, Sonneggstrasse 5, 8092 Zürich, Switzerland

5 National Seismological Centre, Department of Mines and Geology, Lainchur, Kathmandu, Nepal

The crustal geometry of continental subduction zones is a key parameter to understand the geodynamics of collisional belts. In one hand, it enables to better assess the isostatic state of the range and the behaviour of the plates involved in the collision. On the other hand, the geometry of the crust beneath collisional mountain belt has an influence on the shape of the plates interface where largest earthquakes nucleate.

The Himalayan arc is the most spectacular example of continental subduction. It results from the ongoing collision between Indian and Eurasian plates and extends laterally over 2500 km. Over the last three decades several geophysical studies including gravimetry and seismological methods have been undertaken to image this structure. These methods reveal a deepening of the Moho depth from 35 km to 75 km, which is associated to a Bouguer anomaly decrease of ~500 mGal. But, as most these previous studies focused on Central Nepal, we can wonder whether our current understanding of the Himalayas also holds along the entire arc.

To better constrain lateral variations of crustal structures along the Himalayas, 366 new gravity data points from Western Nepal to Eastern Bhutan have been acquired over five field campaigns. In addition to the available gravity anomalies dataset, these new measurements enable to compare several arc-perpendicular gravity anomaly profiles. Our results suggest east-west variation of the wavelength associated to the flexure of the Indian plate. Finally to understand these observed variations, we perform 2D finite-element thermomechanical modelling to assess the lateral variability of the effective elastic thickness of the Indian plate over more than 1200 km of the Himalayan arc.

Facilitating Geodesy Data Sharing: UNAVCO Participation in the Joint European Union - United States COOPEUS Project

Fran Boler¹, Chuck Meertens¹, Stuart Wier¹, Meghan Miller¹

¹UNAVCO, Boulder, Colorado, USA (boler@unavco.org)

The Plate Boundary Observatory (PBO), operated by UNAVCO, is the geodetic component of the US National Science Foundation-funded EarthScope Facility. A primary scientific objective of EarthScope is quantifying the three-dimensional deformation and its temporal variability across the active boundary zone between the Pacific and North American plates. To achieve this goal, UNAVCO has installed GNSS, strain, and seismic instrumentation at over 1,200 sites in the western US. UNAVCO also manages processing, analysis and distribution of PBO data and products under EarthScope's open data policy.

COOPEUS, the European Union project to strengthen the cooperation between the US and the EU in the field of environmental research infrastructures, will link EarthScope and the European Plate Observing System (EPOS) in joint research infrastructure enhancement activities that will ultimately advance international geodesy data sharing. (COOPEUS also links a broad set of additional EU and US based Earth, oceans, and environmental science research entities in joint research infrastructure enhancement activities.)

To enhance data sharing within the US, UNAVCO and several partner geodesy data centers have implemented the Geodesy Seamless Archive Centers (GSAC), a web services based technology to facilitate the exchange of geodesy metadata and delivery of geodesy data and products to users. These services utilize a repository layer implemented at each data center, and a service layer to identify and present any data center-specific services and capabilities, allowing simplified vertical federation of metadata from independent data centers. Within the context of COOPEUS, we envision that EarthScope-EPOS partnership could leverage GSAC or similar technologies to further advance data sharing among multiple geodesy data centers.

Fast error analysis of continuous GPS position time series

MS Bos

CIIMAR/CIMAR, University of Porto, Portugal

RMS Fernandes

University of Beira Interior, IDL, Portugal

Delft Earth-Oriented Space Research (DEOS), The Netherlands

SDP Williams

National Oceanography Centre, Liverpool, United Kingdom

L Bastos

CIIMAR/CIMAR, University of Porto, Portugal

University of Porto, Faculty of Science, DGAOT, Portugal

Session 4. Earth Observation Systems and Reference Frames, Observation Techniques, Methods and Data Analysis

It is now well accepted by the GPS community that temporal correlations need to be taken into account during the analysis of GPS position time-series to estimate a realistic linear trend error. However, the noise properties that describe these temporal correlations are not known a priori and also need to be estimated from the data. The Maximum Likelihood Estimation (MLE) method is the most widely used method to determine these noise properties. Hackl et al. (2011) criticized the MLE method of being computational demanding. Bos et al. (2008) already presented a MLE method that made the computation time proportional to a quadratic function of the number of observations instead of a cubic function. A drawback was that this method did not allow for data gaps which are normally present in real life GPS time-series. This problem has been solved and we have developed a MLE method that varies from a quadratic to a cubic function of the number of observations for growing number of data gaps. Santamaría-Gómez et al. (2011) analysed the weekly solutions of 275 globally distributed stations using the CATS software (2008), which does not employ this fast MLE method. We will repeat their study of the noise in GPS time-series with our fast MLE method but using the new, detrended, UR5 solutions (Santamaría-Gómez, 2012) which contains 326 GPS stations. Various noise models will be used and their relative merits will be discussed. In addition we will present the results for the analysis of the daily position time-series analysis of the Scripps Orbit and Permanent Array Center (SOPAC) data set which contains around 1400 stations.

The Long and Slow Nucleation of Most Large Interplate Earthquakes

Michel Bouchon¹, Jean Schmittbuhl², Virginie Durand¹, David Marsan³, Hayrullah Karabulut⁴

¹Centre National de la Recherche Scientifique and Université Joseph Fourier, Grenoble
ISTerre, BP 53, 38041 Grenoble, France

²Centre National de la Recherche Scientifique and Université de Strasbourg
EOST, 5 rue Descartes, 67084 Strasbourg, France

³Université de Savoie
ISTerre, 73376 Le Bourget du Lac, France

⁴Kandilli Observatory and Earthquake Research Institute, Bogaziçi University
KOERI, 81220 Cengelköy, Istanbul, Turkey

It has long been known that many earthquakes are preceded by foreshocks. However, the mechanisms which generate foreshocks and the reason why they occur before some shocks and not others remain unknown. We show, by analyzing seismic catalogs in some of the world best documented areas, that there is a remarkable contrast between the earthquakes which take place along the interfaces of the tectonic plates and the ones which result from the internal deformation of the plates. Most of the large ($M \geq 6.5$) shallow plate-interface earthquakes which have occurred in the well-instrumented areas of the North Pacific over the last 12 years have been preceded by an acceleration of seismic activity, indicating the presence of foreshocks. The location of these shocks and the contrast observed with intraplate earthquakes, for which foreshocks are much less frequent, suggest that the plate interface begins to slip slowly long before it ruptures.

strategies to develop early warning tsunami-induced tilt for the 2007, M=7.6, Tocopilla and the 2010, M=8.8 Maule earthquakes, Chile, from long base tiltmeter and broad-band seismometer records.

F. Boudin¹, S. Allgeyer², P. Bernard³, H. Hébert⁴, M. Olcay⁵, M. El-Madani³, B. Schurr⁶, M-F. Esnault³, R. Madariaga², G. Asch⁶, I. Nunez⁵, M. Kammenthaler⁷

¹ Géosciences Montpellier, Place Eugène bataillon, 34095 Montpellier, France. Email : frederic.boudin@gm.univ-montp2.fr

² Ecole Normale supérieure de Paris, 45, rue d'Ulm, 75230 Paris cedex 05, France.

³ Equipe de Sismologie, Institut de Physique du Globe de Paris, 1 rue Jussieu, 75252 Paris Cedex 05, France.

⁴ CEA:DASE/LDG, centre DAM île de France, Arpajon, France.

⁵ Universidad Arturo Prat, Iquique, Chile

⁶ GFZ-Potsdam, Potsdam, Germany.

⁷ Hergauchamps 68160 Saintes Maries aux Mines, France

SUMMARY

We present a detailed study of tsunami-induced tilt at in-land sites, to test the interest and feasibility of such analysis for tsunami modeling and early warning. We analyzed the tiltmeter and broad-band seismometer records of the northern Chile, IPOC arrays, and detected a clear signature of the tsunamis generated by the 2007 Tocopilla (M=7.5) and of the 2010 Maule (M=8.7) earthquakes. We showed that this signal is dominated by the tilt due to the elastic loading of the oceanic floor, with a smaller effect of the horizontal gravitational attraction and inertial acceleration. The Maule tsunami has been numerically modelled assuming the seismic source of Delouis et al. (2010) and taking a 600 m grid bathymetric map, correctly fitting the 3 tide gauges records of the area (Antofagasta, Iquique, and Arica). The elastic response to the tsunami load on solid earth is calculated every minute with the classical, static solution provided by summation in Love numbers, providing the tilt and displacements at the IPOC in-land sites. At all stations at distance less than 20 km (7 STS2, 2 long base tiltmeters), we correctly modelled the first hours of the tilt signal for the Maule tsunami. The only phase mismatch is for the close site (3 km), more sensitive to local, unmodelled details of the sea level change. For these large scale sea level perturbations (100 km and more of offshore extension) and a nearly rectilinear coast line, we find a tilt response of 0.005 to 0.01 micro-radians at 7 km from the coast line, in response to a sea level amplitude of 10 cm - a tilt decaying by a factor of 2 at 30 km from the coast. For the Maule earthquake, we observe a clear tilt signal starting 20 minutes before the arrival time of the tsunami at the nearest point of the coast line, due to the long range tilt effect of the oceanic load. This capability of tilt or seismic sensors to “weight” distant tsunamis before they arrive has been successfully tested with a scenario megathrust in the southern Peru- northern Chile seismic gap. Inland measurements of tsunamis also smoothes out short, often unmodelled wavelengths of the sea level perturbation, thus providing robust, large scale images of the tsunami. Furthermore, such instruments are not expected to saturate even for the largest run-ups, nor to suffer from near coast tsunami damages. They are valuable instruments for monitoring tsunamis in complement with tide gauge arrays. Our analysis demonstrates the potential of high-resolution in-land measurements for contributing to the modeling and the early detection of large tsunami; a potential which is growing fast, with the steady increase of near coastal, in-land monitoring arrays, specially in subduction regions.

Keywords: Tsunamis, Earth rotation variations, Lithospheric flexure, Elasticity and anelasticity, Transient deformation, Time series analysis, Time variable gravity, Global change from geodesy, South America, Pacific Ocean, Sea level change, Early warning

Monitoring of Ground Deformation in the Haoud Berkaoui Oil Field (Sahara, Algeria) Using Time Series Analysis of SAR Images

Seyfallah Bouraoui (1), Mustapha Meghraoui (1), Rachid Bougdal (2), Ziyadin Cakir (3)

(1) IPG Strasbourg, CNRS-UMR 7516, France

(2) FSTGAT, USTHB, Algeria

(3) Dept. of Geology, ITU, Turkey

We investigate the surface displacement in the Haoud Berkaoui (Algerian Sahara) area, a locus of an oil well accident since 1978, using an advanced times series analysis. The Haoud Berkaoui area also includes numerous wells that served for oil extraction starting from 1970s. Among all wells, OKN32 and OKN32bis collapsed due to dissolution of evaporitic rocks inducing rapid ground subsidence and eventually a spectacular 320-m-diameter crater and ~80-m-depth as per today. We apply the small baseline (SB) and the PS-InSAR (Persistent Scatterer) methods to retrieve deformation maps and displacement time series from ESA - SAR images (ERS1 and ERS2) acquired between 1992 and 2002. Our analysis delimits the subsidence area and shows an average 1.5 mm/year subsidence located around the OKN32 (oil well) and in the direction of Ouargla city. We also evaluate the possible propagation and the direction of subsidence by studying the spatial temporal variation of subsidence together with the distribution of the other oil wells in the same area. An elastic model with volume decrease is calculated to correlate the surface subsidence with the dissolution-collapse at depth. The study of this incident helps in the understanding of the subsidence process and the mitigation of further underground collapse that may affect neighboring urban areas.

Key words: sinkhole, subsidence, underground dissolution, Small Baseline InSAR, surface deformation.

High resolution loading estimates for precise geodetic observations

Jean-Paul Boy

EOST/IPGS (UMR 7516 CNRS-UdS), 5 rue René Descartes, 67084 Strasbourg, France.

The precision of modern geodetic observations requires the correction of global loading effects due to the global circulation of surface geophysical fluids. We present here a new loading service, providing global maps of horizontal and vertical surface displacements at high resolution (0.5 degree and 3 hours), as well as time series for fundamental ITRF (International Terrestrial Reference Frame) sites.

Atmospheric loading contributions are computed using surface pressure data provided by the European Centre for Medium-Range Weather Forecast (ECMWF) operational model. We provide two different models of the ocean response to pressure forcing: the classical inverted barometer (IB) hypothesis, and a dynamical response using MOG2D barotropic ocean model (Carrère & Lyard, 2003). We also provided the loading contributions due to continental water storage variations using the GLDAS/Noah model (Rodell et al., 2004). Loading series are both computed in the center-of-mass of the total Earth system (CM) and in center-of-figure (CF) reference frame starting from January 2002.

We show some general characteristics of the induced displacements, including the annual, diurnal (S1), semi-diurnal (S2) components as well as the linear trends. In addition, we validate these loading products by comparison with GPS observations.

THE GEOID AND THE STRESS STATE IN THE LITHOSPHERE OF WESTERN EUROPE

Thierry Camelbeeck¹, Olivier de Viron², Michel Van Camp¹ and Dimitri Kusters¹

¹ Royal Observatory of Belgium, avenue circulaire 3, B-1180 Brussels, Belgium

² Université Paris Diderot, PRES Sorbonne Paris Cité, Institut de Physique du Globe, UMR 7154 CNRS, Bâtiment Lamarck, case 7011, 5 rue Thomas Mann, 75205 Paris Cedex 13, France

Abstract

The tendency of lithosphere to deform in response to internal body forces related to lateral variations of the surface topography and of the density is expressed by the gravitational potential energy (GPE). We investigate whether the short wavelengths GPE spatial variations can induce local stress perturbations explaining the complexity of the present-day tectonics in Western Europe. We show that it is possible to infer this local stress contribution from the geoid used as a proxy of the GPE and we propose a method that allows determining the principal direction of horizontal stress generated at the local scale in the lithosphere as well as the associated tectonic style from the second spatial derivatives of a geoid height grid.

By applying this method to a passive margin, the Bay of Biscay, we obtain extensive local stress sources in the continental part of the margin and compressive sources in its oceanic part. The associated local deviatoric stress tensor corresponds to what is expected in such geological configuration: the maximum horizontal principal stress is respectively parallel and perpendicular to the margin, respectively in the continental and oceanic lithosphere.

By comparing the local stress contribution from the geoid in Western Europe with the stress derived from the World Stress Map database (WSM), we analyze the relative importance of the stress sources to the sum of the other possible plate interiors stress contributions. The stress pattern from the second derivatives of the geoid is dominated by short space wavelength fluctuations (a few tens to a few hundreds of km) in the tectonic style and in the direction of the maximal horizontal principal stress σ_H which presents a bimodal distribution in direction: NW-SE and NE-SW. There is a fair agreement between our σ_H directions and the ones in the WSM, but the NE-SW σ_H orientation, even if it is present, is less represented in the WSM data set. This difference can partly be explained partly by the main orientation of GPE gradient at regional scale but also likely by the influence of stresses propagated in the European plate and associated with the collision between Africa and Europe. Those two stress components are weaker than the local stress in the Pyrenees where the agreement between earthquake fault slip directions and the direction of shear stress from the local sources acting on the fault planes is striking and suggests the predominance of the local stress pattern.

Fault Kinematics and mechanics at the seismic cycle time-scale from Experimental Approach.

Y.Caniven, S.Dominguez, R.Soliva, R.Cattin, M.Peyret, C.Romano

Université Montpellier II, Lab. Géosciences Montpellier, UMR 5243, Place E. Bataillon, 34095
Montpellier cedex, France

Session : Seismotectonics and the Earthquake Cycle

Geodetic measurements including trilateration, GPS and Insar as well as seismological data extend over less than one century. The average seismic cycle duration extends from hundred to a few thousands years. This short time scale does not allow then to clearly constrain the role of key parameter such as friction, rheology, geometry, stress and strain rate that control the kinematics and mechanics of active faults.

To solve this time scale issue, we developed an experimental approach that reproduces several hundreds seismic cycles along a strike-slip fault. The model is constituted of two polyurethane foam plates and a basal silicone layer, which simulate the behaviour of an elastoplastic upper crust and a ductile lower crust, respectively (Fig.1a). A computerized motoreductor system allows displacing of compartments at a very low velocity (a few $\mu\text{m/s}$) and on an opposite sens.

Surface horizontal strain field is quantified by sub-pixel correlation of photo recorded every 16 μm of displacement. For each experience we obtain 2000 measurements of horizontal velocity field (Fig.1b). The analyse of model interseismic and coseismic horizontal surface displacements and their comparison to seismogenic natural faults demonstrate that our analog model reproduces correctly both near and far field surface strains. To compare experiences, we've developed several algorithms that allow studying the main spatial and temporal ruptures characteristics. We also performed surface velocity field inversions to assess the spatial distribution of slip at depth along the fault plane.

Our first results suggest that far field boundary velocity conditions play a key role on earthquake magnitude. Low strain rate generate large size events and high strain rate numerous small earthquakes and creeping. This behaviour is most probably controlled by the brittle/ductile coupling at the base of the foam plates. For a high strain rate, viscous forces in the silicone layer increase as well as coupling at the base of the foam plates. These force the fault to slip at a velocity close to the far field velocity. For a low strain rate, silicone almost behaves as a newtonian fluid and viscous forces strongly decrease allowing the fault to locked. Normal stress is also a key parameter that controls both location and size of earthquakes. The major ruptures tend to localise where the normal stress is highest. In nature, these mechanical coupling variations along the fault plane may exist with asperities. A set of experiences will be intended to test in particular the role of friction heterogeneity on fault plane.

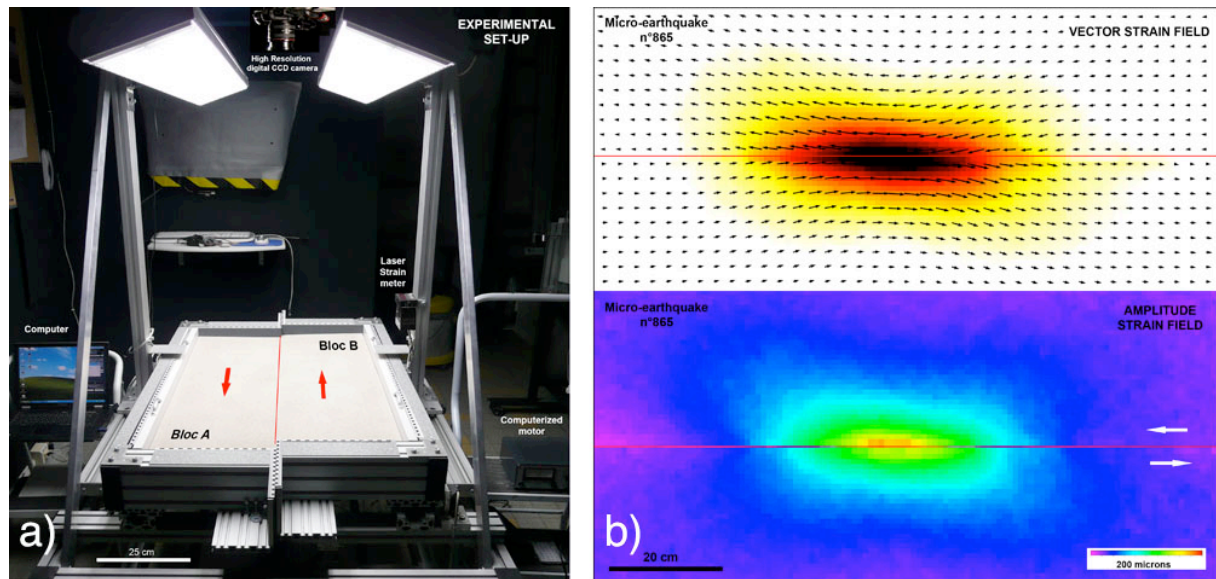


Figure 1 : a) Experimental setting to study the seismic cycle. ; b) Example of analogue earthquake with horizontal velocity field (top) and displacement amplitude map (bottom).

Seismic cycle stress change along the Himalayas over the last 900 years

RODOLPHE CATTIN¹, ROSER HOSTE-COLOMER¹, THÉO BERTHET¹, GYÖRGY HETÉNYI²

- 1 Géosciences Montpellier, UMR5243–CC60, Université Montpellier 2, Place E.Bataillon, 34095 Montpellier cedex 5, France, cattin@gm.univ-montp2.fr
- 2 Swiss Seismological Service, ETH Zürich, Sonneggstrasse 5, 8092 Zürich, Switzerland, gyorgy.hetenyi@sed.ethz.ch

The Himalayan arc, which extends continuously along 2500 km, is one of the most spectacular manifestations of continental subduction. About 20 mm/yr of the present-day India-Eurasia convergence is accommodated across the Himalayas by interseismic loading and seismicity, which reveals some significant lateral variations, especially in the Bhutan Himalaya where present-day seismicity rate is low. This low seismicity is a matter of concern, as it may reflect two opposite fault behaviours: (1) a creeping zone or (2) a zone of stress accumulation for future great earthquakes. A host of information is now available regarding the major (M~8) earthquakes that occurred in this area over the last centuries, including Central-eastern Himalaya (1100), Central Himalaya (1505), Shillong plateau (1897), Kangra (1905), Bihar (1934) and Assam (1950).

Taking advantage of previous paleoseismological studies, we combine major faults' geometry and estimated slip to compute stress interaction during earthquake cycles along the Himalayan arc over the last 900 years. Co-seismic stress due to major past earthquakes and secular stress loading of the major thrust fault system is computed using dislocation models in an elastic homogeneous half-space. Taken together, these two stress models result in a Coulomb failure stress model that predicts the state of stress change of the seismogenic frontal thrust fault in the Himalayas over the studied time-period. Several scenarios are tested to take into account the lack of constraints for the mean slip and the lateral extent of the past great earthquakes.

Our results are compared to the present-day seismicity distribution along the Himalayan arc. We will discuss the relative effect of aseismic versus seismic deformation by studying the role played by interseismic loading. We will pay a specific attention to the Coulomb stress in Bhutan and to the robustness of our results with respect to the used parameters.

