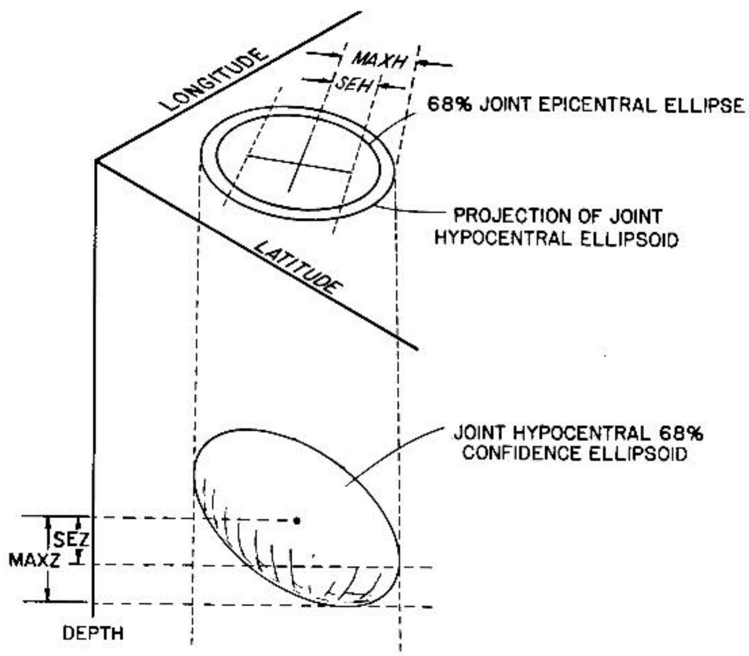
HYPOELLIPSE: A Computer Program for Determining Local Earthquake Hypocentral Parameters, Magnitude, and First-Motion Pattern

By John C. Lahr



Open File Report 99-23
Version 1.1

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 1999
Revised: 2012

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit *http://www.usgs.gov* or call 1–888–ASK–USGS

For an overview of USGS information products, including maps, imagery, and publications, visit *http://www.usgs.gov/pubprod*

To order this and other USGS information products, visit *http://store.usgs.gov*

Suggested citation:
Lahr, J.C., 1999, revised 2012, HYPOELLIPSE: a computer program for determining local earthquake hypocentral parameters, magnitude, and first-motion pattern: U.S. Geological Survey Open-File Report 99-23, version 1.1, 119 p. and software, available at http://pubs.usgs.gov/of/1999/ofr-99-0023/.

Contents

Chapter 1. Introduction to HYPOELLIPSE

➢ *1.1 Program summary*

HYPOELLIPSE is a computer program for determining the hypocenters of local or near regional earthquakes and for each event the ellipsoid that encloses the 68 per cent confidence volume. The program was originally developed on the Lawrence Berkeley Laboratory CDC7600 computer (Lahr, 1979) and was subsequently modified to run on the U.S. Geological Survey (USGS) Honeywell MULTICS (Lahr, 1980), the Stanford Linear Accelerator Center IBM 168, the USGS DEC VAX11/785, the IBM PC, and most recently on the SUN SPARCstation. Travel times are determined from a horizontally-layered velocity-structure, from a linear increase of velocity with depth, from a linear increase of velocity over a half-space, or from a previously generated travel-time table. With the travel-time-table option, gradients are allowed in all layers, but there can be no velocity discontinuities. Arrival times for the first arrival of P waves and S waves, and S-minus-P interval times can be used in the solutions. Arrival times for refractions, such as Pn, even at distances where they do not arrive first, can also be used. Each arrival can be weighted according to the reading clarity, the epicentral distance to the station, and the deviation of its residual from the mean. The hypocenter is found using Geiger's method (Geiger, 1912) to minimize the root-mean-square (RMS) of the travel-time residuals. The magnitude of each event is calculated from the maximum amplitude and/or the signal duration. The program includes a station history database, so that magnitudes will always be computed with the correct response function and gain. First motions can be plotted on the printer using an equal-area, lower-hemisphere, focal projection. The azimuth and apparent velocity of a plane wave crossing the array from a distant source can also be determined.

➢ *1.2 Changes from previous version*

This report documents the current version of HYPOELLIPSE which is operating on SUN SPARCstation computer systems at the University of Alaska Geophysical Institute (UAGI) in Fairbanks, Alaska, and at the USGS in Menlo Park, California. This version supersedes HYPOELLIPSE Version 2 (Lahr, 1989) and incorporates many changes, including:

January 1989

Changed the input keyword for velocity specification (see 2.2.2) from 'CRUSTAL' MODEL to 'VELOCITY' MODEL. 'CRUSTAL' MODEL will still work, however.

April 1989

Removed the DIST option from the INSTRUCTION record. Added the option of specifying the event type and processing state on the INSTRUCTION (see 2.2.6.3) and SUMMARY (see 2.4.1) records. Changed the default, relative standard-errors for weight codes 1-3 from 3.0, 7.5, and 15.0 to 5.0, 10.0, and 20.0, respectively (see 2.2.3.13)

June 1989

Increased the delay-array dimensions to allow up to 10 delay models. Allow added delay models (6-10) to be read after the station list (see 2.2.5.5). Decreased the station arrays from 500 to 400 stations. Added three subroutines called by USEDLY to apply spatially varying station delays (see Chapter 7). Added the processing status and the event type to the summary and the instruction records (see 2.4.1 and 2.2.6.3**).**

August 1989

Modified the format of the station list to allow joint processing of historic and current data from the USGS and the UAGI. Two different telemetry delays are now allowed for a given station at one time and six independent polarity histories can be maintained.

May 1990

Added a simple linear increase with depth velocity-model option with a user-specified reference elevation. For networks in areas with great relief, such as on volcanoes, this allows earthquake travel times to be correctly calculated, even for stations that are at a lower elevation than the hypocenter.

March 1991

Revised the travel-time routines to allow the stations to be "embedded within the model," (see TEST(8) and TEST(9) in section 2.2.4). This was necessary for regions of shallow seismicity with large topographic variations, such as near volcanoes, to allow earthquakes to be located at elevations above some or all of the recording stations. The travel-time-table subroutines have been modified based on suggestions J.A. Snoke.

April 1991

Added option for scaling the normal equations (TEST(34)) and made the minimum damping value a variable (TEST(35)). See 2.2.4.

May 1992

Added computation of median amplitude-magnitude (MDXM) and median coda-magnitude (MDFM) to the printed summary line (see 2.3.6). Modified the station-list records to allow control over which stations are used in computing the average magnitude (see 2.2.5.3).

September 1992

Added the computed depth field to the end of the summary record. Original depth field in cols. 30-34 may be optionally set to 0.0 for negative depths (see TEST(9)).

June 1994

Three-letter station codes are now right justified within the program. Either upper or lower case letters are allowed. The order of the stations in the stations list file must still be alphabetical with the 3-letter codes prior to the 4-letter codes. For example, the following stations would be entered in this order:

ab1 abc abz zzz abcd bcde zzzz.

November 1994

Added TEST(51) (see 2.2.4) to set distance beyond which travel-time tables will be used. This allows for P- or S-arrivals at distances beyond the limit for the flat-earth approximation.

June 1996

Increased array dimensions to allow up to 25 velocity models.

November 1998

Made Y2K changes for HYPOELLIPSE following the plan that Fred Klein is using with HYPOINVERSE. Refer to the manual for specific information about running HYPOELLIPSE. The notes below describe the Y2K changes and are reflected in the manual.

The summary records are the same, except every column is pushed to the right by two spaces to allow for the century. When an event is run that starts with a summary record:
1) if the summary record is in the new format, with / in column 83, then the century is set to the first two columns.
2) If the summary record is in the old format, with / in column 81, then the century is set to TEST(55) (see 2.2.4). TEST(55) is a new variable, which sets the default century.

If the event does not start with a summary record, which will be the case on the first run, then the century is determined by TEST(55). In every case, the output summary and archive files will include the century in columns 1-2 and a '/' in column 83.

The phase (arrival time) records are unchanged. The century is set by the summary record, if available and if in the new format, or by TEST(55).

The format of the time-dependent station records (see 2.2.5.3) has been changed. In the columns where the expiration date was set by yrmody hrmn, which were read by (i6, i4) the new format has cnyrmody hr, which is read by (i8, i2). No other columns on these records are modified.

