# The Global Seismic Hazard Assessment Program (GSHAP) - 1992/1999

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**Abstract**
The United Nations, recognizing natural disasters as a major threat to human life and development, designed the 1990-1999 period as the International Decade for Natural Disaster Reduction (UN/IDNDR; UN Res. 42/169/1987). Among the IDNDR Demonstration Projects is the Global Seismic Hazard Assessment Program (GSHAP), launched in 1992 by the International Lithosphere Program (ILP) and implemented in the 1992-1999 period. In order to mitigate the risk associated to the recurrence of earthquakes, the GSHAP promoted a regionally coordinated, homogeneous approach to seismic hazard evaluation. To achieve a global dimension, the GSHAP established initially a mosaic of regions and multinational test areas, then expanded to cover whole continents and finally the globe. The GSHAP Global Map of Seismic Hazard integrates the results obtained in the regional areas and depicts Peak-Ground-Acceleration (PGA) with 10% chance of exceedance in 50 years, corresponding to a return period of 475 years. All regional results and the Global Map of Seismic Hazard are published in 1999 and available on the GSHAP homepage on http://seismo.ethz.ch/GSHAP/.

**Key words** *earthquakes – seismic hazard assessment – UN/IDNDR – seismic risk mitigation*

## 1. Introduction

The United Nations, recognizing natural disasters as a major threat to human life and development, designed the 1990-1999 period as the International Decade for Natural Disaster Reduction (UN/IDNDR; UN Res. 42/169/1987). The Decade goals were to increase worldwide awareness, foster the prevention and reduce the risks of natural disasters, through the widespread application of modern science and technology. As the first, necessary measure toward the implementation of risk reduction strategies, the Scientific and Technical Committee (STC) of the UN/IDNDR has endorsed international demonstration projects designed to improve the assessment of natural hazards (earthquakes, volcanoes, tropical hurricanes, floods, ...). Among these is the Global Seismic Hazard Assessment Program (GSHAP), launched in 1992 by the International Lithosphere Program (ILP) with the sponsorship of the International Council of Scientific Unions (ICSU) and the support of international scientific agencies (IUGG, IUGS, IASPEI) and of UNESCO.

Earthquakes are the expression of the continuing evolution of the Earth planet and of the deformation of its crust and occur worldwide; while the largest events ($M > 7.5$) concentrate on plate boundary areas and active plate interiors, large and moderate earthquakes ($6 < M < 7.5$) may take place, if rarely, in all continental areas. In general, the largest seismic hazard values in the world occur in areas that have been, or

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are likely to be, the sites of the largest plate boundary earthquakes. However, the notion that the primary targets for seismic hazard assessment should be the areas of high seismicity is incorrect. Events of moderate and small dimensions ($5 < M < 6.5$) occur virtually everywhere and may turn catastrophic in earthquake prone areas with poor building construction practice, as tragically shown by numerous recent tragedies. Vulnerability to disaster is increasing as urbanisation and developments occupy more areas that are prone to the effects of significant earthquakes.

Minimization of the loss of life, property damage, and social and economic disruption due to earthquakes depends on reliable estimates of seismic hazard. National, state, and local governments, decision makers, engineers, planners, emergency response organizations, builders, universities, and the general public require seismic hazard estimates for land use planning, improved building design and construction (including adoption of building construction codes), emergency response preparedness plans, economic forecasts, housing and employment decisions, and many more types of risk mitigation. The GSHAP was designed to provide a useful global seismic hazard framework and serve as a resource for any national or regional agency for further detailed studies applicable to their needs, by coordinating national efforts in multi-national, regional projects, reaching a consensus on the scientific methodologies for the seismic hazard evaluation and ensuring that the most advanced methodologies be available worldwide through technology transfer and educational programs.

The GSHAP embodies many of the strategies and priorities of the IDNDR, filling a critical gap cited by many countries in attempting to assess properly the seismic hazard of their territory. In order to mitigate the risk associated to the recurrence of earthquakes, the GSHAP promoted a regionally coordinated, homogeneous approach to seismic hazard evaluation; the ultimate benefits are improved national and regional assessments of seismic hazards, to be used by national decision makers and engineers for land use planning and improved building design and construction. The implementation of sound seismic hazard estimations into policies or seismic risk reduction will help a focus on the prevention of earthquake effects rather than intervention following the disasters.

The GSHAP was implemented in the 1992-1999 period. All regional activities have been completed by 1998 and all regional results and the GSHAP Map of Global Seismic Hazard are published in 1999 and are available on the GSHAP homepage on http://seismo.ethz.ch/GSHAP/. This report summarizes the development, the regional activities and the achievements of the GSHAP.

## 2. Seismic hazard

The seismic hazard is defined as the probabilistic measure of ground shaking associated to the recurrence of earthquakes. Seismic hazard maps depict the levels of chosen ground motions that likely will, or will not, be exceeded in specified exposure times. Hazard assessment commonly specifies a 10% chance of exceedance (90% chance of non-exceedance) of some ground motion parameter for an exposure time of 50 years, corresponding to a return period of 475 years.

The assessment of seismic hazard is the first step in the evaluation of the seismic risk, obtained by convolving the seismic hazard with local site effects (anomalous amplifications tied to soil conditions, local geology and topography) and with the vulnerability factors (type, value and age of buildings and infrastructures, population density, land use, date and time of the day). Frequent, large events in remote areas result in high seismic hazard but pose no risk; on the contrary, moderate events in densely populated areas entail small hazard but high risk. All measures of seismic risk reduction – *i.e.* seismic building coe zonation – rely on accurate seismic hazard assessment.

The assessment of seismic hazard measures our understanding of the recurrence of earthquakes in seismogenic sources. The basic elements of modern probabilistic seismic hazard assessment as implemented by GSHAP (Cornell, 1968; McGuire, 1993a; Muir-Wood, 1993; Basham and Giardini, 1993) can be grouped into four main categories:

1) *Earthquake catalogues and databases* – The compilation of a uniform database and catalogue of seismicity for the historical (pre-1900), early-instrumental (1900-1964) and instrumental periods (1964-today) (Guidoboni and Stucchi, 1993).

2) *Earthquake source characterization* – The creation of a master seismic source model to describe the spatial-temporal distribution of earthquakes, using evidence from earthquake catalogues, seismotectonics, paleoseismology, geomorphology, mapping of active faults, geodetic estimates of crustal deformation, remote sensing and geodynamic models (Muir-Wood, 1993; Pantosti and Yeats, 1993; Trifonov and Machette, 1993).

3) *Strong seismic ground motion* – The evaluation of ground shaking as function of earthquake size and distance, taking into account propagation effects in different tectonic and structural environments and using direct measures of the damage caused by the earthquake (the seismic intensity) and instrumental values of ground motions (Boore and Ambraseys, 1993).

4) *Computation of seismic hazard* – The computation of the probability of occurrence of ground shaking in a given time period, to produce maps of seismic hazard and related uncertainties at appropriate scales (McGuire, 1993a).

The assessment of seismic hazard in different areas of the globe is hindered by political boundaries and technical limitations (McGuire, 1993b).

