13. The Geophysical Institute (GPI) today

Ellen Gottschämmer, Thomas Bohlen, Thomas Forbriger, Petra Knopf, Joachim Ritter, and Friedemann Wenzel

13.1 The Geophysical Institute today and its role within the KIT

Whereas the inception and buildup of the GPI took place within the framework of the Universität Karlsruhe (TH), the modern GPI is part of the Karlsruhe Institute of Technology (KIT, www.kit.edu). On October 01, 2009, the Karlsruhe Institute of Technology was founded by a merger of Forschungszentrum Karlsruhe GmbH and Universität Karlsruhe (TH). KIT bundles the missions of both precursory institutions: a university of the state of Baden-Württemberg with teaching and research tasks and a large-scale research institution of the Helmholtz Association conducting program-oriented provident research on behalf of the Federal Republic of Germany. Within these missions, KIT is operating along the three strategic fields of action of research, teaching, and innovation.

Since January 2014 the institutes at KIT are grouped into five disciplinary divisions, and GPI belongs to KIT division V *Physics and Mathematics* (Bereich V). GPI also belongs to the KIT Department of Physics (KIT-Fakultät für Physik) that organizes teaching and academic affairs and that is attached to division V *Physics and Mathematics*. The GPI strengthens the mission of the KIT especially in the fields of research and teaching, providing the base for innovations in geophysical measurement technology and methodologies to process and interpret huge –often incomplete – geoscientific datasets in contexts such as Earth's internal structure or earthquake disaster mitigation.

Interdisciplinary KIT research is also organized in centers. The KIT Energy Center and KIT Climate and Environment Center are supported with GPI contributions. The KIT process leads to many new partnerships with institutions at Campus South (CS, the former university) and North (CN, the former Helmholtz research center). In addition to the close connection to the Institute of Applied Geosciences in both, research (Earth's structure, geothermal resources, ...) and teaching, we cooperate with the Institute of Meteorology and Climate Research (CN and CS), the Center for Disaster Management and Risk Reduction Technology (CEDIM) including the Institute for Nuclear Energy Technologies, the Institute for Technology Assessment and Systems Analysis, the Institute for Nuclear Waste Disposal, and others.

13.2 Current Research at GPI

We focus on the theoretical challenges of seismology, computer-intensive modeling, and inversions of geophysical observations, as well as on experimental seismology. Our objectives are the development and improvement of exploration methods for hydrocarbons and other underground resources, the development of seismology-supported reservoir management methods, extending the knowledge on the formation, dynamics, and structure of the solid Earth, and the quantification, forecasting, and early warning of natural disasters in a geological/geophysical context.

13.2.1 Applied Geophysics

The members of the research field Applied Geophysics investigate and develop seismic imaging techniques and their application to different spatial scales. Topics include borehole and tunnel exploration and imaging, environmental and engineering geophysics (ground and groundwater related), and hydrocarbon exploration. Currently, the working group is focusing its efforts on the massive-parallelized simulation and inversion of full elastic wavefields for reflection seismic imaging and near surface seismic characterization using shallow seismic surface waves. Scientific work related to these topics is conducted as part of industry cooperations, national and international research programs, and the Wave Inversion Technology consortium (WIT). The developed scientific software for seismic wave simulation and full waveform inversion is distributed under the GPL-licence on www.opentoast.de.

13.2.2 Natural Hazards and Risks

GPI is part of the KIT Center Climate and Environment, and the Helmholtz program ATMO. The Center for Disaster Management and Risk Reduction Technology (CEDIM, www.cedim.de) is the KIT structure within which hazards and risks and their mitigation are addressed. The GPI works on seismic hazard assessment, seismic risk and loss estimations, development of models for shelter needs, and socio-economic vulnerability and resilience on global scale. For earthquakes in particular, we are developing deterministic and probabilistic risk analyses as well as methods to analyze and estimate associated damages and other risks from buildings and infrastructural facilities. In addition we study earthquakes induced or triggered by mining activities, geothermal energy production, CO_2 sequestration, and other processes and safety conditions of waste disposals.