Events spanning the end of a month or the end of a year. The phase records for a given event must all have the same year and month. If the arrivals do include times on the last day of the month (and/or year) and the first day of the next month, increasing the number of seconds beyond 59.99 accommodates this situation. A phase-record for an event near the end of 1999, for an arrival on January 1, 2000, at 0 hours, 0 minutes, and 13.11 seconds would look like this:

```
RED IPU0 991231235973.11
```

A set of events can also span the 1999 - 2000 time boundary, but not if events in both 1999 and 2000 have no summary records, as TEST(55) will have to be either 19 or 20.

For the transition from 1999 to 2000 one could:

Run all of the events up until the end of 1999 with TEST(55) (see 2.2.4) set to 19. Once all of the 1900's data has been run once, the summary record that precedes the phase records will be in the new format and have 19 in the first two columns.

When first-time processing of data for 2000 begins, change TEST(55) to 20.

The "begin station list" record used to have yrmody for the date of the first event in the run. This has been changed to cnyrmody (century-year-month-day).

The file y2ksta.f is the UNIX source for a simple filter program to convert an old station list into the new format. The SUN executable is y2ksta. This program is a filter that reads standard input and writes to standard output.

To run the program on stations.old to produce stations.new:

y2ksta <stations.old >stations.new

On a PC, y2ksta.for and y2ksta.exe are the source and executable codes for fixing a station list that you are currently using. This is only necessary if the stations list has time-dependent stations parameters. y2ksta.ex must be downloaded and then renamed y2ksta.exe.

The best way to test that the new version is working the same as the old version is to compare the archive files generated by each version. The only problem with this comparison is that the summary records written by the new version include the century. The program del_cent.f (UNIX executable is del_cent) will remove the century from summary records generated by the new version to make the comparison easier.

To run it on new_version.arc to generate modified_new.arc:

del_cent <new_version.arc >modified_new.arc

Then comparison can be made with:

diff old_version.arc modified_new.arc

January 1999

Corrected the vp/vs calculations in subroutine line3 to prevent divide by zero errors should the computed vp/vs ratio equal 1.0.

February 1999

Modified subroutines npunch, phasin, and opfls to correct an error related to time-dependent station parameters.

Modified subroutines xfmags.f and uamag.f to allow for dates between 1970 and 2069 in the University of Alaska station calibration system.

February 2000

Modified subroutines hycrt, hyset, and hytab to correct a potential dimensioning problem due to the value of NLYR.

➢ *1.3 Notes for programmers*

Some of the array dimensions are set via parameter statements in the file params.inc. These include:

NSN, the maximum number of stations in the station list.

NPA, the maximum number of phases per earthquake.

LMAX, the maximum number of velocity records allowed to define velocity models.

MMAX, the maximum number of velocity models.

The setting for these parameters for SUN and PC versions are:

	SUN	PC
NSN	1,501	70
NPA	1,024	140
LMAX	96	36
MMAX	25	10

The number of calibration records allowed in the UAGI magnitude subroutine (MX_REC in UAMAG.FOR) is reset from 1,000 for the SUN version to 100 for the PC version to save additional array-memory space.

A binary search of the station list is used in the function PHAIND. If the search does not work on your computer, then another version of PHAIND, which is commented out, can be used.

The subroutines PHAGT and NPUNCH use the back slash character (\), which must be doubled (\\) on UNIX systems.

The subroutines DUBL, ERSET, JDATE, OPENFL, OPFLS, and TIMIT use non-standard FORTRAN code that will work only on SUN systems and must be modified for use with a PC or VAX system. The alternate code is included in each subroutine, and is enclosed in 'C PC', 'C UNIX', or 'C VAX' comment statements. For UNIX systems, HYPOELLIPSE works with the program XPICK, which stops and starts HYPOELLIPSE by communicating through sockets. For this reason, the main program HYMAIN.FOR and subroutine INIT.FOR are replaced with the main program HYPOE.C and subroutines INITIAL.F, SETUP_SERVER.C, LISTEN_SERV.C, FDGETSTR.C, and CLEANUP.FOR. For UNIX systems, the subroutine GETBIN.F is used to read calibrations data in binary format for the UAGI stations.

The .EXE code provided for an IBM PC or compatible computer requires that an 8087 coprocessor be installed. With the current array dimensions, at least 575 Kbytes of free memory must be available for program execution.

The files used by HYPOELLIPSE are:

FILE UNIT NO.	READ	WRITE	CONTENTS	TYPICAL SUFFIX
8	X		Input control parameters and earthquake data (Program prompts for name of this file).	.DAT
4		X	SUMMARY record file optionally generated.	.SUM
6		X	Final summary showing warning messages and the average residual for each station.	.LOG
9		X	Printed output from execution.	.OUT
2	X	X	Station parameter scratch file.	.1ST
3	X	X	Station parameter scratch file.	.2ST
11		X	Archive-phase file optionally generated.	.ARC
12		X	Alternate input file used with the JUMP option (see 2.2.6.5).	

13		X	Final station corrections when automatic revision has been used (see 2.2.3.17).	.NST
14	X	X	Scratch file for SUMMARY and input records.	.3SC
15	X	X	Scratch file for archive records.	.4SC
16	X	X	Scratch file for temporary message storage.	.5SC
17	X		Definition of cylindrical delay-regions.	
21	X		Travel-time tables for velocity model 26.	.C26
22	X		Travel-time tables for velocity model 27.	.C27
23	X		Travel-time tables for velocity model 28.	.C28
24	X		UAGI calibration data file.	

Chapter 2. HYPOELLIPSE Users Guide

➢ *2.1 Introduction*

HYPOELLIPSE has been developed to meet some of the research needs of the USGS and is in a constant state of modification and revision to meet new needs and implement new ideas. There are many subtle uses of the various options, and a complete description of these would expand the current work to book length. The program and manual are not error-free, and the author would greatly appreciate feedback on any errors or problems encountered.

The number of "options" available is large, and hence a new user may have trouble deciding where to begin and which options to use. The easiest course is to start out by specifying only the minimum amount of information necessary to run the program, including station locations, velocity model, and a few sets of earthquake arrival times. Then review section 2.2 for modifications to the default parameters or additional calculations required by your data set. After the run, refer to section 2.3 to interpret the printed output.

The choice of which velocity model and which variable layer thickness options to use will depend upon how much information one has about the region of study. Some of the possible choices are described below.

Very little is known about the velocity structure.

In this case a single, simple model consistent with available information could be used. The linear increase with depth over a half-space model might be chosen, in that few assumptions need to be made.

Detailed information is available about the thickness of the upper sediment-layer.

In this case, a single, simple model could be used with the thickness of the upper layer varying from station to station. VMOD of section 2.2.3.5 would be set equal to 0.0. On the STATION LIST records (section 2.2.5) the layer thickness for variable layer model 1 would be filled out for each station, and the preferred layer-thickness model for each station would be set equal to 1.

The region covered by the network includes two or more distinct velocity structures, which are well known.

In this case the multiple velocity structure option could be used. Each station would be assigned to one of the velocity models, and that model will always be used to calculate traveltimes to that station. Note that ray tracing is not done so that a shallow earthquake whose waves pass through a number of different velocity structures in the earth will be poorly modeled. However, events deeper than the velocity variations will be modeled relatively well.

Alaska data

In the case of Alaska data, three different velocity models are used, depending upon the location of the earthquake. The station delays may also be a function of earthquake location (see Chapter 7). Selection of the correct velocity model and station delay is done by the subroutine USEDLY (see 2.2.3.6), which has been set up specifically for the Alaska region. This subroutine would need to be modified for use with data from another region. These options allow all of the events from a very large area to be run in chronological order without pre-sorting by the source area.

Fault zone time delays

Work in California indicates that there is a low-velocity zone along the San Andreas Fault. To model this situation, two delays are assigned to each station, one termed delay-model 1 and the other termed delay-model 2. In addition, the stations on the east side of the fault are assigned the delay-model preference number 1, while those on the west side are assigned the number 2. The delay-model used (1 or 2) in locating a particular earthquake is determined by the delay-model preference number of the closest station to the event. For example, an earthquake near station XYZ on the west side of the fault would use delay-model 2. Delay-model 2 has fault zone delays added to the delays of stations on the east side of the fault. The reverse would be true for the earthquakes on the east side of the fault.