National boundaries are the most significant element of discontinuity in seismic hazard assessment; indeed, input data and the hazard itself are generally assessed for the implementation of national-scale building zoning. Consider for example the situation in Europe, where at the start of GSHAP all the basic elements for a homogenous seismic hazard assessment were lacking: a unified earthquake monitoring system (short period, broadband, strong-motion), regional travel-time tables and homogeneous location procedures, homogeneous magnitude scales, unified seismic catalogue and seismic source zoning, common strong motion attenuations, regional coordination for SHA; as a consequence, we lacked also a common regional hazard assessment and common engineering requirements. While the situation has now improved under the efforts of the European Seismological Commission, of GSHAP, and of other seismological organizations and projects, the subdivision of the European-Mediterranean area in several individual test areas for the implementation of GSHAP (Grünthal *et al.*, 1999a) testifies to the difficulty of by-passing national boundaries.

A second limitation regards the quality and availability of the basic data needed for seismic hazard assessment, which varies greatly around the world and influences the quality of the hazard. Instrumental seismic catalogues covering the last 30 years exist for all areas of the world; however, the accuracy of hypocentral locations and especially the determination of earthquake size (at least ten different magnitude scales are still commonly used, and several tens of regional regressions exist) strongly depend on the availability of monitoring networks; uneven station coverage results in uneven completeness of regional catalogues for moderate-size events. A complete instrumental catalogue will span only a few decades, while the recurrence of large earthquakes in active areas may need characteristic period of hundreds or thousands of years (for example, a comparison of the instrumental seismicity of the last 30 years with the location of the historical earthquake disasters in the Mediterranean basin shows how some areas have experienced devastating earthquake in the past, while displaying little or no recent activity). The need to compile accurate catalogues of historical earthquakes is hindered by the uneven availability of reliable historical sources in different parts of the world and by the inherent difficulty of searching and analysing these sources. In the end, the most complete catalogue cannot characterize the seismogenic process where large earthquakes return every few or tens of thousands of years, *i.e.* in areas of active plate interiors and diffuse continental deformation; seismic zoning attempted without sufficient background information from geology proves to be very uncertain and in many areas of the world today geology is providing key input, allowing to associate the historical earthquakes to specific seismogenic features (through evidences from seismotectonics, paleo-seismology, geomorphology, mapping of active faults, geodetic estimates of crustal deformation, remote sensing and geodynamic models) and to build alternative models of seismic zonation.

The quality of the data available from the catalogues and seismotectonics conditions the hazard assessment and the choice of methodology to be used for the hazard assessment. Four different approaches are available and commonly used:

– *Historical determinism* maps the maximum intensity of earthquake effects recorded in known historical times, to represent, with appropriate corrections, the highest intensity to be expected in the future.

– *Historical probabilism* builds a statistical model of seismogenic sources to reproduce the historical record of seismicity (location in space and time, frequency-size distribution).

– *Seismotectonic probabilism* incorporates geological evidence (prehistoric record of paleoseismic activity, geomorphology, rates of crustal deformation from land and space geodesy, neotectonic and geodynamic modelling) to supplement the historical record of seismicity in building a seismic source model covering earthquake cycles up to a few thousands years.

– *Time-dependent seismotectonic probabilism*: the use of non-Poissonian statistics allows to take into account not only the periodicity of earthquake recurrence but also the time elapsed since the last significant earthquake, as a most significant parameter in assessing the future seismic activity.

The adoption of these different approaches leads to largely different expectations of short-term seismic hazard for locations characterized by similar seismo-tectonic setting and different seismic histories. Seismic hazard is assessed in some nations still using historical probabilism, relying essentially on the catalogue and often only on the instrumental catalogue, while others are already experimenting with time-dependent hazard assessment.

A further element of division across political boundaries is the geographical size of the country, which conditions the integral probability that a country experience an earthquake and the scale of the input data and of the seismic hazard maps, often to the point of making them incompatible in border areas.

Finally, a disciplinary boundary remains in many countries between Earth scientists (geologists, seismologists, geophysicists) and earthquake engineers responsible for the implementation of hazard in zoning schemes for building construction practice.

The GSHAP aimed at reducing these limitations, by assessing hazard in a coordinated, multidisciplinary and multi-national approach. To this end GSHAP implemented a common seismotectonic probabilistic method at global and regional scale and adopted Peak-Ground-Acceleration (PGA) for hazard mapping, a short-period ground motion parameter that is proportional to force and the most commonly mapped ground motion parameter, because current building codes that include seismic provisions specify the horizontal force a building should be able to withstand during an earthquake. Short-period ground motions affect short-period structures (*e.g.*, one-to-two story buildings, the largest class of structures in the world).

The site classification is rock everywhere except Canada and the United States, which assume rock/firm soil reference ground conditions.

## 3. Design principles

The GSHAP has been designed as a Decade demonstration project, adopting and implementing the following design principles:

1. Hazard assessment as the prime input for the implementation of risk mitigation strategies.
2. Scientific research as a key to engineering applications.
3. Maintain high scientific standards.
4. Ensure consensus and enlarge participation at all levels.
5. Enforce a multi-disciplinary approach to seismic hazard assessment.
6. Work across boundaries.
7. Enhance the role of developing countries.
8. Ensure technology transfer.
9. Focus on key geographical and border areas.
10. Ensure the implementation of regional and global results in national policies.

## 4. GSHAP history

8.91 Following the ICSU request to provide scientific input for IDNDR demonstration activities, ILP initiates the planning and preparation for the GSHAP.

3.92 The UN/IDNDR Scientific and Technical Committee endorses the GSHAP as a Decade demonstration project.

6.92 The GSHAP is launched with a Technical Planning Meeting in Rome, to focus the consensus of the scientific community on the development of a multi-national and multi-disciplinary approach to seismic hazard assessment, to define schedule and structure of the program.

92-93 The first year is devoted to the definition and implementation of the regional and management structure, the establishment of the program in the international scientific and engineering communities, the coordination with other UN/IDNDR activities, the establishment of a funding strategy.

7.93 The GSHAP Planning Volume is published (Giardini and Basham, 1993), containing all program documents, a revision of the existing status-quo in global seismic hazard and the technical guidelines for the GSHAP implementation.

93-95 The first implementation phase is devoted to implement the key strategic elements of the program: the operation of regional centres in all continents and the activation of multinational test areas for seismic hazard assessment in regions of high seismotectonic significance.

8.95 Program evaluation at the IUGG XXI General Assembly in Boulder.

95-97 The second implementation phase extends the GSHAP coverage to more test areas and regions covering the most of the world.

8.97 Regional results are presented and evaluated in a special meeting (Thessaloniki, IASPEI General Assembly); plans for the final phase of GSHAP are drawn.

97-99 The final phase focuses on the completion of regional hazard assessment, on the compilation of all regional databases and results, on the compilation of the GSHAP map of global seismic hazard, on the dissemination of GSHAP products and materials (special volumes, maps, web).

7.99 The GSHAP map of global seismic hazard is presented at the IDNDR Closing Conference in Geneva and at the IUGG XXII General Assembly in Birmingham.

