Andreas Zbinden, Dr. Erik Ruettener, Dr. Peter Geissbuehler, Dr. Michael Spranger
Paper # 1055, Zurich, 06/19/2003

Probabilistic Hazard Modeling With ArcGIS: A Competitive Approach

Converium, a leading reinsurance company, manages the risk out of its written business using third party and in-house developed hazard models. Thousands of stochastic events of perils such as earthquake, windstorm, hailstorm, etc. are used for probabilistic hazard assessment.

Especially for countries where no commercial models are available, tools have been developed that allow fast and professional prototyping and generation of hazard maps and standardized event sets. The chosen approach is an efficient and accurate method which will show that its application can be used in the wide field of natural hazards.

Introduction

Hazard models in the insurance and reinsurance business are used to evaluate loss potentials and to assess risk accumulation, i.e. geographic concentration of risks as a result of adding dependent risk profiles. Several third-party models are available and used in Converium's pricing and accumulation control workflow. Modeling of loss potentials is a key factor for quantifying risks (=expected loss) in a (re-)insurance contract, monitoring and controlling of risk accumulation is essential to not expose a company to unbearable losses.

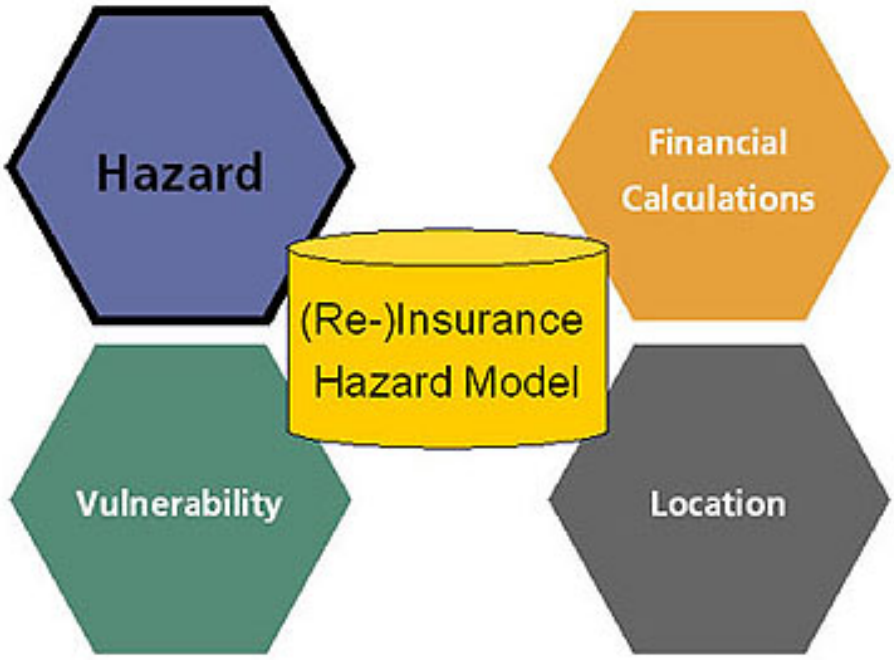
Within Converium, the Natural Hazards Team is responsible for these tasks, and therefore develops, implements and maintains hazard models for various perils (e.g. earthquake, storm) and regions.

The 4 modules of a (re-)insurance hazard model:

Hazard: Describes frequency and severity and the phenomena accompanying the event which may cause the damage or loss and is covered in this paper.

Vulnerability: Estimates the damageability of a building in case an event of a certain intensity happens.

Location: Information on the modeled locations. Can be either detailed (e.g. coordinates, street level address) or aggregated (e.g. CRESTA zone, county) information.



Financial Calculations: Covers (re-) insurance conditions like deductibles, limits, layers.

Fig.1: 4 modules for hazard modeling.
This paper concentrates on the hazard module

Despite their importance, the areas of modeling vulnerabilities, exposure and insurance conditions are not covered in this paper. It concentrates on an ArcView based tool called PHASE (Probabilistic Hazard Simulation Engine) that allows an efficient and reliable development of probabilistic event sets for use in our hazard models.
PHASE generates stochastic events that describe the characteristics of probable scenarios, i.e. the geographic distribution of possible storm tracks or earthquake occurrences.

