NOAA TECHNICAL MEMORANDUM NWS AR-38

THE ALASKA TSUNAMI WARNING CENTER

Thomas J. Sokolowski
Alaska Tsunami Warning Center
Palmer, Alaska

National Weather Service, Regional Headquarters
Anchorage, Alaska
March 1990

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National Weather Service Alaska Region
Environmental and Scientific Services Division
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The Alaska Tsunami Warning Center

Thomas J. Sokolowski

ABSTRACT. The Alaska Tsunami Warning Center (ATWC) has implemented many major changes in order to provide timely and effective tsunami warning services for coastal populations in Alaska, and the west coasts of Canada and the lower 48 States. The basis for these improvements was the integration of computers and associated developments into the ATWC's operations. New concepts, technique developments, procedures, computers, and equipment were implemented which resulted in a highly automated tsunami warning system which analyzes data from potential tsunamigenic earthquakes in real-time, and immediately disseminates necessary critical information to affected coastal populations. These advancements are leading toward an automated expert system. The present system has been exercised for seven recent potential tsunamigenic earthquakes and has proven to be very timely with tsunami warnings being issued in an average of 11 minutes after the origin time of an earthquake.

Seismic and tide data networks have been enlarged to improve the accuracy and timeliness in locating and sizing earthquakes, and for confirming the existence of a tsunami. New techniques and equipment are being implemented to collect, analyze and process tide data via micro computers. In-house and cooperative efforts in tsunami modeling, tide height determinations during expected time of arrivals of tsunamis at different locations, and impact areas will be valuable input for future applications in an expert system.

All critical warning and watch information messages are generated by computers which are linked to a satellite and high speed teletypewriter communication systems for rapid dissemination of information. The ATWC's community preparedness efforts have been expanded to aid those individuals who may be caught in the immediate vicinity of a violent earthquake and its subsequent tsunami.

1. Introduction

The Alaska Tsunami Warning System was established in Palmer, Alaska in 1967 as a result of the great earthquake that occurred in the Prince William Sound area on March 27, 1964. This earthquake alerted State and Federal officials to the need for a facility to provide timely and effective earthquake and tsunami information for Alaska and the northern Pacific. The city of Palmer, located 40 miles north of Anchorage, was selected as the site for a primary Center. Two other Centers, located at Sitka and Adak, were incorporated into the system. After an extensive real-time data telemetry network was established, the ATWC became operational using manual methods to fulfill its missions.

Initially, the tsunami watch and warning responsibility for Alaska was shared by the three Centers located at Adak, Sitka and Palmer. In later years, the responsibility to provide all tsunami warning services for Alaska was transferred to the Palmer Center. In 1973, the ATWC was transferred to the National Weather Service's Alaska Region. In 1982, ATWC's responsibility was enlarged to

include the coastal areas of British Columbia in Canada, and the U.S. west coast. This additional responsibility made the ATWC the largest regional tsunami warning center in the Pacific Basin, covering more than 4300 linear miles of coast line in Alaska, Canada, Washington, Oregon, and California.

To improve the ATWC's tsunami warning services, it became necessary to integrate computers into the ATWC operations and to design an expert automated system. In general, an expert system in the tsunami warning system is one which can rapidly determine a potential tsunami threat from a source region for immediate use by intended recipients. Further, for a warning system to be effective, it must address at least the following three main parts: obtain data; analyze the data; and disseminate data/information to intended recipients. If one part fails, the warning system has failed. The initial areas that were identified for improvement concerned: (1) automatic detection and analysis of seismic data in real-time; (2) immediate dissemination of critical earthquake and tsunami information; (3) automatic detection and analysis of tidal data in real-time or near real-time; (4) rapid discrimination of tsunamigenic from non-tsunamigenic earthquakes; and (5) reasonable estimates of probable tsunami wave heights and areas of inundation in the path of a tsunami.

Since regional tsunami warnings are based upon seismic data alone, (1) and (2) became primary concurrent goals. Previous computer concepts by Sokolowski and Miller (1967), Sokolowski (1974), and Sokolowski (1978) began to be implemented at the ATWC. During the early 1980's, many operational changes began to replace the highly dependent manual methods with more sophisticated ones which used a mini computer to automatically collect seismic data to determine an earthquake's location and magnitude in real-time, and to immediately disseminate critical earthquake and tsunami information (Sokolowski et al., 1983). To further improve the ATWC, the mini computer system concept was replaced with a distributed micro computer concept by Sokolowski (1985). During the remainder 1980's, the ATWC continued to become highly automated (Sokolowski et al., 1989) with warnings issued in an average time of 11 minutes from an earthquake's origin time. These new approaches reduced the time to issue a warning by more than 50%. Also, they standardized procedures and increased the quality and quantity of data processed and information disseminated. During the latter part of 1989, the communication part of the system was enhanced with the installation of a satellite communication system for immediate dissemination of critical information to the Tsunami Warning System (TWS) recipients. It became operational in February, 1990, for the dissemination of watches and warnings to the ATWC's areas of responsibilty. This paper discusses some of the operational areas in the Alaska Tsunami Warning Center in more detail, and proposes future areas selected for development and enhancements.

2. Missions

The primary mission of the Alaska Tsunami Warning Center is to provide timely tsunami watches and warnings for Alaska, California, Oregon, Washington, and British Columbia in Canada, for potentially tsunamigenic earthquakes that occur in those regions. For non-tsunamigenic earthquakes, or earthquakes outside of the ATWC's areas of responsibility, earthquake parameters and other associated information are appropriately disseminated to: Alaska Division of Emergency Services; Alaska Air Command; National Earthquake Information Center in Colorado (NEIC); PTWC in Hawaii; USGS-Menlo Park Research Center in California; University of Alaska's Geophysical Institute in Fairbanks; Japan Meteorological Agency, Tokyo; Royal Observatory, Hong Kong; agencies in Canada; news media; and to many other recipients including both State and Federal disaster preparedness agencies. Although numerous non-tsunamigenic earthquakes are automatically detected and processed each month, only a small number of these earthquakes are released to officials and the public.

This service is provided on a 24 hour basis, for each day of the year, by two duty personnel. During those times that the Center is not manned, the duty personnel are in a paid standby duty status which requires that they respond to the Center within 5 minutes after being alerted that a significant earthquake has occurred. To ensure a rapid response to earthquakes occurring at night, weekends, or holidays, all personnel are required to live within 5 minutes travel time to the Center. They are notified of the occurrence of an earthquake, or irregularities in the Center's operations, by a sophisticated radio-alarm system which is linked to a computer system.

In addition to the above missions, the ATWC personnel: process and disseminate collected data; participate in fulfilling interagency cooperative agreements; create and implement software; and, conduct technique and equipment development to improve the present system. These improvements involve both the reactive and predictive areas of the ATWC's operational system. The reactive part concerns minimizing the response time between the occurrence of a tsunamigenic earthquake and the issuance of a tsunami warning to people in coastal areas. Specifically, this part seeks improvements in: computer applications, communications; present techniques and development of advanced ones; equipment and instruments; software development and/or modifications; community preparedness; and, operational procedures. The predictive part involves both in-house and cooperative work efforts with other experts and/or agencies concerning areas, such as, tsunamigenic earthquakes and zones, source mechanisms, and tsunami formation, propagation, run-up, and interaction with coastal shores.

The ATWC has both formal and informal cooperative agreements with many agencies and institutions. The agreements concern telemetry of seismic and tide data; seismic and tide site installations; cooperative technique and equipment developments; communications; equipment maintenance; and the exchange and analysis of data. Some of these agreements involve daily collecting, processing, and

archiving data for appropriate agencies. Additionally, past recorded data from the ATWC network are archived at the ATWC and made available to visiting scientists to assist them in their work projects.

3. Seismic and Tide Networks

The ATWC is a large geophysical data acquisition Center which has access to data from 4 networks owned and maintained by the ATWC, U.S. Geological Survey at Menlo Park (USGS-Menlo), National Earthquake Information Center (NEIC), and the University of Alaska at Fairbanks. Figure 1 shows the geographical locations of only those stations whose data are being processed by a computer. From time to time, data from different seismic stations in the networks are used to ensure a continuous flow of quality data to the ATWC.

The ATWC's network consists of 16 seismic sites located at remote places throughout Alaska ranging from the far western Aleutians to Sitka, Alaska. The data are telemetered in real-time by satellite and microwave with very little interruption of data flow from the remote sites. The data are archived on various types of recorders, computer disks and magnetic tapes. In addition to the 16 short period seismometers, long period seismometers are collocated at Shemya, Adak, Sand Point, Sitka, and Palmer sites. Through an interagency agreement with NEIC, the ATWC telemeters 14 channels of data to the NEIC in Golden, Colorado. In return, the ATWC receives 14 channels of real-time seismic data telemetered from NEIC's network from California to the east coast of the U.S. The ATWC also records real-time short period data from networks operated by the USGS-Menlo and the University of Alaska. Long period data are also telemetered to the ATWC via NEIC from a PTWC seismic site in Hawaii. From this accumulation of data, 23 short period and 9 long period sites' data are routed into the ATWC's computer for real-time processing to determine earthquake parameters, and for immediate information dissemination to the appropriate disaster agencies and other hazard Centers.

