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Review of the National Tsunami Hazard Mitigation Program (NTHMP)

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(Per letter of invitation from Dr. Evans dated 9 Jan. 2001)

I tend to be critical during reviews, and I have tried very hard to find something to criticize about the NTHMP. I have been unsuccessful in that attempt. NTHMP is an outstanding program. Most of the original goals have been met or exceeded, although in some cases the magnitude of the tasks did result in the scaling back of initially overly optimistic goals. The program is a model of how academics and state and federal personnel can work together to the great benefit of the U.S. public. NTHMP has already had a large impact on public awareness and planning in many Pacific coastal communities. This impact will definitely grow as more communities acquire inundation maps, produce tsunami emergency plans and disseminate NTHMP educational materials. Plans for the next five years are quite appropriate to maintain NTHMP's momentum and continued success. To ensure NTHMP's complete success I urge funding at the full requested level of $4 million per yr.

NTHMP is an ambitious program. With only modest direct funding from the federal government the program has made great strides toward accomplishing the ultimate goal of making U.S. Pacific coast communities "tsunami ready". Two factors stand out as major contributors to the success of the program:

(i) strong but inclusive leadership, always focused on the ultimate goal of tsunami hazard mitigation, and therefore flexible to the needs of the users, e.g., the emergency managers, who must prepare the public to respond to tsunami dangers;

(ii) enthusiastic cooperation among the personnel of the three federal agencies (NOAA, FEMA & USGS), five state governments (Alaska, Washington, Oregon, California & Hawaii), and four academic institutions (UAF, USC, UH and OGI), who are working toward the common goals of (a) better understanding of tsunami dangers, such as extent of inundation, (b) tsunami detection and warning, and (c) public education and preparedness.

Hazard Assessment. For NTHMP to have a significant impact on mitigating the damage by tsunamis on lives and property, it must be successful on many academic and practical levels, but perhaps the foremost, and technically most difficult, is the preparation of accurate tsunami inundation maps. Time and again, the emergency managers present at the NTHMP review attested to the fundamental importance of such maps for galvanizing the preparation of public education and emergency plans. With such maps in hand, community and business leaders can readily understand their vulnerabilities.

The initial goal of the NTHMP to provide preliminary inundation maps for all at-risk U.S. coastal communities was quickly determined by the NTHMP Steering Group to be unrealistic due to the technical difficulties inherent in the computation of such maps. A more modest revised goal for the first 5 years of NTHMP, to provide inundation maps for as many high-priority at-risk communities as possible with the limited time and resources available, has been met. Given the map production capabilities now in place in each of the five states, NTHMP is proposing a large acceleration of map production in the next five years, which I believe is technically feasible because of the strength of the state/federal partnership.

Since my background in oceanography and fluid mechanics permits me to understand the inundation mapping component of the NTHMP in more depth than other components such as public education, I would like to convey some detailed impressions of the mapping program here. First and foremost, despite some concerns listed below, I must emphasize that the most important issue regarding the inundation maps is that they exist; that is, even those maps based on the simplest 1-dimensional models, such as those models that have long been used to produce the inundation maps for Hawaiian communities, are much, much better than having no maps at all. Once a map exists, it should be updated - with continuing feedback from local planners - as the modeling technology and environmental information (e.g., bathymetry and topography) improve, in order to be more useful to local planners. However, it is unlikely that such improvements will have the magnitude of impact that the inception of the map had. Therefore, given that most U.S. Pacific coast communities have no tsunami inundation maps, the NTHMP goal for the next five years to accelerate tsunami inundation map production, even if the methodology is occasionally the less accurate coarse-grid, is highly appropriate.

The current program of tsunami inundation map production has some worrisome characteristics. Each state employs its own numerical formulation of the fluid equations. The models are not identical, although I'm told they yield similar results. Furthermore, each state makes different assumptions about the appropriate "worst case" scenarios to be used in calculating inundation. These "worst case" scenarios are often heavily weighted toward local tsunamis, created either by an earthquake or by a subaerial landslide. So the first logical problem is whether, given that the inundation maps are employed by the emergency managers to determine evacuation routes, it makes sense to use an inundation map based on a locally-generated tsunami for such route determination, since the advanced warning for these tsunamis is not going to be more than a few tens of minutes? On the other hand, insofar as the emergency managers prefer a simple map indicating the single overall "worst case" inundation scenario (e.g., Eisner et al., 2001), and if nearfield tsunamis are expected to be larger than farfield tsunamis, then basing the inundation maps, and thus the evacuation routes, on nearfield tsunamis does make practical, if not logical, sense.

