

Please Return

HIG-65-16

EARTHQUAKE EPICENTER DETERMINATION USING δt DATA

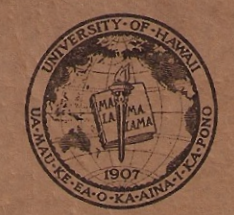
by
GEORGE PARARAS-CARAYANNIS
and
JAMES SASSER

DECEMBER 1965

Prepared for
OFFICE OF NAVAL RESEARCH
UNDER CONTRACTS NO. Nonr 3748(01) AND NO. Nonr 3748(03)

THE STATE OF HAWAII

HAWAII INSTITUTE OF GEOPHYSICS
UNIVERSITY OF HAWAII





Earthquake Epicenter Determination Using δt Data

by

George Pararas-Carayannis

and

James Sasser

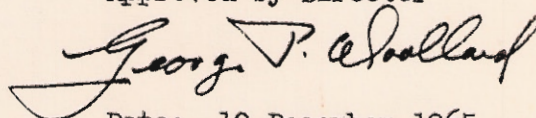
December 1965

Prepared for

Office of Naval Research
under contracts No. Nonr 3748(01) and No. Nonr 3748(03)
and
the State of Hawaii

Reproduction of this report in whole or in part is permitted for
any purpose of the United States Government

Approved by Director



Date: 10 December 1965

Table of Contents

	<u>Page</u>
Abstract	1
Introduction	2
Discussion	4
Use of Charts	5
Spherical Hyperbola Program	7
Conclusions	12
Acknowledgments	12
Bibliography	14

Appendix

- a. Flow chart of the spherical hyperbola program
- b. Computer program and subroutines
- c. Example of computer output of the coordinates of points along δt curves (2-minute contour) for Honolulu-Sitka
- d. Example of computer-drawn δt curves for Honolulu-Tucson (from 35N to 60N, and 120E to 160E)
- e. δt chart for Tucson, Arizona - Honolulu, Hawaii
- f. " " " Honolulu, Hawaii - Hong Kong
- g. " " " College, Alaska - Honolulu, Hawaii
- h. " " " Sitka, Alaska - Honolulu, Hawaii
- i. " " " Tucson, Arizona - College, Alaska
- j. " " " Tucson, Arizona - Sitka, Alaska
- k. " " " Sitka, Alaska - College, Alaska

The disadvantage of the (P-0) method lies in the possibility that the circles may not intersect at all or that if they do, they may intersect at more than one point. In either case, the epicenter location will not be a point on the globe but will lie somewhere in a roughly triangular-shaped area, bounded by the non-intersecting circles, or by the points of intersection, in the event the circles do intersect. Adjustment, therefore, has to be made in the origin time in order to obtain intersection at a point.

Another defect of the (P-0) method is that the arrival of the S-wave is often difficult to distinguish in the seismological record because of the residual radiation of P-waves; hence, the actual distance cannot always be calculated with accuracy.

Similarly, seismographs of greater sensitivity, or seismographs located at nearby stations, may record arrival of foreshocks which often precede the main shock and give an under estimate of the epicentral distance. In addition, if an earthquake is deep, other errors may be introduced in the estimation of origin time.

A method that utilizes the difference in the arrival times of P-waves (δt) observed at any two seismic stations has been proposed for testing against the current (P-0) techniques. This method is not new but has been used extensively by the Japanese in locating the epicenters of earthquakes generating tsunamis locally, by the SOFAR Triangulation Network (Woollard, 1947), and by the LORAN Navigational System.

location. This is explained further in the section on the use of the charts.

The advantage of the δt chart method lies in the fact that it greatly reduces the possibility of errors by reducing to a minimum the number of computations made at the time the epicenter of an earthquake is determined. There is also no need to assume an origin time.

A set of P-wave travel charts covering the Pacific Ocean area were developed for the Seismic Sea-Wave Warning System. These charts were based on data compiled by hand and by digital computer.

The following stations were used for the development of these charts:

Honolulu, Hawaii

Tucson, Arizona

Hong Kong

College, Alaska

Sitka, Alaska

A flow chart of the seismic spherical hyperbola program used in the compilation appears as Appendix 1. Appendix 2 gives the computer program used. Appendices 3 through 9 give the δt charts computed and plotted to date.

Use of Charts

As soon as an earthquake is recorded at three different stations and the three different arrival times of P-waves are known, reference is made to the charts which include the three stations. For example,

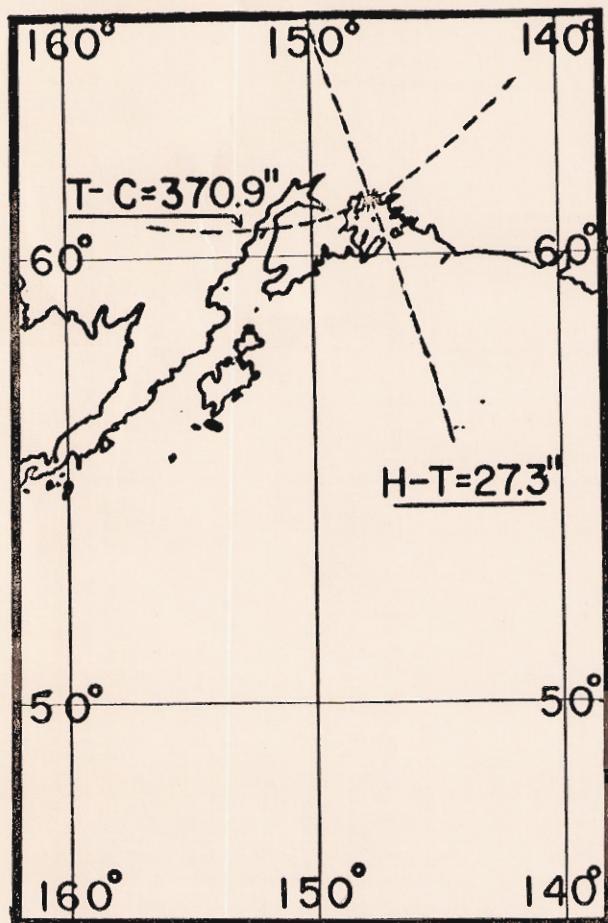


Fig. 1. Determination of the epicenter of the Alaska earthquake of 28 March 1964, using δt charts of Tucson-College and Honolulu-Tucson.

for the Alaska earthquake of March 28, 1964, if the arrival times of P-waves are known for College, Alaska; Tucson, Arizona; and Honolulu, Hawaii; any two of the three possible sets of charts or all three sets can be used.

For the example cited, reference is made to the δt chart for Honolulu-Tucson. Arrival time of P-waves at Honolulu was 03 43 53.8 Z, and at Tucson 03 43 26.5 Z. The difference in the arrival times is 27.3 seconds. A piece

of transparent plastic is then superimposed on the chart for Honolulu-Tucson and the δt curve

for 27 seconds time difference is traced on the plastic, as well as the geographical coordinates of the area. The arrival time of P-waves at College was 03 37 15.6. The difference in the arrival times at Tucson and College was 370.9 seconds. The same piece of plastic is then superimposed on the chart of Tucson-College and another δt curve, corresponding to the difference in the arrival times of these two stations, is traced. The intersection point of the two curves gives the earthquake epicenter (Fig. 1). As an additional check, the δt chart of Honolulu-College

could also be used in a similar manner. The determination of the Alaska earthquake epicenter by this method was found to be 61.0N, 147.5W. The epicenter location given in the March 1964 Seismological Bulletin for this particular earthquake is 61.0N, 147.8W. The difference in the two determinations is only $.3^{\circ}$ of longitude, which proves that the δt method is quite accurate.