Poisson ratio variation between different velocity models and within one velocity model

If desired, the ratio of the P-wave velocity to the S-wave velocity (Vp/Vs) may be specified independently for each velocity model and for each model layer. A simple use of this option would be to specify a different Vp/Vs ratio for each velocity model, but constant within each model. A more complex use would be to vary the Vp/Vs ratio within each model.

➢ *2.2 Specifications for the data-input records*

The input records for this program provide three types of information:

Parameters specific to each user and required for program operation such as the four-character code and location of each station and the velocity model(s) to be used in travel-time calculations;

Parameters that control the iterative location procedure or that specify which of the available output options are to be used;

Arrival-time data to be used in the location of each earthquake.

Except where otherwise noted, items 1 and 2 above have the following format: Columns 1 through 18 contain a keyword which is scanned to determine the number and type of free format variables on the remainder of the record. The directions for each input item indicate how many variables are required and whether they are real, integer, or character. For example,

Format: VELOCITY real, real, real

would indicate that the keyword is VELOCITY and that three real variables must be specified. All columns beginning with an ! mark are ignored, so comments may be placed on any input parameter record. Records starting with C* are processed as comments, and the contents are written to the output file. Note that the number of variables on each record must agree with the instructions, so leaving columns 19 and above blank is not equivalent to specifying a value of 0.0, but instead will generate an error message. If two records with the same keyword in columns 1 through 18 are found, the second one encountered will update the value(s) specified by the first.

Each of the input items is described below. In many cases, the parameters have default values, which are enclosed in brackets, []. If the default is desired, then the record does not need to be included in the input file. The order of sections 2.2.1 through 2.2.5 makes no difference <u>except</u> that the RESET TEST(1) record, which specifies the Vp/Vs ratio, must precede the VELOCITY model records (see 2.2.5).

WARNING: Do not include any tabs on the data-input records. Fortran will not read the record as expected, but the problem can be very difficult to understand, because the record will look correct when printed or viewed with a text editor.

- *2.2.1 Jump record - Format: JUMP character*

If a record of the form JUMP FILENAME is encountered, where JUMP begins in column 1 and the filename is in columns 6-55, then input is switched to the file 'FILENAME'. Input resumes from the original input file after an end-of-file is reached. The jump file may not include any additional JUMP records. A JUMP record may not be imbedded within the STATION LIST records or within an earthquake's PHASE records. A JUMP record after the ARRIVAL TIMES NEXT record or between the earthquakes may optionally contain in columns 56-65 the contents of the start of the next record to be processed. For example, if the columns 56-65 contain the character string '7901' followed by 6 blanks, then all of the records will be skipped until one beginning with '7901' is found. All of the records encountered prior to that one will be skipped.

- *2.2.2 Travel-time calculations*

Both the velocity models and the travel-time tables may be used by HYPOELLIPSE in computing travel times.

- 2.2.2.1) Velocity model specifications (Models 1-25)

  Format: VELOCITY real, real, real

The maximum number of velocity model records that can be used is given in section 1.3. There are three types of model that may be specified and up to 25 models may be defined by up to 96 records (10 models and 36 records on the PC). Models are placed in order starting with model 1. For these models a reference elevation, Eo (see Test(8) in section 2.2.4), is specified for the highest elevation in the region in kilometers above sea level. The "top" of the model is set to Eo. Earthquake depths are still computed with respect to sea level, so negative depths, up to -Eo km are allowed. Station elevations on the station records must be specified in meters above sea level. Specification of Eo allows for the correct location of earthquakes within a region of great topographic relief, such as within a volcano; travel times and take-off angles are computed correctly, even to the stations that are at a lower elevation than the hypocenter.

Constant velocity in each layer.

The three real variables to be specified are the P-phase velocity (km/s), the depth to top of layer (km), and the Vp/Vs ratio. The first record of each model must have a depth of 0.0 km specified. The model may consist of from 1 to 19 layers over a half space for the SUN version and 1 to 11 layers over a half space for the PC version. Embedded low velocity zones are allowed. For example, a 5-km thick layer with velocity of 5.2 km/s and a Vp/Vs ratio of 1.85 over a 7.0 km/s half space with a Vp/Vs ratio of 1.78 would be specified by the following two records:

VELOCITY	5.2	0.0	1.85
VELOCITY	7.0	5.0	1.78

Linear increase in velocity over a half space.

For this model the velocity increases linearly from Vo at the surface by K km/s per km until the half space is reached at a depth of D km. The velocity within the half space is Vh km/s. To use this type of model, the VELOCITY records are defined as follows:

VELOCITY	Vo	0.0	Vp/Vs
VELOCITY	K	1.0	Vp/Vs
VELOCITY	D	2.0	Vp/Vs
VELOCITY	Vh	3.0	Vp/Vs
VELOCITY	200.	4.0	Vp/Vs

Vp/Vs must be specified on each record and must remain constant.

Linear increase in velocity.

For this model the velocity begins at Vo km/s and increases at a rate of K km/s per km. To use this type of model, the VELOCITY records are defined as follows:

VELOCITY	Vo	0.0	Vp/Vs
VELOCITY	K	1.0	Vp/Vs
VELOCITY	300.	3.0	Vp/Vs

Vp/Vs must be specified on each record and must remain constant.

Example: To specify two models, the first model with 20 km of 6.0 km/s over a half space of 7.5 km/s and the second model with a linear increase with depth starting at 4.0 km/s at the surface, increasing 0.11 km/s per km of depth down to 30 km, overlying a half space with a velocity of 8.1 km/s, the following records would be used:

VELOCITY	6.0	0.0	0.0
VELOCITY	7.5	20.0	0.0
VELOCITY	4.0	0.0	0.0
VELOCITY	0.11	1.0	0.0
VELOCITY	30.0	2.0	0.0
VELOCITY	8.1	3.0	0.0
VELOCITY	200.0	4.0	0.0

A blank record between the models is optional. See the next section (2.2.2.2) for more discussion of the Vp/Vs ratio.

- 2.2.2.2) Vp/Vs ratios

The Vp/Vs ratio must be specified for each velocity layer. If specified as 0.0 then the current value on the TEST(1) will be used. Use of this feature will be described by considering various cases:

For all models to use the same Vp/Vs ratio

In this case set the TEST(1) (see 2.2.4) record to the desired value and place it ahead of the VELOCITY-model records in the program input. Also set the Vp/Vs ratio to zero on all of the VELOCITY records.

For different models to use different Vp/Vs ratios

Specify Vp/Vs ratio on each VELOCITY model record. Do not vary Vp/Vs within a given model.

Variation in Vp/Vs ratio within a given model

This feature is allowed only for models with constant velocity layers (not for the linear-increase models). If the Vp/Vs ratio changes within a given model, then a separate S-velocity model is defined and used for the S-phase travel times. The S-phase model is assigned a number one higher than the corresponding P-phase model. For example, if two models are specified in the input stream, and the first model has a variable Vp/Vs ratio, then three models will be defined and used as follows:

	P-Phase Travel Times	S-Phase Travel Times	Vp/Vs
Stations Using Model 1	Model 1	Model 2	Variable
Stations Using Model 3	Model 3	Model 3	Fixed

In this example, no PRIMARY STATION parameter record should specify velocity model 2. (See 2.2.5)

One limitation of this feature is that the S-P interval times (see 2.2.9) do not use the S model, but instead assume the constant Vp/Vs ratio defined by the TEST(1) record. Another limitation is that each variable Vp/Vs-ratio model uses up two models, so that a maximum of 12 models with variable Vp/Vs may be specified.

- 2.2.2.3) Travel-time-table specification

These are Models 26-28 on the SUN and Models 11-13 on the PC

In addition to the 25 models previously described, up to three velocity models may be specified by travel-time tables. The first, which will be model number 26, is read from file number 21. The second and third are model numbers 27 and 28 and are read from file numbers 22 and 23, respectively. The program prompts for the names of the travel-time tables. See Chapter 6 for the operation of the program TTGEN that may be used to generate a travel-time table. This option uses portions of the code written by Klein (1985) for HYPOINVERSE. Note that the elevation of the top of the models (TEST(8), see 2.2.4) must be zero when the travel-time tables are in use.

