GEOTECHNOLOGIEN

Early Warning Systems in Earth Management

Status Seminar
12–13 October 2009
Technische Universität München

Programme & Abstracts

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Preface

Geo-Hazards, vulnerability, and risk-management are key words in the current discussion about natural phenomena like volcanic eruptions, earthquakes, tsunamis, landslides and rock falls.

In Germany the national programme »Early Warning Systems for Natural Hazards« was launched in 2007 as part of the research and development programme GEOTECHNOLOGIEN to reduce the risks of these natural phenomena. After two years of funding, 11 projects present the results of their research and software development. The following origin objectives of the projects have been widely reached:

1. Development and improvement of measurement and observation systems in real time for only transmission of decisive physical-chemical danger parameters

2. Development and calibration of coupled prognosis models for quantitative determination of physical-chemical processes within and at the surface of the Earth

3. Improvement in the reliability of forecast and prognoses for decision-making and optimization of disaster control measures

4. Implementation of mitigation measures in concrete socioeconomic damage prognoses

5. Development of information systems based on an open spatial data infrastructure that ensure prompt and reliable availability of all information necessary for technical implementation of early warning and for decision-making by disaster managers

The main objective of the second status seminar »Early Warning Systems« is to bring together all participants from the different research projects to discuss the results. Additionally, we have organised for the first time a demonstration of the technical developments in the projects, for example an open spatial data infrastructure or an innovative wireless sensor network. Further investigations in the research programme will concentrate on the integration of the single developments into a coordinated interoperable platform.

Werner Dransch

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»Early Warning Systems for Natural Hazards«
12–13 October 2009, TU München

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ILEWS – Integrative Landslide Early Warning Systems

Bell R. (1), Becker R. (2), Burghaus S. (3), Dix A. (4), Flex F. (5), Glade T. (1)*, Greiving S. (5), Greve K. (6), Jäger S. (7), Janik M. (8), Krummel H. (8), Kuhlmann H. (3), Lang A. (4), Li L. (3), Mayer C. (6), Mayer J. (6), Padberg A. (6), Paulsen H. (9), Pohl J. (6), Röhrs M. (4), Schauerte W. (3), Thiebes B. (1), Wiebe H. (8)

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1. Introduction

Landslides cause fatalities and economic damage all over the world. In most of the cases severe consequences could have been reduced if a reliable and understandable warning had been provided right in time. Since possibilities to predict landslides vary significantly, early warning of landslides is a challenging topic. New technologies are needed to set up reliable early warning systems. However, a well working technical early warning system might not be sufficient, if the issued warning is not understood by the threatened people. Thus, effective early warning must integrate social science, humanities and decision making as well to ensure that the early warning system meets the needs of the involved players and the threatened people.

The main aim of the project ILEWS is to design and implement such an integrative early warning system for landslides, which provides information on future events with regard to local and regional requirements.

Key project targets are:

1. Formulation of an integrative early warning concept for landslides.
2. Investigation and installation of an adapted early warning system on a landslide in Lichtenstein-Unterhausen (Swabian Alb, Germany).
3. Monitoring, parametrisation and modelling of local data.
4. Development of risk management options.
5. Provision of information necessary for early warning.
6. Integration of warning into the respective social processes of decision making. Strengthening the awareness towards underestimated risks that are associated with landslides.
7. Transfer of the concept to an area in South Tyrol with already existent monitoring stations which are not yet networked in the above mentioned manner.

2. Study areas

The study areas are located in the Swabian Alb (Germany) and South Tyrol (Italy). In the Swabian Alb a historically active complex rotational slide in Lichtenstein-Unterhausen is equipped with a new and innovative sensor combination to investigate the landslide movements in detail and to set up and test different kinds of landslide early warning models. Reactivations of at least parts of the landslide cause significant damage at a building.

In South Tyrol research focuses on a debris flow in Nals, where sediments are delivered by sliding processes further upslope, and a complex slide in Pflersch without the installation of new instruments. Whereas in Nals an early warning system was already implemented, there is none available in Pflersch. In South Tyrol regional analyses regarding debris flow triggering rainfall thresholds are carried out.

3. Structure of project and research program

The ILEWS project consists of the following three clusters: Monitoring, Modelling and Implementation.

3.1 Cluster Monitoring

Within the cluster Monitoring local measurements in Lichtenstein-Unterhausen are carried out and data is collected, transferred and stored. More detailed information is listed below.

3.1.1 Measurements

- Slope movement: Inclinometer chain (*continuously*), inclinometer (*periodically*), tacheometric surveying supported by applycation of scintillometer and precision nivellemenents (*periodically to episodicly*)
- Soil moisture: 2D/3D-geoelectric (*every two hours, automated analysis*), TDR-probes (*continuously*), tensiometer (*continuously*), »Spatial«-TDR-cable (*continuously*)
- Meteorology: Temperature, precipitation, wind, radiation, snow (*continuously*)

3.1.2 Data transfer

- Data collection via wires
- Wireless sensor networks
- Temporal storage of data on local servers
- Continous data transfer via DSL to central servers

3.2 Cluster Modelling

Within this cluster data from local measurements is used to setup and test the following early warning models:

- Movement analysis early warning model
- Physical based early warning model
- Empirical early warning model

Furthermore, if rainfall thresholds can be determined, which when exceeded might trigger landslides, the possibility to integrate the weather forecast will be investigated in the respective models.

In addition, historical and current frequency-magnitude relationships will be examined to better understand the general activity of the investigated geosystems and more reliably issue early warnings.

3.3 Cluster Implementation

Within the cluster Implementation modern geoinformatic approaches are applied to manage and spread information, a cooperative risk communication is set up and early warning is integrated into an integrated risk management.

3.3.1 Information management

- Setup of a decision-support information system
- User optimised preparation and visualisation of the results and warnings
- WebGIS, SensorGIS, standardised and interoperable geodata infrastructure

3.3.2 Cooperative risk communication

- Analysis of the general local and regional needs
- Cooperative implementation of the early warning system

3.3.3 Integration of early warning into an integrated risk management

- Definition of protection targets based on damage potentials
- Analysis of alternative management options (e.g. spatial planning, protection measures) based on respective laws and its discussion with the involved actors.

4. Status of the subprojects and intermediate results

In Lichtenstein-Unterhausen (Swabian Alb) new and innovative sensor combinations were installed, which are shown in Fig. 1.

