TRUST

TSUNAMI
HAZARD
REDUCTION
USING
SYSTEM
TECHNOLOGY

PN-ABG-251

68582

THRUST

Third Annual Report

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CONTENTS

Executive Summary.....1

Introduction.....2

Program Management.....2

Pre-Event.....4

Data Collection.....4
Data Analysis.....5
Data Dissemination.....5

Real-Time.....7

Data Collection.....7
Data Analysis.....12
Data Dissemination.....12

Conclusions.....14

References.....15

EXECUTIVE SUMMARY:

The Pacific Marine Environmental Lab was awarded a contract in June 1983 by the Agency for International Development to coordinate the activities of the THRUST Project (Tsunami Hazard Reduction Using System Technology). The project received the endorsement of the country of Chile (Chilean Supreme Decree No. 42) in April 1985. Since that time, two subcontractors, three NOAA components, the Chilean Navy Hydrographic Institute, an AID science advisor, a project director and coordinator have combined their knowledge and skills to produce the following capsulized third year's accomplishments:

1. Improved and developed new products from the tsunami data base,

2. Completed all numerical simulations and compiled maps of inundation used in the Standard Operating Plan,

3. Completed Preliminary Draft of the Standard Operating Plan in December 1985 with Final Draft in review at this time,

4. Completed testing of all instruments at PMEL in Seattle,

5. Installed all instrumentation in Chile,

6. Initiated a one year test and evaluation period for all instrumentation.

Specifics on each above item and other accomplishments are explained in detail in this annual report.

Introduction:

The United States Congress has authorized the Agency for International Development (AID), Office of U.S. Foreign Disaster Assistance (OFDA) to help alleviate suffering from disasters in foreign countries by providing emergency relief. AID/OFDA also helps developing countries achieve adequate levels of preparedness and early warning capabilities by focusing on disaster prevention and mitigation. AID commissioned the Pacific Marine Environmental Laboratory to conduct a pilot project that focuses on disaster prevention and mitigation of tsunamis titled THRUST (Bernard *et al.*, 1982) (Tsunami Hazard Reduction Using System Technology).

One natural hazard that AID has assisted developing countries in is the effects of the seismic sea wave or tsunami. Tsunamis have taken more than 50,000 lives in the last 100 years in the Pacific Basin. 99% of all damaging tsunamis cause damage in their generation zone or source region (Lander *et al.*, 1985). This shows that most of the real damage that occurs from tsunamis is near the source region, within the first thirty minutes of the earthquake. At an average of 500 lives a year and the unknown monetary value of its destructiveness, a tsunami is one of the more devastating natural hazards. The purpose of THRUST is to determine if an early warning system can be designed that would alert a developing country of a potential, locally generated, tsunami hazard within thirty minutes.

The existing Pacific-wide tsunami warning network (Pacific Tsunami Warning Center (PTWC) near Honolulu, Hawaii), due to nature and operational limitations, is hard pressed to issue warnings in less than sixty minutes to developing countries. A majority of these developing countries do not have regional warning systems, so they depend on PTWC for tsunami warnings. The THRUST system has been designed and developed to fulfill that first thirty minutes after tsunami generation. It has also been designed so that many of the developing countries in the Pacific Basin can acquire the technology as well as the instrumentation and establish a regional system (Bernard *et al.*, 1985).

The THRUST concept includes not only the development of instrumentation for an early warning system, but an historical evaluation of the area, numerical analysis and development of new operational procedures in the event of a tsunami warning. This combination of concepts will allow for a more effective early warning system for a developing country. The developing country selected for the THRUST project was Chile. The THRUST concept will be placed in the Valparaiso/Vina Del Mar area. This is a major shipping port for Chile, as well as a major population center. An effective early warning system would prove very beneficial to this populace.

PROGRAM MANAGEMENT

NOAA's Pacific Marine Environmental Lab (PMEL) has served as host for the THRUST program. The director of PMEL, Dr. Eddie N. Bernard, has served as THRUST's project director. Richard R. Behn has served as project coordinator. Dr. Bernard and Mr. Behn have coordinated all efforts of the project from PMEL in Seattle, Washington.

During the third year of THRUST, trips were made to Chile, Washington, and Washington, D.C. All trips were by THRUST components to either attend conferences, coordinate planning meetings or for the installation of THRUST equipment.

The THRUST project was presented in five different areas around the world during the last year. Those meetings were:

1) OCEANS 85 - November 1985 - San Diego, California - R. Behn,

2) Instituto Hidrografico de la Armada (IHA)- February and June 1986 - Valparaiso, Chile - R. Behn and H. Milburn,

3) Interamerican Naval Conference on Oceanography, Hydrography & Research Development - February 1986 - Cartagena, Columbia - Lt. Felix Espinoza (IHA),

4) Interamerican Symposium on Geophysics & Development - April 1986 - Rio de Janiero, Brazil - Jim Buizer (NOAA, Int. Affairs).

A THRUST Monthly Notes was distributed the first day of each month to over twenty five offices around the world. The list includes people in Europe, South and Central America, the South Pacific and the United States. It summarizes THRUST activities that have occurred in each of the working areas (see Diagram 1) during the last month in a capsulized format.

The THRUST project can be divided into six working areas.

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	OPERATIONAL "PREDICTIVE" MODEL	INTEGRATION OF EARLY WARNING DEVICE INTO EMERGENCY SYSTEM

Diagram 1

The next six sections are summaries of the work that was accomplished in the working areas during the third year of THRUST.

PRE-EVENT

THRUST PRE-EVENT
Objectives and Personnel

DATA COLLECTION	DATA ANALYSIS	DISSEMINATION
DEVELOP TSUNAMI DATA BASE	EVALUATION OF HAZARD USING SIMULATIONS	DEVELOPMENT OF EMERGENCY OPERATIONS, PROCEDURES
NATIONAL GEOPHYSICAL DATA CENTER James Lander	SCIENCE APPLICATIONS, INC. Gerald Hebenstreit	NATIONAL WEATHER SERVICE - ITIC George Pararas-Carayannis
PROGRAM MANAGEMENT: PMEL / E. Bernard, R. Behn		

Diagram 2

Data Collection:

Mr. James Lander of NOAA's National Geophysical Data Center (NGDC) coordinated all efforts for the collection of tsunami data. Distribution of the "Tsunamis in the Pacific Basin" map and "Tsunamis in Peru-Chile" catalog continued. The data base presently has information on 4500 locations that have experienced tsunamis (Lockridge, 1986). Updating and adding to the data base is a continuing effort as well. Extensive data from Japan is being added through an agreement with US/Japan Cooperative Agreement on Natural Resources (UJNR).

A thorough review of the data has provided some very interesting statistics. Two major tsunamis were generated in the 19th century near the Peru-Chile boundary. Those two tsunamis were among the most damaging ever recorded both locally and throughout the Pacific Basin. The west coast of South America has produced 41 destructive tsunamis that have claimed more than 30,000 lives in the 20th century. In the last 86 years, one of every three Pacific Wide tsunamis has been generated off the Peru-Chile coast. This region (Peru-Chile) generates 9.1 events per decade. In Chile, once every 25 years, a large earthquake (mag. = 8.2) is generated that affects the entire Pacific Basin. For earthquakes of magnitude 7.5 or greater in this region, 68% of them have generated tsunamis (Lockridge, 1986).

Of the 104 tsunamis that have been generated in the last 100 years, only nine of them have caused damage outside of their area of generation. 99% of all damaging tsunamis cause damage in their generation zone or source region (Lander *et al.*, 1985). The data clearly show that almost all of the damage that occurs from the destructive powers of tsunamis occurs near or in the source region. This evidence demonstrates that regional type warning systems need to be developed. (See section titled "PRE-EVENT, Data Collection" for further details).

Data Analysis:

Dr. Gerald Hebenstreit of Science Applications International Corporation in McLean, Virginia coordinated all efforts for the numerical model scheme of the Valparaiso area of Chile. Dr. Frank Gonzalez of PMEL assisted Dr. Hebenstreit in his numerical modeling simulations and validations.

All numerical modeling was completed during this year. After compilation of the tsunami data base by NGDC, it was decided on that the 1960 Chilean earthquake would be used to verify simulations for the Valparaiso/Vina Del Mar areas. The data from the 1960 event showed that the subsurface displacement (uplift) occurred in the north-south direction, parallel to the coastline. Utilizing that uplift pattern, models were run, and the data showed that local tsunamis approaching from the west and northwest caused the most extensive damage to the Valparaiso/Vina Del Mar areas.

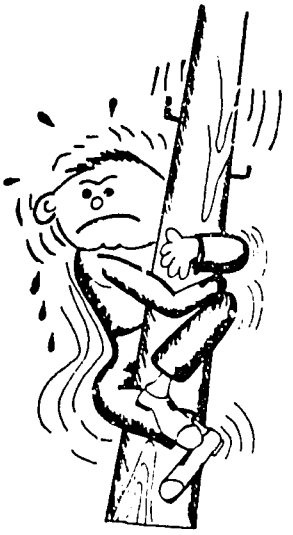
All the inundation data generated by the simulations was transferred onto Valparaiso maps. Projecting these results onto the maps showed that many major roadways, railways, hospitals and evacuation shelters will be inundated during the worst case tsunami. Three maps were prepared to display the data. The first map was a base map of the region, showing topography and streets. The second was an overlay (overlay onto the base map) indicating the locations of different facilities such as rail and road evacuation routes, communications centers, large building usable as refugee centers, hospitals, etc. The third map is another overlay indicating the areas of flooding. The combination of these three maps can illustrate where flooding could occur and also aid in the relief operations that would take place during an event (Hebenstreit *et al.*, 1986). These maps aided in developing the evacuation procedures that were used in the Standard Operating Plan (see section titled "PRE-EVENT, Data Analysis" for further details).

Data Dissemination:

Dr. George Pararas-Carayannis of the International Tsunami Information Center (ITIC) in Honolulu, Hawaii has been working on the development of the Standard Operation Plan (SOP) for the THRUST Project. The SOP will be implemented into a fully coordinated program for disseminating tsunami warnings to the local populace as well as educating the local people about the hazards of tsunamis. Dr. Pararas-Carayannis has been assisted in his efforts by the Instituto Hidrografico de la Armada (Chilean Navy Hydrographic Institute, IHA) in Valparaiso. In November 1985, IHA assumed full responsibility for completing the SOP.

A preliminary draft of the SOP was completed in December 1985 by IHA. The SOP contains six sections (or chapters). They include an introduction, emergency operations plan for Chile, tsunami evacuation procedures, tsunami disaster reporting, references and annexes (Instituto Hidrografico de la Armada *et al.*, 1985). The emergency operations plan includes sections on the existing National Tsunami Warning System, organizational structures responsibilities and functions, tsunami watch and warning procedures, and communications during the event. The evacuation procedures include a diagnosis of the areas covered by the SOP, the pre-event, during the event and after the event procedures, and evaluation of the established procedures. The disaster reporting section

SI UD. ESTA EN
LA PLAYA
O CERCA DE LA COSTA



DECALOGO DE TSUNAMI

Ante este peligro real que en cualquier momento puede azotar las costas de nuestro país, es conveniente tener en cuenta las siguientes recomendaciones

1.- Si vive en la costa y siente un sismo lo suficientemente fuerte como para agrietar murallas espere que dentro de los próximos 20 minutos suceda un Tsunami, la probabilidad de que ocurra es alta

2.- Si es alertado de la proximidad de un Tsunami, no se considere seguro hasta que se encuentre en un cerro a una altura de 30 mts. y preferentemente a 40 mts. sobre el nivel del mar

3.- Si Ud. ve que el mar se recoge ¡CORRA! la mitad de los Tsunamis se presentan primero como un recogimiento del mar, al que deja en seco grandes extensiones del fondo marino. Ha habido muchos muertos por tratar de aprovechar esto para sacar peces o moluscos. No lo hagan. El Tsunami llegará con una velocidad de más de 100 km/h y Ud. no podrá huir

4.- Si Ud. se encuentra en una embarcación o nave cuando es alertado de un próximo Tsunami o siente un fuerte sismo, de inmediato y sin dudar un instante dirija lo más rápido posible su embarcación o nave mar adentro, dado que un Tsunami es destructivo sólo cerca de la costa, de hecho a unas 3 millas de la costa y sobre una profundidad mayor de 150 mts. Ud. puede considerarse seguro

5.- Tenga siempre presente que un Tsunami puede penetrar por un río o estero varios kilómetros tierra adentro, por lo tanto aléjese de ríos y esteros

6.- Si en el lugar en que Ud. vive no hay cerca suficientes alturas, un bosque puede ser una protección de alternativa

7.- Si Ud. es alertado de la proximidad de un Tsunami, además de tomar las precauciones ya indicadas, preocúpese de tener en lo posible un receptor portatil escuchando informaciones de una sola emisora. No cambie de sintonía constantemente dado que podría perder información

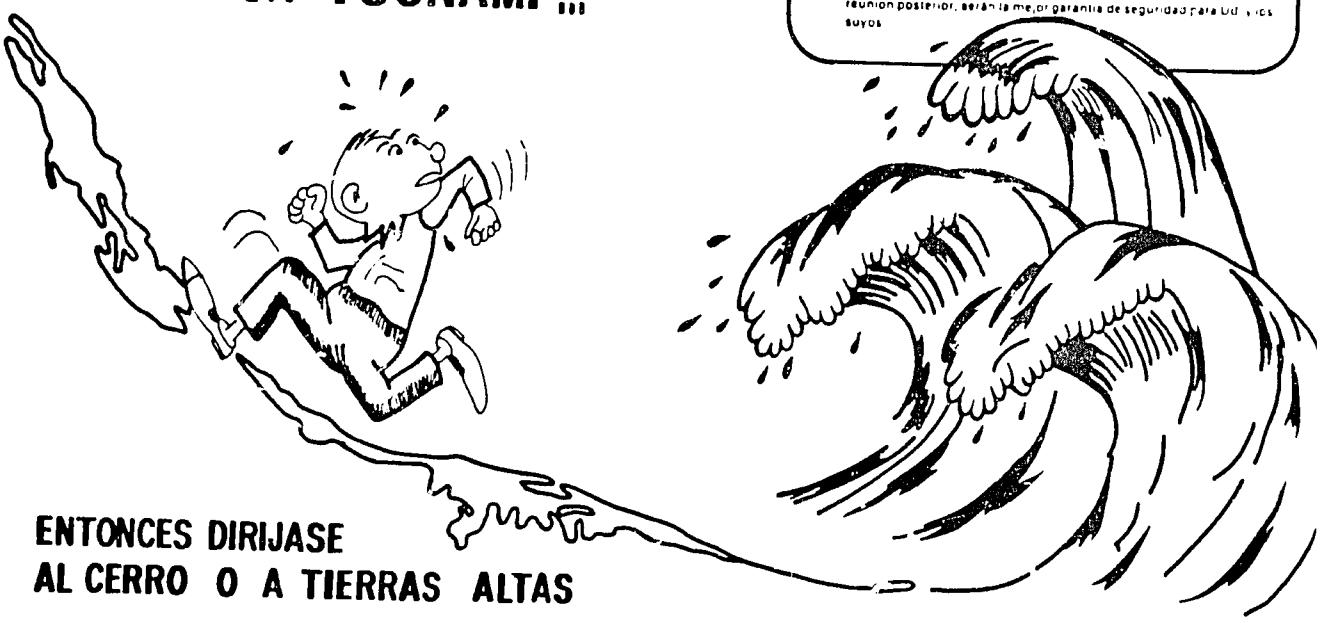
8.- Un Tsunami puede tener hasta 10 o más olas destructivas en un lapso de hasta 12 horas, preocúpese si huye, de tener a mano frazadas o abrigo, especialmente para los niños

9.- No vuelva a los lugares potencialmente amenazados hasta que una autoridad responsable indique que el peligro ha terminado

10.- No olvide que las precauciones que Ud. tome antes de un Tsunami tales como tener instruida a su familia sobre la ruta de huida y lugar de reunión posterior, serán la mejor garantía de seguridad para Ud. y los suyos

... Y UD. DEBE AFIRMARSE
EN ALGO PARA NO CAERSE

!!! TAL VEZ HAYA
UN TSUNAMI !!!



ENTONCES DIRIJASE
AL CERRO O A TIERRAS ALTAS

ADAPTADO DE "ITIC"

IMPRESO Y PUBLICADO POR EL INSTITUTO HIDROGRAFICO DE LA ARMADA DE CHILE
1985

Diagram 3

includes the development of the types of disaster reports that are to be filed after the event. The annex section includes the organizational structure of the related organizations that are included in the SOP, tsunami hazard analysis, tsunami preparedness in Valparaiso and public education (see diagram 3 for example) of area.

All chapters in the SOP are being assembled as a shell, or in a generic format, so it can be easily adapted to any other area of Chile or the world (see section titled "PRE-EVENT, Data Dissemination" for further details).

