2006: STATUS OF TSUNAMI SCIENCE RESEARCH AND FUTURE DIRECTIONS OF RESEARCH

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ABSTRACT

In 2005, Dr. Robert Wiegel compiled "Tsunami Information Sources". The compilation has been made available via a website and has been published as an issue in *Science of Tsunami Hazards*. The compiled references have been assigned keyword descriptions, and compiled in order to review the breath and depth of Tsunami Science publications.

The review indicates that tsunami research involves eight major scientific disciplines: Geology, Seismology, Tsunami Science, Engineering, Disaster Management, Meteorology and Communications. These disciplines were subdivided into many topical subjects and the results were tabulated.

The topics having the largest number of publications include: tsunamigenic earthquakes, numerical modeling, field surveys, engineering models, harbor, bay, and canal modeling and observations, energy of tsunamis, workshops, tsunami warning centers, instrumentation, tsunami catalogs, tsunami disaster mitigation, evaluation of hazards, the aftermath of tsunamis on humans, and AID provided to Tsunami Damaged Communities.

Several areas of research were identified as likely directions for future research, including: paleotsunami studies, risk assessments, instrumentation, numerical modeling of earthquakes and tsunami, particularly the 2004 Indian Ocean event. There is a dearth of recent publications available on tsunami hazards education for the general public.

1. INTRODUCTION

Dr. Robert Wiegel published a bibliography of Tsunami citations in a *University of California Berkeley Hydraulic Engineering Laboratory Report, UCB/HEL-2005-1.* This report entitled, "Tsunami Information Sources," was also published as an issue of the *Science of Tsunami Hazards* (2006). The report compiled tsunami science publications, particularly:

1) Bibliographies, Books and Pamphlets, Catalogs, Collections, Journals and Newsletters, Maps, Organizations, Proceedings, Symposium and Workshops, Videos and photographs (pages 2-13).
2) Articles, Papers, Reports (pages 13-15).

An analysis of the publications listed under Item 2, "Articles, Papers and Reports," was made in order to determine: key areas of research, significant trends in research, and likely future trends (what's hot and what's not).

This analysis was initiated in order to facilitate a comparison of citations, describing tsunami deposits in Keating et al. (2006 in press) with the Wiegel (2005) compilation. This initial effort was then expanded into an overall review of tsunami literature. While this summary was being prepared in the spring of 2006, a second compilation was published, Wiegel (2006b). This second publication includes citations added since the first report and references from publications that fall into the categories of Planning and Engineering Design for Tsunami Mitigation/Protection, and Tsunami Propagation Near-shore. A re-analysis of the entire database is warranted, preferably an analysis involving collaboration between both authors (Wiegel and Keating), and with an expanded computerized indexing involving multiple keywords.

The results of the research, demonstrate that current research is focused in only a few areas and it also suggests that there is a deficiency in educational material on tsunami hazards available in the literature.