The ATWC has access to data from more than 15 tide sites that are owned and maintained by NOAA's National Ocean Survey (NOS) and Canada. Figure 2 shows tide site locations near the coastal areas of Alaska and the west coasts of Canada and the lower 48 States. Through a cooperative agreement with the NOS, the ATWC has transmitters at each of the 8 NOS sites in Alaska for telemetering data to the Center in real-time. The data are transmitted via satellite for immediate confirmation of the existence or nonexistence of a tsunami. Tide data are obtained from the west coast of the U.S. and Canada via teletypewriter, telephone, and micro computer. All U.S. tide sites are owned and operated by the NOS, except for Shemya which is maintained and operated by the ATWC. The ATWC continues to access near real-time data from the NOS's water level telemetry systems (WLTS/WLMS) which are located along the U.S. west coast. This access uses computer-to-computer linking for transmitting selected windows of time periods of tide/tsunami data to an ATWC micro computer for analysis.

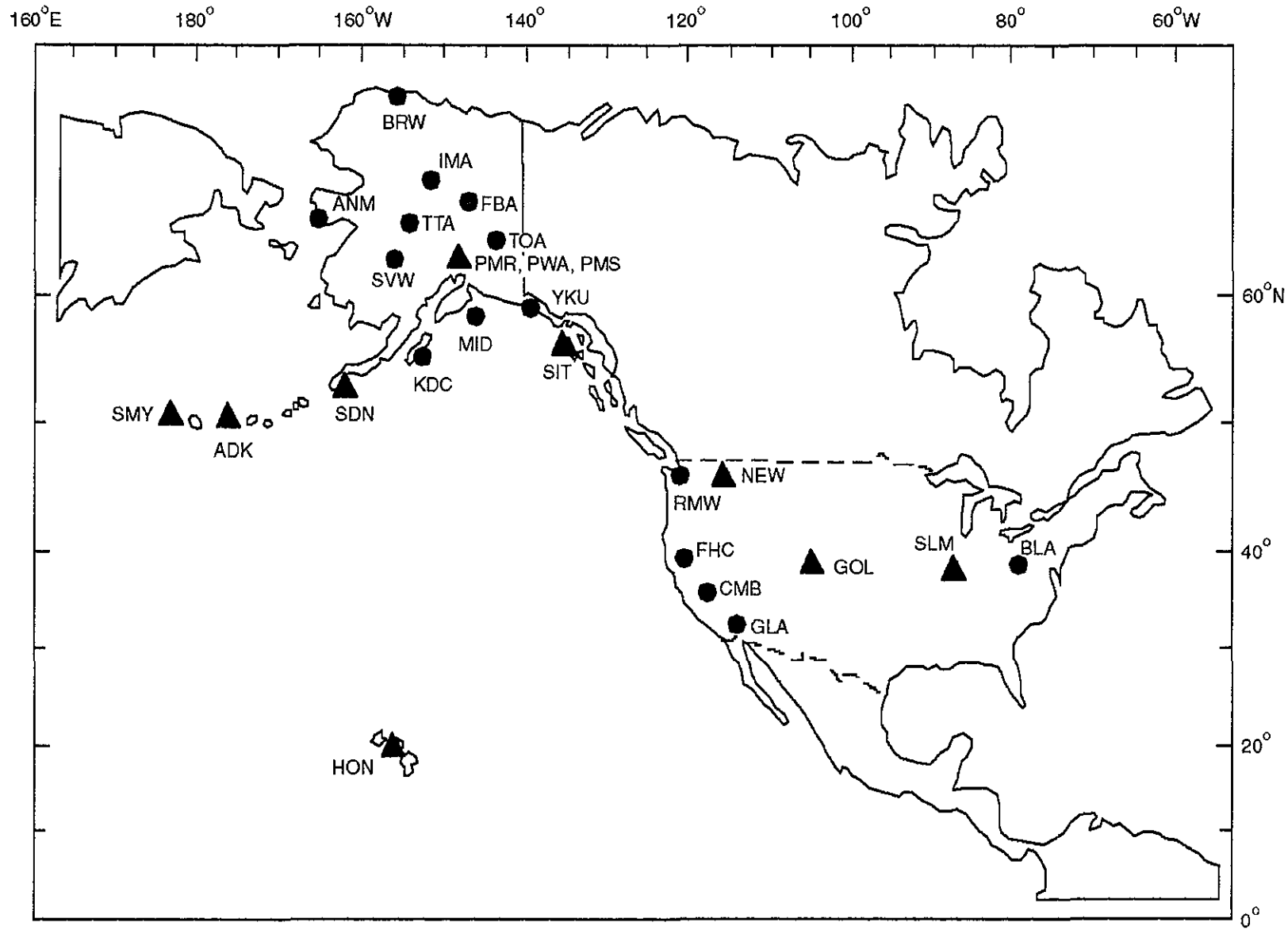

Fig. 1. Map showing seismic site locations that telemeter data to the ATWC in real-time for processing by a computer. The filled circles show the short period seismic sites. The triangles show sites that have collocated short and long period instruments.

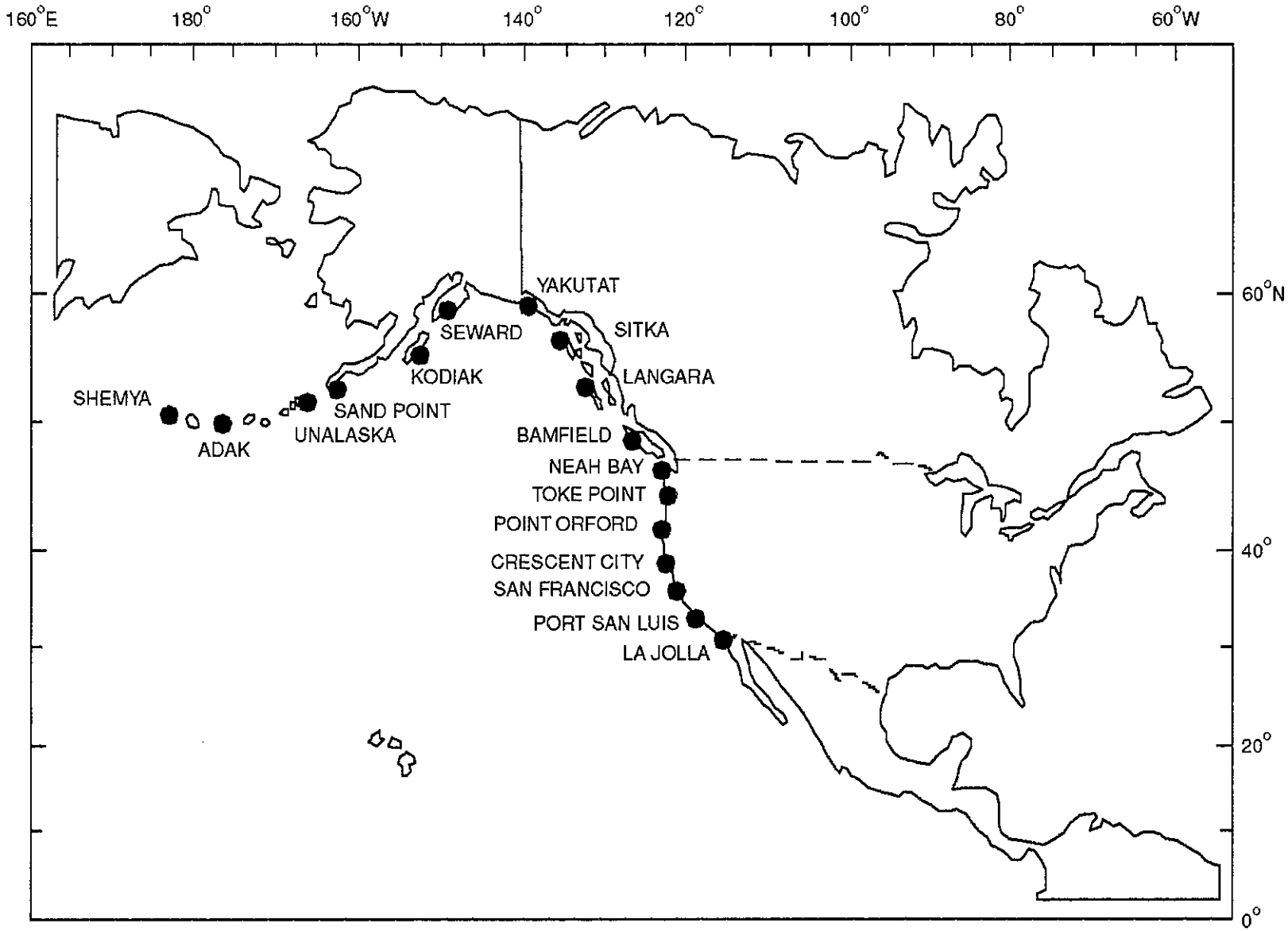

Fig. 2. Map showing the tide site locations near the coastal areas of Alaska, and the west coasts of Canada and the lower 48 States.

4. Preventative Maintenance and Equipment

Equipment maintenance, additions, calibrations, and replacements are critical on-going functions at the ATWC's field sites and the Center. All field sites are visited by ATWC personnel each year, or as soon as possible after equipment failure. These visitations include the seismic network throughout Alaska, Shemya tide site, and ATWC's transmitters at each of the NOS tide sites in Alaska. All of the ATWC's seismometers have automatic sine wave calibrations which are transmitted along with the seismic data so that the computer can automatically monitor and update an instrument's sensitivity. This occurs twice daily for each of the short period seismometers. The calibrations of the long period instruments are checked interactively every week. Tide site visitations are coordinated with the NOS field personnel to minimize cost and maximize aid to each other. At the Center, the incoming seismic and tide data are recorded on multiple gain helicorders, tide recorders, and in micro computer systems. The equipment and systems are monitored daily by personnel and by other electronic equipment, to ensure a continuous data flow to the Center. This preventative program has resulted in very little down time and a continuous flow of high quality data to the Center.