Spherical Hyperbola Program

The original spherical hyperbola program was written by the T-phase division of the Hawaii Institute of Geophysics, to be used in studies of underwater sound generated from earthquakes. This program works quite well under the assumption of nearly constant velocity for underwater sound in the ocean. A number of problems arise however, in modifying the constant velocity program and applying it to seismic wave velocities as obtained from empirically derived travel-time differences, δt , between seismic stations.

Variations in seismic wave velocities are due to density and crustal structure anomalies, and are characteristic of specific regions of the earth. As more data therefore become available, directional velocity anomalies will be determined and corrections will be necessary for the travel-time curves included as appendices of this report.

To date not all of the problems of the spherical hyperbola program have been resolved; however, the program is working effectively in 75% of the particular cases tried.

The travel time difference, δt , between any two stations from a source x is:

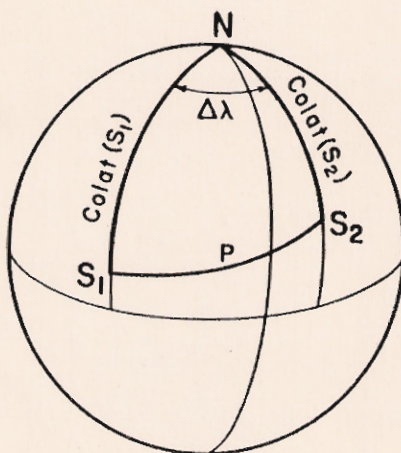
$$\delta t = t_1 - t_2 = \frac{d_1}{c_1} - \frac{d_2}{c_2} \quad (1)$$

where $t_1, t_2, d_1, d_2, c_1, c_2$ are the seismic wave travel times, the distance from source x to each station and velocities between source and stations, respectively. If we are working with sources on the same travel-time difference curve, δt is constant or

$$\delta t = t_1 - t_2 = k \quad (2)$$

Equation (2) is the equation for one of the two branches of a hyperbola. Since in seismic studies we have distances on a spherical earth, the travel times obtained are for spherical distances and equation (2) is thus that for one of the branches of a spherical hyperbola.

If we construct a spherical triangle with the North Pole and two seismic stations as vertices, we have:

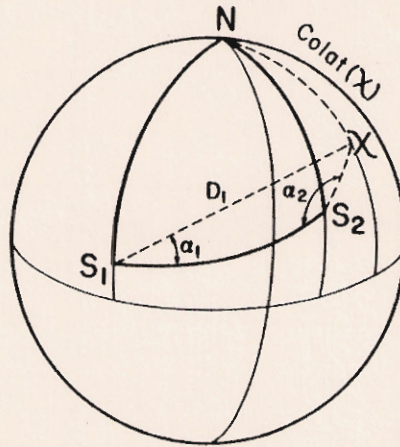


where S_1 and S_2 are the seismic stations, N is the North Pole, P is the great circle distance between S_1 and S_2 on the spherical earth, defined by:

$$P = \cos^{-1}[\cos(\text{COLAT}(S_2)) \cdot \cos(\text{COLAT}(S_1)) + \sin(\text{COLAT}(S_2)) \cdot \sin(\text{COLAT}(S_1)) \cdot \cos(\Delta\lambda)] \quad (3)$$

here, $\text{COLAT}(S_1)$ is the colatitude of S_1 , $\text{COLAT}(S_2)$ is the colatitude of S_2 , and $\Delta\lambda$ is the difference in longitudes between the two stations.

If we add a source χ at angles α_1 with P at S_1 and α_2 with P at S_2 and at distances D_1 from S_1 and D_2 from S_2 , we have the following:



$$D_1 = \cos^{-1}[\cos(\text{COLAT}(X)) \cdot \cos(\text{COLAT}(S_1)) + \sin(\text{COLAT}(X)) \cdot \sin(\text{COLAT}(S_1)) \cdot \cos(\lambda_X - \lambda_{S1})] \quad (4)$$

when X is considered as a source at each increment along a rectangular geographical boundary, the locus of all positions of X defines a travel-time curve with constant δt . Since such curves are continuous, each contour must cross the limits of the rectangular boundary an even number of times.

Given incremental latitudes and longitudes along the boundary, and the distances and travel-time differences from each source point,

X , to the station, we can interpolate along the boundary to obtain the entrance and exit points from the boundary, for each particular δt . Once the latitude and longitude of the entrance point is known, the distance to each station can be obtained by using the travel-time curve and equations (1) through (4).

Using a pre-set distance increment, we can calculate the intermediate distances between the entrance and exit points, assuming δt remains constant. These distances are the same regardless of the orientation of the spherical triangle. In order to determine the latitudes and longitudes of these points, however, the orientation of the spherical triangle with respect to the great circle between the stations must be determined. This determination becomes necessary because both latitude and longitude can be obtained correctly only from a North Pole-oriented triangle. If, for example, X is south of S_2 , the angle α_2 is greater than π . The computer, however, is unable to differentiate quadrants in its arcosine routine, being limited to values between 0 and π . Orientation, therefore, must be specified by some other means, or the geographical coordinates will be computed to be that for X , north rather than south of S_2 .

The solution to this problem comes from a theorem of spherical trigonometry which states that the distance from the pole of any great circle to that great circle is $\pi/2$. Using the great circle between the two stations, therefore, as an "equator", we calculate the latitude

and longitude of the "pole". Then, given the coordinates of X , we can solve for the distance from X to the "pole". If this distance is less than $\pi/2$, α_2 is less than π , since α_2 equals π when X is on the "equator". If this distance is greater than $\pi/2$, α_2 is greater than π , or, since the arcosine routine is limited, $-\alpha_2$ replaces α_2 , i.e., since we are interested in the cos of α , $\cos(\pi + \theta) = -\cos(-\theta) = -\cos\theta$.

The four basic cases which can occur from geometrical considerations are:

- (1) Two crossings of the boundary, both crossings above the great circle;
- (2) Two crossings, both crossings below the great circle;
- (3) Two crossings, one above and one below the great circle;
- (4) Four crossings, two above and two below the great circle.

The first two cases are easy to handle; the last case can be broken into two parts, and the methods for cases (1) and (2) applied to solve it.

The main problem still existing occurs for case (3). In this case the great circle passes through the boundary, and the boundary is near and may often include one or both stations. The solution to this situation has not been found as yet. Use of the constant velocity program from the T-phase studies, which does work for the T-phase, has failed here. The cause may lie in the gradual change of the hyperbolas to ellipses as the station is neared, the situation being analogous to the equipotential lines lying between two point charges of opposite sign

apart, at distance, P, which are hyperbolas at distances far from the charges, but become ellipses very near the charges. It is more probable, however, that the conversion from constant to variable velocities from travel-time curves has created the problem.

The 8t data points were obtained through use of an IBM 7040 computer. Enough information was obtained by computer to allow many of the incomplete parts to be completed by hand. In these cases the plots were drawn with knowledge from the computer-plotted data that the curves were smooth, continuous, and symmetric.