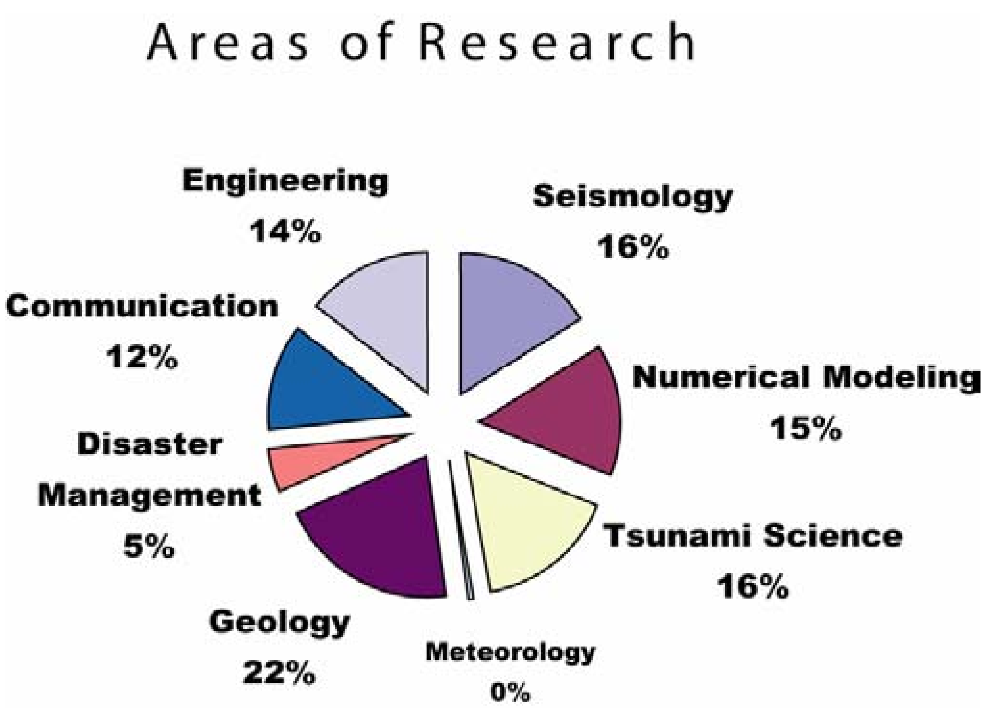
2. METHOLOGY

The bibliography of articles, papers, and reports compiled by Wiegel (2005 and 2006a) consists of citations of tsunami publications. In order to assess the general nature of the publications, each citation (on pages 13-115 of Wiegel, 2005) was assigned a keyword from the title to provide a general category for the major emphasis of each paper; for example, edge wave, long periods, resonance curve, and so on. After the keywords were identified, the citations were divided into disciplinary categories (see Fig. 1), including: Geology, Disaster Management, Communications, Engineering, Seismology, Numerical Modeling, Tsunami Science, and Meteorology, and then tabulated. The distribution of publications by discipline shows there are comparable numbers of publications within the disciplines of: Geology, Engineering, Seismology, Numerical Modeling and Tsunami Science. The citations within each discipline were further subcategorized into topics.

This analysis is based upon several assumptions including: 1) the title of a professional publication will adequately reflect the general subject matter of the paper, 2) a single keyword will adequately describe a publication, and 3) each publication is significant and should be incorporated into the status review. Unfortunately, these assumptions are not valid in many cases. Many of the publications within the bibliography had insufficient information in the title for classification or inclusion in any of the topics used and thus many citations were excluded from this analysis.

In addition, it was found that a single keyword is often inadequate, for example "The Numerical Modeling of Run-up from the 1946 Tsunami in Hilo" would be listed under the discipline of Tsunami Science and the topic Numerical Modeling. A publication entitled, "The Earthquake and Tsunami Involved with the 1975 Kalapana Tsunami" would be tabulated under discipline of Seismology and the topic of Tsunamigenic Earthquake. While a publication titled "The Numerical Modeling of the Tsunami and Earthquake Associated with the 1975 Kalapana Earthquake" would be included under the discipline category of Tsunami Science and the topic of Numerical Modeling. A title such as "The Tsunami Deposits Associated with the 1975 Kalapana Earthquake" would be categorized under the discipline of Geology and subtopic Field Surveys." Finally, the assumption that "the publication is significant and should be incorporated into the review" is impossible to address, based solely upon a title.

Figure 1. This pie chart diagram shows the distribution of tsunami publications by scientific discipline. The numbers on the chart indicate the percentages of the total.



No digital database of publications is ever complete for more data becomes available as the database is being constructed. In building a data base on tsunami deposits (Keating et al., 2006) utilized most of the digital search engines available over the Internet. The results vary greatly from one digital database to another (e.g., Web of Science, Georef, Geobase, etc). Many older publications simply are not available digitally, thus it often proves to be a frustrating experience when searching for older publications. The incomplete nature of the digital databases reflects how they are constructed, emphasizing the addition of the newest publications, over incorporating older material. Also, the sources of citations are different for various databases (now downloaded directly from publishers). These problems reflect the youth of digital databases. As the scientific citations within databases increase and the search engines improve, analyses of publications will become more comprehensive.

