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FEASIBILITY STUDY ON MITIGATING TSUNAMI HAZARDS IN THE PACIFIC

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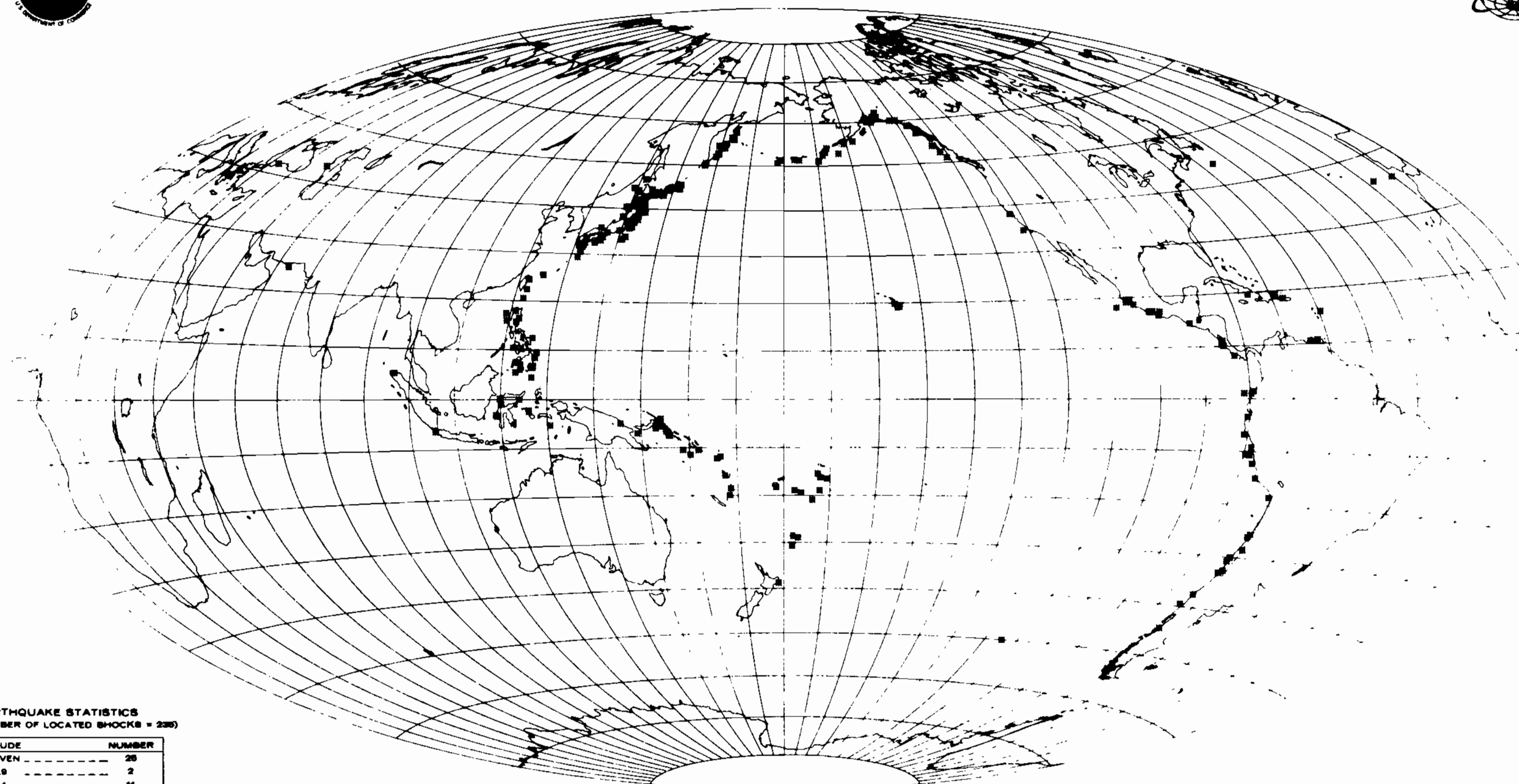
ABSTRACT

This study shows that many aspects of existing U.S. technology have potential applications to the problem of providing early tsunami warning information in developing nations of the Pacific which do not have their own regional warning network. A simple conceptual model is developed which shows how these technologies could be integrated into an early warning "system." The basic elements are described for a demonstration program which would confirm the practicality of such a technologically feasible system. Such a demonstration--to which the acronym THRUST (Tsunami Hazard Reduction Utilizing System Technology) is applied--would be a significant step toward achieving the goal of hazard mitigation in the developing areas of the Pacific community. It is recommended that an active program of tsunami hazard reduction in developing nations be established within the Ofice of U.S. Foreign Disaster Assistance of the Agency for International Development.

TSUNAMI DATA 1876-1976

EPICENTERS OF EARTHQUAKES THAT GENERATED TSUNAMIS

PRODUCED by NOAA/EDS/NATIONAL GEOPHYSICAL and SOLAR-TERRESTRIAL DATA CENTER



EARTHQUAKE STATISTICS
(TOTAL NUMBER OF LOCATED SHOCKS = 235)

MAGNITUDE	NUMBER
NOT GIVEN	25
< 5.9	2
6.0-6.4	11
6.5-6.9	30
7.0-7.4	73
7.5-7.9	46
8.0-8.4	34
8.5-8.9	14

WORLD DATA CENTER A
for
SOLID-EARTH GEOPHYSICS

1. INTRODUCTION

The Agency for International Development (AID), Office of U.S. Foreign Disaster Assistance (OFDA) is authorized by the United States Congress in Chapter 9 of the Foreign Assistance Act of 1961, as amended, to help alleviate suffering from disasters in foreign countries by providing emergency relief and strengthening the ability of developing nations to cope with disasters by increased reliance on their own resources. Helping host countries achieve adequate levels of preparedness and early warning capabilities represents OFDA's principal focus in disaster prevention and mitigation. Historically within the Pacific Basin, one of the most destructive natural hazards is the seismic sea wave, or tsunami, generated by large submarine earthquakes. Since 1850, more than 70,000 lives have been lost in the Pacific due to tsunami (1). Today, several million people live or derive livelihood in tsunami hazard zones in the Pacific.

Since 1965, Pacific nations subjected to tsunami hazards have mutually benefited from the United Nations organization International Coordination Group for the Tsunami Warning System in the Pacific.* In April 1982, this group advanced the resolution that early warning systems be developed for areas exposed to tsunami generated by local earthquakes. The present study addresses the application of available technology, including satellites, for significantly improving early tsunami warning along vulnerable coastal zones in the Pacific basin. Specifically, a program is described which will test and evaluate the utility of these technologies in tsunami hazard mitigation in developing nations.

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* See Appendix A for a relevant survey of international and national tsunami organizations and their interrelationships.

In describing locally generated warning systems, two time periods are essential: the period, be it days, months, or years, prior to the tsunami (pre-event stage) and the first hours after tsunami generation (real time stage). During the pre-event stage, attention focuses on determining the general extent of the tsunami threat in a coastal area and creating a viable emergency evacuation plan for implementation at the time of the disaster. During this time a program of public tsunami awareness and education can be undertaken which can save many lives during the first few minutes of a locally generated tsunami, when no mechanical warning system can be truly effective and a threatened population must rely on its informed instincts. Once a tsunami occurs (the real-time stage), a warning system capable of collecting seismic and water level data, analyzing them, and disseminating hazard information based on them is essential. Japan, USSR, and USA (Alaska and Hawaii) have regional warning systems capable of reacting to a tsunami and issuing a local warning about ten minutes after a local event (2). The other nations of the Pacific, many of which are developing nations, are not as fortunate and must rely on the Pacific Tsunami Warning System (operated at the Pacific Tsunami Warning Center (PTWC) in Honolulu, Hawaii) for warning messages. Present operating limitations prevent actual warnings from being disseminated to most countries in less than one hour from the generation of a tsunami (3).