Probabilistic Hazard Modeling

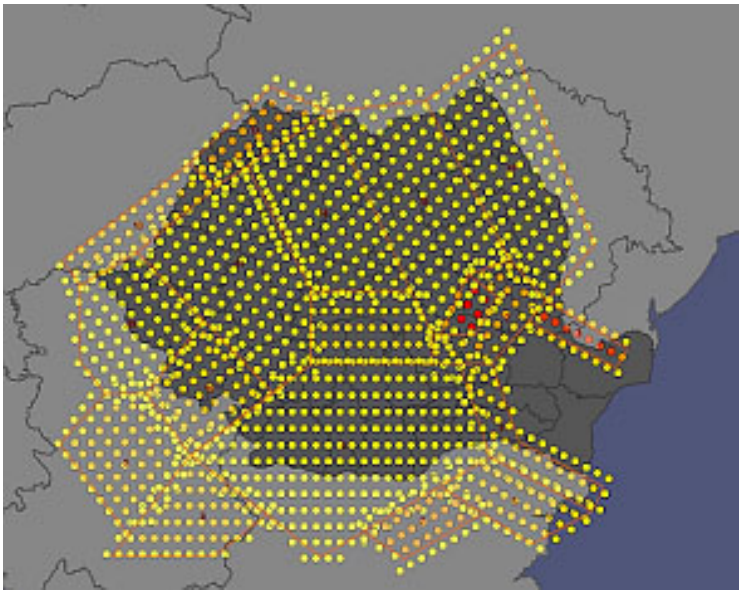


Fig.2: Event Set Romania Earthquake

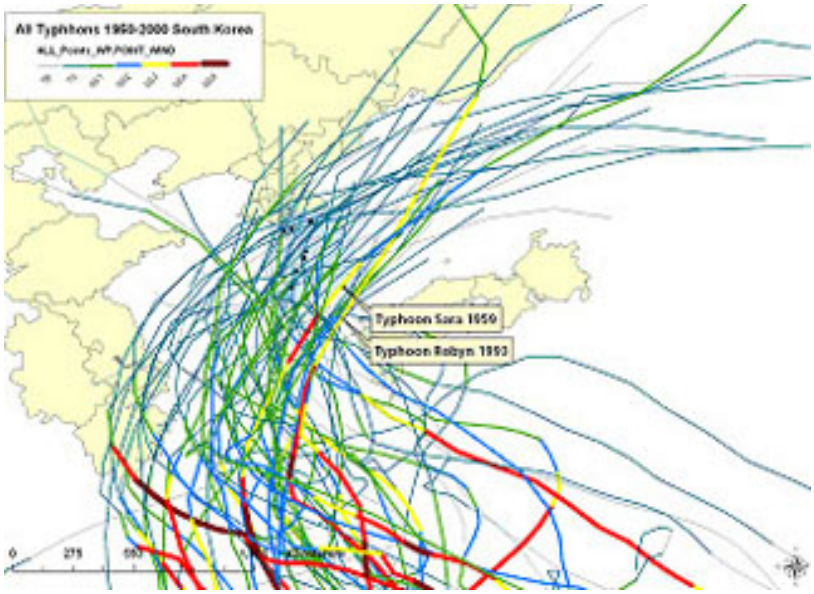


Fig.3: Typhoon Tracks South Korea

State-of-the-art loss modeling is based on probabilistic hazard analysis. A critical step in hazard analyses is the estimation of the recurrence rates of the studied phenomena, e.g. storms or earthquakes. The main

input for determining these rates are the observed historic records, which generally are to short for estimating rates for events with longer return periods. The historic record may also show gaps in the geographic distribution. Frequency-size relations are used to extrapolate historically non-observed events, source zoning and track variations are used to allow for events in all hazard prone regions.
Another challenge when creating these event sets is the trade off between ‘as much events as possible’ to cover every potential event, and ‘as few as possible’ to keep runtimes short and save disk space.