3. RESEARCH CATEGORIES

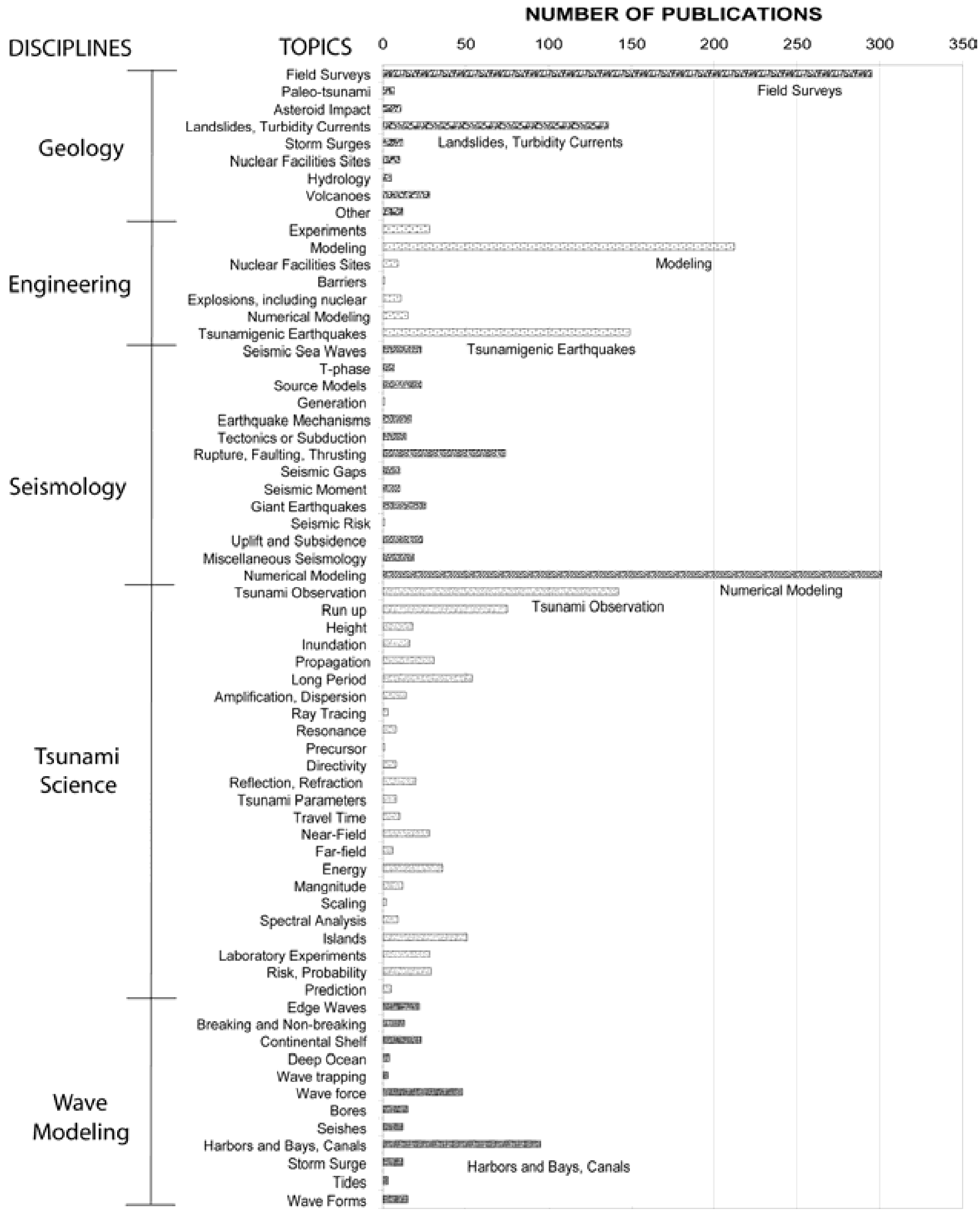
3.1 Subdivision of Disciplines into Research Topics