12.99 Publication of the GSHAP global map and of the GSHAP summary volume on *Annali di Geofisica.*

## 5. Summary of regional activities

To achieve a global dimension, the GSHAP strategy established in Roma in 1992 has been to establish a mosaic of regions under the coordination of regional centers. The goal in the first implementation phase (1993-1995) was to compute the seismic hazard in selected test areas, and to then expand in the second phase (1995-1997) to cover whole continents and finally the globe. This strategy has been maintained in many of the originally established ten regions, while elsewhere the activities focussed directly on key test-areas under the coordination of large working groups. Some areas, specifically the Mediterranean and the Middle East, have been covered by a mosaic of overlapping projects, while elsewhere (*i.e.* parts of Africa and of the Western Pacific rim) the hazard mapping was obtained only at the end of the program by using published materials (Giardini *et al.*, 1999). In specific cases GSHAP allied with existing hazard projects with similar purpose and methodologies, to avoid duplications and strengthen the across-boundary cooperation (*i.e.* in the Balcans and Near-East).

Figures 1 and 2 compare the regional structure of GSHAP as original planned (fig. 1, after Giardini and Basham, 1993) and as implemented in the 1992-1998 period (fig. 2), with a global coverage including original GSHAP regions (outlined in black in fig. 2), GSHAP test areas