Probabilistic Seismic Hazard Modeling using ArcGIS and PHASE

By discussing the processing steps in the PHASE tool, the method of probabilistic hazard analysis following Cornell's approach will be explained. The example focuses on earthquakes and shows the essentials of probabilistic seismic hazard analysis.

1. Define source zones

Based on a historic catalogue of earthquake events, the area of interest is split into seismic source zones. For each zone we assume a uniform geographic distribution of the seismicity. The frequency magnitude relation can be described using a frequency distribution, e.g. the Gutenberg Richter equation:

$$\log(N) = a - bM$$

M: Magnitude
N: Number of events within a specified time period with a magnitude equal or larger than M
a, b: Parameters defining the characteristics of the source zone

Any other distribution (e.g. quadratic, characteristic) can be used as well if the parameters are known.
For the definition of these zones, freeware and shareware tools are available from several universities. Until now, we have used WIZMAP (Musson, 1998) and built an import routine to read the WIZMAP export format into PHASE.

2. Parameterize seismic source zones

For every model, a separate geodatabase is needed. There are no restrictions on projections. The display unit must be kilometers. Once the tool is started, a background layer can be loaded. Then the WIZMAP file is imported, creating a polygon layer with the following fields:

- Shape (Polygon)
- a, a-stdev
- b, b-stdev
- Maximum Magnitude
- Zone Name & ID

During the import, additional fields are added to the attribute table and filled with values:

- Zone orientation:	Using the angle of the longest zone segment as default value
- Zone center coordinates:	Polygon center as default value
- Flag - Frequency Function:	Defaulted to 'Linear'

- Magnitude Ranges:	Default magnitude ranges of 0.5 M are set
- Frequency for Mag Ranges:	Based on magnitude ranges, M max, a and b, frequencies are calculated

In case no WIZMAP file is available, the source zone layer is clearly defined and can be created manually. The same applies for faults as line objects. They are not yet implemented as a standard functionality.

More fields are added during the import and have to be filled with values:

- Frequency Function:	'Linear' (default) or 'Quadratic'
- c, c-stdev:	If a quadratic frequency formula needs to be used: Log(N) = a + bM + cM^2
- Attenuation Function:	Several Functions are available. Additional functions can be added quickly
- Attenuation Parameters:	Depending on the Attenuation function

In order to create an optimized event set, some parameters can be changed interactively:

- Magnitude Ranges:	Magnitude ranges can be changed and the frequencies recalculated.
- Depth:	Depth of the zone in km
- Center Point:	Defaulted to the polygon center and can be moved to any other location. As this point will be an event in the future event set, it can be set to the location of a historic event and later used as a scenario within the whole set.
- Zone Orientation:	Defaulted to the orientation of the longest zone segment and can be adjusted as well to get an optimized set of events.
- Zone Fuzziness:	Defines a border width, where events are weighted less in order to reflect an uncertainty in the location of the zone borders.
- Grid Size:	Defines the distance between the stochastic events (in map units) (Bender & Perkins 1986)
- Dip/Angle:	Defines orientation and dip angle if 3D source zones are used (not yet implemented)