To keep abreast of changes in new equipment and electronics, the ATWC receives many catalogs, brochures, and specifications of new equipment and hardware which are continually researched for improving existing equipment. As funding becomes available, the equipment is enhanced or replaced. In some instances, new equipment is loaned to the ATWC for testing, prior to procurement, to ensure compatibility with existing equipment and computer systems.

5. Radio-Alarm System

The Center's standby duty is a critical element of the ATWC's operations where an immediate response is required of the personnel when the office is not manned, e.g. during evenings, nights, weekends, and holidays. The standby duty personnel are alerted to large earthquakes, or equipment failure, by a sophisticated radio-alarm system (RAS) which is interfaced to the Center's computer system. This state-of-the-art RAS system replaces the previous RAS system described by Sokolowski (1985). The new system permits local, regional, or world wide earthquake information to be immediately transmitted to, and received by, the standby duty personnel to let them know the urgency of the situation, or whether it is a false alarm, telephone call, or equipment malfunction. The RAS system consists of a transmitter, a radio-alarm alphanumeric pager unit with an associated printer (RU), and computer interfacing equipment. The unit can fit in the palm of one's hand and has a LCD display area to view messages received from the ATWC's computer system. Hard copies of the messages are displayed on the printer. The new RAS system uses the previous RAS threshold method as a backup system.

As soon as an earthquake is automatically located and sized by the ATWC's computer system, the computer transmits selected earthquake parameters to remote alphanumeric pagers which are carried by standby duty personnel. A short 80 character message, which contains a literal location, latitude, longitude, magnitude, origin time, average residual, and azimuthal control, is telemetered to RU's pager units and printers. This provides the duty personnel with immediate knowledge of an earthquake's parameters, thus the urgency of the situation. The RU receives other messages from the computer concerning other equipment that is being monitored by the computer, or which alarm was activated. With a push of a button, the standby duty personnel can immediately view an earthquake's parameters which are displayed on the unit's LCD. A beeper tone is activated in the RU as each message is received and stored by the RU unit. The unit can store 16 messages for about a total of 1300 characters which can be scrolled, reviewed, and deleted.

6. Automatic Processing System

Since the early 1980's, the ATWC has been processing earthquakes automatically and interactively using a mini computer system, graphics subsystem, and related peripherals (Sokolowski et. al., 1983). Due to the advances in micro computer hardware and software, the mini computer system was replaced with a Digital Equipment Corporation (DEC) Micro VaxII computer system (Sokolowski et al., 1989). Although the present automatic earthquake processing system is more enhanced than the previous system, many of the key elements were converted by ATWC personnel to the DEC system. The enhancements concentrated on those elements that would improve the ATWC's performance in its missions. A summary of the automatic and interactive processes are given below.

For the automatic processes, thirty-two channels of real-time seismic data are continually monitored in the DEC system. Twenty-three are used for short period data (T_o=1s) and 9 for long period data (T_o=20s). Figure 1 shows the array of stations providing seismic data for processing. Each station's data are sampled at 25 samples/second, however, the long period data are later resampled at 1 sample/second. As the analog signals are sampled by the A/D cards, their data are automatically stored in memory and evaluated for the occurrence of a local, regional, or teleseismic earthquake. Once detected, the onset of the P wave times (P-picks) are determined along with periods and amplitudes of the P waves and Lg waves for appropriate mb or Ml magnitude computations (Sindorf, 1972). The P-pick algorithm used was described by Sokolowski et al., (1983). After a P-pick has been declared, 10 seconds of pre-earthquake and 10 seconds of post-earthquake wave form data are displayed on a graphics terminal for viewing. The computer determined P-pick is distinctly marked on each of the displayed traces and can easily be changed using a mouse, during or after an event. If 4 minutes have elapsed with no P-pick declared on any other channel, the wave form data that have been temporarily saved on disk are deleted. If 5 channels successively declare P-picks with time intervals between P-picks of less then 4 minutes, an earthquake is declared and the 5 P-pick times are used in a location algorithm to determine

an earthquake's parameters. This includes parameters, such as, latitude, longitude, origin time, depth, literal location, and magnitude which are listed on a printer and displayed on video display monitors (VDM's). Associated with the earthquake parameters are the seismic station names, P-pick times, distances, azimuths, residuals, etc. The depth for all automatic locations is fixed at 33km. The major parts of the location program to process earthquakes automatically (Sokolowski et al., 1983) are used in the DEC system. During output processing, incoming signals continue to be evaluated on other channels which have not declared a P-pick. After 7 P-picks have been recorded, and again after 9 P-picks, the earthquake's parameters are recomputed. Additional stations' data continue to be processed unless a user interactively stops the process, or 4 minutes have elapsed after the last P-pick. In either case, a final computation is performed which includes a full magnitude summary in addition to the parameters listed above.

If the location program yields high residuals, the P-pick data are assumed to be erroneous or associated with another earthquake. Each P-pick is successively removed from additional recomputations and the residuals retained. The recomputation with the lowest acceptable residuals is saved and printed. If the computation has unacceptable residuals and there are more than 5 P-times, 2 P-picks are removed and recomputations performed as above. Each of these computational results are available within seconds after the appropriate number of P-picks are available for computations in the location program.

Following an acceptable earthquake location, magnitudes are computed using short period amplitudes that were determined earlier. If an epicenter is within 9 degrees of the station, the Lg data are used for Ml computations; if the distance is 15 degrees or more, the P data are used for Mb computations.

Immediately after an earthquake's parameters and associated data are printed, the information is transmitted to the RAS system to provide the duty personnel with immediate knowledge of an earthquake's parameters. To facilitate operational procedures and the dissemination of critical information, several wall-mounted VDM's are used to show an earthquake's parameters, the epicenter superimposed upon an appropriate map, and specific procedures in conducting an earthquake/tsunami investigation.

Automatic processing of long period data begins after the final automatic location for teleseismic earthquakes of magnitude greater than or equal to 5.5, and for local earthquakes with an Ml greater than 5.0. The long period wave form data are processed at 10 seconds before to 30 seconds after the expected P arrival for a MB magnitude computation. Similarly, this same wave form data are processed for the interval of 1 minute before to 15 minutes after the expected Rayleigh wave arrival time. A summary of the MS and MB magnitudes is printed. The wave forms from which each MB and MS is computed are displayed on another graphics terminal along with the MB and MS values. As broadband equipment becomes available to the ATWC, its data and the techniques as

suggested by Kanamori (1985), and Okal and Talandier (1989), are intended to be implemented for automatic processing.

An automatic retrieval of historical tsunami/earthquake data is performed for those earthquakes that activate the long period processes. Information such as epicenter, magnitude, depth, local tsunami amplitudes, tsunami magnitude, and intensity is printed for all events within 2 degrees about the epicenter. In addition to listing the earthquakes parameters and tsunami information, the total number of past earthquakes that occurred within the the 2 degree region and are over magnitude 7 and 8, are also printed.

Appendix A shows an example of some of the key outputs from the automatic processing system due to the Loma Prieta earthquake of October 17, 1989. A summary of this example is given here. All time codes are in UTC except where indicated. Immediately after 5 P-picks were determined, a solution was output at 00:09:32 placing the epicenter about 70 miles southeast of San Francisco with an initial mb average of 6.5. (Magnitudes (Mb,Ml) are only computed for ATWC's seismic sites. For large events, Mb's are used as an initial size indicator.) About a minute later as data from 2 more seismic stations were received, a second solution was output integrating the additional data. Since data from seismic station TOA was erroneous, it was automatically eliminated from the second solution. A third solution was output after receiving additional data from FBA and SVW. This solution was available about 1.5 minutes after the first solution which used the first 5 P-picks. At this point there is an automatic delay to collect remaining data for a final solution output at 00:12:51. The average mb is 6.2 and the epicenter was placed 50 miles southeast of San Francisco. After the final solution a summary of the long period magnitude computations are output as they are computed from the wave form data from each long period site, cycly-by-cycle.

This example shows some of the features of the ATWC's automatic system such as: the immediate availibility of epicenter locations as data are accumulated; automatic deletion of erroneous data; the ability to refine P-picks during an earthquake; and, rapid magnitude determinations as the long period wave form data are collected.

7. Interactive Processing System

The interactive processing software has been in use at the ATWC since the early 1980's with enhancements added as needed to improve the ATWC operations. It is menu-driven and collocated with the automatic software in the DEC system. Also, this same interactive software is used in a separate IBM 386 micro computer which functions as a degraded backup for the DEC micro system. Except for the P-pick processing algorithm, all major algorithms and processes in the automatic software are also in the interactive software. Access to execute this software is via a dedicated video display terminal (VDT).

The interactive software is used to produce all warning and other critical messages, whether disseminated by voice, teletypewriter, or satellite communication systems. It is also used for generating procedural aids for duty personnel, routine communication messages, and for daily earthquake processing. The major parts of the location program which exist in the automatic system are also in the interactive system. From a menu, an operator can select to: transfer data from the automatic system for concurrent recomputation of an earthquake and/or refinement; transfer results from the automatic system; independently compute an earthquake's parameters via interactive seismic data input; fix or float an earthquake's depth; eliminate erroneous P times; produce many procedural aids for duty personnel; determine water wave travel times; eliminate or add P-times; compute magnitudes (mb,Ml,MB,MS,Mw) interactively; compute epicentral distances and Rayleigh wave arrival times; compute depth from pP phase data; recompute magnitudes from the automatic system with an updated earthquake location; display an epicenter superimposed on an appropriate map on a VDM; or, display a plot of historical tsunamigenic earthquakes, superimposed upon an appropriate geographical map, for visual inspection of a region's past tsunamigenic behavior. The major parts of the location program as described in the automatic system are used in the interactive system.