Conclusions

P-wave travel time curves, as the ones shown in appendices 3 through 9, allow the quick determination of earthquake epicenters and could permit the Seismic Sea-Wave Warning System to issue earlier alerts, more accurate earthquake origin times, and precise tsunami arrival times. This method eliminates the need for repetition of calculations and adjustments in the estimation of origin times. In addition, it gives a precise epicenter location and good estimates of origin times.

Acknowledgments

The work on which this report is based was supported by the Office of Naval Research through contracts Nonr 3748(01) and Nonr 3748(03); and by the State of Hawaii.

We are particularly indebted to Dr. W. M. Adams and Mr. R. H. Johnson for their help and advice. The original spherical hyperbola program was begun by Mr. Norman Chang, and much of the theory and logic

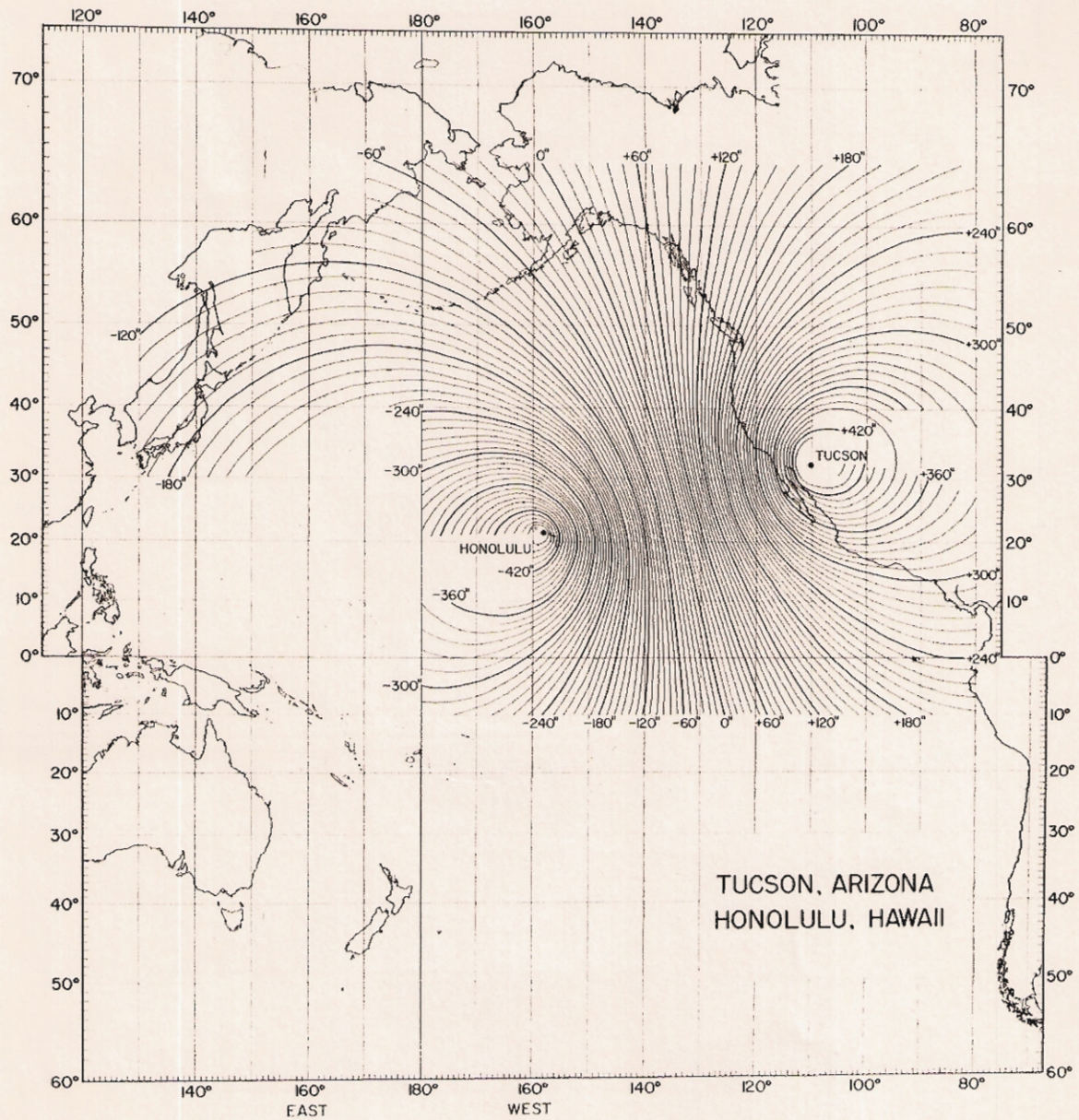
was worked out by the T-phase staff of the Institute.

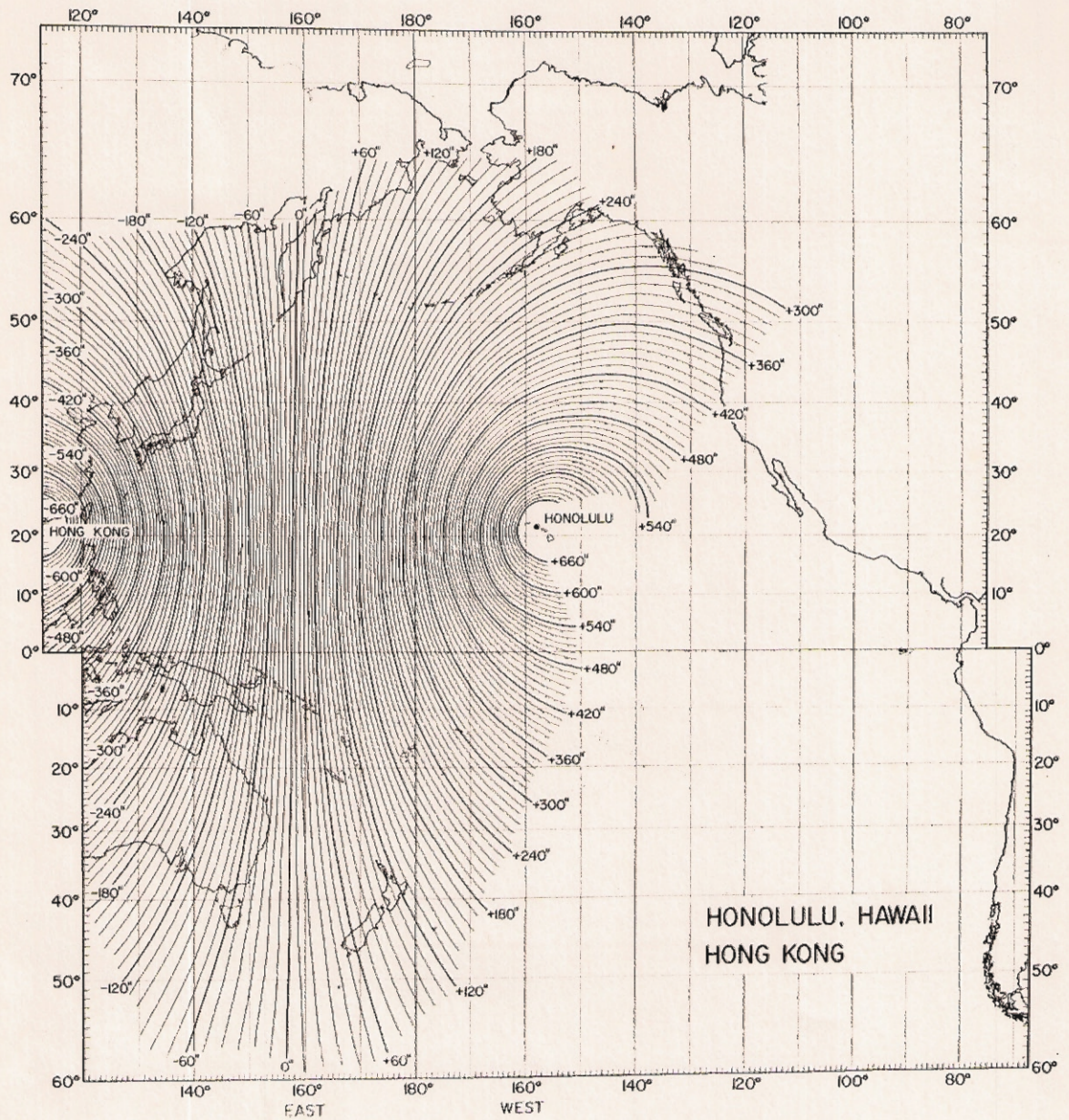
The δt calculations were made at the Statistical and Computing Center, University of Hawaii.