The greatest number of publications (Fig. 1) falls under the discipline of Geology (n= 504), followed by Seismology, Tsunami Science, Engineering and Wave modeling. Each discipline category (listed at left in Fig.2) can be further subdivided into Research Topics. The breakdown by research topic for each of the scientific disciplines is shown in the center column of Fig. 2. Geologic publications (n= 516) were subdivided into nine topical areas. The most frequently published topic, in the discipline of Geology, is geological field surveys of tsunami and paleo-tsunamis (n= 295; see Fig. 2), followed by composite topic of landslides and turbidity currents (n= 136). Within the Engineering Discipline there are 361 publications (Fig. 2). The majority of these publications (n=212) focus on modeling studies.

The research topic most frequently referred to in the discipline of Seismology is the topic Tsunamigenic Earthquakes (n= 149). The second most frequent research topic that was included in the title was the composite category of Ruptures, Faulting, and Thrusts (n= 74).

Under the category of Tsunami Topics (summarized in Figure 2) there are 915 publications. The largest numbers of publications deals with Numerical Modeling (n= 301). Tsunami Observations (N= 142) is the second most popular topic. Wave studies entail a total of 265 publications (Figure 2). The largest number of these studies involves wave behavior in harbors, bays, and canals (n= 95).

Figure 2. (Next Page) This illustration is a histogram, showing the number of publications analyzed by discipline (left column) and topic (center column). On the right is a plot of the number of publications per topic. The horizontal bars show varying shades of stippled patterns indicating the various disciplines involved. The topics of greatest interest (largest number of publications) are labeled on the histogram.



NUMBER OF PUBLICATIONS
DISCIPLINES
TOPICS
0
50
100
150
200
250
300
350
Geology
Engineering
Seismology
Tsunami Science
Wave Modeling
Field Surveys
Paleo-tsunami
Asteroid Impact
Landslides, Turbidity Currents
Storm Surges
Nuclear Facilities Sites
Hydrology
Volcanoes
Other
Experiments
Modeling
Nuclear Facilities Sites
Barriers
Explosions, including nuclear
Numerical Modeling
Tsunamigenic Earthquakes
Seismic Sea Waves
T-phase
Source Models
Generation
Earthquake Mechanisms
Tectonics or Subduction
Rupture, Faulting, Thrusting
Seismic Gaps
Seismic Moment
Giant Earthquakes
Seismic Risk
Uplift and Subsidence
Miscellaneous Seismology
Numerical Modeling
Tsunami Observation
Run up
Height
Inundation
Propagation
Long Period
Amplification, Dispersion
Ray Tracing
Resonance
Precursor
Directivity
Reflection, Refraction
Tsunami Parameters
Travel Time
Near-Field
Far-field
Energy
Mangnitude
Scaling
Spectral Analysis
Islands
Laboratory Experiments
Risk, Probability
Prediction
Edge Waves
Breaking and Non-breaking
Continental Shelf
Deep Ocean
Wave trapping
Wave force
Bores
Seishes
Harbors and Bays, Canals
Storm Surge
Tides
Wave Forms
Field Surveys
Landslides, Turbidity Currents
Modeling
Tsunamigenic Earthquakes
Numerical Modeling
Tsunami Observation
Harbors and Bays, Canals

3.2 RISK REDUCTION CATEGORIES

The majority of publications discussed to this point could be referred to as hazards science and engineering. Publications dealing with human or societal impact, and disaster management and are separated into the basic categories of risk reduction (Fig. 3). These categories include: Disaster Preparedness, Disaster Response, Disaster Recovery, Disaster Mitigation, and Development. These tsunami-related publications were further subdivided into topics such as: Resilience, Crises Management, Removal and Wreckage, Rebuilding, and Mitigation, Evaluation of Hazards, Safety Studies, Emergency Services, Medical Care, Evacuation, Response, Assessment, Survival, Preparation, Prevention, and Protection. A new field of research involves human response to tsunami. The tropics involving human behavior are included in Disaster Response and Recovery.