A gap, therefore, exists in the present warning structure. Developing countries without a regional warning system cannot be alerted about tsunami originating close to their shores until an hour after generation. The purpose of this study is to examine existing U.S. technology to ascertain if an early warning system can be designed to fill this gap in nations with no regional or national warning system. Specifically, the objective is to design a system that can deliver earlier warnings to a developing country within the Pacific or directly to isolated populations centers within ten minutes of tsunami generation.

Thus, the rationale for the study presented in this document is the transfer of existing U.S. technology to developing countries to supplement the Pacific Tsunami Warning System during the first crucial hour of a tsunami.

These technologies can be partitioned into three categories: data collection, data analysis, and information dissemination. Sections 2, 3, and 4 assess the existing technologies in data collection, analysis, and dissemination which are applicable to the warning system and most appropriate for transfer. Other U.S. technologies are available, but have certain drawbacks because they are not easily adaptable to the existing tsunami system.

A number of criteria were used in selecting technologies for use in early warning in local regions. Among these are reliability, compatibility, and availability. The selection criteria also balanced the benefit of the hazard reduction with cost of the system.

In Section 5, we present a conceptual system which synthesizes the technologies discussed in Sections 2, 3, and 4. Finally, a demonstration program is described in Section 6. The applicability of the demonstration program to many areas of the Pacific can be shown. Implementation, including a site survey and equipment installation in a test area, is a requisite step in developing a satellite-based network throughout the Pacific basin with the potential of saving lives and protecting property from the hazard of locally generated tsunami. Recommendations are listed in Section 7. Acknowledgments and references appear in Sections 8 and 9. Appendix A provides a complete survey of international and national organizations interested in tsunami hazards and their interorganizational relationships.

2. DATA COLLECTION

Since the beginning of the Pacific Tsunami Warning System in 1949, the warning process has been initiated by seimic signals from large earthquakes. The instruments used to detect these signals were largely those developed for routine earthquake and tide monitoring programs. Recent significant advances in data collection technologies have occurred which could be applied to early tsunami warning (2). These include digital recorders, computers and microprocessor technology, and satellite telemetry. Some of these technologies have been used for experimental tsunami warning programs, nuclear-test monitoring, and earthquake prediction programs in developed countries. The technology is, therefore, available for use by developing countries for improving local warnings.

The following is a brief review of the present status of water level and seismic sensor technology relative to the tsunami early warning operations. For this review, the following criteria were selected in assessing current available instrumentation:

- Water level sensors should be capable of recording water level changes to an accuracy of 1 cm for wave periods ranging from 3 to 90 minutes. They should be able to remain on-scale during fluctuations of up to 7 meters beyond tidal ranges at shallow water locations. The sensors should be able to transmit, via satellite or hardwire to any location, digital data recorded at 30-second intervals independent of local power sources. The timing device for the system should be accurate to within one minute in one year.
- Seismic sensors should be capable of recording accelerations to within .01 g over a range of .1 g to 1.0 g. They should remain on-scale during

accelerations up to 1.0 g. Data from these sensors should be digitally processed in real-time to activate a satellite transmission once a certain threshhold has been exceeded. The sensor, processor, and transmitter should also operate independently of local power sources. The system timing device should have an accuracy of one minute in one year.

Equipment components available to create a data collection, processing, and transmitting platform (with possible U.S. suppliers) include:

1) Tide gage (Metercraft; Progress Electronics of Oregon; Handar Corp.)
2) Seismometer (Springnether; Kinemetrics; Geotech)
3) Microprocessors (North American Rockwell)
4) GOES receiver and transmitter (La Barge Corp; Motorola)
5) Solar panels with rechargeable batteries (Solarex)

Progress Electronics of Portland, Oregon, has stand-alone systems available which meet tsunami warning water level criteria. Synergetics Corporation of Boulder, Colorado, has a stand-alone seismic system available for earthquake detection, processing, and transmitting from remote locations.

This evaluation leads to the conclusion that sensors can detect the important parameters for tsunami warning and can transmit raw or processed data via satellite. Indeed, some of these sensors have already been used in test modes for improving the tsunami system. In particular, data from coastal tide gages (bubbler type) and processed seismic data (short-period) have been transmitted via the Geostationary Operational Environmental Satellite (GOES) West system (4, 5). Data from other sensors, such as well-type tide gages, short period and long period seismometers, have been transmitted in analog and digital form to regional warning systems of Alaska, Hawaii, Japan, and USSR (6). At all of these centers, computer-assisted data analysis is either operational or in developmental stages (6). Thus, there are no known limitations on existing sensor technology for immediate application to a satellite-based early tsunami warning system.

One of the most exciting possibilities for improved early warning operations is the automatic triggering capability of these sensors. Previous U.S. application of satellite technologies to the tsunami operation have focused primarily on human-activated interrogation mode. For example, once an earthquake has been detected and located by PTWC, tide gages are manually interrogated for verification of tsunami existence and determination of severity. The principal drawback of this approach for early warning (10-60 minutes after generation) is the time delay encountered in detecting the earthquake, assessing data, and interrogating sensors. Currently, human-activated interrogating systems introduce serious delays of up to one hour, which may be critical for a developing country susceptible to a locally generated tsunami. It is recommended that new satellite-based technology be integrated with the sensor-activated mode to provide more rapid warning information to operational decision-makers and people in charge at the disaster site. This total system is described in more detail in Section 5.

In addition to real-time data collection, historical data on previous tsunami in a particular location are essential to determine placement of instruments, calibration of models, and formation of emergency planning. In particular, historical information of tsunami arrival times, run-up levels, and mitigation measures is necessary. Local bathymetric and topographic data are also required to support model studies in threatened areas.

3. DATA ANALYSIS AND MODEL STUDIES

This section addresses the data analysis, data products and modeling needed to provide the background for planning decisions, risk determination, and educational material development in support of awareness of primary tsunami hazards and response to natural or system warnings.

One of the principal tools for tsunami data analysis is the use of models of one type or another. These allow studies to be carried out during the periods between actual events. Equally important is applying existing and currently evolving techniques for modeling tsunami evolution for the improvement of both the tsunami warning and the hazard mitigation capabilities. A useful approach is the recognition that tsunami evolution can be described by three phases.

- generation and behavior in the immediate source area,
- propagation away from the source area and toward coastlines, and
- interaction (possibly destructive) with the environment near, at, and on the shorelines.

This three-phase structure helps to point out the different information requirements for tsunami warning procedures and for hazard mitigation planning.

TSUNAMI WARNING

A system designed to warn people about a specific hazard should have several goals. It should be able to ascertain quite rapidly that a threatening hazard has developed, generate an assessment of the seriousness of the threat, and communicate this information to threatened populations in sufficient time for them to take action to save their lives and protect their property. A warning system must, in addition, be able to achieve these goals repeatedly and accurately in order to establish its credibility and thus maximize its effectiveness. In order to be an effective tool for saving lives and property, the ideal tsunami warning system should be able to either generate on its own or to tap into established sources of information concerning all three phases of tsunami evolution.

HAZARD MITIGATION

The development of hazard mitigation plans takes place over a much longer time scale than the tsunami warning process. Such plans might concentrate on the most difficult phase of tsunami evolution--the coastal interaction phase. These plans must take into account a wide variety of factors. These include questions such as which portions of a coastal area are or have been most severely threatened by tsunami? Where would the damage to life and property be most significant? What are the probabilities of such events occurring in ten years? fifty years? a century? What type of disaster relief preparations should be made? How effective would measures such as strict zoning, land use plans, increasingly stringent building codes, and coastal barrier construction be in reducing the hazard?

TSUNAMI MODELS

The next question to be addressed is how tsunami models could help fill requirements. Tsunami modeling, in simple terms, is an attempt to simulate or approximate the behavior of a physical phenomenon. Tsunami models of one or more of the three phases of evolution have been in use for the last several decades. These models can be grouped into three categories:

Hydraulic models are attempts to recreate in wave tanks and with physical models the processes observed in actual situations.

Analytical models reflect attempts to strip the complicated tsunami process down to its basic physical elements and translate these into tractable systems of equations. Functional solutions to these equations are then found. The goal is not to faithfully recreate observations, but rather to combine the various forcing mechanisms in an appropriate fashion, so that the model waves behave in a manner qualitatively similar to physical waves.