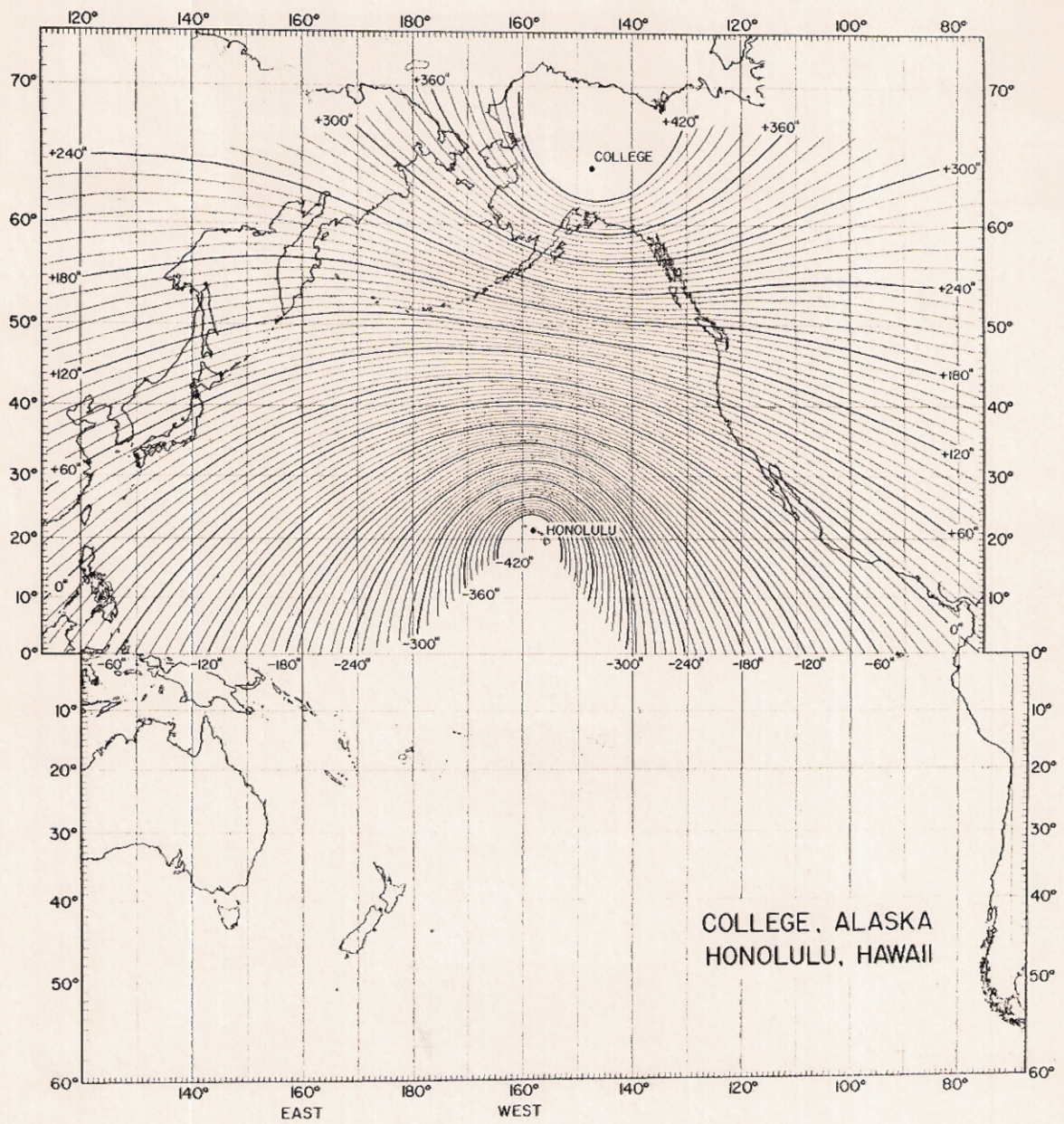
We would like to express our appreciation to Mrs. Ethel McAfee for her editorial help, and to Mr. R. Rhodes and Mr. W. Ramsey for the preparation of the final illustrations included in this report.