4.1 Subproject »Geomorphic Modelling«

The overall aim of the subproject »Geomorphic Modelling« is the monitoring of subsurface landslide movement and modelling of early warning using three different approaches: movement-based modelling of early warning, a physically-based model and a statistical-empirical analysis of critical thresholds. In the following the focus lies on the most advanced model, the physically-based modelling of early warning implemented as a web-processing service.

Landslide movement is monitored periodically by mobile inclinometers since 2004 and continuously with an inclinometer chain since 2007. Data is automatically send to the server in field and to the ILEWS database. Movements differ seasonally: Whereas in summer/autumn there is a 8.5 m deep flowing movement following heavy summer rainfalls, in spring sliding movements down to 15 m occur mainly after snow-melting (Fig. 2). In general, both movement types are extremely slow (following the classification of Cruden & Varnes 1996), so that in total the maximum displacement is approx. 1.2 cm from August 2004 to February 2009. Subsurface and surface movement rates were analysed in cooperation with the subproject »Geodetic Modelling«. In some cases movement rates are in good agreement (see also subproject »Geodetic Modelling«).

Drilling cores were taken in field and sampled in the laboratory to analyse e.g. grain size distribution, moisture content and shear parameters. Based on the results of the laboratory analysis and geophysical surveys by the subproject »Moisture Geoelectric« a general subsurface model was created. This model is the basis for the physically-based early warning model using the Combined Hydrology and Stability Model (CHASM), which was initially developed by e.g. Anderson 1990 and Wilkinson et al. 2002. This model is used for the calculation of most likely

Fig. 1: Locations of installations in Lichtenstein-Unterhausen (Swabian Alb, Germany)

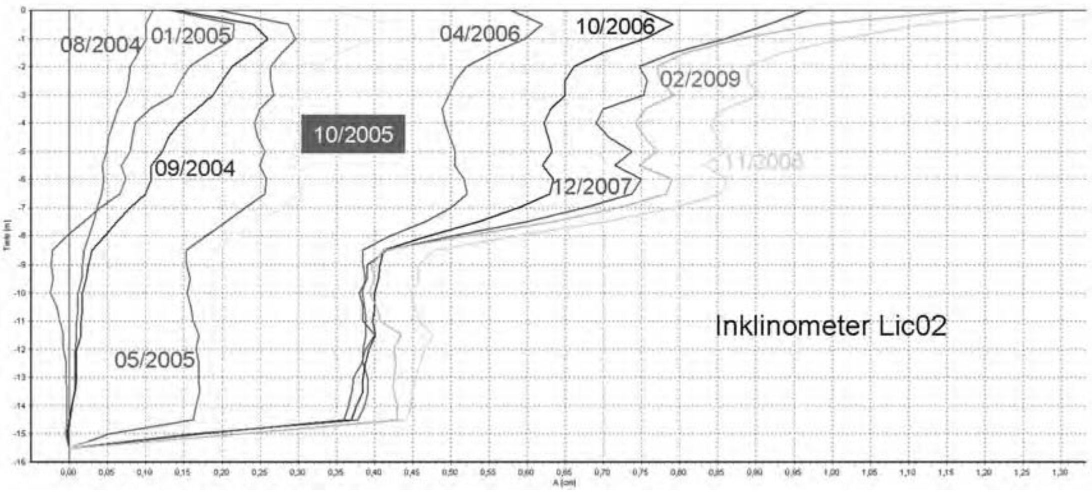

Fig. 2: Measured subsurface displacements at inclinometer Lic02

shear-surfaces. Furthermore, the model is implemented as a web processing surface (by subproject »Info-management«) to enable the web-based calculation of early warning.

Generally, two features are implemented as web-processing: an automated and an user-initiated calculation of slope stability. The automated computing is performed along two profiles. The first is along the geoelectric monitoring profile (run by project partner »Moisture Geoelectric«) and has a length of 135 m, the second one is 300 m long and reflects the situation of a full reactivation of the landslide body. The user-initiated feature allows calculation of slope stability along freely selectible profiles. Additionally the user can select from rainfall scenarios and initial soil-moisture states and start the slope stability calculation by a conventional web-browser.

The web-processing service is implemented and currently runs on test data regarding soil-moisture. The full integration of real-time measurements of soil moisture and rainfall, and eventually weather forecasts is expected for late 2009. Rainfall scenarios are based on the German weather service's KOSTRA2000 atlas (Koordinierte Starkniederschlags-Regionalisierungs Auswertungen) and comprise storm events with varying duration (1 hour to 72 hours) and probability of occurrence (1 to 100 years).

Up to date the movement-based early warning model which follows the very promising approach of Petley et al. (2005) by analysing the reciprocal movement rate over time could not be applied due to the extremely slow movements and the missing significant acceleration of the landslide which is essential for this approach. However, if the landslide starts to accelerate the approach will be applied and further developed.

The third early warning model applies the statistical analysis of critical thresholds in all data regarding slope movement, soil moisture and weather conditions. First analysis were carried out and will be intensified as soon as the improved analyses and visualisation tools of the subprojects »SensorGIS« and »Info-Management« are available.

Furthermore, the transferability of the concepts outlined to the study sites in South Tyrol have been discussed with the Geological Survey of the South Tyrol. Whereas it seems that the technical early warning systems developed by ILEWS is not suitable for the very active landslides in the debris-flow catchment in Nals, it might be beneficial to be applied to the landslide in Pflersch.

First rainfall thresholds for the initiation of debris flows were derived at a regional scale