REAL-TIME

THRUST REAL-TIME
Objectives and Personnel

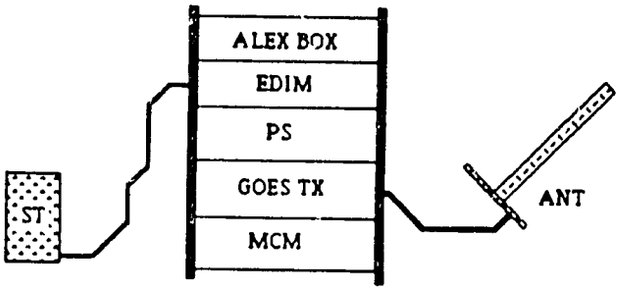
DATA COLLECTION	DATA ANALYSIS	DISSEMINATION
SENSOR DEVELOPMENT INSTRUMENT + PROCESSING + TRANSMISSION PACIFIC MARINE ENVIRONMENTAL LABORATORY Hugh Milburn	OPERATIONAL "PREDICTIVE" MODEL	INTEGRATION OF EARLY WARNING DEVICE INTO EMERGENCY SYSTEM PACIFIC MARINE ENVIRONMENTAL LABORATORY Hugh Milburn CYBERLINK, INC. Peter McManamon
PROGRAM MANAGEMENT: PMEL/E. Bernard, R. Behn		

Diagram 4

Data Collection:

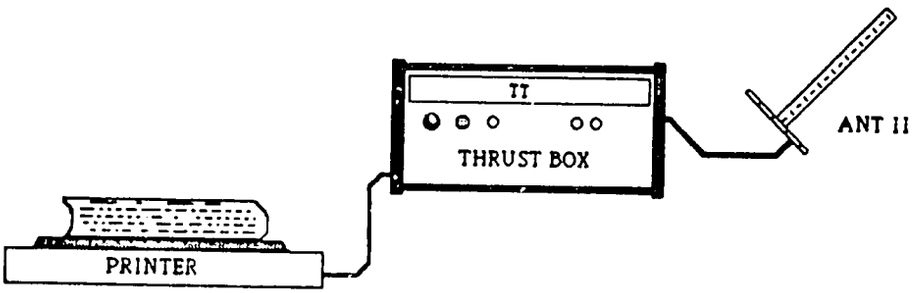
PMEL has been responsible for assembling and testing the instrumentation for the THRUST project. Mr. Hugh Milburn, group leader of the EDD division, has coordinated all efforts in the area. During the third year, the instruments have gone from concepts, drawings and schematics to fully assembled, operational instrumentation packages. The final configuration of the instruments is seen in figures 1, 2 & 3.

Testing of the THRUST instrumentation began in August 1985 at PMEL in Seattle. The system was tested on a daily basis. The daily test was to simulate an earthquake, which would start the Synergetics Data Collection Platform (DCP) transmitting its' four random report addresses. The addresses would go through the GOES system (described in detail in Data Dissemination section and figure 5) and back (as an emergency address) to the Real Time Processors (RTP's) (located at PMEL in Seattle and CyberLink in Boulder) where the emergency message would be printed. The transmission log (log of all transmissions made) and emergency messages (messages printed by RTP) were checked to verify all outbound addresses had a corresponding printed emergency message. Test of the Water Level Sensor (WLS) was conducted in the same



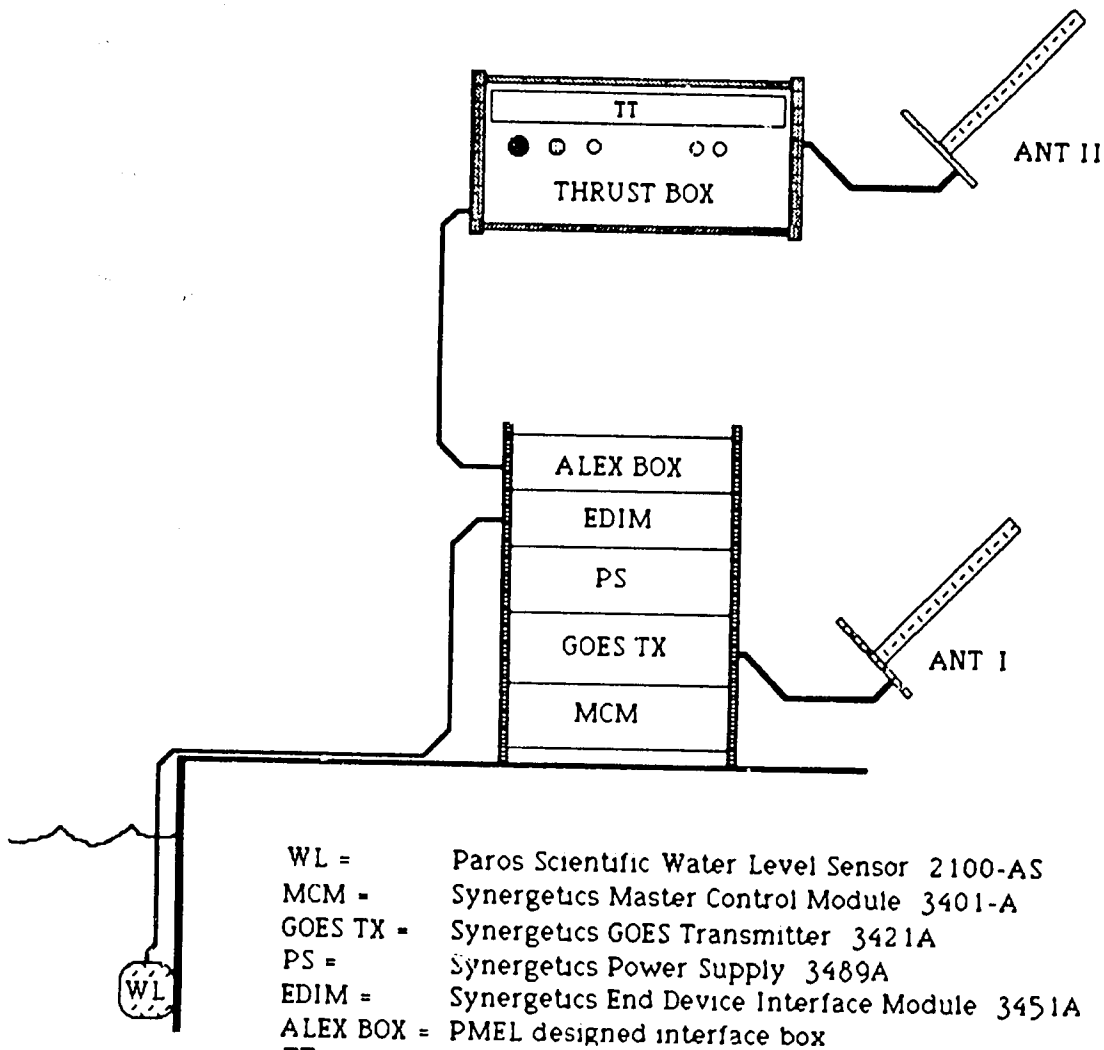
ST = Kinemetrics VS-1 Vertical Seismic Trigger
MCM = Synergetics Master Control Module 3401-A
GOES TX = Synergetics GOES Transmitter 3421A
PS = Synergetics Power Supply 3489A
EDIM = Synergetics End Device Interface Module 3451A
ANT = Synergetics Cross Yagi Antenna 18A
ALEX BOX = PMEL designed interface box

Figure 1



PRINTER = Epson RX-8 Printer
TT = Kinemetrics True Time Receiver 468-DC
ANT II = Kinemetrics Helix Antenna A-468HX
THRUST BOX = Commodore 64 Personnel Computer
Power Supply
Alarm Interface
Inverter

Figure 2



WL = Paros Scientific Water Level Sensor 2100-AS
MCM = Synergetics Master Control Module 3401-A
GOES TX = Synergetics GOES Transmitter 3421A
PS = Synergetics Power Supply 3489A
EDIM = Synergetics End Device Interface Module 3451A
ALEX BOX = PMEL designed interface box
TT = Kinemetrics True Time Receiver 468-DC
ANT I = Synergetics Cross Yagi Antenna 18A
ANT II = Kinemetrics Helix Antenna A-468HX
THRUST BOX = Commodore 64 Personnel Computer
Power Supply
Alarm Interface
Inverter

Figure 3

manner, except it was noted that the WLS changed from a normal tidal sampling mode to a tsunami detection mode when the emergency address was received.

During the last week in February 1986, two technicians traveled to Chile to install the first phase of the instruments. With the assistance of the staff at IHA, the team installed all antenna and associated antenna cables at the lighthouse and at IHA in Valparaiso. The seismic trigger and its' associated cables were installed at IHA. Three Chilean Navy divers installed all underwater cables, clamps and WLS at the pier. The final task was to prepare the sites for the instruments that were to be installed during the next trip. The team of 7 people was able to complete this first phase of the installation in 10 working days.

The second phase of the installation was in June 1986. Two PMEL technicians, again, with the assistance of the IHA staff, installed the remaining THRUST instrumentation. The last seismic trigger with it's respective GOES transmitters was installed at the University of Chile in Santiago. The RTP was installed at IHA. The THRUST boxes and GOES transmitters for the WLS's were installed at the lighthouse located on pier in the Valparaiso harbor. This second phase of work was completed in 10 days with a team of 6 technicians.

The entire THRUST system began it's 12 month test and evaluation period immediately following the completion of the second phase of installation. During this evaluation period, all instruments will be monitored by the GOES system and personnel at PMEL on a daily basis.

The THRUST system is set up as an early warning system for tsunamis. As an added feature, the system is also collecting tidal data on a daily basis. When the WLS is not in the tsunami mode, it is in a tidal sampling mode. This allows the WLS to sample at a one data point per minute rate and average that over a 15 minute period, so one data point is gathered for each 15 minute period. This data point is stored as well as each consecutive 15 minute data point for a four hour period. Then, once every four hours, the data is transmitted through the GOES East satellite and stored at CDA. The tidal data as well as any tsunami data is extracted daily by PMEL.

The PMEL VAX 11/785 computer automatically calls GOES every night and extracts the messages that were placed in the THRUST file during the last 24 hour period. Those raw messages are printed out each day. This raw data is then placed in a smoothed format that lists all transmissions by date, time, from which instrument (i.e. Valparaiso Trigger - Test, WLS - Tsunami Data), GOES address, transmission parameters and satellite channel. The tide data and tsunami data is also placed in a format that lists which sensor, address, Julian Date and time, transmission parameters, battery power, forward power, temperature at the DCP and the tidal data or tsunami data (see figure 4 for example). The tide and tsunami data is then plotted. All the above data is printed out each and every day and filed.

Records of all failures and down time will be kept along with all the transmissions to and from the GOES satellite. At the end of the test period, all these data will be assembled, analyzed and included in the final report (see section titled "REAL-TIME, Data Collection" for further details).

SUMMARY OF RECEIVED WDCS INFORMATION.

06/18/86 08:19	WATER LEVEL SENSOR I - TSUNAMI DATA	82609522	23006194 5	48-0NN 127E
06/18/86 08:57	WATER LEVEL SENSOR I - TIDE DATA	82609522	23006572 0	49-0NN 21E
06/18/86 08:58	WATER LEVEL SENSOR II - TIDE DATA	82604086	23006561 9	46-0NN 21E
06/18/86 10:46	SANTIAGO SEISMIC TRIGGER - TEST	82606546	23010463 6	46-2NN 115E
06/18/86 10:49	SANTIAGO SEISMIC TRIGGER - TEST	82606546	23010492 9	46-2NN 115E
06/18/86 10:50	SANTIAGO SEISMIC TRIGGER - TEST	82606546	23010503 3	46-2NN 115E
06/18/86 10:51	SANTIAGO SEISMIC TRIGGER - TEST	82606546	23010515 7	47-2NN 115E
06/18/86 11:13	WATER LEVEL SENSOR I - TSUNAMI DATA	82609522	23011131 5	49-0NN 127E
06/18/86 12:52	SANTIAGO SEISMIC TRIGGER - TEST	82606546	23012562 4	46-2NN 115E
06/18/86 12:54	SANTIAGO SEISMIC TRIGGER - TEST	82606546	23012542 3	46-2NN 115E
06/18/86 12:55	SANTIAGO SEISMIC TRIGGER - TEST	82606546	23012553 5	46-2NN 115E
06/18/86 12:56	SANTIAGO SEISMIC TRIGGER - TEST	82606546	23012565 9	46-2NN 115E
06/18/86 12:57	WATER LEVEL SENSOR I - TIDE DATA	82609522	23012572 0	48-0NN 21E
06/18/86 12:58	WATER LEVEL SENSOR II - TIDE DATA	82604086	23012561 9	46-0NN 21E
06/18/86 15:13	WATER LEVEL SENSOR II - TSUNAMI DATA	82604086	23015134 5	46-0NN 127E
06/18/86 16:13	VALPARAISO SEISMIC TRIGGER - TEST	82602546	23016135 2	50+0NN 115E
06/18/86 16:15	VALPARAISO SEISMIC TRIGGER - TEST	82602546	23016151 1	50+0NN 115E
06/18/86 16:16	VALPARAISO SEISMIC TRIGGER - TEST	82602546	23016163 0	50+0NN 115E
06/18/86 16:17	VALPARAISO SEISMIC TRIGGER - TEST	82602546	23016175 5	50+0NN 115E
06/18/86 16:57	WATER LEVEL SENSOR I - TIDE DATA	82609522	23016572 0	48-0NN 21E
06/18/86 16:58	WATER LEVEL SENSOR II - TIDE DATA	82604086	23016561 9	46-0NN 21E
06/18/86 20:57	WATER LEVEL SENSOR I - TIDE DATA	82609522	23020572 0	48-0NN 21E
06/18/86 20:58	WATER LEVEL SENSOR II - TIDE DATA	82604086	23020561 9	46-0NN 21E
06/18/86 22:35	WATER LEVEL SENSOR I - TSUNAMI DATA	82609522	23022325	48-0NN 127E
06/19/86 00:12	WATER LEVEL SENSOR I - TSUNAMI DATA	82609522	23000123 3	49-0NN 127E
06/19/86 00:36	WATER LEVEL SENSOR II - TSUNAMI DATA	82604086	23000361 5	46-0NN 127E
06/19/86 00:57	WATER LEVEL SENSOR I - TIDE DATA	82609522	23005772 0	49-0NN 21E
06/19/86 00:58	WATER LEVEL SENSOR II - TIDE DATA	82604086	23005619	46-0NN 21E
06/19/86 03:15	WATER LEVEL SENSOR I - TSUNAMI DATA	82609522	23003151 6	48-0NN 127E
06/19/86 04:57	WATER LEVEL SENSOR I - TIDE DATA	82609522	23004572 0	48-0NN 21E
06/19/86 04:58	WATER LEVEL SENSOR II - TIDE DATA	82604086	23004561 9	46-0NN 21E

TIDE DATA -- WATER LEVEL SENSOR I.

82609522 23006572 0	49-0NN 21E	BATT=1520	FWD PWR= 401	TEMP= 25.09					
06/18/86 05:11	2061.392	2056.455	2054.950	2051.49[illegible]	2050.818	2049.643	2050.818	2049.050	
06/18/86 07:11	2052.581	2055.516	2057.260	2063.154	2065.503	1923.166	2079.016	2086.062	
82609522 23012572 0	48-0NN 21E	BATT=1525	FWD PWR= 401	TEMP= 25.09					
06/18/86 09:11	2093.694	2100.745	2106.375	2116.591	2124.912	2132.439	2140.065	2147.090	
06/18/86 11:11	2153.561	2160.596	2167.634	2173.496	2177.020	2181.125	2182.295	2184.640	
82609522 23016572 0	48-0NN 21E	BATT=1544	FWD PWR= 401	TEMP= 25.52					
06/18/86 13:11	2165.312	2165.220	2165.220	2181.123	2178.779	2175.255	2168.220	2163.529	
06/18/86 15:11	2156.493	2148.653	2140.651	2122.698	2123.045	2114.243	2105.440	2095.455	
82609522 23020572 0	48-0NN 21E	BATT=1525	FWD PWR= 401	TEMP= 25.52					
06/18/86 17:11	2037.236	2077.642	2069.027	2061.979	2053.756	2047.293	2043.174	2037.298	
06/18/86 19:11	2032.397	2030.634	2029.071	2028.434	2027.896	2030.634	2032.010	2034.360	
82609522 23006572 0	49-0NN 21E	BATT=1536	FWD PWR= 401	TEMP= 25.52					
06/18/86 21:11	2039.061	2043.174	2049.043	2055.168	2060.906	2066.078	2072.557	2081.365	
06/18/86 23:11	2087.236	2093.107	2099.571	2106.027	2110.135	2115.417	2108.375	2121.285	
82609522 23004572 0	48-0NN 21E	BATT=1525	FWD PWR= 401	TEMP= 25.52					
06/19/86 01:11	2121.812	2126.572	2127.159	2127.159	2127.159	2125.399	2123.638	2096.029	
06/19/86 03:11	2114.653	2113.070	2106.614	2102.506	2096.629	2089.585	2085.475	2077.642	

Figure 4

Data Analysis:

Dr. Gerald Hebenstreit completed the real-time data analysis by developing the message that is printed on the RTP. Diagram 5 is an example of the message that is printed by the RTP at IHA.

VALPARAISO ALERT

A STRONG EARTHQUAKE OCCURRED AT 1733 Z ON AUG. 11, 1986 IN THE VICINITY OF THE CITY OF VALPARAISO. CONTACT THE FOLLOWING AUTHORITIES:

- OFICINA NATIONAL DE EMERGENCIA TELEPHONE NO. 718333
- DEPARTMENT OF GEOPHYSICS TELEPHONE NO. 6968686

AND ADVISE THEM OF THIS EARTHQUAKE ALERT AND DISSEMINATE THE ATTACHED TSUNAMI WATCH MESSAGE.

TSUNAMI WATCH

ESTABLISH A TSUNAMI WATCH. A TSUNAMI MAY ACCOMPANY THIS EARTHQUAKE. IF A TSUNAMI OCCURRED, THE WAVE WILL REACH THE COAST, AT THE SHOWN LOCALITIES, AT THESE TIMES:

VALPARAISO	0 TO 3	MINUTES
COQUIMBO	40	MINUTES
CALDERA	60	MINUTES
TALCAHUANO	75	MINUTES
CHANARAL	75	MINUTES
CORRAL	85	MINUTES
ANTOFAGASTA	85	MINUTES
ILSA DE CHILOE (ANCUD)	100	MINUTES
TOCOPILLA	100	MINUTES
IQUIQUE	120	MINUTES
ARICA	140	MINUTES

REMEMBER, THIS IS ONLY A TSUNAMI WATCH. NO TSUNAMI HAS BEEN OBSERVED BUT ONE MAY OCCUR.

Diagram 5

As seen by the above message, the primary function of the RTP is inform the proper officials that a seismic event has occurred, notify certain key personnel, and to predict the arrival time of the tsunami, if one exists (Hebenstreit, 1984 & 1986).