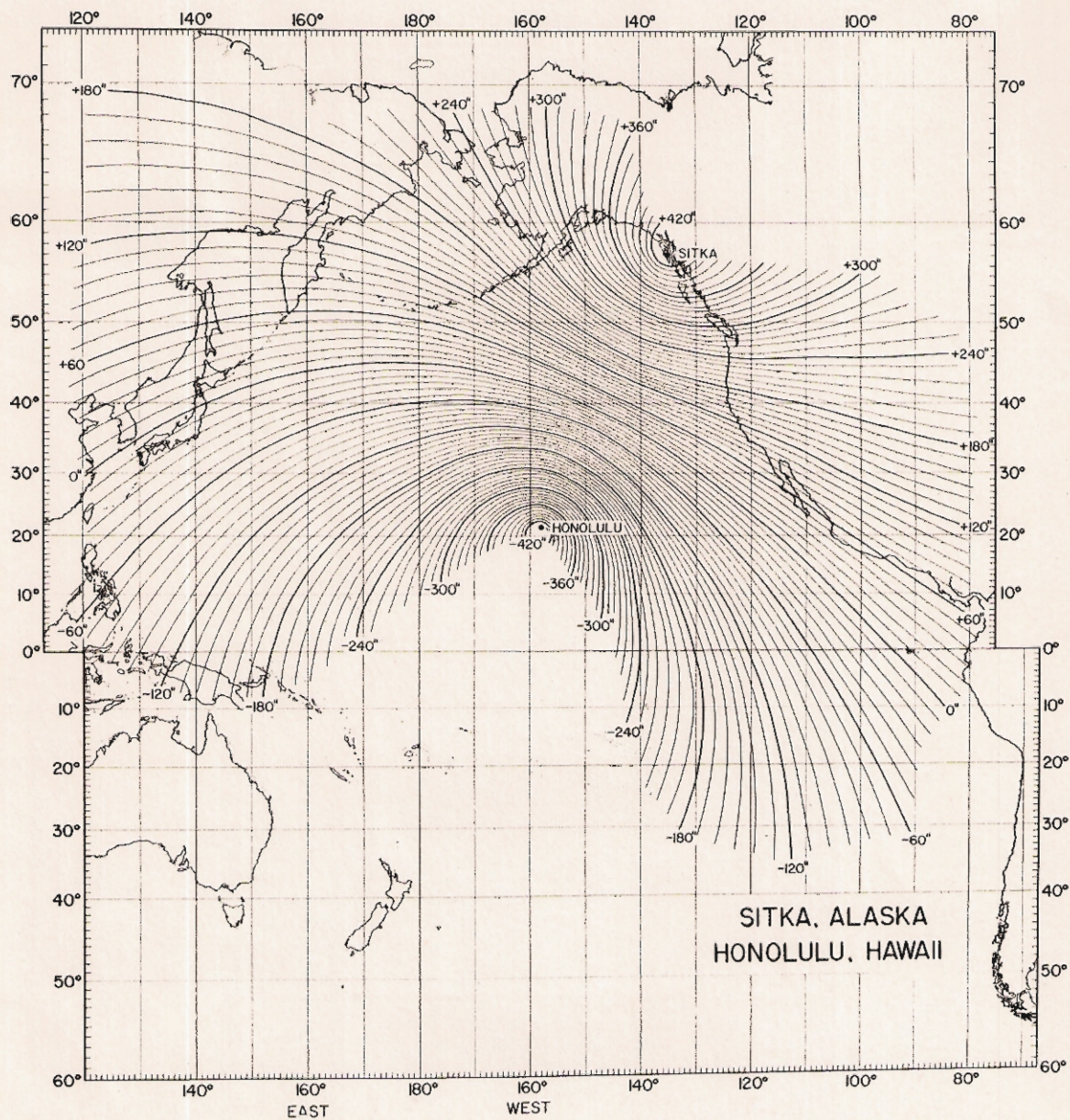
Bibliography

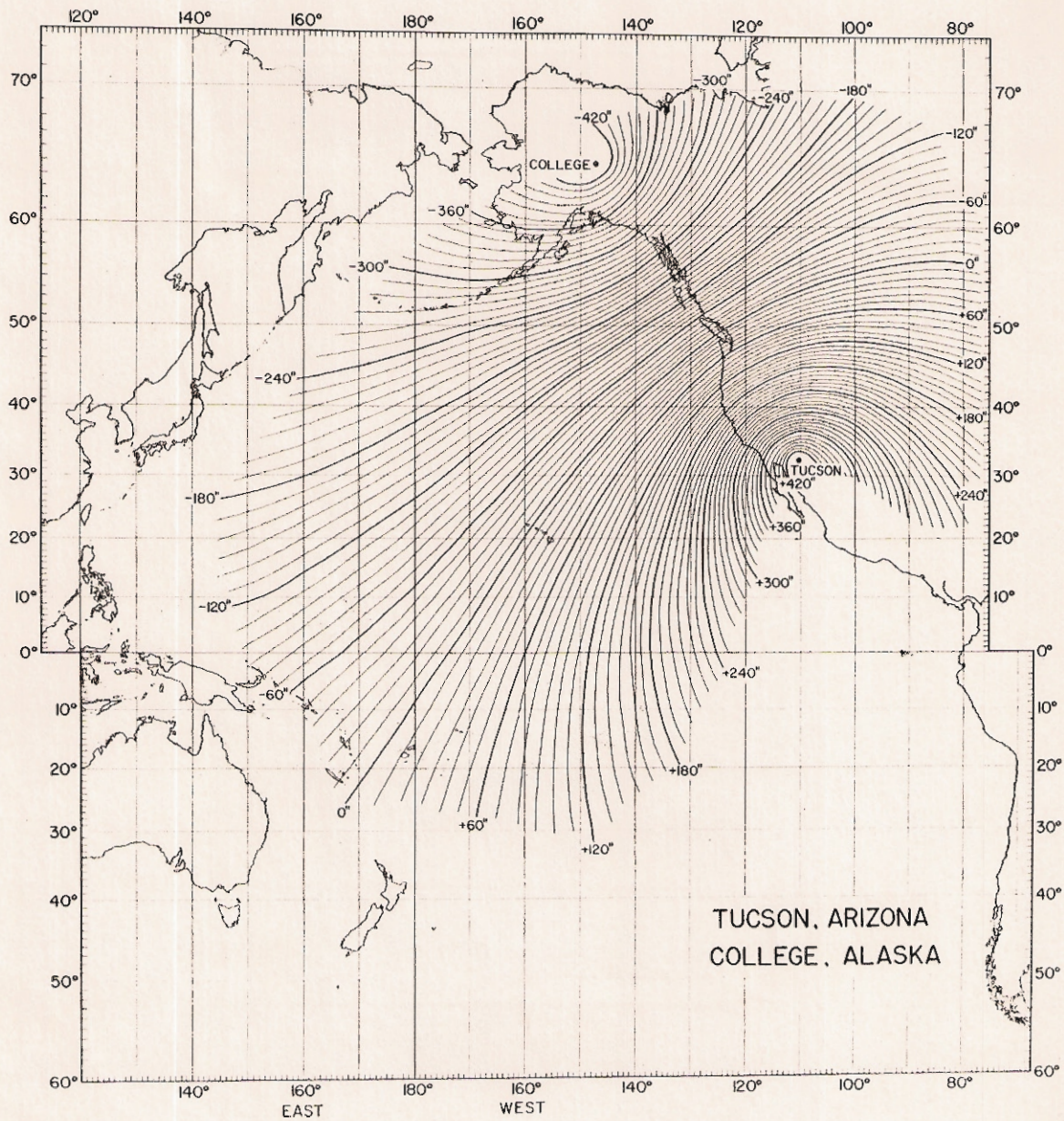
1. Macelwane, J. B., Introduction to theoretical seismology,
Part I. Geodynamics, St. Louis University, 1932.
2. Woollard, G. P., A manual for SOFAR observers, WHOI SOFAR Project,
July 1, 1947.
3. Barbour, L. H. and G. P. Woollard, SOFAR triangulation methods,
Reference no. 49-38, Woods Hole Oceanographic Institution,
August, 1949.
4. Triangulation tests of the northeast Pacific SOFAR network, by
SOFAR Research Group, Applied Research Division for U. S. Navy
Electronics Laboratory NE 011103 Report 175 Problem 2A1a, April
1950.
5. Seismological Bulletin, U. S. Department of Commerce, Coast and
Geodetic Survey, March 1964.