Instrumentation has been incorporated with the category of Hazards Science since instruments are the tools of scientists. However the topic is also associated with warning systems (Disaster Preparedness Category). The Instrumentation topic only contains only 48 publications. This is surprising since the monitoring of earthquakes and tsunami is extremely dependent upon instrumentation. The topics of maps and bathymetry, photography, indexes, glossary, lists, catalogs, history, data processing and computer codes have also been listed under the category Hazards Science. Finally, publications on re-insurers, insurance, land management, political demands, AID, and dealing with bureaucrats and reporters have been included under the categories Disaster Mitigation and Development.

In summary, the topics having the most publications include categories such as field surveys, source mechanisms, numerical modeling and studies involving tsunami effects on harbors, bays and canals. The least number of publications fall in the categories of seismic and tsunami risk, precursors and/or predictions, and education. This suggests a need for increased efforts in the topics of education and tsunami risk.

4. INTERACTIONS

While, much of the material that has been published in the "Tsunami Information Sources", and summarized here, is basic research, any knowledge related to tsunami research directly or indirectly benefits society. Thus it is important to reflect on how Tsunami research contributes to Public Risk Reduction. An interesting report on several aspects of Hazard Management associated with the 2004 Indian Ocean Tsunami is available on the Internet (Cosgrave et al., 2006).

The interaction between science, disaster management policy and education has been summarized in Figure3 where each category of activities contributes directly to a reduction of deaths, injuries and property loss (Risk Reduction). The principle components of risk reduction are illustrated within this figure as a series of overlapping circles. This concept of "circles within a circle" represents the overlapping areas of expertise needed to facilitate risk reductions. The illustration includes: Science, Disaster Preparations, Disaster Response, Disaster Recovery, Disaster Mitigation, Development and Environmental Change. In large part, the publications of tsunami scientists and engineers falls in the category of "Science". In order to facilitate risk reductions, individual scientists should work with, and provide technical information, to all others workings toward the goal of Risk Reduction.

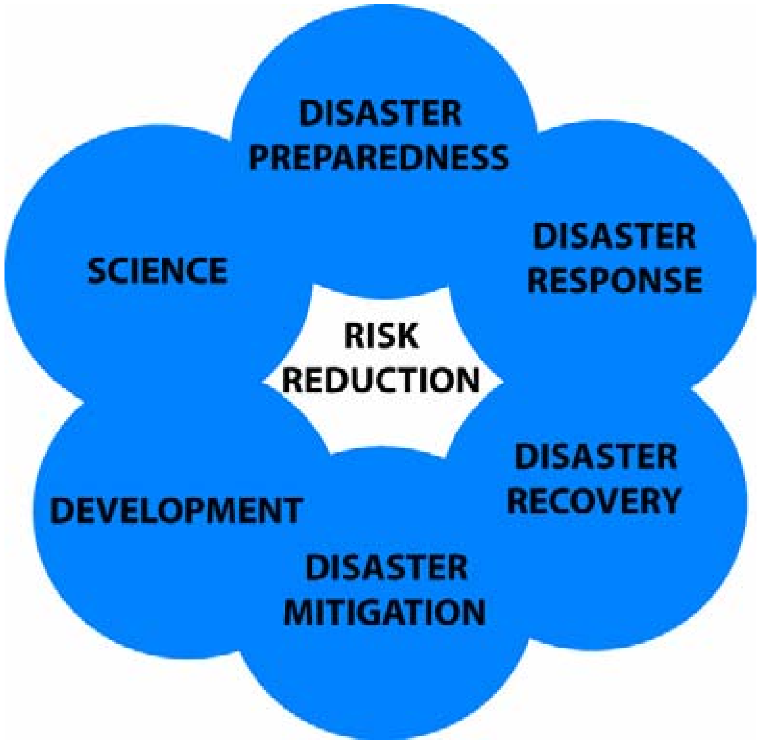


FIGURE 3. The illustration above shows the principle components of Risk Reduction with the research topics reviewed in this manuscript included in the illustration. An effort to reduce damage from natural disasters (and particularly tsunamis) involves cooperation between individuals working in all fields.