Data Dissemination:

Both Mr. Hugh Milburn of PMEL and Dr. Peter McManamon of the CyberLink Corporation in Boulder, Colorado have combined their efforts in this area of the project. This areas major concentration of work has been in coordinating the GOES system requirements with the requirements of the THRUST project. These requirements have resulted in THRUST being assigned ten addresses for the GOES system. Two of the addresses are self-timed/random report mode (a total of four addresses), two are random report mode only and the other four are for the downlink from the Command Data and Acquisition Center (CDA).

The final operational THRUST system works in the following manner (see figure 5). When an earthquake occurs, the seismic sensor triggers the DCP to

send an address via the random report mode of the GOES system. This address is sent through the GOES East satellite to CDA. This process takes no longer then 15 seconds after the sensor is triggered. When the address is received at CDA, it is interpreted as an emergency message and is given top priority for action. This action is to immediately send a corresponding address through the GOES West satellite, then through the THRUST box at each of the RTP and WLS sites. The process of sending the address from CDA to the RTP or WLS could take as long as 30 seconds or as short as 1 second. The THRUST boxes are constantly scanning the transmissions from the GOES West satellite, searching for the address that will initiate the RTP or WLS to change from a standby mode to the operational mode. In the operational mode, the RTP begins to print out its emergency message and the WLS begins it's increased sampling rate or tsunami mode.

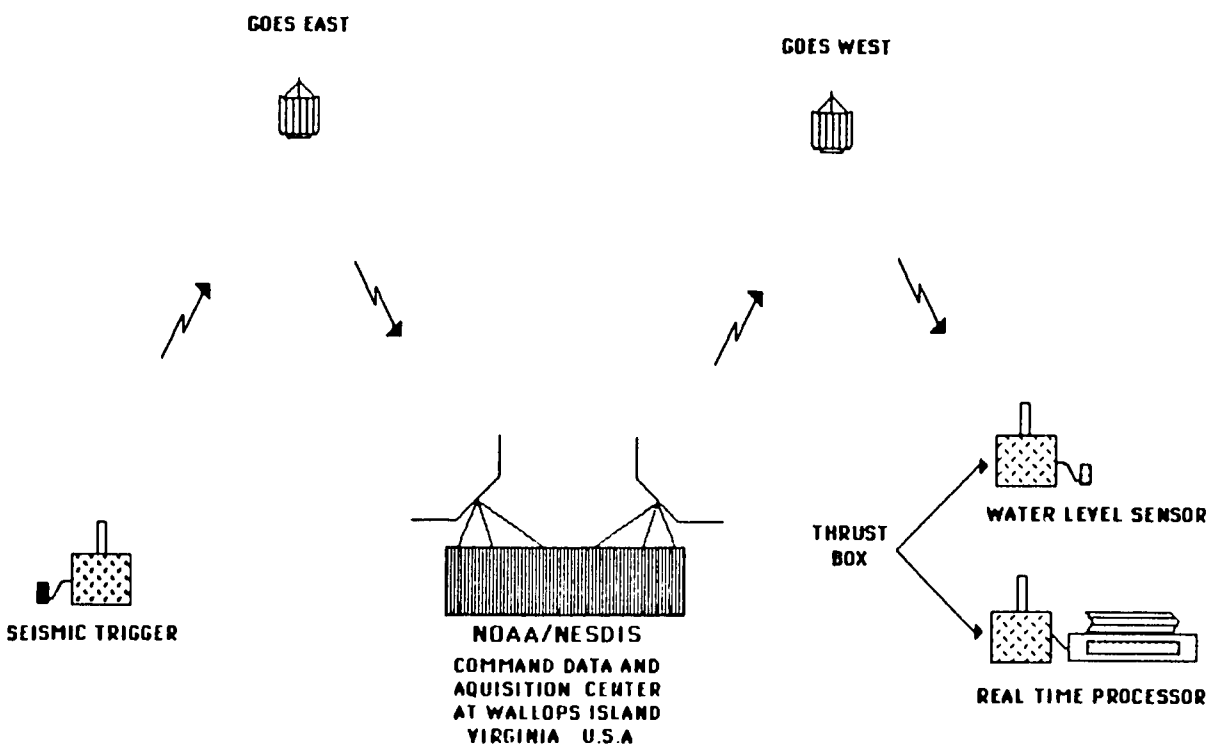


Figure 5

Three years ago, when the project was first funded, it was anticipated that the entire process (mentioned above) would take in the order of 10 minutes or more. Now, after all the tests were completed at PMEL, the time for that entire process has been reduced dramatically. During the testing period, after the seismic sensor was triggered, the RTP and WLS would change to the operational mode in as little as 50 seconds. It has also taken as long as seven minutes. *The average time from event to printed message is about 2 minutes, almost 5 times faster than designed!* This is much better then originally planned. This time factor will be monitored during the test and evaluation period.

One requirement of THRUST was to test the system on a daily basis. This has been accomplished and is done each day. The seismic trigger, randomly and twice a day, sends a test message through GOES East, then onto CDA, back through GOES West and on to the RTP. The RTP responds to this test by printing (for example) "Valparaiso Test August 18 at 1201". That test not only test the seismic trigger and DCP, but also tests the GOES system, the THRUST box at each site and the RTP. The WLS is test in a different manner. The DCP at the WLS randomly changes from the tidal sampling mode to the tsunami sampling mode once a day for a one hour period. This test insures that the WLS, DCP and GOES system are working correctly. These test of the system are completed each day and are recorded by PMEL daily and filed (see sections titled "REAL-TIME, Data Dissemination" and "REAL-TIME, Data Collection" for further details).

Conclusions:

All work in the Pre-Event area of the THRUST project has been completed. The project was designed so that each of the three pre-event working areas of the project complimented each other in their respective tasks. The data base was established first, and was used to produce the "Tsunami in the Pacific Basin, 1900-1983" map and the "Tsunamis in Peru-Chile" catalog of data. With figures indicating that 68% of all earthquakes originating near the Peru-Chile border, with a magnitude greater than 7.5, generate tsunamis and that 99% of all damage from tsunamis occurs in the generations zone, the data base has shown that a regional-type early warning system is needed for areas like South America. The data base was then used to select the proper event to compare and verify all numerical modeling simulations that were completed for the area. These simulations provided the data that was used as a basis for preparing evacuation maps. The maps aided IHA, the city government of Valparaiso and Vina Del Mar in the formulation of the evacuation procedures that were established in the SOP for the area. The evacuation procedures, along with emergency operating plans, tsunami disaster reporting, and new public education programs have been combined to form the new, comrehensive Standard Operating Plan for Chile.

The Real-Time work of the THRUST project is 75% completed at the end of year three. All instruments are installed and in the operational mode in Chile and U.S. The test and evaluation of the instruments will continue for a 12-month period. To date, the instrumentation has encountered some problems due to power fluctuations. Power surge suppressors have now been installed on all equipment and should solve the power related failures. All data disseminated from the instruments is being recorded and archived at PMEL. These data are reviewed on a daily basis for any failures or problems. All these data, failures and minor problems will be annotated and included in the final report which will be published in August 1987.

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PRE - EVENT

Data Collection
Data Analysis
Data Dissemination

THRUST
THIRD ANNUAL REPORT

Data Collection

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HISTORICAL TSUNAMIS IN THE PACIFIC BASIN

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ABSTRACT. The Pacific Basin was divided into ten regions, and historical data were compiled for each region. As the Japanese word "tsunami" suggests, the Japan area situated near a collision zone for two crustal plates has generated the most tsunamis (247), and most of the damage has been confined to that area. Across the Pacific to the southeast lies the South American coast, another zone of plate collision, that has spawned many tsunamis (91). The records of the area report 13 events that were devastating not only locally, but as far away as Hawaii and Japan. Further, magnitude 7.5 earthquakes are more likely to generate tsunamis along the coast of South America. The North Pacific area has generated events with far-reaching effects. Five of the nine tsunamis that were damaging outside their source regions in the last 100 years were generated in the arc stretching from the Kuril Islands and Kamchatka across the Aleutians to the Gulf of Alaska. Hawaii is the area most often damaged by tsunamis generated elsewhere in the Pacific Ocean basin. But the west coast of North America, although frequently the site of earthquakes, has generated only seven damaging tsunamis.

1. INTRODUCTION

Our purpose is to discuss historical tsunami data available at the National Geophysical Data Center (NGDC) and to compare the potential for future damaging tsunamis as defined by the historical records. We will begin by defining "tsunami," a Japanese word meaning "harbor wave," as a series of waves generated in the ocean or a small, connected body of water by an impulsive disturbance. The definition includes water waves generated by ocean-bottom displacement owing to earthquakes, submarine landslides, or volcanoes. NGDC's effort in compiling tsunami data is complemented by the efforts of two other governmental agencies within the National Oceanic and Atmospheric Administration: the Pacific Marine Environmental Laboratory, a research institution, and the National Weather Service that operates the Pacific Tsunami Warning Center. World Data Center-A for Tsunamis is collocated with NGDC.

1.1 Types of Data and Terms

We have divided the Pacific Basin into ten geographic regions (see fig. 1) to facilitate the study and comparison of historical tsunamis affecting each region. A further breakdown of geographic regions into tectonic areas is planned. Each event will be identified by (a) geographic region, (b) tectonic area, and (c) event year, month and day. Tsunamis occurring outside the Pacific Basin are identified in the same way. (Our data base at NGDC contains information about 389 such events outside the Pacific Basin.) The following tsunami parameters are included in our data base: (1) information about the source, including date of generation, type of source (e.g., volcanic, earthquake, landslide), location of source, depth and magnitude of earthquake where appropriate, and (2) information about the tsunami including maximum runup height (maximum water height above mean sea level for event), tsunami magnitude ($m = \log_2\sqrt{H}$ where H is the maximum runup height) or intensity, ($I = \log_2\sqrt{2H}$) and local runup (maximum water height above mean sea level at given location), damage, deaths, arrival time, and travel time for each location experiencing the tsunami. Although we have information on 4500 locations that have experienced tsunamis, our still-incomplete data are constantly being updated and revised. A validity code from 0 (erroneous report) to 4 (definite tsunami) is assigned to each event. The validity code is necessary to prevent erroneous entries (i.e. storm surges, erroneous dates) from being reentered in the data base. The only events discussed in this paper are those having a validity = 2 (questionable tsunami) or higher.

The types of data available for each of the ten regions vary, as does the completeness of the tsunami historical record. Table 1 gives the extent of record for each of the ten regions, but does not indicate the completeness of the record. For example, some sparsely settled areas may have recorded an especially devastating event centuries ago, but have experienced only sporadic tsunamis in the intervening years. Also given are the number of known tsunamigenic events in each region since earliest times. These numbers were complied from historical accounts and are dependent not only on the number of actual events in a region, but also on the accuracy of the recordkeeping for the region.

1.2 Recorded Tsunamis

Regions can also be compared using the number of tsunamis that were recorded there. This number includes both local and remotely generated events. (For the purpose of this paper, a "local event" is defined as one in which the damage or effects occurred in the same region as the event source. A "remote-source" event is one that had its source outside the region where the damage was recorded. One type of local event may have the damage confined to the source region. Another type of local event may have caused damage in the source region and also have caused damage outside the source region. It is then both a "local event" and a "remote-source" event. Table I compares local and remote-source tsunamis. Four regions (Hawaii, S. Pacific, Japan, and the W.

coast of N. America) have recorded a number of tsunamis from other regions. For example, Japan has recorded tsunamis from Indonesia, the Philippines, Kamchatka/Kuril Islands, and the west coast of South America. Areas such as New Guinea/Solomon Islands, Indonesia, Kamchatka and Peru/Chile record fewer remote-source tsunamis, perhaps because there is less involvement in tide measurement or because the areas are protected by Osland chains and deep ocean trenches.

Table I. Extent of Historical Records

REGIONS	EARLIEST RECORD	NUMBER OF EVENTS APPEARING IN LITERATURE	NUMBER OF TSUNAMI OBSERVED OR RECORDED IN LAST 100 YEARS	
			Local Source	Remote Source*
Hawaii	1813	14	7	63
S. Pacific/ New Zealand	1848	41	34	45
New Guinea/ Solomon Is.	1768	78	68	7
Indonesia	416	123	56	1
Philippines	49 BC	71	51	20
Japan	173	247	110	52
Kamchatka/ Kuril Is.	1737	52	43	10
Alaska/ Aleutians	1788	38	26	21
W. Coast N.& Central America	1732	60	31	31
W. Coast S. America	1562	163	91	10

* Several regions may record the same event.

1.3 Damaging Tsunamis

Much of the interest in tsunamis focuses on their damage potential. Fig. 2 compares the total number of undamaging events, the total number of damaging events, and the total number of events that caused at least moderate damage. Of 104 damaging tsunamis in the last 100 years, only 9 caused damage beyond their source region. The epicenters of these events are located on the map in Figure 3. In the last 100 years the only regions to produce such tsunamis are Japan, Kuril/Kamchatka region, Alaska/Aleutian Islands, and the coast of South America.

Figure 4 summarizes the frequency of occurrence of damaging tsunamis by region for the last 100 years. Note that South America has generated

tsunamis that were destructive to five other regions. Hawaii, for example, has generated only three locally damaging tsunamis (those whose damage is limited to the generating region), but has experienced damage from nine remotely generat d tsunamis. All four source regions for remotely damaging tsunamis have produced tsunamis damaging to Hawaii.

1.4 Tsunami Damage v.s. earthquake magnitude

Another factor related to tsunami damage is earthquake magnitude. Figure 5 shows that two-thirds of the damaging tsunamis are associated with earthquakes of magnitude 7.5 or larger. It is interesting to compare the actual numbers of all earthquakes of 7.5+ magnitude that generated tsunamis in each of the ten regions. The highest percentage of magnitude 7.5 and larger earthquakes that generated tsunamis occurred in South America (fig. 6). An earthquake of this magnitude along the coast of South America has the highest potential for generating tsunamis in the Pacific Basin. Of course, some damaging tsunamis are generated by earthquakes of magnitude less than 7.5.

2. TSUNAMI CHARACTERISTICS OF EACH PACIFIC BASIN REGION

2.1 Hawaii

Property loss resulting from tsunamis in Hawaii has exceeded $110 million, and more than 400 people have lost their lives. Unlike other regions of the Pacific, Hawaii incurs most of its tsunami damage from remote-source tsunamis. In the last 100 years there have been seven local tsunamis, three of which have caused damage. Hawaii has also been damaged by nine remote-source tsunamis. At least 63 such other tsunamis generated in every quadrant of the Pacific Basin have been recorded or observed in Hawaii. Eleven major tsunamis generated outside Hawaii have achieved the maximum recorded runup outside the generating area in Hawaii. Tsunamis generated in the East and South Pacific do not cause damage in Hawaii, because their energy is confined by island chains. Of all the Pacific regions, Hawaii is clearly the most vulnerable to tsunami damage from outside sources.

2.2 South Pacific/New Zealand

A low population density and a protected location give this region the smallest tsunami-related death toll of any Pacific Basin region. The people who have inhabited these regions have kept few written records, which accounts for this region having the shortest history of tsunamis of all regions. Because New Zealand, Australia, and the South Pacific Ocean areas are protected from tsunamis that affect the rest of the Pacific Basin by a system of deep trenches, island networks, and shallow seas, they have escaped major tsunami damage from remote-source tsunamis. The only significant source of damaging tsunamis outside the region is the west coast of South America. Tsunamis from the west coast

of South America are frequently recorded in this area, but seldom cause damage. Several large earthquakes along the Kermadec-Tonga trench have generated local tsunamis, but damage from these events has been limited.

2.3 New Guinea/Solomon Islands

Though incomplete, historical data give evidence of 78 tsunamis in the New Guinea-Solomon Islands. This region is among the top four regions for tsunamis that caused moderate damage. More than 400 deaths have resulted from tsunamis in the last 100 years in this region. One-eighth of all tsunamis in this region have been produced by or associated with volcanism. The most disastrous such tsunami was caused by the volcanic explosion at Ritter Is. in March 1888. The sources of most tsunamigenic earthquakes in this region lie within the seismically active tectonic zone that extends along the Solomon Islands chain and across Northern New Guinea. Many earthquakes in this area did not produce a displacement of the sea floor, and hence did not produce tsunamis. Others may have produced tsunamis that escaped detection. Although 10 of the tsunamigenic earthquakes recorded in this region had magnitudes > 8.0, none produced damage outside the New Guinea-Solomon Islands region. Usually the same bathymetric features that prevent large waves from escaping the region also protect the area from remote-source tsunamis, but the area did experience a 2-m tsunami from the great Chile earthquake of May 22, 1960.

2.4 Indonesia

One of the earliest records of a tsunami in the Pacific Basin was produced in this region by the catastrophic eruption of Mount Kapi in 416 A.D. The tsunami that followed drowned most of the residents of the Northern Sunda District. Volcanism has been associated with more than one-fifth of the 50 destructive tsunamis recorded since earliest times, and accounted for more than half of the tsunami-related death toll of 50,000. Earthquakes, however, do generate local tsunamis in this area, and at least seven tsunamigenic earthquakes had magnitudes > 8.0. Most of the tsunamis that have been reported from this area have occurred in the Banda, Molucca, and Celebes Seas of Eastern Indonesia. A few have been reported from the northeastern quarter of the South China Sea, the Java-Makassar Strait region, and the Indian Ocean side of Indonesia. Twelve of the 56 events in this region in the last 100 years were moderately damaging. The tsunami death toll in this area in the last 100 years is more than 5,300.

2.5 Philippines

This region has the oldest record of a tsunami (49 B.C.). However, it also has the smallest number of events per decade, suggesting that the historical record is incomplete. Earthquakes in the Sulu Sea and in the northeast part of the South China Sea, as well as on the Pacific shores of these islands, have generated local tsunamis. Thirteen destructive tsunamis are known to have occurred in the Philippine Islands. Two of

these events--one in 1863 and the recent 1976 event--together count for more than 95% of the death toll of 45,600. Of the eight events that caused damage in the region in the last 100 years only five were moderately damaging. At least one remote-source tsunami generated in Chile was reported in the area, but other Pacific Basin events may have escaped detection. Two areas in this region have the potential to generate tsunamigenic earthquakes. The first is a seismic gap north of Taiwan in the East China Sea along the Ryukyu Trench, and the second is off the east coast of Mindanao. The death toll from tsunamis in the last 100 years is more than 5,000.

