Exploring Georisks – Securing Georesources

Research Perspectives for Solid Earth System Research During Next Decade

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1 Introduction

Describing and understanding nature has been one of the fundamental goals of geoscientific research over the last centuries. Several research directions stretching from upper atmosphere physics and planetology, oceanography and physics of the solid earth all the way to mineral physics and properties of earth materials were established to advance geosciences. During the last centuries each of these disciplines developed into a research section of its own with very specific techniques and goals and the advance in each field was tremendous. With the worlds population steadily increasing the human impact on our environment becomes more and more obvious and over the last two decades geosciences are challenged to predict future environmental developments or even develop models to manage it including recommendations to political decision makers. This marks a major transition requiring a major effort in the development of interdisciplinary research programs as geoscientists are required not only to address topics of current interest but also to provide a framework to address complex future issues. This requires fundamental basic sciences that is guided by a long term vision.

1.1 History of the Institute of Geophysics in Hamburg

The Institute of Geophysics (IfG) was founded in 1964 as Institute of the Physics of the Earth. At that time the specialities meteorology, oceanography and physics of the solid Earth were all united in the Institute of the Physics of the Earth. Although now formally being separate institutions there are still strong ties between the different disciplines due to the physical nature of problems that we deal with and owing to the organisational link through the “Zentrum für Meeres- und Klimaforschung” (ZMK). The strong links are also expressed by the common first 2 years of any of these majors as well as in common colloquia and seminars. The seismological observatory in Hamburg Harburg (founded in 1898) is part of the Institute of Geophysics. The IFG also operates the seismological station Bad Segeberg, which is part of the regional seismological network of Germany.

In the mid 80ties the Institute of Geophysics actively participated in the foundation of the ZMK, which was formally inaugurated in 1989 by the Meteorologisches Institut, Institut für Meereskunde, Institut für Biogeochemie und Meereschemie, Institut für Hydrobiologie und Fischereiwissenschaft, der Forschungstelle ”Sustainability and Global change” and the Institute of Geophysics. One of the main goals of the ZMK is fostering interdisciplinary research in the area of atmospheric and ocean sciences. The contributions of the Institute of Geophysics provide the link between processes in the solid earth and their interaction and exchange with the oceans and atmosphere. The IfG was also involved in the foundation of the ”Zentrum für Marine und Atmosphärische Wissenschaften” (ZMAW) that hosts the institutions of the ZMK as well as the Max Plank Institue of Meteorology and parts of the GKSS in Geesthacht. The ZMK as well as the ZMAW reflect the aforementioned change in research strategies towards research programs.

During the 90ties and the beginning of the new century the Institute of Geophysics was exposed to severe cuts in personal due to the general financial downsizing of academic institutions. The loss of 50% of the professor positions as well as technicians and scientific employees resulted in obvious cuts in research as well as teaching capacities. At the same time the institute was exposed to a complete reorganisation of its scientific staff owing to retirements. In the late 90s the Institute appointed a scientific employee in the field of applied marine seismics, and in 2000 a C3 position in marine seismology was filled. The vacant C4 position of marine geophysics and geophysical volcanology was appointed in 2003. Currently the institute holds 3 professorships and 3 permanent research positions. In addition there are 4 technical support positions and a PhD position. On average there are 10-15 scientist at the Ph.D or PostDoc level employed by the department through external grants.

1.2 Institute expertise and past research profile

At least for the last two decades the research profile of the IfG was dominated by research projects in the area of marine and applied geophysics. In case of marine geophysics methodical studies, regional case studies, basic sciences, and instrument development were carried out to address questions like the origin of the ocean floor. The institute earned a reputation in the development of ocean bottom seismometers and ocean bottom sources. Furthermore it is the only University institute that holds a marine gravimeter. The mediteranean area was and still is one of the regional targets of the institute. Onshore and offshore wide angle seimics surveys, gravity and magnetic measurements and a few reflection seismic surveys were carried out to investigate the crustal structure and to foster new insight into the geodynamics of the Earth. In recent years the institute has developed a strong research program in seismology with emphasis on moment tensor solutions, propagation of cracks and the release of seismic energy.

The institute has a long lasting tradition in the development of techniques for the most accurate and efficient target-oriented modelling and imaging using seismic and acoustic methods. Strong ties to the energy industry were acquired and lead to the participation in the "Wave Inversion Technology" consortium (www.wit-consortium.de) in 1997. The consortium is still running and is supported by several international oil producing companies. The institute has a strong commitment in the support of young scientists. In recent years two PhD students of the institute received international awards.

2 Long research perspectives in physics and chemistry of the Earth's interior

Physical, chemical as well as biological processes control most if not all of the dynamic processes inside the solid Earth. Through exchanging energy, matter and momentum they interact with the oceans and the atmosphere in many ways resulting in an Earth system of high complexity. Studying the interior of the Earth has traditionally been a subject of geophysical, mineralogical, chemical and petrological studies, whereas the oceans and the atmosphere are studied by meteorologist, biologist, and oceanographers. This demonstrates that Earth system research is a truly interdisciplinary subject.