In order to present a review of tsunami science within this risk reduction framework, the scientific disciplines, as well as topics (and number of publications) have been applied (in Figure 4) to the Risk Reduction scheme, just discussed.

3.2 STRIKING LACK OF EDUCATION PUBLICATIONS

Education is listed under the heading Development and topic Educational Efforts. The total number of publications is four. This is number is woefully inadequate.

Despite the devastating loss of lives during the 2004 Indian Ocean Tsunami, the experience proved that many people did survive because they had a rudimentary knowledge of tsunami. In order to prevent deaths due to tsunami we need both Tsunami Warning Centers and PUBLIC EDUCATION.

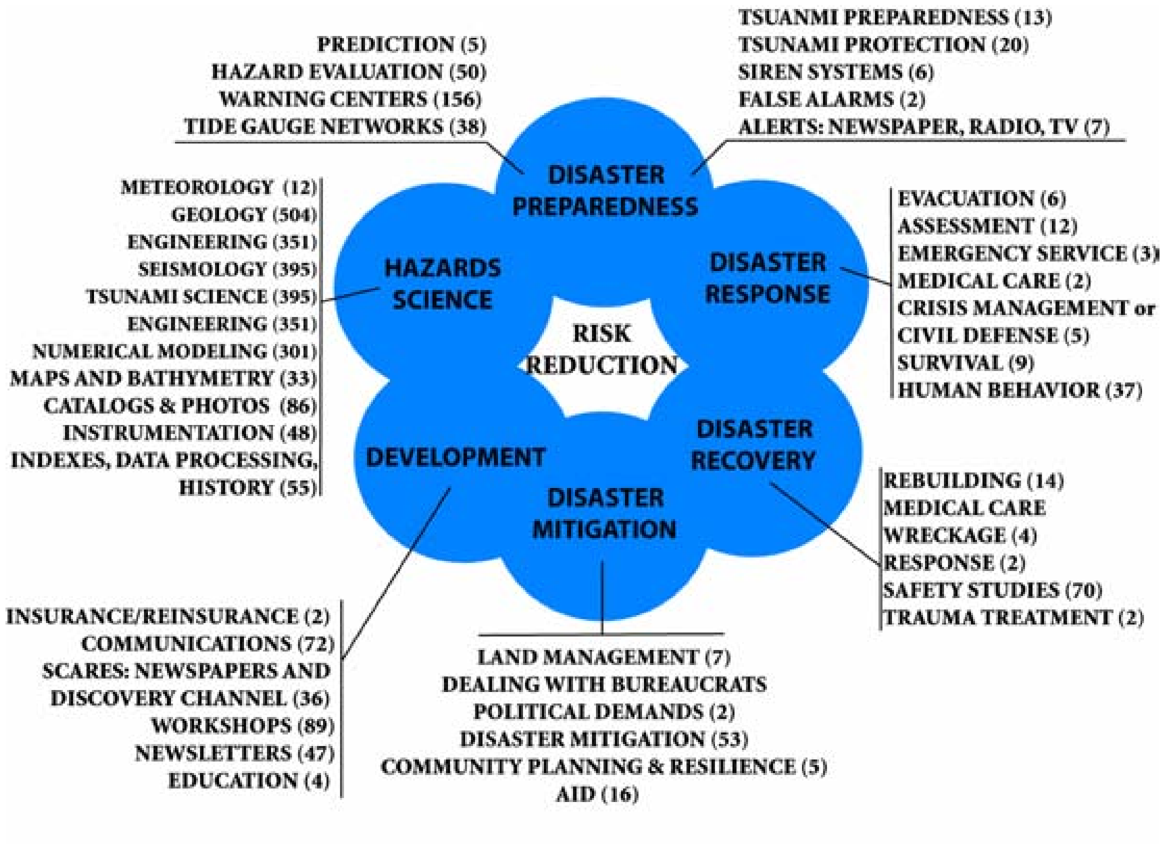


Figure 4. A basic risk reduction scheme is shown above as overlapping shaded circles. Lists of disciplinary and topical categories have been added to the margins of the figure, with the number of publications (listed in parenthesis). These results are based upon a keyword analysis of citations within the "Tsunami Information Sources"(Wiegel, 2005 and 2006a).

An experience of unwise human behavior from Honolulu can provide important insights into the global need for tsunami hazards education. During the last tsunami warning in Honolulu, an estimated 400 surfers went to the shore to surf the tsunami waves. Had even a moderate tsunami occurred many of these 400 surfers would have landed in the lobbies of the Waikiki Hotels and other sites of devastation and would have contributed significantly to the casualties. To remedy this situation, a CD was produced that warns surfers and divers of the dangers of tsunami (He'e Nalu, in references). This CD has been distributed to the public through surf and dive shops. The majorities of individuals living in Hawaii moved here or were born after the last destructive tsunami in Hawaii and many lack knowledge of the devastating effects of tsunami inundation.

4. FUTURE DIRECTIONS

In 2003, a summary of publications related to tsunami deposits (Fig. 5) was presented at the fall meeting of the Am. Geophysical Union (Keating, 2003). The data available at that time demonstrated an exponential expansion of publications on tsunami deposits. This expansion should continue into the foreseeable future, partially fueled by the research associated with the 2004 Indian Ocean Tsunami. It is likely that continued research into establishing the recurrence rates of tsunami, in tsunami inundation prone areas, will allow us to better assess risk, regionally and locally.