Monitoring and modeling of interseismic creep of the North Anatolian Fault at Ismetpasa using Persistent Scatterer InSAR

Esra Cetin (1,2), Ziyadin Cakir (2), Ugur Dogan (3), Ahmet M. Akoglu (4), Haluk Ozener (5), Semih Ergintav (6), Mustapha Meghraoui (1)

(1) EOST - Institut Physique du Globe Strasbourg (UMR 7516), Geodynamics and Active Deformation, Strasbourg, France (e.cetin@unistra.fr),

(2) Dept. Of Geology, Istanbul Technical University, Istanbul, Turkey,

(3) Dept. Of Geodesy, Yıldız Technical University, Istanbul, Turkey,

(4) King Abdullah University of Science and Technology, Saudi Arabia,

(5) Bogazici University, Kandilli Observatory, Dept. of Geodesy, Istanbul, Turkey

(6) TUBITAK, Marmara Research Center, Kocaeli, Turkey

Creeping along the Ismetpasa section of the North Anatolian Fault was discovered over half a century ago. However, its spatiotemporal nature is still poorly known due to lack of geodetic and seismological studies along the fault. Analysis of ERS (C-band) data acquired between 1992 and 2001 suggested an average creep rate of 9 ± 3 mm along a fault segment of ~ 70 km long despite the difficulties arising from limited number of images available, atmospheric artefacts and low coherency that are common in classical long-term InSAR studies (Cakir et al., 2005). These inferences have been supported by a recent study of stacked PALSAR (L-band) interferograms spanning the period between 2007 and 2010 (Fialko et al., 2011). In this study, we use the Persistent Scatterer InSAR technique to better constrain the spatiotemporal characteristics of the surface creep. We analysed 55 Envisat ASAR images on 2 descending tracks (479 and 207) between 2003 and 2010 and calculated InSAR time series. The results reveal clearly the gradual transition between the creeping and locked segments of the NAF west of Ismetpasa. Its eastern termination is scarcely determined and near west of 33.4E since creep signal is disturbed by the postseismic deformation of the A.D. 2000, Orta earthquake. The length of the creeping section therefore appears to be approximately 81.5 km. The creep rate is also tightly constrained and found to be in the range of 10 ± 2 mm/yr near to Ismetpasa, consistent with the GPS measurements from a small-aperture geodetic network near Ismetpasa and recently reported PALSAR measurements (Fialko et al., 2011). Elastic screw dislocation modelling suggests shallow creeping depth (< 5 km).

Seven years of postseismic deformation following the 2003 Mw=6.8 Zemmouri earthquake (Algeria) from InSAR Time Series

Esra Cetin (1,2), Mustapha Meghraoui (1), Ziyadin Cakir (2), Ahmet M. Akoglu (2,3), Omar Mimouni (4), Mouloud Chebbah (5)

(1) EOST - Institut Physique du Globe Strasbourg (UMR 7516), Geodynamics and Active Deformation, Strasbourg, France (e.cetin@unistra.fr),

(2) Dept. Of Geology, Istanbul Technical University, Istanbul, Turkey,

(3) King Abdullah University of Science and Technology, Saudi Arabia,

(4) Universite des Sciences et Techniques Houari Boumediene, Algiers, Algeria

(5) Agence National des Ressources Hydrauliques, Blida, Algeria

We study the postseismic surface deformation of the Mw 6.8, 2003 Zemmouri earthquake (northern Algeria) using the Multi-Temporal Small Baseline InSAR technique. InSAR time series obtained from 31 Envisat ASAR images from 2003 to 2010 reveal sub-cm coastline ground movements between Cap Matifou and Dellys. Two regions display subsidence at a maximum rate of 2.0 mm/yr in Cap Djenet and 3.5 mm/yr in Boumerdes. These regions correlate well with areas of maximum coseismic uplifts, and their association with two rupture segments. Inverse modeling suggests that subsidence in the areas of high coseismic uplift can be explained by afterslip on shallow sections (< 5 km) of the fault above the areas of coseismic slip, in agreement with previous GPS observations. The earthquake impact on soft sediments and the ground water table southwest of the earthquake area, characterizes ground deformation of non-tectonic origin. The cumulative postseismic moment due to 7 years afterslip is equivalent to an Mw 6.3 earthquake. Therefore, the postseismic deformation and stress buildup has significant implications on the earthquake cycle models and recurrence intervals of large earthquakes in the Algiers area.

scientific session: 3. Seismotectonics and the Earthquake Cycle

Reassessment of the source of the 1976 Friuli, NE Italy, earthquake
sequence from the joint inversion of high-precision levelling and
triangulation data

D. Cheloni, N. D'Agostino, E. D'Anastasio and G. Selvaggi
Istituto Nazionale di Geofisica e Vulcanologia, Via Vigna Murata, 605–00143 Roma, Italy. E-mail:
daniele.cheloni@ingv.it

In this study, we revisit the mechanism of the 1976 Friuli (NE Italy) earthquake sequence (main shocks M_w 6.4, 5.9 and 6.0). We present a new source model that simultaneously fits all the available geodetic measurements of the observed deformation. We integrate triangulation measurements, which have never been previously used in the source modelling of this sequence, with high-precision levelling that covers the epicentral area. We adopt a mixed linear/non-linear optimization scheme, in which we iteratively search for the best-fitting solution by performing several linear slip inversions while varying fault location using a grid search method. Our preferred solution consists of a shallow north-dipping fault plane with assumed azimuth of 282° and accommodating a reverse dextral slip of about 1 m. The estimated geodetic moment is 6.6×10^{18} Nm (M_w 6.5), in agreement with seismological estimates. Yet, our preferred model shows that the geodetic solution is consistent with the activation of a single fault system during the entire sequence, the surface expression of which could be associated with the Buia blind thrust, supporting the hypothesis that the main activity of the Eastern Alps occurs close to the relief margin, as observed in other mountain belts. The retrieved slip pattern consists of a main coseismic patch located 3–5 km depth, in good agreement with the distribution of the main shocks. Additional slip is required in the shallower portions of the fault to reproduce the local uplift observed in the region characterized by Quaternary active folding. We tentatively interpret this patch as postseismic deformation (afterslip) occurring at the edge of the main coseismic patch. Finally, our rupture plane spatially correlates with the area of the locked fault determined from interseismic measurements, supporting the hypothesis that interseismic slip on the creeping dislocation causes strain to accumulate on the shallow (above ~ 10 km depth) locked section. Assuming that all the long-term accommodation between Adria and Eurasia is seismically released, a time span of 500–700 years of strain-accumulating plate motion would result in a 1976-like earthquake.

A new class of tiltmeters and seismometers based on optic fiber Fabry-Pérot interferometry: results and use for active tectonics

Jean Chery(1), Frederick Boudin(1), Michel Cattoen(2), Han Cheng Seat(2), Patrick Chawah(3), Guy Plantier(3), Anthony Sourice(3), Pascal Bernard(4), Christophe Brunet(4), Stephane Gaffet(5), Daniel Boyer(5)

1. Geosciences, CNRS, Montpellier, France.
2. OSE-LAAS, CNRS, Université de Toulouse-INPT, France.
3. ESEO, Angers, France.
4. IPGP, Paris, France.
5. LSBB, CNRS, Nice, France.

Measurements of strain and vibrations due to seismic and volcanic processes are mandatory for the understanding and the monitoring of the behaviour of these systems. In the future, risk mitigation will depend on our capability to detect in a reliable way small precursors of large seismic and volcanic events and to assess the seismic/aseismic spatial and temporal distribution and evolution of crustal strain in these unstable systems. The robustness of strain and motion detection is primary linked to measurement accuracy, but also to the number and repartition of instrument. This implies that instrument cost and maintenance are essential for the development of networks.

To date, only GPS sensors are robust enough to be deployed for long period of time with limited problem of maintenance. Seismometers and strainmeters capabilities are often plagued by numerous technical problems limiting their usefulness. On the basis of existing or prototype sensors, we developed new instruments (seismometers, tiltmeters, strainmeters) using an interferometric motion measurement. Both Laser source and fringe analysis are connected to the mechanical sensor with long optic fiber (0.1 – 3 km) depending on applications (volcanoes, sea bottom) The fiber signal transmission appears to be a major improvement by comparison with usual electric wires (cost, data channels, lightning, weight). Also, the absence of embedded electronic on the sensor is a guarantee for reliability and toughness.

The developed optical device includes a double modulation of the Laser Diode's wavelength, aiming to reconstruct the displacement of the mechanical sensor with a nanometric resolution. Differential measurements also lead to correct internal sensor drift as well as the influence of atmospheric forcing. Three instruments (seismometer, hydrostatic tiltmeter, borehole tiltmeter) have been developed and tested at the Laboratoire Souterrain à Bas Bruit (LSBB), Vaucluse. We will herewith present the development of the instruments and their performance after 9 months of data recording. We will finally discuss the use of this technology for Earth sciences projects.

Thermal and Compositional Controls on African Seismicity

T. J. Craig*, J. A. Jackson

Bullard Laboratories, Department of Earth Sciences, University of Cambridge,
Cambridge, CB3 0EZ, UK

*tjc52@esc.cam.ac.uk

Preferred session: 2 - The role of continental faults in the Mediterranean, Africa and Middle-East.

Using teleseismic waveform inversion, along with depth-phase analysis, we constrain the centroid depths and source parameters of large African earthquakes. The majority of seismic activity is concentrated along the East African Rift System, with additional active regions along stretches of the continental margins in north and east Africa, and in the Congo Basin. The localisation of deformation appears to be dominated by a combination of forces on the base and at the edges of the plate (at long wavelength) and inherited intra-lithospheric structure (at short wavelength).

Across Africa, seismogenic thickness varies in correlation with lithospheric thickness, based on surface-wave tomography, with regions of thick lithosphere being associated with seismogenic thicknesses of up to 40 km. In regions of thin lithosphere, the seismogenic thickness is typically limited to ≤ 20 km. Larger seismogenic thicknesses also correlate with regions that have dominant tectonothermal ages of ≥ 1500 Ma. The correlation between seismogenic thickness, lithospheric thickness, and tectonothermal age, is likely to be related to the presence of a strong, anhydrous lower crust.

Areas with increased seismogenic thickness also correspond to areas with increased fault length and basin width, consistent with the thickness of the elastic layer in these regions controlling the scale of deformation. This has implications for the structure and evolution of such areas, and the related seismic hazard, with an increased seismogenic thickness resulting in the potential for larger earthquakes.

Spatio-temporal distribution of tectonic strain accumulation and release in the Apennines from decadal geodetic rates and 400 years of historical seismicity

Nicola D'Agostino
Centro Nazionale Terremoti
Istituto Nazionale di Geofisica e Vulcanologia
Via Vigna Murata 605
00143 Roma
Italy

e-mail: nicola.dagostino@ingv.it

In actively deforming regions elastic strain energy is supplied by the relative motion of the plates, with intermittent release of stored energy resulting in earthquakes. In a region where all the accumulating geodetic strain is, on the long term, completely released by earthquakes the ratio M_R between the rates of seismic energy accumulation and release should approach unity. On the other hand $M_R \sim 1$ is rarely achieved because of uncomplete catalogues, inaccurate geodetic rates and short-term temporal fluctuation that cluster seismic events in time. Here I compare decadal geodetic strain rates with the last 410 years of seismic moment release in the Apennines (Italy) to assess the spatio-temporal distribution of tectonic strain accumulation and release. I suggest that over the last 410 years seismic release has kept pace with strain accumulation from tectonic loading. Although this study suggests that, on average $M_R \sim 1$, the spatial analysis of moment deficit distribution indicates that unreleased strain allows several parts of the Apennines to generate a $M > 6.5$ event. I will also discuss what conditions allow $M_R \sim 1$ in the Apennines, starting from the suggestion that any estimate of seismic moment rate hinges on the product between the observation time interval, the regional strain rate, and the dimension of the sampling area.

Title:

Fault bends : behavior during the interseismic period constrained by SAR interferometry

Authors :

Simon Daout (1), G. Ducret (2), C. Lasserre (1), M.-P. Doin (2), R. Jolivet (3), R. Grandin (2), Sun Jianbao (4), Zheng-Kang Shen (5), J.-M. Nocquet (6), Y. Klinger (7)

(1) ISTerre, Grenoble, France, (2) ENS, Laboratoire de Géologie, Paris, France, (3), Caltech Seismological Laboratory, Los Angeles, USA, (4) Institute of Geology, CEA, Beijing, Chine, (5) Peking University, School of Earth and Space Science, Beijing, China, (6) Géoazur, Nice, France (7), IPG Paris, France

Corresponding author :

Cecile Lasserre, ISTerre, BP 53, 38041 Grenoble Cedex 09, France,
cecile.lasserre@ujf-grenoble.fr

Scientific session : Seismotectonics and the Earthquake Cycle

Abstract :

Fault geometry is among the key parameters that controls the initiation, propagation and arrest of seismic events. For example, earthquakes have been observed to nucleate or terminate near geometrical irregularities along faults (major azimuth changes, extensional or compressive jogs, branching of secondary faults...). The coseismic slip distribution is also clearly influenced by the fault segmentation. During the coseismic phase, fault inter-segment areas are usually associated with local slip minimum. This minimum should be compensated over the entire seismic cycle, possibly by volumic deformation or by creep in the seismogenic zone at different stages of the seismic cycle.

We use SAR interferometry to investigate the behavior of a selected fault bend along a major strike-slip faults in China : the 15 km-large Tianzhu pull-apart basin in the middle of the Tianzhu seismic gap (Haiyuan fault). The objectives are both methodological (extracting a small deformation signal in mountainous areas by InSAR) and thematic (understanding the role and behavior of such inter-segment areas). The most recent developments of our interferometric chain NSBAS (that takes into account, in particular, DEM and atmospheric delays corrections before unwrapping, Doin et al., 2011) are tested to compute and analyse time series of interferograms built from the complete Envisat data archive over the past 10 years. The results are compared and validated by the analysis of GPS data available on the selected study site.

ALERT-ES project: Development of an Earthquake Early Warning System (EEWS) for SW Iberian Peninsula

J. Martin Davila (1), E. Bufo (2), X. Goula (3), A. Pazos (1), M. Carranza (2), Y. Colom (3), Mireya Lopez (1, 4), J. Garate (1), A. Udias (2), A. Roca (3), C. Rioja (4), J.A. Jiménez (4), L. Lozano (5), L. Mendoza (1), A. Zollo (6), W. Hanka (7), R. Madariaga (8), M. Harnafi (9)

- (1) Real I. Observatorio Armada, ROA, Spain (mdavila@roa.es)
- (2) Universidad Complutense de Madrid, UCM, Spain (ebufo@fis.ucm.es)
- (3) Institut Geologic de Catalunya, IGC, Spain (xgoula@igc.cat)
- (4) Universidad de Cadiz , UCA, Spain
- (5) Instituto Geografico Nacional, IGN, Spain
- (6) Universita Federico II, Naples, Italy
- (7) Geoforschung Zentrum, GFZ, Germany
- (8) Ecole Normale Supérieure, ECS, France
- (9) Université Mohammed V-Agdal, UM5-A, Morocco

San Fernando Naval Observatory Geophysical Department (ROA; Spain) is involved in real-time GNSS Geodetic and Seismic earthquake studies, both them in collaboration with other Institutes. The former approach is being carried out in collaboration with the Technical University of Darmstadt (TUD), and partial results are presented in the presentation “The Mw 5.1 Lorca Earthquake Successfully Recorded by GPS” (Mendoza et al.). Within the real time seismic studies, early warning applications are being developed under ALERT-ES (“Sistema de Alerta Sísmica Temprana: Aplicación al Sur de España”) Spanish funded project. The main goal of ALERT-ES is to study the feasibility of an Earthquake Early Warning System (EEWS) for SW Iberian Peninsula due to the potentially damaging earthquakes that occur in the zone Cape S. Vicente-Gulf of Cadiz (S. Iberia) zone, an area characterized by the occurrence of large and damaging earthquakes, such as the 1755 Lisbon ($M_{max}=X$) or 1969 S. Vicente Cape ($M_s=8.1$) events. The basic hypothesis for the EEWS is “the first seconds of the earthquake P wave carries the information of its size, and in consequence, of its damaging capacity, while damages are produced by later arrival waves, like S and Surface waves which carry the energy”. This provides a time interval to issue a warning if P waves are analyzed before S and Surface waves arrival. ALERT-ES is a coordinate project among three Spanish institutes: UCM; IGC and ROA with the participation of researchers from other Institutes, and has two different parts: the development of algorithms for the rapid estimation of the magnitude from the very beginning of P-waves for S. Vicente Cape, South Iberia earthquakes, and the development of the corresponding new software modules, dealing with detection, event declaration and location, and their implementation in EarthWorm and SeisComP platforms integrated in a real time system. A pilot experience will be carried out in the last months of the project.

Invited key-note
Session: "Subduction zones and giant earthquakes"

Controlled source seismic imaging of subduction zones; what can we learn from the down-going plate

M. Delescluse⁴, M. R. Nedimovic^{1,2}, D. J. Shillington¹, S. M. Carbotte¹, A. Becel¹, J. P. Canales³, H. Carton¹, S. C. Webb¹ & H. Kuehn²

¹ Lamont-Doherty Earth Observatory, Columbia University, NY, USA

² Department of Earth-sciences, Dalhousie University, Halifax, NS, Canada

³ Woods Hole Oceanographic Institution, Woods Hole, MA, USA

⁴ Laboratoire de géologie de l'ENS, UMR 8538, Paris, France

Subduction zones in the world are monitored in real time, mostly by spatial arrays of geodetic sensors and seismometers. Co-seismic slip distributions now reach unprecedented resolution for the most instrumented regions (e.g., the Tohoku rupture area in Japan). While the main slip patches and asperities of recent giant earthquakes are well defined, as well as the kinematics of their rupture, there is still a lot to understand about what structures and/or processes limit the extent of the rupture zones (1) and contribute to the locked or aseismic nature of the plate interface (2).

We here focus on what can be learned from marine studies involving controlled source seismic imaging of the interplate interface and of the down-going oceanic plate. We discuss two marine geophysics cruises that have been recently conducted by LDEO and Dalhousie University using R/V Marcus G. Langseth and its modern seismic acquisition system (6600 cu. in. tuned gun array and 8 km long streamers). These are the 2011 ALEUT Project that targeted the Alaska subduction zone and the 2012 Ridge2Trench Project that targeted the Juan de Fuca (JdF) plate and Cascadia subduction zone.

Central point of the JdF Ridge2Trench cruise is the important question of the origin of fluids in the subduction system. The Cascadia subduction zone shows evidence for hydration of the JdF oceanic plate, with intra-slab earthquakes detected under/above the oceanic Moho and active arc-volcanism, both generally related to de-watering of the slab. The Cascadia subduction is also well known for Episodic Tremor and Slip (ETS), for which the mechanics of aseismic slip can be explained by fluid overpressure. However, the incoming JdF slab is very young (9 Ma) and theoretically too warm to incorporate large amount of water through serpentinization of the mantle. The proximity of the JdF spreading-ridge offers a unique opportunity to study, through reflection and refraction seismics, the hydration of the oceanic crust and upper mantle from the ridge to the trench, and its variation along the trench. Intraplate faults are the likely fluid paths used to hydrate the plate. Therefore, the along-strike variations in hydration may be related to N-S variations in the stress regime within the JdF plate as it enters the Cascadia subduction zone, but also to both the orientation of the ridge-generated fault fabric relative to the trench and along-trench variations in the thermal state of the JdF plate.

The ALEUT cruise in 2011 focused on a section of the Alaska-Aleutian subduction zone from the Shumagin Gap in the SW, across the Semidi Segment in the middle, and to the SW Kodiak Island in the NE. The highly coupled Kodiak Asperity has ruptured in the Mw 9.2 1964 earthquake. The variably coupled Semidi Segment has last ruptured in 1938 and is thought to have a recurrence rate of 50-75 years. The poorly coupled Shumagin Gap is thought to behave aseismically. The Alaska subduction zone is particularly interesting to investigate because the entire seismogenic zone and the downdip transition to aseismic slip are accessible by sea. Based on previous observations showing different megathrust reflector properties as a function of the aseismic (ductile) or locked (brittle) nature of the rupture plane, one of the main goals of this cruise is to verify the possibility of mapping these different behaviors through reflection seismics. Initial processing of the acquired data shows varying plate interface reflections to depth greater than 30 km,

and along-strike variations in the reflection expression of splay faults.

Advances in our understanding of the subduction systems using controlled source seismic data are not only dependent on collecting new data using advanced systems but also on our ability to apply advanced imaging technology to such data to extract additional information. We present perspectives in seismic imaging using full-waveform inversion of the seismic wave-field that has the potential to greatly impact future research. For shallow targets (using long streamer MCS profiles) or deep targets (using high density OBS profiles), waveform tomography inversions bring velocity field imaging to the resolution of the fault, making it a powerful tool for detecting fluids or velocity inversions in general. The full waveform approach may open a new era in the observation of structures and processes impacting the subduction systems.

**Seismic and aseismic deformation along the East African Rift System from a reanalysis
of the GPS velocity field of Africa**

Aline Déprez, Cécile Doubre, Frédéric Masson and Patrice Ulrich
IPGS, Université de Strasbourg/EOST, CNRS
5 rue Descartes
67084 STRASBOURG Cedex, France

The geodetic coverage of Africa has been improved in the last few years, so the GPS station network is denser and the GPS position time series are longer in the present work than in the prior geodetic studies. We propose here a model, which confirms in a large part the precedent studies and in particular it is consistent with the existence of two additional plates (Victoria and Rovuma), which allow model to fit with the observations. Based on this geodetic model, we compute velocities along plate boundaries and thanks to a scalar form of the Kostrov relation, a geodetic moment rate is estimated. In terms of seismology, we evaluate a cumulative moment rate based on earthquakes catalogues. The comparison between energy release estimates by geodesy and by seismology allows us to clearly observe the differences of behavior along the EARS. The pattern depicts along the rift by percentage of geodetic moment seismically accommodate, bring out a significant control of the thermal structure associated with different states of rifting evolution.

Visco-elastic deformation of the lithosphere around the lake Siling Co in Tibet

Marie-Pierre Doin(1), Cedric Twardzik, Gabriel Ducret, Cécile Lasserre(2), Stephane Guillaso(3) and Sun Jianbao(4)

(1) Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris Cedex 05, France

(2) ISTERre, Grenoble, France

(3) University of Technology, Berlin, Germany

(4) Chinese Earthquake Administration, Beijing, China

This study attempts to constrain the lithospheric strength in Central Tibet by studying the rebound of the lithosphere subjected to loading due to lake Siling Co water level increase. This lake is a large (1600 km²) endoreic lake at 4500 m elevation located North of the strike-slip right lateral Gyaring Co fault, and South of the Bangong Nujiang suture zone, on which numerous left-lateral strike slip faults are branching. The Siling Co water level has strongly changed in the past, as testified by numerous traces of palaeo-shorelines, clearly marked until 60 m above present-day level. Altimetric measures show that during the period 1995-1999 the Siling Co water level remained stable, while it increased by about 1.0 m/yr in the period 2000-2006. The increase rate gradually stepped down to 0.2 m/yr in 2008-2011. To extend the lake level observation duration, we extract the lake contour from all cloud-free LANDSAT images available on the USGS GLOVIS server. The lake surface, used as a proxy for lake elevation, shows that the water level in the Siling Co lake in Tibet was more or less stagnant from 1973 to 1999. A clear seasonal signal is superimposed on the interannual trend.