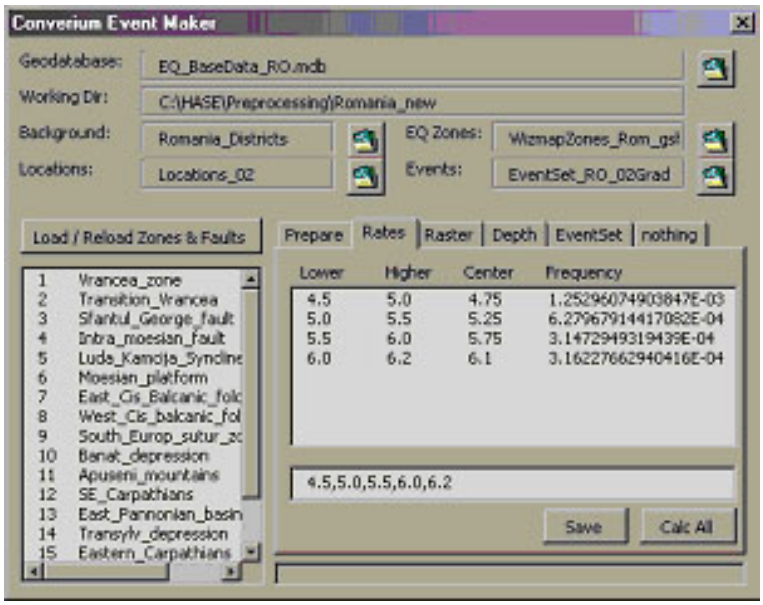


Fig.4: PHASE Screenshot

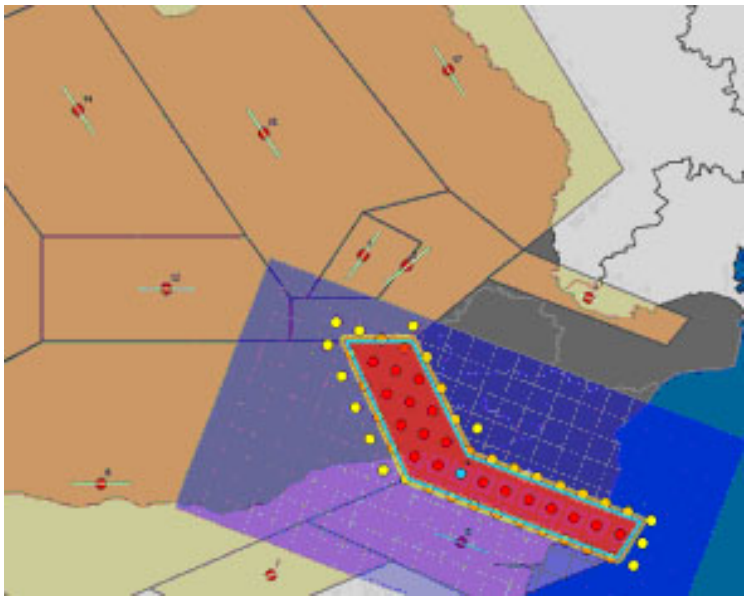


Fig.5: Screenshot: Zones, grid and events

3. Create and optimize events for every zone

Based on zone orientation, fuzziness and grid size, a grid is laid over the source zone and the grid cell centers used as event locations. The events get weighted proportional to the area which the grid cell shares with the source zone, reflecting the source zone boundary uncertainty.
The tool allows selecting every single zone, applying the above parameters and creating the events for the zone. Once all parameters are set, the whole event set can be created which usually takes a few minutes for several hundred event locations.

4. Calculate event set

In order to create an event set for our modeling tools, we need locations where we would like to measure the effect of an event. For example, this can be the polygon centers of a municipality's layer. For a given layer, the tool creates this location layer. During the development of an event set, one might be more interested in evenly distributed locations. The result can then be interpolated more easily to a hazard map than from unevenly distributed municipality centers.