The inter-state model differences suggest a potential liability issue. Applied to the same community the different models, with their different "worst case" scenarios, may yield different inundation regions. In the event of a catastrophe in which a community that was deemed "safe" was inundated by a tsunami, the state might find it difficult to defend its particular tsunami preparedness program if a neighboring state was employing a more cautious inundation mapping approach.

It would seem to be common sense to either standardize the inundation mapping models or use a suite of models in each state. Furthermore, for calculating the inundation maps, both the present "worst case" scenarios and a probabilistic suite of locally- and remotely-generated tsunamis should be employed. This last assertion echoes one of the issues that Gonzalez et al. (2001) wish to address under future funding for NTHMP inundation mapping.

A clear impediment to the production of accurate tsunami inundation maps is the lack of availability of accurate high-resolution bathymetry and topography. It is beyond the capability of the NTHMP to acquire these data in the field, so I fully concur with NTHMP's proposed strategy to further strengthen relationships with the NOS and USGS agencies that are responsible for the collection of coastal bathymetric and topographic data.

An outstanding aspect of the mapping program has been the communication between the map-makers and the end users, the emergency managers. It is clear (e.g., Priest et al., 2001; Eisner et al., 2001) that feedback from the users strongly influenced the nature of the final products. This is as it should be. In the future, as map maintenance becomes operational, I believe the utility of the inundation maps could be further enhanced by providing the users with a simple "quality metric" on each map and its iterative successors.

There are many aspects of the map making process which will affect the quality of the final product, such as the accuracy of bathymetric/topographic data. In many situations, there may be historical or pre-historical inundation data with which to validate the modeled inundation. The relevance of all these quality issues is unlikely to be fully grasped by every emergency manager. A single metric, standardized for all the states, that incorporates all these issues into a single evaluation of the accuracy of the inundation map would communicate more quickly the quality of each map and its successors and thereby improve the utility of the maps, especially as communities try to become "tsunami resistant" by modifying their infrastructures (e.g., the locations of hospitals, schools, fire stations) to be less vulnerable to tsunamis.

One can also imagine that, as tsunami modeling capabilities improve, such products as maps of maximum current speeds, in addition to maps of maximum inundation, would be useful to local planners, for instance for the establishment of the Building and Land Use Guidance component of NTHMP's Mitigation element..

Warning Guidance. The achievements of this component of the NTHMP triune are nothing less than superb. The CREST project (Oppenheimer et al., 2001) within the NTHMP, benefiting from large in-kind contributions of man-power and equipment from the USGS and the States, exceeded its ambitious goals to upgrade and expand relevant U.S. seismic networks and communication links. The program also benefited from improvements to the nationwide seismic network undertaken by other agencies. CREST has resulted in the most significant reduction in two decades of the response times by the U.S. tsunami warning centers for evaluating the tsunamigenic potential of earthquakes (e.g., McCreery, 2001). While the improvements are measured in just a few minutes to tens of minutes (representing up to 50% reductions in response times), such improvements are highly significant, especially when emergency managers are faced with the prospect of a locally-generated tsunami arriving at their shores within a few tens of minutes after an earthquake. CREST's plans for the next five years, including communication upgrades and operation of the existing seismic monitoring system, are quite appropriate for NTHMP goals.

The DART project (Bernard et al., 2001), by deploying all its planned real-time tsunami detection buoys, is successfully addressing a very important problem with regard to the issuance of tsunami warnings; that is, once an earthquake has been determined to be potentially tsunamigenic, how can it be determined whether a destructive tsunami has actually been generated? Traditionally, the U.S. tsunami warning centers have relied on sea level gauges at continental coastal and Pacific island stations to determine if a tsunami has actually been generated. These stations remain highly valuable for this purpose, but the well-known problem with this approach is that island stations are not uniformly distributed in the Pacific, leaving large gaps between tsunamigenic regions such as the Alaska Aleutian Subduction Zone and U.S. coastal communities around the North Pacific. Furthermore, it is known that, for particular structures of subaerial earthquakes or landslides, the generated tsunami can be directionally focused so that its largest amplitudes are directed away from nearby sea level stations (e.g., Bernard et al., 2001).

The only way to close the gaps in tsunami surveillance is to have open ocean stations specifically designed for this purpose. The DART buoys employ well-tested sensor technology with customized tsunami detection software and state-of-the-art telemetry to provide real-time monitoring of sea heights near the most dangerous (to U.S. coastal communities) tsunamigenic zones, the Alaska Aleutian Subduction Zone, the Cascadia Subduction Zone and the South American Seismic Zone. The buoys have an exceptional data return rate of 98%. In the next five years, four more DART buoys are proposed for deployment, an appropriate expansion of the existing array, I believe, in order to ensure adequate tsunami surveillance.