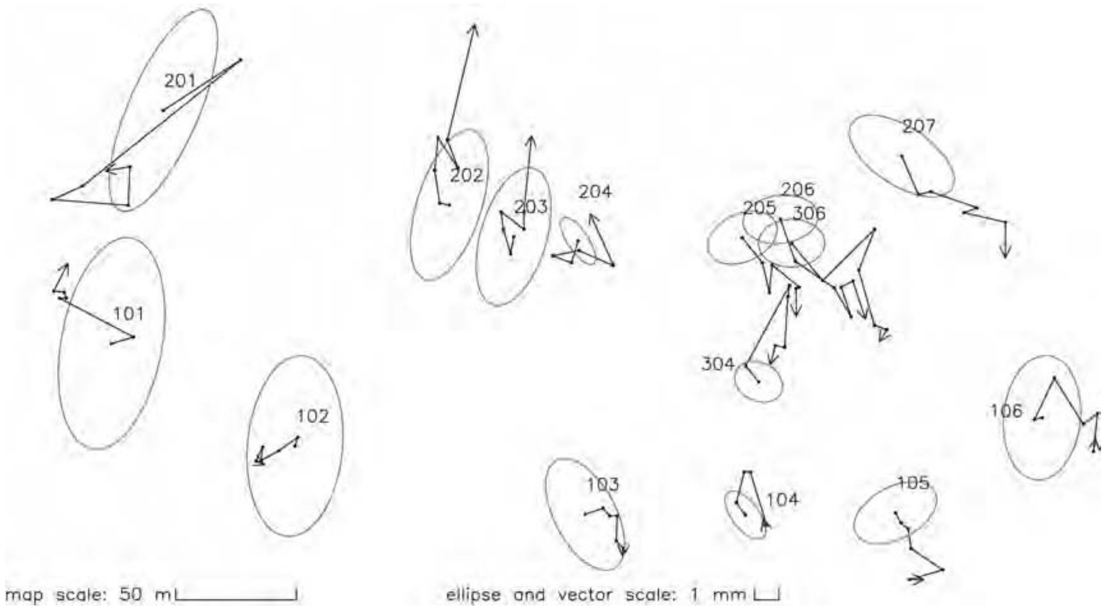

Fig. 3: Results of the deformation analysis out of multiple two-epoch–comparisons (Measuring dates: Nov 2007, Mar 2008, Aug 2008, Sep 2008, Nov 2008, Mar 2009, Jun 2009)

for South Tyrol based on data from weather stations. Currently, it is analysed if the utilisation of rainfall radar data might confirm or even improve the derived thresholds.

In a last step it will be tested how the models applied can automatically support each other. Finally, numerous interviews were carried out together with the subprojects »Communication« and »Management« (see their reports for main results).

4.2 Subproject »Geodetic Modelling«

The aim of the subproject »Geodetic Modelling« is the surface surveying of the extremely slow moving landslide with different geodetic methods and the development of a complex landslide model to describe current and predict future movements.

To survey the landslide, seven epochs have been measured until now. These measurements were done by precise levelling and surveying of a precise geodetic tacheometry network. The results of the basic deformation analysis of the tacheometric network are shown in Fig. 3. Significant movements of the landslide can be found in the area around three different pointgroups: the point 201, the points 202 to 204, and the area of the points 205 to 207. All of these points are placed on or near the upper street of the research area, where the gradient of the slope is higher than at the points 101 to 106 on the lower street. Because of the higher gradient in this area, higher movement rates were expected, which are now confirmed by the surveying. The movements at the points 205 to 207 show a constant downhill movement, overlaid by sideward movements. Though these sideward movements cannot be fully explained until now, they are confirmed by inclinometer measurements near the point 306 carried out by subproject »Geomorphic Modelling« (see also Burghaus, Bell and Kuhlmann 2009). The movement in point 201 is interpreted as an effect of swelling and shrinking of clayrich soils in the underground, following dry and wet periods. Levelling results support this hypothesis. The recent uphill movement of the points 202 to 204 might indicate some rotational sliding movements. Rotational movements could also be found in inclinometers Lic02 and Lic04 of the subproject »Geomorphic Modelling«, but in February 2009. Lic05 is pretty close to the point 204. Unfortunately, there the uphill movement is not as strong as at the other locations and the uphill movement in February cannot be recognised by the periodic tacheometric measurements.

At present a complex landslide model is under development, which shall include next to the geodetic measurements also data from other sensors like inclinometers, soil moisture sensors, tensiometers, precipitation sensors, etc. This landslide model shall give the possibility to predict future movements of this landslide depending on precipitation and soil moisture.

Another advanced method to monitor landslides in real time is GPS Measurement. Thereby GPS real time series analysis is one of the major parts, providing the important basis for identifying a landslide. To get the observations, one GPS experiment was carried out in Bonn because GPS cannot be used in Lichtenstein-Unterhausen due to limited satellite visibility and the extremely slow movement rate.

If the GPS observations with high sampling rate are correlated, the shaping filter can be used to describe the long term movement of correlated measurement deviations. The accuracy of the processed time series can be improved by the usage of Kalman filter with shaping filter. Because of the similarity and the difference between the deformation and outlier, the Kalman filter with shaping filter is used to detect and distinguish deformations and outlier simultaneously and is discussed how to determine the state vector when deformation and outlier occurred. The details of the results can be seen in Li & Kuhlmann (2008a).

Two other methods were also used to reduce the coloured noise and detect the deformation epochs with less time delay: sequential algorithm and finite impulse response (FIR) filter. The FIR filter removes noise by weighing the previous observations. Kalman filter removes noise from the signal by using the initialisation and the propagation of error covariance statistics. For the static GPS measurement, the accuracy is in the order of a few millimetres. Different methods have different ability to detect the deformation. For example, the Kalman filter with shaping filter can detect the deformation of 5 mm. The sequential algorithm can detect the deformation of 1 mm, but it causes larger time delay than the other two methods. A thorough comparison of these three methods has been made in Li & Kuhlmann (2008b). Such high accuracies of the GPS measurements are only possible to get if 7–8 satellites are contemporaneously available. Unfortunately, this is not given in the study area Lichtenstein-Unterhausen. In other landslide areas with better satellite availability GPS measurements using one of the developed methods enables the monitoring of even extremely slow landslides.

4.3 Subproject »Setup Monitoring«

The most important objective of this subproject is the coordination and hardware-related integration of heterogeneous field sensors into a unified, robust and simple to-use measurement system, as a standalone component of an extensive landslide early warning system.

A slide-prone hill slope is a system with an internal state reacting to external loads and forces. The inner state is determined by quasi-static morphological characteristics (e.g. soil type, grain size distribution, landscape formation, stratification) and time varying soil hydraulic variables such as soil moisture, suction, and pore water pressure. Both static and dynamic variables define the soil mechanical stability at a given time. Therefore, diligent monitoring of soil hydraulic variables is crucial to assess time varying slope stability. Moreover, the load to the system, i.e. precipitation in the form of rain and snow, has to be captured, too. The system reacts to the load depending on the current state of inner stability.