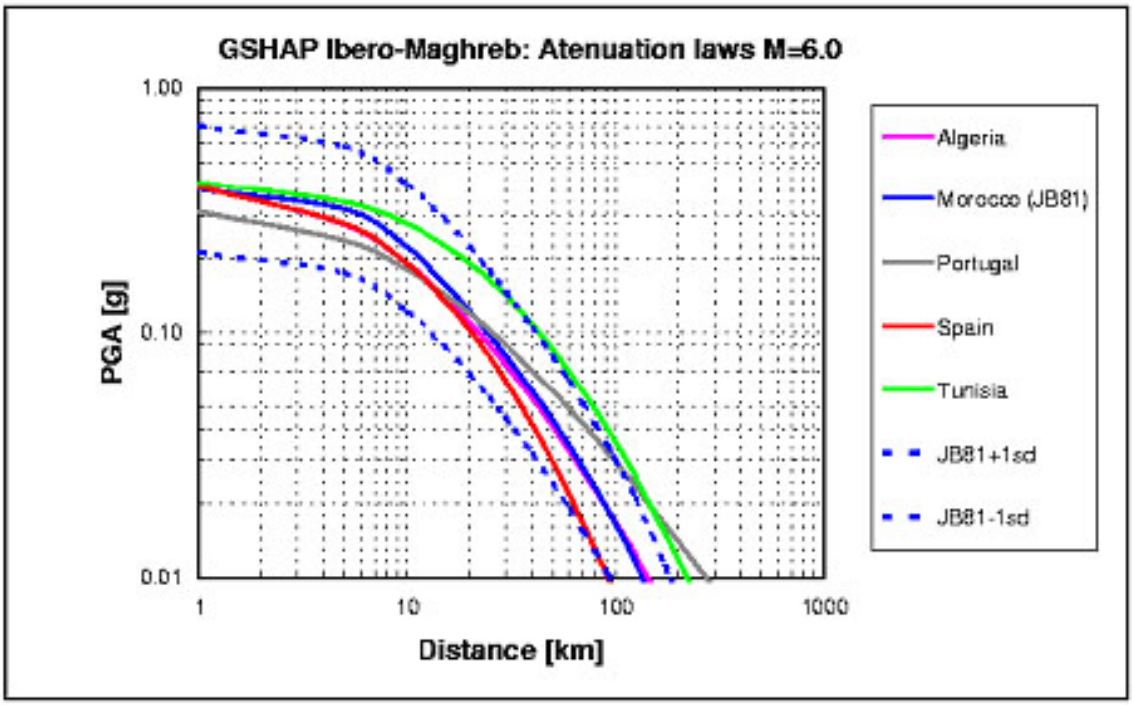


Fig.6: Attenuation function used in the Ibero-Maghreb (Jimenez et al. 1999)

For every event, PHASE now calculates the attenuation, based on the attenuation function and the supplied parameters. If needed, the attenuation can be calculated with directionality.

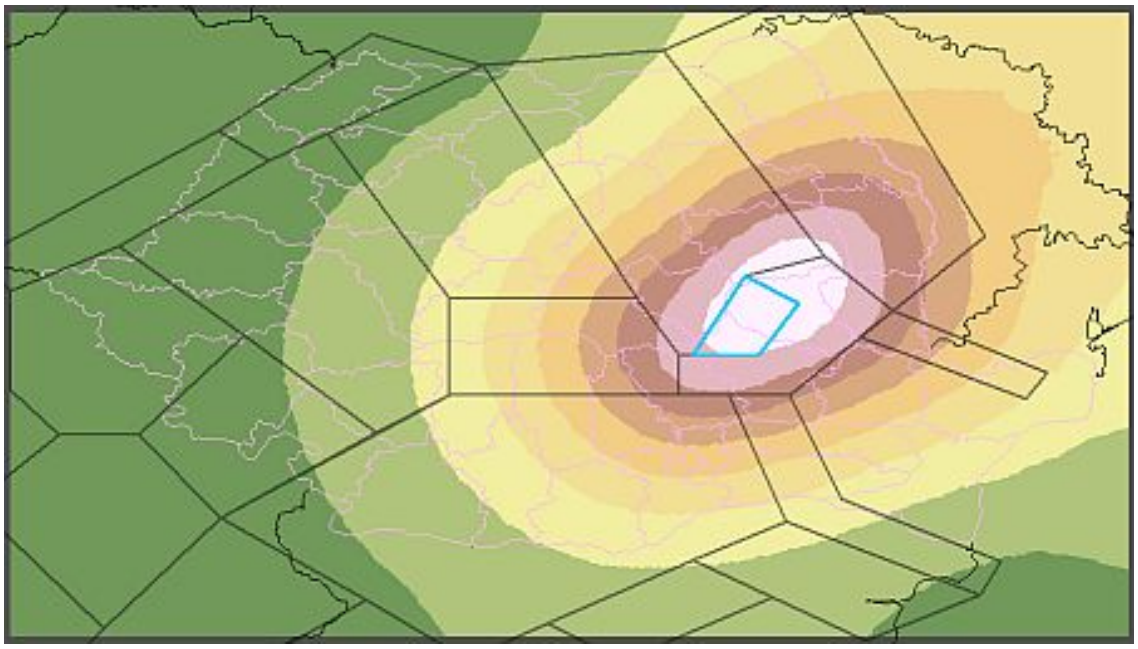


Fig.7: Directionality in the attenuation for the Vrancea seismic source zone in Romania