The Vp/Vs-velocity ratio is specified for each travel-time model (see 6.5), and is used for computing S-phase travel times. However, if the specified Vp/Vs ratio is negative, then the next model will be used for computing the S-phase travel times. For example, if model 26 specifies a negative Vp/Vs ratio, then model 27 will be used for the S-phase travel times for the stations assigned to model 26, and in this case no station may be assigned to use model 27.

- 2.2.2.4) Elevation corrections

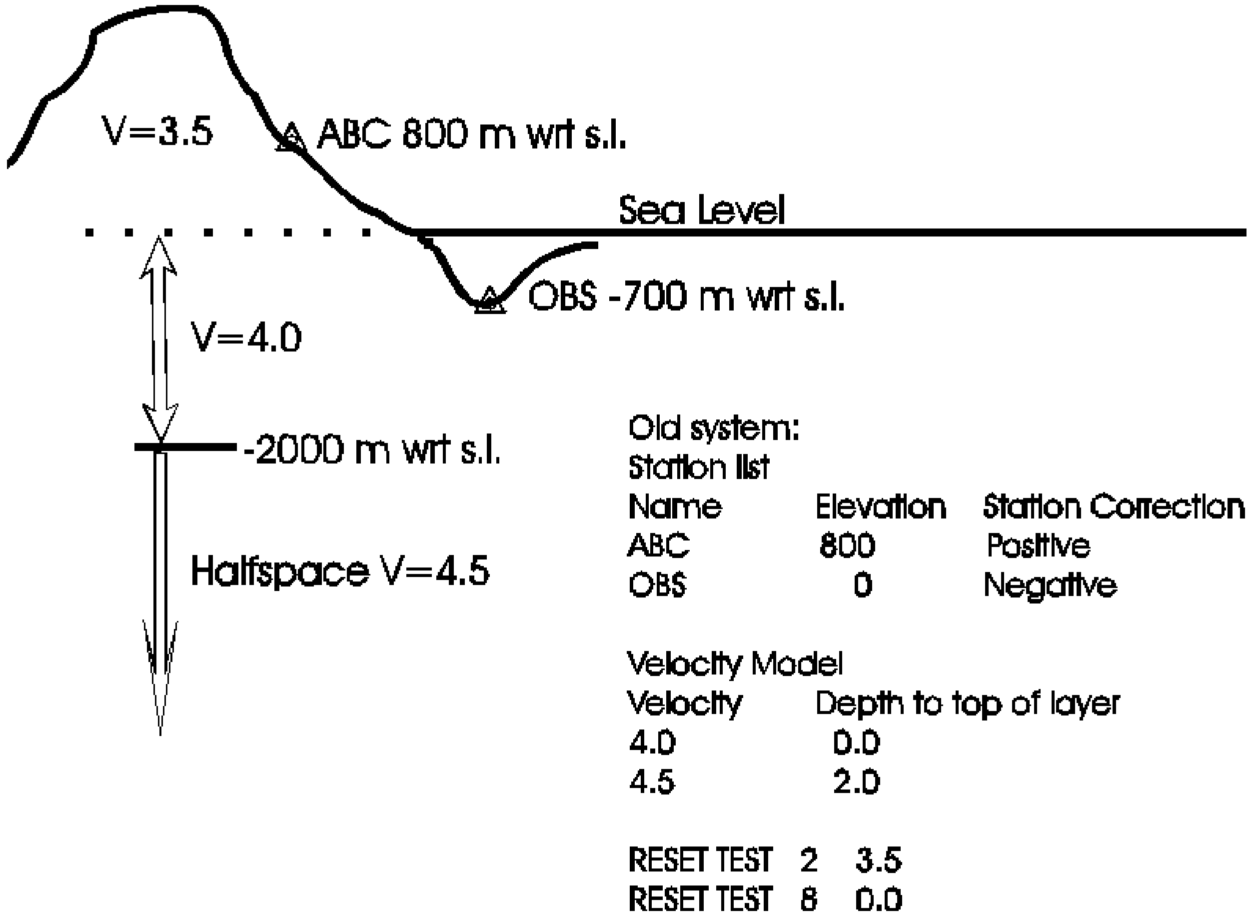
For stations using travel-time tables, the elevation delay is computed from the station elevation (E) divided by the apparent vertical velocity within a surface layer with velocity VS. VS is specified by TEST(2) (see 2.2.4). By using apparent velocity, the elevation correction will vary from a maximum of E/VS for vertical incidence to a minimum of zero for a horizontal direct path. This formulation is reasonable for refracted ray paths but will underestimate the elevation delay for direct ray paths with non-vertical incidence at the surface.

For stations using travel-time calculations, the method above is only used to compute the elevation correction if the elevation of the top surface of the layer models is set to zero by the TEST(8) record (see 2.2.4).

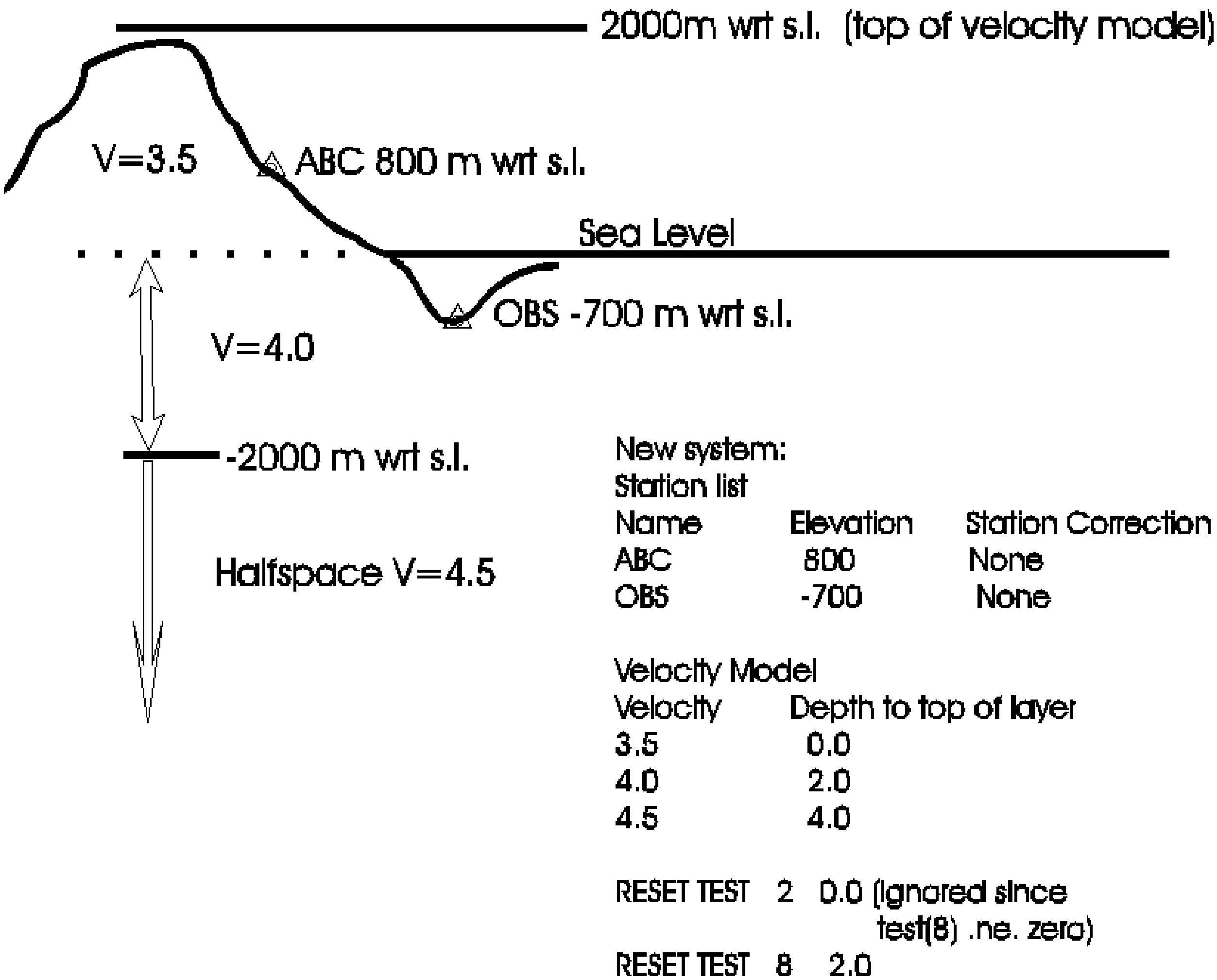
If the elevation (in km above sea level) of the surface of computed travel-time models set by the TEST(8) record is not zero, then the stations with lower elevations are "embedded" within the model, while stations with higher elevations are fixed at the surface. In this case elevation corrections are not needed and the value of TEST(2) is ignored. Note that earthquakes may occur above the "embedded" stations, and that in this case travel times and angles of incidence are correctly computed. See Figures below for an example of the use of "embedded" stations.