To fulfil the particular needs for a robust, flexible and scalable soil monitoring system a distributed soil hydraulic measuring system including a weather station for the main atmospheric variables (temperature, pressure, precipitation, wind, radiation) has been set up in close cooperation with subproject »Geomorphic Modelling«. The technical components chosen are well known for their reliability. Among these are IMKO Time Domain Reflectometers (TDR) measuring soil moisture reliably even under problematic soils revealing electromagnetic wave dispersion (e.g. clay) and energy dissipation (saline soils), and widely used tensiometers by UMS to measure the soil matric potential. TDRs and tensiometers were installed in pairs in three different depths (approx. 2 m, 5 m, and 10 m) along nine vertical profiles. Seven vertical profiles are aligned along two perpendicularly crossing transects.

A Spatial TDR (STDR) system, which is still under construction, complements the soil water monitoring. Spatial TDR allows the derivation of spatially continuous dielectric profiles along elongated TDR wave guides such as custom-built three wire ribbon cables. This is done by inverse parameter estimation similar to tomography. Moisture profiles are yielded from dielectric profiles my means of calibration functions. The special STDR ribbon cable with RF relays at each side right at the junction to the coaxial feeding cable has already been built and buried. Both feeding cables will be connected to a custom-designed RF multiplexer allowing for the TDR measurement from both sides. The development of control software is the final step.

To test different data collection and dissemination schemes data is collected partly by means of solar powered data loggers storing information locally and transferring it periodically to an internet host and partly by means of a common PC set up in a container installed on site connected to the grid and the internet. For remote sensors a wireless sensor network is under construction (in cooperation with subproject »Sensor GIS«.

A significant part of a modular monitoring system is a dedicated, self-contained database to provide a harmonised way of data sharing. PostgreSQL has been chosen as object relational database management system (ODBMS). Such a powerful tool alleviates the perusal of raw measuring data, assessment of data quality and health of sensors. Moreover, it provides standard import and export interfaces. The monitoring database is linked to the central ILEWS database and forms an important part of the early warning system. Even so it can be run solely and hooked up to another system to ensure modularity and scalability.

To get a fast access to the quality of service data (sensors available, data loggers reachable, hosts running) Nagios has been installed and is still under test. In fact Nagios is an open source computer system and network monitoring software application, but is extremely flexible and extensible, so that it can be used to inform and alert an operator about the health of the monitoring system via email, SMS, or web frontend. It could even be trained to disseminate alerts possibly generated by the early warning system.

Soil moisture and weather data is analysed in cooperation with the subprojects »Geomorphic Modelling« and »Moisture Geoelectric«.

4.4 Subproject Moisture Geoelectric

Pilot surveys had been performed at the landslide location in Lichtenstein-Unterhausen prior to the installation of the D.C. resistivity monitoring system, using seismics and DC resistivity. The aim was to find the best configuration for the monitoring setup and to provide a model of the subsurface, and especially the potential landslide body. The latter was derived in cooperation with project partner »Geomorphic Modelling«. Based on the results of the pilot survey a DC resistivity monitoring system has been installed, consisting of two perpendicular geoelectrical lines. Every two hours a measurement is carried out and the raw data saved locally. In cooperation with the project partner »SensorGIS« the raw data are then transferred via an FTP-connection to the central database, and also to »Moisture Geoelectric«, where data is processed further. The monitoring system is remote controlled via an OpenVPN connection, which allows for maintenance, troubleshooting and changing of system parameters without the need of on site inspection.

The raw data are processed in several steps:

- Visualisation of the data sets in so called pseudo sections. In cooperation with »SensorGIS« the possibility of web-based data visualisation was implemented.
- A series of procedures to clean the data from outliers etc.
  - Cutting off datum points above 1200 Ωm and below 1 Ωm
  - Using mean and median filters
- Sorting the data into a continuous time series for each electrode configuration
- Converting the raw data into a special file and data format for future use with inversion software *(Res2DInv)*.
- Piping the transformed data into the inversion software *(Res2DInv)*.
- The inversion results are sorted into timelines to be able to follow changes with time.

A crucial point in this procedure is the elimination of outliers. Only a clean data set will provide reliable information for further analyses, and the possibilities of automatic outlier removal are limited. A short look at the visualised data usually provides better results than programmed algorithms. Nonetheless the automation is useful, as large quantities of data are produced every day and this approach significantly reduces the effort of manual data processing. Checking for unusual results after the inversion process can indicate corrupt data sets which can be cleaned by hand afterwards.

The calibration of the measured apparent resistivity values with the measurements from the TDR probes provided by project partner »Setup Monitoring« has so far produced indifferent results. Not every change in TDR data can be assigned to changes in resistivity, and vice versa.

One possibility to observe the changes in subsoil parameters is the so called time lapse inversion. Here the differences between several data sets are processed, not the data sets themselves.

Several time lapse inversions have been carried out around specific points in time where changes in soil moisture, or rain events were recorded. For example the data sets from February 23rd to 26th 2009 show fluctuations in TDR data, especially for the sensor triple 30003, 30002, 30013, and rain events are recorded in this period of time (Fig. 4). Fig. 5 shows a line plot of a selected data point from the resistivity monitoring for the same period. With the use of time lapse inversion the changes in soil moisture can be followed. The inversion results also indicate that sensor 30002 may be positioned inside a clay lens,