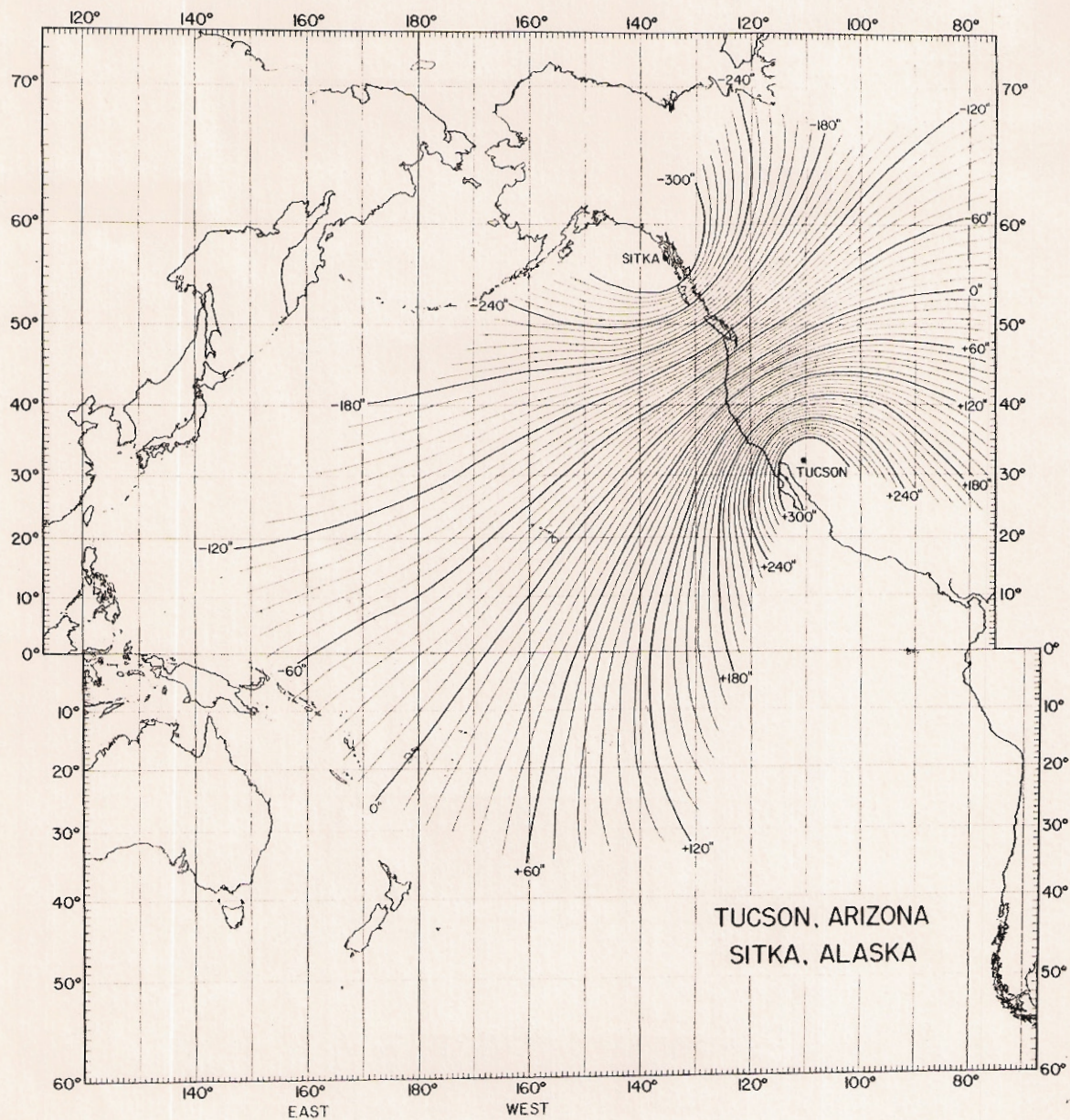


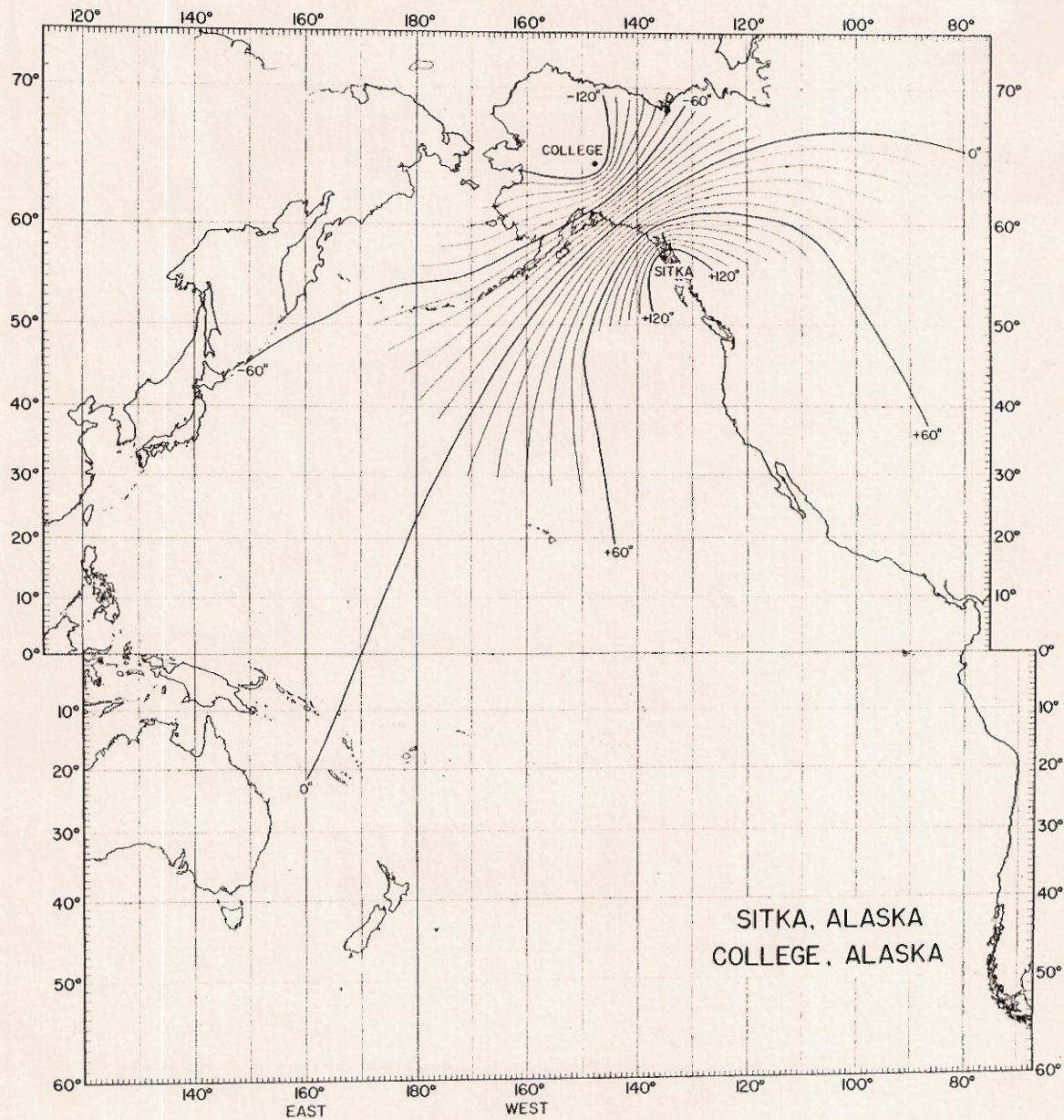














Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION	
Hawaii Institute of Geophysics University of Hawaii Honolulu, Hawaii 96822		Unclassified	
2b. GROUP			
3. REPORT TITLE			
Earthquake Epicenter Determination Using δt Data			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)			
5. AUTHOR(S) (Last name, first name, initial)			
Pararas-Carayannis, George and Sasser, James			
6. REPORT DATE		7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1965		42 pp., 7 charts	5
8a. CONTRACT OR GRANT NO.		9a. ORIGINATOR'S REPORT NUMBER(S)	
Contract No. Nonr-3748(01); and b. PROJECT NO. Nonr-3748(03)		HIG-65-16	
c.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.			
10. AVAILABILITY/LIMITATION NOTICES			
no limitation			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY	
none		Office of Naval Research	
13. ABSTRACT			
<p>Theoretical time-differences in the arrival of P-waves at different seismic stations around the Pacific are compiled by digital computer. Time-difference curves (δt) are plotted for a number of seismic stations on a number of charts. These charts allow the quick determination of earthquake epicenters. A modified version of the spherical hyperbola program that is used in the compilation is included, as well as compiled travel-time difference charts.</p>			