A consequence of allowing the surface of the models to be above sea level is that earthquakes may also occur above sea level, and will in this case be given a negative depth. This depth value given on the printed output and on the summary record in columns 113-117 could then be negative. The TEST(9) record (see 2.2.4) is used to control how the depth will be entered on columns 34-36 of the summary record. If TEST(9) is 0.0 then this field of the summary record has the same value as columns 113-117. If, however, the TEST(9) value is not equal to 0.0, then negative depths will be reported as -00 on the summary record in columns 34-36. This was done to accommodate some older software that reads the summary records but does not expect any negative depths.

The following diagrams illustrate the input parameters for the "old" and "new" ways of dealing with elevation corrections. In the "old" system, ocean bottom stations can not be accommodated because negative depths are not allowed. In the illustration for the "new" system, note that stations below sea level are given a negative elevation.



"Old" System of Accommodating Station Elevations. The velocity model is defined only below sea level and negative elevations are not allowed.



"New" System of Accommodating Station Elevations. The "top" of the velocity model is 2 km above sea level and negative elevations are allowed.

- *2.2.3 Option records*

This set of records is optional. Include only those required.

- 2.2.3.1) Printer option record - Format: PRINTER OPTION Integer

Code	Printed output

-2	Only warning messages.
-1	Date and time of each earthquake and warning messages.
0	Final solution for each event showing the residuals at each station.
[1]	Above plus one line per iteration. [ ] denotes default value.
2	Above plus residuals at each station for each iteration
3, 4, or 5	Above plus details from many subroutines. Used for debug purposes only.

- 2.2.3.2) Summary option record - Format: SUMMARY OPTION Integer

See 2.4.1 for the SUMMARY record format and 2.2.15 for the archive format.

Code	SUMMARY record output
0	No SUMMARY records
[1]	SUMMARY records on FILE4
2	SUMMARY records on FILE4 and ARCHIVE-PHASE FILE on FILE11
3	ARCHIVE-PHASE FILE on FILE11
4	PHASE records in input format with "fake" arrival times on FILE11 (see 2.2.13 for example of use)

- 2.2.3.3) Magnitude option record - Format: MAGNITUDE OPTION Integer

Local magnitude (XMAG) and coda magnitude (FMAG) are computed from formulas given in Chapter 4.

Code	Preferred magnitude used on the SUMMARY record and in the final output line (See 2.2.17, 1.3.5, and 2.4.1)
[0]	XMAG (Amplitude magnitude)
1	FMAG (coda length magnitude)
2	(XMAG + FMAG)/2
3	Prefer FMAG but use XMAG if FMAG is not calculated

4	Prefer XMAG but use FMAG if XMAG is not calculated

(Add ten to the code for median rather than the average value to be used as the preferred magnitude.)

The MAGTYP in column 80 of the SUMMARY record is set to X, F, or A, (corresponding to XMAG, FMAG, and average) to denote which type of magnitude was used. If no location can be obtained, then the magnitude is left blank and MAGTYP is set to K.

If the code is negative, the calculation will be based on the F minus S (F - S) rather than the F minus P (F - P) time. F - P is still entered on the ARRIVAL TIME records as the coda length, but the S-P interval is subtracted. If S has not been read, the S residual is greater than (F - P)/10., or the computed S weight is zero, then the calculated rather than the observed S-P interval is subtracted. See 2.2.17 for the use of magnitudes computed outside of HYPOELLIPSE.

- 2.2.3.4) Tabulation option record - Format: TABULATION OPTION Integer

The tabulation at the very end of each run gives various statistics such as the average residual for each station.

Code	Events included in the final tabulation
0	No tabulation
±1	Tabulation for A quality only
[+2]	Tabulation for A and B quality
-2	Tabulation for A and B quality
±3	Tabulation for A, B, and C quality
±4	Tabulation for A, B, C, and D quality

Positive for quality based on error ellipsoid.
Negative for quality defined in HYPO71 (Lee and Lahr, 1972).
See 2.3.5 for definition of A, B, C, and D.

- 2.2.3.5) Variable-layer option record

Format:

VARIABLE LAYER	Integer	Integer	Integer
	NLAY	VMOD	LOWV

This record is required for the variable-layer-thickness option. NLAY is the number of the layer to be varied, VMOD determines how the layer-thickness model is chosen, and LOWV is set to 1 if an equal and opposite change in the thickness of the layer below the variable layer is to be made.

For each station two thicknesses are specified for the variable layer, a model 1 thickness and a model 2 thickness. In the calculation of each travel-time two stations are considered, the closest station to the epicenter and the receiving station. VMOD is used to specify which of three options is desired:

VMOD	Usage
+1	The thickness specified for the receiving station's preferred model (1 or 2) is used. For example, the station STA has the layer thickness for variable-layer model 1 equal to 3 km, and model 1 is its preferred layer-thickness model. Then all of the travel times to station STA will use 3 km as the variable-layer thickness. With this option only one thickness needs be specified for each station.
0	The depth to the lower boundary of the variable layer is calculated for the receiving and for the closest station. If the hypocentral depth is below the average of the two lower-boundary depths, then the receiving station's variable-layer thickness is used. For shallower depths, the lower-boundary depth is set to the average of the receiving station's and closest station's lower- boundary depths.
-1	The thickness model (1 or 2) preferred by the closest station to the epicenter is used to determine the variable-layer thickness used at each station

Example of variable-layer-model velocity in the case where the first-layer thickness is variable and LOWV equals 1:

VELOCITY STRUCTURE AS SPECIFIED ON CRUSTAL STRUCTURE RECORDS

Depth 0 – Top of 5 km/s layer
Depth 10 – Top of 6 km/s layer
Depth 15 – Top of 7 km/s layer

VELOCITY STRUCTURE WHEN VARIABLE LAYER (1) THICKNESS EQUALS 5 KM

Depth 0 – Top of 5 km/s layer
Depth 5 – Top of 6 km/s layer
Depth 15 – Top of 7 km/s layer

Note that in this example no station should be given a variable-layer thickness greater than 15 km.

- 2.2.3.6) Delay model, velocity model, and starting depth option record

Format: SELECT DELAY Integer-code

If the code is positive, which is the default, the delay-model used (1-9) will be the one preferred by the closest station. The velocity model used will be the one preferred by each station, as indicated on the primary station record (2.2.5.2)

If the code is less than or equal to zero, then the subroutine USEDLY is used to control the delays, velocity model and starting depth of each event. Subroutine USEDLY, as distributed, has been tailored for use in processing data from Alaska, and would need to be modified for another region. The current, Alaska, algorithm in USEDLY, which is used when the code is negative, does the following:

Reads the first record following the SELECT DELAY record for the name of a file defining the cylindrical-delay regions.

Selects a velocity model to match earthquake location. Northern model if north of 62.5°N, southern model if south of 62.5°N unless within a cylindrical region or within the Gulf of Alaska. The velocity model is updated before each iteration, but not after the iteration defined by TEST(37).

The delay model is set to one unless the earthquake location is within a cylindrical-delay region or within the Gulf of Alaska. The Gulf uses delay model 5 and delay models 2, 3, and 4 are assigned to cylinders. Up to 10 delay-models may be specified. The delay-model selection is updated each iteration, but not after TEST(37). Chapter 7 describes the use of cylindrical regions in more detail.

Sets an upper limit on the maximum starting depth depending on each event's starting location. Section 2.2.12 summarizes how the first trial depth is determined.