The data stream from the DART is telemetered to tsunami warning centers and is readily available in real-time from PMEL's web site. I expect the impact of these data on the process of evaluating tsunami dangers to be considerable. Tsunami warnings arising from earthquakes in the covered zones should be significantly more accurate and timely.

I have only a couple of thoughts regarding possible improvements to the program over the long run. GPS measurements of surface elevation *might* provide an alternative technology for tsunami surveillance. This is a technology research issue that would need to be funded from other sources, but if the substantial technological problems could be surmounted it might prove to be more cost-effective in the long run, or at least might be a useful backup in case a DART bottom pressure instrument failed.

Deep ocean observatories (National Research Council, 2000), both standalone and networked to the coast (e.g., NEPTUNE, off the U.S. northwest coast; NEPTUNE, 2000), will likely be a reality in a few years. Both seismometers and seafloor pressure gauges are part of the planned suite of standard instruments to be deployed at these observatories, which will have real-time telemetry capabilities. Both the CREST and DART objectives could benefit from these additional measurement capabilities.

Mitigation. I feel less qualified to evaluate this element of NTHMP. For me the review of this element was almost entirely educational. I appreciated learning how emergency management, public education and infrastructure assessment all affect hazard mitigation. I can say that I am very impressed with the breadth of useful products produced to aid local planners and the public, and with the quantitative measures employed to determine if coastal communities are becoming more aware of tsunami hazards (i.e., Jonientz-Trisler, 2001). They clearly are.

Local, state and federal planners are fully engaged in very productive interaction to enhance hazard mitigation. Only the most politically sensitive goals (e.g., the Building and Land Use Guidance Element) are not being accomplished in a timely manner. The Mitigation element has great momentum now and a clear vision for the future. It should be allowed to move forward as planned.

References

Bernard, E.N., F.I. Gonzalez, C. Meinig, and H.B. Milburn, 2001: Early detection and real-time reporting of deep-ocean tsunamis. *Review of the U.S. National Tsunami Hazard Mitigation Program*, Seattle, WA, 7 August, 2001, NOAA/PMEL, pp. 85-96.

Eisner, R.K., J.C. Borrero, and C.E. Synolakis, 2001: Inundation maps for the State of California. *Review of the U.S. National Tsunami Hazard Mitigation Program*, Seattle, WA, 7 August, 2001, NOAA/PMEL, pp. 55-69.

Gonzalez, F.I., V.V. Titov, H.O. Mofjeld, A.J. Venturato, and J.C. Newman, 2001: The NTHMP Inundation Mapping Program. *Review of the U.S. National Tsunami Hazard Mitigation Program*, Seattle, WA, 7 August, 2001, NOAA/PMEL, pp. 17-42.

Jonientz-Trisler, C., 2001: The Mitigation Strategic Implementation Plan: Toward tsunami-resistant communities. *Review of the U.S. National Tsunami Hazard Mitigation Program*, Seattle, WA, 7 August, 2001, NOAA/PMEL, pp. 107-147.

McCreery, C.S., 2001: Impact of the National Tsunami Hazard Mitigation Program on operations of the Pacific Tsunami Warning Center. *Review of the U.S. National Tsunami Hazard Mitigation Program*, Seattle, WA, 7 August, 2001, NOAA/PMEL, pp. 97-105.

National Research Council, 2000: Illuminating the Hidden Planet: The Future of Seafloor Observatory Science. National Academy Press, Washington, D.C.

NEPTUNE - North East Pacific Time-series Undersea Networked Experiments, 2000: "NEPTUNE: A Fiber-Optic Telescope to Inner Space." Web page available at http://www.neptune.washington.edu.

Oppenheimer, D., A. Bittenbinder, B. Bogaert, R. Buland, L. Dietz, R. Hansen, S. Malone, C.S. McCreery, T.J. Sokolowski, and C. Weaver, 2001: The CREST Project: Consolidated reporting of earthquakes and tsunamis. *Review of the U.S. National Tsunami Hazard Mitigation Program*, Seattle, WA, 7 August, 2001, NOAA/PMEL, pp. 71-83.

Priest, G.R., A.M. Baptista, E.P. Myers III, and R.A. Kamphaus, 2001: Tsunami hazard assessment in Oregon. *Review of the U.S. National Tsunami Hazard Mitigation Program*, Seattle, WA, 7 August, 2001, NOAA/PMEL, pp. 43-53.