Numerical models begin with sets of equations similar to those used in analytical models. Computational, rather than functional, solutions are sought, usually by means of digital computers. These solutions should closely conform to observations.

All three types of models have been used successfully in examining the various aspects of tsunami evolution (7). Numerical models, because of their great flexibility and relatively low cost, seem to have the greatest utility for tsunami research (8, 9, 10).

Tsunami models can be quite useful in both hindcast and forecast modes. That is, they can be used either to reconstruct what happened during a historical event or to estimate what might possibly occur in the future. Both of these uses provide a strong foundation of basic information to draw upon for both long-term hazard planning and real-time warning.

In the hindcast mode, models can help to shed new light on what actually happens when a tsunami occurs. They can be used to fill gaps in areas where observational data is scarce. And they can be used to analyze ways in which protective measures could have helped to reduce damage and destruction.

If models are to be used in this mode, a detailed compilation and analysis of existing observational data must also be undertaken. The primary purpose is to provide as much data as possible for verifying and calibrating model results so that they conform closely to historic reality. A second purpose is to place the tsunami (both real and model) into their proper historical perspective in terms of frequency of occurrence and severity. This information would be valuable on both regional and basin-wide scales by depicting the nature of the threat for planning and education purposes.

In the forecast mode, models can be used to augment the historical data base to estimate threat levels due to tsunami which have not yet happened. This could include not only worst-case or once-in-200-year tsunami, but also less severe, but quite possible, events. They can also provide travel time information for augmenting existing charts.

In both modes, tsunami models can be applied to both long-term planning and real-time warning.

Hazard Planning

Models can provide information to eliminate many omissions in our existing knowledge. On a basin-wide scale they can be used to delineate areas of most severe threat due to tsunami generated in specific regions. On a finer scale they can be used to fill in gaps in tide gage coverage along coastlines for both historical and hypothetical events. This type of information can be used to develop threat levels and probability-of-occurrence estimates in Pacific coastal locations. Coastal models can be used to locate high-risk areas for flooding and guide both land use requirements and building codes. Highly detailed run-up models could even be used to develop scenarios for disaster preparedness exercises.

Real Time Warning

Tsunami models can also play a key role in warning operations. If a warning system were able to rapidly acquire information on the location, magnitude, areal extent, and tsunami potential of an earthquake, an existing data base of similar cases could identify threat probabilities throughout the

Pacific. The most useful product, in terms of determining appropriate response, would be to supplement notice that a tsunami has been generated with estimates of its severity.

Data Products

A useful product for public information could be a map illustrating the tsunami occurrences and effect within the Pacific basin. This would summarize in a visual form the history of destructive tsunami on a Pacific-wide and local basis. A revised travel time chart for local and Pacific basin tsunami could be prepared using new digital bathymetric data for any location.

In order to provide the data needed to support later modeling, analysis and dissemination activities, local coastal bathymetry and elevations, tsunami effects, run-up and arrival time data and information on local disaster warning infrastructure must be gathered.

4. DISSEMINATION OF INFORMATION

The Pacific Tsunami Warning System detects major earthquakes in the Pacific region, evaluates the earthquake tsunami potential in terms of epicenter and Richter scale magnitude, determines if a tsunami has been generated, and issues appropriate warnings and information to minimize the hazards of tsunami. The international monitoring system is composed of twenty-two seismic stations and approximately 50 tide stations throughout the Pacific Ocean. The international warning system employs teletypewriter and voice communication links to acquire data and disseminate tsunami information to seventeen nations. Transmission times range from 10 minutes to one hour, depending on the efficiency of communication relay points. Regional warning systems for locally generated tsunami exist for Hawaii, Alaska, Japan, and USSR. These monitoring systems are real-time links from seismometers and tide gages to the respective centers (6). Local tsunami warnings in these systems may be issued on the basis of earthquake information alone.

In general, warnings delivered by these centers include earthquake locations (±50 km), earthquake Richter scale magnitude (±.3), tsunami arrival (±20 min), and reports of tsunami wave heights as recorded by tide gages (6). The earthquake parameters and tsunami arrival times throughout the Pacific are usually disseminated by PTWC to the 54 international warning points within one hour after the occurrence of an earthquake. The time of receipt of tsunami wave reports at PTWC varies with the travel time of the tsunami from its origin to the tide gages, the dependability of equipment and observers, and the communication links.

Development of satellite communication offers significant opportunities for both collecting and disseminating warning information. NOAA's Geostationary Observational Environmental Satellite (GOES) provides a transmission pattern for the whole eastern Pacific (Figure 1).* The GOES operating system includes a data collection system (for use with sensors described in Section 2) that can receive information from a sensor and relay this information through the satellite to a central point for distribution. For Pacific-wide tsunami warning application, the data would be transmitted to the command and data acquisition station (CDA) at Wallops Island, Virginia, then retransmitted to the PTWC. The time of transmission from sensor to PTWC can be as short as one minute in "real time."

The GOES West operating system can also interrogate remote sensors by command initiation from CDA. In this mode, a coded address is initiated and transmitted via satellite in real-time to the platform. The platform receives a command that activates a preprogrammed set of instructions. Normally, the command from the satellite is a 50-bit serial code containing an identifier, a platform number, a priority, a primary and secondary address, a standard validation code, and a time code. The interrogation code can serve as an early warning alert by substituting one of the normal codes through modification of the operating system at CDA (11). For more technical details of the GOES communication system, see Appendix B.

A Disaster Alert System

Ideally, for a disaster alert system, a comprehensive message describing the potential disaster conditions, parameters, and prognosis is desirable. But in real emergencies a minimum amount of factual material is available to issue

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* Failure of the imaging scanner on the GOES West satellite Nov. 25, 1982, did not affect the communications capability. The following discussions about the GOES West are still valid.