For events in the Gulf of Alaska, fixes depth at 10 km.

- 2.2.3.7) Missing stations option record - Format: MISSING STATIONS Integer-code

Code	Effect
0	The station list will be searched after each event is located for stations that would possibly improve the earthquake solution quality. Stations are listed which are closer to the epicenter than the third-closest station used to compute the solution or that would reduce the GAP (see 2.3.6) by 30° or more.

[1]	A search for "missing" stations is not conducted.

Searching for missing stations requires that the entire station list be initialized, so this option can not be used with a negative code on the BEGIN STATION LIST record. (See 2.2.5)

- 2.2.3.8) Sort option record - Format: SORT OPTION Integer-code

Code	Effect
[0]	Stations are listed in the output in order of increasing epicentral distance.
1	Stations are listed in the same order as the input ARRIVAL TIME records.

- 2.2.3.9) Compress option record - Format: COMPRESS OPTION Integer-code

Code	Effect
0	Printout is compressed by not skipping to the top of a new page for each solution.
[1]	Printout for each earthquake starts on a new page.

- 2.2.3.10) Debug option record - Format: DEBUG OPTION Integer-code

Code	Effect
[0]	This option is not called into play and no additional record is needed.
1	This option is used and the record below must be included:

Debug limits record - the following format must be used:

(10X, F5.2, 5X, F5.2, 5X, F5.2, 5X, i5, 5X, i5, 5X, i5)

For example:

1-10	11-15	16-20	21-15	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65
Max RMS	0.65	PRES	1.00	SRES	1.00	NWOUT	2	NMAX	8	SEMX	25

The words are typed only for your convenience and the order of the variables is fixed. The value of any variable that is not specified will be read as zero. This setup would give a detailed printout of travel times, residuals, etc., for each station only for "Debug events" defined by:

RMS > MAX RMS, 0.65 s, or
Largest P-Res with computed weight greater than 0.2 > PRES = 1 s, or
Largest S-Res with computed weight greater than 0.2 > SRES = 1 s, or
Combined number of P and S readings weighted out by the program > NWOUT = 2, or
(this excludes readings assigned weight-codes 4-8)
Total number of iterations > NMAX = 8, or
The maximum error estimate > SEMX = 25 km.

The DEBUG OPTION can be used with the COMPRESS OPTION so that each event will not start on a new page.

TABLE OF DEBUG OPTIONS		
CODE	EVENT PRINTOUT	SUMMARY RECORD
[0]	Controlled by PRINT OPTION.	Controlled by SUMMARY OPTION
+1	Summary line for good events. Detailed for debug events.	For both good and debug events
-1	Same as for +1	Only for good events
+2	No print for good events. Detailed for debug events.	For both good and debug events
±3	Detailed for all events To rerun debug events with only critical stations set TEST(44) = 1.0	For both good and debug events

- 2.2.3.11) Find the global minimum in depth - Format: GLOBAL OPTION Integer

This option is now set up to find the best solution in regions where the depths vary from the surface to 100 km or more. This option can not be used if the hypocenter is fixed on a plane, so TEST(47) (see 2.2.4) must be set to 0.0. Also, a global solution will not be attempted if the instruction record fixed location indicator is set for fixed depth (1) or fixed hypocenter (7 or 9).

TABLE OF GLOBAL OPTIONS

Code	Effect
[1]	GLOBAL OPTION is turned off.
0	Global search option is turned on. The "global" search begins by solving two fixed-depth solutions: S(1) with the event at the Earth's surface (z = -TEST(8)) and S(2) with z first fixed at DEEPZ = TEST(42) km below sea level and then allowed to go free. If the depth of S(2) is within 0.1 km of the surface, the surface solution is reported. If the depth of S(2) is less than CUTZ = TEST(27) km below sea level and ➢ the surface RMS is significantly lower than RMS of S(2) then a free depth solution starting at S(1) is reported. ➢ the RMS of S(2) is significantly less than the surface RMS, then S(2) is reported. ➢ neither solution has significantly lower RMS, so the one with lower RMS is reported and the printer output file will give the RMS and depth of both solutions. If the depth of S(2) is greater than or equal CUTZ = TEST(27) below sea level then a solution S(3) with z fixed at SHALZ = (CUTZ - TEST(8))/2.0 km below sea level is computed. ➢ If the RMS of the surface solution S(1) is less than the RMS of S(3) then find a free-depth solution called S(4) starting at S(1). ▪ If the difference in depth between S(3) and S(4) is less than DEEPZ/10.0 then use S(4) as the reported solution. ▪ If the solutions S(3) and S(4) are more than DEEPZ/10.0 km apart, then if S(4) has significantly lower RMS value it is reported as the final solution. if S(4) does not have significantly lower RMS than S(3), both are reported to the printed output, and S(4) is taken as the final solution. ➢ If the RMS of the surface solution S(1) is greater than the RMS of S(3) then find a free-depth solution called S(4) starting at S(3). ▪ If the difference in depth between S(1) and S(4) is less than DEEPZ/10.0

	then use S(4) as the reported solution. ▪ If the solutions S(1) and S(4) are more than DEEPZ/10.0 km apart, then if S(4) has significantly lower RMS value it is reported as the final solution. if S(4) does not have significantly lower RMS than S(1), both are reported to the printed output, and S(4) is taken as the final solution.

The error limits reported to the output and to the SUMMARY record are the greatest deviations of depth with RMS less than RMSLIM (See Chapter 3.2 for the definition of RMSLIM), even if there are intervening peaks in the RMS. This limit is approximately equivalent to one standard deviation in depth.

For different networks and regions, the values of DEEPZ and CUTZ may need to be adjusted for best results.

- 2.2.3.12) Residual option record - Format: RESIDUAL OPTION Integer

After the initial location of an earthquake, the printed output can be checked for large residuals. When the original seismograms are reviewed to correct errors, inexperienced processors can be influenced in their revisions by the printed computer residual. Printing the calculated value of the residual may be hazardous and ***not*** recommended because, in many cases, the true error, if any, is not reflected by the individual residuals.

To prevent this ill-advised feedback, the "preliminary option" may be used.

TABLE OF RESIDUAL OPTIONS	
Code	Effect
0	Prints station residual in "residual" format, as described below.
[1]	Prints station residual in normal format.

The "residual" format consists of the following:

P and S residuals less than 2.25 s are shown only in absolute value and are rounded to the nearest 0.5 s. The printed residual (Rp) is related to the absolute value of the calculated residual (R) as follows:

$0 < R \leq .25$	Rp = 0
$0.25 < R \leq .75$	Rp = 0.5
$0.75 < R \leq 1.25$	Rp = 1.0

$1.25 < R \le 1.75$	Rp = 1.5
$1.75 < R \le 2.25$	Rp = 2.0

Large residuals are flagged. For residuals (R) that have not been weighted out automatically by the program, an * is placed after the residual if it meets one of the following criteria:

P Residuals

- R > 0.6 for one of the closest five stations
  R > 0.9 for distance less than 150 km
  R > 1.5 for epicentral distance less than 350 km

S Residuals

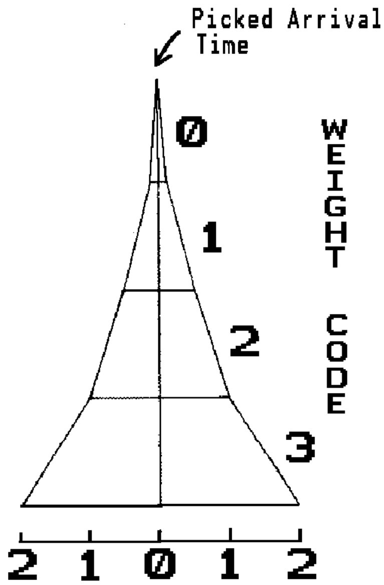
- R > 0.9 for one of the closest five stations
  R > 1.5 for epicentral distance less than 150 km
  R > 2.0 for epicentral distance less than 350 km

- 2.2.3.13) Weight assignment option

Format: WEIGHT OPTION Real Real Real

The relative weight assigned to each reading is dependent upon an integer weight-code, which can range from 0 for the most impulsive to 4 for readings that are too uncertain to be used in the hypocentral solution. It is recommended that TEST(29) (see 2.2.4) be set to minus the standard error of the best readings, and that these readings be assigned zero weight-code. Less certain readings are then assigned larger weight-codes. If, for example, weight-codes of 1, 2, and 3 are to be assigned to readings that have standard errors that are 5, 10, and 20 times less certain than the best, respectively, then the three WEIGHT OPTION parameters should be set to 5, 10, and 20. For processing Alaska seismic data, 0, 1, 2, and 3 weight-codes are assigned to readings with standard errors ranging up to 0.1, 0.5, 1.0, and 2.0 s, respectively.