The ground motion associated to the water level increase is studied by InSAR using all available 56 ERS and 51 Envisat data on descending tracks 491 and 219 in the period 1992-2010, obtained through the Dragon ESA-MOST cooperation program. A redundant network of small baseline differential interferograms is computed with perpendicular baseline smaller than 500 m. The ERS and Envisat networks overlap in time, thus insuring measurement continuity. The coherence is quickly lost with time (over one year), particularly to the North of the lake because of freeze-thaw cycles. Interferograms are corrected for stratified atmospheric effect and residual orbital trends. The interferograms covering the period 1992-1999 show no detectable deformation, whereas the ones covering the period 2000-2010 present a clear bowl shape pattern centered on the lake that extend from the shore to about ~100 km from the lake center. The amplitude is about 5 mm/yr close to the lake shores. To increase the signal to noise ratio, the interferograms are first analysed in time assuming a constant deformation shape. We then obtain the temporal evolution of the deformation amplitude : it remains constant for the period 1992-1999, and increases from 2000 until 2010. This curve thus closely follows the lake level temporal evolution. The average spatial deformation pattern is then extracted for the period 2000-2010. Furthermore, we provide and discuss uncertainties on ground motion time series, focusing on the quantification of turbulent atmospheric noise and of the azimuthal phase ramp.

Both the temporal evolution and the average velocity map are used to explore possible rheological models. The elastic model is based on elastic moduli extracted from V_p/V_s profile derived from INDEPTH III experiment. It could explain the observed subsidence rates if elastic moduli are about twice lower than the one derived from the lithosphere seismic velocity profiles. We discuss whether the increase in elastic moduli due to local fluid pressure disequilibrium in nearby pores, when the medium is crossed by high frequency waves, could explain this discrepancy. However, kernels of surface displacements to elastic properties at depth show little sensitivity to the shallowest (first 10~km) parameters, where one expects that the cracks may not

be closed. We also explore delayed poro-elastic effects, taking place over longer time periods (over years or more, depending on pore diffusivity). In conclusion, the ground displacement observations are not likely to be explained by reduced effective elastic properties of the crust. By contrast, a visco-elastic model with a low viscosity lower crust (about 5×10^{18} Pa.s) provides a good fit to the data. Although the ground motion appears well correlated to water level fluctuations, delays resulting from viscous relaxation do not strongly change the temporal evolution and in fact yields a slightly better fit to the observed temporal evolution than the elastic model.

*Strain accumulation in the Southern Andes (25°-35°S) observed by
ERS and Envisat SAR data*

Gabriel Ducret(1), Marie-Pierre Doin(1), Raphael Grandin(1) , Anne Socquet(2), Christophe Vigny(1) , Marianne Métois (1) and Marta Bejar Pizarro (3)

(1) Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris Cedex 05, France

(2) ISTerre, Université Joseph Fourier, Grenoble, France

(3) Instituto Geologico y Minero de Espana, Madrid, Spain

Surface measurements of ground motion help constrain the along-strike and along-dip variations of interseismic coupling along subduction interfaces, defining their segmentation. This is of primary interest as earthquake location and magnitude may be controlled by the extent of coupled patches and the propagation across one or several consecutive segments. In the case of the Chilean subduction, the coupling and segmentation definition is debated.

We here focus on the 25-35°S portion of Chilean subduction zone, located between Taltal (~25°S) and Constitution (~35°S), which has been accumulating tectonic strain since the mid-20th century. The Nazca plate there subducts under the South American plate with a velocity around 7 cm/year. Three main earthquakes in the last decade surround this area : the 1995 Antofagasta (M=8.1) and the 2007 Tocopilla (M=7.7) earthquakes to the North and the 2010 Maule (M=8.8) earthquake to the South. A few seismic swarms occurred in recent years : the Punitaqui (~30°S) crisis in 1997 and the swarms in the Copiapo (~27°S) region in 1973 and 2006. The background seismicity is mainly located along the plate interface and less frequently within the overriding plate. The seismicity rate is varying from South to North with a maximum seismicity located around La Serena area (~30°S).

The coupling distribution along the 25-39°S subduction interface is constrained by an heterogeneous GPS data set (Métois et al., 2012). Low coupling rates are inferred for La Serena area, framed by locked portions of the interface further North and South. GPS data also suggest that the Copiapo area corresponds to a local minimum of coupling. Further North, between 28°S and 25°S, the GPS network is there too sparse to constrain coupling variations.

In this study, we use InSAR (Interferometric Synthetic Aperture Radar) to provide additional insights on interseismic strain accumulation. The available ERS and ENVISAT archive (1992-2010) on 4 tracks (53, 96, and 325) between 25°S and 35°S is particularly poor. In order to benefit from most available SAR images, we processed interferograms with perpendicular baselines reaching up to 600 m and temporal baselines exceeding 7 years, thus with a poor coherence. Wrapped interferograms are corrected from DEM errors effects and from stratified atmospheric delays, before filtering. The unwrapping starts in areas with the highest coherence and proceeds with a decreasing coherence threshold. Unwrapped interferograms are then flattened in range and azimuth, before being inverted to yield a time series of delay maps in the satellite Line Of Sight (LOS) direction.

The second step is to separate atmospheric patterns from the deformation signal, and to isolate the interseismic component from the earthquake-related deformation. The co- and post- seismic deformation associated with the swarm of Copiapo in 2006 are extracted by principal component analysis and the application of a parameterized model. They are inverted together with the constraint given by one GPS station located further inland. Post-seismic motion on the interface appears deeper and slightly offset to the South with respect to the co-seismic rupture. The effect of the swarm is then removed to construct an average interseismic LOS velocity map. A preliminary comparison shows an overall agreement with the detrended LOS displacement predicted from the coupling model derived from GPS velocities.

Fault activity in the Manda Hararo rift in Afar (Ethiopia) using Interferometric Synthetic Aperture Radar

Dumont S.(1), Socquet A.(2), Grandin R.(3), Doubre C.(4) , Klinger Y.(1), Jacques E.(1)

(1) Tectonics Lab, IPG Paris, France,(2) ISTerre, Grenoble, France,(3) ENS, Paris, France
(4) IPG Strasbourg, France

A major rifting episode began in September 2005 in Afar with the intrusion of a 65-km-long mega-dike inducing an average opening of 5 m at the surface in the northern part of the Manda Hararo rift (Grandin et al., 2009 ; Wright et al., 2006). From 2006 to present, 13 following successive intrusions have been monitored using InSAR and seismic survey, which allow the estimate of a total magma volume of 1.013 km³ that is 55 % of the volume of the first mega-dike. Using InSAR time series, Grandin et. al (2010) highlighted transient deformation during the inter-diking periods at the center of the Manda Hararo rift segment, suggesting the refilling of a crustal magma reservoir feeding the 2005–2009 dikes. We focus here on the InSAR signal due to creeping faults between dike intrusions in order to study the magmato-tectonic interactions and the tectonic extension along spreading segments and answer to the following questions: Is the fault activity on surface only triggered by the magmatic intrusions at depth? Is there a relation between the amount of extension accommodated by magmatic dilatation and the intensity of fault slips during inter-dyking periods? Is there an influence of the evolution of the crustal magma reservoir on the tectonic deformation? How do the faults grow and interact over the whole rifting period?

The floor of the Manda Hararo rift is intensely dissected by normal faults and fissures, which have been mapped using optical images (SPOT images, QUICKBIRD images) together with SAR interferograms and coherence images. Using the current database consisting in more than 150 Envisat SAR acquisitions along 4 different tracks, we first map the activated faults during each inter-dyking periods, and we then extract the horizontal and vertical displacement profiles along the fault from the interferograms.

The spatial distribution of active faults suggests a control by the movements of magma within the crust, especially above the area affected by the inflation/deflation of the crustal magma chamber in the center of the rift. We do not observe any relationship between the location of the faults activated after the intrusion and the area of the dyke emplacement. These faults seem to be activated mainly in response to the refilling of the main magma chamber. However slips on faults are observed in the southern region of the Dabbahu volcano over 6 months after the first dike. These observations have been made only for the first 6-month inter-dyking period. Together with geodetic and seismic data, they suggest the effect of the discharge of the Dabbahu reservoir into the September 2005 dike.

At a smaller scale, we investigate the fault growth and then the interactions within a fault population for 2 inter-dyking periods (after September 2005 and January 2007 dikes). The slip patterns are well-conserved through a complete inter-diking period. Most of minimal slip localization are well-correlated with change in the fault strike or with relay zone of connecting faults. Furthermore we observe a shape similarity of these transient slip patterns and the long-term deformation given by the scarp heights suggesting that the long-term tectonic deformation within the rift is mainly controlled by the magmatic activity.

Poster preferred

Towards a fusion of GNSS, SAR-Interferometry and Precise Levelling Data in the Upper Rhine Graben Area

T. Fuhrmann, A. Knöpfler, M. Mayer, M. Westerhaus, K. Zippelt and B. Heck

Geodetic Institute, Karlsruhe Institute of Technology, Germany

In recent years, dense GNSS (Global Navigation Satellite Systems) permanent networks have been established widely, the new PS-InSAR (Persistent Scatterer SAR Interferometry) method became operable and multiple repeated precise leveling lines are available to estimate recent displacements of the Earth's surface. Simultaneously, geodetic reference frames and processing models have been greatly improved. The available data provide a unique opportunity to derive detailed maps of surface movements. However, a joint interpretation is not straight forward since each method relies on its own characteristics (e.g., database, sampling interval, spatial resolution, reference frame and processing model). Problems to be solved are inherent especially to (i) major differences in the temporal and spatial resolution of the involved methods which require a careful test of suitable interpolation methods, (ii) different time-dependent reference systems, and (iii) changing geometry of the Persistent Scatterer networks as well as the imprecisely known dimensions and locations of the PS points. Although several fusion approaches are published, a fully formulated methodology for a stringent integration and unification of the various data types and their homogeneous combined analysis is still missing today.

The border region between Germany, France and Switzerland where dense and overlapping multi-sensor networks are available, is a suitable test area to proceed towards a fusion of different geodetic data. In 2008, a transnational network called GURN (GNSS Upper Rhine Graben Network) was established in close cooperation between the Geodetic Institute of Karlsruhe Institute of Technology (GIK-KIT, former Karlsruhe University) and the Institut de Physique du Globe de Strasbourg (IPGP-EOST). GURN actually consists of approx. 80 permanently operating GNSS sites in Germany, France and Switzerland with a typical distance of 40 km. A continuous database exists since 2002. Besides GNSS, a kinematic analysis of repeated precise levelling data obtained by the ordnance survey of Germany, France and Switzerland is carried out at GIK-KIT. The levelling lines were measured up to five times within the last 100 years, allowing for an assessment of average vertical displacement rates with a precision of 0.2 mm/year. The third geodetic component is PS-InSAR (C-band, X-band), which will be used to fill gaps and to significantly increase the number of points within the levelling loops.

In the presentation we will review the characteristics of the geodetic networks existing in the Upper Rhine Graben Area and discuss our strategy to consistently link the different observation methods in a multi-techniques approach as well as to facilitate a joint rigorous geodetic displacement analysis.

Session 4:

Earth Observation Systems and Reference Frames, Observation Techniques, Methods and Data Analysis (M. Becker, H. Ozener, Z. Altamimi)

Vertical Displacements in the Upper Rhine Graben Area Derived from Precise Levelling Data

T. Fuhrmann, M. Westerhaus, K. Zippelt, and B. Heck
Geodetic Institute, Karlsruhe Institute of Technology, Germany

The analysis of precise levelling data enables an accurate determination of vertical displacement rates at levelling benchmarks, if repeated measurements at identical benchmarks are available. In order to gain detailed insight into vertical crustal deformations in the Upper Rhine Graben (URG) area, a consistent analysis of levelling measurements carried out in Germany, France and Switzerland is in progress at the Geodetic Institute, Karlsruhe Institute of Technology. The data used for this study was primarily measured by the surveying authorities of the participating countries to contribute to a terrestrial height system. As levelling lines were remeasured up to five times within the past 100 years, the calculation of reliable vertical displacement rates with accuracies of about 0.2 mm/a is possible.

The available measurement data are inhomogeneous because of different accuracies (e.g., because of the instrumentation) and measurement dates (from 1891 to 2011). To consider the different measurement dates the geodetic dataset is analysed using kinematic network adjustment. Within this approach the exact dates of the measurements are used in a time-dependent model for the estimation of vertical displacement rates. To account for different accuracies the data are divided into groups, w.r.t. country, date, levelling order, and iterative variance component estimation is applied.

In the Eastern part of the levelling network the magnitudes of estimated displacement rates are of the order of 0.15 mm/a on average, which is in an overall agreement with tectonic concepts. Since the formal error of the adjustment is of the same order of magnitude, only rates above this value can be treated as significant. One significant feature of the displacement field is located in the south-eastern part of the URG and will be studied in more detail within the presentation. A comparison of benchmark heights of

consecutive measurement epochs is used to provide a detailed assessment of this area. It turned out that the surface displacements are influenced by mining activities. However, it seems unlikely that mining is responsible for the observed 40 km wide subsidence bowl. Therefore, other reasons like groundwater usage and slip on existing faults are discussed.

In general, the separation between anthropogenic deformation (e.g., induced by mining or groundwater usage), environmental deformation (e.g., geochemical processes, hydrological changes) and tectonic deformation is challenging, as the subsurface processes are not known in detail. Some examples for non-tectonic deformations will be discussed within the presentation (e.g. strong subsidences in French mining areas).

The investigation of all available precise levelling data in the URG area largely contributes to a deeper understanding of the internal processes detected at the surface.

Abstract submitted to session :

4. Earth Observation Systems and Reference Frames, Observation Techniques, Methods and Data Analysis

High rate, high accuracy Earth deformation monitoring using GPS – Application to the Japanese 2011 earthquake

François Fund¹, Felix Perosanz¹, Flavien Mercier¹, Sylvain Loyer²

¹Centre National d'Etudes Spatiales (CNES), 18 avenue Edouard Belin, 31400, Toulouse, France

²Collecte Localisation Satellites (CLS), 8-10, rue Hermès, Parc Technologique du Canal, 31520 Ramonville Saint-Agne, France

Abstract

Recent developments at the CNES-CLS IGS Analysis Center provided an unique property to the satellite precise orbits and clock products delivered to the scientific community. They make possible the localisation of an isolated GPS antenna using ambiguity fixed un-differenced GPS phase observations . In this Integer Precise Point Positioning (IPPP) mode, the accuracy is constant in space and time and positions are absolutely referenced. In a classical differencing process however, the accuracy is baseline-dependant and only the coordinate differences relatively to a reference station is accessible. CNES-CLS products are routinely included in the weekly final IGS products and are used for several geosciences applications.

First, we present how these products are routinely generated and their properties. Then, we present how they can be used in a PPP mode for Earthquake. The presentation focuses on the Sendai Earthquake (March, 11th of 2011) observed thanks to the Japanese GEONET GPS network. We present an accurate spatial and temporal analysis of co-seismic displacements. In a further extend, this presentation show current performances of IPPP and how future GALILEO satellites may improve the results.

Long-term growth of the Himalaya inferred from interseismic InSAR measurement

Raphaël Grandin (1), Marie-Pierre Doin (2), Laurent Bollinger (3), Béatrice Pinel- Puységur (3), Gabriel Ducret (2), Romain Jolivet (4), and Soma Nath Sapkota (5)

- 1. Institut de Physique du Globe de Paris, UMR 7154, F-75005 Paris, France*
- 2. Ecole Normale Supérieure, UMR 8538, F-75231 Paris, France*
- 3. CEA, DAM, DIF, F-91297 Arpajon, France*
- 4. California Institute of Technology, Pasadena, 91125, CA, USA*
- 5. Department of Mines and Geology, National Seismological Centre, Lainchaur, Kathmandu, Nepal*

The rise and support of the 5000 m topographic scarp at the front of Indian-Eurasian collision in the Himalaya involves long-term uplift above a mid-crustal ramp within the Main Himalayan Thrust (MHT) system. Locking of the shallower portion of the flat-ramp-flat during the interseismic period also produces transient uplift above the transition zone. However, spatial and temporal relationships between permanent and transient vertical deformation in the Himalaya are poorly constrained, leading to an unresolved causal relationship between the two. Here, we use interferometric synthetic aperture radar (InSAR) to measure interseismic uplift on a transect crossing the whole Himalaya in central Nepal. The uplift velocity of 7 mm/yr at the front of the Annapurna mountain range is explained by an 18–21 mm/yr slip rate on the deep shallow-dipping portion of the MHT, with full locking of the mid-crustal ramp underlying the High Himalaya. The transient uplift peak observed by InSAR matches spatially with the long-term uplift peak deduced from the study of trans-Himalayan river incision, although models of the seismic cycle involving thrusting over a ramp of fixed geometry predict an ~20 km separation between the two peaks. We argue that this coincidence indicates that today's mid-crustal ramp in central Nepal is located southward with respect to its average long-term location, suggesting that mountain growth proceeds by frontward migration of the ramp driven by underplating of material from the Indian plate under the Himalaya.

**Determination of Strain Accumulation along Tuzla Fault and its Vicinity,
Western Turkey**

Emre Havazli and Haluk Ozener

Bogazici University, Kandilli Observatory and Earthquake Research Institute,
Department of Geodesy, Istanbul, Turkey

A GPS network was installed to determine the velocity field and strain rates along the Tuzla fault in the Aegean region. It is located in an area of ~55x35 km, and it is defined by 16 sites. Tuzla fault is approximately 42 km long with NE–SW trending lineaments, and lies between the towns of Menderes and Cape Doganbey. The velocity field was obtained based on four GPS campaigns carried out annually between 2009 and 2012. Three sites were selected to detect vertical deformation and precise leveling technique was applied. Analysis of GPS data show that velocities reach 30 ± 2 mm/yr and are consistent with the present-day tectonic deformation of the region. Precise leveling results indicate a vertical displacement in the area. However, more repeated analyses with longer time intervals are required to clarify whether or not vertical deformation occurs. Furthermore, principal components of crustal strain along the Tuzla fault were obtained from GPS velocities. The magnitudes are in the range of 3-281 nstrain/yr. The strain rates agree with the seismicity and the directions of the calculated strain rates reflect the expected behavior of NE–SW extension of the Aegean region.

Remote sensing for moderate earthquake deformations in the Eastern Mediterranean

M.Ilieva, P. Briole, P. Elias, D. Dimitrov

The area of the Eastern Mediterranean is characterized by complex tectonic regime which is a consequence of the drifting of African and Anatolian plates towards the Eurasian. The result is intensive seismicity with numerous small to strong events. The current investigation is focused on several moderate earthquakes in the region – Lefkada (2003, M 6.3), Konitsa (1996, M 5.3) and others. Using remote sensing and comparison with other techniques the deformations of the crust in the range of 2 fringes (5.6 cm) are detected.

Spatial and temporal variations of the shallow creep along the Haiyuan fault (Gansu, China) revealed by InSAR

Romain Jolivet(1), Cécile Lasserre(2), Thibault Candela (2), François Renard (2), Marie-Pierre Doin(3), Yann Klinger (4), Gilles Peltzer(5), Rong Dailu(6)

- (1) Tectonic Observatory, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena 91125, CA, USA.
- (2) Institut des Sciences de la Terre, UMR 5275, Université Joseph Fourier, CNRS, Grenoble, France
- (3) ENS, Laboratoire de Géologie, 24, rue Lhomond, 75231 Paris Cedex 05, France
- (4) Institut de Physique du Globe de Paris, Sorbonne Paris Cité, Univ. Paris Diderot, UMR 7154, CNRS, Paris, France.
- (5) UCLA, Departement of Earth and Space Sciences, 595 Charles Young Drive East, Los Angeles, CA 90095-1567, United States
- (6) Chinese Earthquake Administration, Seismological Institute of Lanzhou, Lanzhou, China

Constraining where and how strain accumulates along faults is a key in the understanding of the earthquake cycle. While some fault sections are locked at the surface during the interseismic period and can produce major earthquakes, some others creep at shallow depth, releasing aseismically part of the accumulated strain. Here, we identify and analyse the behavior of a 35 km-long creeping segment along the Haiyuan fault in Gansu, China, one of the major left-lateral fault that accomodates relative block motion in Tibet. Along this segment, the average shallow creep rate over the 2003-2009 period is ~ 5 mm/yr, equivalent to the present day tectonic loading rate. However, this shallow creep rate locally reaches higher values, suggesting temporal variations.

We use Envisat ASAR data, spanning the 2003-2009 period, to produce time series of the ground deformation along the Haiyuan fault at the junction between the 1920, $M \sim 8$, earthquake ruptured section and the 240 km-long millennial Tianzhu seismic gap. We analyse data from 1 descending and 2 ascending tracks using the ROI_PAC processing chain and the NSBAS, small-baseline time series analysis software, designed to enhance coherence in areas of high topography gradients. SAR images, focused using a common doppler value, are combined into interferograms applying an adaptive topographic spectral range filtering technique, that optimizes coherence. Assuming a linear relationship between the tropospheric phase delay and the topography, we estimate the atmospheric phase delay and residual orbital errors using a joint inversion method on each unwrapped interferogram. We finally apply a smoothed time series analysis to derive the temporal behavior of the shallow creep.

Our analysis reveals a variable surface creep rate: between 2003 and 2007 and between 2008 and 2009, the surface creep rate is about 2-3 mm/yr, while it reaches 10-15 mm/yr between 2007 and 2008. Such modulation may be related to the micro-seismic activity, the acceleration of creep being triggered by one or the two biggest events along the segment during that period. We then investigate the decadal creep rate variations, comparing the ground deformation rate maps from Jolivet et al., 2012, spanning the 2003-2009 period with those from Cavalié et al., 2008, spanning the 1993-1998 period using ERS data. We show a creep migration to shallower depth and/or a creep rate increase during this 20 years period.

Finally, we compare the surface creep along-strike distribution and its temporal evolution with the fault geometry. We show a self-affine along-strike distribution of both surface creep and surface fault geometry, invariant with time, suggesting a geometric control of aseismic slip along that fault segment. Furthermore, we show that creep is made of interacting slip bursts organized along fault asperities, permanent at the scale of our observations. This behavior of the aseismic slip strikingly echoes with the seismic behavior of faults.

Earthquake Cycle Research in North Iceland

Sigurjón Jónsson¹ and Sabrina Metzger²

¹*King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia*

²*Institute of Geophysics, ETH Zurich, Switzerland*

Inter-disciplinary research efforts have been carried out during the past decade to improve the knowledge about past and potential future earthquakes in North Iceland. This seismically active area is a transform zone, linking the active rift system in northern Iceland to the Mid-Atlantic Ridge to the north of the island. The transform zone is usually referred to as the Tjörnes Fracture Zone (TFZ) and it mainly consists of two parallel lineaments, the Grímsey Oblique Rift and the Húsavík Flatey Fault (HFF), with a possible microplate in between. Earthquakes of magnitudes up to 7 have occurred on both transform structures during the past centuries.

Among ongoing research activities are geodetic observations of the plate-boundary deformation, revision of historical accounts to search for previously unidentified information on historical earthquakes in the region, installation of a strong-motion network to study local site and relative amplification effects within the town of Húsavík, multi-beam bathymetric surveys to better determine the location and structure of the HFF, and core-drilling into lake sediments in search for turbidites or other information on pre-historic earthquakes.