2.6 Japan

It is appropriate that the word "tsunami" is Japanese, because the Japan region has not only experienced the largest number of tsunamis (more than 250), but it also has sustained the most destruction to property and the largest number of deaths. Seventy-three damaging tsunamis in the Japan region since 684 A.D. have resulted in more than 100,000 deaths. Although most of the tsunamis in the Japan region have been produced along its east coast, a few damaging events such as the 1983 tsunami have been produced in the Japan Sea. Not only has Japan been an active source area for tsunamis, it has also been the recipient area for remote-source tsunamis produced in the neighboring Kurils and Kamchatka area, and a few events from the distant coast of South America have reached the area. Two major seismic gaps exist in this region. One is located along the northeast coast of Honshu, and the second is located along the coasts of Kyushu and Shikiku in Southern Japan. These tectonic features ensure that Japan will continue to be a potential source of both local and Pacific Basin tsunamis.

2.7 Kamchatka/Kuril Islands

Incomplete records since 1780 of the sparsely settled Kamchatka-Kuril Islands region list only ten destructive tsunamis and only a few tsunami-related deaths. This remote area has (at least in the past) had few structures to be damaged. The epicenters of the tsunamigenic earthquakes form two systems. The main system extends along the east coast of Kamchatka and the Kurils; the secondary system lies in the northern part of the Sea of Japan and the Tartar Strait. An interesting phenomena unique to this region are the large blocks of ice that often accompany the tsunami waves when they hit shore. The northeast coast of Kamchatka has an area of great seismic potential and should be monitored carefully. A tsunami generated in the area in 1952 caused $2.1 million in property damage in Hawaii. This is an important source region for remote-source tsunamis (see fig. 3).

2.8 Alaska/Aleutians

Twelve destructive tsunamis have been recorded in Alaska, and at least three have generated massive tsunamis in the Pacific Basin (fig. 3).

These have produced extensive damage outside Alaska, particularly in Hawaii. Alaskan earthquakes have also generated massive landslides that have produced wave heights up to 525-m in enclosed bay areas. When seismic gaps are closed by large earthquakes in the Gulf of Alaska, along the Alaskan Peninsula, and in the central Aleutians, massive destructive tsunamis may be generated. This area also has the most apparent potential for producing damaging tsunamis on the West Coast of the United States.

2.8 West Coast North and Central America

Destructive local tsunamis have not been generated on the west coast of the United States, but they have been generated to the south, along the Mexican and Central American coast, and to the north off the west coast of Northern and Southern Canada. Nine remote-source tsunamis that caused more than $10 million in property damage and 15 deaths on the west coast of the United States show the potential hazard for this area. Two seismic gaps exist along the coast of southern Mexico. Locally damaging tsunamis have been produced along the west coast of Mexico in the past and will no doubt be produced there again.

2.9 West Coast South America

This region has produced 41 destructive tsunamis that have claimed more than 30,000 lives. In addition, one of every three Pacific-wide tsunamis in the 20th century has been generated in Peru or Chile. This region has generated the largest number of damaging tsunamis affecting the entire Pacific Basin. An earthquake of sufficient magnitude to generate a tsunami that would affect the entire Pacific Basin (mag.=8.2) occurs in Chile once every 25 years on the average. This region has the largest number of events per decade (9.1). An interesting characteristic of large magnitude earthquakes (mag. $\geq$ 7.5) is that out of 38, 26 generated tsunamis (68%). This percentage is more than twice as great as other regions with high tsunamigenic potential (Alaska, 33%; Japan, 26%). A major gap along the Pacific-South American plate boundary exists from the coast of Southern Peru to Northern Chile along the "big bend" in the South American coastline. This area, which has a history of highly destructive earthquakes and tsunamis, has the potential for producing large tsunamis in the future.

3. SUMMARY

Several regions have high potential for generating remote-source tsunamis, both because they generated such tsunamis historically and because they contain seismic gaps having the potential for generating large magnitude earthquakes. These are the Kamchatka-Kuril region, the Alaska/Aleutians and the coast of South America. Hawaii is the region most vulnerable to remote-source tsunamis from these regions and should carefully monitor all three remote-source regions. The west coast of the United States has incurred the most damage from tsunamis generated

in the Alaska/Aleutians and should direct its attention toward the study of historical tsunamis that have occurred in these seismic gaps. The Southwest Pacific is relatively protected by its bathymetry and has in the past incurred only minor flooding from Peru-Chile tsunamis. However, since there is the potential for the generation of a major tsunami at the Peru-Chile border, the Southwest Pacific area, which has an incomplete historic record and has grown in population since past major events, may want to monitor the Peru-Chile coastline for tsunamigenic earthquakes.

Other regions have the potential for generating devastating local tsunamis. Japan is such a region and should direct its attention toward mitigating the effects of the large number of local tsunamis likely to be generated there. Past events in Japan have taken a huge toll in human life. Indonesia must also be concerned with its potential for producing damaging local tsunamis with large death tolls. Peru and Chile also have had entire coastal cities washed away by local tsunamis. Two major tsunamis were generated in the 19th century in the seismic gap near the Peru-Chile boundary. These tsunamis were among the most damaging ever recorded both locally and throughout the Pacific Basin.

We have shown some of the comparisons that can be made using the historical tsunami data file at the National Geophysical Data Center. We have also shown some of the limitations in the data and pointed out areas where additional research is needed.

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Data Analysis

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USA

3. VALPARAISO SIMULATIONS

Early in the contract period, discussions with Sr. Lorca indicated that the Chilean IHA would like to have additional work done on the simulations of the tsunami threat in Valparaiso. One course of study requested was the development of a finer scale model (1/4 km resolution) than had been used in the earlier simulations (1/2 km resolution). Since IHA was able to supply small-scale (1:10,000) charts of Valparaiso and Viñã del Mar, developing such a grid could be done with relative ease and the task was begun. The fine-scale maps provided a truer representation of the inland topography than had been available from the older 1:30,000 scale topographic charts used in the earlier studies (Hebenstreit, 1984).

The first question to be addressed was whether or not going to a finer resolution grid would significantly enhance the information content of the simulations. Because the previous 1/2 km grid had been derived from older charts, two new grids had to be developed in order to compare results. One was the 1/4 km grid requested by the Chileans. The second was a new 1/2 km grid derived by smoothing the 1/4 km grid, using arithmetic averages of four adjacent squares as shown in Figure 1. Although the two grids would have different scales, differences in the locations of major topographic features should be quite small. This was not true of the differences between the two grids developed from different base maps. Figure 2 indicates two areas of the new base map which are noticeably different from older maps. In area A, Reñaca, the valley is somewhat narrower than shown on previous maps; in area B, Viña del Mar, the area to the south of the railroad is depicted at a higher elevation on the new maps. These variations will result in differences in predicted inundation zones between models based on the two topographic charts.

No full analysis of the differences between the fine (1/4 km) and coarse (1/2 km) grid could be carried out,

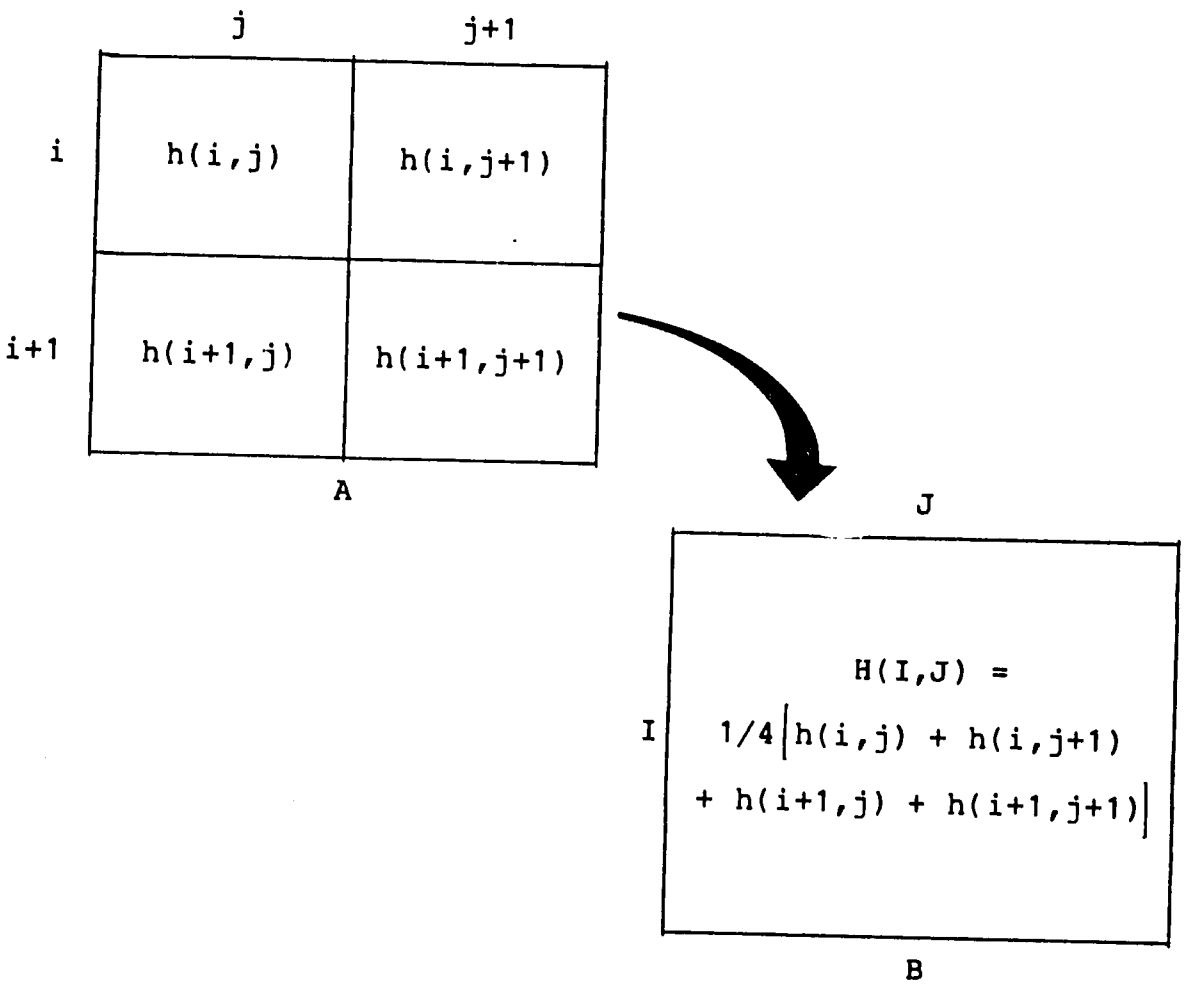

Figure 1
Mapping the 1/4-km grid (A) onto the 1/2-km grid (B)

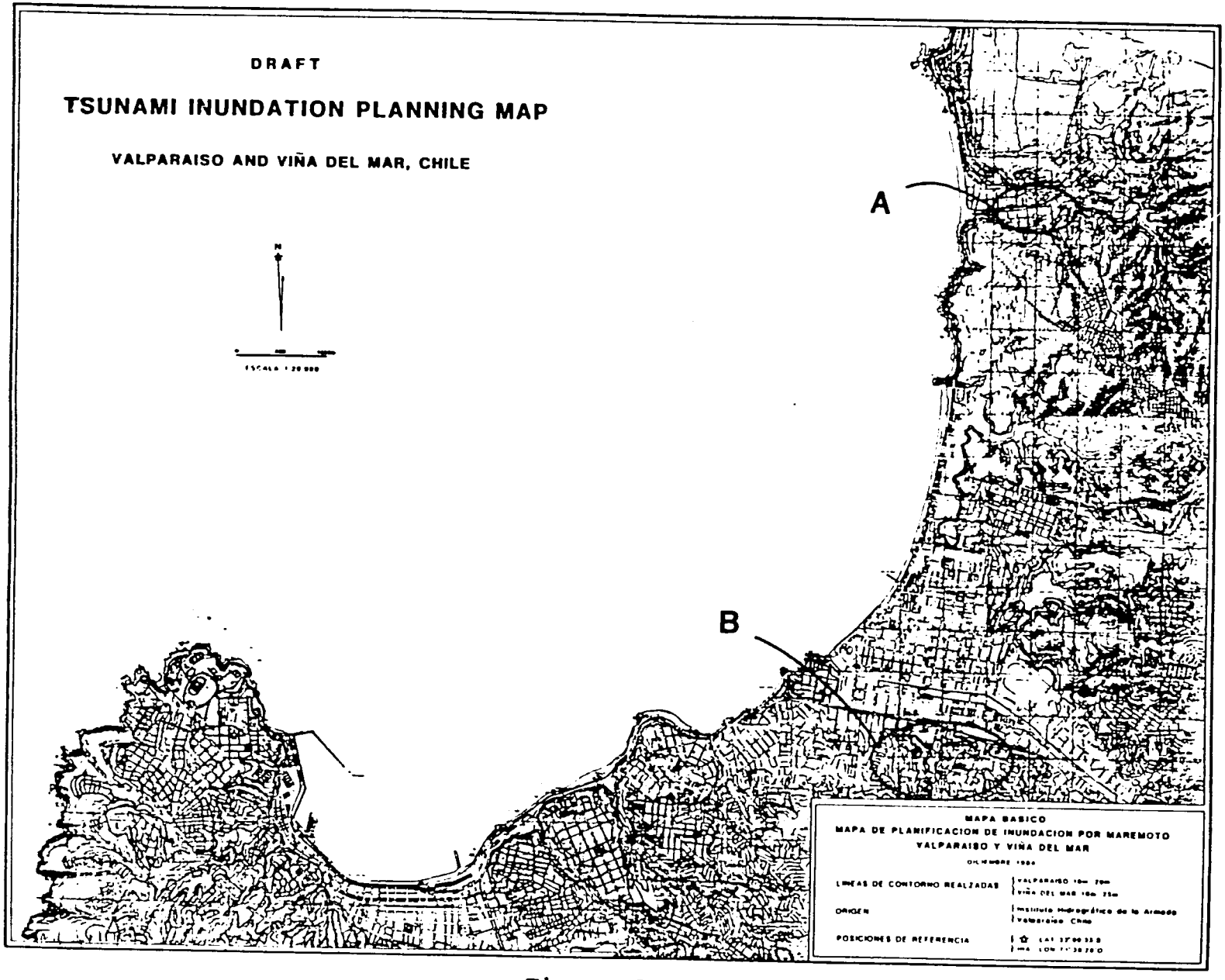

Figure 2

New, higher-resolution base map of Valparaiso and Viña del Mar. In the circles areas, topography is noticeably diferent from that of earlier charts.

primarily because of the 8-fold increase in computation time caused by using the fine grid model. The time and expense involved in running the fine grid model would have put too great a strain of the limited resources of the contract, and thus the intercomparison was not carried out. A general examination of the differences for one test case seemed to indicate that only very little additional information could be gained from the finer grid, but this conclusion could not be fully substantiated.

During the course of re-examining the model, Dr. Gonzalez (PMEL) and Dr. Hebenstreit (SAIC) came to the conclusion that the way in which subsidence is imposed on land topography is physically inconsistent. The earthquake displacement distance (positive d for uplift, negative d for subsidence) is added to the initial land elevation (h) above mean sea level (MSL). If the sum of these numbers (h+d) is positive, then the corresponding water elevation (η) value at that point is set to zero (i.e., no water surface wave above MSL at that point). But if the sum is negative, the corresponding displacement is set equal to the subsidence value. This has the effect of lowering the sea surface <u>below</u> the final (subsided) land value. Figure 3a depicts this process. The effect of this method will be felt most strongly at low-lying grid points just shoreward of the land-sea boundary, where subsidence is most likely to depress the land below MSL. The model determines whether or not a grid block should flood by testing the water elevation difference between it and neighboring blocks. If the water elevation value imposed on a land block is too low initially, the difference between it and the water elevation value of an adjacent block will be too great and (1) the block would flood prematurely or (b) too much water would flow into the block.

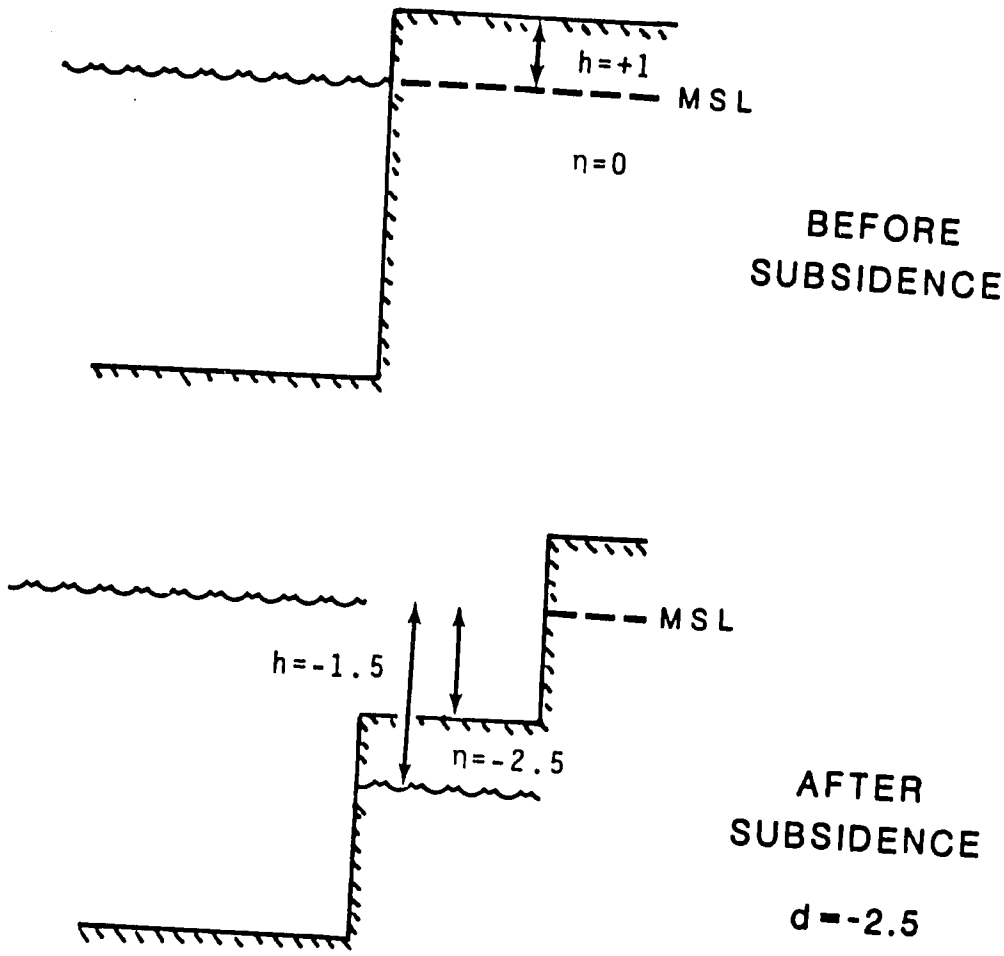

Figure 3a
Old Scheme for Imposing Subsidence Below MSL on a Coastal Point

In order to eliminate this source of error, the scheme depicted in Figure 3b was imposed on the model. In this method, if a land grid block subsides below MSL (i.e., $h+d < 0$), then the water elevation is set to the new land elevation ($\eta = h+d$). This could be looked at as imposing a thin film of water on the block, but is more physically realistic than the previous scheme.