The graph below is used to assign weight-codes according to these limits.



Reading Uncertainty (s)

The default weight and corresponding relative standard error corresponding to each weight-code is given in the table below:

WEIGHT-CODE	STANDARD ERROR (S)	STANDARD ERROR RELATIVE TO READINGS WITH WEIGHT-CODE ZERO	COMPUTED WEIGHT
0	0.1	1.0	1.0
1	0.5	5.0	1/25
2	1.0	10.0	1/100
3	2.0	20.0	1/400
4	INFINITE	INFINITE	0.0

To change the default weight assignments, include a record with WEIGHT OPTION starting in Column 1 followed by the relative standard errors for weight-codes of 1, 2, and 3. For example, the default weights that used to be set in older versions of HYPOELLIPSE could be reset with:

WEIGHT OPTION 1.33 2. 4.

- 2.2.3.14) Ignore summary records - Format: IGNORE SUMMARY REC Integer-code

Code	Effect
[1]	The starting location parameters (latitude, longitude, depth, and origin time) may be taken from the SUMMARY record. (see 2.2.12)
0	The SUMMARY record will be ignored in determining the starting location parameters.

- 2.2.3.15) Header content record - Format: HEADER OPTION Any alphanumeric heading

Used to write a heading of up to 50 characters above each earthquake in the output.

- 2.2.3.16) Comment records - Format: C* Any Comment

Any record with C* in columns 1-2 will be printed out during program execution but is otherwise ignored. Comments may not be imbedded within the station list.

- 2.2.3.17) Relocate after revising the delays - Format: RELOCATE Integer-code

This will cause the input file to be rewound and rerun N = Code times. Prior to each rerun, the station delays for delay-model 1 will be revised by adding the event-weighted, average station residual. At the end of the job a file is generated on Unit 13 with one record for each station used. These records are in the format of the primary station records. (see 2.2.5) The P- and S-delay field for delay-model 1 will contain the revised station delays. The field for delay-models 2 through 5 will be blank. The default is Code = 0.

- 2.2.3.18) Uofacal option - Format: UOFACAL OPTION Filename

Used to specify the name of the file that contains calibration data in the format used by the UAGI. (see 4.2.3). Type UOFACAL beginning in column 1 and the filename in columns 19-68.

- 2.2.3.19) Reset all control parameters to the initial default values

Format: STANDARD TEST

- 2.2.3.20) Constants noprint option - Format: CONSTANTS NOPRINT Integer

Controls whether the station list, the user-specified constants, and the control options will be written to the output file.

Code	Effect
0	Do not write out these items.
[1]	Write out these items.

- 2.2.3.21) Blank source option - Format: BLANK SOURCE One-Character Code

The station list may contain calibration, polarity, and telemetry-delay information for various sources of data. The arrival-time records have columns to specify the source of the P- and S-arrival times, the first motion, and the amplitude. However, some sets of arrival-time data may not have any source code entries. The BLANK SOURCE code specified on this record will be used whenever the arrival-time source code is blank in computing delays, magnitudes and corrected polarities.

- *2.2.4 Reset test records - Format: RESET TEST Integer Real*

These records have RESET TEST typed starting in column 1 and beginning in column 19 the test number and the new value for the test variable. All of these records are optional and need be included only if a non-default value is required.

Test No.	Default Test Value	Description
1	1.78	Ratio of P-wave to S-wave velocity
2	5.0	P-phase velocity for elevation corrections (km/s). If the value is negative, make no elevation corrections. If zero, use first-layer velocity for elevation corrections. If greater than zero, use this for elevation corrections. In the latter case, value must be less than first layer P-phase velocity. Used with computed models if TEST(8) = 0 and with travel-time tables.

Trial Location		
3	0.0	First trial latitude (degrees). North positive. If TEST(3) or (4) = 0, then ignore. See 2.2.12 for use.
4	0.0	First trial longitude (degrees). West positive. If TEST(3) or (4) = 0, then ignore. See 2.2.12 for use.
5	-99.0	Used for first trial depth (km with respect to sea level) unless equal -99 or unless Global Option is in effect. See 2.2.12 for use.
6	0.0	RMS may optionally be computed at additional points on a sphere surrounding the final hypocenter. This is the radius of the sphere (km). If zero, no auxiliary RMS values are calculated. If negative, and if one or more points have lower RMS than the final solution, continue iteration once starting at point with lowest RMS value.
7	10.0	Focal Mechanism Plot. Minimum number of first motions for a first-motion plot to be made. If negative, make a second plot showing station codes.
8	0.0	Elevation of top of computed models with respect to sea level (km).
9	0.0	If not zero, reset negative depths in summary record cols. 32-36 to -00. True depth below (positive) or above (negative) sea level always given in cols. 113-117 of the summary record..
Distance Weighting		
10	0.0	Apply distance weighting on this iteration. See also TEST(11) and (12).
11	50.0	XNEAR = Greatest distance (km) with assigned weight multiplied by 1.0
12	100.0	XFAR = Least distance (km) with assigned weight of multiplied by 0.0. See also TEST(46).
13	50.0	Azimuthal Weighting. Apply azimuthal weighting on this iteration. Warning: this option has not been tested.

Truncation Weighting		
14	50.0	If there are 6 or more phases, then weight out large residuals on this iteration. See also TEST(15).
15	10.0	Give zero weight to residuals greater than this (s).
Boxcar Weighting		
16	50.0	If there are 6 or more phases, then apply boxcar weighting on this iteration. See also TEST(17), (34) and (35).
17	2.0	Give zero weight to residuals greater than this times the standard deviation (s).
Jeffrey's Weighting		
18	50.0	Begin Jeffrey's weighting on this iteration. (See also TEST(34) and (35)).
19	0.05	Use Jeffrey's weighting only if RMS is greater than this (s).
20	0.05	Mu of Jeffrey's weighting function

Test No.	Default Test Value	Description
21	9.0	Maximum number of iterations allowed
22	35.0	Limit change in focal depth to approximately this amount (km).
23	0.7	If move would take earthquake above surface, move this proportion of the way to the surface
24	35.0	Limit change in epicenter to approximately this amount (km).
25	40.0	Fix depth if epicentral change greater than this (km).
26	0.002 5	Stop iterations if adjustment squared is less than this (km).
27	20.0	Global solution option: if deep solution converges below this

		depth with respect to sea level, continue at a depth half way between this depth and the surface of the velocity models. See also TEST(42).
28	0.0	To fix the hypocenter on a plane, set absolute value of this equal to azimuth of plunge line of plane (0^o to 360^o measured clockwise from North). If negative, then a free solution will be determined starting at the best location on the plane. See also TEST(30) and TEST(47).
29	-0.1	If TEST(29) is positive, the standard error of readings assigned zero weight-code is set equal to the RMS residual, unless there are zero degrees-of-freedom or the estimated reading standard error falls below TEST(29). In that case TEST(29) is used for the standard error of the readings. If TEST(29) is negative, the standard error of the zero weight-code readings is always set equal to minus TEST(29). See also 2.2.3.13.
30	0.0	Used if TEST(28) is positive, causing solution to be fixed on a plane. If positive, this is dip of plunge vector of the plane. See also TEST(28) and TEST(47). If negative, then fix epicenter and solve only for depth and origin time, ignoring TEST(47).
Duration Magnitude Parameters (See also TEST(40) and (43))		
31	-1.15	C1, constant
32	2.0	C2, *log((F-P) * FMGC)
33	0.0	C3, *DELTA
34	0.0	If not equal 0, scale the normal equations.
35	0.001	Minimum damping of normal equations.
36	100.0	Maximum first trial depth (km), if computed from P-arrival times.
37	3.0	If termination occurs before this iteration, set iteration number to this and continue. Prevents iteration from stopping before all forms of weighting have been applied. After this iteration, velocity and delay models will not be changed by the SELECT DELAY (2.2.3.6) option.