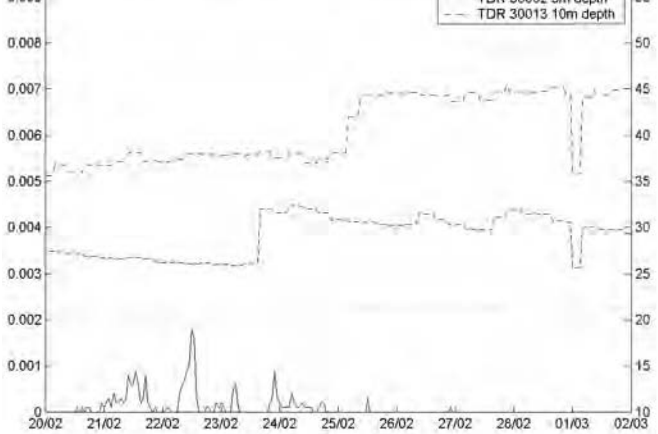

Fig. 4: Raw data of the TDR sensors

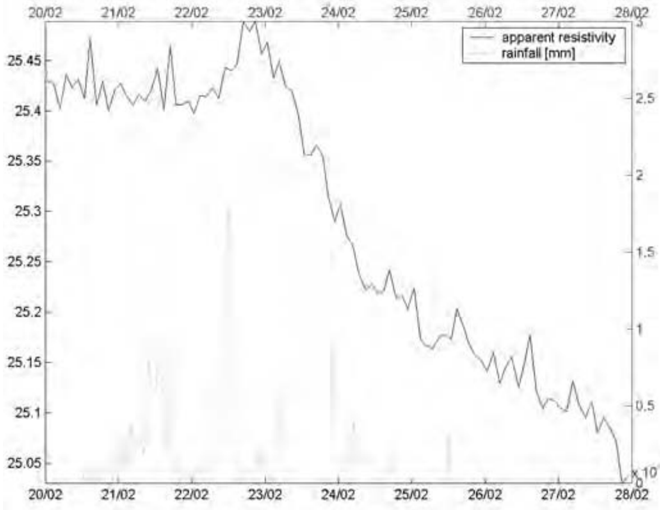

Fig. 5: Rain events and apparent resistivity for a selected data point

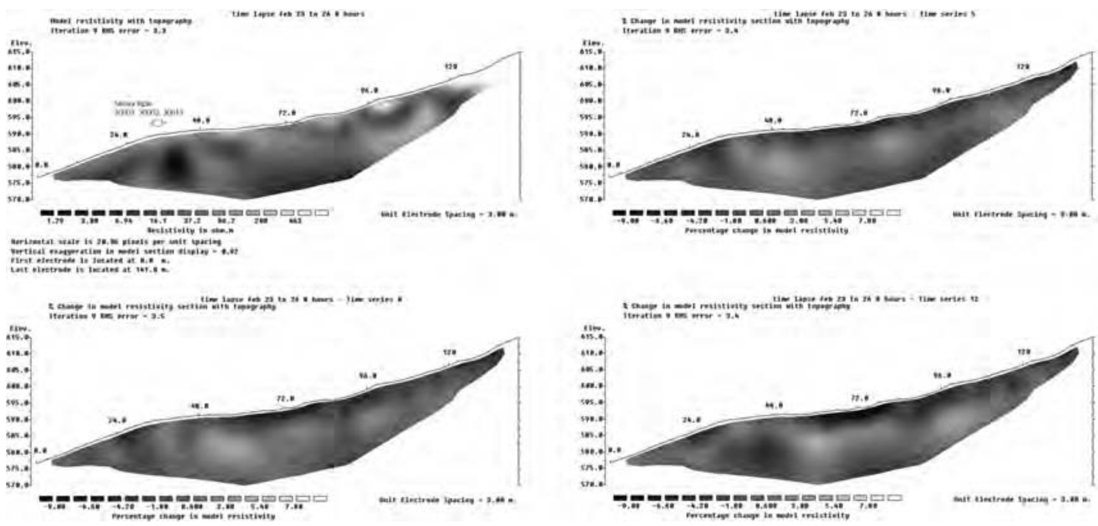

Fig. 6: Result of the time lapse inversion. The first image shows the reference model, the other the change in resistivity in percent relative to the reference model at different times

resulting in damped amplitudes in TDR data. The other sensors do not react in the same way, only sensor no. 30005 shows an increase in soil moisture, which corresponds to the near-surface saturation changes visible in the time lapse results (Fig. 6).

The above results show the great potential of using DC-resistivity measurements for soil moisture monitoring. With the DC-resistivity-monitoring water paths within the landslide body as well as the temporal infiltration of rainwater into the underground can be analysed and visualised. Both effects are essential for the early warning modelling of landslides.

4.5 Subproject »CoreSDI«

»CoreSDI« is responsible for the technological foundation of a Spatial Data Infrastructure for early warning applications in ILEWS. A Spatial Data Infrastructure (SDI) is an infrastructure connecting a multitude of distributed resources (data and services) and providing a well-defined set of users with the means to access these resources through standardised interfaces. The infrastructure of an early warning system (EWS) is highly complex. EWS incorporate sensors, databases, data processing via GIS, forecast and model generation, computer networks and other user devices, as well as procedures for the handling of results. Significant problems arise on a syntactical and semantical level when combining heterogeneous components in complex systems. OGC interoperability testbeds and pilot projects show the traditional technologies being replaced by Sensor Web, Open Web Services and Web Processing Services. The services are based on the Web Service paradigm and originate from the OGC Spatial Web approach. These technologies are more suitable for achieving interoperability than traditional technologies. Each Web Service is responsible for a single spatial information task and is deployed in an infrastructure of several different modules.

Because of the high level of complexity, it was necessary for »CoreSDI« to do a thorough analysis of the requirements of data providers and customer needs prior to the modeling of the SDI architecture. In the ILEWS project the SDI consists of technical components like sensors for measuring subsurface movements, data generated by these sensors, services for accessing this data as well as organisational components like the rule set for data access. »CoreSDI« is concerned with developing the actual architecture of this SDI to facilitate the use of data generated by the project partners. The SDI is necessary for satisfying the informational and communicational needs of the other parts of the project. For this task a tight cooperation between the subprojects »SensorGIS«, »Info-Management« and »CoreSDI« has been established. Together with these project partners a data model was developed, that is used for storing data generated by the sensors in the central database.

Sensors including meta information and their input and output properties can be described using SensorML documents. The SensorML standard developed by the OGC specifies »models and XML encodings that provide a framework within which the geometric, dynamic, and observational characteristics of sensors and sensor systems can be defined (www.opengeospatial.org/standards/sensorml). »CoreSDI« supports the project partners by creating SensorML documents for some of the sensors used in the project. The SensorML documents are also utilized when setting up Sensor Observation Services (SOS) providing the sensor measurements in a standardized way so these services could be integrated into the project's SDI.

Further activities of »CoreSDI« apart from those mentioned above, include providing advice to the project partners that implement and run the SDI, as well as supporting all users of the project's SDI. The »CoreSDI« part of the project aims at providing a flexible infrastructure for spatial data management and processing to the project partners.

4.6 Subproject »SensorGIS«

Integrative landslide early warning systems are dependent on sensors, computers, transmission technology and other hardware. Sensor data in conjunction with historical facts from archives and information gleaned from interviews with people involved in the process constitute an information system that is designed to furnish early warnings. The aim of »SensorGIS« in the current project was to provide an infrastructure to process incoming data and to facilitate easy access to the latter through an interactive, web based client.

Since the last science report in 2007 a lot of sensors were installed in the research area in Lichtenstein-Unterhausen. Amongst these are dc-resistivity-, soil-moisture-, soil-suction-, soil-temperature-, meteorology- and inclinometer-sensors. Apart from measurements for a geodetic mesh all other sensors take readings at regular intervals and transmit their data automatically to the central database via a container installed on location, that is connected to the power grid and to the internet.