In order to test the effect that this change would make, two coarse-grid runs were made; one run used the old scheme and one the new. The case of a tsunami approaching from due west was used (see Hebenstreit, 1984) in the comparison.

The differences between the two runs are significant. Maximum flood depths at most land points are lower with the new scheme than with the old. The decrease can be as much as 30%, although usually it is on the order of 15-20%. The one exception is in Valparaiso, where maximum waves along the shore are higher with the new scheme. This may indicate that some of he energy which, under the old scheme, would have flooded inland at Viña del Mar has propagated along the shore and come inland farther south.

Despite the significant drop in water levels, only slightly fewer grid blocks were flooded under the new scheme than under the old. Given the nature of the land topography around Valparaiso, i.e., several stream valleys separated by steep ridges, it is clear that topographic barriers are more important than initial conditions in determining where the water goes.

Figures 4 and 5 show predicted inundation areas in the Valparaiso area as the result of waves approaching from

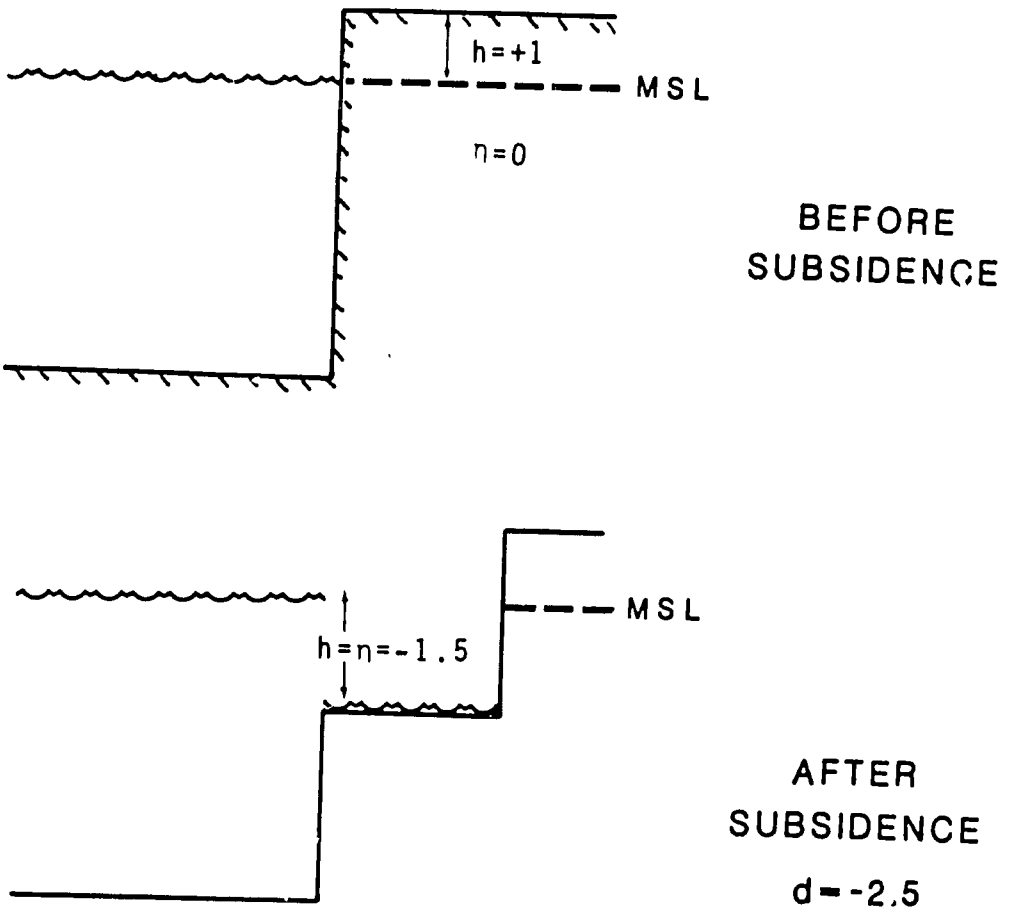

Figure 3b
New Scheme for Imposing Subsidence Below MSL on a Coastal Point

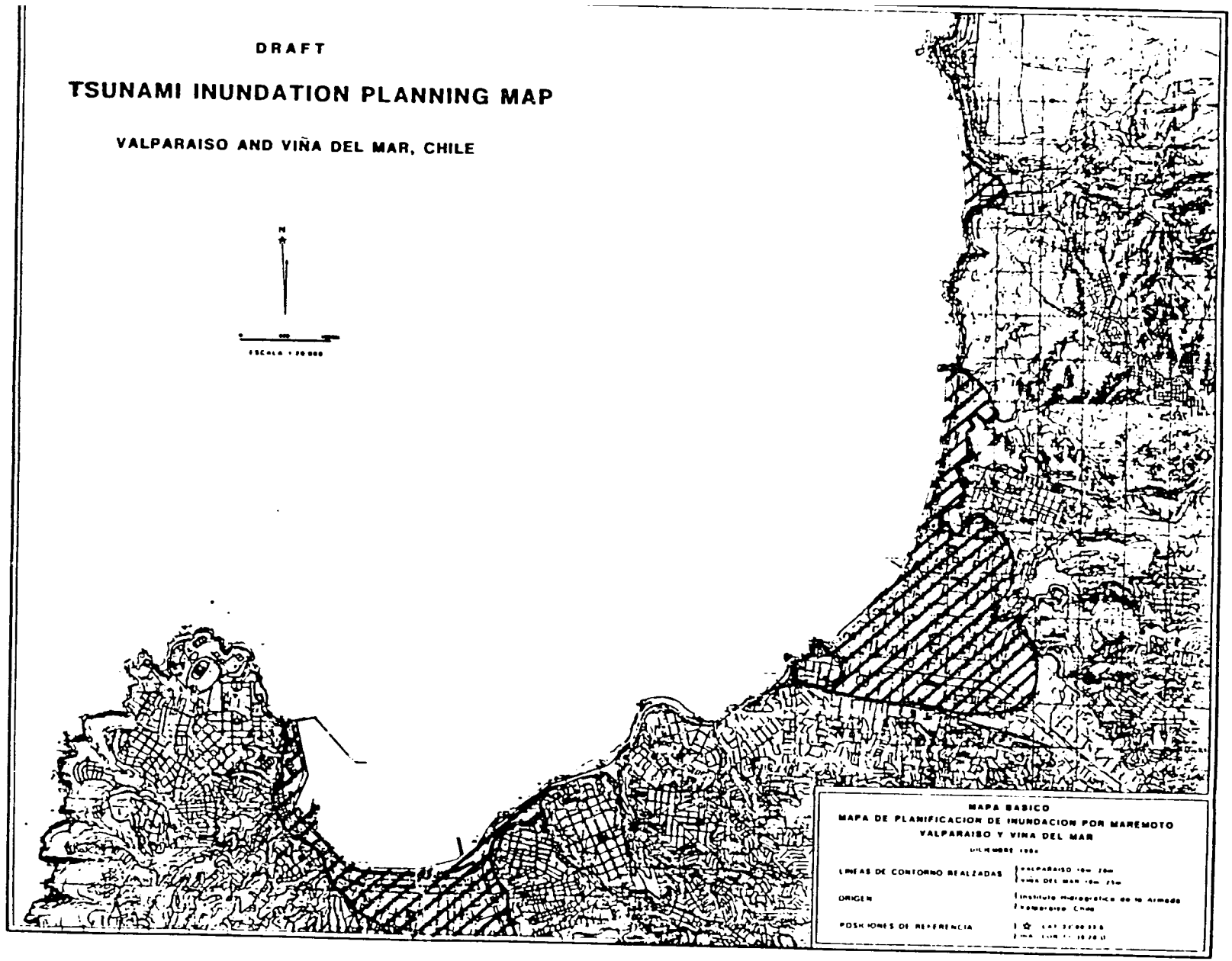

Figure 4

Inundation area prediction by the model for a tsunami approaching from due west

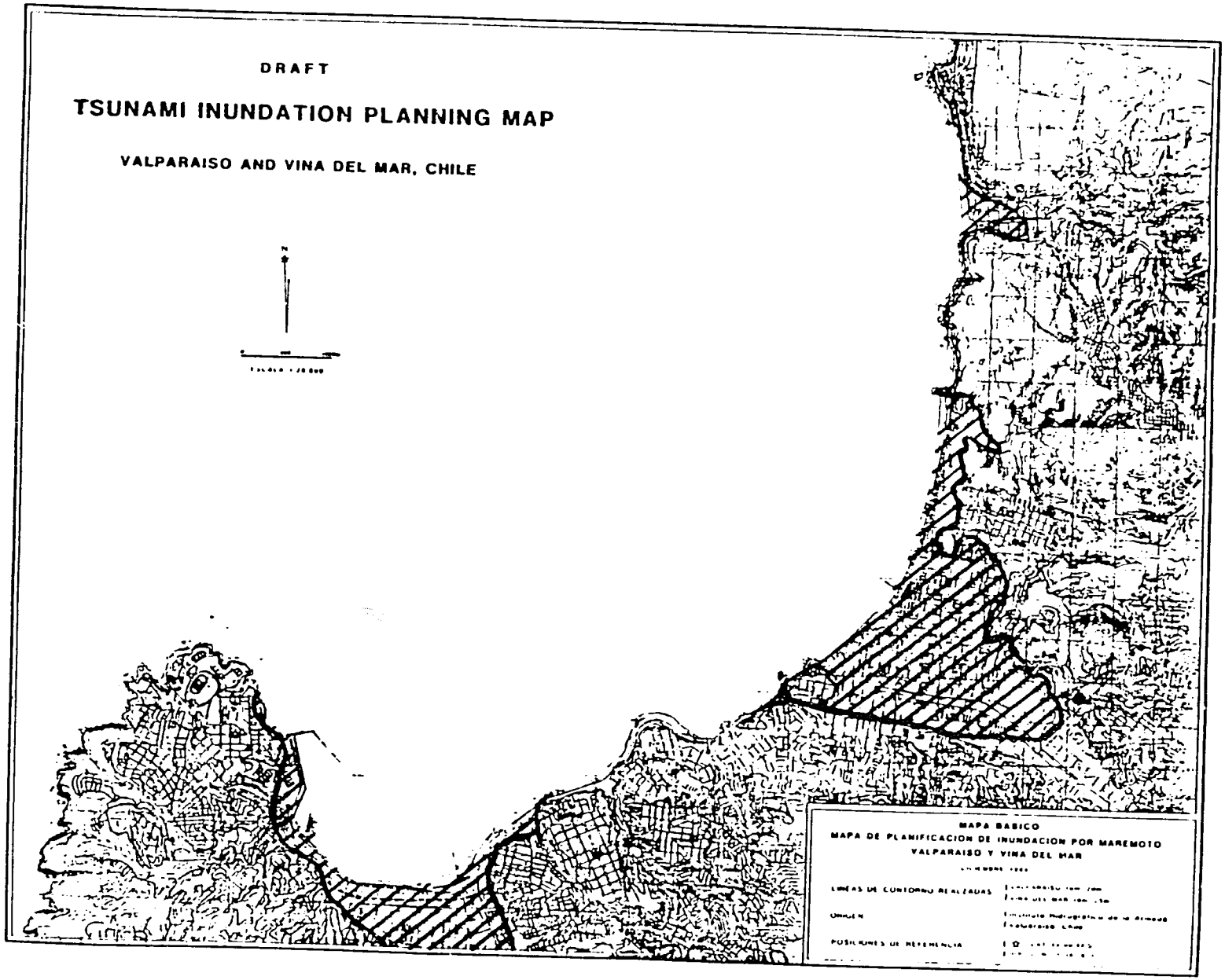

Figure 5

Inundation area prediction by the model for a tsunami approaching from the northwest

either the west (Figure 4) or the northwest (Figure 5). The differences are not great, although waves from the northwest do drive water somewhat farther into Reñaca and Viña del Mar.

The comparison between Figures 4 and 5 and the corresponding figures (4.5 and 4.7) in the previous study (Hebenstreit, 1984) underscores the effect of the revised model topography. Predicted flooding in Viña del Mar and Reñaca extended much farther inland in those earlier simulations, primarily because of the greater areas of low-lying land depicted on older maps. It seems clear, for example, that the area of higher elevations south of the railroad in Viña del Mar is relatively secure, as is the area farther inland along Estero Marga Marga.

4. INTEGRATION OF MODEL RESULTS

In most cases, model studies of this type stop once simulations have been completed and general conclusions drawn. The THRUST program is different in that it represents an attempt to integrate various aspects of the tsunami problem--instrumentation, modeling, and data collection--into a single system designed to reduce tsunami hazards. With this goal in mind, one additional step was taken with the model results in order to both demonstrate the usefulness of such simulations and to educate civil officials as to the nature of their hazard.

Figure 6 represents the approach used in this study. Three maps have been prepared. The first (lower right) is a base map of the region, showing topography and streets. The second (center) is an overlay indicating the locations of the types of facilities, such as rail and road evacuation routes, communications centers, and large buildings usable as refugee centers, which could be needed in

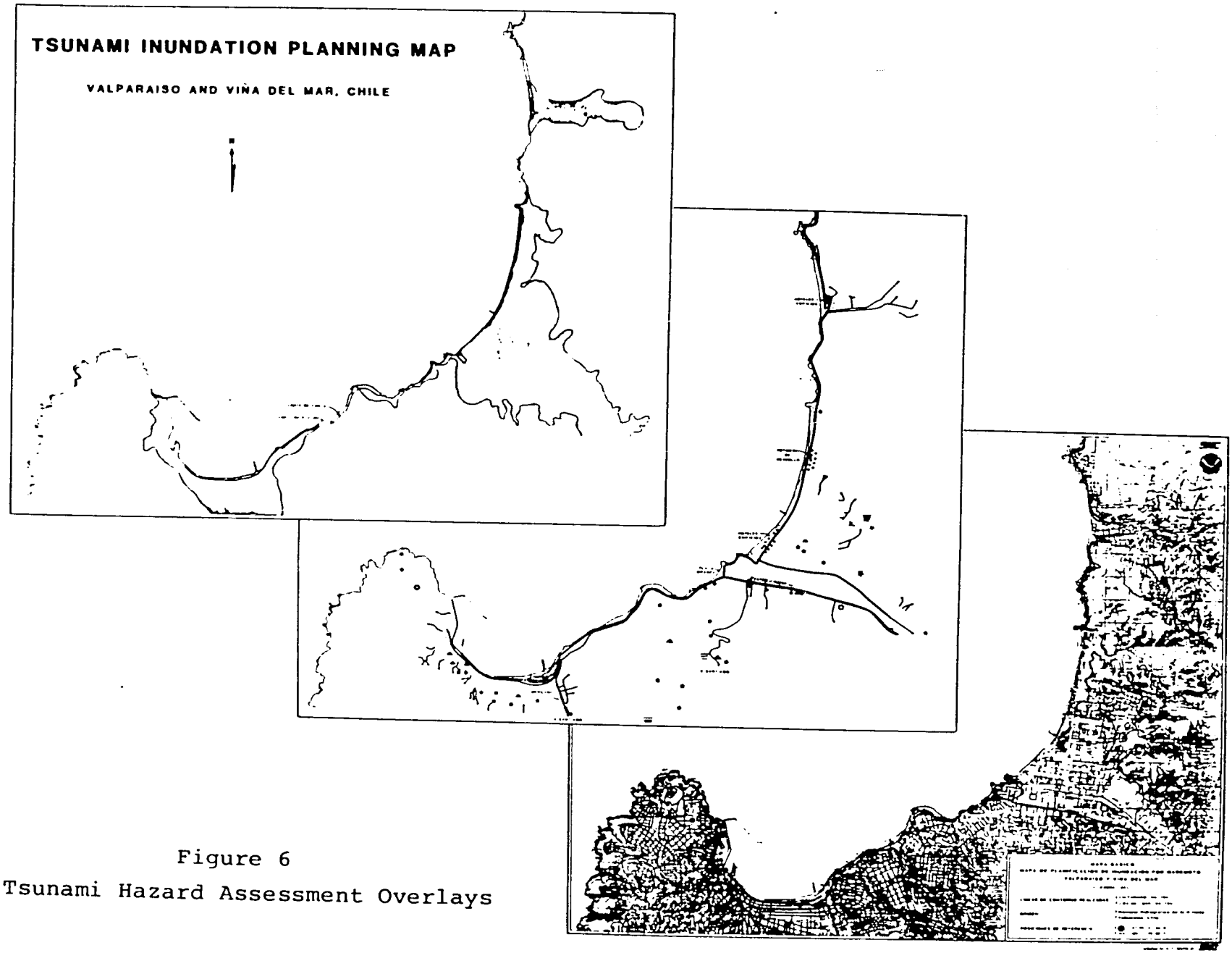

Figure 6
Tsunami Hazard Assessment Overlays

order to mount evacuation and disaster relief efforts. The third (upper left) is an overlay indicating the areas which simulations show could be flooded. The combination of these three pieces can illustrate not only where flooding could occur, but also how the flooding could hinder relief operations. Presentations such as these should serve to transfer simulations from the theoretical realm to the practical realm. Sets of these maps have been provided both to PMEL and to IHA.