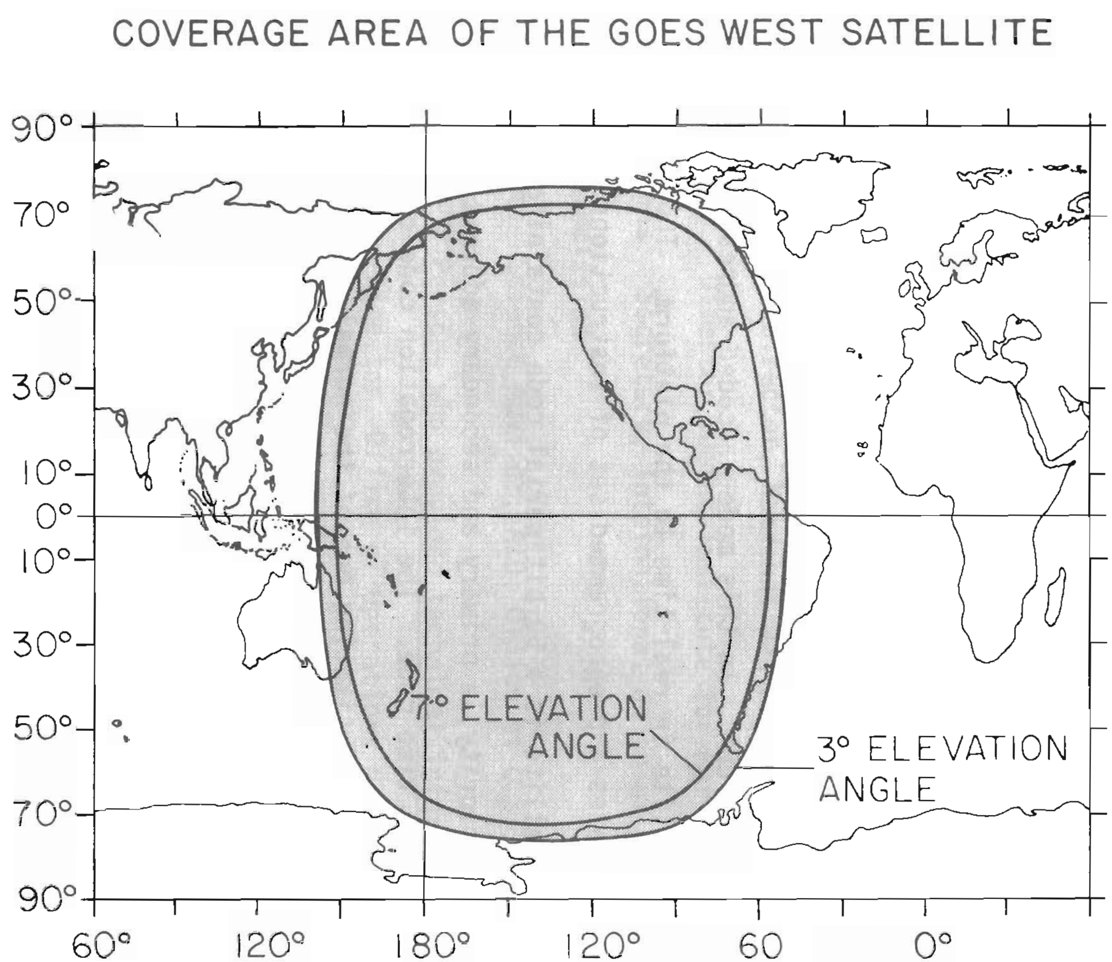
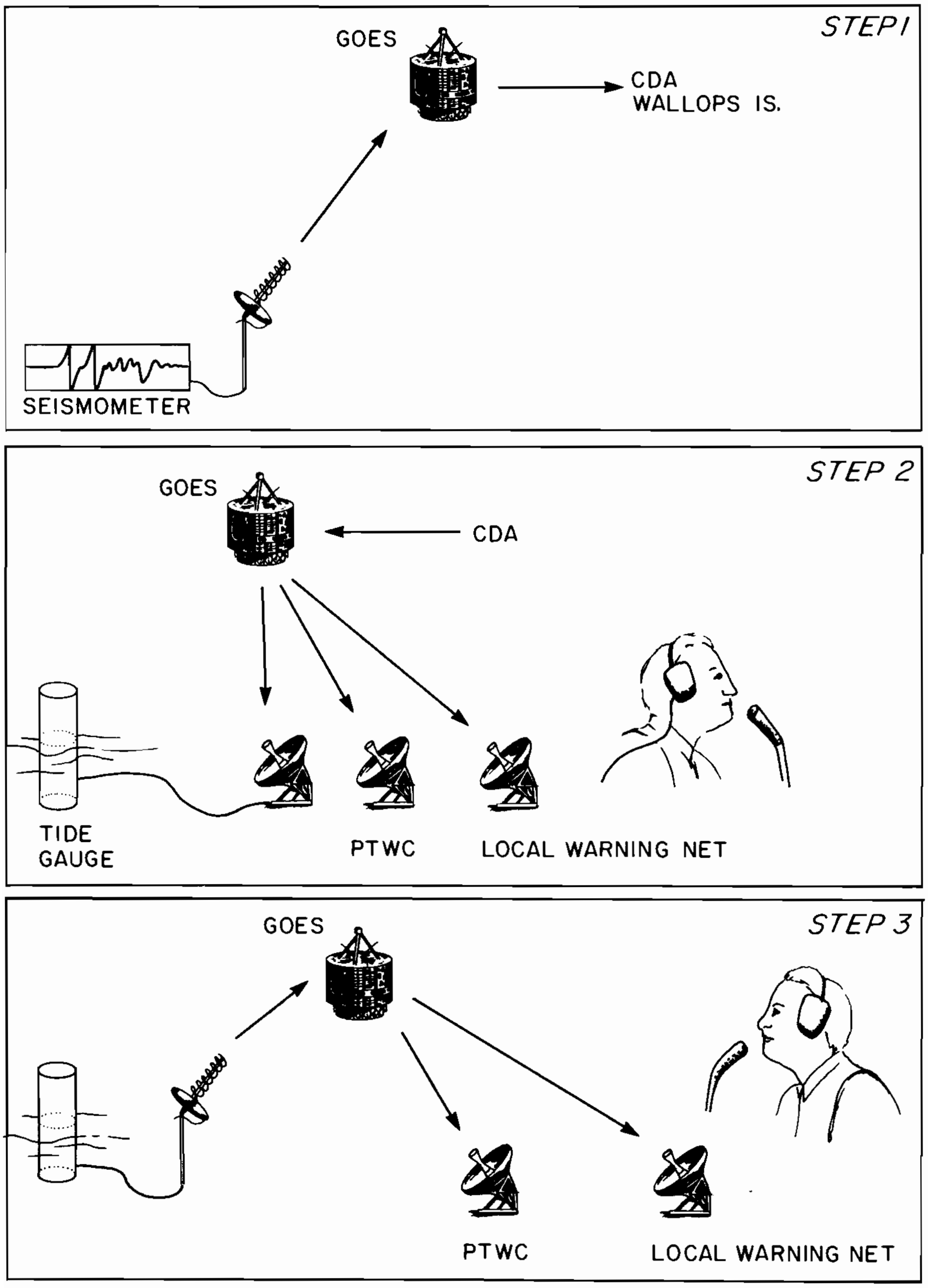


Figure 1. Coverage area of GOES West Satellite

a warning. The decision to extend this warning to a given population might require additional information not available from a warning service or possibly not available at all. An electronic device could provide a basic alert and a suggested course of action. Figure 2 shows a basic alerting system. The required elements are antennas, receivers, independent power sources, sensors and alarms. The antennas are a simple, harsh environment model that can endure a corrosive salt atmosphere and wide temperature variations. The receiver is a dual-conversion solid-state model with all of the electronics necessary to strip the coded information from the transmitted signal and, through the use of built-in microprocessors, to broadcast information. A receiver with provisions for receiving either normal or alert code must be used.

At remote sites, a set of solar panels would provide independent power for the data collection platform. In an operational system, the panels would be large enough to power the complete system and batteries capable of powering the system for several days to cover a period of power loss would be included.

Critical and threshhold levels can be established which trigger a sensor's transmission to the satellite. GOES can then automatically transmit messages which notify authorities and trigger any one of a wide variety of automatic alarm devices (sirens, bells, voice broadcasts, etc.). Then incoming information can, for example, trigger the printing of messages, in the form of narrative sentences, previously stored in a microprocessor memory of the receiver. The microprocessor can also initiate alarm relay to remote locations. Verbal announcements stored in the microprocessor may be released in the local language and sirens sounded in any order or combination desired. This can all be accomplished automatically or under human control.



Seismic sensor(s) or tide sensor(s) receive stronger-than-threshhold signal, alerts GOES of pertinent data.

GOES automatically issues two messages. One instructs tide gages to begin transmitting data. The second alerts PTWC and the local warning net that an alarm has been tripped. Local authorities decide whether or not to issue a warning.

The gage data is transmitted to GOES and thus to both PTWC and the local warning net. Both organizations have additional information to supplement earlier warnings/watches.

Figure 2: Local tsunami warning network operations.

Thus, by utilizing existing technologies with slight modification, an early warning event-activated system can be installed in disaster-prone developing nations without regional warning systems. Such a system could reduce alerting time from one hour to as little as one minute. The time-saving alert coupled with a well designed local contingency plan could save many lives.

5. SYNTHESIS OF TECHNOLOGIES AVAILABLE FOR TRANSFER

The previous three sections have shown that the technology exists to improve estimates of tsunami hazards and to establish rapid dissemination of localized early warnings. Appropriate configuration of these elements will constitute a conceptual model that represents a significant advance in early tsunami warning. In terms of previous three sections, the conceptual model can be described in the following fashion:

Data Collection -

A. Pre-event: historical data on tsunami run-up, times of arrivals and effects will assist in emergency planning and model verification. Bathymetric and topographic data are necessary inputs for model simulations.

B. Real-time: data collection will be initiated by the triggering of seismic or water level devices of the tsunami system. Reports from water-level sensors are still required to determine the existence and severity of tsunami. Both sensor types must be in communication with PTWC. It is desirable, but not necessary, that the sensors be directly linked to a local warning network in addition to the satellite link.