Two servers, one productive and one as a backup, were configured with the necessary software and located in Bonn and Heidelberg, Germany, respectively to ensure the redundancy and fail-safe setup needed for an early warning system. Once a day data is transferred from the apparatuses in the field and the backup server synchronises itself with the productive server. Should the main server cease functioning the IP address would automatically be mapped to the second server without it being noticeable by the user and thus enabling uninterrupted service. The system administrator would receive an automated message so that the problem can be rectified.

Apart from being involved in the technical setup described above SensorGIS was instrumental in storing and visualising incoming data. For storage purposes a PostgreSQL database is used in combination with the PostGIS library that enables the direct storage of geo-objects. For visualisation purposes the PHP framework *symfony* was used to program graphical user interfaces (GUIs) in cooperation with subproject »Info-Management« that allow interactive viewing and analysis of the data. Provided the user has appropriate rights data can also be modified or deleted.

Bringing the abundance of data online compounded an initial assumption: The system is designed to be used by experts who are familiar with the data and who know how to extract the appropriate information from the tables and graphs. Another initial idea was to make the system also accessible to local decision makers and the interested public as a target group. Interviews conducted by the subprojects »Communication«, »Management« and »Geomorphic Modelling« revealed that this target group basically is not interested at all because there is none to extremely little perceived risk. This result has had a fundamental influence on the design of the second GUI, developed in cooperation with »Info-Management« and »Communication«, which was made as simple as possible to accomodate the wishes of this target group.

Another aspect of the system being built is the interoperability with other systems. In this respect standards of the Open Geospatial Consortium (OGC) are being met and to date the web mapping service (WMS), web feature service (WFS), web processing service (WPS) and sensor observation service (SOS) standards have been implemented. Adhering to these standards will allow future expansion of the system because other services based on standards will easily fit into the given architecture. In the same measure services of ILEWS can easily be integrated into other systems. Interoperability tests will be conducted together with the research projects SLEWS, alpEWAS and EWS-Transport.

4.7 Subproject Info-Management

The subproject on information management, in close cooperation with the subprojects »SensorGIS« and »Core-SDI«, has developed and tested the database model and use case definitions for ILEWS. The database model includes sub-models for the complete monitoring components of the field instrumentation, which is transferred remotely to two database servers. Additional data models for socio-economic as well as for historic data have been designed. The geospatial components used are compatible to OGC-standards. The two database servers, located in different geographical locations, work as synchronized backups for each other, so that in case of malfunctioning of one of them, the substitute can jump in. The collaboration development process is supported by the PHP-web-development framework Symfony.

In close cooperation with the subproject »Geomorphic Modelling« the slope-stability model CHASM (University of Bristol) was implemented as an OGC-compatible Web Processing Service (WPS). The model can be operated automatically or manually. In the first case it is fed by design rainfall scenarios derived from the German weather service's KOSTRA-Atlas, which are compared to the monitoring data. The design rainfalls have been integrated in the data model, too. In manual mode the WPS can be »fed« with local datasets of a modeling specialist, in which case the terrain and subsurface data are located on the server but model parameters will be set by the modeler. Technically, CHASM has been implemented by software wrapper classes. The conceptual setup of the WPS is shown in Fig. 7.

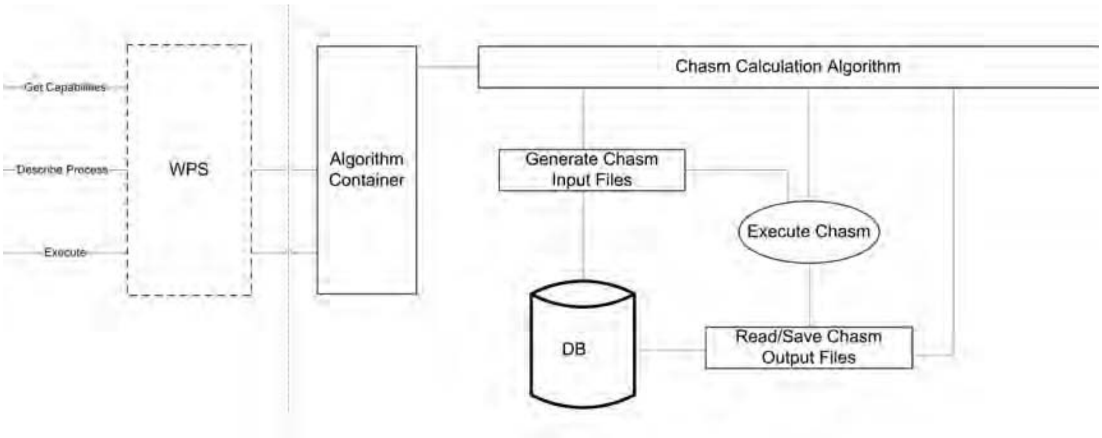

Fig. 7: Schematic description of the WPS setup for slope stability modeling

In a further cooperation among the subprojects »Info-Management«, ›SensorGIS« and ›Communication«, and based upon the findings of the latter subproject an hierarchical warning system has been designed and is currently being implemented. An automated database analysis will issue a preliminary warning. However, due to the complex nature and mainly due to the very low frequency of movements in the study area of Lichtenstein-Unterhausen, a final warning will only be issued after at least one expert has ruled out.

Several AJAX-based data visualisations have been developed and implemented. The most important ones are the integrative real-time visualisation for the field monitoring data and the tools for controlling and visualising the slope stability model.

4.8 Subproject »Communication«

The subproject »Communication« would like to break new ground by penetrating the complexity of social actor systems with the help of cooperative interviews and by developing sensible solutions in collaboration with the involved players. For early warning systems to be functioning and efficient, they have to be thought as integrative chains. In doing so the players are not to be the last link of the chain, but those who should play a central role during the whole development of an early warning system. If the players merely have a significance as social variable to be calculated, the social implementation of early warning will remain a »black box«. Therefore, the endusers are the centre of interest for the subproject.

The subproject »Communication« aims to clarify general local and regional needs regarding to a landslide early warning system. Interestingly, intermediate results show that local authorities, stakeholders as well as residents do not show any interests in any landslide risk management strategy. They are not interested in a landslide early warning system at all. Local people do not see any necessity for such a system. Stakeholders are little sensitive towards infrequent events such as landslides. The potential damage is often underestimated by decision makers and the public.