The geodetic observations have already provided significant results. Here we have used InSAR observations to identify and model several volcanic deformation sources and used the results to correct GPS station velocities to isolate the steady plate-boundary deformation. The GPS velocities and modeling show that both transform structures in the TFZ actively accommodate the ~ 2 cm/year relative motion between the ridge segments to the south and to the north. About 2/3 of the transform motion seems to be taken up by the GOR, but only 1/3 by the HFF, which corresponds to ~ 6.8 mm/year slip-rate. The results also indicate that the locking depth on the HFF is surprisingly shallow, or only ~ 6.2 km, which is likely a consequence of the high temperature gradient in the area. Despite the shallow locking depth and slower slip-rate, the accumulated slip-deficit of the HFF since the last large earthquakes in 1872 is equivalent to a magnitude 6.8 earthquake.

This result is of grave concern for the town of Húsavík, which is located directly on the HFF. However, it must be kept in mind that this magnitude estimate is based on several assumptions, e.g. that the 1872 earthquakes completely relieved the fault of accumulated stresses, that the stressing rate has been uniform since 1872, that the locking depth is uniform along the entire fault, and that all the accumulated moment would be released in a single earthquake. To learn more about these assumptions, we are improving the GPS measurement network along the fault and investigating more thoroughly the influence of the Krafla rifting episode (1975-1984) on the accumulated stress on the HFF.

Kinematics of the eastern Caucasus near Baku, Azerbaijan

Fakhraddin Kadirov¹, Michael Floyd^{2,*}, Akif Alizada¹, Ibrahim Guliev¹, Robert Reilinger², and Robert King²

1. Geology Institute, Azerbaijan National Academy of Sciences, Baku, Azerbaijan

2. Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, USA

* Corresponding author (mfloyd@mit.edu)

Abstract

The potential for large, shallow earthquakes and their associated seismic hazard in the eastern Caucasus, an area of dense population and sensitive industrial infrastructure, remains speculative based on historical precedent and current geologic and seismologic observations. Here we present updated and expanded results from a GPS network between the northern edge of the Lesser Caucasus and Greater Caucasus, providing geodetic constraints to the problem. A significant contractional strain rate is observed in a profile over a distance of about 150 km across the Kura Basin. We attribute this to inter-seismic strain accumulation on buried fault structures and present simple elastic dislocation models for their plausible geometry and slip rate based on the known geology, seismicity and the GPS velocities. Due to the close proximity of the strain anomaly to Baku, and the If it is indeed the case that the contraction is due to inter-seismically locked faults, this has implications for the seismic hazard in the region.

Tectonic geomorphology and active megathrust traces in the East-Himalayan Syntaxis

Elise Kali^{1,2}, Paul Tapponnier¹, Jérôme van der Woerd², Swapnamita Choudhury³, Saurabh Baruah⁴, A. K. M. Khorshed Alam⁵, Aktarul Ahsan⁵, Catherine Dorbath², and Paramesh Banerjee¹

1 Earth Observatory of Singapore, Nanyang Technological University, <elise.kali@unistra.fr>

2 Institut de Physique du Globe, Strasbourg, France

3 Wadia Institute, Dehra Dun, India

4 North-East Institute of Science and Technology, Jorhat, India;

5 Geological Survey of Bangladesh, Dhaka, Bangladesh

The East Himalayan syntaxis remains a puzzle. Active faults are poorly mapped, and slip-rates, uncertain, partly due to regional partitioning. Controversy persists on the exact sources of two of the greatest continental earthquakes ever recorded (12/06/1897, $M \approx 8.5$, Shillong; 15/08/1950, $M_w = 8.7$, Assam), which reportedly produced no primary surface ruptures. By combining fieldwork with high-resolution satellite image interpretation, we revisited the tectonic geomorphology of the main range-fronts in NE India and Bangladesh and identified, from their surface signature, the most active thrusts.

In Arunachal-Pradesh, we found outstanding tectonic escarpments 8 to 30 m high along the Himalayan and Mishmi foothills. Near Wakro and Roing, steep scarps cutting proximal terrace deposits and fluvial risers unambiguously result from co-seismic faulting. Most likely, they formed during the 1950 earthquake and previous comparable events. On the footwall of the high cumulative scarp near Tezu, beheaded tree stumps encrusted with gravels attest to burial by massive 1950 debris flows. Near Pasighat, the Main Frontal Thrust lifts progressively older terraces of the Siang river up to higher and higher levels westwards. Dating of terrace deposits and surfaces is in progress to constrain the timing of deposition and uplift with complementary techniques (cosmogenic isotopes, ^{14}C , OSL).

Overall, the Shillong plateau tilts northwards, with a marked contrast between its northern and southern edge. To the north, its gently sloping surface, which abrades Proterozoic basement, is incised only a few hundred meters by the Brahmaputra and tributaries. Uplifted Proterozoic inselbergs protrude far north of the river, towards the Himalayan range-front, which precludes the existence of a large, recent, south-dipping thrust along the north side of the plateau. To the south, by contrast, the plateau towers 1200-1500m above the Bangladesh plain and deep Surma basin. It is sharply truncated by an abrupt flexure dented by the steep canyons of headward-retreating catchments. At the foot of the flexure, the spectacular escarpment of the active South Shillong Thrust (SST) follows the Dauki Fault in the east and Chokpot Thrust in the west. It separates flexed Eocene Limestones from steeply south-dipping marine Miocene shales. West of Chokpot, one young, $\approx 6\text{m}$ -high scarp, of probable seismic origin, was found along this thrust. All geological and geomorphic indicators thus concur at different scales to suggest the SST was the most likely source of the 1897 earthquake.

In Bangladesh, we confirmed the presence of emergent thrusts along the topographic front of the Chittagong-Sylhet foldbelt. The clearest one, near Shazibazar, follows the prominent scarp truncating the west limb of the broad, asymmetric Raghunandan Hills anticline. Linear tectonic scarps similarly cut gently east-dipping Quaternary sandstone monoclines along the west sides of the Lalmai and Tarap Hills. Such cumulative escarpments, whose heights reach tens of meters, likely grow through co-seismic rupture of the plate-boundary mega-thrust beneath the fold-belt, as it ramps up to the surface along the west side of the Meghna river basin.

Crustal deformation prior to the 2011 Tohoku earthquake, Japan, from the continuous GPS data of the dense GEONET network.

Emilie Klein^{1,2}, Jean-Mathieu Nocquet¹, Lucie Rolland¹, Pierre Bosser³, Tran Dinh Trong¹, Toshihiro Yahagi⁴, Mathilde Vergnolle¹, Anthony Sladen¹

(1) UMR Géosciences Azur, 250 rue Albert Einstein, 06560 Valbonne, France - (2) ENSG, 77455 Marne-la-Vallée, France - (3) ENSG/LAREG, IGN, 77455 Marne-la-Vallée, France - (4) GSI, 1 Kitasato, Tsukuba 305-0811, Japan

The GEONET GNSS network in Japan, operated by the Geospatial Information Authority of Japan (GSI), with more than 1200 stations over the whole country, offers an unprecedented opportunity to study the processes of the seismic cycle, which led to the giant earthquake of Tohoku Oki on March 11, 2011, with moment magnitude $M_w=9.0$. Up to now, most studies have focused on the coseismic displacement induced by the rupture. In this study, we present an analysis of 15 years of GPS measurements before the earthquake, with the goal of defining the strain accumulation and release history prior the Tohoku Oki earthquake.

The first step of our study consists in processing the GPS data of the whole GPS network from 1997 to 2011. To process such an amount of sites, we adopt a Precise Point Positioning strategy using the Gipsy-Oasis II 6.1.2 software released by the Jet Propulsion Laboratory. We then derive steady velocities, and the co- and post-seismic displacements. We use the strategy of Tran and Nocquet (2012, this conference) to automatically search for jumps in the time series and separate from known environmental phenomena like annual and semi-annual effects, and also artefacts due to equipment changes. Unmodelled residual effects are then analyzed in terms of transients events in the vicinity of the epicenter of the Tohoku Oki earthquake.

Title:

On the determination of highly precise coordinate time series using GURN (GNSS Upper Rhine Graben Network) data

Authors:

Andreas Knöpfler (1), Michael Mayer (1), Frederic Masson (2), Patrice Ulrich (2), Bernhard Heck (1)

Affiliations:

- (1) Geodetic Institute, Karlsruhe Institute of Technology, Karlsruhe, Germany; email: {andreas.knoepfler; michael.mayer; bernhard.heck}@kit.edu
- (2) Institut de Physique du Globe de Strasbourg, CNRS Strasbourg University, Strasbourg, France

Abstract:

In April 2008, the Institut de Physique du Globe de Strasbourg (Ecole et Observatoire des Sciences de la Terre, EOST, Strasbourg, France) and the Geodetic Institute (GIK) of the Karlsruhe University (now KIT, Karlsruhe Institute of Technology, Karlsruhe, Germany) established an international cooperation called GURN (GNSS Upper Rhine Graben Network). Within the GURN initiative, these institutions are cooperating in order to carry out research in the framework of the transnational project TOPO-WECEP (West and Central European Platform), which succeeds the former project EUCOR-URGENT (Upper Rhine Graben Evolution and NeoTectonics). The research within GURN is focussing on GNSS (Global Navigation Satellite Systems) observations in order to detect recent crustal movements, which are expected to be very small ($< 1\text{ mm/year}$). At the Wegener Symposium 2008 (Darmstadt, Germany), this research initiative made an appearance for the first time.

At the Wegener Symposium 2012, progress and recent research activities will be presented. The focus will be on the generation of highly precise coordinate time series, which are the basis of velocity and strain fields.

The approx. 80 GURN sites have very different characteristics (e.g., providing agency, establishment date, monumentation, data quality, instrumentation) which are changing

with time, therefore one important research aspect is dealing with quantification and reduction of site-specific aspects (e.g., antenna, multipath). The presentation will discuss the potential of PPP-related stacking approaches and quantify changing multipath environment.

Besides PPP (Precise Point Positioning), differential GNSS is applied to the GURN data. Within the data evaluation process, the GIK (Bernese GNSS Software) and EOST (GAMIT/GLOBK) are using different software and strategies. The comparison of these results guarantees reliable results. In addition, the quantification of operator noise and reference frame noise is enabled. The presentation will focus on the effect of different reference frame handling at GIK and EOST propagating into coordinate times series.

Session:

4. Earth Observation Systems and Reference Frames, Observation Techniques, Methods and Data Analysis

Application of bistatic TanDEM-X SAR-interferometry to observe topographic changes at the summits of Merapi, Indonesia and Colima Volcano, Mexico

Julia Kubanek, Malte Westerhaus and Bernhard Heck

Geodetic Institute, Karlsruhe Institute of Technology (KIT), Englerstraße 7, 76131 Karlsruhe, Germany (Julia.Kubanek@kit.edu)

Abstract for session 6: Magmatic processes and crustal deformation

Synthetic aperture radar interferometry (InSAR) has proven to be a useful tool to monitor deformations at dome-building volcanoes. The phase difference of two or more monostatic radar images taken at different times serves as the basis for generating digital elevation models (DEMs) and deformation maps of the area of investigation. The main limitations of former earth observing radar satellites such as ERS, Envisat and TerraSAR-X are changing backscattering conditions as well as the varying atmospheric composition during two different satellite passes. Furthermore, monostatic radar images are not appropriate to observe changes caused by dome growing or other redistribution of volcanic material for the reason that large deformations lead to a loss of coherence between two image acquisitions.

The new German TanDEM-X (TerraSAR-X **add-on** for **D**igital **E**levation **M**easurement) mission is formed by two nearly identical satellites. While flying in a close formation, the two earth observing satellites, TerraSAR-X and TanDEM-X, receive two radar images of the same area at the same time. The images are therefore, in contrast to the repeat-pass mode, nearly absolutely coherent and allow observing substantial deformations and volume changes at volcanoes.

The main aim of the present study is to identify advantages and limitations of the TanDEM-X mission to monitor topographic changes of active dome-building volcanoes. We want to develop and implement a method to measure mass accumulation and surface deformation rates using double differential InSAR, i.e. by evaluating differences between two or more bistatic acquisitions. Our test sites, the Colima Volcano in Mexico and the Merapi in Indonesia, are both dome-building volcanoes with varying activity. Long-lasting dome-building phases are interrupted regularly by phases of dome collapses, often leading to pyroclastic flows and redistribution of volcanic deposits. Furthermore, the availability of extensive ground truth data for both test sites is essential to validate the spaceborne data and results.

We present a first series of partial DEMs derived from Merapi and Colima Volcano by double differential SAR-interferometry using TanDEM-X data. The satellites acquire images during ascending and descending orbit passes. Hence, the northeast-southeast as well as the northwest-southwest sectors of the volcano edifices are displayed. Our findings confirm that very accurate and detailed DEMs can be derived from the TanDEM-X mission. A first time series analysis of Merapi-DEMs gives promising results, indicating the possibility to quantitatively access volume changes at the volcano summit. However, the exact correlation of the different DEMs has turned out to be the main problem.

Upper bound deformation in the Upper Rhine Graben from GPS data - First results from GURN (GNSS Upper Rhine Graben Network)

**Maximilien LEHUJEUR, Frederic MASSON¹, Patrice ULRICH¹, Cécile DOUBRE¹,
Andreas KNOEPFLER², Michael MAYER², Bernhard HECK²**

- 1: Institut de Physique du Globe de Strasbourg
Strasbourg University / CNRS
5 rue Descartes
67084 Strasbourg Cedex
FRANCE
- 2: Geodetic Institute, Karlsruhe Institute of Technology (KIT)
Englerstr. 7, D-76128 Karlsruhe
Karlsruhe
GERMANY

In September 2008, the Institut de Physique du Globe de Strasbourg (Ecole et Observatoire des Sciences de la Terre, EOST) and the Geodetic Institute (GIK) of Karlsruhe University (TH) established a transnational cooperation called GURN (GNSS Upper Rhine Graben Network). Within the GURN initiative these institutions are cooperating in order to establish a highly precise and highly sensitive network of permanently operating GNSS sites for the detection of crustal movements in the Upper Rhine Graben region.

The Rhine Graben is the central, most prominent segment of the European Cenozoic rift system (ECRIS) of Oligocene age which extends from the North Sea through Germany and France to the Mediterranean coast over a distance of some 1100km. It is a 300 km long and 40 km wide SSW-NNE trending rift, extending from Basel (Switzerland) to Frankfurt (Germany). It is limited to the west by the Vosges mountains and to the east by the Black Forest. Culminating in ~1500m in elevation, these two massifs represent the Eocene-Oligocene rift shoulders, but a large part of the differential uplift is much younger. The graben is bounded to the north by the uplifted area of the Rhenish Massif. To the south, the Leymen, Ferrette and Vendlincourt folds represent the northernmost structural front of the Jura fold and thrust belt.

The presentation will discuss the first results concerning the upper bound deformation in the Upper Rhine Graben region. A large focus will be given about the processing of the time series and the correction of the offsets.

Blending of reprocessed GNSS coordinate time series parameters with geological data

Stefan Leinen¹, Matthias Becker¹, Gwendolyn Läufer¹ and Rouwen Lehné²

¹ Institute of Geodesy, Section Physical and Satellite Geodesy, Technische Universität Darmstadt, Petersenstr. 13, 64287 Darmstadt, Germany (leinen@ipg.tu-darmstadt.de, becker@ipg.tu-darmstadt.de, laeuer@ipg.tu-darmstadt.de)

² Institute of Applied Geosciences, Section Geo-Resources & Geo-Hazards, Technische Universität Darmstadt, Schnittspahnstr. 9, 64287 Darmstadt, Germany (lehne@geo.tu-darmstadt.de)

Abstract

For a regional SAPOS CORS network in the federal state of Hesse with 25 stations and some anchor sites of IGS and EPN, six years of GPS data have been reprocessed to derive accurate and consistent coordinate time series. Based on daily network solutions coordinate time series parameters like velocities, offsets in case of antenna changes and annual periodic variation have been estimated. The estimation process includes the fitting of a sophisticated stochastic model for the time series which accounts for inherent time correlation.

The original purpose of the processing is the monitoring of the reference station stability in order to verify the integrity of the reference station network. But in addition the results are blended with geological data to see if both types of data, recent geodetic analysis and information from geology, do agree or if there are discrepancies.

First the reprocessing of the GNSS data and the estimation of coordinate time series parameters will be shown. From the results the derived velocity field will be discussed in detail. Special emphasis will be on the intra-plate deformation: for the horizontal component the residual velocity field after removal of a plate rotation model is presented, while for the vertical velocities the datum-induced systematic effect is removed in order to analyze the remaining vertical motion.

The residual velocity field is then matched with the geology for Hesse, here a simplified version of the general geological map of the federal state of Hesse, scale 1:300.000. Input data has been blended using ArcGIS 10. Correlation of both vertical and horizontal movements with major geological structures reveals good accordance. SAPOS stations with documented significant subsidence are mainly located in tertiary Graben structures such as the Lower Hessian Basin (station Kassel), the Wetterau (station Kloppenheim) or the Upper Rhine Graben (Station Darmstadt). From the geological point of view these structures are supposed to be subsiding ones. Other major geological features, i.e. the Rhenish Shield as well as the East Hessian Bunter massif are supposed to be affected by recent uplift. SAPOS stations located in these regions match the assumed movement (e.g. Weilburg, Wiesbaden, Bingen, Fulda). Furthermore SAPOS-derived horizontal movements seem to trace tectonic movements in the region, i.e. extension along the tertiary Graben structures, including a sinistral strike slip component. However, a more detailed analysis is needed to confirm the link between detected movement and geodynamic processes.

Abstract intended for Scientific Session 4: Earth Observation Systems and Reference Frames, Observation Techniques, Methods and Data Analysis

Taiwan Continuous GPS Geodetic Array: The deformation rate and apparent seasonal variation from 1994-2010

Kuan-Chuan Lin^{1,2}, Jean-Mathieu Nocquet², Jyr-Ching Hu¹, Bertrand Delouis²

¹ Department of Geosciences, National Taiwan University, Taipei, Taiwan

² Geoazur, University of Nice - Sophia Antipolis, Nice, France

Abstract

We have collected 390 Continuous GPS stations and got precise coordinates by GAMIT and GLOBK from 1 January 1995 to 31 December 2010 in ITRF2008. The variations of sites were analyzed by the deformation rate, the seasonal effect, the coseismic and the residual in PYACS. We characterized the deformation before and after the 12 large earthquakes ($M_w \geq 6$) including the $M_w=7.6$ Chi-Chi earthquake of Taiwan on 21 September 1999. The apparent seasonal variations could be explored from the time series. In east-west component, the identical annual effects could be found in Hualien, Chiayi and Taichung region. The significant vertical annual patterns were observed about 18.9~10.6 mm in Pingtung plain and Coastal plain. With respect S01R, the stations of Coastal Range to Lanhsu showed the horizontal deformation rates are 39.2~87.9 mm/yr towards azimuth $316^\circ \sim 307^\circ$. The stations in the northern Taiwan revealed clockwise velocities in the range 11.2~35.3 mm/yr towards azimuths $283^\circ \sim 296^\circ$. In the vertical deformation rate patterns, the largest subsidence occurred at Coastal plain (Changhua-Yunlin) about -50.2 ± 0.3 mm/yr. The significant subsidence appeared in the northern Coastal Range about -14.2 ± 0.2 mm/yr, but the uplift in the southern Coastal Range about 5.96 ± 0.1 mm/yr respectively. We also investigated the fault slip of Jiasian earthquake that occurred on the southwestern Taiwan on 04th March 2010. The main shock located at Longitude=120.71, Latitude=22.9, $M_w=6.4$, depth=22.6 km was published from Central Weather Bureau. The maximum horizontal and vertical uplift of surface offset is $29.8\text{mm} \pm 1.0\text{mm}$ and $30.6\text{mm} \pm 5.1\text{mm}$ at GS51. The fault geometry and motion were modeled by joint inversion which including the CGPS station, teleseismic and strong motion records. We built the first fault model with strike/dip/rake = 311/33/37 except for the point source corresponding to the hypocenter which corresponds to strike/dip/rake = 316/40/44. The first segment is about 39 km*48 km along the strike and dip which dominated the main slip. The second fault is 33 km*33 km and strike, dip and rake is 020/25/108. It controlled the all data very well especially in CGPS surface offset. Since the improvement of the data fitting is clear, especially for the CGPS. It provides that there could be more than one blind fault in southwestern Taiwan.

Superconducting gravimeter measurements for land surface model assessment

Laurent Longuevergne, Simon Gascoin, Jean-Paul Boy, Sandro Rinaldi,

Agnès Ducharne, Nicolas Florsch, Jacques Hinderer

Abstract

A new method is investigated to validate the water budget simulation by a land surface model at the scale of several hundreds of meters using superconducting gravimeter monitoring. In contrast with traditional soil moisture probes, a superconducting gravimeter provides a non-destructive, integrative, stable and well-calibrated measurement of soil water storage variations. The potential of this method is demonstrated using a 7-year time series from the Strasbourg observatory (France). The Catchment Land Surface Model (CLSM) is set up and forced by high resolution meteorological data at the scale of a hill where the superconducting gravimeter is located. Simulated water storage variations and gravity data show a good agreement at seasonal time scales. Furthermore, gravity data also reveals that the evapotranspiration computed by the CLSM is overestimated during the 2003 heat wave that occurred in Europe. Superconducting gravimeters, which are currently being turned as field instruments, are thus a promising tool to isolate specific or systematic errors in land surface flux modeling, and to improve the model robustness in terms of soil moisture simulation.

Block model at the Hatay Triple junction in N-W Syria and S-E Turkey from GPS data inversion

Yasser Mahmoud^{1,2}, Ziyadin Cakir³, Frederic Masson¹, and Mustapha Meghraoui¹,

- (1) IPGS, CNRS/University of Strasbourg, France (yasser.mahmoud@unistra.fr),
- (2) Department of civil engineering, Tishreen University, Syria,
- (3) Department of Geology, Istanbul Technical University, Turkey.

Abstract:

The active deformation at the Hatay Triple junction (HTJ) in northwest Syria and southeast Turkey is represented by finite number of rotating elastic spherical blocks limited by faults. GPS derived horizontal velocities are inverted using “DEFNODE” program for the fault parameters and block angular velocities. We are using GPS vectors from our dense regional GPS network reinforced by other GPS solutions in the region. GPS velocity fields are combined together by performing a rotational transformation in order to put them in the same reference frame. We test different tectonic configurations trying to minimize the data misfit of our model using a reduced chi-square statistic: $\chi_n^2 = (\sum r^2/s^2) / \text{DOF}$. Residuals were calculated for different models in order to define the best fit to the known kinematic configuration of the region.