Data Analysis -

A. Pre-event: historical data analysis, coupled with numerical models, provides estimates of potential inundation levels for planning purposes. These investigations are essential to designate hazard areas and safety zones for disaster planning.

B. Real-time: real-time data can be used to update warning information calculated in the pre-event data analysis. They can also be used to monitor and continuously refine warning information as the tsunami propagates throughout the Pacific.

<u>Dissemination</u> -

A. Pre-event: emergency preparedness will require the establishment of a local infrastructure to respond to a tsunami. Public education is the foundation of proper response to a tsunami alert. Dissemination of information on the procedures and dangers of tsunami will take the form of workshops, media coverage, school programs, and other vehicles to keep the public aware of the hazard.

B. Real time: or near-real-time dissemination of warnings for developing countries can be accomplished by the application of satellite technology as described in Section 4.

With the conceptual framework as a guide, a demonstration program could be implemented for one population center to demonstrate the utility of the system. This program is described in detail in Section 6. The products derived from this demonstration are transferrable for use in the Japanese GOES system and the Indonesia PALAPA system, thereby providing a proven technology to other countries interested in tsunami hazard mitigation but outside the range of GOES West. Such a program will provide data to PTWC much more rapidly, thus allowing for earlier alerting of the Pacific System. It will also foster cooperation among agencies that have an interest in U.S. tsunami hazards mitigation.*

This conceptual model should be considered a generalized framework. As such, it has inherent limitations because localized details have been omitted. Each application of this model must reflect the geophysical, oceanographic, and socio-political character of the specific site. The geophysical characteristics will determine seismic instrument design and placement; oceanographic characteristic

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* See Appendix A for U.S. organizations concerned with tsunami hazards.

will determine water level gauge placement and design; and socio-political characteristics will determine the emergency system design. The successful integration of these factors is a difficult task which must be accomplished on a case-by-case basis. The lack of a detailed elaboration of these factors is not meant to minimize their impact; such a discussion, however, is well beyond the scope of this feasibility study.

6. THRUST PROGRAM

The conceptual model described in Section 5 can quite readily be turned into a demonstration program--Tsunami Hazard Reduction Utilizing System Technology (THRUST)--to mitigate tsunami hazards in the Pacific Ocean. The first step of this program is to test the conceptual model described in Section 5 at one population center in a developing country.

Table I illustrates the THRUST pilot study. The study is subdivided into the three functional areas of data collection, data analysis, and information dissemination; each area is partitioned into pre-event and real-time frames. Thus, one could interpret the first row of the matrix as development of the emergency operating system that is activated by the real-time second row. Both time frames must be considered for a system that will reduce tsunami hazards.

During the pre-event stage a data base would be developed to provide historical information on tsunami run-up, arrival times and tsunami impacts. Additional data would be collected on the bathymetry of the local coastline, the topography of the land, and local tidal ranges. These data would be used to simulate historical tsunami events. The historical data would help validate and calibrate the numerical model while information on the physical morphology would be used to construct the model. Once the numerical model has been verified (simulations closely resemble historical data), then hypothetical simulations will be conducted for worst case scenarios. The selection of scenarios will be based upon geophysical information relating to the most probable earthquake's areal extent, magnitude, and vertical displacement which could occur close to the test area. The combination of historical data and model simulations provides an extended data base from which to to create emergency operating plans. Although this extended data base has drawbacks (it depends on the quantity and quality of the real data base), it represents the best technique of supplying data where none exists. From these data, zones of hazard and safety can be constructed and evacuation plans established. In many cases, these data can also provide building code guidelines.

An earthquake activates a seismic instrument. This instrument then transmits a signal to the GOES satellite system (satellite and CDA) that responds by automatically transmitting an alert code to an alarm device at the warning site designated by local authorities. The alarm device instantly responds by initiating a set of prerecorded instructions based upon the emergency plans established before the tsunami. A human will make the final determination about issuing a tsunami warning based upon predetermined criteria. Thus, a human will make the *decision*, and he will have enough information within 5 minutes of the earthquake to make such a decision *intelligently*. In addition to the early alert signal from the GOES satellite, other signals are sent to interrogate tide gages about the earthquake source. These water level data are sent to PTWC and to the local authorities for faster confirmation of tsunami activity. The impact of the THRUST program will be an early warning system for the local population near the source *and* faster dissemination Pacific wide by PTWC.

In choosing population centers for a pilot demonstration, consideration was given to tsunami hazard potential, access to GOES West satellite, and national commitment to the program. Using these criteria, two cities in two South American countries were selected (Lima, Peru, and Valparaiso, Chile). It is recommended that *only one site* be chosen for the pilot study, but two are offered in case one country is not suitable. A site survey team should evaluate both locations and determine the host country on the basis of technical capacity and institutional commitment to implementing the demonstration and maintaining continued operations.

TABLE I
THRUST-SCHEMATIC PILOT STUDY

FUNCTIONAL AREA Time Frame	DATA COLLECTION	DATA ANALYSIS	DISSEMINATION
Pre-Event	Develop Tsunami Data Base	Evaluation of Hazard using Simulations	Development of Emergency Operations/Procedures
Real-Time	Sensor Development Instrument + Processing + Transmission • Seismic • Water Level	Operational "Predictive" Model	Integration of Early Warning Device into Emergency System

7. RECOMMENDATIONS

In recognizing AID/OFDA's role and responsibility in coordinating international disaster assistance, including prediction and early warning, it is recommended that

1) An ongoing program in tsunami hazards' reduction for developing countries of the Pacific basin be established in AID/OFDA,
2) AID/OFDA's early warning program strategy with respect to tsunami hazard be strengthened through support of a THRUST pilot program explained in the preceding sections <u>and</u>
3) AID/OFDA's early warning program strategy be further strengthened through public education programs that promote proper understanding and reaction to tsunami warnings.

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Mr. G. Burton: Director, Pacific Tsunami Warning Center

Mr. R. H. Hagemeyer: Director, National Weather Service Pacific Region

Dr. Dennis Moore: Director, Joint Institute for Marine and Atmospheric Research

Dr. Harold Loomis: Secretary, International Union of Geodesy and Geophysics Tsunami Commission

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<u>Persons who provided technical information</u>

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Mr. Mickey Moss: Assistant Chief, Pacific Tides Party

Mr. Harold Clark: Engineer, Alberquerque Seismological Laboratory

Mr. Charles Vermillion: Engineer, National Aeronautical and Space Administration

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Dr. Jimmy Larsen: Research Oceanographer, Pacific Marine Environmental Laboratory

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Appendix A

Tsunami Organizational Relationships

Tsunami Organizational Relationships

Tsunami related activities and responsibilities are scattered through a number of international and national governmental and scientific organizations. They range from scientific research and engineering to hazard mitigation and warning activities.

On the pages 33-36 is a schematic which attempts to identify the key international and U.S. bodies and to show their relationships. There are also substantial national organizations in Japan and the USSR which are not identified. The organizations indexed by numbers in the upper left corner are described as follows.

I. International Programs

1. International Coordination Group for the Tsunami Warning System in the Pacific (ITSU).

ITSU consists of representatives of 22 Pacific Basin nations. It meets about every other year to 1) effect liaison among participating countries at the technical level, 2) ensure exchange of information regarding techniques of tsunami forecasting, 3) coordinate with IOC, WMO, and IUGG and 4) provide essential secretarial services for IOC. It makes recommendations regarding improvements in the system which require action by member states. Contact can be made through the Intergovernmental Oceanographic Commission, UNESCO, 7, Place de Fortenoy 75700 Paris.

2. IUGG Tsunami Commission

IUGG Tsunami Commission promotes tsunami research and applications by providing a forum to hold meetings and symposia and otherwise provide for the exchange of scientific information about tsunamis, and for providing advice on tsunami problems to appropriate organizations. The tsunami commission is sponsored jointly by IASPEI and IAPSO It meets every two years alternating with the IUGG General Assembly every four years and separate symposia in the interim. One of its roles is to review the World Data Center Guide to International Data Exchange for tsunami data. As with most scientific organization the chairmanship and secretariat change regularly. Contact can be made through the ICSU Secretariat, 51 Blvd de Montmorency, 75016 Paris, France.