UNCLASSIFIED TECHNICAL REPORTS DISTRIBUTION LIST
for OCEANOGRAPHIC CONTRACTORS
of the GEOPHYSICS BRANCH
of the OFFICE OF NAVAL RESEARCH
(Revised August 1964)

DEPARTMENT OF DEFENSE

- 1 Director of Defense Research
& Engineering
Attn: Coordinating Committee
on Science
Pentagon
Washington, D. C.
- 1 Attn: Office, Assistant Director
(Research)

Navy

- 2 Office of Naval Research
Geophysics Branch (Code 416)
Washington, D. C. 20360
- Office of Naval Research
Washington, D. C. 20360
- 1 Attn: Biology Branch (Code 446)
- 1 Attn: Surface Branch (Code 463)
- 1 Attn: Undersea Programs (Code 466)
- 1 Attn: Field Projects (Code 418)
- 1 Commanding Officer
Office of Naval Research Branch
495 Summer Street
Boston, Massachusetts 02110
- 1 Commanding Officer
Office of Naval Research Branch
207 West 24th Street
New York, New York 10011
- 1 Commanding Officer
Office of Naval Research Branch
219 S. Dearborn Street
Chicago, Illinois 60604

- 1 Commanding Officer
Office of Naval Research Branch
1000 Geary Street
San Francisco, California 94109
- 1 Commanding Officer
Office of Naval Research Branch
1030 East Green Street
Pasadena, California 91101
- 10 Commanding Officer
Office of Naval Research Branch
Navy #100, Fleet Post Office
New York, New York
- 1 Oceanographer
Office of Naval Research
Navy #100, Box 39
Fleet Post Office
New York, New York
- 1 Contract Administrator
Southeastern Area
Office of Naval Research
2110 "G" Street, N.W.
Washington, D. C. 20007
- 1 ONR Special Representative
c/o Hudson Laboratories
Columbia University
1145 Palisade Street
Dobbs Ferry, New York 10522
- 6 Director
Naval Research Laboratory
Attn: Code 5500
Washington, D. C.

(Note: 3 copies are forwarded by the
above addressee to the British Joint
Services Staff for further distribution
in England and Canada.)

- | | |
|---|--|
| <p>1 Oceanographer
Office of the Chief of Naval Operations
OP-09B5
Washington, D. C.</p> <p>1 Commander
U. S. Naval Oceanographic Office
Washington, D. C.
Attn: Library (Code 1640)</p> <p>1 U. S. Naval Branch
Oceanographic Office
Navy 3923, Box 77, FPO
San Francisco, California</p> <p>Chief, Bureau of Naval Weapons
Department of the Navy
Washington, D. C.</p> <p>1 Attn: FASS</p> <p>1 Attn: RU-222</p> <p>1 Office of the U. S. Naval
Weather Service
U. S. Naval Station
Washington, D. C.</p> <p>1 Chief, Bureau of Yards & Docks
Office of Research
Department of the Navy
Washington, D. C.
Attn: Code 70</p> <p>1 Commanding Officer & Director
U. S. Navy Electronics Laboratory
San Diego, California 92152</p> <p>1 Attn: Code 3102</p> <p>1 Attn: Code 3060C</p> <p>1 Commanding Officer & Director
U. S. Naval Civil Engineering
Laboratory
Port Hueneme, California
Attn: Code 154</p> <p>Commanding Officer
Pacific Missile Range
Pt. Mugu, California</p> <p>1 Attn: Code 3145</p> <p>1 Attn: Code 3250</p> <p>1 Commander, Naval Ordnance Laboratory
White Oak, Silver Spring, Maryland
Attn: E. Liberman, Librarian</p> | <p>Commanding Officer
Naval Ordnance Test Station
China Lake, California</p> <p>1 Attn: Code 753</p> <p>1 Attn: Code 502</p> <p>1 Commanding Officer
Naval Radiological Defense Laboratory
San Francisco, California</p> <p>1 Commanding Officer
U. S. Naval Underwater
Ordnance Station
Newport, Rhode Island</p> <p>Chief, Bureau of Ships
Department of the Navy
Washington, D. C.</p> <p>1 Attn: Code 373</p> <p>1 Officer-in-Charge
U. S. Navy Weather Research Facility
Naval Air Station, Bldg. R-48
Norfolk, Virginia</p> <p>1 U. S. Fleet Weather Facility
U. S. Naval Station
San Diego, California</p> <p>1 Commanding Officer
U. S. Navy Air Development Center
Johnsville, Pennsylvania
Attn: NADC Library</p> <p>1 Superintendent
U. S. Naval Academy
Annapolis, Maryland</p> <p>2 Department of Meteorology &
Oceanography
U. S. Naval Postgraduate School
Monterey, California</p> <p>1 Commanding Officer
U. S. Naval Underwater Sound Lab
New London, Connecticut</p> <p>1 Commanding Officer
U. S. Navy Mine Defense Laboratory
Panama City, Florida</p> <p>1 Commanding Officer
U. S. Fleet Weather Central
Department of the Navy
Washington, D. C.</p> |
|---|--|

- 2 Officer-in-Charge
U. S. Fleet Numerical Weather Facility
U. S. Naval Postgraduate School
Monterey, California

Air Force

- 1 Hdqtrs., Air Weather Service
(AWSS/TIPD)
U. S. Air Force
Scott Air Force Base, Illinois
- 1 ARCRL (CRZF)
L. G. Hanscom Field
Bedford, Massachusetts

Army

- 1 Army Research Office
Office of the Chief of R & D
Department of the Army
Washington, D. C.
- 1 U. S. Army Beach Erosion Board
5201 Little Falls Road, N. W.
Washington, D. C.
- 1 Army Research Office
Washington, D. C.
Attn: Environmental Sciences Division

OTHER U. S. GOVERNMENT AGENCIES

Chief, Input Section
Clearinghouse for Federal Scientific
and Technical Information, CFSTI
Sills Building
5285 Port Royal Road
Springfield, Virginia 22151

- 20 Defense Documentation Center
Cameron Station
Alexandria, Virginia
- 2 National Research Council
2101 Constitution Avenue, N.W.
Washington, D. C.
Attn: Committee on Undersea Warfare
Attn: Committee on Oceanography
- 1 Laboratory Director
Biological Laboratory
Bureau of Commercial Fisheries
P. O. Box 6121, Pt. Loma Street
San Diego, California

- 1 Commandant (OSR-2)
U. S. Coast Guard
Washington, D. C.

- 1 Commanding Officer
Coast Guard Oceanographic Unit
Bldg. 159, Navy Yard Annex
Washington, D. C.

- 1 Director
Coast & Geodetic Survey
U. S. Department of Commerce
Washington, D. C.
Attn: Office of Oceanography

- 1 Geological Division
Marine Geology Unit
U. S. Geological Survey
Washington, D. C.