A block model with the new Iskenderun and Amanous micro blocks and three major blocks of Arabia, Anatolia, and Sinai is essential to explain the GPS vectors. The estimated relative slip rates on faults are similar to other published estimations with some exceptions. The Karasu Fault shows a sinistral slip rate of 4.0 ± 1.0 mm/yr and a compressional behavior with a revers slip rate of 2.1-2.7 mm/yr, which contradicts with the extensional nature proposed by previous studies. The Dead Sea fault experiences a relative slip rate of $\sim 3.5 \pm 0.3$ mm/yr along all its segments. We also define a new Euler pole for the relative angular velocity of Anatolia-Arabia Euler pole at (27.61°N, 45.127°E, 0.391 ± 0.056 °/Myr), and a Sinai-Arabia Euler pole at (31.012°N, 46.464°E, 0.202 ± 0.067 °/Myr). A 15 km of locking depth is estimated for the EAF, 4-5 km deeper than that of the Dead Sea Fault. The East Anatolian Fault is however partially locked down to the depths of 30 km with no significant extension or compression. In general,

slip rates and kinematics of faults are consistent with the geological observations in the region.

Characterization of the dynamics of slope movements with image correlation techniques

Jean-Philippe Malet (1), Julien Travelletti (1,2), Julien Gance (1,3), André Stumpf (1,4),
Grzegorz Skupinski (4), Christophe Delacourt (5)

(1) Institut de Physique du Globe de Strasbourg, Strasbourg, France; (2) Bureau d'Etudes Géologiques, Approz-Nendaz, Suisse; (3) Bureau de Recherches Géologiques et Minières, Orléans, France; (4) Laboratoire Image, Ville, Environnement, Strasbourg, France; (5) Institut Universitaire Européen de la Mer, Brest, France.

The objective of this work is to present the applicability of image correlation techniques (applied to different image sources and platforms; e.g. very-high resolution terrestrial or airborne optical photographs, very dense airborne or terrestrial laser scanning point clouds) to characterize the dynamics of active slope movement such as continuously active landslides or rock glaciers. The method has been developed to characterize the kinematics of slope movements in the range of several centimeters to several decimeters per year. The images are processed with a hierarchical multi-resolution cross-correlation algorithm applied on the full resolution images. The method allows to characterize the heterogeneous displacement field of slope movements in time and space, and to produce displacement maps. In some cases, the deformation pattern can be inferred from the displacement maps, if enough spatial resolution is available. The performance of the technique is evaluated on several datasets (e.g. Super-Sauze landslide, La Valette landslide, Chauvet rock glacier) and its accuracy defined using differential GPS surveys as reference measurements. The sources of error affecting the results are discussed. Because the proposed methodology can be routinely and automatically applied, it offers promising perspectives for operational applications like, for instance, in early warning systems.

The Magmatic system beneath Torfajökull volcano: A combination of radar and seismic interferometric observations

Joana Martins¹, Andy Hooper¹, Deyan Draganov¹, Elmer Ruigrok¹, Bob White²
Delft University of Technology, Delft, The Netherlands.
University of Cambridge, Cambridge, United Kingdom

Magmatic plumbing systems beneath active and moderately active volcanoes are often poorly constrained. A better knowledge of the shape, size and location of the magma bodies would enable us to better predict magma movements preceding an eruption.

Displacements estimated from radar Interferometric observations can be used in geophysical modelling to constrain pressure changes in the magma systems. However, the resolution of the inferred magma chamber is typically poor.

More insight on magmatic systems can be gained using active-source reflection seismic surveys, which detect velocity contrasts at the edges of the magma bodies. The drawback of this technique is that controlled sources surveys are expensive. As an alternative, seismic interferometry by cross-correlation of natural signals leads to the generation of new seismic records that simulate local sources, rendering man-made sources unnecessary.

We have applied radar interferometry (InSAR) time series techniques over Torfajökull volcano, and we detect a pattern of subsidence beneath the south-western part of the caldera, ongoing since at least 1993, at rates of up to $\sim 13 \text{ mm yr}^{-1}$. We interpret this deformation to be the result of a cooling magma chamber. We modelled the signal with an ellipsoidal uniform pressure source with a NE-SW orientation at $\sim 5 \text{ km}$ depth, located beneath the volcano caldera.

For the seismic-interferometry processing, we used a set of 14 seismic stations oriented in SE-NW direction to retrieve the reflections along this line. The goal is to obtain a 2D subsurface velocity model, which will later be applied as a constraint in the currently used InSAR modelling.

In this study, we present the first results of this experiment and detail how we intend to explore a combination of radar and seismic-interferometry observations.

Slip rate and locking depth of the southern Dead Sea fault revisited from new GPS measurements

Frédéric Masson¹, Yariv Hamiel², Mahmoud Al-Qaryouti³, Aline Deprez¹, Yann Klinger⁴, Amotz Agnon⁵

- 1- IPGS/EOST Université de Strasbourg/CNRS
- 2- Geological Survey of Israel
- 3- Seismology Division, Natural Resources Authority, Jordan
- 4- IPGP, CRNS
- 5- Institute of Earth Sciences, The Hebrew University of Jerusalem

The Dead Sea Fault is a major strike-slip fault bounding the Arabia plate and the Sinai subplate. On the basis of three GPS campaign measurements, 12 years apart, at 19 sites distributed in Israel and Jordan, complemented by Israeli permanent stations, we compute the present-day deformation across the southern segment of the Dead Sea Fault, the Wadi Araba fault.

Preliminary elastic locked-fault modelling of fault-parallel velocities provides a slip rate of ~ 4 mm/a and a best fit locking depth of ~ 8 km. The slip rate and the locking depth are slightly smaller than previous results based only on 2 campaigns. The slip rate is close to the slip rate estimated northward.

Combining absolute gravity, GPS and GRACE to better constrain continental dynamics from GIA to great subduction earthquakes

S. Mazzotti^{1, 2}, J. Henton³, A. Lambert⁴, N. Courtier⁴, H. Dragert^{4, 2}

1- Géosciences Montpellier, Université Montpellier 2, France

2- School of Earth and Ocean Sciences, University of Victoria, Canada

3- Geodetic Survey Division, Natural Resources Canada, Canada

4- Geological Survey of Canada, Natural Resources Canada, Canada

High-precision absolute gravity (AG) observations are sensitive to vertical motion of the observation site as well as mass redistribution within (and below) the underlying deforming crust. Combined with GPS data and gravity observations from GRACE, AG data define local deformation gravity gradients (DGG = ratio of gravity rate to vertical velocity) and provide a unique set of tools to study continental and global dynamics. We present a first example for the mid-continent region of North America (central Canada and USA), where long-term collocated AG and GPS measurements at 7 sites define a DGG of -0.17 ± 0.01 microGal/mm, symptomatic of ongoing glacial isostatic adjustment (GIA) since the last glacial maximum. For one additional site, Saskatoon, the higher DGG is associated with a large water-storage anomaly. This 600 – 1000 km-scale anomaly centered on the Saskatchewan and Winnipeg River basins is characterized using GRACE data corrected for GIA signal on the basis of the AG/GPS DGG. The second example is associated with earthquake-cycle dynamics of the northern Cascadia subduction zone, where AG measurements have been made for over a decade at 7 sites located in the forearc and backarc regions of the subduction zone. Combined with new GPS data, AG data show a poorly defined DGG and no agreement with the subduction model-predicted gradient. However, we find that (1) stations closer to the subduction fault see a larger mass increase than stations further away and (2) positive gravity residual rates are correlated with interseismic strain rates from the locked subduction fault. Comparison with coseismic gravity changes observed by GRACE for great subduction earthquakes (e.g., Maule 2010, Japan 2011) suggest that the positive gravity rates on the Cascadia forearc may be related to earthquake cycle dynamics, for example shortening and closing of cracks in the forearc crust due to interseismic loading of the subduction fault.

To session 1: *Subduction zones and giant earthquakes (C. Vigny, M. Simons, L. Rivera)*

**Constraint of the interseismic deformation in the Mw 9.0 Tohoku-oki earthquake area:
Insights from paleogeodesy and paleoseismology**

Mustapha Meghraoui¹, Shinji Toda², Matthieu Ferry³, Silke Schmidt¹, Hiroyuki Tsutsumi⁴, Koji Okumura⁵, Tsuyoshi Haraguchi⁶

1 Institut de Physique du Globe, UMR 7516, Strasbourg, France

2 DPRI, Kyoto, Japan

3 Geosciences Montpellier

4 Dept. of Geophysics, Kyoto University

5 Hiroshima University

6 Osaka University, Japan

Field investigations in earthquake geology, geodesy and paleoseismology (paleotsunami) are conducted in coastal Honshu and 2011 Tohoku-Oki earthquake area in the frame of the PALET project (ANR – JSPS Flash programme). The aim is to constrain the seismic cycle and long-term behaviour of the subduction zone mega-thrust using the uplift of coastal terraces, successive large events and subsidence from paleotsunami records and trenching of the Itozawa reactivated fault. Leveling and GPS measurements revealed that coastal Honshu was affected by subsidence at a rate of 1-2 mm/yr from 1900 to 2001. The postseismic deformation infers relaxation along the subduction zone and indicates up to ~15 cm uplift of the coastline until June 2012. In our work, we compare the late Pleistocene (stage 5e) and Holocene marine terraces with the observed data of the 2011 coseismic and postseismic uplift and subsidence. The late Quaternary tectonic process shows uplifted marine terraces 9e, 7e and 5e at a rate between 0.1 and 0.3 mm/yr along the NE Honshu. We also observe that large values of the coseismic subsidence appear in the area of low uplift rate and significant seismic coupling implying the existence of seismic deficit in southern Honshu. The paleotsunami record in the last 9 ka at different locations along the coastline constrains the recurrence interval of paleoearthquakes. This record also documents the amount of subsidence along the coastline and allows an estimation of the size of past earthquakes. The reactivation of inland normal faults with surface ruptures during the Mw 6.6 11 April 2011 Iwaki earthquake illustrates the fault interaction between the subduction zone and continental faults in the Honshu region. Paleoseismic investigations across the 2011 surface ruptures (Itozawa fault) indicate the repetition of similar earthquake faulting in the past probably triggered by large and very large earthquakes ($M > 8$) along the subduction zone. The Tohoku-Oki earthquake filled the gap along the Japan trench subduction zone as a response to the 9 cm/yr convergence rate. Significant coseismic and postseismic deformation in the continental domain results from the low-angle (12°) subducting Pacific plate and related ~400-km-long 2011 earthquake rupture. The interseismic deformation documented in this work suggests the large scale segmentation of the subduction zone.

Submitted as an oral abstract for session “4. Earth Observation Systems and Reference Frames, Observation Techniques, Methods and Data Analysis (M. Becker, H. Ozener, Z. Altamimi)”

PBO and next generation high-rate real-time geodetic networks for active earthquake processes

David Mencin*(1), Diego Melgar(2), Yehuda Bock(2) and Charles Meertens(1).

*Presenting Author (mencin@unavco.org)

(1) UNAVCO, Boulder, CO

(2) SCRIPPS, UCSD, San Diego, CO

Recent advances in GPS technology and data processing are providing position solutions with centimeter-level precision at high-rate and low latency. These data will have the potential to improve our understanding of the geophysics of earthquakes and earthquake source properties and profoundly transform rapid event characterization and warning.

UNAVCO, through the Plate Boundary Observatory (PBO) element of the NSF EarthScope initiative operates nearly 350 high-rate real-time GPS (RT-GPS) stations along the Western coast of North America and Alaska. UNAVCO is also in the process of developing a community plan for the use of real-time GPS data and associated products within the UNAVCO and EarthScope community.

In addition UNAVCO operates a network of 75 borehole strainmeters high-rate real-time geodetic constraints with sensitivities at the scale of 10^{-11} strain, significantly better than RT-GPS at short time scales.

A key area of research taking place in the UNAVCO community, being conducted at SCRIPPS, is the integration of RT-GPS and seismic instruments to capture the full near- and far-field displacements, with high accuracy in three dimensions, for strong-motion events of magnitude 5.5 or higher. Geodetic only inversions utilizing the strain data have been also performed for events of magnitude less than 5.5 using the strainmeter data at the University of Colorado with support from UNAVCO. Both projects demonstrate a new paradigm for studying the processes of large earthquakes and the hazards they pose utilizing the EarthScope and PBO as a next generation geodetic network.

Submitted as an oral abstract for session “2. The role of continental faults in the Mediterranean, Africa and Middle-East (M. Meghraoui, T. Wright, J-M. Nocquet)”

A geodetic component to GONAF borehole observatory (NW Turkey)

David Mencin, UNAVCO (presenting author)

Mike Floyd (MIT)

Robert Reilinger (MIT)

Marco Bohnhoff (GFZ-Potsdam)

Georg Dresen (GFZ-Potsdam)

Fatih Bulut (GFZ-Potsdam)

Semih Ergintav (TUBITAK)

The Geophysical Observatory at the North Anatolian Fault (GONAF) is a collaborative effort of the GFZ-Potsdam, AFAD-Ankara, JAMSTEC, Kandilli Observatory/Bogaziçi University-Istanbul and the University of Auckland co-funded through the ICDP, GFZ and AFAD. GONAF was designed as a borehole-based seismometer network located around the offshore part of the North Anatolian Fault (NAF) close to Istanbul and along the Princes Islands fault segment very near Istanbul. This segment includes the transition between the 1999 Izmit rupture ($M=7.4$) and a seismic gap in the Sea of Marmara thought to be capable of generating a $M\sim 7.6$ event (Parsons et al., 2000; Science). A principle objective of GONAF is to study physical processes associated with the earthquake cycle along this transitional segment of the NAF.

Recent discussions between the GONAF team, CU, MIT and UNAVCO have resulted in an initiative to include a more formal geodetic component to the project using co-located permanent GPS stations and new borehole strainmeters. This addition is expected to provide direct and quantitative information on fault slip rates and locking depths as well as possible fault creep events. This expansion is motivated by two prior geodetic observations: GPS stations north of the Marmara Sea and within 10 km of the fault show no evidence of strain accumulation (Meade et al. 2002; GRL, Reilinger et al. 2006; JGR) and the central segment of the Izmit coseismic fault that experienced super shear rupture during the earthquake (Bouchon and Karabulut, 2008; Science) is currently experiencing creep behavior extending to the surface at the full pre-earthquake rate of strain accumulation (Cakir et al., 2012; Geology). The absence of strain north of the fault was highly unexpected and raises the possibility that fault creep may play a larger role in the earthquake cycle in this location than previously expected. This presentation will present the anticipated role of geodetic observations in the GONAF Project and the expected precision of GPS and strainmeter measurements for constraining steady fault slip (GPS) and fault creep events (strainmeters).

Title:

The Mw 5.1 Lorca earthquake successfully recorded by GPS.

Authors:

Leonor MENDOZA (*)^(1,2), José MARTÍN DÁVILA (1), Jorge GÁRATE (1), Matthias BECKER (2)

(1) San Fernando Naval Observatory, Cádiz, Spain

(2) Technische Universität Darmstadt, Germany

(*) leonor@roa.es

Abstract:

On May 11th, 2011, 16:47 UTC, a Mw 5.1 magnitude earthquake hit the town of Lorca (Murcia Region, Spain) and its shaking was successfully recorded from a GPS station located in the vicinity. The receiver is included in a regional network called Meristemum, whose data will be the study case presented here.

Using the high-rate data recorded from continuous GPS (CGPS) receivers, a near-real time kinematic GPS processing using differential positioning by the Bernese V 5.0 Software is performed. The results are afterwards filtered, and compared with a Precise Point Positioning approach processed by RTKLIB Software. Results and capabilities of both approaches are analyzed in terms of standard deviations and performance.

Processed and filtered 1 Hertz GPS data clearly resolve the periodical oscillations caused by the earthquake with amplitudes up to two centimeters in the North-South direction. In East-West direction, as well as in height, amplitudes up to a centimeter are clearly visible. The feasibility of a real-time natural hazard monitoring system is discussed.

Observation of strain rate variations by a quartz-tube extensometer in the Sopronbánfalva Geodynamic Observatory, Hungary

Gyula Mentés

Geodetic and Geophysical Institute, Research Centre for Astronomy and Earth Sciences,
Hungarian Academy of Sciences, Csatkai E. u. 6-8, 9400 Sopron, Hungary.
Tel: +36-99-508348, Fax: +36-99-508355, E-mail: mentes@ggki.hu.

Abstract

In 1990, a quartz tube extensometer was installed for recording Earth tides and recent tectonic movements in the Sopronbánfalva (a suburb of Sopron) Geodynamic Observatory (SGO) of the Research Centre for Astronomy and Earth Sciences, Geodetic and Geophysical Institute, of the Hungarian Academy of Sciences. The SGO is located on the Hungarian–Austrian border in the Sopron Mountains. The area belongs to the extensions of the Eastern Alps. The observatory is an artificial gallery driven into gneiss.

The presentation shows the construction of the extensometer, the high-precision calibration of the instrument, the stability investigation of the observatory – instrument system.

Strain data recorded by the extensometer shows a long-term compressive strain rate. On the basis of the 21 year continuous data series, an average strain rate of $-5.36 \mu\text{str/y}$ was determined. The results of the measurements show that the rate of tectonic movement is not constant. During the period 1993-2001, the strain rate accelerated to a maximum of $-8.6 \mu\text{str/y}$ in 2001, and then decelerated again between 2002-2010 to approx. $-2.5 \mu\text{str/y}$ in 2010.

Scientific session:

4. Earth Observation Systems and Reference Frames, Observation Techniques, Methods and Data Analysis (M. Becker, H. Ozener, Z. Altamimi)

or

5. Solid Earth dynamics from surface and satellite gravity observations (J. Hinderer, S. Zerbini, R. Biancale)

The Pingding segment of the Altyn Tagh Fault (91°E): Slip rate determination from cosmogenic radionuclide dating of offset fluvial terraces.

A-S. Mériaux¹, J. Van der Woerd², P. Tapponnier^{3,4}, F.J. Ryerson⁵, R. C. Finkel⁶, C. Lasserre⁷, X. Xu⁸.

1: School of Geography, Politics and Sociology, Newcastle University, Claremont Road, NE1 7RU, United Kingdom.

2: IPGS-EOST, UMR 7516 CNRS, Université de Strasbourg, 5, Rue Rene Descartes 67084 Strasbourg Cedex, France

3: EOS, Nanyang Technological University, N2-01A-09, 50 Nanyang Avenue, Singapore 639798

4: Institut de Physique du Globe de Paris, CNRS UMR 7154, Paris, France

5: Lawrence Livermore National Laboratory, PO Box 808, L-206, Livermore CA 94550

6: Earth and Planetary Science Department, University of California, Berkeley 371 McCone Hall , Berkeley, CA 94720-4767

7: ISTerre, Maison des Géosciences, BP53, 38041 Grenoble CEDEX 9, France

8: Central Earthquake Administration, Beijing, China

Morphochronologic slip-rates on the Altyn Tagh Fault (ATF) along the southern front of the Pingding Shan at ~90.5°E are determined by cosmogenic radionuclide (CRN) dating of seven offset terraces at two sites. The terraces are defined based upon morphology, elevation and dating, together with fieldwork and high-resolution satellite analysis. The majority of the CRN model ages fall within narrow ranges (<2 ka) on the four main terraces (T1, T2, T3 and T3'), and allow a detailed terrace chronology. Bounds on the terrace ages and offsets of 7 independent terraces yield consistent slip-rate estimates. The long-term slip-rate of 14.7 ± 1.5 mm/yr is defined at the 95% confidence level, as the combined rate probability distribution of the rates obtained from each terrace. It falls within the bounds of all the rates defined on the central Altyn Tagh Fault between the Cherchen He (86.4°E) and Akato Tagh (~88°E) sites. This rate is ~10 mm/yr less than the upper rate determined near Tura at ~87°E, in keeping with the inference of an eastward decreasing rate due to progressive loss of slip to thrusts branching off the fault southwards but it is greater than the 9 ± 4 mm/yr rate determined at ~90°E by GPS surveys and other geodetic short-term rates defined elsewhere along the ATF. Whether such disparate rates will ultimately be reconciled by a better understanding of fault mechanics, resolved transient deformations during the seismic cycle or by more accurate measurements made with either approach remains an important issue.

GPS constrains on modern geodynamical motion in the Ossetia region of the Great Caucasus: preliminary results

Vadim Milyukov¹, Alexey Mironov¹, Grigory Steblov³, Valery Drobishev², Haryton Hubaev², Anatoliy Kusraev², Khadji-Murat Torchinov², Vladimir Shevchenko³

¹Lomonosov Moscow State University, Sternberg Astronomical Institute, Moscow, Russia
(vmilyukov@yandex.ru)

²Vladikavkaz Scientific Center of Russian Academy of Science, Vladikavkaz, Russia

³Institute of Physics of the Earth of Russian Academy of Science, Moscow, Russia

The Ossetia part of the Great Caucasus is located within the Trans-Caucasian uplift. According to modern understanding this large structure is the northern ending of the planetary-scale structure - the East-African-Trans-Caucasus rift zone. This region, being one of the most tectonically active regions of the Caucasus, was not covered by satellite geodetic measurements made in the Caucasus and surrounding areas since the early 1990s [Shevchenko, V.I. et al., 1999; Reilinger, R. S. et al., 2006].

The network of survey-mode sites was established in this area during the campaigns of 2010-2011. This network crosses from north to south the main tectonic structures of the Ossetia part of the Great Caucasus: the northern and southern slopes of the Great Caucasus ridge, the Tibskii thrust fault, the Northern Caucasian step, the Orkhevskii thrust fault, the Georgian block. The main profile of the network is oriented from north-east to south-west. The other two profiles are transverse to the main one and are oriented from west to east. The first of them is located along the southern and northern borders of the Orkhevskii thrust fault, covering the area of the Racha 1991 earthquake, with release to the Gagra-Dzhava zone. The second of them passes along the northern slope of Great Caucasus Ridge, its new sites will cross a series of thrusts of the Rocky Ridge.

The GPS data measured during two-years campaigns were processed using the GAMIT/GLOB software. As the reference sites we use the permanent GPS stations of the Northern Caucasus deformation array [Milyukov et al., 2010]. The GPS-derived velocities provide some constrains on the geodynamical motion of the study area and complement the velocity field obtained for the surrounding areas. The resulting velocities will provide the first relatively complete and detailed pattern of modern horizontal displacements of some elements within the Caucasian mountain structure.

REFERENCES

- Shevchenko et al. (1999), *Physics of the Solid Earth*, № 9, 3-18.
Reilinger, R. S. et al. (2006), *J. Geophys. Res.*, B05411, doi:10.1029/2005JB004051.
Milyukov, V.K. et al. (2010), *J. Geodyn.* 49, 216–223.

Earth's free oscillation following the 2011 Tohoku earthquake detected by dense GPS array in Japan

Yuta Mitsui, Grad. Sci., Hokkaido Univ.

Kosuke Heki, Grad. Sci., Hokkaido Univ.

The Tohoku earthquake on March 11, 2011, occurred at the subduction plate boundary east off Japan. Since its moment magnitude was Mw9.0, earth's free oscillations with sufficiently large amplitude are expected. In fact, Igel et al. (2011) showed toroidal free oscillations using a laser sensor with ultrahigh precision. The free oscillations would be also detectable by conventional observations with seismometers or gravimeters as the 2004 Sumatra earthquake (Park et al., 2005).