Once an earthquake's parameters are determined, a variety of critical messages can be generated which include warnings, watches, press releases, and tide queries. These messages are disseminated over a teletypewriter system, National Warning System, and over the National Weather Service satellite system to appropriate agencies. For tsunami warning and watch messages, the warning and watch areas are taken from a table for the particular epicentral region and magnitude. Estimated tsunami times of arrival for various locations in Alaska, British Columbia, and the West Coast are integrated into these messages.

8. Earthquake/Tsunami Investigations

Every earthquake that activates the ATWC's RAS initiates an earthquake/tsunami investigation (ET) which culminates in processing the earthquake routinely or in the issuance of a watch/warning (WW). The first procedural steps for any ET is to determine an earthquake's location and magnitude. A WW is issued when the magnitude of an earthquake has exceeded a predetermined threshold, and the earthquake's location is near a coastal area from Kamchatka through southern California. The minimum threshold magnitudes for issuing a tsunami warning are dependent upon an area and its past tsunamigenic history, and currently range from 6.75 to 7.1. When an earthquake's magnitude has exceeded an area's threshold, a limited geographical area is placed in a warning status. Other geographical areas, outside the warned area, are placed in a watch status. As techniques and developments become more definitive and accurate, magnitude thresholds and the areas subjected to watches and warnings will be modified to minimize evacuations of coastal inhabitants.

After the initiation of a WW, tide site's data that are nearest the epicenter are monitored for the existence of a tsunami. Upon confirmation that a significant tsunami has been generated, the previously designated watch areas are upgraded to a warning which could be expanded. The WW is cancelled if an insignificant or no tsunami has been generated. Earthquakes that are smaller than threshold, but important to hazard officials, are processed on a routine basis and the information disseminated to appropriate officials.

Due to the ATWC's automation, an earthquake's location is available within seconds after 5 or more seismic stations receive data from a large earthquake. The main delay introduced in locating an earthquake is due to the P wave travel time from the hypocenter to the network of seismic sites. Earthquake locations for earthquakes in Alaska, and the west coasts of Canada and the U.S. are available within 1 to 6 minutes after the origin time. A WW is issued for an earthquake based upon the Richter MS magnitudes or the ATWC's regional magnitudes (Whitmore and Sokolowski, 1987). The travel time of the Rayleigh wave introduces a delay in sizing an earthquake. This delay is dependent upon the distance of a long period site from an earthquake source. Therefore, to decrease the delay time for determining MS magnitudes to within 15 minutes, the ATWC has established long period Alaskan sites at Shemya, Adak, Sand Point, Palmer, and Sitka, and uses a few of NEIC's long period sites in the lower 48 states. Figure 3 shows the minimum time (circles) required to determine an MS magnitude (issue a warning) using long period sites between 5 to 20 degrees from a source. If a long period instrument is further than 20 degrees away, the time delay will be more than 15 minutes.

9. Tsunami Warnings

Since inception to the present time, 14 warnings have been issued by the ATWC with seven occurring during the period from 1986 through 1989. Two of the earthquakes (MS=7.7, 6.6) occurred about the Adak area in 1986 on May 7 and 17, and one (MS=6.7) in the Unalaska area on February 27, 1987. Three of the earthquakes (MS=6.9, 7.6, 7.6) occurred on the Pacific Plate, just south of the Yakataga seismic gap on November 17 and 30, 1987, and March 6, 1988. The remaining earthquake (MS=6.9) occurred on September 4, 1989 east of the Shumagin Is. Figure 4 shows the actual response time, in minutes, to issue warnings from the origin times of the above earthquakes. Five of the seven earthquakes for which tsunami warnings were issued occurred during standby duty hours, i.e. when the duty personnel are not in the Center. Only the May 7, 1986 and Nov 30, 1987 earthquakes occurred during office hours for which warnings were issued in 8 minutes.

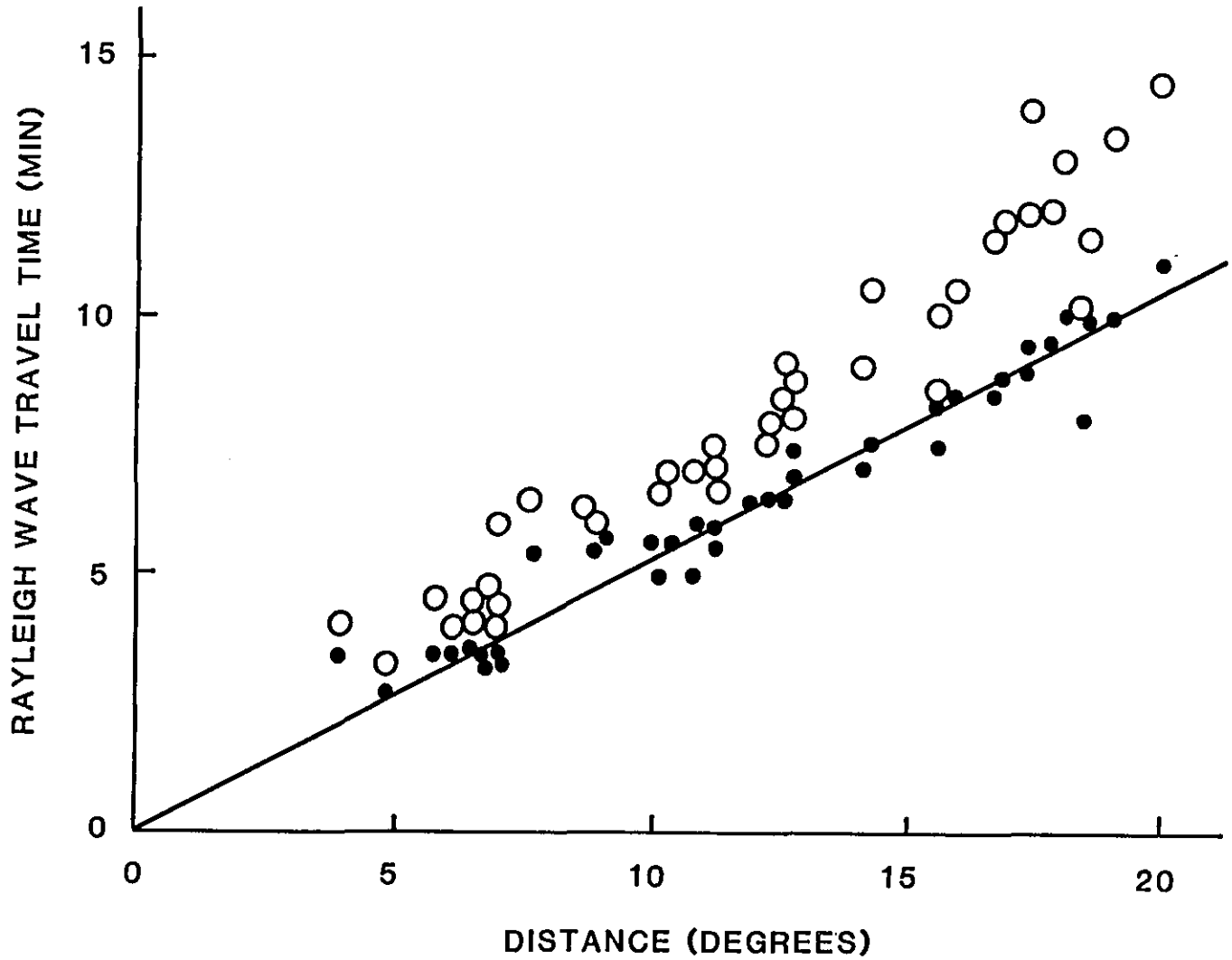

Fig. 3. Graph showing the Rayleigh wave travel time plotted as a function of distance. Dots indicate the wave travel time for various distances. Circles indicate the minimum time for the Rayleigh wave (18-22 seconds) to develop to a maximum for initially determining MS magnitudes (issue a warning).