II. National Programs

3. UJNR Task Committee on Storm Surge and Tsunamis

This Task Committee meets annually with the UJNR Panel on Wind and Seismic Effects to present technical findings and review activities by government agencies in the two countries. Recommendations for joint activities or data exchanges are made. Contact can be made through Bureau of Standards, Structures Division, Gaithersburg, Md., which provides the focus for the U.S. side.

4. US/USSR System of Simultaneous Warning on Tsunami

This activity is part of the US/USSR Environmental Protection Agreement. Members from the U.S. and USSR meet occasionly to develop agreements for joint projects. The U.S. Project Leader is Dr. Eddie Bernard, Pacific Marine Environment Laboratory, 3711 15th Avenue Northeast, Seattle, Washington 98105.

III. U.S. Government

5. Marine Services Branch

This branch currently provides the staff support for NWS Headquarters in Washington for coordinating the tsunami warning program. Dr. Glenn Flittner, head of the branch, is the U.S. national contact to ITSU.

6. Alaska Tsunami Warning Center

This activity provides tsunami warning for the Alaskan and U.S. West Coast Region by centrally recording seismometers and tide gauges at its Palmer, Alaska facility. It coordinates closely with the Pacific Tsunami Warning

Center and the USGS National Earthquake Information Service.

7. The Pacific Tsunami Warning Center

The PTWC at Ewa Beach, Oahu, is the hub of the Pacific Tsunami Warning Service and relies on locally recording seismometers and communicated seismic and tide observations from around the Pacific to provide tsunami warnings to participating organizations around the Pacific. It also provides local warnings for the State of Hawaii.

8. International Tsunami Information Center

The ITIC performs a coordinating, monitoring, and advisory role to the Member States of the ITSU relative to the tsunami warning system and tsunami hazards. It publishes the informative "Tsunami Newsletter" several times each year. It provides technical advice to developing countries, welcomes guest workers, and develops educational meterial. It is operated by the NWS for the IOC. Address: P.O. Box 50027, Honolulu, Hawaii 96850.

9. Pacific Marine Environmental Laboratory

PMEL engages in research relative to tsunamis and supports research at the Joint Institute for Marine and Atmospheric Research (JIMAR) at the University of Hawaii. (Address: 3711 15th Ave. N.E., Seattle, WA 98105)

10. World Data Center-A

WDC-A operates under general guidelines recommended by relevant international scientific bodies. In the field of tsunami, this is the IUGG Tsunami Commission. The WDC-A collects information on the occurrence and effects of tsunamis including seismic and mareographic records, photography, and histories. It produces data products such as publications and maps. Guest workers are welcome. Address: WDC-A for Tsunamis, NOAA/I/GCI, 320 Broadway, Boulder, Colorado 80303.

11. USGS National Earthquake Information Service

The NEIS relates to tsunamis in providing a service to locate earthquakes worldwide and determine their magnitude in a matter of a few minutes to several hours. They coordinate with the PTWC and ATWC by exchanging results and data. Address: USGS Branch of Global Seismology, NEIS, Box 25046, Stop 967, Federal Center, Denver, Colorado 80225.

12. Department of State/AID office of Foreign Disaster Assistance

OFDA has activities both for recovery assitance and hazard mitigation for a wide range of disasters affecting developing countries.

13. Federal Emergency Management Administration; Office of Disaster Reponse

The FEMA Office of Disaster Response has the Federal responsibilities to respond to U.S. disasters of all types including tsunamis. They have an interest in hazard assessment as well.

14. FEMA Office of Natural and Technological Hazards

Office of Natural and Technological Hazards provides the chairmanship of the Interagency coordinating committee for the Earthquake Hazard Reduction Program, which also includes some tsunami elements.

15. National Science Foundation

The NSF Division of Civil and Environmental Engineering supports research and workshops related to tsunamis under the Earthquake Hazard Reduction Program.

16. WES Hydraulics Laboratory at Vicksburg, MS, conducts tsunami research and has produced expected tsunami run-up maps for the Federal Insurance Administration.

17. Coastal Engineering Research Center

The COE at Ft. Belvoir, MD, undertakes tsunami research as funded.

18. Office of Nuclear Reactor Regulations

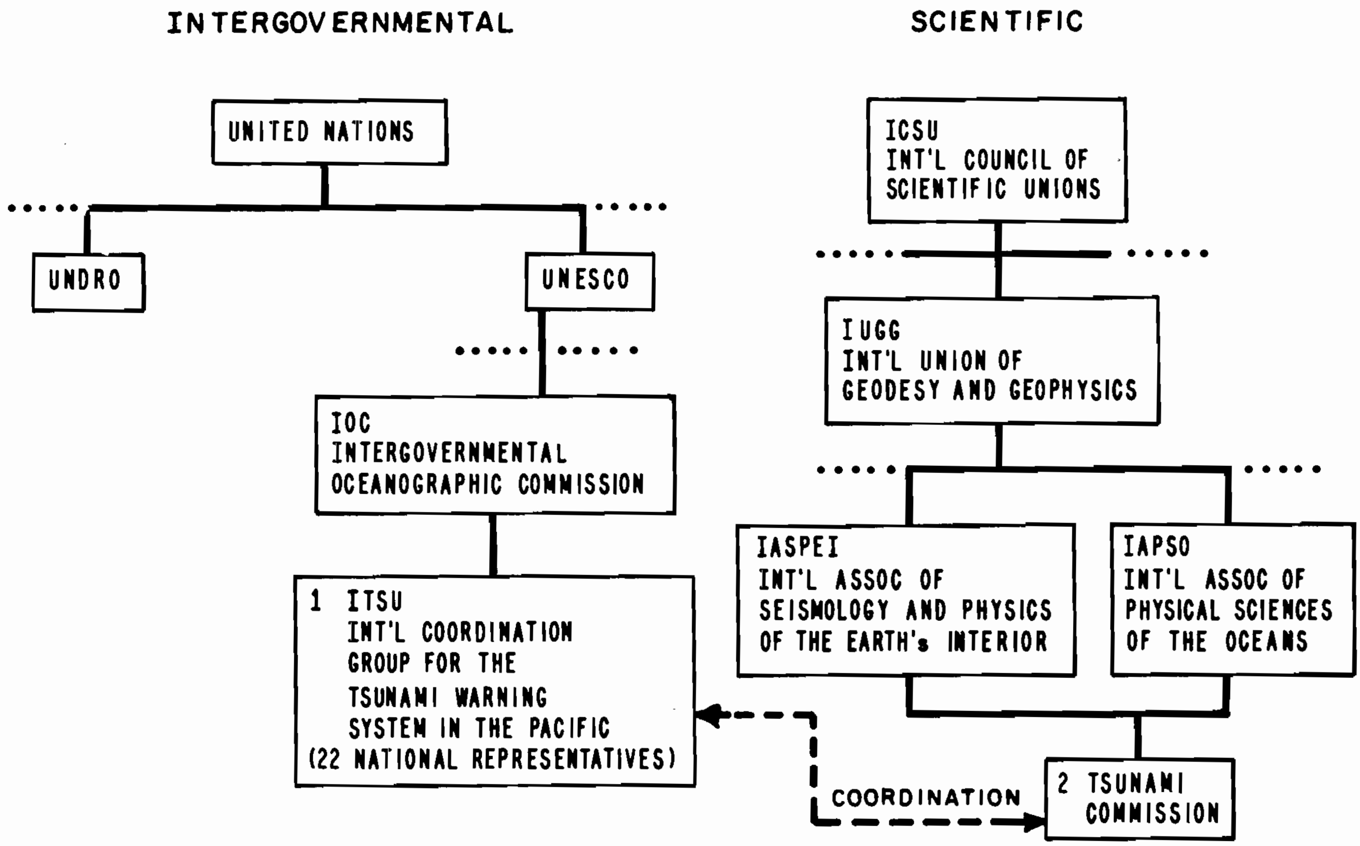
The Nuclear Regulatory Commission (NRC) has the responsibility for siting nuclear facilities and is required to evaluate the effects of natural phenomena on the safety of these structures. NRC has funded research to determine tsunami behavior for Pacific sites.