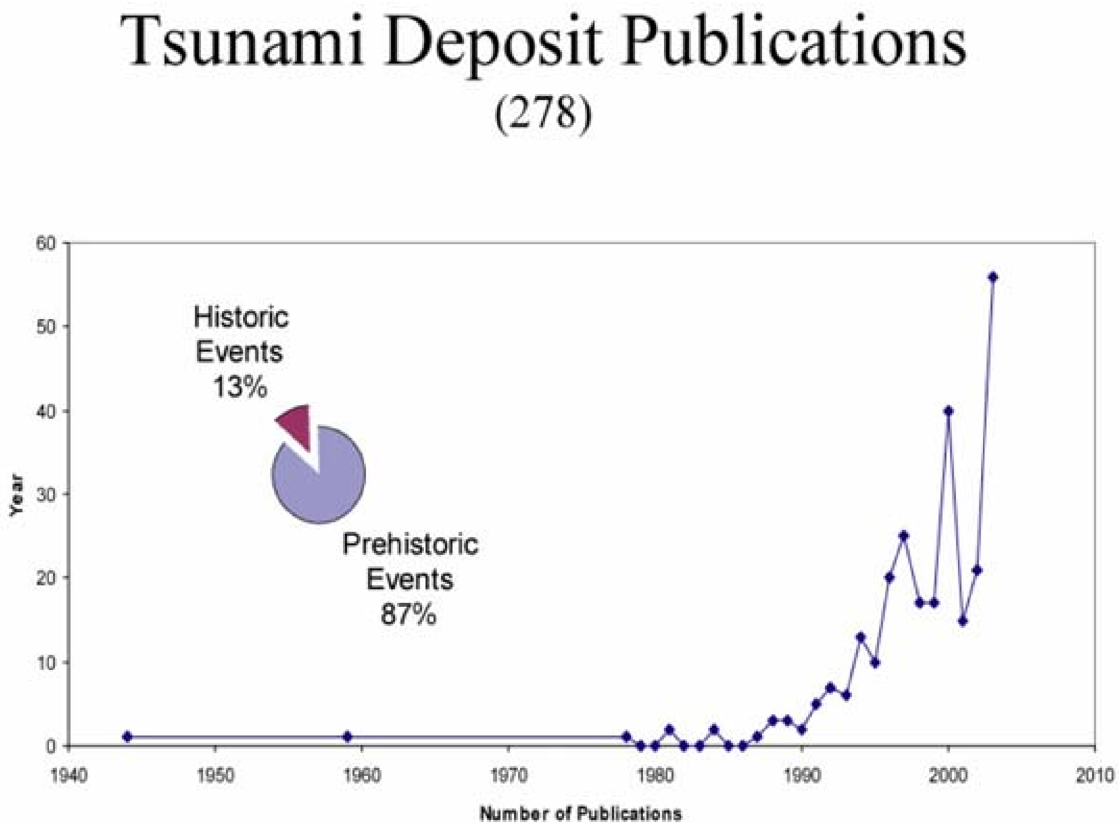


FIGURE 5. This illustration shows the number of publications describing tsunami deposits that were published between 1940 and 2003. Based upon the rapid increase in publications, the topic of paleo-tsunami recorded in sedimentary deposits is clearly one of the fastest growing areas of tsunami research.

5.1 RISK ASSESSMENT

In the past two years, there has been a series of devastating natural disasters (a giant tsunami, earthquakes, tornadoes, hurricanes on the Gulf coast and elsewhere) that challenge the capabilities of the insurance and re-insurance industries to cover the costs of natural disasters. It has become obvious that society as a whole needs accurate risk assessment (and management) that is based upon reliably determined rates of tsunami reoccurrence. Furthermore, the reoccurrence rate must be established at a regional level and perhaps a local level. Adequately funded paleo-tsunami deposit studies might allow us to make valid risk assessments for highly populous, and therefore highly expensive, risk management areas.

5.2 STORM VS. TSUNAMI DEPOSITS

In order to establish reoccurrence rates for tsunami we must be able to differentiate storm deposits from tsunami deposits. In consultation with scientists at the University of South Florida, the author and collaborators have begun to look at this issue and the investigations appear very promising.

5.3 INSTRUMENTATION

NOAA has actively been developing a system of deep ocean pressure monitoring systems (Tsunameter system or DART buoys). These instruments have a potential to allow rapid monitoring and evaluation of tsunami, facilitating warnings and evacuation (Bernard, 2005). This advance in instrumentation could lead to more timely and more accurate warnings and thus save lives. And it will lead to many new publications!