Here, we report the signals of the free oscillations using a dense GPS network in Japan (GEONET). We stack 18 hour data about 300 stations near the source of the Tohoku earthquake. The GPS data are originally provided by GSI and analyzed by a precise point positioning method using the RTnet software.

The analyzed data reveal clear spectral peaks for typical spheroidal oscillations (${}_0S_3$, ${}_0S_{7-0}S_{32}$). The signals appear both in horizontal and vertical directions, although levels of background noise are different. Besides, in other 18 hour data for 1 day after the Tohoku earthquake, the signals disappear but different spectral peaks appear around 3.3mHz, 6.6mHz, 9.9mHz, and 13.2mHz. They might reflect artificial clock corrections in the analysis of GPS data.

On the occurrence of the 2011 Tohoku earthquake: role of preseismic stress accumulation and coseismic absolute stress release on a weak fault

Yuta Mitsui, Grad. Sci., Hokkaido Univ.

Yoshihisa Iio, DPRI, Kyoto Univ.

Yukitoshi Fukahata, DPRI, Kyoto Univ.

The 2011 Tohoku earthquake occurred at the subduction plate boundary east of northern Honshu on March 11, 2011. The moment magnitude was $M_w 9.0$, far larger than recent $M7$ -class earthquakes in the region.

In two recent papers (Mitsui et al., 2012; Mitsui et al., in press), using mechanical simulation models, we proposed a possible scenario for the occurrence of the $M9$ megaquake based on the following observed facts: (1) The $M7$ -class earthquakes in this region did not fully release the accumulated slip due to the plate convergence (e.g., Yamanaka and Kikuchi, 2004), and seemed causing stress increase around the hypocenter of the $M9$ Tohoku earthquake. (2) In the $M9$ Tohoku earthquake, extremely large slip more than 50m occurred near the Japan trench (e.g., Ito et al., 2011). (3) Many normal-fault-type aftershocks were distributed in a wide region around the subducting plate interface (e.g., Asano et al., 2011).

In our scenario, we owed the extremely large slip at the shallow subduction part to a dynamic weakening mechanism of thermal fluid pressurization due to shear heating. Such a mechanism can cause the extremely large coseismic slip over an area where quasistatic slip, namely, afterslip of $M7$ -class earthquakes or spontaneous slow slip events, takes place. The preseismic stress accumulation around the hypocenter of the $M9$ Tohoku earthquake due to the recent $M7$ -class earthquakes helped the seismic rupture propagate, leading to the triggering of the dynamic weakening mechanism. The thermally weakening mechanism could be associated with the normal-fault-type aftershocks via almost complete release of absolute stress.

If our scenario is true, slight differences of stress state in the shallow subduction part can result in drastically different coseismic slip. Moreover, possible spatiotemporal changes of the hydraulic conditions along the plate interface may also contribute the nonlinear effect of stress state on coseismic slip.

References

Asano, Y., T. Saito, Y. Ito, K. Shiomi, H. Hirose, T. Matsumoto, S. Aoi, S. Hori, and S. Sekiguchi, "Spatial distribution and focal mechanisms of aftershocks of

- the 2011 off the Pacific coast of Tohoku Earthquake”, *Earth Planets Space*, 63, 669–673, 2011
- Ito, Y., T. Tsuji, Y. Osada, M. Kido, D. Inazu, Y. Hayashi, H. Tsushima, R. Hino, and H. Fujimoto, “Frontal wedge deformation near the source region of the 2011 Tohoku-Oki earthquake”, *Geophys. Res. Lett.*, 38, L00G05, 2011
- Mitsui, Y., N. Kato, Y. Fukahata, and K. Hirahara, “Megaquake cycle at the Tohoku subduction zone with thermal fluid pressurization near the surface”, *Earth Planet. Sci. Lett.*, 325-326, 21-26, 2012
- Mitsui, Y., Y. Iio, and Y. Fukahata, “A scenario for the generation process of the 2011 Tohoku earthquake based on dynamic rupture simulation: role of stress concentration and thermal fluid pressurization”, *Earth Planets Space*, accepted for the special issue “The 2011 Tohoku earthquake”
- Yamanaka, Y., and M. Kikuchi, “Asperity map along the subduction zone in northeastern Japan inferred from regional seismic data”, *J. Geophys. Res.*, 109, B07307, 2004

Using seismic and GPS data for hazard estimation in some active regions in Egypt

Abdel-Monem Sayed Mohamed

National Research Institute of Astronomy and Geophysics, Geodynamics, Helwan, Cairo, Egypt
(abdel_monem@yahoo.com, 202 2554 8020)

Egypt rapidly growing development is accompanied by increasing levels of standard living particular in its urban areas. However, there is a limited experience in quantifying the sources of risk management in Egypt and in designing efficient strategies to keep away serious impacts of earthquakes. From the historical point of view and recent instrumental records, there are some seismo-active regions in Egypt, where some significant earthquakes had occurred in different places. The special tectonic features in Egypt: Aswan, Greater Cairo, Red Sea and Sinai Peninsula regions are the territories of a high seismic risk, which have to be monitored by up-to date technologies. The investigations of the seismic events and interpretations led to evaluate the seismic hazard for disaster prevention and for the safety of the dense populated regions and the vital national projects as the High Dam. In addition to the monitoring of the recent crustal movements, the most powerful technique of satellite geodesy GPS are used where geodetic networks are covering such seismo-active regions. The results from the data sets are compared and combined in order to determine the main characteristics of the deformation and hazard estimation for specified regions. The final compiled output from the seismological and geodetic analysis threw lights upon the geodynamical regime of these seismo-active regions and put Aswan and Greater Cairo under the lowest class according to horizontal crustal strains classifications. This work will serve a basis for the development of so-called catastrophic models and can be further used for catastrophic risk management. Also, this work is trying to evaluate risk of large catastrophic losses within the important regions including the High Dam, strategic buildings and archeological sites. Studies on possible scenarios of earthquakes and losses are a critical issue for decision making in insurance as a part of mitigation measures.

Seismicity and 10-years recent crustal deformation studies at Aswan region, Egypt

ABDEL-MONEM S. Mohamed; Haggag H. MOHAMED; Mohamed SALEH and Nadia ABOU-ALY

National Research Institute of Astronomy and Geophysics, Helwan, Cairo

Abstract

Aswan region considers as one of the most important areas in Egypt where the biggest national project is constructed, the High Dam, as well as its importance from the tourism, environmental and economic point of view. Such a choice has been motivated by the fact that both seismic and geodetic data needed for the current investigation have been collected and become available for Aswan region since 1982, where in November 1981 an earthquake occurred with a magnitude 5.5 in the vicinity of the High dam. Since 1982, several study programs were initiated for monitoring seismicity, underground water behavior and recent crustal movements. GPS observations were carried out by Aswan geodetic network since 1997 and repeated twice a year until now. Analysis of the repeated 10-years GPS campaigns from the network revealed horizontal movements at the level of 7–10 mm/a. Main characteristics of the seismotectonics of the Aswan region are investigated based on the geodetic results and the recently recorded seismic activity from 1982 to 2010. The results from these data sets are compared and combined in order to determine the main characteristics of deformation and hazard estimation in the Aswan region. The estimated strain rate tensors show compression and tension components directed in the WNW-ESE and NNE-SSW directions that are consistent with the P- and T-axes derived from earthquake fault plane solutions, respectively. The network area has been suffered from post-seismic deformation during the present interval; hence an increase in the general earthquake activity in the area could be expected.

Episodic slow slips and asynchronous with seismic swarms in the northern Andes subduction zone

Jean-Mathieu Nocquet¹, Juan Carlos Villegas Lanza^{1,2}, Martin Vallée¹, Patricia Mothes³,
Frédérique Rolandone⁴, Paul Jarrin³, Mohamed Chlieh^{1,2}, Hernando Tavera², Marc
Regnier¹, Yvonne Font^{1,3}, Monica Segovia³

¹Geoazur, University of Nice, CNRS, IRD, OCA, Valbonne, France

²Instituto Geofísico del Perú, Lima, Peru

³Instituto Geofísico, Escuela Politécnica Nacional, Quito, Ecuador

⁴ISTEP, University Pierre et Marie Curie, Paris VI, Paris, France

Rapid subduction of the oceanic Nazca plate beneath the South American continent (6 cm/yr) results in large mega-thrust earthquakes with a recurrence time of 150-300 ~years in Chile and southern Peru. First GPS measurements carried out since 2008 in central-northern Peru and Ecuador indicate that a ~1200 km long segment of the Nazca/South America subduction zone shows weak to null coupling, implying a seismic cycle drastically different from the rest of the Andean subduction. Within this context, we document two shallow slow slip events that have occurred in northern Peru and central Ecuador, both associated with significant micro-seismicity and amount of slip. The 2009 northern Peru event lasted for ~7 months and was detected by both continuous and campaign GPS measurements. Inversion of the total slip shows that a shallow (5-20 km) patch of 90x90 km slipped up to 45 mm, leading to an equivalent magnitude of $M_w=6.7$. The whole sequence was synchronous with an increase of micro to moderate seismicity with 4 events of magnitude close to $M_w=6$. Location of seismicity seems to occur primarily along the edges of the main slip area. Although no sequence of mainshock-aftershock dominates the seismicity pattern during the whole event, the sequence consists in 4 major earthquakes characterized by foreshocks occurring days to hours before each major event, and then followed by significant clustered aftershocks and aseismic slip. One of the magnitude 6.0 earthquake occurred at very shallow depth and shows peculiar characteristics: (1) large post-seismic displacement is observed after the main shock, (2) oppositely to the other events, no cluster of aftershocks is

observed after the main shock (3) the main event has a long rupture duration compared to its moderate magnitude. In central Ecuador, south of the rupture of the great Mw=8.8 1906 Colombia-Ecuador earthquake, a one week long slow-slip event involved a ~2 cm westward displacement recorded at an island located 35 km from the trench and 8-10 km above the subduction interface. During this period, more than 650 micro-earthquakes have been observed. While no clear sub-sequence is identified during this short event, the seismicity seems to be partitioned between several families of repeating earthquakes and individual events. The total seismic moment release accounts for at most 1% of the total released estimated from geodetic data. Both observations therefore support the view that seismicity was entirely triggered by the stress change induced by the aseismic slip. Both events suggest that a significant part of the weak stress accumulation along the northern Andes subduction zone is released through slow slips and synchronous seismic swarms.

Present-day kinematics of the Mediterranean: a comprehensive overview of GPS

results

Jean-Mathieu Nocquet

Geoazur, Université de Nice Sophia-Antipolis, CNRS-INSU, IRD, OCA, 250, rue A. Einstein, F-06560 Valbonne, France

Session 2

I combine recently published GPS results to derive a geodetic horizontal velocity field consistent at the scale of the Mediterranean and the surrounding Alpine belts. The velocity field is then used to discuss the boundary conditions around each major deforming area in the Mediterranean, to describe the main patterns of motion and deformation, to critically review the existing kinematics models and to finally point out the main unresolved kinematics questions. Strain rate in Europe north of the Alpines belt is dominated by the signature of the Glacial Isostatic Adjustment and tectonic strain remains below the current accuracy of GPS results. In the western Mediterranean, deformation is restricted to the Betics, the Alboran and the Moroccan Rif, with west-to-southwestwards motion with respect to Iberia, which is part of stable Europe. Shortening, consistent with the relative Nubia/Eurasia plate motion, is found throughout the Maghrebides, but the distribution of deformation in northern Africa remains largely unknown. The central Mediterranean is dominated by the counter-clockwise rotation of the Adriatic. The junction between the southern Adriatic domain and Nubia has yet to be firmly established. The deformation over a wide area, east of the Maghrebides, in Tunisia and the gulf of Sirte in Libya still remains to be quantified. In the eastern Mediterranean, the velocity field is dominated by a general anti-clockwise rotation and a general trend towards the Hellenic trench, with velocity magnitude increasing with decreasing distances from the trench. This trend is observed not only in the Aegean and Anatolia, but also in the southern Balkans. Geodetic results emphasize that the convergence of the Nubia and Arabia plates towards Eurasia directly controls the deformation across only very few segments along the plate boundary zone. Additional processes are therefore required to explain the observed velocity field and deformation pattern.

A general overview of changes of the earth crust due to earthquakes, land slide and other geological phenomena in the territory of Albania; Monitoring of these changes

by
Bilbil Nurçe¹, Ibrahim Milushi², Gezim Gjata¹, Sokol Allaraj¹

¹Faculty of Civil Engineering, Polytechnic University of Tirana, Albania

²Institute of Geosciences, Energy, Water and Environment, Polytechnic University of Tirana, Albania

Abstract

Albania is characterized by a complex geological construction, with a great variety of rocks and strong over thrusts (up to some tens km) of the tectonic units. Tectonic style is complex, but the most typical feature is the over thrusting of the tectonic units from the east towards the west. The areas of over thrusting edges are characterized by large faulting zones and therefore the soil sliding and rock erosion by waters is very strong in many areas. While, the plain of these over thrusts at relatively high depths, in certain sectors, generate earthquakes of small to medium magnitude. A conspicuous phenomenon is the presence of gypsum and anhydride diapirs. Territories where these diapirs spread are characterized by an intense dynamism and strong deformations of the earth crust. River network, relatively developed, with east-west flow direction, generally cross-cutting the geological structures, form in many cases, deep valleys and canyons. Along these valleys are encountered many dynamic areas as concerning the land slide and erosion that often lead to strong changes of the earth crust. Regarding seismic activity, Albania is characterized by a relatively high seismicity. The territory of Albania is stroked by earthquakes of low to the average magnitude, seldom powerful earthquakes have been recorded (> 5 Richter scale). Although this, the effect of some strong earthquakes on the land and in several residential areas was relatively large. Some earthquakes have caused strong deformations of the land as well as destruction and land subsidence of some residential areas in the past 2300 years. Based on the terms of the distribution of earthquakes and their connection with geological structures have been identified several belts (lineaments) of high seismic activity such as: the belt of the Adriatic (eastern edge of Adria), the belt of Vlore - Lushnje - Elbasan - Diber, the belt of Korce - Oher - Peshkopi, the belt of Vlore - Tepelene and some areas as Lezha – Ulcin, Borsh-Kardhiq, Shkoder-Peje, Vlore - Tepelene etc.. Earthquakes in Albania are monitored by a digital online network and seismic events are reported in real time, while monitoring of sliding and other dynamic geological phenomena are done manually.

Recent Creep Rate of Ismetpasa Segment of North Anatolian Fault (Turkey) inferred from 7-years GPS Observations

Haluk Ozener¹, Semih Ergintav², Ugur Dogan³, Ziyadin Cakir⁴, Asli Dogru¹, Bulent Turgut¹, Onur Yilmaz¹, Kerem Halicioglu¹, Asli Sabuncu¹, Emre Havazli¹

The study area is situated in the central part of the creeping segment of North Anatolian Fault (NAF), extending from the vicinity of Ismetpasa in the west to Hamamli village in the east (350 km east of Istanbul). The largest known earthquakes in this region occurred in 1944 (Gerede earthquake, Mw=7.2) and in 1951 (Kursunlu earthquake, Mw=6.9). Both earthquakes were related with NAF and cover the Ismpetpasa region from west to east, respectively. Creep at Ismetpasa has been studied in different time scales with different techniques by various researchers since its discovery by Ambraseys in 1969. Data coming from these studies provides us that the average creep rate is approximately 7mm/yr between the years of 1969 and 2002. Since 2005, we apply GPS technique annually on the micro-geodetic network that made up of 6 sites installed in 1972 by General Command of Mapping. We present results from 7 years of GPS observations of creep at Ismetpasa section of NAF. According to our results, the creep rate is around 8mm/yr and it shows exponential decrease since 1944 earthquake. In order to improve our understanding of creeping, geodetic data (conventional surveying, GPS, InSAR, LIDAR) should be combined with other observations such as strainmeters, hydrological, etc.

Shallow evolution of Santorini volcano constrained by InSAR and GPS measurements

Michelle M. Parks¹, Juliet Biggs², Susanna Ebmeier¹, Philip England¹, Tamsin A. Mather¹, Paraskevi Nomikou³, Kirill Palamartchouk^{1,4}, Xanthos Papanikolaou⁵, Demetris Paradissis⁵, Barry Parsons¹, David M. Pyle¹, Costas Raptakis⁵, Vangelis Zacharis⁵

¹ *Department of Earth Sciences, South Parks Road, Oxford, OX1 3AN, UK.*

² *School of Earth Sciences, University of Bristol, Bristol, BS8 1RJ, UK.*

³ *Department of Geology and Geoenvironment, University of Athens, Athens, Greece.*

⁴ *School of Civil Engineering and Geosciences, University of Newcastle, Newcastle upon Tyne, NE1 7RU, UK.*

⁵ *Higher Geodesy Laboratory, National Technical University, Athens, Greece.*

Santorini, a major caldera volcano in the South Aegean, entered a period of unrest in January 2011. This was characterised by the onset of detectable seismicity and caldera-wide uplift. For the past 360,000 years, the volcano has generated major explosive eruptions every 20,000 to 30,000 years, which are separated by phases during which andesite shields and dacite lava domes are built by multiple smaller effusive eruptions. Since the last major eruption ~1620 BC (Minoan eruption) Santorini has been in a dome-forming phase. Here we present measurements of surface deformation prior to and during the recent period of unrest using Interferometric Synthetic Aperture Radar (InSAR) and GPS data collected from a network of 10 continuous GPS receivers installed on the caldera complex.

Observations from 1993-2010 using the ERS and Envisat satellites show subsidence on the Kameni islands which can be interpreted as loading by recent lava flows or degassing of a shallow magma body. The onset of the unrest was marked by an increase in the rate of micro-seismic activity beginning in January 2011; at the same time, the coordinates of continuous GPS stations operating on Santorini began to deviate from their longer-term average velocities. We have used Envisat and TerraSAR-X to measure ground deformation since March 2011. We convert this signal into sub-surface volume increase by treating the displacements as arising from a pressure increase at depth within an elastic crust. The best fitting spherical source has an effective volume in the range 10-20 million cubic metres, and is centred slightly to the north of Nea Kameni at a depth of 4.4 kilometres. This is equivalent to 10% to 50% of the volumes of recent dome-forming eruptions of the volcano. Preliminary GPS analysis suggests the rate of uplift is now decreasing and we will present the updated time-series.

Magmatic dyking and recharge in the Asal Rift, Republic of Djibouti

Gilles Peltzer^{1,2}, Cécile Doubre³, and Jelena Tomic^{1,4}

(1) University of California, Los Angeles, California

(2) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

(3) Institut de Physique du Globe de Strasbourg, France

(4) Now at Exxon-Mobil, Houston, Texas

The Asal Rift, Republic of Djibouti, has been the locus of a major magmatic event in 1978 and seems to have maintained a sustained activity in the three decade following the event. We compare the dyking event of 1978 with the magmatic activity occurring in the rift during the 1997-2008 time period.

We use historical air photos and satellite images to quantify the horizontal opening on the major faults activated in 1978. These observations are combined with ground based geodetic data (trilateration and leveling) acquired between 1973 and 1979 across the rift to constrain a kinematic model of the 1978 rifting event, including bordering faults and mid-crustal dykes under the Asal Rift axis and the Ghoubbet Gulf. The model indicates that the structure located ~3-7 km under the surface of the Asal segment deflated during the 1978 event and that the extension was concentrated at shallower depth in the crust, resulting in the opening of faults, dykes and fissures between the two main faults, E and γ . These findings suggest that, during the 1978 event, magmatic fluids transferred from a mid-crustal reservoir to the shallow structures, injecting dykes and filling faults and fissures.

Surface deformation observed by InSAR during the 1997-2008 decade reveals a slow, yet sustained inflation and extension across the Asal Rift combined with continuous subsidence of the rift inner floor. Modeling shows that these observations cannot be explained by visco-elastic relaxation, a process which mostly vanishes 20 to 30 years after the 1978 event. However, the InSAR observations over this decade are well explained by a kinematic model in which an inflating body is present at mid-crustal depth, approximately under the Fieale caldera, and shallow faults accommodate both horizontal opening and down-dip slip. The total geometric moment rate, or inflation rate, due to the opening of the mid-crustal structure and the deeper parts of the opening faults is $3 \times 10^6 \text{ m}^3/\text{yr}$. Such a volume change per year corresponds to ~ 1-2% of the total volume of magma estimated to have been mobilized during the 1978 seismo-magmatic event.

The comparison of the 1978-dyking and post-dyking models of rift suggests that the source of the injected magma during the 1978 event lies at mid-crustal depth under the Fieale caldera and appears to be recharging at a sustained rate more than 20 years after the event. Whether this rate is a transient rate or a long-term rate will determine the time of the next magma injection in the shallow crust. However, at the current rate, the 1978 total volume would be replenished in 50-100 years.

Mexico City, a sinking city

D. Poreh¹, T. van Dam¹, E. Cabral-Cano²

¹University of Luxembourg 6, rue Richard Coudenhove-Kalergi, Luxembourg

²Departamento de Geomagnetismo y Exploración, Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad Universitaria, México

Mexico City is rapidly subsiding as a result of ground water withdrawal exceeding ground water recharge there for many years. Previous authors have reported on the rate of subsidence by using continuous GPS, INSAR, and Persistent Scatter Interferometry (PSI). We extend the results of these analyses also by means of INSAR, GPS, and optical remote sensing data. 52 ENVISAT, one Landsat ETM+ image, and data from 9 GPS stations have been analyzed. Our data span the 2002 - June 2010 time frame. We find an average annual change of 30 cm in elevation that is in agreement with the previous studies. However, the longer time series allows us to identify accelerations in the subsidence as well. Our INSAR results have been compared with GPS data in the same time interval, and demonstrate a high level of correlation (up to 0.988). The Support Vector Machine (SVM) method is also used to classify the city's population density. This allows us to compare the subsidence rate with population density using Landsat ETM+ image classification. The comparison indicates that regions with a high population density represent the regions with highest amount of subsidence. The areas of greatest subsidence is also associated with regions having the maximum thickness of fluvial sediments.

Keywords: Mexico City, subsidence, synthetic aperture radar (SAR), GPS, interferometry, persistent scatterer interferometry (PSI).

The two magma chambers problem in volcano deformation

Eleonora Rivalta

GFZ Potsdam, Helmholtzstrasse 7, 14467 Potsdam, Germany

rivalta@gfz-potsdam.de

The pattern of volcano deformation during unrest often suggests that inflation or deflation at one or more magma chambers have occurred; sometimes the deformation pattern suggests dike injection, sometimes more deformation sources are present. A common observation is that the volumes lost and gained by the sources does not add up to zero, suggesting the contribution of a deeper magma reservoir. However, inverting the deformation data for multiple sources reveals difficult, in particular when the sources are one on top of the other. In this presentation, I will give an overview of the multiple lateral dike injection events where this type of mismatch has been observed (Kilauea, Hawaii; Manda-Harraro segment in the Afar rift, Ethiopia; Izu Islands, Japan; Fernandina, Galapagos), and illustrate how magma and rock compressibility may cause this 'volume multiplication'. I will also discuss, on the basis of published and unpublished theoretical and numerical results, the physical reasons of why source interaction can make it prohibitive to invert for multiple sources at the same time, and show how magma and rock compressibility may be responsible of other recurrent patterns and effects, such as the characteristic trend observed for the seismicity forefront linked to the propagation of the dike tip, or the significant isotropic and CLVD components often found in moment tensor solutions in volcanic areas.