Financial support is provided by KIT-funding, FP6- and FP7- European Union programs, the Geotechnology Program of the Ministry of Education and Sciences, the Deutsche Forschungsgemeinschaft (DFG) and funds of the Global Earthquake Models. We cooperate with firms in the insurance sectors and are part of the Willis Research Network.

Research Topics and Projects

Earthquake Risk and Early Warning

- Seismic Hazard and Risk for Spatially Distributed Systems (DFG)
- 3D Effects of Seismic Ground Motion in the Taipei Basin and Implications for Hazard and Risk (DFG)
- Earthquake Disaster Information System for the Marmara-Region (EDIM)
- Early Warning System for Transport Lines (EWS-Transport)
- Seismic Early Warning (FP-6: SAFER; FP-7: REAKT)

Vulnerability and Damage

- ATMO Helmholtz Programs
- REAKT (www.reaktproject.eu) aims at earthquake early warning
- MATRIX (www.matrix.gpi.kit.edu/) on multi hazard and risk assessment
- NERA (www.nera-eu.org/) earthquake hazard & risk assessment
- SYNER-G (www.vce.at/SYNER-G/) on lifeline vulnerability
- Global Earthquake Model Private Public Partnership (www.globalquakemodel.org/)
- WBI Natural Disaster Management Learning Program
- Earthquakes and Megacities Initiative (EMI)
- CATDAT - Damaging Natural Disaster Databases (Earthquakes, Floods, Volcanoes)

13.2.3 Seismology

The research field *Seismology* is engaged with measuring, analyzing and modeling of seismic wave fields as well as instructing students who are actively included in the research projects. There are two major research facilities: The KArlsruheBroadBand Array (KABBA) and the Black Forest Observatory (BFO). KABBA consists of 42 broadband recording stations which can be installed world-wide for seismological experiments (see Ritter, this volume). The BFO is situated in an old mine where there are stable and perfect conditions to observe extremely low-amplitude signals, especially in the very low frequency band of a few millihertz (see below and Zürn, this volume).

Currently the main research focus is experimental seismology using KABBA (Fig. 13-1). These mobile recording stations measure precisely the ground motion from near-field shaking to tiny teleseismic waves (nanometer scale). KABBA was deployed within four major field experiments in Romania, the Upper Rhine Graben, Scandinavia and California. In addition, other research projects were conducted mainly in connection with seismic noise studies and induced seismicity. KABBA data are stored in the KABBA data center where they can be downloaded for internal work as well as externally. The other foci of the research field *Seismology* are the improvement of seismic instruments, the determination of the structure of the Earth’s crust and mantle, the understanding of seismic noise and the analysis of microseismicity, partly embedded in international collaborations.

Seismology at KIT-GPI is widely linked within KIT and contributes to the KIT Center Energy and the KIT Center Climate and Environment. Examples of recent joint projects conducted in co-operation with other KIT institutes include:

- Determination of seismic site effects in Bucharest together with the Institute for Rock and Soil Mechanics and the Institute for Applied Geosciences,
- Study of the relationship between seismic noise and meteorological phenomena with the Institute for Meteorology and Climate Research,
- Study of deformations in the Upper Rhine Graben with the Geodetic Institute, the Institute for Rock and Soil Mechanics and the Institute for Applied Geosciences,
- Investigations of fault frictional properties via the relationship between microseismicity and tremor source parameters at the San Andreas Fault in Cholame, California (KIT Young Investigator Group Project).