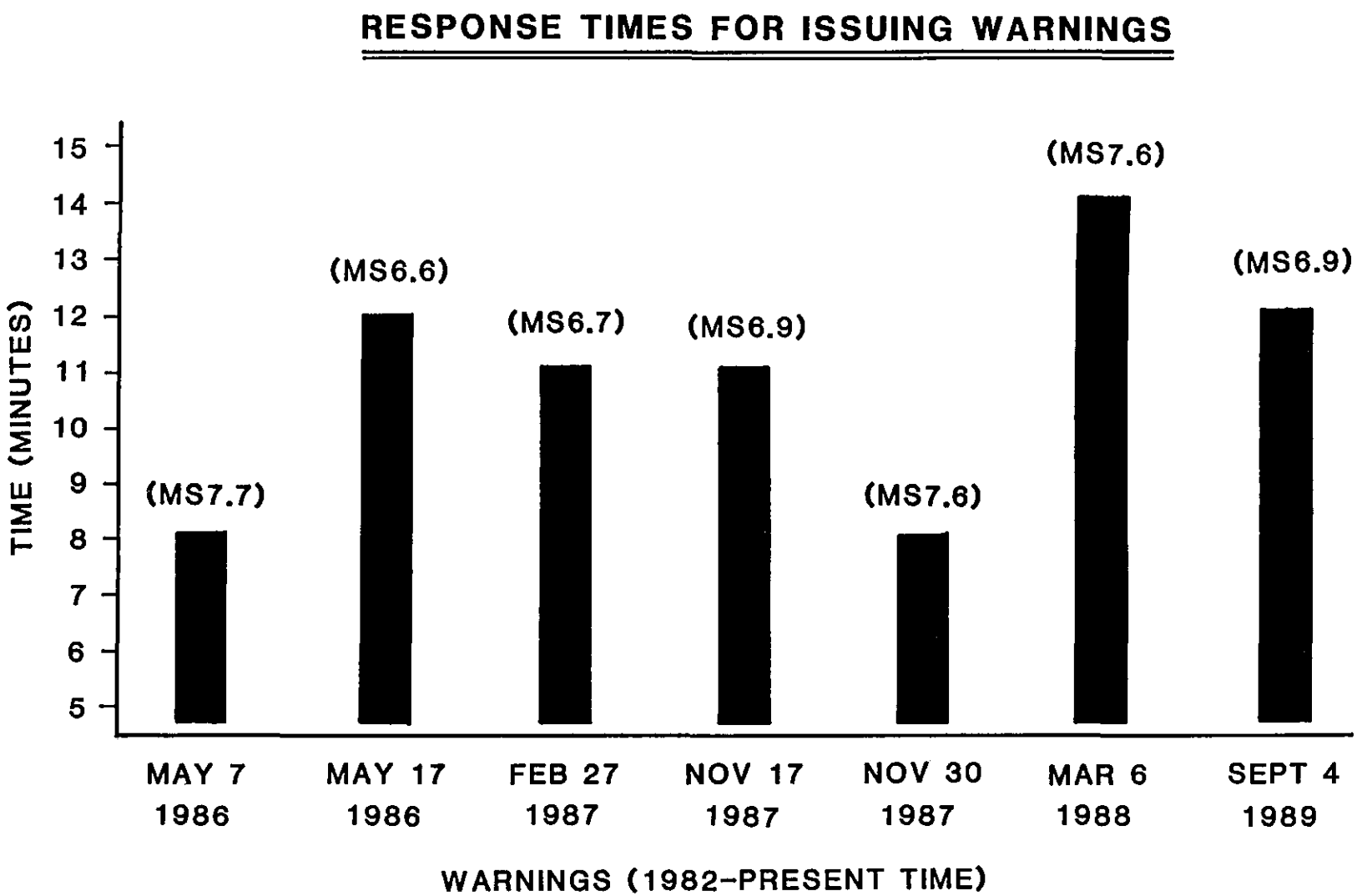

Fig. 4. Graph showing the response times to issue warnings from the earthquake origin time during the period from 1982 to the present time.

10. Historical Earthquake/Tsunami Data Bases

The ATWC maintains a historical tsunami and earthquake data bases that were obtained from the National Geophysical Data Center (Lander and Lockridge, 1989) and from the National Earthquake Information Center. Menu-driven software was created to search the data bases for requested data and lists these on a printer. Figure 5 shows a block diagram to retrieve historical data. The tsunami data base is used during all warnings to determine past hazard occurrences in and about an earthquake source to facilitate decision-making. The earthquake data base contains more than 7000 earthquakes of magnitude 6.0 or greater that have occurred in the Pacific Basin. Earthquake information can be retrieved by year, latitude/longitude, or by Flinn-Engdahl region numbers. The earthquake data base is cross referenced to the tsunami data base which contains more than 1100 historical tsunamis that have occurred in the Pacific Basin. The tsunami information (wave heights, damage, etc.) can be retrieved by latitude/longitude, year, and area. This information can be in summary (condensed) or detailed (expanded) form.

11. Communications

The methods for disseminating emergency and routine information (U.S. Department of Commerce, 1989) are by the National Warning System (NAWAS), Alaska Warning System (AKWAS), National Weather Wire Satellite System (NWWS), VHF radio system, high speed teletypewriter system (TTY), commercial telephones, Alaska Division of Emergency Services, VHF radio system, VHF Weather Radio, HF Marine Weather Radio, Emergency Broadcast System (EBS) through the National Weather Service, and EBS and HF via the Coast Guard. These are shown in Figure 6. The NAWAS, a voice disseminating system, is the primary one used to alert disaster officials in the U.S. and Canada of large earthquakes. The AKWAS, which is the State side of NAWAS, permits immediate voice communication with Alaska disaster officials. The NWWS and high speed VDT teletype system provide recipients with hard copies of watch/warning and other information. All of these systems are monitored and tested very frequently to ensure that they are operational.

Communication transmissions to the ATWC that concern incoming real-time data communication circuits are checked on a daily basis with immediate corrective actions implemented as problems surface. The computer systems, which are interfaced with the teletype VDT and the NWWS for dissemination of warnings, are checked daily. As problems surface, immediate actions are taken to correct the problem or improve the equipment. Additionally, the ATWC maintains a list of critical telephone numbers that are frequently checked for validity to ensure contact with primary hazard officials during warning situations.

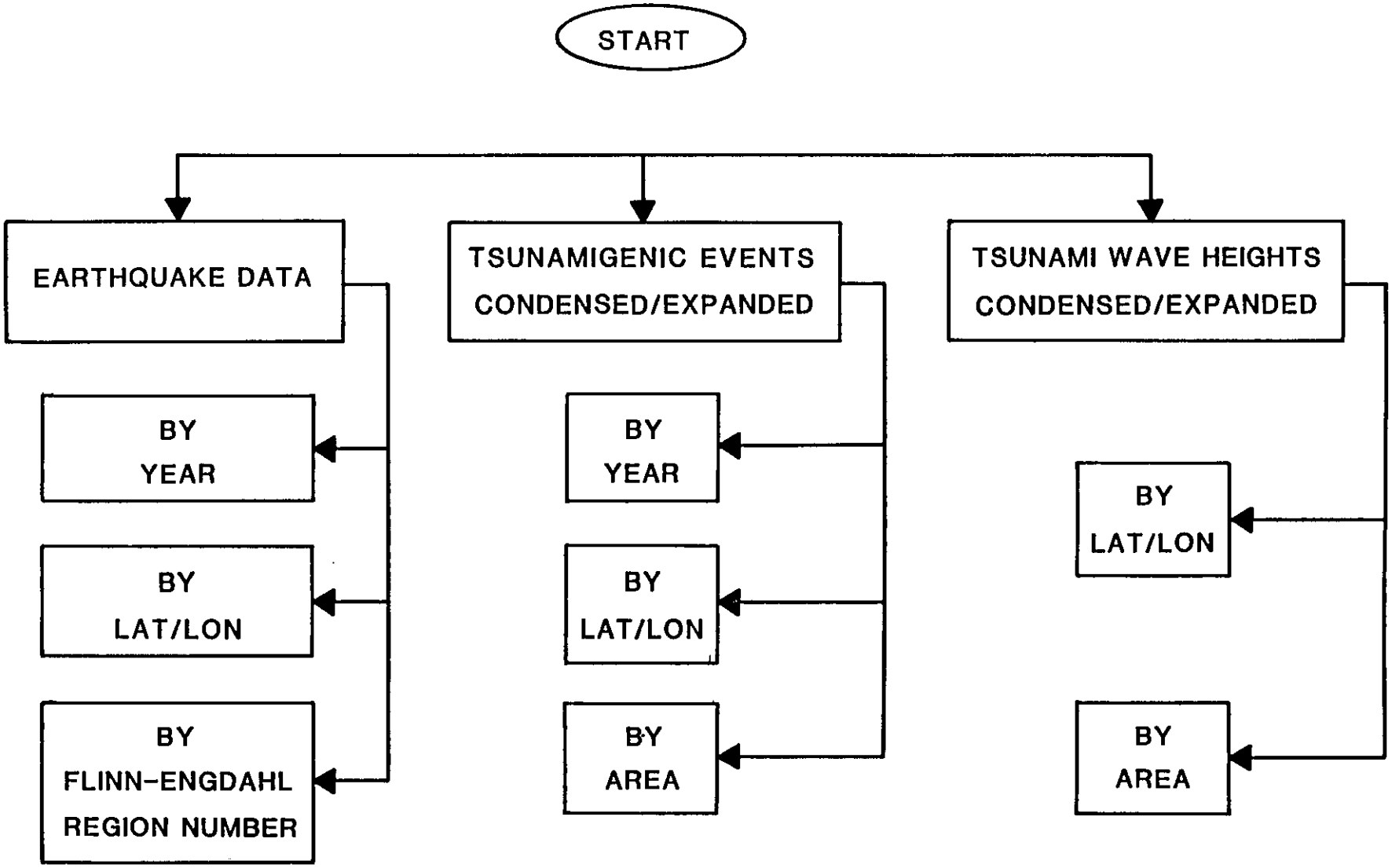

Fig. 5. Block diagram showing different methods to retrieve historical tsunami and earthquake data.