5. PRESENTATIONS

During the course of this contract, Dr. Hebenstreit served as author or co-author of three different presentations. The first was an invited paper at the Workshop on the Technical Aspects of Tsunami Analyses, Prediction, and Communication held at Sydney, British Columbia, 29-31 July 1985. The text of the paper is included as Appendix B of this report. An expanded version is being prepared for submission to the Tsunami Society journal.

The second paper, "Near source tsunami simulation of Valparaiso Harbor, Chile" was presented at the IUGG International Tsunami Symposium at Victoria, British Columbia, 6-9 August 1985. A summary of the paper is attached as Appendix C.

The third paper, "Preliminary model results of the 1985 Chilean tsunami," was presented at the AGU Fall Meeting in San Francisco. This paper, while not actually a part of the THRUST project, is a logical offshoot of it. The abstract of the paper, which is being prepared for submission to the Journal of Geophysical Research, is attached as Appendix D.

6. REFERENCE

Hebenstreit, G.T., 1984: Pre-event Data Analysis in THRUST, SAIC Report SAIC-84/1811, Science Applications International Corp., McLean, VA.

40

Data Dissemination

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TSUNAMI EMERGENCY OPERATIONS PLAN FOR CHILE

PRELIMINARY DRAFT

December 1985

42

TABLE OF CONTENTS

I. INTRODUCTION
1. The Tsunami Threat
2. The Pacific Tsunami Warning System
3. The THRUST Project

II. TSUNAMI EMERGENCY OPERATIONS PLAN FOR CHILE
1. Purpose of the plan
2. The National Tsunami Warning System
3. Existing Organizational Structure for Emergency Operations (Responsabilities and Functions)
A. Overview
B. National Disaster Agencies
C. Regional Disaster Agencies
D. Provincial Disaster Agencies
E. Other Supporting Organizations
4. Tsunami Watch and Warning Emergency Procedures
A. Coordinating Instructions
B. Tsunami Watch
C. Tsunami Warning
5. Tsunami Warning Communications
A. Regional Disaster Agencies
A.1. Regional Emergency Committee
A.2. National Emergency Network
B. Central Disaster Agencies
B.1. Hydrographic Institute Responsabilities
B.2. ONEMI Responsabilities
C. Commercial Broadcast Industry
D. Valparaíso Communications Network
D.1. Information and Communications Center (Provincial Committee of Emergency)
D.2. Other Supporting Networs

III. TSUNAMI EVACUATION PROCEDURES

1. Introduction
   - A. Objetives
   - B. Diagnosis
     - B.1. Risk areas
     - B.2. Available Resources
     - B.3. Functions
2. Actions
   - A. Pre-event actions
     - A.1. Security areas
     - A.2. Evacuation Routes
     - A.3. Simulation Exercises
     - A.4. Public Education
   - B. During a Tsunami
     - B.1. Warning Dissemination Procedures
     - B.2. Mobilization of Operative Resources
       - Emergency Operations Groups
       - Social Care Groups
     - B.3. Mobilization of the Public
     - B.4. Educative Reinforcements
       - Emergency Instructions
       - Situation Information
   - C. Actions After a Tsunami
     - C.1. Warning Cancellation
       - Dissemination
       - Demobilization
3. Evaluation

IV. TSUNAMI DISASTER REPORTING

1. Purpose
2. Concept
3. Required Disaster Reports
   - A. Spot Reports
   - B. Periodic Disaster Reports (PERDISREP)

4. Special Reports
   A. Field Team Reports
   B. Damage Assessment
   C. Damage Survey Reports
   D. Special-purpose Reports
   E. After-action Reports

5. Procedures
   A. Channels
   B. Coordination
   C. Content
   D. Termination

6. Sample formats of PERDISREP
   A. PERDISREP Nº 1 "Earthquake Report"
   B. PERDISREP Nº 2 "Provincial Situation"
   C. PERDISREP Nº 3 "Regional Situation"
   D. PERDISREP Nº 4 "National Situation"

V. REFERENCES

VI. ANNEXS

Annex 1: Organization of the Country
   Fig. 1.- Organizational Plan to Deal with Earthquakes or Other Catastrophes
   Fig. 2.- National Tsunami Warning System Organization
   Fig. 3.- Tide Stations in Chile
   Fig. 4.- Seismic Stations in Chile
   Fig. 5.- Tsunami Data Information and Warning Flow

Annex 2: Tsunami Hazard Analysis
   1. Purpose
   2. Causes of Tsunamis
   3. Historical Tsunamis in Chile
      A. Originating in Chile
      B. Originating Abroad
      C. Detailed Tsunami Information
      D. References

Annex 3: Tsunami Preparedness in Valparaíso

1. Purpose
2. Concept
3. Responsabilities and Functions
4. Plans and Training

Annex 4: Tsunami Public Education in Valparaíso

1. Purpose
2. Concept
3. Responsabilities and Functions

I. INTRODUCTION

1. The Tsunami Threat

Tsunamis are caused by large earthquakes centered under or near the ocean, by the vertical displacement of the sea floor along and around an underwater fault. Resulting displacement of the water surface generates a series of tsunami waves, which travel rapidly in all directions across the ocean. Volcanic eruptions and underwater avalanches or landslides can also produce destructive tsunamis. Earthquake's magnitude, depth of focus, the water depth in the region of tsunami generation, the amount of vertical crustal displacement, and other such source parameters will determine the size, orientation and destructiveness of a tsunami. Tsunamis travel rapidly across the ocean and their speed varies with the square root of the water depth. It is this relationship which permits prediction of tsunami arrival times at all points in the Pacific Ocean. However, tsunami run-up (the vertical distance between the maximun height reached by the water on the shore and the mean-sea-level surface) is impossible to predict at the present time. Underwater topography and coastal configuration will determine to a large extent the heigth and destructiveness of a tsunami.

The West Coast of South America is delineated by the eastern edge of the NAZCA tectonic plate, and is characterized by extreme seismicity. Many offshore faults exist in the area, and offshore earthquakes have generated destructive tsunamis along the Chilean coast in the past. Historically tsunamis have been well-documented since the days of the Spanish conquest. Thus, Chile was inundated by three catastrophic tsunamis in the latter part of the 16th century - in 1562, 1570, and 1575; by two tsunamis in the 17th century - in 1604 and 1657; by two tsunamis in the 18th century - in 1730 and 1751; by six tsunamis in the 19th century - in 1819, 1822, 1835, 1837, 1868 and 1877; and by three more destructive tsunamis in the present century - in 1906, 1922 and 1960.

Tsunamis were responsible for the destruction of Valdivia in 1575, of Concepción in 1751, and of Arica in 1868. The 1960 Chilean earthquake and tsunami were the largest events of this century. Chile, especially between the parallels of 36º and 47º South latitude, is a region of incredible volcanic and seismic instability.

Tsunamis of distant origin have also been destructive in Chile and these too present a potential threat in the future. Annex 2 is a well-documented historical catalog of tsunamis in Chile.

2. The Pacific Tsunami Warning System

After the devastating Aleutian tsunami of April 1, 1946 struck the Hawaiian islands, efforts to develop an early tsunami warning system were initiated by the U.S. Coast and Geodetic Survey. The warning system had to detect and locate rapidly, earthquakes in the Pacific Region and, if one occurred in an area where tsunami generation was possible, to determine quickly whether a tsunami had, in fact, been generated. In addition a method had to be developed to predict accurate arrival times of the tsunami at various places.

Initially the Tsunami Warning System was to supply tsunami watch and warning information to the U.S. civil authorities and various military headquarters in the Hawaiian Islands for dissemination to military bases throughout the Pacific and to the islands of the U.S. Trust Territory of the Pacific. Beginning in October 1953, warning information also was given to the civil defense agencies of California, Oregon and Washington.

The great destruction caused by the May 1960 Chilean tsunami prompted a large number of countries and territories to join the tsunami warning system. Within four years, another catastrophic tsunami was generated that spread throughout the Pacific. The great Alaskan earthquake of 1964 generated a devastating tsunami that demolished much of Crescent City, California. Other areas of the Pacific region were also affected, especially the area surrounding the Gulf of Alaska where the earthquake occurred. The need for an international system was now more apparent than ever.

The objetives of the International Tsunami Warning System are to detect and locate major earthquakes in the Pacific region, determine wether they have generated tsunamis, and provide timely and effective information and warnings to the population of the Pacific in order to minimize the hazards, especially those to life and property.

3. The THRUST Project

There are areas in the Pacific for which the Pacific Tsunami Warning Center (PTWC) in Honolulu cannot provide suitable warning information within one hour after tsunami generation. A need exists for regional early warning systems which can react within ten minutes after a potentially tsunamigenic event has occurred.

The scope of the work of the THRUST Project entails the development of tsunami and earthquake data base, verification of a tsunami numerical model, preparation of hazard assessment maps for the coastline combining historical and modelling results, the establishment of tidal and se ic

sensors using satellite telemetry to provide early warning information, and finally, the integration of the new early warning technology to an existing local system. The present Tsunami Emergency Operations Plan for Chile integrates the THRUST components into the Chilean Tsunami Warning System.

II. STANDARD OPERATING PLAN FOR CHILE

1. Purpose of the Plan

Tsunamis and their effects can be greatly reduced if disaster control plans are thoroughly specified before a tsunami event occurs and if rapid dissemination of warning information can be accomplished during the short time interval immediately following the generation of the tsunami.

Effective disaster planning and preparedness include the enactment and enforcement of legislation, rules, regulations, zoning codes and building codes that are designed to prevent or mitigate the effects of tsunami hazards.

The purpose of this operational manual is to achieve effective preparedness and understanding of the tsunami hazard in Chile and to organize in a systematic fashion a prompt, fully coordinated program of tsunami warning dissemination which will insure prompt and flexible response by the populace, thus minimizing loss of life and property when the disaster strikes.

The THRUST System makes use of advanced water level and seismic sensor instrumentation installed in Valparaíso and Santiago, transmitting data in real-time via the Geostationary Operational Environmental Satellite (GOES) System, to provide real-time data collection and tsunami warning dissemination. The warning information must be communicated to threathened communities in sufficient time for them to take appropiate action in saving lives and protecting property. Thus, this plan is essencial in testing and evaluating the THRUST pilot project and becoming an integral part of the Tsunami System in Chile. Emphasis is placed in this plan on people and their needs before, during and after the tsunami threat which may range from a local emergency affecting relatively few to a major disaster affecting large number of people.

2. The National Tsunami Warning System

The System was officially inaugurated in Chile on July 30, 1964 under the jurisdiction of the "ydrographic Institute of th Chilean Navy. In January 1965 the Hydrographic Institutte was designated as the official representative of Chile to the International Tsunami Warning System(ITSU).

Several other organizations are involved in seismic data collection, warning dissemination and population evacuation, under different government ministries (Annex 1). A comprehensive national emergency plan exists for Chile, dealing with all type of disasters. Figures 1 and 5 in Annex 1 are a government organization plan and a data and information flow in case of disasters as tsunamis. Each ministry and each organization within each ministry has its own emergency plan which is implemented in case od a natural disaster.

Although a number of organizations within the different ministries play an important role in the event of a natural disaster, there are only three organizational entities which play a very important role in geophysical data collection following a large earthquake, in the analysis and interpretation of the data, in the issuance of watches and warnings, and in the implementation of the warning information to safeguard life and property. Their main responsabilities and functions are described below.

The overall coordination of the National Tsunami Warning System is under the Hydrographic Institute (IHA), the sole agency responsible of the issuance of watches and warnings within the country.

The operation of the National Tsunami Warning System is mainly based on the reports given by seismic and tide stations distributed along the country, and on bulletins sent by PTWC.

To detect tsunamis the IHA utilizes mareographic stations at Arica, Iquique, Antofagasta, Caldera, Easter Island, Coquimbo, Valparaíso, Juan Fernandez Island, Talcahuano, Puerto Montt, Punta Arenas, Puerto Williams and Base Arturo Prat (in the Anctartic Chilean Territory).

In 1965 the IHA established general instructions for the National Tsunami Warning System (Publicación IHA Nº 3.014). This plan was considerably improved in 1975 and a new updated plan is under publication. This new version of the plan reflects improvements that were made in the country for a 10-year period and outlines the procedures to be followed by IHA and other Navy authorities in the event of a large earthquake and tsunami. They are based on data and information which may be collected locally or which may originate from the PTWC in Honolulu. The present Tsunami Warning System is adequate in providing sufficient protection for tsunamis which may originate at distant sources.

The Office of National Emergency of the Ministry of Interior (ONEMI), was created in 1974. Its major objetive is to plan, coordinate and execute the necessary activities for the prevention or solution of problems resulting from national catastrophes.

The National Plan of Emergency, published in 1977, outlines the active participation of all ministries, organizations and institutions in the public and private sectors as well as voluntary organizations for activities which will prevent or help to solve problems caused by emergencies such as natural hazards or those created by men. In relation to these objetives ONEMI is presently developing a project, initiated in 1979 entitled "National Mapping of Risks and Prevention of Catastrophes" which has as its goal the identification and control of the different disasters that affect the country.

In order to cover the entire country, ONEMI has organized regional, provincial and local Emergency Committees under the jurisdiction of regional directors, governors and mayors. These Committees coordinate the use of local resources and for technical support are functionally an extension of ONEMI.

The Department of Geology and Geophysics of the University of Chile operates a number of seismic stations and accelerometers throughout the country primarily for research purposes and to determine the seismicity of the region. Organizationally the University of Chile is a governmental institution and it is the only seismological organization in Chile. It has been responsible for providing seismological information on earthquake epicenter and magnitude to IHA.

3. Existing Organizational Structure for Emergency Operations(Responsabilities and functions)

The Governor is empowered by law to exercise authority and control throughout the Province when a disaster or emergency threatens or occurs. The Governor of a Province reports directly to the Administrator of the Region who is empowered by law to exercise authority and control of the situation throughout the Region when a disaster or emergency threatens or occurs.

If a catastrophe affects several Regions, a Chief of Disaster Zone is nominated who exercises complete authority and control of the situation in the affected area.

The permanent Emergency Operating Center, coordinating disaster mitigation and relief is located in the ONEMI Office facilities in Santiago. Alternate Operating Centers or observatiion-control posts, to include motorized mobile facilities, may be activated by the Director of ONEMI as required.

A. Overview

In Chile the basic responsability for disaster planning, preparedness, response and recovery assistance is vested in ONEMI.

An affected region has primary responsability for responding immediately to any disaster situation, whereas the National Emergency Office is responsible for supporting and supplementing the Region efforts and resources as needed.

B. National Disaster Agencies

The National Emergency Office of the Minitry of the Interior (ONEMI), is responsible for the planning, coordination and execution of the activities assigned to prevent or overcome the problems derived from natural or man made disasters, on a national level.

C. Regional Disaster Agencies

The mission of the Regional Administrator is to maintain or restore as soon as possible a normal situation in the Region, adopting the precautionary measures and actions to deal in an effective way with a catastrophe, coordinating the efforts of all the regional organizations.

To coordinate the necessary tasks during an emergency every Region has an Emergency Committee integrated by representatives from all agencies having the necesary resources to deal with natural hazards like: Army, Navy, Air Force, Police, Fire Department, Hospitals, Red Cross, Civil Defense, etc. This Committee will be headed by a Chief of Operations, which is normally the Director of the Regional Emergency Office.

When an emergency occurs, all regional resources are assigned to the Emergency Committee to be used by the Chief of Operations.

The functions of the Regional Emergency Committee are:

- To study and plan the adequate organization to

have a human infrastructure suitable to manage a catastrophe or emergency situation successfully.

- To comply with the directions given by the Ministry of the Interior based on the National Emergency Policy.

- To prescribe the rules and procedures needed for the coordinated actions of the organization.

- To take the appropiate measures directed to restore normality.

- To outline to the community the rules and procedures to be followed in the event of a tsunami or other natural hazards.

- To ask the Ministry of Interior to declare the damaged area as a disaster region.

D. Provincial Disaster Agencies

The coastal provinces are responsible for developing and maintaining Emergency Plans in case of tsunamis, conducting preparedness training and, when disaster threatens or occurs, directing and coordinating response, assistance and recovery operations in their jurisdictional areas under the Provincial Emergency Committee.

E. Other Supporting Organizations

The Armed Forces, Police Corps, Fire Department and Civil Defense provide resources in support of disaster relief operations as needed by the disaster situation.

4. Tsunami Watch and Warning Emergency Procedures

A. Coordinating Instructions

- A tsunami watch or warning will be released by the Hydrographic Institute to the following:

a. Central Navy authorities
b. Coastal cities Navy authorities
c. Navy Operations Headquarters
d. ONEMI
e. Chief of Operations of the Valparaíso Regional Emergency Office

- ONEMI has primary responsability for notifying coastal areas civil authorities likely to be affected by tsunamis. Upon receipt of a tsunami watch or warning, ONEMI will forward information as deemed necessary via the fastest communications means to all areas likely to be affected.

- Regional and Provincial authorities will take immediate action, upon receipt of a tsunami warning to disseminate the information to all coastal communities in their areas.

- Coastal communities, upon receipt of a tsunami warning, have the responsability to take al necessary action to minimize the loss of life and property.

- Accordingly, the Administrator of each Region and the Governors and Mayors, are required to prepare disaster response plans to effectively carry out their assigned and implied responsabilities to deal with all contingencies concerning tsunamis including the rules and procedures to teach the community about damage prevention, individual and collective attitude before a disaster and financial support for the operation of the Plan.