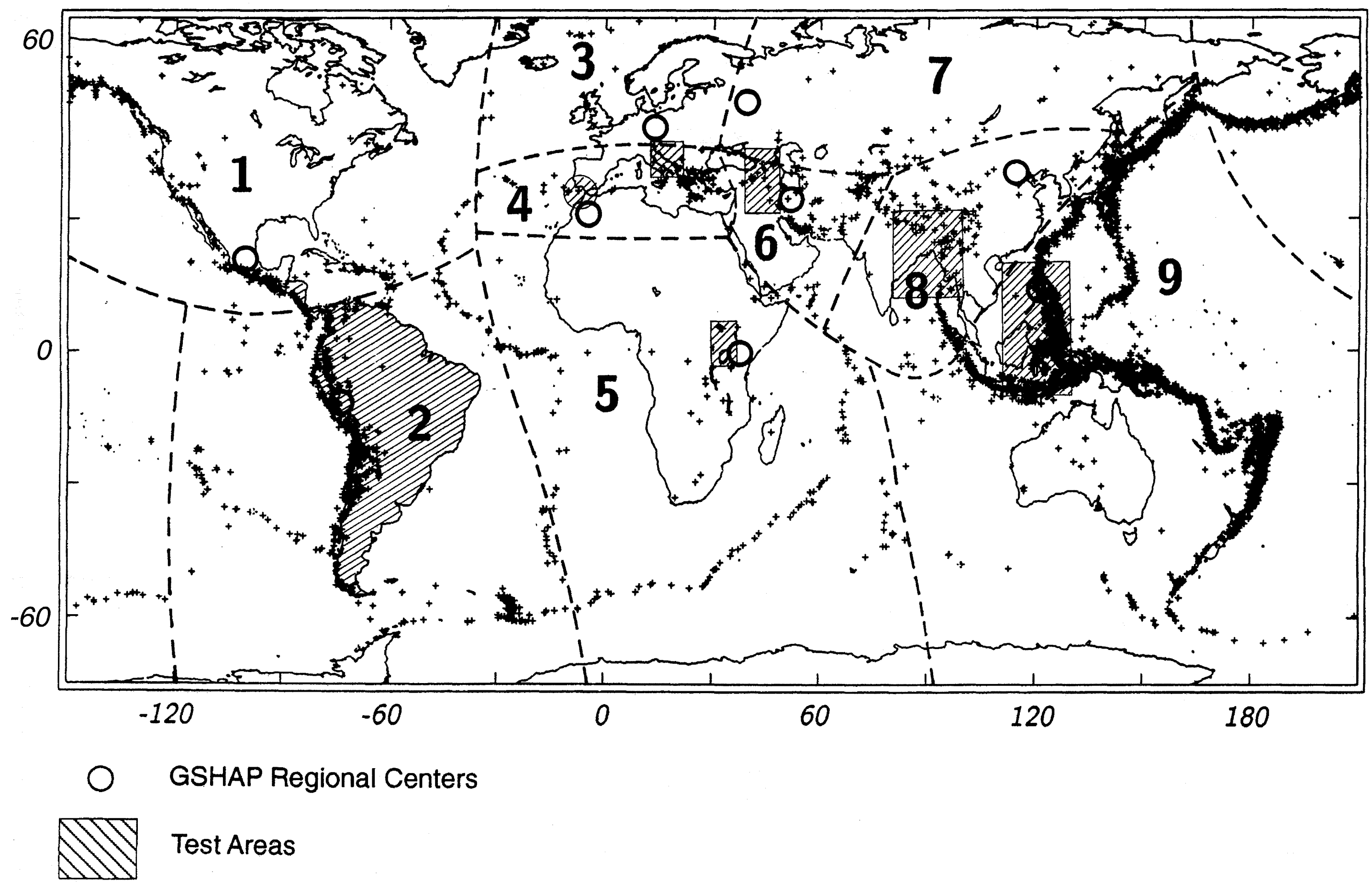


**Fig. 1.** The regional structure of GSHAP as original planned in 1992 (fig. 3 after Giardini and Basham, 1993).

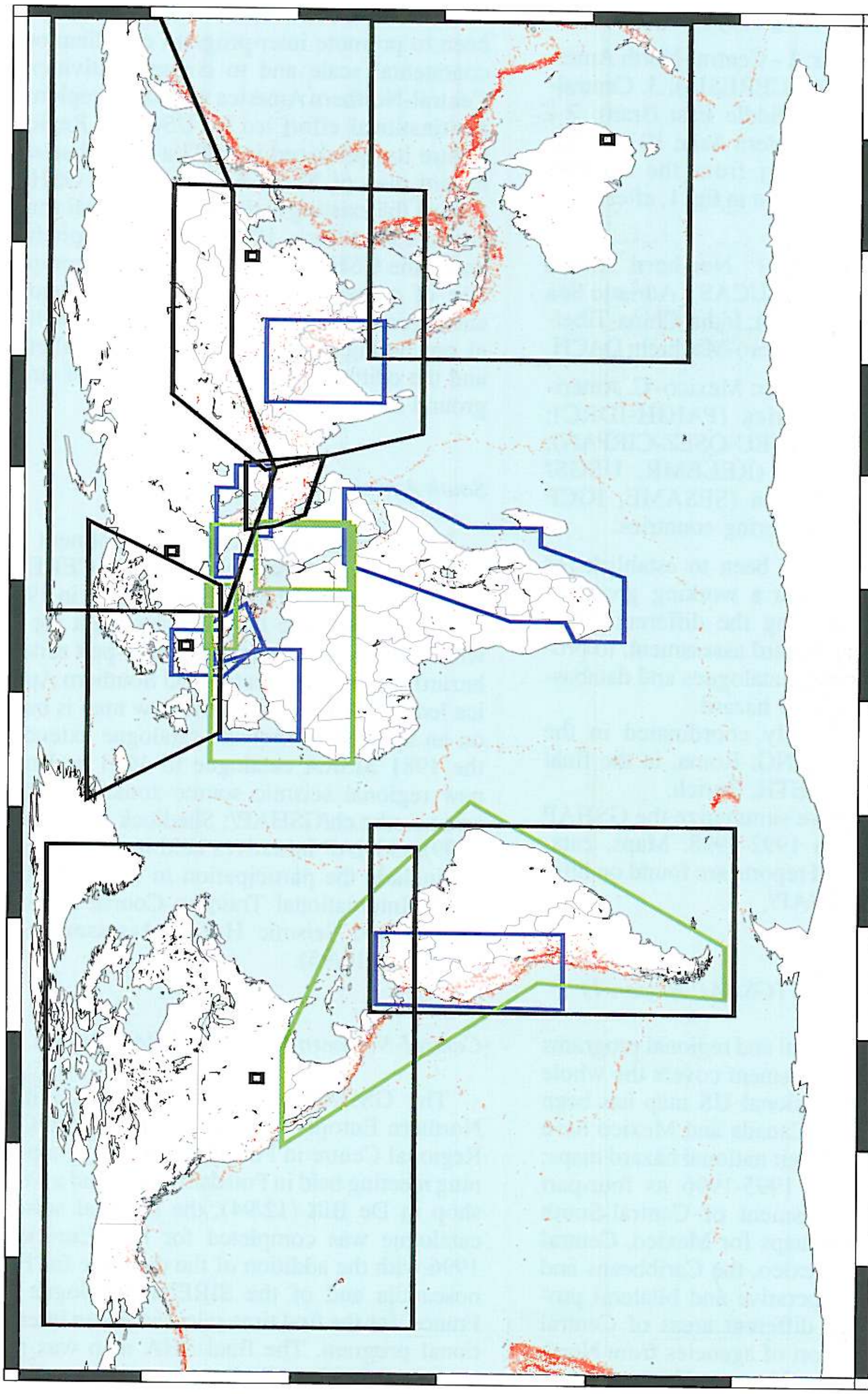

**Fig. 2.** The regional structure of GSHAP implemented in the 1992-1998 period, including original GSHAP Regions: 1 - Central-North America; 2 - South America/CERESIS; 3 - Central-Northern Europe; 6 - Middle East/Iran; 7 - Northern Eurasia; 8 - Eastern Asia; 10 - South-West Pacific (in black), numbering from the GSHAP subdivision in fig. 1; GSHAP Test Areas: PILOTO, CAUCAS, ADRIA, East African rift, India-China-Tibet, Ibero-Maghreb, DACH (in blue), and cooperating projects: PAIGH-IDRC, Circum Pannonian basin, Eastern Mediterranean, SESAME, Turkey (in green).

(in blue) and Cooperating Projects (in green):

– *GSHAP Regions*: 1 - Central-North America; 2 - South America (CERESIS); 3. Central-Northern Europe; 6 - Middle East (Iran); 7 - Northern Eurasia; 8 - Eastern Asia: 10 - South-West Pacific (numbering from the original GSHAP subdivision, shown in fig. 1, after Giardini and Basham, 1993).

– *GSHAP Test Areas*: Northern Andes (PILOTO); Caucasus (CAUCAS); Adriatic Sea (ADRIA); East African Rift; India-China-Tibet-Myanmar-Bangla Dash; Ibero-Maghreb; DACH.

– *Cooperating Projects*: Mexico-C. America-Caribbean-S. America (PAIGH-IDRC); Circum Pannonian Basin (EU-QSEZ-CIRPAN); Eastern Mediterranean (RELEMR, USGS/UNESCO); Mediterranean (SESAME, IGCP 382); Turkey and neighboring countries.

The general rule has been to establish for each region or test area a working group of national experts covering the different fields required for seismic hazard assessment, to produce common regional catalogues and databases and to assess regional hazard.

GSHAP was globally coordinated in the 1992-1997 period by ING, Roma, in the final 1997-1999 period by ETH, Zurich.

In the following we summarize the GSHAP regional activities in 1992-1998. Maps, catalogues, databases and reports are found on http://seismo.ethz.ch/GSHAP/.

*Central-North America (GSHAP Region 1)*

A network of national and regional programs in seismic hazard assessment covers the whole region: the new provisional US map has been released in 1996 and Canada and Mexico have also recently revised their national hazard maps; PAIGH completes in 1995-1996 its four-part seismic hazard assessment of Central-South America, producing maps for Mexico, Central America South of Mexico, the Caribbeans and South America; cooperative and bilateral programs are active in different areas of Central America under support of agencies from North America and Europe (Norway, European Union). In this framework the role of GSHAP has been to promote inter-program coordination at continental scale and to connect activities in Central-Northern America with other regions. A multinational effort led by USGS as Regional Centre has produced in 1997 a unified seismic hazard map of North-America under GSHAP, joining the existing national and regional source zonings (Shedlock, 1999). Additional products under the GSHAP banner include the compilation of a new global instrumental earthquake catalogue, starting from the scanning and digital processing of the ISS and BCIS Bulletins, and the editing of a new compilation of strong ground motion attenuation laws.

*South America (GSHAP Region 2)*

The whole South American continent has been selected as test area under the CERESIS Regional Centre. CERESIS completed in 1995-96 the new seismic hazard assessment for the whole continent, as part of the four-part seismic hazard mapping of Central and Southern America led by PAIGH/IDRC; the new map is based on an updated earthquake catalogue extending the 1981 SISRA catalogue to 1991 and on a new regional seismic source zonation (http://seismo.ethz.ch/GSHAP/; Shedlock and Tanner, 1999). GSHAP initiatives held in South America include the participation in the UNESCO-GFZ «International Training Course on Seismology and Seismic Hazard Assessment» in Costarica (10/95).

*Central-Northern Europe (GSHAP Region 3)*

The GSHAP implementation in Central-Northern Europe was coordinated by the GFZ Regional Centre in Potsdam. Following a planning meeting held in Potsdam (7/93) and a workshop in De Bilt (12/94), the regional seismic catalogue was completed for NW Europe in 1996 with the addition of the database for Fennoscandia and of the SIRENE catalogue for France, for the first time released for an international program. The final SHA map was presented in 1997, including the whole territory north of 46°N and the seismic hazard for France completed also south of 46°N (Grünthal *et al.*, 1999b). A unified hazard assessment for the German speaking countries (Germany-Austria-Switzerland) was produced in 1996 by national teams including seismologists and engineers, under the coordination of GFZ at Potsdam, as preparatory work for the implementation of the new european seismic building construction code (EC8). DACH has also been promoted as GSHAP test area (Grünthal *et al.*, 1999b). In addition, an independent zonation is now available for Poland, Czech Republic and Slovakia, coordinated by Prague University.

*Middle East (GSHAP Region 6)*

The Regional Centre at IIEES, Tehran, has coordinated activities in the area with a direct involvement in the CAUCAS test area and with workshops organized in Tehran (1/93, 5/95, 5/99) and Ashgabad (10/94) (Tavakoli and Ghafory-Ashtiany, 1999).

*Northern Eurasia (GSHAP Region 7)*

The GSHAP Regional Centre in Moscow, JIPE, has coordinated the seismic hazard mapping for the whole territory of the former U.S.S.R. A five-year program, initiated before the FSU break-up and interrupted during the period of more intense political turmoil, has been restarted, leading to the compilation of the seismic catalogue and the SHA, using for the first time a probabilistic approach. Technical workshops were held in Beijing (4/93, 10/94), Bishkek (9/95) and Moscow (4/96, 9/97). The area has been subdivided in five blocks, and the regional hazard maps in MSK were completed in 1998 (Ulomov *et al.*, 1999).