Referring to these findings and in contrary to all expectations as well as the research results of the DFG-project InterRisk the involved stakeholders show only a very little willingness to cooperate. Therefore, it was exceedingly difficult to carry out the the cooperative risk communication and the cooperative implementation of the early warning system on the local level with the involved stakeholders. The interpretation of the qualitative interviews with the involved stakeholders at the Swabian Alb shows that they do not need any precise information. They only want very few and simplified information, for example in terms of a

»flashing red light signal«. Interviews were carried out together with subprojects »Management« and »Geomorphic Modelling«.

Results of several cooperative interviews as well as a workshop with experts in South Tyrol confirm the experiences for the investigation area South Tyrol. Experts on the regional level at the provincial government take responsibility for prevention measures such as development, implementation and maintenance of early warning systems. In collaboration with the involved players in South Tyrol and together with the subproject »Management« risk management options beyond technical early warning systems have been discussed. Thus, in the scope of an integrative risk management approach, existing vulnerabilities and action alternatives have to take into account.

The implementation of the landslide early warning system and so the development of the user interface has to take these findings into account. The user interface, cooperatively developed with the subprojects SensorGIS and Info-management has two profiles. The »nonprofessional« user profile is for interested nonprofessionals, which need simplified information about the current slope situation. They get these information in form of a traffic light status lamp. The »professional user« can see all the data, interpreted data as well as raw data, after a personal log in. This second status group has to check the system after a critical threshold is exceeded. These experts (e.g. system developer as experts for a special module (e.g. »Moisture Geoelectric«), responsible institutions (e.g. regional authorities), administrative district responsible for emergency management etc.) decide if there is any error in measurement or if the situation is truly critical. Depending on this data check the traffic light turns red or green again and further action can take place if necessary.

The requirements on the system (which information, detailedness of the information, reliability of the information) vary, depending on the the particular situation. The physical and social processes are specific, depending on the slope stability and the social setting. Any landslide as well as any social setting is specific to the situation and not representative and generalisable because of the complexity of the social and physical processes. The landslide early warning system developed by the ILEWS project provides the opportunity to customise the components to a particular situation and enduser's option.

In general, the responsibilities and competencies for landslide risk management of involved actors play a decisive role for the implementation of an early warning system. Surprisingly the regional level gains in importance. Organisations at the regional scale, for example the state office for geology, resources and mining or the regional planning administration have a large scope and flexibility in decision making and designing the risk management process. In this context landslide risk management options can be developed together with these organisations. The consideration of landslides in the regional plan in the Swabian Albs on the recommendation of the ILEWS project exemplifies the possibilities of developing risk management options (see subproject »Management«).

Generally, the important role of different social systems and the application of the Social System theory of Niklas Luhmann (Luhmann 1984) could be confirmed. The method of cooperative interviews turned out to be very successful to investigate the social processes in the context of early warning. The results of the subproject »Communication« make a substantial contribution to the technical development of the landslide early warning system.

4.9 Subproject Management

An early warning system has to be developed according to the requirements of its users who are identified by subproject »Communication«. This calls for an important role that the management of information as well as the dissemination of information (risk communication) have to play.

Research objective of the subproject »Management« is to broaden the perspective and to provide the stakeholders in the case study areas with an appropriate consideration of action alternatives. An early warning system however is only one of many options. Moreover, an early warning system may not have to be understood as a single isolated measure of which the implementation is based only on the identified hazard. Actually, existing vulnerabilities and action alternatives have to be considered, too.

In line with the envisaged integrated approach, different and sometimes alternative measures may compete with each other. Criteria for the assessment of measures – that have been defined in co-operation with local stakeholders – are especially the protection goals for hazard-prone areas but also aspects of efficiency and effectiveness.

The analyses took place in two study areas: the municipality of Lichtenstein (Swabian Alb / Germany) and the municipality of Nals (South Tyrol / Italy). The report is focused on the Italian case study, because the municipality of Nals is much more affected by landslides (esp. debris flows / rock falls). Moreover, precise information about frequency and magnitude of landslides were only available for Nals. On the contrary, landslides in the Swabian Alb are known as regional phenomena with low probability and of mostly low velocity. However, the given damage potentials in the threatened residential area »Im Weingarten« were analysed based on recovery costs. The estimated sum is about 18.6 Mio. € + 1.7 Mio. € for public infrastructure. The project concentrated nonetheless finally on recommendations for regional planning in order to keep landslide prone areas as much as possible free of further development or, if not possible, adjust the technical building design according to the given threads. This scientific advice has been integrated as »Vorbehaltsgebiet« (reserve zone) into the regional plan for the district of Neckar-Alb by the regional planning association. This is the first case ever where landslide proneness is regarded as important by regional planning in Germany.

An instrument called »Gefahrenzonenplan«, is obligatory for municipalities in the Italian study area of South Tyrol (see provincial ordinance GZP/KSR). According to this instrument, each land-use type, defined by the urban land-use plan, gets related to a specific loss potential rank between level 1 (not vulnerable) and level 4 (highly vulnerable). The results are shown by a so called »Karte der Schadensanfälligkeit« (damage susceptibility map). Moreover, a hazard map is part of the »Gefahrenzonenplan«. Hazard prone areas are classified by four classes from H 0 = not endangered to H 4 = Very high hazard intensity. Overlaid with the damage susceptibility of hazard prone areas, a risk map is the final outcome, consisting of four risk classes from low to very high risk.

In the framework of the ILEWS-project these maps have been compiled by the sub-projekt »Management« for the community of Nals. Due to the fact that there is currently no land-use plan in force for the community of Nals, the presented map had to be worked out on basis of existing land-use data.

In addition to these maps which are obligatory for each community, the existing damage potentials within hazard-prone areas of the study areas have been identified and processed at meso-scale (at the level of land-use types). The overall damage potential is about 70 Mio. €. Moreover, an examination at micro-scale within the identified hazard-prone areas was carried out.

The main focus lays on subjects of high economic values, such as buildings and technical infrastructure. Social values (human lives, health) and the environment were subordinated. Here, no current real estate values, but the recovery costs were considered. These costs were estimated on basis of the official land register and combined with the construction cost index, which is in Italy (South Tyrol) part of the official statistic. Finally, annual estimated losses, which result from the probability of the regarded natural hazards, were calculated. The probability of natural hazards was only available for the Italian case study. This fact can be seen without difficulty for the German case study, since the building plots are only affected by a landslide of currently extremely low velocity (as mentioned above).