- 1 Director of Meteorological Research
U. S. Weather Bureau
Washington, D. C.

- 1 Director
U. S. Army Engineers Waterways
Experiment Station
Vicksburg, Mississippi
Attn: Research Center Library

- 1 Laboratory Director
Bureau of Commercial Fisheries
Biological Laboratory
450-B Jordan Hall
Stanford, California

- 1 Bureau of Commercial Fisheries
U. S. Fish & Wildlife Service
Post Office Box 3830
Honolulu 12, Hawaii
- 1 Attn: Librarian

- 1 Laboratory Director
Biological Laboratory
Bureau of Commercial Fisheries
P. O. Box 3098, Fort Crockett
Galveston, Texas

- 1 Laboratory Director
Biological Laboratory, Auke Bay
Bureau of Commercial Fisheries
P. O. Box 1155
Juneau, Alaska

- 1 Laboratory Director
Biological Laboratory
Bureau of Commercial Fisheries
P. O. Box 6
Woods Hole, Massachusetts
- 1 Laboratory Director
Biological Laboratory
Bureau of Commercial Fisheries
P. O. Box 280
Brunswick, Georgia
- 1 Laboratory Director
Biological Laboratory
Bureau of Commercial Fisheries .
P. O. Box 428
La Jolla, California
- 1 Bureau of Sport Fisheries & Wildlife
U. S. Fish and Wildlife Service
Sandy Hook Marine Laboratory
P. O. Box 428
Highlands, New Jersey
Attn: Librarian
- 1 Director
National Oceanographic Data Center
Washington, D. C.
- 2 Defence Research Member
Canadian Joint Staff
2450 Massachusetts Avenue, N. W.
Washington, D. C.
- 2 Library, U. S. Weather Bureau
Washington, D. C.
- 1 Director, Biological Laboratory
Bureau of Commercial Fisheries
Navy Yard Annex, Building 74
Washington, D. C.
- 1 Director, Bureau of Commercial
Fisheries
U. S. Fish & Wildlife Service
Department of Interior
Washington, D. C.
- 1 Dr. Orlo E. Childs
U. S. Geological Survey
345 Middlefield Road
Menlo Park, California

- 1 Dr. John S. Schlee
U. S. Geological Survey
c/o Woods Hole Oceanographic
Institution
Woods Hole, Massachusetts

- 1 Chief of Scientific & Technical
Publication Staff
Office of Director
U. S. Coast & Geodetic Survey
Mailing Code C-12
Washington, D. C.

RESEARCH Laboratories

- 2 Director
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts
- 3 Project Officer
Laboratory of Oceanography
Woods Hole, Massachusetts
- 1 Director
Narragansett Marine Laboratory
University of Rhode Island
Kingston, Rhode Island
- 1 Bingham Oceanographic Laboratories
Yale University
New Haven, Connecticut
- 1 Gulf Coast Research Laboratory
Ocean Springs, Mississippi
Attn: Librarian
- 1 Chairman, Department of
Meteorology & Oceanography
New York University
New York, New York
- 1 Director
Lamont Geological Observatory
Columbia University
Palisades, New York
- 1 Director
Hudson Laboratories
145 Palisade Street
Dobbs Ferry, New York
- 1 Great Lakes Research Division
Institute of Science & Technology
University of Michigan
Ann Arbor, Michigan
- 1 Attn: Dr. John C. Ayers

- 1 Dr. Harold Haskins
Rutgers University
New Brunswick, New Jersey
- 1 Director
Chesapeake Bay Institute
Johns Hopkins University
Baltimore, Maryland
- 1 Mail No. 353
The Martin Company
Baltimore 3, Maryland
Attn: J. D. Pierson
- 1 Mr. Henry D. Simmons, Chief
Estuaries Section
Waterways Experiment Station
Corps of Engineers
Vicksburg, Mississippi
- 1 Director, Marine Laboratory
University of Miami
#1 Rickenbacker Causeway
Miami, Florida 33149
- 1 Nestor C. L. Granelli
Department of Geology
Columbia University
Palisades, New York
- 2 Head, Department of Oceanography
& Meteorology
Texas A&M University
College Station, Texas
- 1 Director
Scripps Institution of Oceanography
La Jolla, California
- 1 Allan Hancock Foundation
University Park
Los Angeles 7, California
- 1 Head, Department of Oceanography
Oregon State University
Corvallis, Oregon
- 1 Department of Engineering
University of California
Berkeley, California
- 1 Director
Arctic Research Laboratory
Barrow, Alaska
- 1 Dr. C. I. Beard
Boeing Scientific Research Laboratory
P. O. Box 3981
Seattle, Washington
- 1 Head, Department of Oceanography
University of Washington
Seattle, Washington
- 1 Geophysical Institute of the
University of Alaska
College, Alaska
- 1 Director
Bermuda Biological Station
for Research
St. Georges, Bermuda
- 1 Technical Information Center, CU-201
Lockheed Missile and Space Division
3251 Hanover Street
Palo Alto, California
- 1 University of Pittsburgh
Environmental Sanitation
Department of Public Health Practice
Graduate School of Public Health
Pittsburgh, Pennsylvania
- 1 Director
Hawaiian Marine Laboratory
University of Hawaii
Honolulu, Hawaii
- 1 Dr. F. B. Berger
General Precision Laboratory
Pleasantville, New York
- 1 Mr. J. A. Gast
Wildlife Building
Humboldt State College
Arcata, California
- 1 Department of Geodesy & Geophysics
Cambridge University
Cambridge, England
- 1 Applied Physics Laboratory
University of Washington
1013 NE Fortieth Street
Seattle, Washington
- 1 Documents Division - ml
University of Illinois Library
Urbana, Illinois

- | | |
|--|---|
| <p>1 Director
Ocean Research Institute
University of Tokyo
Tokyo, Japan</p> <p>1 Marine Biological Association
of the United Kingdom
The Laboratory
Citadel Hill
Plymouth, England</p> <p>1 Central Library
Lockheed-California Company
Dept. 72-25, Bldg. 63-1, Plant A-1
Burbank, California</p> <p>1 New Zealand Oceanographic Institute
Department of Scientific and
Industrial Research
P. O. Box 8009
Wellington, New Zealand
Attn: Librarian</p> <p>1 President
Osservatorio Geofisico Sperimentale
Trieste, Italy</p> <p>1 Advanced Research Projects Agency
Attn: Nuclear Test Detection Office
The Pentagon
Washington, D. C.</p> <p>1 Director
Water Chemistry Department
Hydraulic Laboratory
University of Wisconsin
Madison, Wisconsin 53706</p> <p>1 American Biophysical Research Laboratory
P. O. Box 552
Lansdale, Pennsylvania</p> <p>1 Department of Geology & Geophysics
Massachusetts Institute of Technology
Cambridge, Massachusetts</p> <p>1 Institute of Geophysics
University of Hawaii
Honolulu, Hawaii</p> <p>1 Dr. Wilbur Marks
Oceanics, Inc.
Technical Industrial Park
Plainview, New York</p> | <p>1 Mr. Neil L. Brown
Bissett-Berman Corporation
2941 Nebraska Avenue
Santa Monica, California</p> <p>1 Dr. Keith E. Chave
Marine Science Center
Lehigh University
Bethlehem, Pennsylvania</p> |
|--|---|