*Eastern Asia (GSHAP Region 8)*

Following in the original framework planned in Rome, 1992, the hazard mapping for the whole Eastern Asia originates from the expansion of the test area initially established in the border region of China-India-Nepal-Myanmar-Bangla Dash. The regional mapping has been coordinated by the SSB Regional Centre in Beijing, in coordination with the other Regional Centres (JIPE, Moscow, and AGSO, Canberra) and with the direct assistance of the USGS. The hazard incorporated the results of the technical meetings held in Beijing (10/93, 10/94) and Hyderabad (3/96). All Eastern Asian countries have participated directly in this regional effort, with the exclusion of Japan, for which an existing national hazard map was incorporated (Zhang *et al.*, 1999). In addition, the «Eastern Asia Natural Hazards Mapping» project, led by the GSJ, has compiled seismicity maps for the whole Eastern Asia region from China to Japan to Indonesia at 1:5 million scale; planning meetings were held in Tsukuba (6/93) and Yokohama (5/94), and two technical workshops in Tsukuba (9/94, 9/95). The EANHM project coordinated its activities with the GSHAP centres in Asia (SSB) and Australia (AGSO).

*South-West Pacific (GSHAP Region 10)*

Activities in this vast area have progressed in independent sub-areas (Australia, New Zealand, Papua New Guinea, Tonga-Fiji, Vanuatu and Solomon Islands), with a coordinating «South-West Pacific/South-East Asia Regional Meeting» hosted by AGSO in Melbourne (11/95). Given the peculiar character of the whole area, including only island states with no direct boundaries, the approach has been to merge national hazard maps with a careful selection to ensure homogeneity; Australia and New Zealand have also produced revised national maps. AGSO of Canberra has coordinated the integration of the national products in the regional map, including in the later phase Indonesia and Philippines (McCue, 1999).

*Northern Andes (PILOTO)*

Five Andean countries (Bolivia to Venezuela) and four European countries cooperated in the PILOTO program («Test Area for Earthquake Monitoring and Seismic Hazard Assessment»), launched under GSHAP and sponsored by the European Union (Ct.94-0103), to produce in 1997 a unified SHA for the Andean region. Activities included the integration of national earthquake catalogues and source zonings in common regional databases, a coordinating meeting in occasion of the Regional Seismological Assembly in Brasilia (8/94), regional SHA workshops held in Bogota (10/95, 1/97) and Quito (6/97) and a joint ILP/PILOTO «Training Course in Paleoseismology» held in Venezuela (2/97) (Dimaté *et al.*, 1999).

*Iibero-Maghreb*

GSHAP has promoted the reactivation of the former ESC program. Activities to produce a first generation of SHA for the Ibero-Maghreb area by 1997 have been coordinated by the CSIC of Barcelona. Workshops were held in Granada (5/94), Rabat (12/95) and Barcelona (12/96, 5/97), with partial support from IGCP/SESAME, the first in occasion of the UNESCO/USGS «6th International Forum on Seismic Zonation: First Ibero-Maghreb Region Conference». In 1996 the CNCPRST of Rabat, the GSHAP Regional Centre, became the «Centre Euro-Méditerranéen d'Evaluation et de Prevention du Risque Sismique or Seismic Hazard Assessment (CEPRIS)» under the Open Partial Agreement on Natural Disasters of the European Council, with the mandate of coordinating activities in the Ibero-Maghreb and Western Mediterranean areas (Jiménez *et al.*, 1999).

*ADRIA*

This project includes all countries bordering on the Adriatic Sea, from the Alps to Greece, coordinated by OGS of Trieste. A new geodynamic model for the whole Central Mediterranean, the seismic zoning map, the combined earthquake catalogue and the new hazard maps, in spectral ground motion parameters, have been compiled during a series of regional workshops (Trieste 7/94, Athens 9/95, Ljubliana 10/95, Pisa, 2/98) and presented in Tel Aviv at the ESC (8/98) (Slejko *et al.*, 1999).

*Eastern Mediterranean*

GSHAP, the UNESCO/IUGS IGCP n. 382 (SESAME: Seismotectonics and seismic hazard assessment in the Mediterranean), the European Seismological Commission (IASPEI) and the UNESCO/USGS RELEMR are coordinating their activities, to produce a unified hazard mapping for the area, including Turkey, Syria, Lebanon, Cyprus, Israel, Jordan, Egypt, Palestine, Saudi Arabia and the Arabian peninsula. In 1996 SESAME organized its first «Training Workshop on Seismotectonics and Seismic Hazard Analysis in the Eastern Mediterranean Countries» in Cairo (12/96); a second workshop was held again in Cairo (12/97) focussing on the compilation of the active fault map and regional SHA. RELEMR includes hazard mapping from Turkey to the Red Sea; following initial planning meetings in Cairo (10/93) and Paris (5/95), technical meetings and regional coordination meeting were held jointly with SESAME in Cyprus (12/96, 12/97), Thessalonicki (8/97), Amman (5/98) and Tel Aviv (8/98) to produce the first regional PGA map, under the coordination of ETH Zurich (Grünthal *et al.*, 1999a). The PGA maps for Turkey, Greece and Iran have been independently produced under national programs (Erdik *et al.*, 1999). In the last workshop organized by RELEMR in Istanbul (10/98), a new strategy to build common earthquake catalogue, source zones and hazard has now been established for the whole region.

*CAUCAS*

The Test Area for SHA in the Caucasus is coordinated by GSHAP with IASPEI and INTAS support (Ct.94-1644), joining seismological institutions from the Caucasian republics, Russia, Turkey and Iran. Starting in 1994, multinational working groups produced an integrated regional earthquake catalogue (historical and instrumental), a new model of seismic lineaments and seismic zoning, and comparative SHA following probabilistic, deterministic, mixed probabilistic-deterministic and areal probabilistic methodologies. Workshops were held in Tehran (1/93), Moscow (9/93), Ashgabad (10/94), Tehran (5/95), Yerevan (7/96) and Tbilisi (7/97). A comprehensive report has been distributed in 1997, summarizing the results. The NATO-ARW «Historical and Prehistorical Earthquakes in the Caucasus» (Ct.95-1521) was held in Armenia (7/96) and produced a comprehensive proceedings volume published by Kluwer (Giardini and Balassanian, 1997; Balassanian *et al.*, 1999).

*African rift*

The «Eastern and Southern Africa Regional Seismological Working Group», with support from the Swedish Government, Bergen University, the BGS, IASPEI and GSHAP, held periodic workshops to compile the regional earthquake catalogue and SHA for the African rift area. Workshops were held in Entebbe (8/94), Addis Abeba (1/95), Bulawayo (2/96) and Bergen (6/97) and for the first time eight of the nine participating countries have a national seismic hazard map, including site-specific hazard estimates for the capital cities along the Rift (Midzi *et al.*, 1999). A second initiative was directed by the Regional Centre at the University of Nairobi, who organized a regional planning meeting in Nairobi (11/93) and hosted the UNESCO/GFZ «International Training Course in Seismology and Seismic Hazard Assessment» (Nairobi, 9/97).