19. Joint Institute for Marine and Atmospheric Research

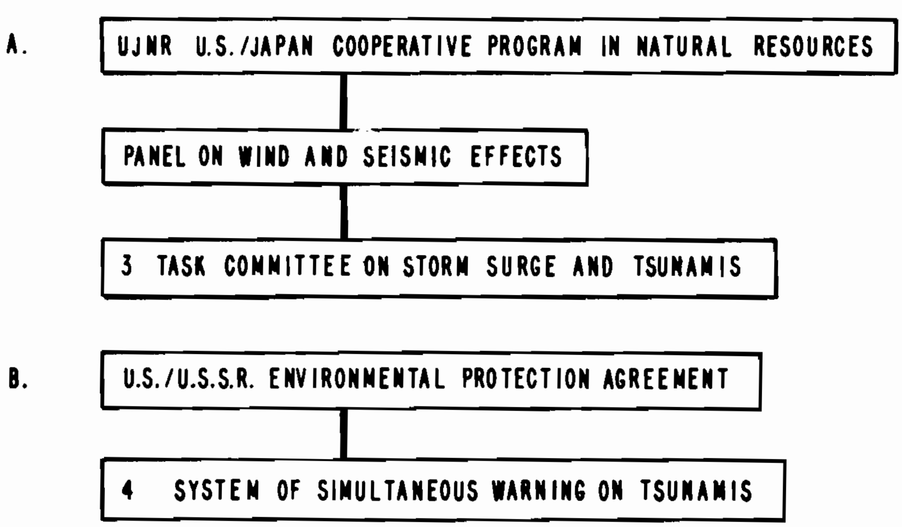
JIMAR has been and is involved in tsunami research. It is sponsored in part by NOAA's Environmental Research Laboratories, Pacific Marine Environmental Laboratory and the University of Hawaii at Honolulu.