In an international context the seismological research is integrated in initiatives such as the ESF program TOPO-EUROPE or the European Seismological Commission. Examples for international seismological experiments are

- URS (URban Seismology) experiment: the seismic wavefield in the city of Bucharest was studied for the analysis of lithospheric structure, site effects for earthquake waves as well as seismic noise characterization. This project was a collaboration with the National Institute for Earth Physics in Bucharest.
- MAGNUS (MAntleinvestiGations of Norwegian Uplift Structures): the goal was to explore the deep structure of the Scandinavian Mountains and to understand the current forces which sustain the high topography. This project was a collaboration with the universities of Aarhus, Copenhagen and Oslo as well as NORSAR. Follow-up research is in planning.
- PERMIT (Parkfield Experiment to Record MIcroseismicity and Tremor): for a better understanding of earthquake rupture processes, tremor was measured at the San Andreas Fault near Parkfield and Cholame, California in a collaboration with the University of California, Riverside.

Bachelor, master and PhD students are instructed in various seismological techniques such as seismic wave analysis, seismic instruments, data processing, array seismology and seismic tomography (Fig. 13-2). Field excursions demonstrate geoscientific themes such as tectonic structures, Earth materials and monitoring systems.

Fig. 13-1: Calibration test with the KABBA instruments in the basement of KIT-GPI. The mobile recording units measured coincidently for two months in order to detect possible instrument malfunctions and to compare the instrument response functions**.**

Fig. 13-2: Instructing students in the installation of a seismological station in the field.

The success of the teaching efforts is reflected in student prizes as well as excellent evaluation of the courses by the students. Students are involved as student research assistants in ongoing projects by conducting field work and analysing high-quality KABBA and BFO data sets for their thesis work.

13.2.4 Black Forest Observatory

The Black Forest Observatory (BFO) is a joint research facility of the Karlsruhe Institute of Technology (KIT) and the University of Stuttgart. Since 1971 it is operated in cooperation of the geophysical and geodetic institutes of both universities. BFO is manned with two scientists and one technician. Main activities of the observatory fall into four categories, which are 1) observation and publication of a continuously recorded multi-parameter geodynamic data set, 2) research, 3) hosting of guest-experiments, and 4) teaching.

The location of the observatory (48.3301 °N, 8.3295 °E) in the middle of the Black Forest was carefully selected at large distances to potential anthropogenic sources of noise. The instruments are deployed in a former silver mine in competent granite rock at a depth of up to 170 m below the surface and at up to 700 m distance from the entrance of the mine. This provides a thermally very stable environment. Two air-locks provide additional protection against air-pressure variations and ensure thermal stability. Because of these favorable conditions and the excellent high precision instruments operated at BFO the observatory is internationally well known as one of the most sensitive sites for long period observations, providing international standards for the scientific community, e.g. for recordings of Earth's free oscillations.

The Black Forest Observatory operates broad-band seismometers (STS-1 and STS-2), gravimeters (superconducting gravimeter SG056, LaCoste Romberg earth-tide gravimeter ET-19), tiltmeters (Askania borehole tiltmeter, Horsfall fluid tiltmeter), three invar-wire strainmeters, magnetometers (GSM-90 Overhauser magnetometer, three Rasmussen fluxgate magnetometers) and a permanent GPS-station. These are supplemented by regularly repeated magnetic base-line measurements and observations of absolute gravity as well as the recording of several environmental observables (air-pressure, humidity, wind speed, precipitation, temperature). Some of the latter are used to correct geodynamic recordings for remaining disturbances. The data are published in near-real-time through international data centers (IRIS DMC at Seattle, SZO at the BGR in Hannover, Intermagnet in Edinburgh, GNSS data center at the BKG in Frankfurt, GGP-ISDC at the GFZ in Potsdam). The recordings are used by many research groups around the globe. Data is made available free of charge to scientific projects as well as to the general public.