*China-India-Nepal-Myanmar-Bangla Dash*

The GSHAP test area has been established in the border region of China, India, Nepal, Myanmar and Bangla Dash, under the direction of the SSB of Beijing, the GSHAP Regional Centre and the NGRI of Hyderabad; it is the first time that this type of regional framework is effectively operating in the region. Activities initiated with a planning meeting in Beijing (10/93), followed by the preliminary compilation of regional catalogues and by technical workshops in Beijing (10/94) and Hyderabad (3/96), to produce the final earthquake catalogue, seismic source zoning and SHA presented at the ASC Assembly in Tangshan (8/96) and the 30th International Geological Congress in Beijing (8/96) (Bhatia *et al.*, 1999).

*Circum-Pannonian*
*(EU-QSEZ-CIPAR CT.94-0238)*

The «Quantitative Seismic Zoning of the Circum-Pannonian Region» project includes the countries of the Circum-Pannonian basin (Hungary, Romania, Slovania, Croatia, Albania) in addition to Italy and U.K. While the aim of this independent project was to produce a deterministic hazard assessment for the region, a specific source zoning (1997) and probabilistic hazard assessment (1998) were produced by BGS, Edinbourgh, for comparison with the deterministic results and for inclusion in SESAME and GSHAP (Musson, 1999).

*Mediterranean (IGCP n. 382 SESAME)*

The UNESCO/IUGS International Geological Correlation Program n. 382 «Seismotectonics and Seismic Hazard Assessment in the Mediterranean» (SESAME) has the goal of coordinating and integrating the results obtained in the Mediterranean and Middle East regions by the different project active in the areas: ADRIA, Ibero-Maghreb, Circum-Pannonian, Eastern Mediterranean, Central-Northern Europe, African rift, CAUCAS. SESAME is implemented in the 1996-2000 period and has so far co-sponsored many of the events in the different regional programs, culminating in the first compilation of regional hazard presented at the 1998 ESC assembly (Tel Aviv, 8/98) (http://seismo.ethz.ch/GSHAP/). A separate program «A Basic European Earthquake Catalogue and Database for the Evaluation of Long-Term Seismicity and Seismic Hazard» (BEECD, EU Ct. 94-0479), coordinated by IRRS of Milan, has produced a regional seismic catalogue covering the European part of the Mediterranean (http://emidius.irrs.mi.cnr.it/BEECD/).

## 6. The GSHAP map of global seismic hazard

The GSHAP global map of seismic hazard integrates the results obtained in the regional areas (Giardini *et al.*, 1999) and depicts peak-ground-acceleration with 10% chance of exceedance in 50 years, corresponding to a return period of 475 years. Three of the GSHAP regional centres acted as focal points to collect and merge the existing results in large continental areas: USGS, Colorado, for the Americas; GFZ, Potsdam, for Europe-Mediterranean-Africa-Middle East; SSB, Beijing, for Central-Eastern Asia; AGSO, Canberra, for Australia-Western Pacific margin. An editorial committee has prepared technical specifications for the final compilation of the regional reports, the databases and the hazard maps. Global coordination was provided by ETH, Zurich. The map has been assembled and published at USGS, Golden Colorado.

## 7. Six years of GSHAP workshops

A key factor in the GSHAP implementation have been the technical workshops, organized in occasion of major international assemblies and more often as independent events to bring together national experts from all the disciplines involved in the assessment of seismic hazard. These meetings were held at project or interproject scale, with up to a hundred and more participants. The following list reviews the sequence of workshops, as detailed in the regional activities above.

| | |
|---|---|
| Rome, 6/92 | Tehran, 1/93 |
| Beijing, 4/93 | Potsdam, 7/93 |
| Moscow, 9/93 | Beijing, 10/93 |
| Ixtapa, 4/94 | Granada, 5/94 |
| Trieste, 7/94 | Brasilia, 8/94 |
| Entebbe, 8/94 | Nairobi, 9/94 |
| Ashgabad, 10/94 | Beijing, 10/94 |
| De Bilt, 12/94 | Addis Abeba, 1/95 |
| Wellington, 1/95 | Tehran, 5/95 |
| Boulder, 7/95 | Erice, 8/95 |
| Athens, 9/95 | Bishkek, 9/95 |
| Bogota, 10/95 | Ljubliana, 10/95 |
| Melbourne, 11/95 | Rabat, 12/95 |
| Bulawayo, 2/96 | Hyderabad, 3/96 |
| Moscow, 4/96 | Yerevan, 7/96 |
| Tangshan, 8/96 | Reykjavik, 9/96 |
| Cairo, 12/96 | Cyprus, 12/96 |
| Barcelona, 12/96 | Bogota, 1/97 |
| Venezuela, 2/97 | Barcelona, 5/97 |
| Quito, 6/97 | Bergen, 6/97 |
| Tbilisi, 7/97 | Thessaloniki, 8/97 |
| Moscow, 9/97 | Cyprus, 10/97 |
| Cairo, 12/97 | Pisa, 2/98 |
| Amman, 5/98 | Golden, 7/98 |
| Tel Aviv, 8/98 | Istanbul, 10/98 |
| Hyderabad, 12/98 | Birmingham, 7/99 |

## 8. GSHAP global programs

Another key element of the GSHAP implementation is the pursue of activities and tasks devoted to the improvement of the global practice of seismic hazard assessment.

*Uniform instrumental global seismic catalogue* – With the aim of extending the global instrumental earthquake catalogue and database, now available since 1964 (ISC, NEIC), to cover the whole century, work is in progress at USGS and the University of Colorado on the digital scanning and processing of the ISS and BCIS Bulletins and on the relocation of a uniform global catalogue, using modern travel-times and location procedures.

*Software for seismic hazard assessment* – The goal of across-boundary integration of seismic hazard databases and products was identified in the Rome 1992 planning meeting as crucial to the global implementation of GSHAP. The «seismotectonic probabilistic approach» was selected as a standard for global SHA application, to allow the comparison and integration of regional maps and zonations. To implement this strategy, an integrated software package dealing with all the steps of seismotectonic hazard computation, FRISK88M, has been made available free of charge by Risk Engineering for GSHAP applications to all test areas and regional centres.

*Multidisciplinary approach to seismic hazard assessment* – The global evaluation of seismic hazard requires the characterization of the earthquake cycle over recurrence times spanning from $10$-$10^2$ years in active tectonic areas to $10^3$-$10^5$ years in areas of slow crustal deformation. A primary goal of GSHAP has been to implement a multisciplinary approach to seismic hazard assessment introducing the results from geological disciplines dealing with active faulting (neotectonics, paleoseismology, geomorphology, geodesy) to complement the historical and instrumental records of earthquakes. This goal has been pursued with several initiatives:

i) The adoption of the seismotectonic probabilistic approach for global application reflects the aim to incorporate the geological input to characterize the earthquake recurrence in space and time.

ii) The workshop on «Active Faulting Studies for Seismic Hazard Assessment», held in Erice (Sicily, 9/95), brought together specialists in active faulting studies with seismologists and engineers responsible for developing assessment methodologies and for leading major national seismic hazard programs from all continents, to explore new trends in active faulting studies and verify the extent to which the geological input is being used in seismic hazard assessment practice. The workshop produced a document of recommendations, circulated worldwide (Boschi *et al.*, 1996).

iii) GSHAP and the ILP Projects «II-2: Maps of Major Active Faults» and «II-3: Earthquakes of the Late Holocene» conducted joint activities, including the 1996 NATO/ARW «Historical and Pre-historical Earthquakes in the Caucasus» and the «Training Course in Paleoseismology and Active Faulting in South America» in 1997.

iv) Scientific articles illustrating strategies and examples in multidisciplinary seismic hazard assessment have been published on proceedings volumes and scientific journals; among these, the GSHAP Volume (Giardini and Basham, 1993) includes seminal papers on the integration of the geological input in seismic hazard assessment.