W phase source inversion using the high-rate regional GPS data of the 2011 Tohoku-oki earthquake

Luis Rivera¹, Hiroo Kanamori² and Zacharie Duputel²

1) Institut de Physique du Globe de Strasbourg, Université de Strasbourg/CNRS, France

2) Seismological Laboratory, California Institute of Technological, Pasadena, California

The 11th April 2012 offshore Sumatra earthquake strikingly demonstrates the importance of rapidly knowing the focal mechanism of large earthquakes in order to allow for a reliable tsunami forecast. We would like to address here the question of using GPS data to reduce the time delay for obtaining the source parameters of large earthquakes. During the last 3 years, W phase inversion method has proved to be a powerful tool for rapid determination of the overall source properties of large earthquakes. Robustness, rapidity and versatility are the main assets of the algorithm. Until now the emphasis has been on global applications as performed, for example, at the National Earthquake Information Center (NEIC, USGS) or the Pacific Tsunami Warning Center (PTWC, NOAA). These implementations provide moment tensor solutions within 30-60 min after the origin time of moderate and large worldwide earthquakes. They rely on the global high gain broadband network and exploit the very long period contents of the data segments between the P arrival time (T_p) and $T_p + 15\Delta$ s/°. The algorithm was originally designed to handle very large earthquakes and the 2011 Tohoku-oki, earthquake is a typical target for it. Valuable results for tsunami warning purposes were obtained 20 min after the origin times of this event. However this time delay is still too long for near field tsunami warning purposes. Since the delay results essentially from the wave propagation time, in order to reduce it we have to turn the attention to regional data. In such case the original W phase time window definition is no longer appropriate since it dramatically shrinks at very short distances. For regional applications, we use a constant duration time window of 180 s starting at the P arrival time. Then, for an epicentral distance of $\Delta = 6^\circ$ this data segment is available 260 s after the origin time. In other words a solution using data within 6° would be available 5 min after origin time. The 2011 Tohoku-oki event is again an ideal case for testing regional application. The enormous amount and wide variety of regional high quality seismological and geodetic observations available for this earthquake represent a unique opportunity to advance faster tsunami warning using regional data.

We use the high-rate GPS data (1 Hz) from GEONET provided by the Geospatial Information Authority (GSI, Japan). The dataset we used contains three components of ground displacement at 414 stations with epicentral distances ranging from 0.6° to 5.1° . We tested different network geometries by selecting stations subsets according to different choices of the minimal epicentral distance and the minimal inter-station distance. In spite of the poor azimuthal coverage (gap $> 200^\circ$) the overall results are very promising with M_w ranging from 8.8 to 9.2 and accurate fault geometries. All these solutions are potentially available 5 min after the origin time. Since the network is very dense, we can still obtain good and stable solutions by severely subsampling the network, for example taking only stations separated by more than 0.5° (51 stations). It also appears that using too close stations (e.g., $\Delta \sim < 3^\circ$) can lead to biased solutions. This is certainly related to the point source representation of the source we use.

Our results demonstrate the potential of high-rate, low-latency GPS data for providing very fast tsunami warning.

Session: Subduction zones and giant earthquakes

New insights on coseismic ionospheric disturbances induced by a well observed intra-continental earthquake, the 2011 Van earthquake in Eastern Turkey

L. Rolland¹, M. Vergnolle¹, J.-M. Nocquet¹, J.-X. Dessa¹, F. Tavakoli², A. Sladen¹, F. Cappa¹

¹ *Géoazur, Observatoire de la Côte d'Azur - University of Nice - UMR CNRS 7329
250 av. A. Einstein, 06560 Valbonne, France.*

² *National Cartographic Center, Geodetic Department, Meraj Ave. Azadi Sq., P.O. Box
13185-1684, Tehran, Iran.*

Choice of scientific session : 7. Scientific results related to the Geohazard Supersites initiative

A part of the seismic energy radiated by earthquakes is transferred to the surrounding fluid envelopes (ocean and/or atmosphere) through dynamic coupling. Global Navigation Satellite Systems (GNSS) have already shown their capability of sounding seismic waves travelling in the upper and ionized part of the atmosphere, namely the ionosphere. So far, most studies have documented the ionospheric disturbances triggered by large subduction earthquakes. In particular, recent studies on the great 2011 Tohoku Oki earthquake, Japan, have shown the ability of GPS observations to complement the seismological and geodetic ground observations, predominantly limited to continental areas. Understanding the processes, characterizing the parameters driving them, and improving their modelisation are needed to fully make use of these new observations, so that they can be used in earthquake source studies.

We thus focus on a spatially well observed intra-plate thrust earthquake, the Mw 7.3 Van earthquake (2011/10/23, Eastern Turkey), to investigate new constraints on coseismic ionospheric disturbances. We use GPS and GLONASS data from the TUSAGA-Aktif Turkish permanent network made available at <http://supersites.earthobservations.org/van.php> and from the IPGN Iranian permanent network. The sites and satellites distributions offer an unprecedentedly good coverage of the ionosphere, close-by and also all around the epicentral area. We analyse the fluctuations in the ionospheric delay of GNSS radio signals (linked to the ionosphere Total Electron Content or TEC) together with the ground coseismic displacements.

As expected, we observe the first ionospheric perturbations less than 10 minutes after the earthquake origin time. Besides, the high signal-to-noise ratio of the detected TEC perturbations reveals that strong vertical displacements have taken place during the seismic rupture. Using 3D acoustic ray tracing in a stratified atmosphere, we also show that these perturbations are consistent in space and time with the propagation of an acoustic pulse launched at ground level near the epicentral area. We compare the estimated origin to the vertical displacement distribution near the fault plane.

More unexpectedly, we also clearly observe that disturbances located north and south of the epicenter have a first negative and positive polarities, respectively. It comes out that this feature is systematically observed on other events that occurred in the northern hemisphere, which could suggest that non-linear ionospheric coupling effects are coming into play. Additionally, we highlight that the ionospheric observation pattern is consistent with the rupture geometry revealed by field investigations and ground geodetic observations. We finally conclude on the sensitivity of GPS and other GNSS to measure coseismic vertical displacements, both from direct positioning and from ionospheric sounding.

Title:

Geodynamic signals in the occasion of large earthquakes in the recording of the interferometric water tube tilt meter, Lohja, Finland

Author: Hannu Ruotsalainen

Finnish Geodetic Institute

Geodeetinrinne 2

Masala, Kirkkonummi

Finland

email:firstname.lastname@fgi.fi

Abstract:

Interferometric water tube tiltmeter is very sensitive to different kind of geophysical signals - from microseism to earth tide tilt and loading signals. Some examples of those longperiod geodynamic signals are shown. After large earthquakes toroidal modes of free oscillations of the earth are clearly observed with tiltmeter and modes are interpreted according models. Microseismic and longer period signals recorded with the tilt meter in the occasion of recent large earthquakes are shown and their spectral characteristic features are studied.

Deformation Field and Velocity Vectors for the Egyptian Territory Deduced from Permanent GPS Data

Mohamed Saleh (1,2), Matthias Becker (1), Abd el-Monem Sayed Mohamed (2), Nadia Abou-Aly(2), Salah Mahmoud (2), and Hassan Khalil (2).

(1) TU Darmstadt, Institute of Physical Geodesy, Darmstadt, Germany (saleh@ipg.tu-darmstadt.de, +49(6151)164512), (2) National Research Institute of Astronomy and Geophysics, Helwan, Egypt.

Due to the occurrence of rare but large Earthquakes, an Egyptian program for studying the recent crustal movements and its relation to earthquake activity was initiated. In 2006, The National Research Institute of Astronomy and Geophysics, Helwan, Egypt started the establishment of the Egyptian Permanent GPS Network (EPGN). By the beginning of 2007 four stations already were established and working. In 2008 another two stations became operational followed by another three stations in 2009 and finally another six stations were established. In addition to these 15 stations, which were established and are administrated by NRIAG, there is a station in Alexandria organized by the French “Centre d’Études Alexandrines” (CEALX) that is used as a station in the EPGN in addition. Nowadays 16 station are operational and an extension to 20 by the end of 2012 is expected.

This presentation aims to throw light upon the present state of the recent crustal movement of the whole of Egypt. The collected EPGN data of the last six years are processed by using Bernese software V. 5 according to the IGS standards. In addition selected IGS, AFREF, and EPN sites are processed for reference frame definition. This is intended to be the first comprehensive analysis of this permanent network. We will present the present date of the horizontal velocities, geodetic time series, strain field and block rotation estimates.

Multiscale deformation monitoring at Colima Volcano using TerraSAR-X interferometry and camera observations

Authors: Salzer JT (1), Walter TR (1), Legrand D (2), Bretón M (3), Reyes GA (3)

Affiliations: (1) GFZ Potsdam, Germany, (2) UNAM, Mexico, (3) University of Colima, Mexico

Colima is an explosive dome building volcano in Mexico, with steep slopes and limited possibilities for monitoring the activity of the dome itself. We have acquired TerraSAR-X data in spotlight mode for ascending and descending tracks over Colima, to obtain a high spatial resolution of up to 2m, and a temporal resolution of 11 days. By interferometric processing, this data now allows the detection of modifications of the dome, as well as compaction of the lava flows emplaced during previous eruptions. We combine the InSAR data with optical camera data in order to monitor the growth of the dome, as well as the lateral extrusion of the lava lobe, a viewing direction which is not covered by InSAR. The camera data was analysed using spatial digital image correlation to measure pixel displacements, giving an estimation for the extrusion rates of the dome. Here, we present results of the Colima InSAR and camera time series, in combination showing deformation on scales from millimeters to metres.

**Coseismic displacements and Holocene slip rates for two thrust faults
at the mountain front of the Andean Precordillera (~33°S)**

Silke Schmidt ^{a,b}, Ralf Hetzel ^{a,*}, Eric Salomon ^{a,c}, Francisco Mingorance ^d, Andrea Hampel ^e

^a*Institut für Geologie und Paläontologie, Westfälische Wilhelms-Universität Münster, Corrensstraße 24,
48149 Münster, Germany*

^b*Institut de Physique du Globe, UMR 7516, 5 Rue René Descartes, 67084 Strasbourg, France*

^c*Institut für Geowissenschaften, Johannes Gutenberg-Universität Mainz, Johann-Joachim-Becher Weg
21, 55128 Mainz, Germany*

^d*Instituto de Mecánica Estructural y Riesgo Sísmico, Universidad Nacional de Cuyo, Casilla de Correo
405 – Correo Central, 5500 Mendoza, Argentina*

^e*Institut für Geologie, Leibniz Universität Hannover, Callinstrasse 30, 30167 Hannover, Germany*

During the last 250 years several destructive earthquakes occurred along the eastern margin of the Andean Precordillera, where GPS data reveal a shortening rate of ~2 mm/a (Kendrick et al., 2006). However, the epicenter of most earthquakes could not be determined and the seismic behavior for the majority of active thrust faults is largely unknown. To fill this gap we investigated two range-bounding thrust faults near Mendoza city, the 48-km-long Peñas and the 31-km-long Cal thrust faults, using fault scarp profiles, paleoseismic trenching and age determinations of the deformed terraces T₁–T₄. Fault scarps on the lowest terrace level T₁ reveal vertical offsets of 0.8–1.0 m for both faults, which are interpreted as coseismic displacements during the last earthquake. Together with the fault dip angle of 25–32°, these offsets indicate that both faults are capable of producing magnitude M_W ~6.9 earthquakes, which confirms the magnitude estimated from the fault lengths and is furthermore corroborated by a magnitude M_S ~7.0 event on the Cal fault that destroyed Mendoza in 1861. Older terraces show stepwise increasing cumulative offsets, indicating that elastic strain energy was repeatedly released during strong earthquakes. For example at the Peñas thrust fault the ~3.3-ka-old terrace T₂ is offset by ~1.9 m and the ~12-ka-old terrace T₃ is displaced by ~11 m (Schmidt et al., 2011). A cliff section cut in terrace T₂ confirms the 1.9 m uplift of T₂ and revealed older horizons that are vertically displaced by 2.7 m. Thus, the last three earthquakes presumably generated identical offsets of ~0.9 m and had a similar magnitude. The shortening along the Peñas thrust occurred at a rather constant rate of ~2.0 mm/a during the past 12 ka; i.e. a similar value as the present-day shortening at the eastern margin of the Precordillera.

In contrast, the slip rate at Cal thrust fault, which extends into Mendoza city, has recently accelerated since three terraces (T₂ to T₄) vertically offset by ~2.6, ~3.6, and ~7.0 m, respectively, yielded ages of ~0.8 ka (OSL), ~3.9 ka (¹⁴C), and ≤12 ka (¹⁰Be) and are (Schmidt et al., 2011). A trench excavated on the ~800-years-old terrace T₂ exposes coarse-grained sediments, which are deformed by three east-vergent folds (F₁–F₃). Finite element modeling shows that coseismic folding above the tip of a blind thrust fault is a physically plausible mechanism to generate these folds. Their retrodeformation yields total displacements of ~2.0 m, ~2.4 m, and ~0.5 m on the underlying fault splays, respectively (Salomon et al., in revision). The displacement of ~2.0 m recorded by fold F₁ is interpreted as the result of the 1861 M_S ~7.0 earthquake, whereas F₂ and F₃ were presumably generated during the penultimate event, which likely had a similar magnitude. Thus, two strong earthquakes occurred on the Cal thrust fault during the last ~800 years, which indicates the serious threat to the one million inhabitants of Mendoza city.

Kendrick, E., et al. (2006). Active orogeny of the south-central Andes studied with GPS geodesy, *Rev. Asoc. Geol. Arg.* 61, 555–566.

Schmidt, S., et al. (2011). Coseismic displacements and Holocene slip rates for two active thrust faults at the mountain front of the Andean Precordillera (~33°S), *Tectonics* 30, TC5011.

Salomon, E., et al. (in revision). Repeated near-surface folding during late Holocene earthquakes on the Cal thrust fault near Mendoza city (Argentina), *Bull. Seismol. Soc. Amer.*

***Vertical deformation of northeastern Honshu coastline: from minutes to thousands of years –
Implications on the earthquake cycle along the Japan trench***

Silke Schmidt¹, Mustapha Meghraoui¹, Koji Okumura², Esra Cetin^{1*} & Shinji Toda³

¹Institute de Physique du Globe, UMR 7516, Strasbourg, France.

²University of Hiroshima, Japan

³DPRI, Kyoto, Japan

*Also at Istanbul Technical University, Turkey

The M_w 9.0 Tohoku-oki earthquake of March 11th 2011 revealed strong co- and postseismic deformation that contributes to the understanding of coastal deformation along subduction zones. Here we study the short and long term vertical deformation along the northern Honshu Island coastline (36.5°-41.5°N) in the frame of the PALET (ANR-JSPS)* project to outline the regional dependency of the rates and reveal indicators on the earthquake cycle.

West of the epicenter of the M_w 9.0 earthquake (38.2°N), up to 1.2 m coseismic coastal subsidence was revealed by leveling and GPS measurements (e.g. GSI, 2012a). The subsidence decreases continuously from the epicentral area towards the north and south and extends from Tokyo at 35°N to 40°N, i.e. over the complete ~550 km of the 2011 earthquake rupture length. The postseismic deformation indicates relaxation and uplift of the coastline in the range of up to ~15 cm until June 2012 (i.e. ~12% of coseismic subsidence) (GSI, 2012b).

In contrast to the coastal coseismic subsidence, late Quaternary marine terraces indicate that uplift prevails along the entire coastline in geologic timescales. Meaningful uplift values related to the tectonic plate interface can be obtained for northern Honshu (38.2°-42°N) since no active onshore faulting have been identified along a large section of this coastline. In this area, the distance between the coastline and the subduction trench reaches 290 km in the north, 180 km in the center and 250 km in the south. Accordingly, the depth of the subducting Pacific plate beneath the coastline varies even stronger between ~80 km in the north and ~45 km in the center. In this area terraces of marine isotope stage MIS5e (Eem, 125 ka) occur 38-43 m above sea level in the north and 16-28 m above sea level in the center and south, thus they indicate uplift rates of ~0.3 mm/a to ~0.13 mm/a, respectively. This rate and its variation are confirmed by the heights of ~230 ka old MIS7 terraces. Before the 2011 earthquake few earthquakes ruptured the Japanese trench at the latitude of relatively low long-term uplift rates, whereas in northernmost Honshu a sequence of recent large earthquakes (M_w 7.4-8.2, e.g. 1960, 1968, 1989, 1994) affected the latitudes with high long-term vertical deformation. These results illustrate the different interseismic behavior of the southern and northern part of the Japan subduction zone.

*PALET: PALeoseismology and paleotsunami of the Tohoku Earthquake region; ANR: Agence Nationale de la Recherche; JSPS: Japan Society for Promotion of Science

Interplay of seismic and aseismic deformations along faults: An experimental approach

J. Schmittbuhl, O. Lengliné, J.P. Ampuero, M. Bouchon

Observations of earthquake swarms and slow propagating ruptures on related faults suggest a close relation between the two phenomena. Earthquakes are the signature of fast unstable ruptures initiated on localized asperities while slow aseismic deformations are experienced on large stable segments of the fault plane. The spatial proximity and the temporal coincidence of both fault mechanical responses highlight the variability of fault rheology. However, the mechanism relating earthquakes and aseismic processes is still elusive due to the difficulty of imaging these phenomena of large spatiotemporal variability at depth. Here we present laboratory experiments that explore, in great detail, the deformation processes of heterogeneous interfaces in the brittle-creep regime. We track the evolution of an interfacial crack over 7 orders of magnitude in time and 5 orders of magnitude in space using optical and acoustic sensors. We explore the response of the system to slow transient loads and show that slow deformation episodes are systematically accompanied by acoustic emissions due to local fracture energy disorder. Features of acoustic emission activities and deformation rate distributions of our experimental system are similar to those in natural faults. On the basis of an activation energy model, we link our results to the Rate and State friction model and suggest an active role of local creep deformation in driving the seismic activity of earthquake swarms.

Ref : [Lengliné et al, ESPL, 2012, in press]

Invited key-note, 2012 Wegener General Assembly
Session: "Subduction zones and giant earthquakes"

Imaging coseismic slip along subduction megathrusts: recent progress and future challenges

Anthony Sladen
Université de Nice Sophia Antipolis (UNS) – CNRS – IRD – Observatoire de la Côte d'Azur
Sophia-Antipolis
250 rue Albert Einstein
06560 Valbonne, France
email: sladen@geoazur.unice.fr

Space geodesy, which really started to be applied in the early nineties, improved drastically our ability to image the slip distribution of major subduction earthquakes, providing complementary information to the routinely used teleseismic data: while teleseismic data require to solve simultaneously the spatial and time components of slip distribution, geodetic data only depend on the spatial distribution of slip. Yet, the inverse problem of recovering the slip distribution remains an ill-posed problem with non-unique solutions. Over time, the networks have improved in coverage, reliability and accuracy, theoretically reducing the non-uniqueness of the problem. But the variability of solutions published for the recent and highly instrumented M9.0, 2011 Tohoku-Oki earthquake illustrated once again the need to (1) better understand the non-uniqueness of the solution and (2) to improve the integration of existing or new data. Probably stimulated by the continuously increase of data of the last ten years, significant developments have been made to tackle those two problems. In this presentation, I will provide an overview of these new observations and methodological contributions, and discuss their implication on the future of coseismic slip imaging in the context of subduction zones.

Short to long-term segmentation of the subduction seismogenic zone: what interpretations?

Anne Socquet
anne.socquet@ujf-grenoble.fr

Invited key-note

Session: "Subduction zones and giant earthquakes"

Understanding what factors limit the seismic ruptures is a key question for risk mitigation and for our understanding of the physical processes occurring on seismogenic fault zones. In areas defined as seismic gaps, characterized by a reduced seismic activity, statistical models fail predicting the occurrence of future large earthquakes. The last megathrust earthquakes that devastated the coasts of Chile in 2010 and Japan in 2011 ruptured fault sections that were locked before the earthquakes, while ruptures terminations correspond with coupling lows. A fine mapping of interseismic coupling and its spatial variations thus appear as key parameters in assessing the faults' seismic potential.

The seismogenic zone of subductions seems segmented, both along-dip and along strike. A shallow region ($< \sim 35$ km depth), mostly locked during the interseismic period, would be constituted of large-scale asperities that would entirely rupture during mega-thrust earthquakes, releasing important co-seismic slip, thus largely contributing to the tsunami generation, but radiating rather little seismic energy at high-frequency. A deeper transitional zone (~ 35 – 55 km depth), partially locked during the interseismic period, would be characterized by a complex brittle-ductile behavior where aseismic slip and seismic ruptures can coexist, and that seems to be mostly responsible for the generation of high-frequency destructive seismic waves. There, intermediate M_w earthquakes could rupture small-scale asperities and aseismic creep pulses may occur in the post-seismic or interseismic periods. The existence of an along-strike segmentation of the subduction zones is now well-established. This segmentation is marked either by the extent of past earthquakes, by lateral variations of coupling or by structural complexities on the subducting and / or overriding plate.

The limits of the seismic ruptures – and therefore of highly coupled areas during the interseismic period – are usually explained by variations of mechanical behavior on the faults interface. Transitional areas, showing a partial coupling between large earthquakes and where post-seismic afterslip is mostly concentrated, are often interpreted as an interfingering of patches characterized either by a “velocity weakening” or a “velocity strengthening” mechanical behavior. However, little is known about what actually controls these variations of mechanical behavior within the seismogenic zone. Numerical studies suggest that normal stress variations on a fault interface or pore pressure variations of fluids trapped at the interface may cause the mechanical behavior to change from a stable creep to an unstable stick-slip regime. However, correlations exist between low coupling zones, areas affected by post-seismic creep pulses and long-term geomorphic features that remain to be understood. A physical mechanism, persistent over several seismic cycles, should therefore control the spatial variations of the seismogenic zone. There are growing evidences that the structure and geometry of the subduction contact may decisively influence the mechanism controlling the segmentation. Geometrical irregularities on the subduction contact can generate a damage zone and fractures in the upper plate, modifying the seismic behavior in that region of the contact (creating for example, low-coupled aseismic barriers). Studies usually attribute these geometrical barriers to the subduction of oceanic ridges, although the role of the tectonic structure of the upper plate seems to be under-considered.