The detection of the toroidal background free oscillations of the Earth with BFO data received international attention (Kurrle and Widmer-Schnidrig, 2008). Other prominent examples of research at BFO are the detection of Coriolis coupling of toroidal modes (Zürn et al. 2000), the first unambiguous detection of the fundamental toroidal mode (Widmer et al., 1992), and the until then unnoticed coupling between atmosphere and spheroidal modes of the Earth after large volcanic eruptions (Zürn and Widmer, 1996). BFO research also contributed to the understanding of potential sources of noise and the improvement of observation methods (e.g.: Zürn and Widmer, 1995; Zürn and Wielandt, 2007; Zürn et al., 2007; Forbriger, 2007). References are listed in chapter 11 of this issue (Zürn, Listening to the Earth – the Schiltach Observatory).

The well-known outstanding data quality of the observatory along with its high-quality instruments operating since several decades, makes BFO an attractive place for testing new instruments. Thus, the observatory is a much valued host for guest experiments. Recently seismic sensors newly designed for international space missions (SELENE2 to the Moon, In-Sight to Mars) were evaluated at BFO. Since 2010 an iSTS-1 seismometer with optical interferometric pick-up, designed at IGPP (Scripps, UCSD) is operated as a prototype installation in the BFO vault. Also commercial manufacturers of high-quality instruments (like Streckeisen, Nanometrics, or GWR) have accepted the challenge. These are only a few examples.

Besides being involved in scientific projects beyond BFO at the institutes of both universities, for BFO researchers teaching is a serious task as well. In particular the Master's program at KIT benefits from the scientific expertise made available through the observatory in courses on seismic instruments. Students have the option to gain experimental skills during the BFO-Winterschool. Periodically offered trips to the observatory allow a first contact with observatory seismology to undergraduates.

13.3 Teaching

Following the Bologna declaration, the Geophysics diploma degree course at the GPI was replaced by a Bachelor’s degree course, starting in winter semester 2008/09, and a Master’s degree course, starting in 2011/2012. Both courses are lively demanded, with more than 100 students enrolled in Geophysics at the moment. While the Bachelor’s degree course is implemented for several years and well established by now, the first Master students finished their studies just last year, i.e. in 2013. Furthermore, there are still a few diploma students who are expected to complete their studies in the very near future. At GPI, teaching has a high significance, which is reflected in several teaching awards received by members of the GPI within the last years.

Fig. 13-3: GPI students at the building site of the Gotthard base tunnel, Switzerland, December 2010 (photograph by Niklas Thiel).

Fig. 13-4: GPI students at the KTB drilling site (German deep continental drilling site), July 2012 (photograph by Ellen Gottschämmer).

13.3.1 Bachelor's degree course

As the former diploma degree course, the current Karlsruhe Bachelor's degree course, is characterized by a strong focus on Physics and Mathematics, especially during the first semesters. The students attend courses in Classical Experimental Physics, Classical Theoretical Physics, and Higher Mathematics together with the students of Physics, followed by a course in Modern Experimental Physics and the Classical Physics Laboratory Course. Additionally, students get a broad education in Geophysics with Geophysical Laboratory and Field Courses, courses in Experimental Geophysics, and Computing in Geophysics. Students have to complete internship, carried out in a Geophysics company or organization for the duration of approx. six weeks. Geology is taught in several courses including Field Geology. Further practical experience can be gained in Exercises on Geology and during a Geodetic Surveying Course. Specialization is obtained by the choice of several Electives individually picked from courses in Geosciences and other subjects. The Bachelor degree program is accomplished by working on a first scientific project, the Bachelor thesis.

The emphasis on Physics and Mathematics is rather a specialty than the standard in many Geophysics degree courses today. Only six universities in Germany at all offer a Bachelor degree in Geophysics with focus on Physics and Mathematics, while at other universities the Geophysics degree course has been substituted by a more general Geosciences degree with the possibility to specialize in Geophysics, either during an advanced phase of the degree course, or when taking a Master degree afterwards. At GPI in Karlsruhe however, we offer both, a fundamental qualification in Geophysics including a sound education in Physics, Mathematics and Geosciences, as well as an advanced Geophysics program for those who want to specialize further in our research topics, during the Master's degree course.