ACTIVITIES RELATED TO TSUNAMIS

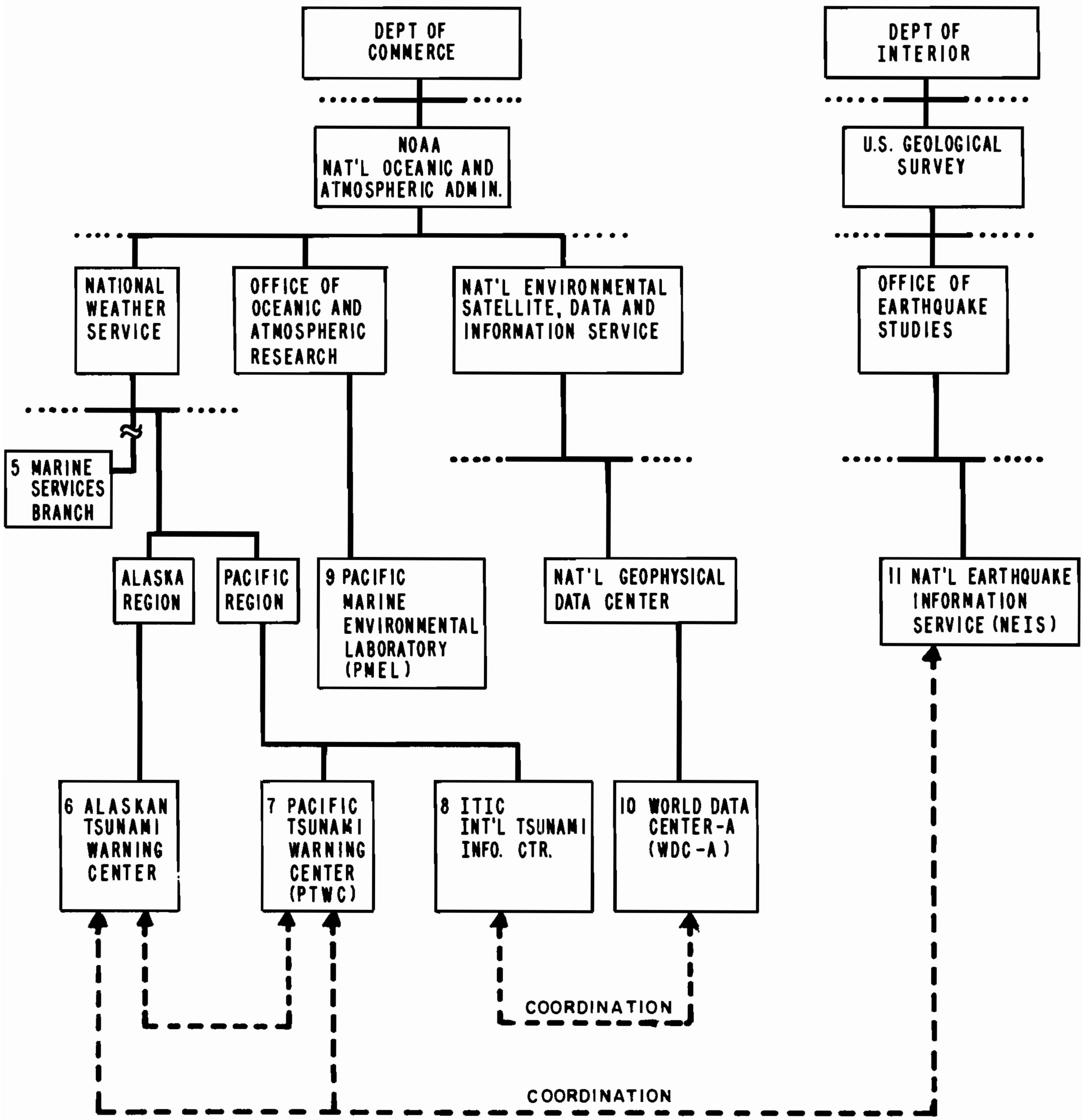
I INTERNATIONAL

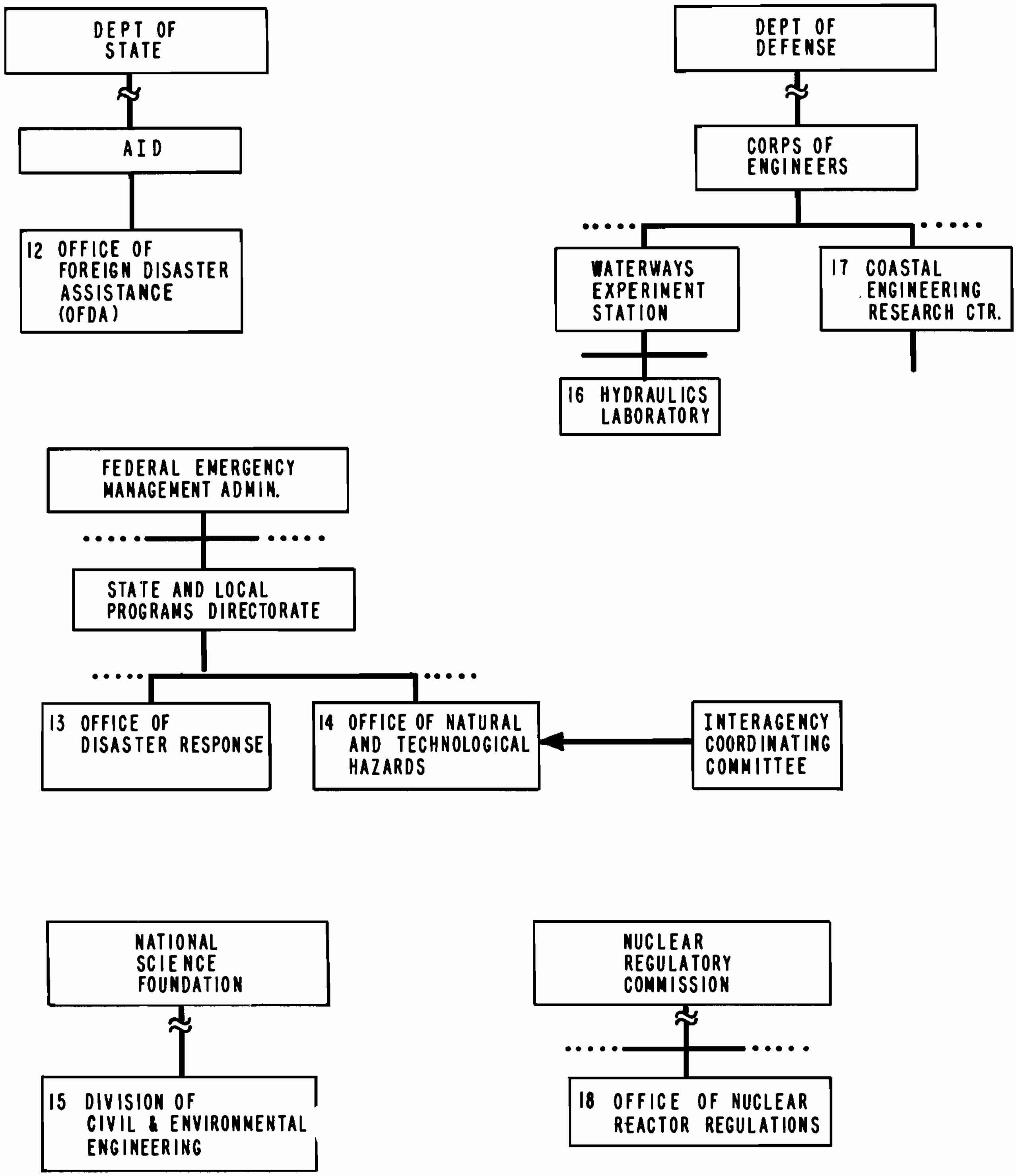


II NATIONAL PROGRAMS

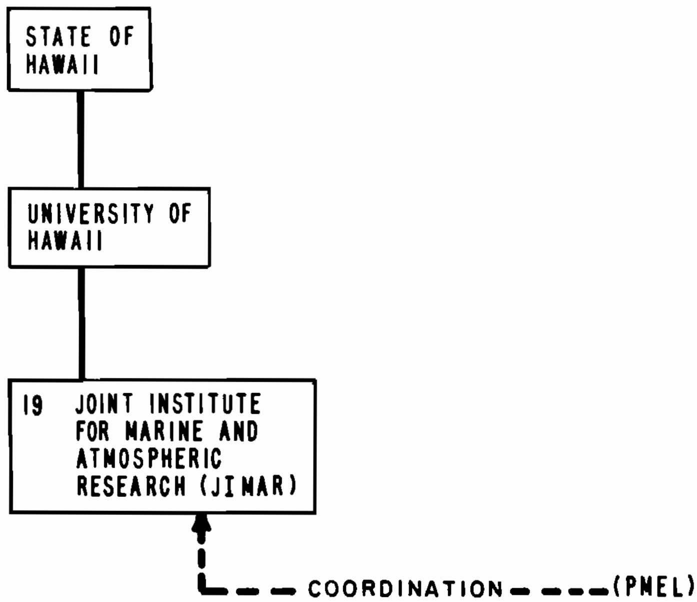


III U.S. GOVERNMENT




DEPT OF STATE
AID
12 OFFICE OF FOREIGN DISASTER ASSISTANCE (OFDA)
DEPT OF DEFENSE
CORPS OF ENGINEERS
WATERWAYS EXPERIMENT STATION
17 COASTAL ENGINEERING RESEARCH CTR.
16 HYDRAULICS LABORATORY
FEDERAL EMERGENCY MANAGEMENT ADMIN.
STATE AND LOCAL PROGRAMS DIRECTORATE
13 OFFICE OF DISASTER RESPONSE
14 OFFICE OF NATURAL AND TECHNOLOGICAL HAZARDS
INTERAGENCY COORDINATING COMMITTEE
NATIONAL SCIENCE FOUNDATION
15 DIVISION OF CIVIL & ENVIRONMENTAL ENGINEERING
NUCLEAR REGULATORY COMMISSION
18 OFFICE OF NUCLEAR REACTOR REGULATIONS

IV OTHER


STATE OF HAWAII
UNIVERSITY OF HAWAII
19 JOINT INSTITUTE FOR MARINE AND ATMOSPHERIC RESEARCH (JIMAR)
COORDINATION
(PMEL)

Appendix B

The Role of the GOES Satellite

THE ROLE OF THE GOES SATELLITE

J. Gordon Vaeth
Director of Satellite Operations
NESDIS

The National Environmental Satellite, Data, and Information Service (NESDIS) of the National Oceanic and Atmospheric Administration operates a GOES (Geostationary Operational Environmental Satellite) continuously at 135° West.

In addition to imaging the earth, broadcasting facsimile products, and monitoring the space environment, this GOES-West, as it is called, carries a Data Collection System (DCS). The DCS collects observations made *in-situ* by remote platforms (buoys, river gages, tide gages, ships, aircraft, etc.) and relays them through GOES to the NESDIS Command and Data Acquisition Station at Wallops, Virginia. From Wallops the data are communicated to NESDIS facilities at Camp Springs, Maryland, and thence to the user community.

GOES DCS platforms can be interrogated through and by the spacecraft at 468 MHZ. Because they are relatively few (compared to those that turn themselves on automatically) the system has a large number of unused platform addresses. These variable bits in these dummy addresses can be used to convey warning information.

A DCS interrogation message consists of an initial 4 bits (to send a time code), followed by 15 synchronization bits, followed by a 31-bit address (of which 10 are error-correcting bits and 21 are variable). Those 50 bits are transmitted at a rate of 100 bits per second, making for an addressing rate of one every half-second. A first interrogation/addressing transmission can be followed, if desired, by another in which the 21 variable bits are used to command the station addressed to do something--which for tsunami warning would be to select a certain "canned" or stored watch or warning message from a computer and display or type it out.

The warning receiving station activated by these interrogations would be a modification of an existing off-the-shelf GOES Time Coder Receiver, a printer, and some type of simple message storage device. A demonstration of the basic equipment, showing its ability to display and print out time and station addresses can be made.

The actual operation scenario remains to be determined. A logical sequence for test and demonstration could consist of the following:

A

(a) A seismometer platform senses an event above a pre-set thresh-hold level, automatically and immediately reports on a dedicated tsunami warning DCS channel, then continues to report its observations at pre-selected intervals (it would also turn itself on once a day for a readiness check).

(b) upon receiving this event report via Wallops, the DCS Data Handling subsystem at Camp Springs would select the proper advisory message number and insert it into the outgoing GOES DCS interrogations stream in the 21 variable bits of the address of the warning receiving stations along, for example, the Chilean or Peruvian coasts.

(c) the receiving station responding to the interrogation/command, would then call up the proper message, display, and print it.

B

(d) next tide gages would have to be activated to confirm whether a tsunami has been generated; this can be done in two ways:

(1) receipt of the original seismic event information by the DCS data handling subsystem could be programmed automatically to trigger "turn on and report" interrogation messages to the gages.

(2) the gages could operate on a continuous "on the ready" status, awaiting a greater than threshold event that would cause them to activate and report.

(e) depending upon the tide gage reports, the DCS Data Handling subsystem would insert in the command stream to the warning receiving station the number or numbers of the Warning/Evacuation messages that it should call up from its memory, display, and print out.

C

(f) if would then be up to the local authorities to act on that information.

Some comments on the above.

(1) The reporting seismic and tide gage stations could be designed to provide quantitative measurement data <u>or</u> (for maximum simplicity and low cost) simply register the fact that a greater-than-thresshold event has taken place at its location.

(2) non-interrogated platforms would be cheaper and more reliable (because they have no receivers in them).

(3) Although the above is based on conveying warning information via DCS platform interrogation addresses, an alternate mode is possible--using the first 4 bits of every interrogation message when those 4 bits are not required to broadcast the time code. This would require a time-sharing arrangement with the National Bureau of Standards.

(4) But most importantly: somewhere in the system there must be a decision-maker (human or computer) to select the particular warning messages to be sent; how this is to be accomplished is yet to be identified.