## 9. Cooperation with other agencies

The implementation of GSHAP relied on the cooperation with several international scientific agencies, commissions and programs.

*International Lithosphere Program (ILP)* – ILP has launched GSHAP (ILP Project II-0) and established its worldwide operation. The integration between GSHAP and the ILP Projects «II-2: Maps of Major Active Faults» and «II-3: Earthquakes of the Late Holocene» was planned since the beginning and joint activities were conducted, as listed above.

*International Association of Seismology and Physics of the Earth's Interior (IASPEI)* – Seismic hazard assessment is a multidisciplinary effort geared at integrating the input from different geophysical and geological disciplines represented in IUGG and IUGS; however, the traditional affiliation of seismic hazard is within IASPEI and here GSHAP has found the largest support. Several IASPEI commissions and working groups had an active role in the GSHAP implementation: the «Commission on Earthquake Prediction and Hazard» run jointly with GSHAP the Caucasus test area, the «Committee for Developing Countries» and the «Commission for the IDNDR» have been kept closely informed and involved in GSHAP activities, the «Working Group on Earthquake Risk and Losses» is active within the RELEMR program and joined efforts in Moscow and Beijing, the «European Seismological Commission» effectively coordinated GSHAP activities in the larger European-Mediterranean area and allocated special sessions to GSHAP within its annual assemblies, and the newly formed «Asian Seismological Commissions» has done the same in the Asian region.

*UNESCO* – UNESCO is very active in the field of seismic risk assessment and mitigation and has provided overall support to GSHAP activities. In particular, GSHAP worked in close coordination with three UNESCO programs:

i) the UNESCO/USGS program «Reduction of Earthquake Risk in the Eastern Mediterranean Region» is integrated in the framework of regional test areas activated by GSHAP in the larger Mediterranean area;

ii) the UNESCO/IUGS International Geological Correlation Program n. 382 «Seismotectonics and Seismic Hazard Assessment of the Mediterranean» is one of GSHAP test areas;

iii) GSHAP participated in the UNESCO/GFZ «International Training Courses in Seismology and Seismic Hazard Assessment» in 1995 in Costarica and in 1997 in Kenya.

*International Council of Scientific Unions (ICSU)* – GSHAP is one of the programs selected by the ICSU Committee for IDNDR as scientific contribution to the IDNDR. ICSU has been very supportive of GSHAP since its beginning, providing guidance, encouragement and managing funds which have helped to promote GSHAP activities in several key areas.

*International Association of Earthquake Engineers (IAEE)* – The need to close the bridge often existing between the scientific and engineering communities working in seismic hazard and risk assessment was recognized in the GSHAP planning and the cooperation with the engineering community has been established. The IAEE «World Seismic Safety Initiative» has recognized GSHAP and accepted GSHAP observers at the WSSI Board of Directors (Vienna, 8/94) and at the Pacific Conference on Earthquake Engineering (Melbourne, 11/95); representatives of the engineering community sit on the GSHAP Steering Committee.

*European Council (EC)* – The EC Open Partial Agreement on Major Disasters has named the CNCPRST of Rabat, one of the GSHAP Regional Centres, as the «Centre EuroMediterraneen d'Evaluation et de Prevention du Risque Sismique or Seismic Hazard Assessment» (CEPRIS), with the mandate of coordinating activities in the Ibero-Maghreb and Western Mediterranean areas.

*World Meteorological Organization (WMO)* – The WMO Hydrology and Water Resources Department implemented for the UN/IDNDR its «System for Technology Exchange for Natural Disasters» (STEND), an information exchange programme aimed at increasing awareness of available technology through the dissemination of knowledge about the different methodologies used in fields related to natural hazards. The GSHAP Regional Centres have been included in the list of STEND focal points for knowledge transfer.

*Earthquake and Megacities Initiative (EMI)* – The final years of the Decade are shifting the emphasis on the protection of megacities, moving from hazard assessment to engineering applications and risk mitigation strategies. Several UN sponsored initiatives are under way, including the ILP's «Earthquake and Megacities Initiative». Under request by ICSU and the IDNDR, GSHAP computed in several regions site-specific hazards as input for megacities programs.

## 10. Funding

The GSHAP implementation and the activities of the Regional Centres and test areas required significant funding. GSHAP has secured support from different sources:

a) Funds provided or raised by the Regional Centres have been instrumental to organize workshops and conduct activities at the Regional Centres (*i.e.* at GFZ, SSB, IIEES, JIPE, USGS).

b) Support was provided by ING, Roma, the GSHAP Coordinating Centre in the 1992-1997 period, to organize general GSHAP events such as the 1992 Technical Planning meeting in Rome, the publication of the GSHAP Volumes, the 1995 Workshop on «Active Faulting Studies for Seismic Hazard Assessment» in Erice. In the final phase (1997-1999), coordination and support have been provided by ETH, Zurich.

c) Projects submitted to international funding agencies for scientific research and cooperation provided significant support for the implementation of the test areas in South America (CEC Ct.94-0103 PILOTO), the Caucasus (INTAS Ct.94-1644 CAUCAS; NATO-ARW Ct.95-1521), the Mediterranean (EC/OPA CEPRIS; IGCP n. 382 SESAME).

d) Yearly support has been provided throughout the project by ILP, ICSU and IASPEI; occasional contributions have been made by UNESCO and Kinemetrics.

e) Local and national organizations all over the world have allowed and often supported the participation of individual scientists in GSHAP activities.

f) Several international projects and multi-national areas in seismic hazard assessment were supported by other agencies in different areas of the world (*e.g.*, RELEMR, EANHM, QSEZ-CIPAR, BEECD, PAIGH), in coordination with GSHAP.

## 11. Steering Committee

The GSHAP implementation and activities were supervised by the Steering Committee, composed by reknown experts in seismic hazard assessment and earthquake engineering from all the world: H. Gupta (Chair, India), P. Basham (Secretary, Canada), N. Ambraseys (U.K.), D. BenSari (Morocco), M. Berry (ILP, until 1996), E. Engdahl (IASPEI), M. Ghafory-Ashtiany (Iran), A. Giesecke (CERESIS), P. Grandori (Italy), A. Green (ILP, from 1996), D. Mayer-Rosa (Switzerland), R. McGuire (U.S.A.), R. Punong-Bayan (Philippines), B. Rouban (UNESCO), G. Sobolev (Russia), G. Suarez (Mexico), P. Zhang (China). The Steering Committee members have been instrumental in setting guidelines, conducting regional activities, raising support and participating in the global programs of GSHAP.