So, for every hazard-prone building in Nals (South Tyrol) the annual amount of (financial) loss were detected. Depending from the phenomenon, its frequency and the damage potential of a certain building, the estimated annual losses are of about 1.700–6.800 € per object. For the next working stage, several mitigation measures will be compared with the early warning system. Here, the building and working costs have to be identified, to be able to estimate the effectiveness and efficiency of the mentioned alternatives. This allows a prioritisation of the implementation of early warning systems in different landslide-prone areas depending from the cost-benefit ratio.

4.10 Subproject History

The aim of the subproject consists of developing methods for measuring the frequency and the magnitude of landslides on a historical time scale. This was operated in two landslide-prone regions, and was based on two different researches in the Swabian Alb and compared to the region of South Tyrol. With these results and combined with methodological experience gained, statements can be made about how future historical analysis can be included in an effectively working early warning system.

At first, we deepened our researches concerning the area of interest, the Swabian Alb region, by taking the already investigated, hand-written archive sources from the former DFG-project InterRISK and constipating the timeline which goes back to the 15th century. After this, important information on time, location, trigger and size of the damage of the event was implemented in a database, constructed by the subproject »SensorGIS«. Furthermore, a multitemporal, GIS-based land-use-analysis was carried out for the region of the community of Lichtenstein-Unterhausen based upon historical maps and aerial photographs. In addition, historical landslides found in the archives were exactly located in the study region.

Parallel to this, systematic research in archives from Tyrol and South Tyrol was done. This also led to a high amount of discoveries for the area of investigation about so far unknown and not yet enough documented landslides dating back to the 16th century. The historical original sources not only give information about the spatiotemporal spread of the events, but also include important information on natural and anthropogenic triggers, on the process itself and the handling of natural disasters by former societies. Research was concluded by adding an amount of discovered maps, plans, engravings and paintings to the hand-written sources, which could help to precise the localisation of the events.

After finishing the explorative phase, the collected historical material was and will be further prepared to integrate it to the central database. So the data will be available for other subprojects, especially Geomorphic Modelling, to make them accessible for an early warning system.

To generally conclude: the deeper the digging in the existing historical sources, the clearer the awareness of a lack of knowledge about former natural events is. Furthermore, whilst so called »natural-chronics« offer a large amount of – unassigned – data, it is shown that as soon as this data is compared to archival sources, it can be found out how rare and fragmentary the present level of knowledge is. It seems that until now the relevant archival inventory was ignored and it was content to copy from the existing time- and event-courses of the 19th century without ever questioning their credibility because of missing source records and so questioning their scientific value. But for a meaningful early warning system especially exact historical data about the trigger and the spatiotemporal spread of the events in form of preferably long and dense time-courses is not only informative but essential.

5. Benefits of an integrative project

Developing integrative landslide early warning systems is quite complex and involves experts from various disciplines and totally different scientific backgrounds. But only by integrating these different experts all important questions can be thoroughly tackled, which cannot be done by single experts. In the past often very promising technical developments finally failed because they were developed without regard to the actual needs.

In the following a selection of some excellent results are listed which mainly were achieved only due to the integrative approach of ILEWS:

- Reliable soil moisture information, which is essential for the early warning system and especially for extending the early warning times, can only be derived from the new and innovative sensor combinations by the close cooperation of geophysisicists, physicists, geomorphologists and computer scientists.
- A detailed picture of current surface and subsurface movements can only be detected due to the combination of geomorphological and geodetic experts.
- An user optimised frontend of the web-based early warning information system was developed which meets the specific local and regional requirements. This could only be achieved based on the cooperation of computer scientists, technicians and social scientists.
- Only due to the cooperation of a spatial planner, a social scientist and a geomorphologist and based on their comprehensive scientific advice landslide prone areas will be integrated as reserve zones into the regional plan for the district of Neckar-Alb by the regional planning association. It is the first time ever this happens in Germany.

Above all the project profits a lot from the intensive interdisciplinary discussions regarding the most important questions like: Which requirements must the early warnings system fulfil? How can critical thresholds be defined? Who are the involved actors? What is the legal framework for setting up an early warning system and for reducing natural risks in general?

6. Collaboration with other research projects

Regarding the spatial data infrastructure developed in ILEWS, interoperability tests will be conducted together with the research projects SLEWS, alpEWAS and EWS-Transport. Based on SensorML documents and a sensor observation service (SOS) it will be tried to integrate data from the ILEWS sensors into the Demonstrator developed by EWS-Transport. Due to the research fields of enduser demands and requirements for an effective warn- and risk management ILEWS cooperates with the research project SLEWS.

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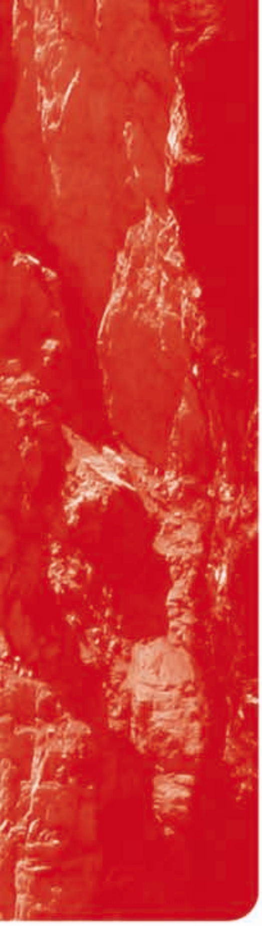

Early Warning Systems in Earth Management

In addition to currently implemented measures for establishing an early tsunami warning system in the Indian Ocean, the German Federal Ministry of Education and Research (BMBF) has launched a portfolio of 11 research projects for developing and testing early warning systems for other natural geological catastrophes. The projects are carried out under the umbrella of the national research and development programme GEOTECHNOLOGIEN.

The overall aim of the integrated projects is the development and deployment of integral systems in which terrestrial observation and measurement networks are coupled with satellite remote sensing techniques and interoperable information systems. All projects are carried out in strong collaboration between universities, research institutes and small/medium sized enterprises on a national and international level.

The abstract volume contains the presentations given at the »second Status Seminar« held in Munich, Germany, in October, 2009. The presentations reflect the multidisciplinary approach of the programme and offer a comprehensive insight into the wide range of research opportunities and applications.

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