The long term goals in solid Earth systems research that appear to be relevant for the future research of the IfG are in the area of

- improving our understanding of natural hazards,
- improving methods to locate natural resources,
- understanding the role of water in the earth system,
- transfer of matter and momentum between the geosphere, hydrosphere, and atmosphere, and
- development of complex coupled Earth system models which allow reliable predictions of future developments in order to support political decisions.

The importance of water in the Earth system is manyfold: a) it controls the properties of material in the Earth interior and thereby seismic and volcanic activity, and b) it is probably the most important liquid to mankind. Understanding water cycles, its storage, and proper management will be a challenging task.

The impact of natural disasters on society becomes increasingly important as more and more people, especially in developing countries are affected. Moreover, regional catastrophes like a major volcanic eruption in Japan or a large earthquake in California have global impacts since they affect the regional infrastructure and industry. This global impact emphasizes the importance of this research even for nations who are not directly exposed to natural disasters. There is a desire for all nations to actively participate in understanding natural hazards and its prediction.

Providing natural resources such as energy or raw material to society is already becoming increasingly difficult. The steady rise of crude oil or steel prices are a visible signal. Resources are limited and it is an important task for geosciences to improve methods to locate new resources and to assure that existing natural deposits are exploited to its maximum. We note, however, that on the long run geosciences cannot solve the problem of limited resources and a society has to find ways to reduce or reuse most of its natural resources.

Understanding the transfer of matter between the spheres of the Earth will be essential for assessing a) global material cycles (like methane or CO_2), and b) extracting the true human impact on the environment. Studying global material cycles in the solid earth involves among others sedimentary basins and subduction zones as major sinks in the earth system and volcanoes as a still not well defined source of gas emissions. The transfer of momentum is almost unknown until today but recent seismological research reveals background free oscillations. Their source is still unknown but it is presumed that the source is the interaction of the solid Earth with the oceans and the atmosphere. This may provide a natural source of seismic energy which could be used for long term seismological monitoring purposes.

The development of complex Earth system models including the interaction between the solid Earth, the oceans and the atmosphere is probably most important for societal reasons. Geoscientist are more and more in a position where they are expected not only to explain why the Earth system acts like it does but to predict what happens if e.g. we reduce or increase our input of greenhouse gases (like CO_2) into the oceans and the atmosphere. Question like this require models where the parts of the Earth system which are not immediately relevant to the problem at hand are parameterized properly and combined with numerical models simulating the complex behavior of the problem. This requires the development of new numerical and data assimilation techniques that allow a fast, but still detailed exploration of the parameter space controlling the problem.

3 The future research profile of the institute

With these long term goals in mid, there are several short and medium term research goals and priorities which need to be addressed in the next 5 to 10 years. Instead of giving an overview on all potential aspects, we restrain ourselves to those which are relevant to the research addressed by the IfG. Part of the development of the future research vision was to identify those areas of high expertise and first rate research as well as instrument availability at the IfG.

Dynamics of the earth interior

In order to advance our understanding of the Earth interior with respect to processes in a) tectonically active regions such as subduction zones or b) in the vicinity of submarine volcanoes, ocean island, mid ocean ridges we need to improve our instrumental coverage with broadband seismic stations, deformation, gravity and magnetic measurements in the marine environment. Seismology is still at the forefront in imaging of the Earth interior and an enhanced coverage, especially in the oceans will lead to an improved understanding of dynamic processes inside the Earth. The advent of dense arrays of broadband receivers will also require the development of new techniques for processing the large data volumes produced by these arrays and to establish suitable technologies to reduce the data to the important parts for an optimal subsurface imaging and subsurface physical characterization. The subsurface image is still one of the most important tools for the geodynamical interpretation and modeling. The combination of seismic and potential methods will improve the image of the Earth's interior.

Deployment of permanent offshore stations will be supplemented by regional high resolution marine experiments. Continuous deformation measurements in the marine environment, if possible at GPS precision, are still missing at all and we will develop reliable submarine tiltmeters that complement our seismological work. This will significantly improve model verification. Questions to be addressed by this improved coverage include high resolution imaging of the earth interior, especially subduction zones which are the source for at least 50% of all natural disasters that occur on Earth. Alongside these instrumental and modelling efforts we need to improve our understanding of earthquake source mechanisms and volcanic processes.

Improving hazard mitigation

Closely related to our seismological work are our general efforts in the area of hazard mitigation with respect to volcanic and seismic risks. Eary warning of either major earthquakes or volcanic eruptions is still a major challenge. For earthquakes the location and time of occurence are rather unknown.