13.3.2 Master's degree course

The Master's program at KIT usually takes two years. In the first year, the students take courses in order to specialize in advanced geophysical subjects, all closely related to our research areas, such as Theory of Seismic Waves, Seismological Signal Processing, Array Processing, Seismic Imaging, Physics of Seismic Instruments, Inversion, Tomography, and Engineering Geophysics. The second year of the Master degree course is entirely dedicated to the preparation of the Master thesis. The thesis work is closely tied to the ongoing research at GPI. The Master program is attractive also to students from other universities and other disciplines as demonstrated by the enrollment of such students. The different background and qualification of these students is considered as challenge but also enrichment for both, teaching and learning.

13.3.3 Geophysics for other degree courses

Lectures given by members of GPI are also attended by students from other degree courses. Within the Department of Physics, Geophysics is established as an Elective within the curriculum of the Bachelor's degree program in Physics and Geophysics can be chosen as a secondary subject in the Master's degree program in Physics. However, traditionally the major part of external students comes from the Department of Civil Engineering, Geo- and Environmental Sciences, studying Applied Geosciences. Those students attend the course Introduction to Geophysics 1, and take part in both, the Geophysical Laboratory and Field courses. Due to the highly increased demand over the last years, recently a new Geophysical Field course was established, especially developed for students from the Department of Civil Engineering, Geo- and Environmental Sciences.

Apart from those courses, which are part of the curriculum of the degree course Applied Geosciences, several students attend our lectures as a facultative subject, especially courses in the context of natural hazards, e.g. Introduction to Volcanology or Geological Hazards and Risks. The latter one is also part of the curriculum of GRACE, the KIT Graduate School for Climate and Environment, as well as part of the immersion program of the Bachelor's degree courses Economics Engineering and Industrial Engineering and Management within the Department of Economics and Management.

13.3.4 Development of number of geophysics students at GPI

Both, the Geophysics Bachelor's and the Master's degree courses are lively demanded and working to capacity. The number of Geophysics students in Karlsruhe continuously

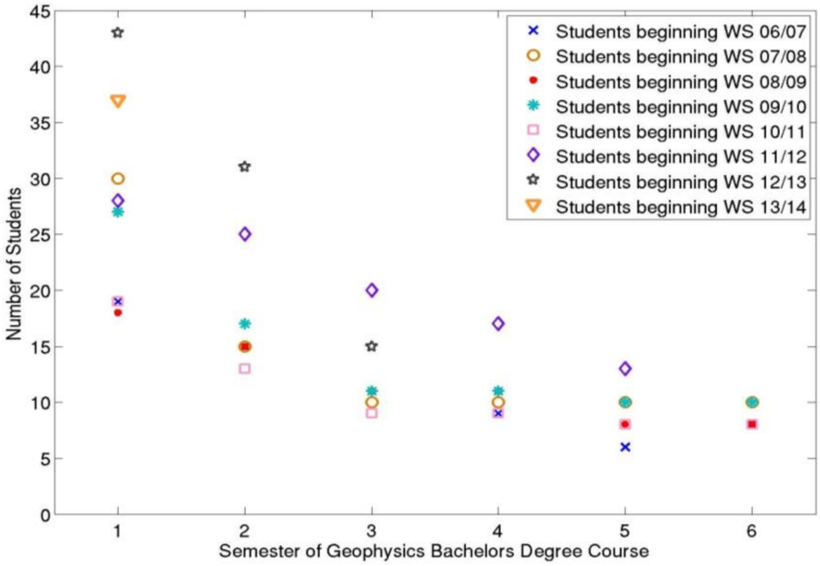

Fig. 13-5: Number of Geophysics Bachelor students over the past eight winter semesters (WS).

increased over the last years (Fig. 13-5), and exceeded 100 students every semester since winter semester 2012/13. Most of those students were enrolled in the Bachelor's degree course, but since the transfer quote to the Master's program is almost 100%, and additional Master's students come from other German and foreign universities (Fig. 13-6), the number of students enrolled in our Master's program is expected to increase within the next years.