**An added-value source model of the Haiti earthquake -
model robustness estimates from a fully joint optimization of seismic and geodetic
data**

Henriette Sudhaus & Sebastian Heimann

Helmholtz Centre Potsdam GFZ, Telegrafenberg, 14473 Potsdam, Germany

Through the Geohazard Supersite initiative that provided access to SAR products of the Japanese ALOS satellite it became possible for many research teams to study the source characteristics of the devastating 2010 Haiti earthquake on a relatively common data basis. We have gained a good picture of the general characteristics of this earthquake from all these analyzes and additionally profit from the variety of results on this earthquake as they reveal both a common ground and differences. So far it is agreed on that a considerable part of the seismic energy radiated by the oblique left-lateral strike-slip earthquake was apparently not released on a segment of the Enriquillo-Plantain Garden Fault (EPGF), a major strike-slip fault crossing Hispaniola. Instead, a large portion of slip is thought to have occurred on a northward-dipping thrust fault located slightly north of the EPGF. Apart from that, however, the Haiti earthquake source models differ widely. For instance, it remains unclear whether or not the earthquake ruptured multiple distinguishable fault segments, and whether these might have included a part of the EPGF or not. Furthermore, the modeled dip of the northward located thrust fault differs substantially, by tens of degrees, in the previous studies.

After more than two years after the earthquake it seems we are left with single solutions that point to significant uncertainties in the model parameter estimates and that basically went unaccounted for until now. In our study we head for a more complete picture of the Haiti earthquake. Similarly to the earlier Haiti source studies, we combine measurements of the surface displacement from coseismic interferograms of the ALOS satellite with coseismic GPS data, to which we add pixel offset measurements from TerraSAR-X data. Furthermore, we use seismic data of the GSN network. We join these geodetic and seismic data sets in a non-linear, one-step and fully joint optimization for a simple extended kinematic source model. To do so we balance the different data sets based on empirical data error estimates. In that way the model benefits from the ability of the geodetic observations to resolve the location and lateral extension of the fault and the seismic data possibly help to constrain the dip versus displacement for which there seems to be a trade-off when using the on-shore restricted geodetic data alone. By propagating the data errors to first-order model uncertainties we aim for an added-value Haiti source model and hope to assist the regional hazard assessment.

(we send this abstract to topic 7: "Scientific results related to the Geohazard Supersites initiative")

Main features of the deep structure by earthquake tomography and GPS active tectonics: Case of Rif Mountain (Morocco) and Betic Cordillera (Spain)

Youssef Timoulali

CNRST, Rabat, Morocco
timoulali@cnrst.ma

The Betic–Rif Cordillera is located in the area of interaction between the Eurasian and African plates in the western termination of the Mediterranean Alpine belt. A number of geological and geophysical studies have been carried out to investigate the deep structures and active tectonics in this region. The prior published result of present –day deformation in the Betic-Rif Arc from GPS velocities shows that the convergence between the African and the European plate normally NW-SE, is perturbed in the central part of the Rif Mountain in northern Morocco and in the Central Betic Cordillera of southern Spain. A south-westward motion is recorded in the central part of the Rif with respect to Africa and a west-southwest motion is recorded in south-western part of the Central Betic with respect to Iberia. The present study has two main goals: 1) Use the most actual seismological data from recent earthquakes in Betic–Rif arc for investigated the lithosphere through the application of seismic local tomography techniques. 2) Define the possible structural blocks and explain the GPS velocities perturbation in this region.

With the Spain and Moroccan networks, a large volume of seismic data has been collected and used for investigated the lithosphere in the Betic –Rif Cordillera. The P and S arrival times at 52 stations located at north of Morocco (CNRST, Rabat) and south of Spain (Instituto Geografico National, Madrid) are used for the period between 12/1988 and 12/2008. In this study we use a linearized inversion procedure comprising two steps: 1) finding the minimal 1-D model and simultaneous relocation of hypocenters and 2) determination of local velocity structure.

The resolutions tests results indicate that the calculated images give near true structure for the studied region from 5 to 60 km depth. The resulting tomographic image shows that the presence of two upper crust body (velocity 6.5 km/s) at 3 to 13 km depth between Iberian Betic and Moroccan Rif in the western and in the middle of Alboran Sea also shows the low velocity favouring the presence of melt in the base of these two bodies. The crustal bodies forms tectonic blocks in the Central Rif and Central Betic Cordillera. In the Rif, the crustal body is extended in south western part of the Central Rif, oriented in direction NE-SW and dipping SW. This block is consistent with the GPSs positions that record the south southwest motion in the Rif Mountains. In the Central Betic Cordillera, the crustal body is oriented N-S direction and dipping to the North with west-southwest motion.

The presence of these crustal blocks whose boundaries are well defined by tomography in the Betic-Rif Cordillera, characterized by their own movements recorded by GPS and their interaction with the crustal blocks also defined by tomography in the western part in the Alboran Sea, allows us to define an appropriate geodynamic model for the West Alboran region.

Levy characteristics for the creep velocity distribution of the faults of the Afar region: consequences for the extreme events scaling as function of duration and size.

R. Toussaint, C. Doubre, D. Léobal (IPGS, France)
G. Peltzer (UCLA, USA)
K.T. Tallakstad, K.J. Maloy (Univ. Of Oslo, Norway)
S. Santucci (ENS Lyon, France)

Abstract :

Space and time fluctuations of the slip along faults are often evidenced. We study the statistics of slip distributions measured from continuous measurements using InSAR inversion in the Asal Rift, along normal faults observed during 8 years, with creeping and low seismic activity [1].

Building a spatio-temporal map of the displacement along the fault, we determine a local slip distribution, following a procedure used in previous experiments [2,4,5]. We show that this slip distribution presents some fractal characteristics with long range spatial correlations.

We also show that the local velocity distribution presents a fat tail, implying a velocity slip probability density function with a high velocity asymptotic behavior as $P(v) \sim v^{-1+\alpha}$, with $\alpha \sim 1.5 < 2$, i.e. a distribution with no second moment.

This implies that the Central Limit Theorem fails when the system is considered from an upscaled point of view, and that the average slip velocity, or instantaneous moment distribution measured at different large time and spatial scales, is expected to be non-Gaussian: it is a Levy distribution (or stable distribution) of exponent α [3].

Notably, this allows us to predict the statistics of the extreme events along such faults as function of the scale of observation, with an average slip velocity defined at spatial scale L and time scale T : The maximum observed velocity over windows of size L, T is expected to scale as $v_{\max}(L, T) \sim L^{\gamma} T^{\gamma}$, with $\gamma = 1/\alpha \sim 2/3$.

We also compare these results with the ones obtained on a small scale laboratory system, presenting also both elastic interactions and disorder: Observing the slip velocity of a propagating crack front in experiments carried out in the Physics Dept of Oslo [2,4,5], a similar distribution is observed for the local velocity, and the expected scaling for the extreme events is directly verified.

References:

- [1] Doubre C., and Peltzer G (2007), Fluid-controlled faulting process in the Asal Rift, Djibouti, from 8 yr of radar interferometry observations. *Geology*, 35, 69-72.
- [2] Måløy, K.J., S. Santucci, J. Schmittbuhl and R. Toussaint. Local waiting time fluctuations along a randomly pinned crack front, *Phys. Rev. Lett.*, 96, 045501 (2006).
- [3] Sornette, D., *Critical Phenomena in Natural Sciences* (Springer-Verlag, Berlin Heidelberg, Germany, 2000).
- [4] Tallakstad, K.T., R. Toussaint, S. Santucci and K.J. Måløy, Non Gaussian fluctuations of crack front velocity, *Proc. of the Soft Matter & Complex Flow congress*, Lofoten, Norway, 2012.
- [5] Tallakstad, K.T., R. Toussaint, S. Santucci, J. Schmittbuhl, K.J. Måløy, Local dynamics of a randomly pinned crack front during creep and forced propagation: an experimental study, *Phys. Rev. E*, 83, 046108, 2011.

Automatic analyses of GPS time series for tectonics

Trong Dinh TRAN, Jean-Mathieu NOCQUET

Géoazur, UMR 7329, CNRS, IRD, OCA, University of Nice, France

Daily GPS time series are commonly used to study the crustal deformation. The development of large continuously recording GPS-GNSS networks, including hundreds of sites, makes difficult to carefully look at each individual time series and promotes the need of automatic analysis of large data sets. For instance, offsets and transients signal are found in daily position time series, either due to equipment change or real geophysical processes, leading to possible bias in velocity estimates if not properly identified or handled in the analysis.

In this study we present a set of programs and algorithms that allow fast and robust analysis of daily GPS position time series. The first part of the programs deals with the optimal reference frame definition of the solutions. We use a robust method of expression results in the current ITRF release, using L1 norm to produce daily time series from loosely constrained solutions. The second set of programs is dedicated to the automatic search of the outliers and offsets. The method is based on the variations of rms calculated with respect to the local average position through time to identified windows of anomalous behaviour. Then, differentiation of daily position within the identified time windows allows to perform statistical tests and robustly detect and remove outliers, and offsets.

In this study, we assess the performance and the ability of our approach to correctly handle abnormal problems in the time series using three different large permanent GPS networks in Taiwan, Japan and France. Our results show that the whole of outliers and jumps associated to seismic events are detected. However, the cases of large post-seismic signal and transients still need to be handled manually, although the automatic processing helps the analysis to define periods over which "human" intervention and choice are still required.

GPS velocity field across the Western Altyn Tagh Fault (Tibet), implication on faults mechanics

Philippe Vernant¹, Jiankun He², Jean Chery¹, Weimin Wang², Shuangjiang Lu², Wenfei Kuo³, Wenhai Xia²

1) Laboratoire Geosciences Montpellier, CNRS–Université de Montpellier II, 34095 Montpellier, France

2) Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100058, China

3) Department of Geological Sciences, University of Missouri, Columbia, MO 65211, USA
Corresponding: pvernant@um2.fr

We have established a new survey mode GPS network across the Altyn Tagh Fault in the northern central Tibetan plateau. This network consists of 19 sites between 34° N and 39° N and 85° E and 86° E. From 2009 to 2011, the network has been surveyed for 2 to 3 times. Each site has been surveyed for at least 48 hours with Trimble NetRS receivers and zephyr geodetic antennas. By combining the nearest Continuous GPS sites (KIT3, TASH SELE, POL2, URUM, GUAO, ULAB, IRKT, BJFS, XIAN, KUNM, LHAS, HYDE, IISC), we process the observing data with GAMIT/GLOBK software to obtain the velocity field of the network. From the velocity field, we find that the interseismic strain along the ~400-km length profile is restricted predominately within a very narrow zone with width of about 40-50 km across the Altyn Tagh Fault, thus the crustal blocks on both sides of the fault experience a minimum deformation. We use a screw dislocation model to mimic the velocity field by assuming that the Altyn Tagh Fault is distributed as a simple vertical plane. The preliminary results suggest that for the central segment of the fault at about 86°E, the left-lateral slip rate of the Altyn Tagh Fault is of about 8-9 mm/yr. This is significantly lower than the earlier estimates of the slip rate based on offset of geological markers located 15 km east of the profile, but in agreement with the recently revised geological slip rate of this Altyn Tagh fault segment. Associated with the predicted slip rate, the locking depth of the Altyn Tagh Fault is shallow with a value of about 8-10 km. By correlating with available geodetic results around this large-scale active strike-slip fault, our findings suggest that the slip rate of the Altyn Tagh Fault on its central segment (~500-km long) is quite uniform with a value of about 8-9 mm/yr. The predicted slip-rate pattern, together with the localized strain distribution across the fault and the very shallow locking depth of the fault as revealed by the new GPS network highlights that crustal deformation on north side of the Tibetan plateau could be described as thin rigid blocks divided by active strike-slip fault systems.

Abstract for WEGENER 2012, Strasbourg, France

Session 1. Subduction zones and giant earthquakes

Two successive slow slip events evidenced in 2009-2010 by a dense GPS network in Guerrero, Mexico

**Andrea Walpersdorf¹, Nathalie Cotte¹, Vladimir Kostoglodov², Mathilde Vergnolle^{1,3},
Mathilde Radiguet¹, José Antonio Santiago², and Michel Campillo¹**

¹ *Institut des Sciences de la Terre, Université Joseph Fourier / CNRS UMR5275, Maison des Géosciences, BP 53, 38041 Grenoble Cedex 9, France*

² *Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad Universitaria Del. Coyoacán México D.F. C.P. 04510, Mexico*

³ *now at Géoazur, Université de Nice / CNRS UMR6526, Bât 4, 250 rue Albert Einstein, Les Lucioles 1, Sophia Antipolis, 06560 Valbonne, France*

A large slow slip event (SSE) had been expected for the Guerrero gap for 2010. It was actually observed with an onset in July 2009. Comparison with the preceding large SSEs, which occurred in 2002 and 2006, highlights both persistent characteristics of the Guerrero SSEs (e.g. the localization of slip in the seismogenic part of the subduction interface), and also particularities of the 2009/2010 event (namely two distinct slip patches on the fault interface moving consecutively). The long GPS time series and the density of the GPS network provide evidence that the Guerrero SSEs, like classical earthquakes, have complex features. Despite having very short and relatively regular repeat times (~4 yr), Guerrero SSEs appear aperiodic. A shorter loading time before the 2009/2010 event than before the 2006 SSE seems to produce consistently reduced surface displacements for a group of stations in a core zone.

Towards a global strain map from InSAR and GPS

Tim Wright¹, Matthew Garthwaite¹, Hua Wang², Andy Shepherd¹, Hjung-Sup Jung³, Andy Hooper⁴

¹ University of Leeds, UK

²Guangdong University of Technology, China

³University of Seoul, Korea

⁴Delft University of Technology, Netherlands

By exploiting phase measurements from multiple acquisitions of Synthetic Aperture Radar (SAR) data, interferometric SAR (InSAR) can be used to measure the build up of tectonic strain around locked faults. We have recently presented a new method for combining InSAR results with GPS data to produce regional strain maps [Wang and Wright, GRL 2012]. Here we assess the potential for data from existing and future SAR satellites to produce a global strain map of sufficient accuracy to be useful for seismic hazard assessment.

We first identify a target level of strain using the GPS global strain rate model of Kreemer et al (2003). We find that 90% of earthquake deaths occur in regions straining at rates higher than $1.2 \times 10^{-8} \text{ yr}^{-1}$. Because the accuracy of InSAR measurements is critically dependent on the length scale over which the observations are made, we also define a critical length scale of 100 km, based on the observed distribution of surface deformation around locked faults.

We then review the error budget of individual interferograms; atmospheric noise dominates at length scales of 100 km. We discuss methods for optimum combination of multiple SAR acquisitions to estimate linear deformation rates, and show that methods using connected networks of short-interval interferograms are more accurate than simple stacking. We find that the error on the linear rate is proportional to the (mission length)^{-3/2} and (revisit time)^{1/2}. i.e. to half the error on linear deformation rates, the revisit time must be cut by a factor of four, or the mission duration increased by ~60%. Accuracies of 1.2 mm/yr over 100 km in the satellite line of sight can be achieved with a revisit time of 12 days with a 5 year mission, but to achieve this accuracy with a 3 year mission would require a 3 day repeat.

The ability to measure tectonic strain on particular faults depends critically on the viewing geometry of satellite missions. Conventional SAR missions are poor at resolving surface deformation oriented north-south, since they fly in near polar orbits and have look directions that are near east-west at most latitudes. If we assume coherence can be maintained in all straining areas, Sentinel-1A should be able to resolve tectonic strain for 68% of the surface area straining above our target threshold of $1.2 \times 10^{-8} \text{ yr}^{-1}$ on length scales of 100 km, although this increases to ~80% if ascending and descending data area both acquired. The archive of 7 years of Envisat data should be sufficient to resolve 39% of the area straining above the threshold. The proposed configuration of the shelved DESDYNi mission would be capable of measuring 89% of tectonic strain after 5 years. By contrast, an optimised, dual-beam SAR system, with forward and rear squinted beams, would be capable of resolving all three components of surface deformation with comparable accuracies. We show that 5 years of observations from such a system would be sufficient to resolve strain for 97% of the tectonic zones.

We recommend that (i) Sentinel-1 acquire both ascending and descending data in areas of earthquake hazard, (ii) future SAR mission lengths should be extended for as long as possible, and (iii) dual beam radars are considered as possible a future design.

MONITORING METHODS OF TUNNEL DEFORMATIONS

E. Yavuz¹, F. Köse², N. Ersoy³

¹Yildiz Technical University Vocational School – erolyavuz1962@hotmail.com

²Yildiz Technical University Vocational School – fahriyekose@windowslive.com

³Yildiz Technical University Civil Engineering Faculty – ersoy@yildiz.edu.tr

ABSTRACT

We can monitor tunnel deformations using geodetic or geotechnical methods. We can get absolute coordinates of the target locations in time using geodetic measurements. Relative displacements of the target locations with respect to an initial condition can be usually determined by using geotechnical measurements. We can get also absolute coordinates of the target locations in time, if the initial positions of the targets are determined using geodetic measurements. We can record, process and evaluate deformation measurements in real time using digital recording and telecommunication systems, depending on tunnel excavation method. We can also record deformation measurements manually and process them later in batch mode.

We can usually perform following measurements during deformation monitoring in tunnelling:

- 1. Measurements of tunnel wall convergence:** Tunnel wall convergence (closure) between reference points bolted on the tunnel walls is usually measured with standard metal tape extensometers.
- 2. Deformations at ground surface, including settlements and tilts of surface structures:** These measurements are performed with geotechnical instruments including single- or multi-point borehole rod extensometers, magnetic extensometers, sliding micrometers, inclinometers, probe deflectometers and deep settlement plates. These instruments can be installed either from the ground surface before the tunnel face reaches the area of the instrument or from inside the tunnel.
- 1. Deformations in the ground, around the tunnel or deep below the ground surface:** These measurements are performed using surveying instruments such as precise geodetic leveling and geodetic monitoring using total stations, or using geotechnical instruments like electronic liquid level gauges, electrolytic tilt sensors (electro-levels) surface clinometers/tiltmeters, precise taping, and crack-meters.

IMMERSED TUBE TUNNELS AND SURVEY WORKS

E. Yavuz¹, F. Köse²

¹Yildiz Technical University Vocational School – erolyavuz1962@hotmail.com

²Yildiz Technical University Vocational School – fahriyekose@windowslive.com

ABSTRACT

An immersed tunnel consists of several prefabricated steel shell or concrete tubes. These tubes are constructed on land. They are floated and moved to the immersion site. They are installed one by one. They are lowered and connected to one another underwater. Then, the water is pumped out and the segments are covered with the backfill materials. An immersed tunnel is generally installed in a trench that has been dredged previously in the bottom of a waterway between structures constructed in the dry. All spaces between the trench bottom and the soffit of the tunnel can be a previously prepared gravelbed, or sandbedding pumped or jetted underneath the tunnel. Piled foundations are sometimes used, where soil conditions require them. As construction proceeds, the tunnel is backfilled. The completed tunnel is usually covered with a protective layer over the roof.

Survey works requires high precision in every construction project such as dam, bridge, tunnel etc. There are some steps for the controlling of immersed tube tunnels. These control steps start from land and go on under the sea. Horizontal and vertical control of tunnels are performed by using geodetic control points. Survey works should be performed precisely such a project.

Key words : Tunnel, Immersed Tube, Immersed Tube Tunnels, Geodetic Control

Constraints on the Centroid Moment Tensors from Radial Modes

Eliška Zábranová ^{1,*}, Ctirad Matyska ¹, Ladislav Hanyk ¹, Vojtech Pálinský ²

¹ : Department of Geophysics, Charles University in Prague, Czech Republic

² : Research Institute of Geodesy, Topography and Cartography, Czech Republic

* : Corresponding autor: eliskazabranova@centrum.cz

The 2010 Maule (Chile), 2011 Tohoku (Japan) and 2012 Sumatra earthquakes are the best instrumentally recorded in history of seismology; all of them generated strong free-oscillations. We have used superconducting gravimeter data available within the framework of the Global Geodynamic Project to study constraints on centroid moment tensor of these events. The surface acceleration caused by the radial modes depends on the only one component of the moment tensor M_{rr} and on the centroid depth. For the Maule and Tohoku events determination of M_{rr} values is straightforward from the $0S0$ mode, whereas the analysis of the 2012 Sumatra earthquake is complicated by presence of the strong second event. Moreover, the $1S0$ -mode and $2S0$ -mode amplitudes are more sensitive to centroid depth. The quality factor Q is a key parameter, and its value can substantially influence the results. Therefore, re-evaluation of the modal quality factors is needed.

Time Series Cycle Effect on the Homogeneity and Accuracy of the Egyptian Permanent GPS Network (EPGN)

Khaled Zahran ⁽¹⁾, Nadia Abou-Aly⁽¹⁾, Mohamed Saleh ^(1,2), and Abd el-Monem Sayed Mohamed ⁽¹⁾.

⁽¹⁾ National Research Institute of Astronomy and Geophysics, Helwan, Egypt.

⁽²⁾ TU Darmstadt, Institute of Physical Geodesy, Darmstadt, Germany.

Continuous positions determination using permanent GPS station has been increased on the last few years due its wide applications on the field of geodesy and geodynamics. However, each individual station is affected by specific effects based on its own location. These effects can be due to its local environmental or tectonic effect of the station. On the other hand, inaccurate corrections of time dependent phenomena's, such as body, ocean and atmospheric tides strongly affect the accuracy of the station. Finally, each site selection of the station has its own level of noise. Therefore, removing cycle signals from permanent GPS station increase its accuracy and enable linking different stations together for different objectives. Four different continuous GPS data of the Egyptian Permanent GPS Network (EPGN) were used. Selection of the station has been taken such that every station has its own local environmental and tectonic settings. Positions for EPGN were obtained using the "Precise Point Positioning" (PPP) mode of Bernese V. 5 software. Cycles of different periods have been computed from the position time series of the individual station.

Residual after removing computed cycle signals show higher accuracy of the position determination and more homogeneity when linked with other stations. The cycle signals itself give valuable information's about local environmental and tectonic signals of each station and the elastic parameters of the tidal corrections.

Fourteen years of GPS and gravity measurements in and around Bologna, Italy

S. Zerbini*, M. Errico*, R. Falk, E. Santi*, H. Wziontek**, G. Cappello***

***Dept. of Physics, University of Bologna, Italy**

**** BKG, Frankfurt am Main, Germany**

During 1996 a project, lead by the Department of Physics of the University of Bologna (Unibo), was designed and initiated with the aim to monitor ground deformation and signals related to global/regional processes and local environmental effects. At Medicina, near Bologna, two continuously recording instruments were installed: a GPS station by Unibo and a superconducting gravimeter by the Bundesamt fuer Kartographie und Geodaesie (BKG, Germany). Both instruments are acquiring data since then, thus giving rise to likely the most longevous time series of this type of co-located instruments. Absolute gravity observations (AG) were regularly acquired by BKG and, more recently, also by the Italian Space Agency (ASI). In Bologna, since 1999, Unibo runs a permanent GPS and AG measurements performed by BKG and ASI are also available. A third Unibo GPS station operational since 2003 is located in Loiano, on the Apennines, about 30 km from Bologna. In this site, AG measurements are carried out by ASI. At these three sites, we compare long and short-period signals present in the height and gravity data that are also compared with signals appearing in the time series of the local/regional hydrology. Possible footprints of the sequence of earthquakes which started on May 20, 2012, in the surroundings of Bologna are being investigated both in the GPS coordinates and the gravity time series.