ATWC COMMUNICATION SYSTEM

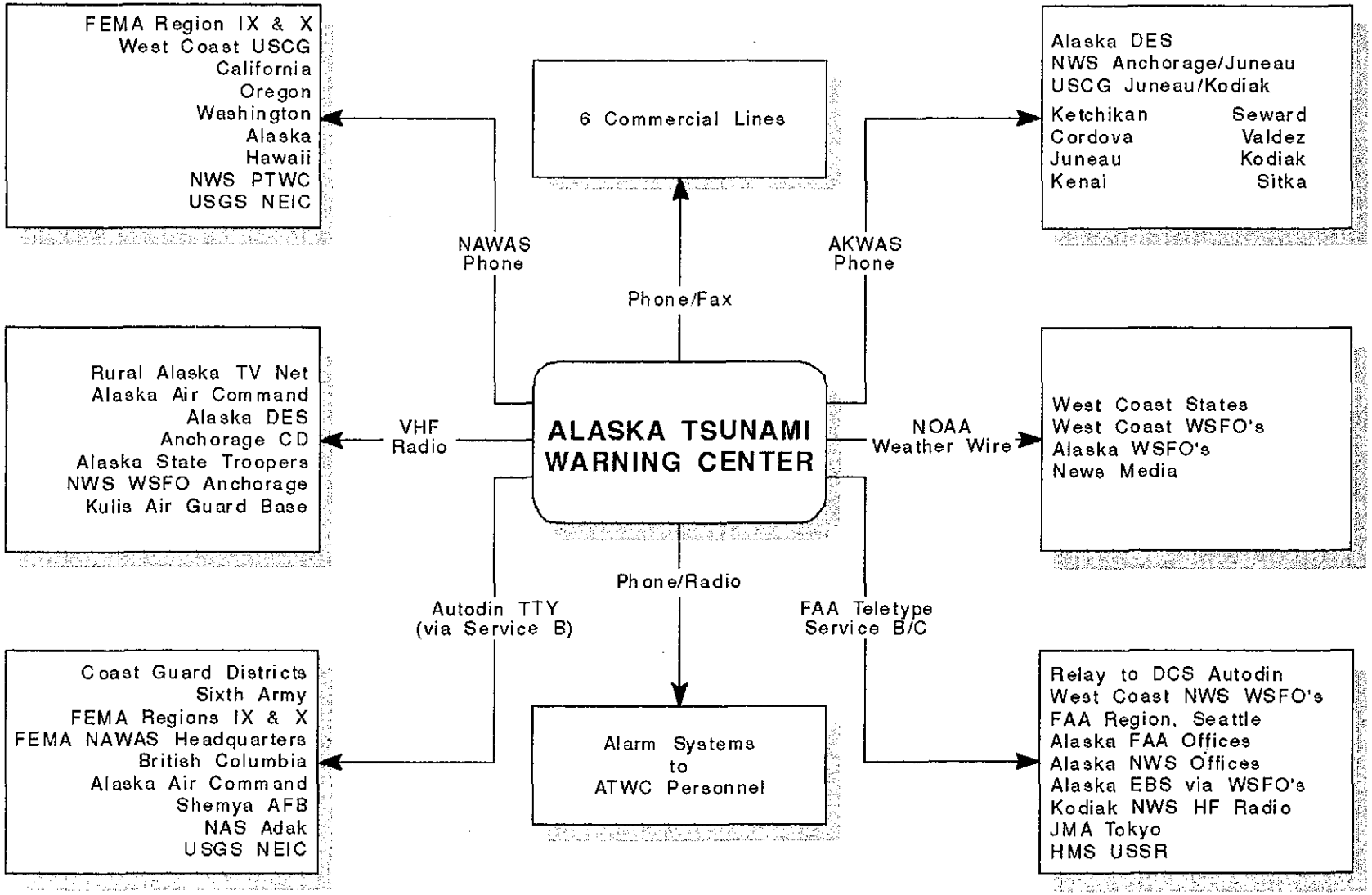

Fig. 6. Block diagram showing the ATWC communication system for disseminating information.

The NWWS was operational in February 1990, for disseminating tsunami watches, warnings, and other information via satellite to recipients in Alaska, Canada, Washington, Oregon, and California. One of the two satellite dishes installed at the ATWC permits information to be transmitted and received, while the other has only receiving capability. This satellite ground station at the ATWC also functions as a backup system for the Alaska Region's ground station located in Anchorage.

12. Community Preparedness

The ability of any warning system to successfully save lives and reduce property damage depends upon getting the information to the public and getting them to respond to the emergency. To maximize the effectiveness of the community preparedness efforts, the ATWC cooperates with the Alaska Department of Emergency Services (ADES) and many other hazard officials on the west coasts of the U.S. and Canada, and the far western Aleutian Is. The aim of this program is to educate the public to help themselves if they are caught in the middle of a violent earthquake and/or tsunami, and to be aware of safety procedures, safe areas, and the limitations of the Tsunami Warning System. In general, the community preparedness presentations include: a slide show concerning earthquake/tsunami effects; discussions concerning earthquakes and tsunamis; a community's particular hazard potential (Carte, 1984) and their expected response; and the ATWC operations, missions, and capabilities.

All professional staff members participate in providing a three part community preparedness program which includes: visits to distant coastal communities from Adak to southern California; visits to local group facilities and schools that are within commuting distance of the ATWC; and tours through the ATWC's facilities. Frequent visitations are made to those areas that are within reasonable driving distance from the Center, and visitations to outlying communities are made each year. Groups, such as schools, are encouraged to video tape the ATWC presentations for later use. Community preparedness is also done via telephone for special requests and projects that are received throughout the year. In addition to the outside visitations and presentations, the ATWC facilities are open to the public each Friday from 1 to 3 in the afternoon for local and other visitors. During these visits to the Center, the staff conducts a tour of the facilities with presentations concerning the TWS.

In addition to this on-going program, special visitations are made by the ATWC staff to the communities that were evacuated during an actual tsunami warning and no significant wave action materialized. The purpose of these visitations is to explain the warning actions to the public and to stress the continued need to respond to emergency tsunami warnings.

13. Micro Computer Concept and An Expert System

Another on-going effort at the ATWC is to seek improvements in the performance of all its missions by creating and implementing new concepts, initiatives, and equipment, and to enhance the effectiveness and efficiency of previous implementations. As a result of a feasibility study, a micro computer concept was introduced by Sokolowski (1985). This concept envisioned the use of several micro computers to address the initial ATWC improvement areas that were stated earlier in leading toward an expert system. The concept is evolutionary in that future tasks and additional micro systems can be integrated into the ATWC operations to enhance both the reactive and predictive parts of the operation. The micro systems are intended to communicate with each other via a local area network (LAN), or function independently, to perform both operational and administrative tasks.

Some initial advantages in using micro computers concern cost effectiveness, equipment, and personnel tasks. For cost effectiveness, there are significant savings in computer replacement costs, peripherals, and supplies which are available from many sources; computer maintenance; and power and space requirements. The micro computer hardware is constantly improving in its capabilities and can function as backups for critical units. They can be networked in a modular manner, so that selective units can be replaced, upgraded, or added as growth dictates. The units can be distributed in different work areas, thus maximizing aid for personnel and minimizing procedural response times in routine or emergency situations. Modular units permit a more effective use of personnel in distributing task assignments, responsibilities, and cross training.

Figure 7 shows the current micro computer concept which envisions 5 separate micro computer systems which are networked via a LAN system to perform their various functions. Several functions are duplicated due to the critical nature of the task, or to facilitate personnel duties and technique developments. The future micro computers are expected to use CPU's of the 386/486/... variety, and make maximum use of common peripherals and equipment for printing, storage, etc. They will also have access to appropriate data bases. For redundancy, the micros have access to the major communication systems, such as the NWWS and TTY systems for disseminating/receiving critical data and information. The micros and associated equipment are being implemented as funding becomes available, and techniques are developed or become available to the ATWC. As additional task requirements evolve, additional micros can be added to the LAN or specific micro(s) can be upgraded. This provides a mechanism for keeping abreast of state-of-the-art equipment and for future technique developments and growth. Given below are summaries of some key functions of the 5 micro computers and associated equipment.

Micro 1 will be used as both a server (supervisor) of a LAN system, and for concurrent processing and analysis of tidal data from Alaska, and the west coasts of Canada and the U.S. The data are available to the ATWC in several ways.