A generic attenuation function can be defined as follows (Reiter 1990):

$$\ln Y = \ln b1 + \ln f1(M) + \ln f2(R) + \ln f3(M,R) + \ln f4(P) + \ln(e)$$

Y: Strong Motion parameter to be estimated, e.g. pga
M: Magnitude of the earthquake
R: Hypocentral distance
P: Covers other source and site effects

The attenuation function used determines the output parameter, usually peak ground accelerations (pga) or intensity (e.g. MMI = Modified Mercalli Intensity) or even spectral acceleration/velocity or displacement.

The calculated event set is basically a list of stochastic events with its impact (MMI, pga) at every location and its associated frequency of occurrence. This list might become very large:

Assume 200 event locations with an average of 8 magnitude steps. For a country with 3000 municipalities, the event set contains 200 x 8 x 3'000 = 4.8 Mio records. By applying a threshold (e.g. earthquakes with an MMI of less than V at location do usually not cause any damage), this amount can be reduced substantially.

For the time being, PHASE writes a comma delimited text file. This is much faster than writing into a geodatabase table (MS Access). Depending on the threshold, this might take several minutes to calculate. By using other programming languages than VBA, this time can certainly be further reduced.

5. Create hazard map

Typical hazard maps show the expected pga or MMI for a certain return period. Therefore, for every location, a probability of exceedance for a certain return period must be calculated. By default, the following return periods are shown: 10, 20, 50, 100, 250, 500 and 1'000 years. If needed, any other return period can be calculated.
For earthquake, a poisson distribution is assumed, implying independence between individual events.

The probability of exceedance can then be calculated as follows:

$$P_n[m > M, t] = \frac{(\lambda t)^n \exp(-\lambda t)}{n!}$$

where Pn[m>M.t] is the probability of having n earthquakes with magnitudes greater than M over a time period t in a given area and lamda is the expected number of occurrence per unit time for that area.

This step is very memory consuming as for the chosen numeric approach; all events per location must be sorted. Here, the chosen threshold helps to speed up the calculation time. The calculation of a typical hazard map takes about two minutes.