For volcanos at least the location of eruptions is well constrained. Aside from this, volcanoes have a well documented history which can be traced back to the early stages enhancing our ability to predict an eruption. However, the individual mechanisms of triggering volcanic eruptions still need to be constrained, although some classical mechanisms are well established. We will focus on exploring external forcing of volcanic systems through, e.g., meteorological factors or triggering through far field earthquakes. This work will be supplemented by basic research that involve processes like the role of water in subduction zone volcanism, dike propagation, conduit flow processes, seismicity generated by magma transport and transport of matter between the geosphere, hydrosphere and atmosphere. Other issues to be investigated are the link between offshore earthquakes and tsunamies and the stability of continental slopes. Particularly in the shelf areas a lot of technical constructions like oil plattforms, ocean cables and pipelines are threatened by slope failure. The investigation of this includes the tectonic history of the area under consideration as well as the material transport and other major geological events like salt tectonics and glaciation.

Securing natural resources and basin dynamics

Aside from exploring the earth interior by passive seismological methods the use of active seismic experiments and the application of potential methods will improve our understanding of sedimentary basins, that are considered the largest resource of mankind. Sedimentary basins harbour a large fraction of our hydrocarbon resources, they are highly relevant as a supply of drinking water, and they may play an important role for waste disposal. Sedimentary basins are also a vital part of the geodynamics of the earth system and for the understanding of global plate tectonics.

For many basins, salt movements and salt tectonics are a major factor in their evolution. Therefore both early and late stage phases of salt movement will be studied in different regional settings. Imaging structures below the salt is still a major challenge for seismic methods and the combination with offshore electrical methods may provide a new tool for sub salt imaging.

Our goal is to advance the understanding of the development, structure, and tectonics of sedimentary basins. This goal will be achieved through dedicated active and passive seismic experiments that explore the sedimentary structures. The increasing data volumes due to new and improved aquisition technologies also require new techniques of seismic data processing. This includes development of advanced models for the propagation of seismic waves in anisotropic media and further developments for the interpretation of time lapse experiments (4D-seismics). The latter will allow detection of small changes in subsurface material properties such as porosity, premeability as a function of time. This will allow a much improved exploitation of deposits, thereby increasing the volume of exploitable natural resources. A key role will be captured by the observation of naturaly or artifically generated acoustic emissions. The classical seismic exploration will adopt techniques from seismology and the processing of the passive data will be enhanced by seismic data processing technology. We foresee that seismology and applied seimics will grow together to an extend not realized in the last decades.

3.1 How do we want to get there

For successfully reaching the goals outlined above the Institute of Geophysics holds a wealth of expertise and instruments to carry out research onshore and offshore expeditions. The instruments are designed to image the subsurface with seismic techniques, to measure the magnetic and gravity field, to analyze earthquakes, or to determine tilting of the sea floor. Some of these instruments are prototypes which were developed in the institute. Currently we have one HBFG proposal funded, where we develop a multiparameter submarine station array. We have also upgraded our marine gravimeter to current technology. A new HBFG proposal was submitted to the University of Hamburg to supplement our multiparameter array with additional hydrophone stations to extend the network. Aside from our instrumental expertise a successful understanding of complex earth processes requires a wide diversity in theoretical approaches. We hold analytical and numerical modelling expertise in the area of seismology, applied seismics, potential fields, sedimentary basins, geodynamics, and volcanology.

In times of limited human and financial resources the individual researchers, working groups, universities and institutes have to combine their particular and oftenly unique experience in order to successfully reach specific research goals. Northern Germany has a well established network among universities (Kiel, Hamburg (ZMK, ZMAW), Bremen) and research centers (AWI, IFM-GEOMAR, GFZ, RCOM) to address complex earth systems processes involving the solid earth, the oceans, and the atmosphere. The IfG does not aim to compete with the GFZ, IFM-Geomar or AWI in running large scale programs that would not be feasible with the limited staff and resources we have. However, we are actively engaged in defining, implementing and executing large programs together with these institutions due to our internationally recognized expertise and the flexibility that is typical for small institutes like the IfG. We currently participate in international programs such as SPICE (Seismic wave Propagation and Imaging in Complex media, EU) and various national initiatives like different SPP's (Schwerpunktprogramme der DFG) and Geotechnologien. We are also actively involved in developing a future SPP in the field of forcing volcanic systems.

4 Role of the Institute of Geophysics in the MIN-Faculty and Centers

The focus of research at the IfG is the solid Earth with an emphasis of Earth system research. There are multiple links between the solid Earth and the hydrosphere and atmosphere. The IfG, a member of the ZMK/ZMAW, considers its main contribution to the ZMK/ZMAW in providing expertise in the field of material transfer out of the solid earth into the sea floor and the atmosphere thereby aiding models that describe material transfer between the geosphere and atmosphere and oceans. We will take a leading role in the field of natural hazard research, which is one of the research topics of the ZMK/ZMAW. Another topic of special interest is the global water cycle that has tremendous impact on material properties in the solid Earth, as well as the impact of submarine landslides, earthquakes, and volcanic activity. With our expertise in solid Earth research, the IfG will also try to develop links to other centers in the MIN-Faculty, who have a focus on solid Earth research.