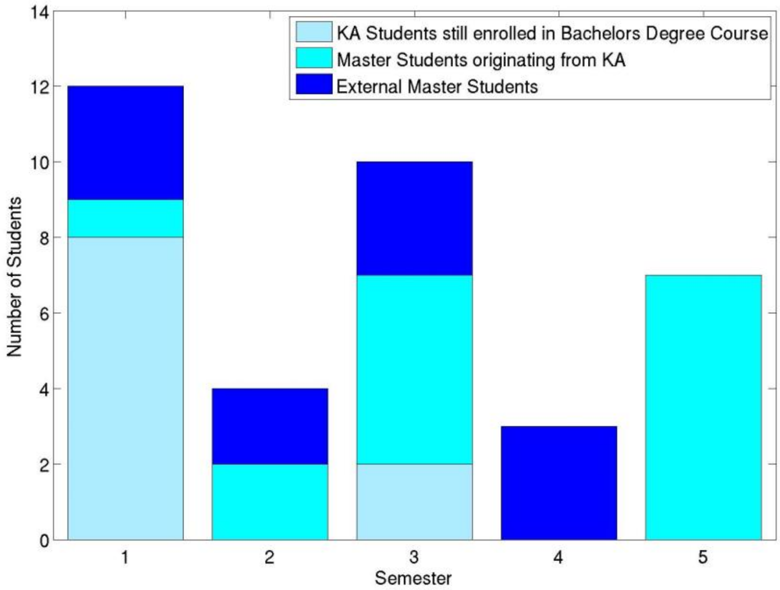

Fig. 13-6: Current number of students in the Geophysics Master course including their background (KA – students which were or still are enrolled as bachelors in Karlsruhe).

13.3.5 New teaching methods and courses

Training for the trainers – the teaching staff of GPI regularly takes part in KIT in-house education and attends courses in several aspects of didactics offered by KIT. This effort has already paid off: The students' evaluation of courses and lectures gave many excellent results within the last years, with a particular success of the courses Geodynamics, Physics of Seismic Instruments, Array Processing, Introduction to Experimental Geophysics, Exercise on Simulation of Seismic Waves, and the Exercise on Hazard and Risk Assessment of Mediterranean Volcanoes, which all received the top grade 1.0. The Exercises on Computing in Geophysics and Introduction to Geophysics have repeatedly been voted for the best tutorial of the Department of Physics.

The Teaching Award of the Department of Physics was granted twice to members of GPI within the last years. In 2010, Thomas Forbriger was granted this award, and Ellen Gottschämmer received the Teaching Award in 2012. The awards were presented during the Annual Academic Celebration events of KIT. The awards and their prize money were the basis for the development of new courses for GPI students. Thomas Forbriger introduced and established a Winterschool, held at the Black Forest Observatory (BFO) for three days every year, to give an opportunity to his students to intensively discuss and learn about the physics of seismic instruments, and to apply what was taught during the classroom lecture.

Furthermore, geophysical excursions are funded by the prize money of the Teaching Award. Excursions play an important role in the electives of our curricula. Since spring 2010 the GPI offers at least one field excursion per semester, organized by Ellen Gottschämmer. These field excursions are meant to show our students work environments where geophysicists are active and offer great insight into different aspects of geophysics. In 2010 two excursions were held, one to the construction site of the Gotthard base tunnel (Fig. 13-3), and one to a geothermal power plant and historical oil fields in France. In July 2011 the field excursion led to the volcanic fields of Eifel mountains and in November 2011 we visited the

Landeserdbebendienst Freiburg (state earthquake survey), and combined this field trip with a visit of an abandoned mine on the Schauinsland mountain in the southern Black Forest. In summer 2012 we conducted a field excursion to the site of the continental deep drilling program KTB at Windischeschenbach (Fig. 13-4), and another one to the construction site of the Karlsruhe “Kombilösung”, a major tunnel project in the city of Karlsruhe.