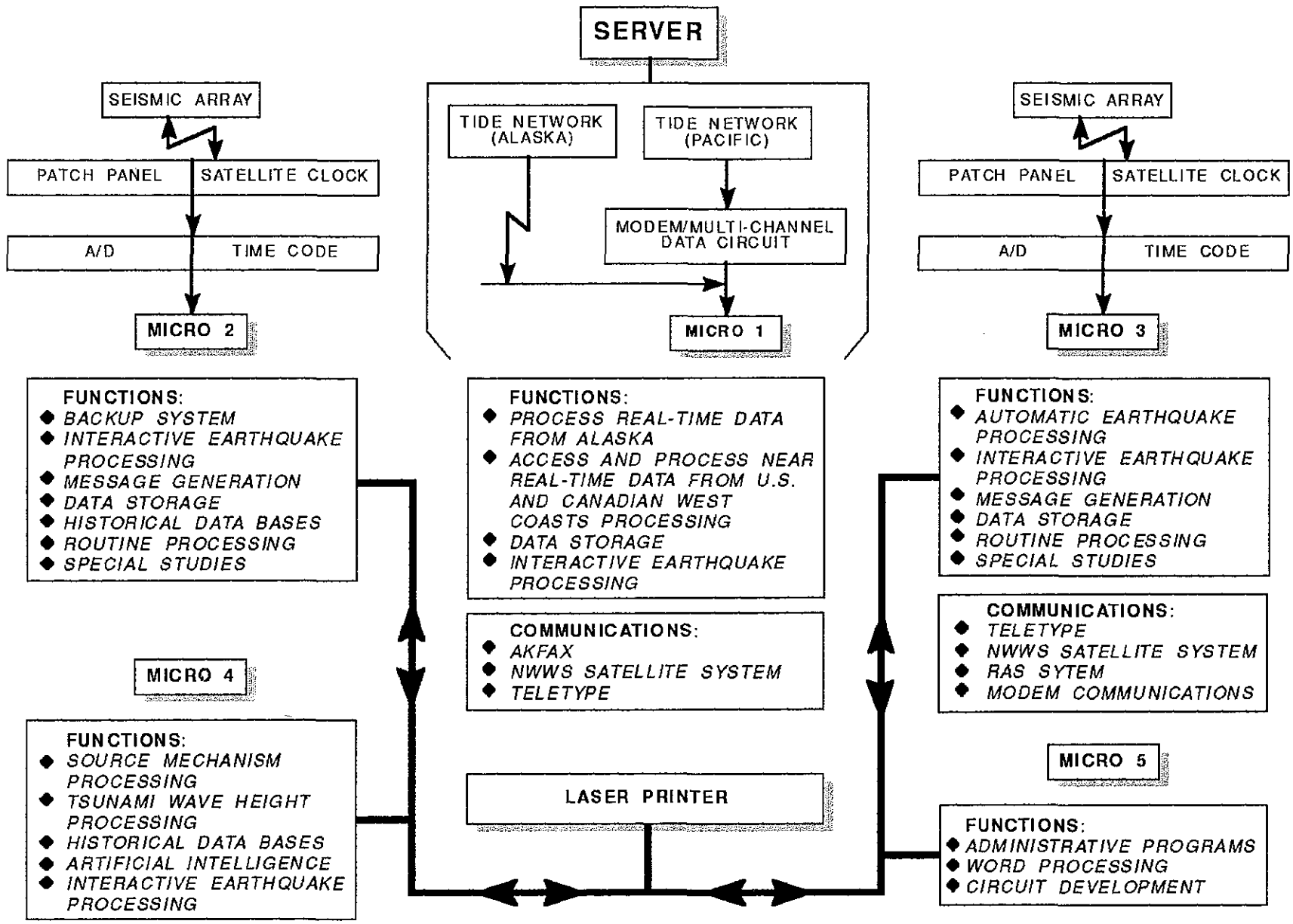

Fig. 7. Block diagram showing a distribution of micro computers which are networked via a LAN system to perform their indicated functions.

First, the NOS's water level telemetry systems have the capability of transmitting datadirectly to the ATWC in real-time from sites in Alaska. They can also transmit tsunami data from the Pacific Basin, via satellite, to the U.S. east coast. These data are available to the ATWC in near real-time through a dedicated circuit (AKFAX) from the east coast to the ATWC for processing and analysis by this micro computer. Finally, this computer will also be capable of receiving tidal data in near real-time via a modem interface to the NOS Pacific sites. The tide station's data will be stored for rapid retrieval, analysis, and archiving. Micro 1, like the other micros, will have access to the the AKFAX, NWWS, TTY, storage devices, and printers.

Micro 3 is the current automatic real-time and interactive system which has been described earlier. It is the primary system for providing tsunami warning services to ATWC's areas of responsibilities. Since this micro has recently been placed into service, its future successor will be of a CPU type given above and does not have a high priority for replacement at this time. For redundancy, this micro has separate interfaces to the TTY, NWWS, RAS, and modem communication systems.

Micro 2 will function as a backup system to Micro 3, for routine processing and special studies. The same seismic array data that are routed to Micro 3 are being monitored and processed by this computer. Its CPU is a 386 type which has an additional CPU for receiving real-time data for subsequent signal processing in real-time. The key algorithms used in the automatic and interactive processing systems have been converted to run on this system. As development progresses, this system (or its successor) will eventually replace the DEC (micro 3) computer system.

Micro 4 will be used for source mechanism and tsunami wave height processing, and other topics which will involve artificial intelligence (AI) applications. Current modelling of past tsunamis has been and continues at the ATWC. Present and future work in this area involves modeling many of the past tsunamigenic events to produce expected tsunami wave heights and currents for various areas. The input for AI evaluation could include such knowledge as, earthquake parameters and source mechanism; actual tide heights at various locations; reasonable estimates of expected tsunami wave heights and currents at various locations; reasonable estimates of expected tsunami inundation from predicted tsunami wave heights, flood data, etc.; historical tsunami data and damage from various source regions; and, historical earthquake data from various source regions. An initial AI study has begun using some accomplished results and existing data bases. This study will be continually enhanced to include other results and data as they are developed or become available to the ATWC.

The remaining micro will be used for administrative programs and routine staff functions. It is also used by the electronic personnel for designing circuitry and generating seismic response curves.

14. Conclusion

The ATWC continues to improve both the reactive and predictive areas of its operations. Since the early 1980's, numerous changes have taken place in areas, such as, operational concepts and procedures - especially in response to emergency situations; micro computer concepts; computers, peripherals and associated equipment; expanded area responsibility; seismic and tide networks; technique developments; community preparedness; and communications for disseminating critical information. The ATWC system is designed for speed, effectiveness, and efficiency. The integration of micro computers and developments have already made a considerable improvement in performing ATWC's missions. The ATWC continues to maximize its efforts toward an expert system that will be able to: (1) automatically detect and analyze seismic data in real-time; (2) immediately disseminate critical earthquake and tsunami information; (3) automatically detect and analyze tidal data in real-time or near real-time; (4) rapidly discriminate tsunamigenic from non-tsunamigenic earthquakes; and (5) determine reasonable estimates of probable tsunami wave heights and areas of inundation in the path of a tsunami. Due to the accomplishments in (1) and (2) above, the average response time to issue a warning has been reduced by more than 50%. In addition to timeliness, procedures have been considerably simplified and standardized.

In earthquake processing: local, regional, and teleseismic earthquakes parameters are automatically computed and sized (mb,Ml) within tens of seconds after receiving appropriate data at real-time seismic sites distributed throughout Alaska and the lower 48 states. The automatic determination of an earthquake's parameters, plus the resident historical data bases has enhanced the quality and quantity of resulting information disseminated to the TWS recipients. Long period seismic instruments have been established at strategic coastal locations in Alaska to decrease the response time in computing magnitudes. The real-time data are automatically sized (MS), cycle by cycle, by the computer. Earthquake parameters are immediately available at the Center, and/or transmitted by a computer and RAS system to the ATWC staff for an immediate response. The new RAS system for alerting standby duty personnel has considerably improved the effectiveness of the ATWC personnel in performing their missions. As funding becomes available for additional micro computers and broad band seismic equipment, enhancements to the ATWC system would include source mechanisms and moment magnitudes for potential tsunamigenic earthquakes.

Tsunami modeling and tide height determinations during expected time of arrivals of tsunamis at different locations are continuing efforts at the ATWC. In-house development is coupled with the transfer of scientific techniques and methods developed by other scientists (Dunbar et al., 1989; and Kowalik and Murty, 1987) for appropriate application to the ATWC requirements. The current and future modeling efforts use many of the past tsunamigenic earthquakes in duplicating their effects. Actual tide heights during expected tsunami arrivals at different locations will have an impact on various localities. The minimum expectations in this area includes maximum predictive wave heights and wave

currents, and inundation zones for different locations in ATWC's areas of responsibilities. The application of these results, along with others, will serve as valuable input for an expert system.

Tidal data continue to be accessed in real-time from sites in Alaska. Tidal data are accessed and analyzed via micro computer(s) in near real-time from Canada and the U.S. West Coast. New NOS tide equipment, and communications via new circuits, satellite, and micro computers will be used in the near future to access and analyze pacific tidal data in real-time and near real-time. A new satellite system ground station was established at the Center which enhances the ATWC's capabilities to immediately disseminate critical information to numerous areas. Getting the public to respond to critical earthquake/tsunami information is a vital part of the ATWC efforts and necessitates a continued educational community preparedness program. This program covers selected areas in large geographical areas, and in cooperation with other agencies and hazard officials. All professional staff members participate in this important part of the ATWC.

The integration of micro computers and on-going in-house and cooperative technique developments are critical to the ATWC's momentum in improving its tsunami warning services to the coastal inhabitants for potential tsunamigenic earthquakes. These continual efforts involve the implementation of new concepts, additional computers, technique developments, and sophisticated equipment. Future efforts are expected to continue in the areas given above, and in other evolving areas such as, artificial intelligence to produce an expert system.

15. Acknowledgments

The author thanks the National Weather Service (NWS) Headquarters and the Alaska Regional Headquarters (Mr. Harry S. Hassel, Director, Mr. Burton D. Goldenberg, Chief Operations) for their continued support in our efforts to automate the Alaska Tsunami Warning Center. The author also thanks those many past and present ATWC Staff members who have made contributions over the years in various parts of automation projects. A special thanks to Mr. Stuart G. Bigler (former Director of the Alaska Region) for his past significant support in ATWC projects that are now being realized. Lastly, the author thanks Ms. Nancy J. Clarke, Ms. Susan Davis, and Mr. Arthur J. Johnson for their help in proof reading and preparation of this article for publication.

16. References

Carte, G., 1984. A tsunami preparedness assessment for Alaska, Sci. Tsunami Haz., 2, P. 119-126.

Dunbar, D., LeBlond, P.H., and Murty, T.S., 1989. Maximum tsunami amplitudes and associated currents on the coast of British Columbia, Sci. Tsunami Haz., v.7, 1, P. 3-44.

Kanamori, H., A numerical experiment on seismic tsunami warning network for Alaska and the Aleutians, Proceedings of the International Tsunami Symposium, IUGG, 1985, edited by T.S. Murty and W.J. Rapatz, P. 30-39.

Kowalik, Z., and Murty, T.S., 1987. Influence of the size, shape and orientation of the earthquake source area in the Shumagin seismic gap on the resulting tsunami. Jour. Phys. Ocean., v.17, 7, P. 1057-1062.

Lander, J.F. and Lockridge, P.A., United States Tsunamis, 1690-1988, U.S. Department of Commerce, NOAA, NESDIS, National Geophysical Data Center, Pub. 41-2, 1989, PP. 265.

Okal, E.A. and Talandier, J., 1989. Mm: A variable-period mantle magnitude, J. Geophys. Res., 94, P. 4169-4193.

Sindorf, J. G., 1972. Determining magnitude values from the Lg phase from short period vertical seismographs, Earthquake Notes, Seismol. Soc. Am., 3, P. 5-8.