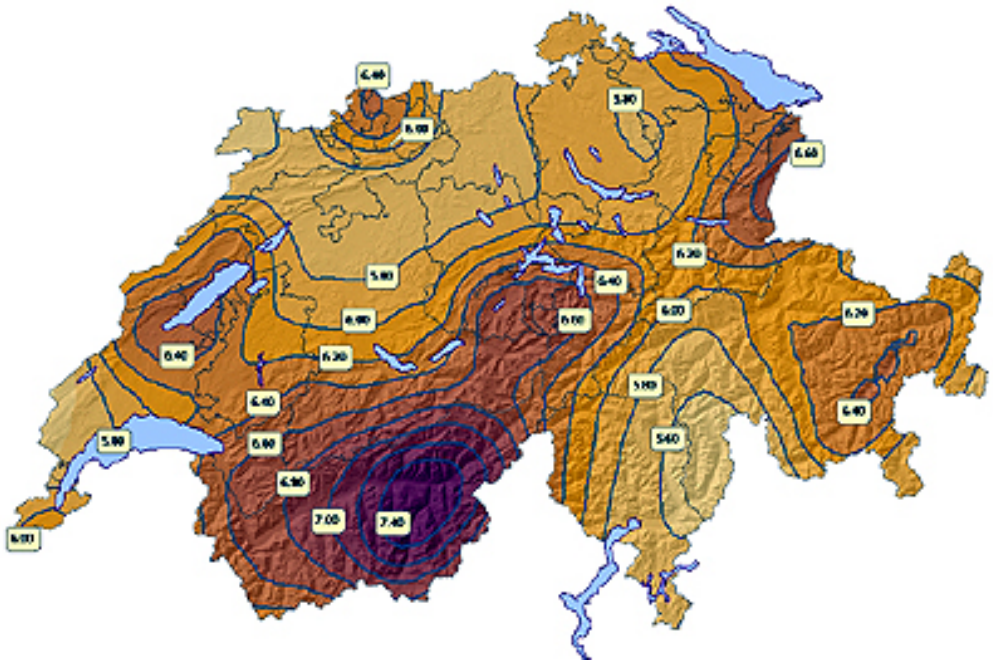


Fig.8: Hazard map for Switzerland, Converium earthquake model 2001

During the development phase, hazard maps can be drawn up for single zones or even displayed for a single event, in order to review frequencies, attenuation functions, directionality and other steps of the process. For actual events, the same functionality can be used to calculate pga/MMI shake maps and to generate event sets, which then can be used to make first loss estimations.

Conclusion

Even if the same functionality could be implemented in other (faster) programming environments, the use of ArcView GIS and ArcObjects have big advantages.
By using standard GIS functionality, the tools could be developed in short time. Even if the workflow is now streamlined as much as possible, changes in the functionality might be necessary due to the variability of the available basic data. Here the high flexibility of the VBA interface is very much appreciated. And as it is not planned to have dozens of users, it is also not so necessary to create a 'dummy-proof' solution.
Standards GIS users with only limited programming knowledge can use PHASE for model development without having to dig into the depths of ArcObjects and its objects, interfaces and enumerations.
For us, the natural hazards team at Converium, this also allows team members with high scientific know how but less programming skills, to build new models.

Outlook

There are several open issues (e.g. modeling of faults, subduction zones), which will be addressed soon. After consolidating the earthquake module, it is planned to implement additional modules for hurricane/ typhoon/windstorm, hail and possibly flood.

The created models will certainly be used for daily pricing and accumulation business. It enables us to fill gaps in our model landscape, to consult on customer specific problems or to contribute in mitigation projects.

References

Bender B., and Perkins, D.M., SEISRISK III. A Computer Program for Seismic Hazard Estimation US Geological Survey, Bulletin 1772, 1987
Cornell, C.A., Engineering seismic risk analysis, Bull. Seism. Soc. Am., 58, 1583-1606, 1968
Gutenberg, B. and Richter, C.F., Earthquake magnitude, intensity, energy and acceleration, Bull. Seismol. Soc. Am. 46, 105 - 145, 1956
Jiménez, María-José and García-Fernández, Mariano: Seismic hazard assessment in the Ibero-Maghreb region. Annali di Geofisica, Vol. 42, N.6, December 1999
Merz, H.A. and Cornell, C.A., Seismic risk analysis based on a quadratic magnitude-frequency law, Bull. Seismol. Soc. Am. 63, pp. 1999-2006, 1975
Musson, Roger M.W.: Probabilistic seismic hazard maps for the North Balkan region. Annali di Geofisica, Vol. 42, N.6, December 1999
Musson, Roger M. W., WizmapII. British Geological Survey Internal Report, 1998
Reiter, L., Earthquake Hazard Analysis. Colombia University Press, New York 1990.
Ruettener, Erik: Institute of Geophysics, ETH-Hoenggerberg, CH-8093 Zurich, Earthquake hazard evaluation for Switzerland
Sellami, Souad: SED, Institute of Geophysics, ETH-Hoenggerberg, CH-8093 Zurich, Seismische Gefaehrdungsanalyse, May 2000

Andreas Zbinden
Risk Modeler & GIS Specialist
Actuarial and Risk Modeling Services
Global Natural Hazards
Converium Ltd.
Phone: ++41 1 639 9113
andreas.zbinden@converium.com

Dr. Peter Geissbuehler
Risk Modeler & GIS Specialist
Actuarial and Risk Modeling Services
Global Natural Hazards
Converium Ltd.
Phone: ++41 1 639 9027
peter.geissbuehler@converium.com

Dr. Erik Ruettener
Manager Natural Hazards
Actuarial and Risk Modeling Services
Global Natural Hazards
Converium Ltd.
Phone: ++41 1 639 9027
erik.ruettener@converium.com

Dr. Michael Spranger
Risk Modeler & GIS Specialist
Actuarial Department
Converium Ltd.
Phone: +49 221 539 1459
michael.spranger@converium.com