B. Tsunami Watch

In the event of an earthquake of magnitude 7.0 or greater, Richter Scale, originating in Pacific waters and sufficient to generate a tsunami, which could produce adverse effects on Chilean coastal communities, the Pacific Tsunami Warning Center (PTWC) will provide the Hydrographic Institute (IHA) with early notification in the form of seismic information message. This message may only state that a major earthquake has occurred and may give no information on magnitude or location. This message will be followed by watches and/or warning messages.

In the event of an earthquake of magnitude 7.8 or greater, originating around Valparaíso area, the seismic triggers in Valparaíso and/or Santiago could be activated. In this case a tsunami watch message will be displayed at the IHA THRUST terminal.

All seismic information and watches messages will be transferred according to Coordinating Instructions.

It must be emphasized that a Tsunami Watch is issued based on earthquake information only, without confirmation of wave activity. For the purpose of urgency, action agencies included within the Tsunami Watch designation, particularly those within 500 Km. from the epicenter may choose to regard a Tsunami Watch as a warning and act promptly.

C. Tsunami Warning

The decision to warn is taken by the IHA with the help of the next given conditions:

a. Tsunami warning message from PTWC.
b. Warning message at the THRUST terminal.
c. Earthquake location and magnitude from Department of Geology and Geophysics.
d. Tsunami recorded at tide station.

Whenever a Tsunami Warning is released by IHA every agency should take immediate and prompt action.

5. Tsunami Warning Communications

A. Regional Disaster Agencies

a. The Regional Emergency Committee is responsible for:

-- Operating and maintaining telecommunications facilities and systems located at the Region and mobile or transportable emergency communications facilities and resources.

-- Coordinating the integration of available telecommunications resources owned and operated by governmental agencies as the disaster situation requires.

-- Warning dissemination, according to the procedures shown on Chapter III.

b. The National Emergency Radio Network, runned by the Chile Ham Club is responsible for:

-- Replace the normal telecommunications channels, whenever they are interrupted because of the disaster.

-- To be an alternative way to evacuate assigned traffic when the normal telecommunication channels are operating.

The assigned frecuencies for the network are as follows:-

BAND	NORMAL FREQ.	ALTERNATE FREQ.
80 meters	3.753 KHz	3.750 KHz
40 meters	7.050 KHz	7.065 KHz
20 meters	14.200 KHz	14.220 KHz
2 meters	145,32 MHz	146,52 MHz

The underlined frequencies in HF as well as VHF are permanent watch frequencies.

B. Central Disaster Agencies

a. The Hydrographic Institute is responsible for:

-- Communicate with all the Navy Operations Offices in the country via dedicated telephones, radio and telex. It also communicates with radio and telex with ONEMI. Different naval authorities are responsible for reporting data to IHA from tide gauges in the event of a large earthquake.

b. The ONEMI is responsible for:

-- Activate the Emergency Operating Center, establishing the degree of alert necessary for the incoming situation. There will be two kinds of alerts: yellow alert or a partial mobilization and Red Alert or general mobilization. Yellow Alert will be declare when a Tsunami Watc is released by IHA. Red Alert in case of Tsunami Warning from IHA.

-- Inform the corresponding Regional Emergency Office Directors of the situation (Tsunami Watch or Warning).

-- Communicate to IHA the seismic parameters calculated by the Department of Geology and Geophysics within 30 minutes after the earthquake.

-- Collect and send to IHA the intensity data available in case there is no epicenter location and magnitude given, within 45 minutes after the earthquake.

C. Commercial Broadcast Industry

The Ministry of Interior can make use of the Broadcast Industry at any time to disseminate throughout the nation or a Region any announcement regarding a disaster situation. The Valparaíso Emergency Operating Center has direct access to Radio Nacional to broadcast emergency instructions to the public.

D. Valparaíso Region Communications Network

The Provincial Committee of Emergency at Valparaíso has an Information and Communications Center, located at Intendencia Building, integrated by:

-- Provincial Emergency Operations Center Radio

-- Police Radio-communications Service

-- Police Mobile Stations

-- Fire Department Communications Service

-- Ham Provincial Network

-- Telex-Chile

-- Commercial Broadcast Stations

-- TV Channel 4

IV. TSUNAMI DISASTER REPORTING

1. Purpose

To prescribe for the National Emergency Operations Center (NEOC) of ONEMI and other agencies the essential kinds of reports and reporting required by ONEMI to support effective direction and control of disaster situations.

2. Concept

Upon the onset of the threat or occurrence of a tsunami, the prompt reporting of information through the most expedient available channels to the Director of ONEMI, and in turn, to all levels of goverment, the media and the public is essential to official decision making and actions required to provide for safety, health and welfare of the public.

One of the basic functions of the National Emergency Operations Center is to record the informations from all the affected Regions of the country in case of a natural hazard.

-- Effective reporting is key to effective communication.

-- Effective communication is key to effective response and assistance in a disaster situation.

Key sources of disaster reporting are on-the-scene police, fire, public works, civil defense coordinators and their assistants. Basic sources of information are local civilians including those victimized by the disaster. At the onset of a widespread tsunami, it is imperative that the Director of ONEMI immediately be notified of the threat or occurrence. Thereafter, the Director must be kept informed od developments, public needs and attitudes on a continuing basis.

3. Required Disaster Reports

A. Spot Reports

Spot reports are transmissions of information of possible immediate value even when the reports usefulness or accuracy may be in doubt. They may be fragmentary and have no prescribe title or format except to include identification of the sender and an "as-of" date-time group. These spot reports will be collected by the

Local Emergency Office and sent to ONEMI by the emergency channels.

B. Periodic Disaster Reports (PERDISREP)

These reports are prepared by ONEMI, commencing with the activation of the Regional Emergency Operations Center, and transmitted periodically to the Director of ONEMI to keep him abreast of what has happened, what is being done, and what is needed by the Region. In effect, a PERDISREP is summation of spot reports received from various observers and sources and evaluated by the NEOC during a given reporting period.

-- The initial periodic report, PERDISREP #1 is initiated by the Department of Geology and Geophysics on the onset of a felt earthquake. Its purpose is to provide ONEMI with an initial estimate of location of the earthquake and its magnitude and the distribution of intensities, with the least delay to be communicated to IHA.

-- The follow-up periodic reports, such as PERDISREP 2, 3 and 4 are intended to convey to ONEMI new information and updated revisions of information including cumulative casualty and damage estimates by communes (districts), provinces, regions and the country situation which reflects the preliminary interpretation and conclusions of ONEMI as to extent of the disaster situation with the least delay.

4. Special Reports

A. Field Team Reports

Immediately following the receipt of the initial PERDISREP, Province-Region Disaster Field Teams may be dispatched to survey and assess the situation and submit "field team reports" to ONEMI. These reports basically convey estimates of casualties, displaced persons and damage to prop rty, both public and private. They do not need prescribed format except to include identification as a "Field Team Report", the sender and a date-time group. Snapshots, sketches, maps and aerial photos may be included. These reports are intended to rapidly convey essential information from the field to ONEMI for evaluation and consolidation into an assessment of the situation for the Ministry of Interior with the least possible delay.

B. Damage Assessment

The Director of ONEMI is responsible for preparing with the least delay following the occurrence of a tsunami a composite report of damage assessment. It accompanies the Director's estimate of the situation with recommendations to the Ministry of Interior. This Damage Assessment is required to accompany the request an Intendant may take for a Presidential declaration of a major disaster.

C. Damage Survey Reports

They are prepared by Province and Regional Specialists and should describe specific damage, scope and cost of repairments if possible.

D. Special-purpose Reports

It is required that all organizations and agencies participating in a disaster situation to exchange timely information. Further, they must keep the Director of ONEMI informed of their activities as necessary to achieve effective coordination and cooperation on a continuing basis. Disaster preparedness training exercises are to be included in this reporting requirement together with other significant information acquired when not confronted with actual disaster situations.

E. After-action Reports

Following a tsunami threat and after warning cancellation by IHA, Intendants, Governors and Mayors will submit to ONEMI written account based upon tsunami log entries, incoming and outgoing reports, observations and experiences. They may be used as a basis for postdisaster critiques and evaluations conducted by the National Tsunami Warning System and for revising internal disaster plans, procedures and checklists.

5. Procedures

A. Channels

-- Disaster information is reported from the scene to the City Mayor or Provincial Governor

by the fastest means available. From the Office of the Governor reports are channeled to the Intendant of the Region who in turn send integral reports to ONEMI.

-- Reporting channels and procedures that are specific to particular emergency functions (evacuation, debris clearance) or situations (radiological accidents, marine oil spills) are outside the scope of this operating plan.

-- Keeping the news media, and in turn the public, informed of the situation is set forth in Chapter III - Tsunami Evacuation Procedures.

B. Coordination

-- Communication and prompt exchange of information on a continuing basis between the Regional and National Operations Centers is essential to mission accomplishment and avoidance of conflicting reports being generated and causing confusion, for example, upon reaching a regional headquarters.

-- Coordination and exchange of inter-agency information can be accomplished by exchange of liaison personnel.

C. Content

a. Information will be reported as briefly as is consistent with clarity and completeness.

b. Proliferation of reporting requirements and kinds of reports will be avoided to minimize administrative and communications workloads within agencies.

c. Guidelines for determining and indicating reliability of information in repoting follow:-

-- "Factual": based upon fact confirmed by identifiable and competent authority or source.

-- "Estimate": based on a rough or approximate calculation resulting from a reasoned opinion or judgment.

-- "Unconfirmed": based on information from questionable sources for which no confirmation has been received.

D. Termination

When the Director of ONEMI determines thar information being reported is no longer essential to effective direction and control of the disaster situation, The Director will cause such reports to be terminated.

6. Sample formats of PERDISREP

A. PERDISREP NUMBER 1

EARTHQUAKE REPORT

At.....hrs of.....198.., ONEMI received through.....the first report of an earthquake at.....area.

At..... hrs Yellow Alert was given (Intern) (Extern)

At..... hrs Red Alert was given (Intern) (Extern)

Technical Report from Dept. of Gelogy and Geophysics

Epicenter: Latitude Longitude Origin time

Magnitude: Richter Scale Depth

Intensities: Write them down under respective column of the Agency giving the intensity information.

Report sent to..... at.....hrs

.....
Chief on Duty

B. PERDISREP NUMBER 2

PROVINCIAL SITUATION STATEMENT

REPORT Nº
DATE

REGION / PROVINCE / COMMUNE	AFFECTED PEOPLE												HOMES		AREAS WITHOUT													
	People			In shelter				out of shelter																				
	DEADS	INJURED	DISAPPEARED	FAMILIES	ADULTS	MINORS	SUB TOTAL PEOPLE	FAMILIES	ADULTS	MINORS	SUB TOTAL PEOPLE	TOTAL AFFECTED PEOPLE	DESTROYED	DAMAGED	DRINKABLE WATER	ELECTRIC POWER	GAS	SEWAGE	TELEPHONE	TELEGRAPH	FLOODED ROADS	DESTROYED BRIDGES	DESTR. RAILWAYS	ISOLATED LOCALITIES	DESTROYED PUBLIC BUILDINGS	DAMAGED PUBLIC BUILDINGS	AFFECTED DAMS	SHIPWRECKS
TOTALS																												

C. OTHER PERDISREP

PERDISREP NUMBERS 3 and 4 have the same format as PERDISREP NUMBER 2 but showing the Regional and National Situation respectively

V. REFERENCES

-- INSTRUCCIONES GENERALES SOBRE EL SISTEMA NACIONAL DE ALARMA DE MAREMOTOS.
Publicación I.H.A. Nº 3.014 2da. Edición (In press)

-- HAWAII REGIONAL TSUNAMI WARNING NETWORK - A COMPREHENSIVE REVIEW.
NOAA/NWS Pacific Region Headquarters, 1979

-- STATE OF HAWAII DISASTER INSTRUCTIONS AND WARNING PROCEDURES.
Civil Defense Division, Department of Defense , January 1984

-- MITIGATION OF TSUNAMI HAZARDS IN THE PACIFIC-PROPOSAL FOR THE PREPARATION OF A STANDARD TSUNAMI EMERGENCY OPERATIONS PLAN FOR CHILE.
International Tsunami Information Center, Feb. 1983.

ANNEX 2

TSUNAMI HAZARD ANALYSIS

1. PURPOSE

To determine the general extent of the tsunami threat in a coastal area. Model will provide information to delineate areas of most severe threat due to tsunamis generated in specific regions and will locate high-risk areas for flooding.

2. CAUSES OF TSUNAMIS

Tsunamis are caused by large earthquakes centered under or near the ocean, by the net vertical displacement of the underwater fault that drops part of the sea floor rapidly. The water surface above also drops generating a series of sea waves.

These displacements of the sea floor can also be produced by volcanic eruptions and submarines avalanches along the slopes of Pacific trenches, events which have been linked to tsunami generation.

But the tsunami-generating process is more complicated than a sudden push against the column of ocean water. The earthquake's magnitude and depth, water depth in the region of tsunami generation, the amount of vertical motion, and the efficiency with which energy is transferred from the earth's crust to ocean water are all part of the tsunami birth equation. Besides, not much is known about the relationship between ocean floor configuration and the shape taken by tsunamis there. It is not completely clear, for instance, why a tsunami wave may be of negligible size at one point along the coast, and much larger at other coastal points nearby. Tsunami run-up, the vertical distance between the maximun height reached by the water on the shore and the mean-sea-level surface, is also impossible to predict at the present time. Nor it is possible to predict whether the destructive component of a tsunami will lie in its powerful surge across a beach, or in a gradual rising of sea level followed by a rapid draining back to sea.

The key known characteristics of tsunamis is that their spped varies with the square root of water depth. It is this relationship which permits prediction of tsunami arrival times at all points in the Pacific Ocean area.

All submarine earthquakes do not produce tsunamis, and all tsunamis are not large enough to cause damage. However, tsunamis have caused the most devastating disasters in the country. Although an earthquake anywhere in the Pacific may generate a tsunami that could seriously threaten any shore in Chile, a locally generated tsunami poses the greater threat because it can strike in a matter of minutes.

REAL - TIME

Data Collection
Data Analysis
Data Dissemination

THRUST
THIRD ANNUAL REPORT

Data Collection

Principal Investigator:

Hugh Milburn
Pacific Marine Environmental Laboratory
Seattle, WA
USA

THRUST

Third Annual Report

Real Time Data Collection

During the third year of the THRUST project, PMEL's Engineering Development Division has coordinated the assemble and testing of all the instrumentation. The final phase was the installation of the equipment in Chile.

In October '85, PMEL began to assemble instruments in the following configuration (figure 1):

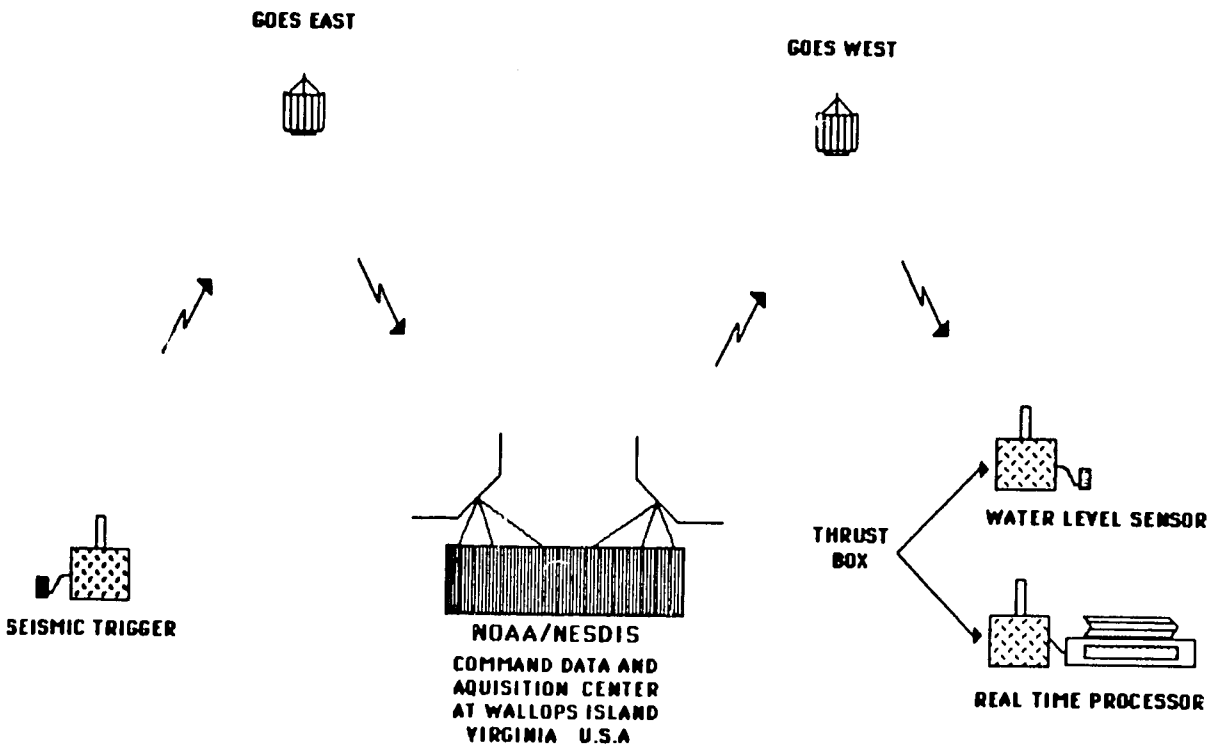
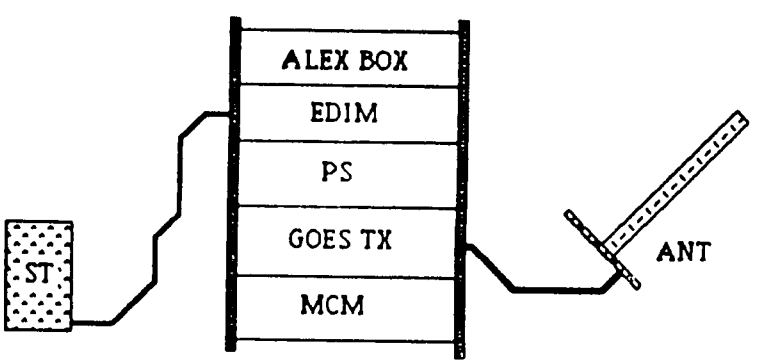


figure 1

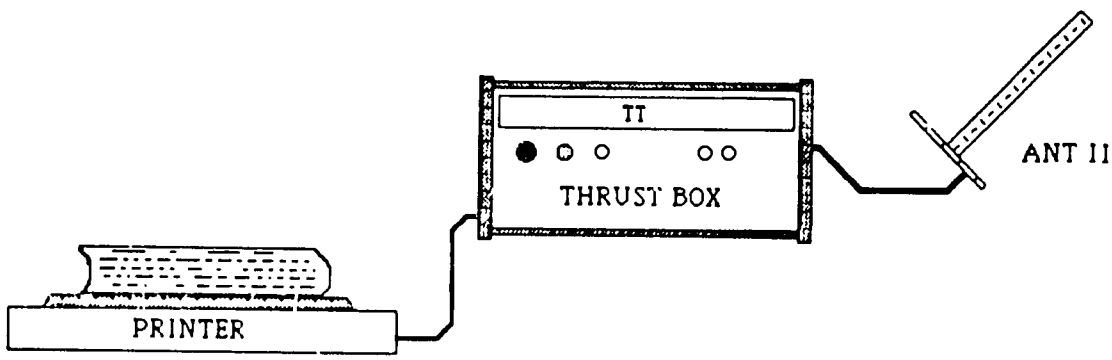
The event that would initiate the entire THRUST system is an earthquake. That vertical ground motion would activate the seismic trigger. Two seismic trigger systems are installed in Chile (see figure 2), one being at the University of Chile in Santiago and the other being located at IHA in Valparaiso. When the ground motions triggers the pre-set threshold (Santiago @ 0.143g and Valparaiso @ 0.126g), it initiates the transmission of the seismic trigger address to the Command Data And Aquisition Station (CDA) via the GOES East satellite. CDA processes the address and automatically transmits the alert address to the Real Time Processor (RTP) and Water Level Sensor via the GOES West satellite.