Fig. 13-7: GPI students at the obsidian flow, Rocce Rosse, Lipari Island, August 2013 (photograph by Martin Pontius).

Fig. 13-8: GPI students close to sulfur fumaroles on Gran Cratere, Vulcano Island, August 2013 (photograph by Johannes Käufl).

Several excursions were led to BFO, one of the excursions especially planned for the students in the first year of the Bachelor's program. In conclusion these excursions, especially for young students, are important for both, motivation, and a better understanding of the topics taught in Physics and Geophysics courses.

A particular course was realized in August and September 2013, when Joachim Ritter and Ellen Gottschämmer led a nine-day field trip to Italian volcanoes (Figs. 13-7 to 13-10). The special emphasis of this course was natural hazard and risk of Stromboli, Lipari, Vulcano and Vesuvius volcanoes. Lectures and exercises were performed in situ, in order to connect scientific content to immediate experience. In November 2013, a field excursion was organized to Staufen, where rapid and damaging uplift occurs following a drilling accident, and to the Mont-Terri rock laboratory in Switzerland.

Fig. 13-9: Crater terrace of Stromboli as seen from Pizzosopra la fossa during the visit of GPI, Stromboli Island, September 2013 (photograph by Martin Pontius).

13.4 Technical infrastructure, computer equipment

The electronics workshop of the GPI runs the maintenance of the scientific instruments and cars of the institute. Engineer Werner Scherer, the head of the workshop, is assisted by the technician Hartmut Thomas. They take care of the wide range of geophysical instruments which are used in the laboratory and field exercises during the student courses. There is equipment for geoelectric, geomagnetic and shallow seismic measurements and the data recording. Werner Scherer and Hartmut Thomas also take care of the seismological KABBA instrumentation including in-house development of instruments. They assist the field experiments as well as instruct scientists and students on the use of the delicate equipment.

At the GPI engineer Petra Knopf and Thomas Nadolny operate about 80 high-end desktop workstations for scientific use. All computers have access to our central storage servers which hold about 20 Tbyte of data. All machines are managed within a 1-Gbit-Network and are backed up at the Steinbuch Centre for Computing (SCC) of KIT. With a 10-

GBit network connection to the SCC at KIT Campus North we are able to stream and store huge amounts of data into so-called 'Large Scale Data Facilities' which guarantee long-term and safe data storage.

We also operate several compute and storage servers for special purposes (e.g. real-time data acquisition). A specially configurated network allows real-time data streaming from a seismic monitoring network (KABBA) by means of cell phone communication and internet

In summer 2012 GPI renewed the equipment in our PC pool. There are now 12 high-end workstations, each with I7-8 core CPUs and 16 GB main memory operated by OpenSuse, available for students doing computer exercises, training, programming etc. We are able to use these pool computer, as well as our desktop machines, to run parallel programs in a clustered environment.

The access to several HPC-Systems is required to solve larger numerical problems (e.g. seismic wave propagation for full waveform inversion by massively parallel FD-simulations), which consumes large data storage as well as computation resources. At KIT/SCC we have access to: HC3-System, a HP XC3000 parallel computing facility, IC2-System: 'Institutscluster II', a large cluster system which is partly financed by the GPI. We also run projects on the computer cluster of 'bwGRID', the 'JUROPA'-cluster at Jülich Supercomputing Centre and at the 'HERMIT'-cluster from HLRS Stuttgart. All these computing facilities are the basis for successful student training and research.

Fig. 13-10: GPI students on Vesuvius, September 2013 (photograph by Joachim Ritter).