## 12. Dissemination of products and results

The dissemination and publication of GSHAP ideas and results started with the GSHAP volume on *Annali di Geofisica* (Giardini and Basham, 1993; 2000 copies). GSHAP activities and results have been presented at the major international and regional assemblies and meetings. Research papers and articles describing the program's approach and regional activities have appeared on scientific journals, special volumes and regional bulletins. Sessions dedicated to GSHAP have been hosted by the assemblies of IASPEI, ESC, ASC and SSA and by other international meetings. GSHAP workshops have been organized in all test areas, as listed above. Progress reports and summaries prepared by the Coordinating Centre have been distributed worldwide (7/92, 11/92, 12/93, 2/94, 9/94, 6/95, 4/96, 1/97, 1/98, 2/99). Periodic summaries have appeared on bulletins and newsletter of IASPEI, ICSU, ILP, AGU.

This GSHAP summary volume (3000 copies) includes all regional reports on the compilation of the databases and the hazard results in the GSHAP test-areas and regions, and the Global Seismic Hazard Map (folded).

The GSHAP map and all associated documentation, including regional reports, maps of seismicity, source characterization information, and GSHAP yearly reports are available freely via the Internet through the GSHAP homepage, http://seismo.ethz.ch/GSHAP/.

## 13. GSHAP failures and limitations

During its implementation, the GSHAP was also criticized.

– It failed to establish efficient large-scale regional programs in areas where significant external funding or local energies were not available (*i.e.* large parts of the African continent), in areas where the scientific community and the national interests are too strong (North America), in areas where the political boundaries are still prevailing (Middle East).

– The balance between science and application was difficult to achieve, with criticisms of having chosen not-high-enough scientific standards (from ICSU) clashing against criticisms of not thinking enough about applications (from the UN/IDNDR).

– GSHAP often interfered with national agendas and priorities, entering in competition with national programs for funding, hazard standards and agendas; in the end these clashes mostly resulted in improved hazard assessment, but they also created frictions.

– While GSHAP focussed on the establishment on regional working frameworks which were very active during the program implementation, the long term future of this cooperation is often doubtful, in absence of appropriate international frameworks, funding and guidelines.

– Disciplinary boundaries are reduced but remain strong.

– The GSHAP, like other demonstration programs, suffered also from overall limitations in the implementation of the UN/IDNDR program: changing priorities, no inter-project coordination, no plans for follow-up projects implementing the results of the demonstration programs in risk mitigation strategies, lack of significant start-up and operational funding. All these elements have resulted in the GSHAP to operate in a rather independent fashion within the seismological and seismic hazard assessment community. A mid-program review conducted by the IDNDR Scientific and Technical Committee helped in focussing the GSHAP results and applications.

## 14. GSHAP successes

In the end, the GSHAP fulfilled in large part the goals and design principles set in 1992. In addition to the regional and global results and mapping listed above, the following should be noted:

– Also because of GSHAP, the global standards in seismic hazard assessment have markedly improved in the last few years, with specific regards to the implementation of multi-disciplinary information, the refinement of the databases, the standardization of the knowledge of earthquake hazards.

– National hazard maps have improved in developed countries involved in across-border cooperation (*i.e.* in Europe) as well as in Third-World countries with no previous experience in SHA (*i.e* the African Rift).

– GSHAP was very aggressive in promoting multi-national cooperation in all continents, with particular emphasis in critical border areas. Some examples: S. Africa worked together with the African Rift framework in a regional scientific program; Russia, Turkey and Iran cooperated together in the Caucasus; China and India cooperated over many years in a sensitive border area; the Andean countries worked together under a unified framework program.

– GSHAP was successful in attracting significant funds to regional SHA. Some examples: NATO financed a scientific meeting in the Caucasus; the first EC-OPA Center was selected in Northern Africa; INTAS and EU funded programs with a large emphasis on coordination.

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**Appendix.** Acronyms.

| | |
|---|---|
| ADRIA | Adria plate GSHAP test area |
| AGSO | Australian Geological Survey Organization |
| AGU | American Geophysical Union |
| ARW | NATO Advanced Research Workshop |
| BEECD | CEC Ct. 94-0497: A basic european earthquake catalogue and database for the evaluation of long-term seismicity and seismic hazard |
| BGS | British Geological Service |
| CAUCAS | INTAS Ct. 94-1644: Test area for seismic hazard assessment in the Caucasus |
| CEPRIS | EC/OPA Centre EuroMediterraneen d'Evaluation et de Prevention di Risque Sismique |
| CERESIS | Centro Sismologico Regional para la America del Sur |
| CNCPRST | Centre National de Coordination et de Planification de la Recherche Scientifique et Technique, Rabat |
| DACH | GSHAP test area covering Germany, Austria and Switzerland |
| EANHM | Eastern Asia Natural Hazards Mapping project |
| EC/OPA | European Council - Open Partial Agreement on Major Disasters |
| ESARS-WG | Eastern and Southern Africa Regional Seismological Working Group |
| ESC | European Seismological Commission (IASPEI) |
| ETH | Swiss Federal Institute of Technology, Zurich |
| GFZ | Geo-Forshungs Zentrum, Potsdam |
| GSC | Geological Service of Canada |
| GSJ | Geological Service of Japan |
| IAEE | International Association of Earthquake Engineering |
| IASPEI | International Association of Seismology and Physics of the Earth Interior |
| ICSU | International Council of Scientific Unions |
| IDNDR | UN International Decade for Natural Disaster Reduction |
| IGC | International Geological Congress |

**Appendix.** Acronyms (*continued*).

| | |
|---|---|
| IGCP | International Geological Correlation Program |
| IIEES | International Institute of Earthquake Engineering and Seismology |
| ILP | International Lithosphere Program |
| ING | Istituto Nazionale di Geofisica, Rome |
| IRRS | Istituto per la Ricerca sul Rischio Sismico, Milan |
| ISC | Internation Seismological Centre |
| IUGG | International Union of Geodesy and Geophysics |
| IUGS | International Union of Geological Sciensces |
| JIPE | Joint Institutes of Physics of the Earth, Moscow |
| NEIC | US National Earthquake Information Centre |
| NGRI | National Geophysical Research Institute, Hyderabad |
| NSF | US National Science Foundation |
| OGS | Osservatorio Geofisico Sperimentale, Trieste |
| PAIGH | Pan-American Institute of Geography and History |
| PGA | Peak Ground Acceleration |
| PILOTO | CEC Ct. 94-0103: Pilot project for regional earthquake monitoring and seismic hazard assessment (EuMe-Andean regions) |
| RADIUS | Risk Assessmentand Diagnosis of Urban Areas against Seismic Disasters project |
| RELEMR | Reduction of Earthquake Losses in the Eastern Mediterranean Region project |
| SESAME | UNESCO/IGCP 382 Seismotectonics and Seismic Hazard Assess. of the Mediterranean |
| SHA | Seismic Hazard Assessment |
| SSA | Seismological Society of America |
| SSB | State Seismological Bureau, Beijing |
| STEND | WMO System for Technology Exchange for Natural Disasters |
| UNAM | Universitad National Autonoma de Mexico, Mexico City |
| UNESCO | UN Educational, Scientific and Cultural Organization |
| USGS | United States Geological Survey |
| WMO | World Meteorological Organization |
| WSSI | World Seismic Safety Initiative |