ST = Kinemetrics VS-1 Vertical Seismic Trigger
MCM = Synergetics Master Control Module 3401-A
GOES TX = Synergetics GOES Transmitter 3421A
PS = Synergetics Power Supply 3489A
EDIM = Synergetics End Device Interface Module 3451A
ANT = Synergetics Cross Yagi Antenna 18A
ALEX BOX = PMEL designed interface box

figure 2

When an alert or test address is transmitted by the satellite to the RTP, the signal is picked up by the antenna, amplified, then down converted, and passed to the True Time receiver (see figure 3). The receiver demodulates the signal and converts it to a serial bit stream. The computer decodes the address and compares it to an alert and test address stored in it's memory. If the address matches the alert address, the computer prints an alert message stored in its memory and outputs a pulse to alarm interface which turns on a audible and visual alarm. If the address matches the test address, the computer only prints the test message. If no match is found, the computer ignores the received address.



PRINTER = Epson RX-8 Printer
TT = Kinemetrics True Time Receiver 468-DC
ANT II = Kinemetrics Helix Antenna A-468HX
THRUST BOX = Commodore 64 Personnel Computer
Power Supply
Alarm Interface
Inverter

figure 3

The uninterruptible power supply for the system is shown in figure 4. The battery charger uses the constant voltage technique to keep the batteries fully charged and to supply the current to the inverter. The inverter converts the DC current to 110 VAC, 60 Hz, which powers the True Time receiver, computer, printer, and 12VDC power supply. If the AC line power goes out, the current is furnished by the batteries. The batteries have enough energy to sustain the system for approximately four hours.

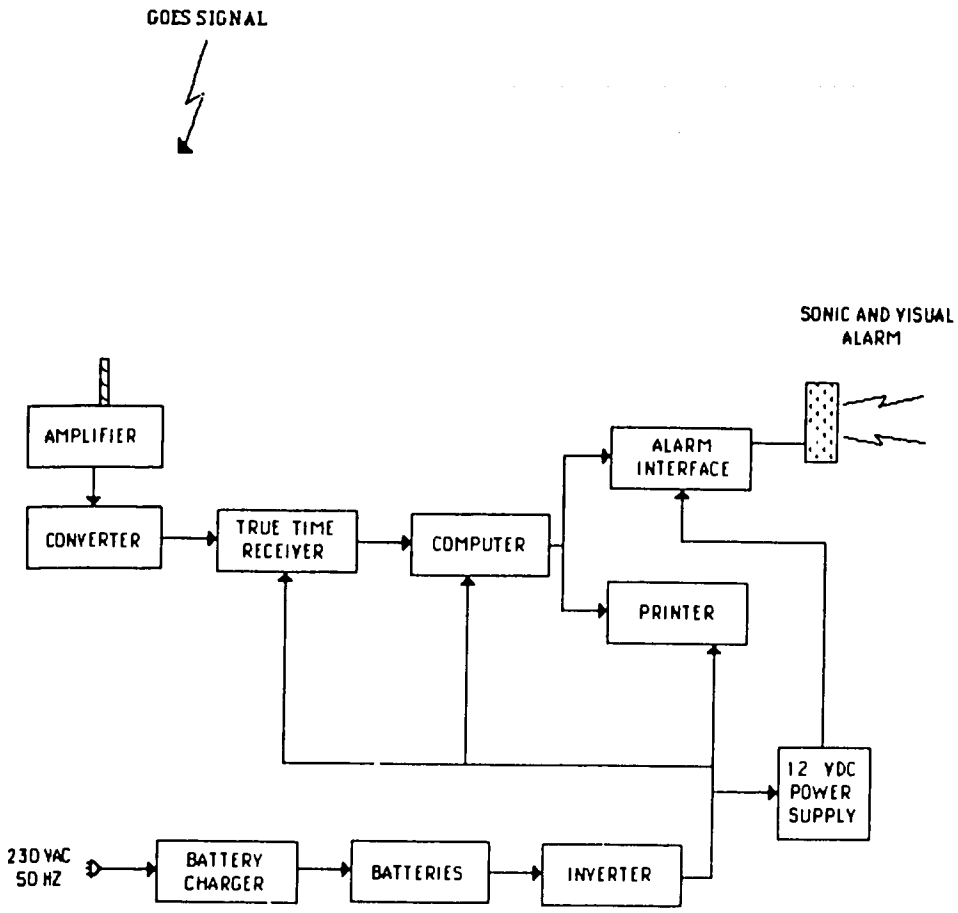
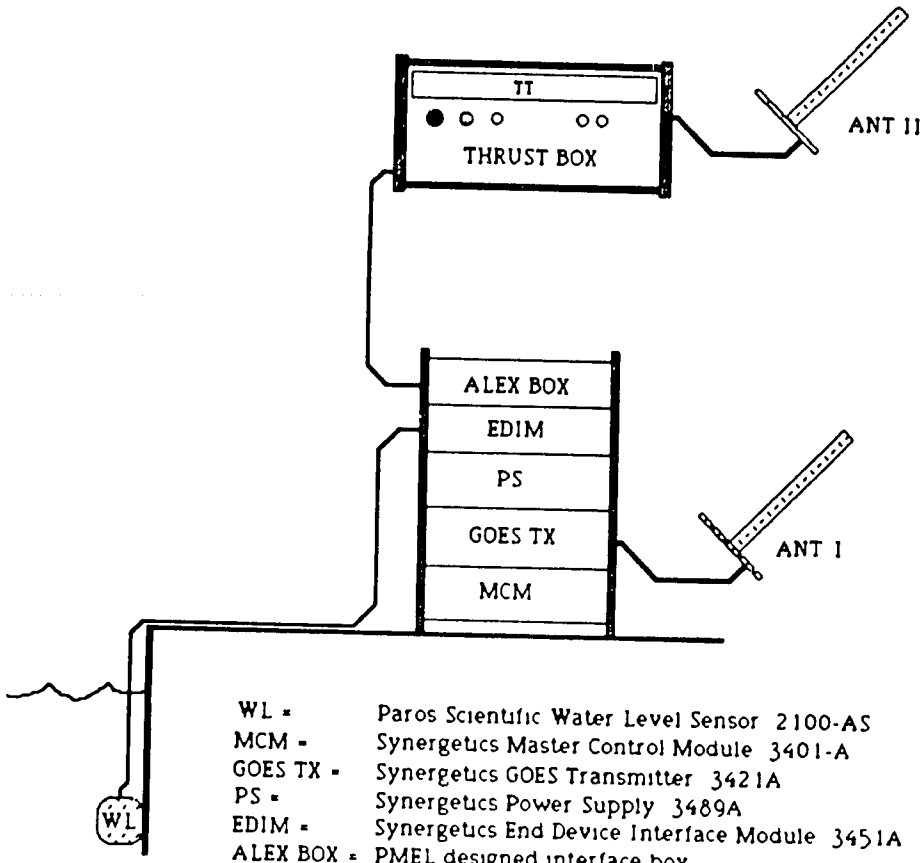


figure 4

The same alert address that initiates the RTP to print its message inititates the water level sensor to begin its Tsunami Detection Mode (TDM) of sampling. The THRUST water water level measurement system consists of the instruments shown in figure 5. Two of these complete systems are installed on the Valparaiso harbor breakwater, with the sensors secured to the seaward side of the wall and the electronics located in the lighthouse.



WL = Paros Scientific Water Level Sensor 2100-AS
MCM = Synergetics Master Control Module 3401-A
GOES TX = Synergetics GOES Transmitter 3421A
PS = Synergetics Power Supply 3489A
EDIM = Synergetics End Device Interface Module 3451A
ALEX BOX = PMEL designed interface box
TT = Kinemetrics True Time Receiver 468-DC
ANT I = Synergetics Cross Yagi Antenna 18A
ANT II = Kinemetrics Helix Antenna A-468HX
THRUST BOX = Commodore 64 Personnel Computer
Power Supply
Alarm Interface
Inverter

figure 5

The gauges, in their normal mode, operate similarly to NOS tide gauges. Data is sampled every minute and averaged over 15 minutes periods and transmitted every four on a self-timed channel on the GOES satellite. The 15 minute averaging periods for one gauge end at 0011 minutes (and at consecutive minute intervals) and the four hour periods end at 0057 (and at consecutive 4 hour intervals). Times for the other gauge are one minute later.

When an address is received on the 468 mhz downlink that indicates a tsunami may be imminent, the THRUST box will command the DCP to go into the TDM. This will cause the DCP to change from a self-timed channel to a random channel, which will have it send back one minute average data in blocks of 20 data points at random intervals which will vary between 2 and 20 minutes, but will average 10 minutes. This mode will be continued for 6 intervals. This will produce one minute data that will have been collected nominally 10 minutes prior to the first alert and continue for 50 minutes after the last alert.

Sensor data accuracy should be + or - 1 cm/year. The sensors are encased in PVC housings and connected with double armored, plastic jacketed three conducter cable with heavy polyethylene jacket that has proven to be very durable. The housing and cable were bolted into the concrete breakwater by divers with stainless steel clamps and expansion sheilds

This entire system has been installed in Chile since the begining of June '86. This system will be monitored by NESDIS and PMEL for a one year test period. Daily tests of the seismic triggers and water level data is obtained by PMEL on a daily basis. These data are inspected each day for failures and maintanence checks of the instruments.

Data Analysis

Principal Investigator:

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McLean, VA
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2. REAL-TIME PROCESSOR SUPPORT

One of the key elements of the THRUST system is the so-called Real-Time Processor (RTP). This microcomputer-based system responds to the triggering signal instigated by strong-motion instruments located in the Valparaiso-Santiago area of Chile. It automatically issues a warning notice to Chilean Tsunami Warning System personnel.

The original concept for the RTP called for a fairly sophisticated system which would determine the approximate location of the source motion, examine data tables of observed and simulated tsunamis arising in the vicinity of the source, calculate likely wave travel times to Chilean coastal cities, and convey the travel-time estimates to Chilean authorities. In discussions with Emilio Lorca (of the Chilean Navy Hydrographic Institute), it became apparent early in the contract that such an elaborate system was neither necessary or desirable. Discussions with Hugh Milburn (PMEL) and Peter McManamon (Cyberlink, Inc.) about the design of the RTP indicated that the microprocessor system would be less sophisticated than originally envisioned, also. The final design of the RTP system calls for warning messages to contain a fixed set of travel times which could apply to tsunamis generated in the general vicinity of Valparaiso.

Three available sources of travel-time estimates were used to develop representative values:

1) NOAA travel-time charts for Valparaiso
2) NOAA travel-time charts for other Chilean cities
3) Observed travel times of the 3 March 1985 tsunami originating southwest of Valparaiso.

It became apparent, as Table 1 shows, that agreement among the three sources is poor. This is probably due to the lack of historical data to assist in calibrating the NOAA charts.

Table 1

Travel Times Between a Tsunami Source at Valparaiso and Selected Chilean Cities

City	Valparaiso Chart	City Chart	1985 Tsunami
Valparaiso	2-3 minutes		3
Coquimbo	40		48
Caldera	60		63
Talcahuano	50	80	77
Chañaral	75		
Corral	80		
Antofagasta	90	120	85
Isla De Chiloé (Ancud)	100		
Tocopilla	100		
Iquique	120		127
Arica	130	180	157

Final values provided to Cyberlink (Appendix A) were weighted toward the observational data if a major difference between travel-time charts and observations occurred. If the travel-time chart value is less than observed, but within a reasonable (subjectively defined) value, that estimate was favored, on the assumption that over-estimates could lead to needless risk for exposed populations. Table 2 lists the values provided for use in the RTP system. Note that the value for Corral is slightly higher than the Valparaiso chart suggests. This occurs because the 1985 data implies that waves would take somewhat longer to reach a southern location than the charts predict.

Table 2
Travel-Time Estimates for Use in the RTP

City	Travel Time	Sources
Valparaiso	0-3 minutes	V
Coquimbo	40	V
Caldera	60	V
Talcahuano	75	L+T
Chañaral	75	V
Corral	85	V+T
Antofagasta	85	T
Isla De Chiloé (Ancud)	100	V
Tocopilla	100	V
Iquique	120	V
Arica	140	V+T

Sources: V = Valparaiso Travel-time Chart
L = Local Travel-time Chart
T = 1985 Tsunami

Data Dissemination

Principal Investigator:

Hugh Milburn
Pacific Marine Environmental Laboratory
Seattle, WA
USA

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CyberLink Corp
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USA

NESDIS Interrogation Channel Operation

The warning messages received from the seismometers via the random reporting channel will be treated by the NESDIS computer as emergency messages. The warning messages will be placed into the transmission buffers ahead of any routine interrogation messages to be sent. At the present time, the PDF instructions for THRUST warning messages are such that the computer will send one, and only one, interrogation message for each warning message received on the random reporting channel.

Subsequent meetings with Bill Mazur of the NESDIS System Engineering Office identified the details of the interrogation channel buffer. The first 60 address buffer is at the World Weather Building computer (CDDF) at Suitland, MD. Messages are placed into this buffer and are transferred as a group of 60 messages every 30 seconds to an interrogation buffer at the CDA computer at Wallops Island.

Emergency messages enter the CDDF buffer at the top (transmitted first) and routine messages enter the buffer at the bottom (transmitted last). However, the emergency messages which enter the top of the buffer are transmitted using a LIFO (last in first out) logic sequence. Hence, the CDDF buffer results in a random delay between 0 and 30 seconds and the emergency messages are rearranged in time sequence according to the LIFO logic sequence.

Upon file transfer to the CDA computer interrogation buffer, the warning messages are then transmitted in sequence. The CDA buffer is actually two separate buffers, each holding 60 messages. One buffer is used to receive the buffer file transfer from the CDDF computer (9600 bits/second) while the other buffer is used to transmit on the interrogation channel (100 bits/second). The transmission rate on the satellite channel is 2 addresses (messages) per second. Hence, a 0 to 30-second delay is to be expected at the CDA computer.

The combined delay between the buffers at the CDA and CDDF computers will then be random within the range from nominally 0 to 60 seconds.

Another delay will result because of additional NESDIS procedures. Once the interrogation message is sent, the message is removed from the interrogation activity table at the CDA computer. This table is scanned every two minutes and the contents are sent back to the CDDF computer. The NESDIS software and the dispatcher will not allow a second interrogation message to be sent until the activity table is sent back to the CDDF computer and the activity table shows that the first interrogation message was sent. This procedure is used by NESDIS to prevent interrogation to be sent out of order. As a result, an added delay of 0 to 120 seconds can be experienced, depending on the exact time that the activity scan is completed relative to the time that the interrogation message was sent. Subsequent discussions with P. Otero of NESDIS confirmed that the aforementioned procedures are currently operational.

The aforementioned procedure has a more important impact, however. The seismometer platform will be programmed to send an alert message (operational or test) within 15 seconds of the threshold crossing trigger (or test signal). If all the above delays are added up, the first interrogation warning message would be sent between 0 to 195 seconds after the trigger. The first repetition of the warning message will arrive at the CDA station between 60 to 90 seconds after the trigger, the second repetition will arrive at the CDA station between 120 to 165 seconds after the trigger, and the third repetition will arrive at the CDA station between 180 to 240 seconds after the trigger. If the repetitions arrive before the activity table is cleared, the repeated interrogation messages will be dropped and will not enter the buffer for transmission. As a result, the number of interrogation warning messages that would be sent if all four uplink random reporting channels were correctly received would vary between 4 and 16 and would be left to chance.

This procedure has been checked with Pat Otero at NESDIS and verified. Since the above procedure is in fact in use, then it will be necessary to request at least four interrogation channel warning messages for each uplink alert message. This would assure that four interrogation channel warning messages would be sent if at least one uplink alert message was received. The maximum number of interrogation channel warning messages which would be sent for one trigger or test event would be sixteen.