5.4 LANDSLIDES

Another instrumental advance that has impacted tsunami research is the utilization of side-scan sonar to map landslides and slumps on the seafloor in areas that were likely to be tsunamigenic. The sea floor images have proven extremely useful in the study of landslides on continental slopes and volcanic edifice failures. It is vitally important that these mapping efforts be coupled with site surveys to establish rock properties, ages, rock types, mechanical properties, etc. Additionally, landslide research has been an important focus in tsunami research in the recent past and is likely to remain an important area of study.

5.5 INTEGRATED INVESTIGATIONS

Many scientists have been involved in scientific investigations associated with the 2004 Indian Ocean Tsunami. Because so many scientists within different disciplines were involved, it is likely that multi-investigator projects will develop that link together observations and measurements on the ground to modeling in the laboratory. In particular, studies of tsunami sediment transport may be linked to models of the carrying power, or destructive power, of the tsunami waves.

5. CONCLUSION

Our understanding of tsunami largely results from direct observation of waves and their effect on shorelines and structures and on the numerical modeling of earthquakes and tsunami. The seismic studies related to the 2004 Indian Ocean Tsunami indicate that extremely long ruptures, actually a series of connected ruptures in space and time, of the sea floor are possible and can generate huge tsunami. Careful numerical analyses of the earthquake and resultant tsunami from the 2004 Indian Ocean event will dominate tsunami publications for the next several years.

6. ACKNOWLEDGMENT

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