Sokolowski, T.J. and Miller, G.R., 1967. Automatic epicenter locations from a quadripartite array. Bull. Seismol. Soc. Am.,57, P. 269-275.

Sokolowski, T.J., 1974. Feasibility Proposal for the Initial Automation of the Tsunami Warning System. National Weather Service, Pacific Region Report. 22pp.

Sokolowski, T.J., 1978. Initial Automation of the Pacific Tsunami Warning Center. (unpublished) 11pp.

Sokolowski, T.J., Fuller, G.W., Blackford, M.E. and Jorgensen, W.J., 1983. The Alaska Tsunami Warning Center's automatic earthquake processing system, Proceedings of the International Tsunami Symposium, IUGG, 1983, edited by E.N. Bernard, P. 131-148.

Sokolowski, T.J., 1985. The Alaska Tsunami Warning Center's Responsibilities and Operations. Sci. Tsunami Haz., 1, P. 23-33.

Sokolowski, T.J., 1985, Mini and micro computer applications at the Alaska Tsunami Warning Center. Proceedings of the International Tsunami Symposium, IUGG, 1985, edited by T.S. Murty and W.J. Rapatz, P. 174-181.

Sokolowski, T.J., and Whitmore, P.M., and Jorgensen, W.J., 1989, The Alaska Tsunami Warning Center's automatic and interactive earthquake processing system, 1989. Presented at the Tsunami Symposium in Novosibirsk, USSR, August 1989. Submitted for publication in Proceedings of the International Tsunami Symposium, IUGG, 1989.

U.S. Department of Commerce, 1989, National Oceanic and Atmospheric Administration, National Weather Service, Communication Plan for the Tsunami Warning System, Eleventh Edition. 123 pp.

Whitmore, P.M. and Sokolowski, T.J., 1987. Rapid sizing of potentially tsunamigenic earthquakes at regional distances in Alaska, Sci. Tsunami Haz., 2, P. 67-76.

Appendix A

Output: Loma Prieta earthquake of October 17, 1989.

Output: Loma Prieta Earthquake of October 17, 1989

```
                    ..........................
                    ...       P-picks      ...
                    .... from other events ....
                    ..........................

                   18-OCT-1989   CMB   00:04:41.9
                   18-OCT-1989   RMW   00:06:51.4
                   18-OCT-1989   ALQ   00:07:18.8
                   18-OCT-1989   GOL   00:07:27.3
                   18-OCT-1989   SIT   00:09:16.8
      EVENT NUMBER 745;   SOLUTION AT: 00:09:32, OCTOBER 18, 1989
-----------------------------------------------------------------------
STA P-TIME    RES  DIS  AZM  MAG     STA P-TIME    RES  DIS  AZM  MAG
-----------------------------------  -----------------------------------
CMB 000441.9 -0.7  1.0  44.0         GOL 000727.3  1.4 12.7  74.4
RMW 000651.4 -0.1 10.1 357.9         SIT 000916.8 -0.3 21.8 339.1 6.5b
ALQ 000718.8 -0.8 12.2  96.9
-----------------------------------------------------------------------
H(Z)..=00:04:25   OCT 18, 1989       LOC...=37.3N   121.2W   DEP=33
H(ADT)=04:04:25pm OCT 17, 1989                      AVG. RES. = 0.7
LOC...= 70 MILES SE OF SAN FRANCISCO, CA.           AZIMUTH   = 118
LOC...= 60 MILES NE OF MONTEREY, CA.
-----------------------------------------------------------------------
                     AVERAGE MAGNITUDE Mb = 6.5

                   18-OCT-1989   PMR   00:10:25.6
                   18-OCT-1989   TOA   00:10:27.1
      EVENT NUMBER 745;   SOLUTION AT: 00:10:45, OCTOBER 18, 1989
-----------------------------------------------------------------------
STA P-TIME    RES  DIS  AZM  MAG     STA P-TIME    RES  DIS  AZM  MAG
-----------------------------------  -----------------------------------
CMB 000441.9 -0.7  1.0  51.5         SIT 000912.3  0.4 21.8 339.7 6.5b
RMW 000649.2 -0.9 10.2 359.5         PMR 000925.6 -1.1 29.8 333.7 5.3b
ALQ 000718.8 -0.6 12.5  96.0         TOA 001027.1X 5.9 29.2 336.4
GOL 000727.3  1.2 13.0  74.2
-----------------------------------------------------------------------
H(Z)..=00:04:20   OCT 18, 1989       LOC...=37.2N   121.7W   DEP=33
H(ADT)=04:04:20pm OCT 17, 1989                      AVG. RES. = 0.8
LOC...= 60 MILES SE OF SAN FRANCISCO, CA.           AZIMUTH   = 122
LOC...= 40 MILES NE OF MONTEREY, CA.
-----------------------------------------------------------------------
                     AVERAGE MAGNITUDE Mb = 5.9

                   18-OCT-1989   FBA   00:10:42.7
                   18-OCT-1989   SVW   00:10:45.2
      EVENT NUMBER 745;   SOLUTION AT: 00:10:55, OCTOBER 18, 1989
-----------------------------------------------------------------------
STA P-TIME    RES  DIS  AZM  MAG     STA P-TIME    RES  DIS  AZM  MAG
-----------------------------------  -----------------------------------
CMB 000441.9 -0.9  1.3  51.5         PMR 001025.6 -0.5 19.8 339.8 5.3b
RMW 000649.2  1.1 10.2 359.7         TOA 001024.1X 6.5 29.2 336.5
ALQ 000718.8 -0.6 12.6  95.9         FBA 001042.7 -0.5 31.7 339.2 6.4b
GOL 000727.3  1.1 13.0  74.1         SVW 001044.9 -0.7 32.0 329.3 6.3b
SIT 000912.3  0.9 21.8 339.8 6.5b
-----------------------------------------------------------------------
H(Z)..=00:04:20   OCT 18, 1989       LOC...=37.2N   121.7W   DEP=33
H(ADT)=04:04:20pm OCT 17, 1989                      AVG. RES. = 0.8
LOC...= 60 MILES SE OF SAN FRANCISCO, CA.           AZIMUTH   = 127
LOC...= 40 MILES NE OF MONTEREY, CA.
-----------------------------------------------------------------------
                     AVERAGE MAGNITUDE Mb = 6.1
```

```
                    18-OCT-1989   SDN   00:10:45.7
                    18-OCT-1989   BLA   00:10:55.9
                    18-OCT-1989   IMA   00:11:05.2
                    18-OCT-1989   ANM   00:11:36.3
      EVENT NUMBER 745;   SOLUTION AT: 00:12:51, OCTOBER 18, 1989
-----------------------------------------------------------------------
STA P-TIME    RES  DIS  AZM  MAG     STA P-TIME    RES  DIS  AZM  MAG
-----------------------------------  -----------------------------------
CMB 000441.9 -0.7  1.4  52.0         FBA 001041.3 -1.4 31.7 339.2 6.4b
RMW 000649.2  1.6 10.3 359.8         SVW 001043.5 -1.5 32.0 329.3 6.3b
ALQ 000718.8 -0.4 12.6  95.8         SDN 001044.9  1.5 31.8 317.3 6.1b
GOL 000727.3  1.3 13.1  74.1         BLA 001050.8 -0.6 32.7  77.2
SIT 000912.3  1.4 21.8 339.9 6.5b    IMA 001104.9 -0.3 34.3 337.5 5.7b
PMR 001025.1 -0.5 29.8 333.8 5.3b    ANM 00132.3  -0.4 37.6 330.8
TOA 001024.1X 4.0 29.2 336.5
-----------------------------------------------------------------------
H(Z)..=00:04:19   OCT 18, 1989       LOC...=37.2N   121.7W   DEP=33
H(ADT)=04:04:19pm OCT 17, 1989                      AVG. RES. = 0.8
LOC...= 50 MILES SE OF SAN FRANCISCO, CA.           AZIMUTH   = 139
LOC...= 40 MILES NE OF MONTEREY, CA.
-----------------------------------------------------------------------
                    AVERAGE MAGNITUDE Mb = 6.2


BEGIN LONG PERIOD MAGNITUDE (LPMB & MS) DETERMINATIONS
      EVENT 745 Long Period Processing: 00:13:28
MAG |  SMY  ADK  SDN  PMR  SIT  NEW  GLD  SLM  HON
LPMB |        6.9  6.8  6.9  OFF  NR   OFF  OFF
MS   |                       6.6C
END  |                  ***       ***  ***
-----------------------------------------------
        MODIFIED AVERAGE: LPMB=6.9, MS=6.6C

                 ........................
                 ... Many other summarys ...
                 ........................

      EVENT 745 Long Period Processing: 00:21:17
MAG |  SMY  ADK  SDN  PMR  SIT  NEW  GLD  SLM  HON
LPMB |        6.9  6.8  6.9  OFF  NR   OFF  OFF
MS   |        6.9  6.8  6.9       6.6C
END  |                  ***  ***  ***  ***
-----------------------------------------------
        MODIFIED AVERAGE: LPMB=6.9, MS=6.9

                 ........................
                 ... Many other summarys ...
                 ........................

END  LONG PERIOD MAGNITUDE (LPMB & MS) DETERMINATIONS
      EVENT 745 Long Period Processing: 00:37:30
MAG |  SMY  ADK  SDN  PMR  SIT  NEW  GLD  SLM  HON
LPMB |        6.9  6.8  6.9  OFF  NR   OFF  OFF
MS   |  6.9  6.9  6.9  6.8  6.9       6.6C
END  |  ***  ***  ***  ***  ***  ***  ***  ***  ***
-----------------------------------------------
        MODIFIED AVERAGE: LPMB=6.9, MS=6.9
```