38	0.0	If 0, use of S arrivals depends upon S-data indicator on INSTRUCTION record. If 1, locate all with and without S arrivals. If 2 locate all with S arrivals. If 3, locate all without S arrivals. If 4, fix all solutions at starting hypocenter, and use S arrival. If negative, use S arrivals only to fix origin time.
39	1.0	Multiply the S and S-P weight-code weights by this factor.

Test No.	Default Test Value	Description
40	0.007	Duration magnitude parameter C4; multiplies the DEPTH (see also TEST(31)-(33) and TEST(43))
41	0.0	If this equals 1, PRINT OPTION is greater than or equal 1, and SUMMARY OPTION equals plus or minus 1, then write a new SUMMARY record after each iteration.
42	75.0	Global solution option: deep starting depth (km with respect to sea level). See also TEST(27).
43	0.0	Duration magnitude parameter C5; multiplies (log ((F-P) *FMGC)**2) (see also TEST(31)-(33) and TEST(40))
44	0.0	If 1, rerun "debug events" again (See 2.2.3.10) with critical stations; if 2, make a second run for all events with critical stations See note below for definition of critical stations.
45	0.1379	X-scale factor for focal mechanism plots. Adjust for printer in use. (See 2.3.9)
46	0.0	If TEST(46) not equal 0.0, distance-weighting constant XFAR (see TEST(12)) will be set to a minimum of 10 km beyond the distance of the TEST(46)th station. If TEST(46) is negative, then any station beyond XFAR that would reduce a gap greater than 60^{o} by 30^{o} or more is given a distance weight of 0.5.

47	0.0	Constraint equation weight for hypocenter fixed on plane. A large value, such as 1000, will prevent out-of-plane movement. If equal to 0, this option is not used. See also TEST(28) and (30). This option may not be used with the GLOBAL OPTION (see 2.2.3.11).
48	6.5	Half-space velocity used for first trial location (km/s).
49	0.0	If absolute value equals 1, compute Vp/Vs and origin time; if equals 2, also make printer plot of S-P vs P. If negative, use this origin time for earthquake location.
50	0.0	Compute this number of fixed depth solutions, starting with Z(1) = -TEST(8) and continuing with Z(i+1) = 1.2*Z(i) + 1.0. The maximum this value can be is 22., which produces a maximum depth of 225 km.
51	1000.0	Beyond this epicentral distance use first travel-time table model.
52	2800.0	Wood-Anderson magnification used in XMAG calculations.
53	1.0	If equal to 1, then assume stations with 4-letter codes ending with e or n are horizontal east-west and north-south stations, respectively.
54	200.0	If 1st computed trial epicenter is greater than this from closest station, start location at closest station.
55	19.0	Default century if not specified on the summary record.

Note on TEST(44) - critical stations

In an effort to speed up the identification of reading errors during preliminary runs of data, an option to automatically rerun each event using only the most important arrivals was developed. In some cases comparing the solution using only critical stations with the normal solution can identify reading errors. In the printed output for critical-station reruns, readings that are not used are marked with an 'X' between the residual and the weight. Critical stations are defined to be:

The closest four stations with P-phase readings that have weight codes less than 4;
b) Additional stations with P- or S-phase readings are considered one at a time and are added only if they reduce a gap of greater than 72^o by 5^o or more;
c) S arrivals are used when available at "critical" stations. If no S arrival is available from a

critical station, then S is used from the closest non-critical station with a weight code less than 4.

▪ *2.2.5 Station list*

The station list is set up so that a complex history of station changes can be maintained, such as the opening and closing dates and changes in gain and polarity (see discussion in 2.2.7). For the southern Alaska seismic network, a complex history beginning in 1971 has been developed. However, in situations where this information is not needed, the station list may consist of just two entries for each station, with many of the fields left blank. Comment records that begin with C* in columns 1 and 2 may be included within the station list.

- 2.2.5.1) Begin station list - Format: BEGIN STATION LIST Integer-code Integer-date

The first record has BEGIN STATION LIST typed in columns 1-18, followed by code and date of the first event to be run. The date includes year, month, and day (for example: 19921028). If the station list contains many stations that expired before the time of the first event, specifying the correct starting date will eliminate the expired stations from the initial printed station list. The STATION records follow this record. (Note that in this Y2K version the date must include the century.)

CODE	Meaning
0 or 1	Print station list updated to date specified and print new station parameters during run as changes occur.
-1	Do not print station list or print new station parameters when a station is updated during run.

- 2.2.5.2) Primary station parameters - Formatted as indicated below.

For each station there is one entry with PRIMARY STATION PARAMETERS, such as latitude and longitude, and one or more entries with TIME-DEPENDENT STATION PARAMETERS, including calibration parameters and polarity indicator. To speed up the search for station parameters, the current version of HYPOELLIPSE requires the station list to be in alphabetical order according to the extended 5-character station code. Right justifying the station code and concatenating the component (z, n, or e) forms this extended name. The station list must be arranged so that those stations with 1-character codes precede those with 2-character codes, which perched those with 3-letter codes, which preceded those with 4-character codes.

Alphabetical order is not required if the alternate version of subroutine PHAIDX, which is included in with the source code, is used. In either case, the first station should be near the center of the network, as it is used as a reference location for calculating the azimuth of approach of a plane wave. A fake station with the code AAA can be used as the first station. See 1.3 for the maximum of number of stations allowed.

Format for PRIMARY STATION PARAMETER records:

Item	Column Nos.		Format
Station Code	1	4	A4
Latitude (Degrees)	5	6	i2
N or blank for North, S for South		7	A1
Latitude (Minutes)	8	12	F5.3
Longitude (Degrees)	14	16	i3
W or blank for West, E for East		17	A1
Longitude (Minutes)	18	22	F5.3

THE FOLLOWING ITEMS ARE OPTIONAL, AND IF LEFT BLANK THE DEFAULT VALUES WILL BE USED.

Item	Default Value	Column Nos.		Format
Elevation (Meters)	0	23	27	i5
Preferred velocity model (SUN: models 1-25 computed, 26-28 from tt table) (PC: models1-10 computed, 11-13 from tt table)	1	28	29	i2
Preferred layer thickness model (1-2)	1		30	i1
Layer thickness for model 1	0.0	31	34	F4.2
Layer thickness for model 2	0.0	35	38	F4.2
Preferred delay-model (1-9)	1		39	i1
P-delay for model 1	0.0	40	43	F4.2
S-delay for model 1	0.0	44	47	F4.2

P-delay for model 2	0.0	48	51	F4.2
S-delay for model 2	0.0	52	55	F4.2
P-delay for model 3	0.0	56	59	F4.2
S-delay for model 3	0.0	60	63	F4.2
P-delay for model 4	0.0	64	67	F4.2
S-delay for model 4	0.0	68	71	F4.2
P-delay for model 5	0.0	72	75	F4.2
S-delay for model 5	0.0	76	79	F4.2
*Component, Blank or Z, N, or E for Vertical, North-South and East-West component stations.	Z		80	A1

*Extended, 5-character, station codes are formed from the station code given in columns 1-4 (shifted to the right) plus the component from column 80. If the component is blank, z is assumed. This 5-character name must agree with the name on the arrival-time record (see 2.2.6.2).

NOTE ON DELAYS: The total delay used for the S-phase is just the S-delay given on the STATION record. [Some earlier versions of HYPOELLIPSE added a term to the S-delay equal to (Vp/Vs ratio)*(P-delay).]

- 2.2.5.3) Time-dependent station parameters

Format for TIME-DEPENDENT STATION PARAMETER records:

Item	Default Value	Column Nos.		Format
Station code		1	4	A4
*			5	A1
If any of the following items are left blank, default values will be used.				
Station weight (Multiplies the weight derived from weight-code. (see 2.2.6.)	1.0	6	9	F4.2
Primary system response code:	1	10	11	i2
0 = for Wood-Anderson 1= USGS Central California Network Standard 2 = EV-17 and Develco 3 = EV-17 and Teledyne 4 = HS-10 and Develco 5 = L-4C and Develco 6 = L-4C and Teledyne 7 = L-4C replacing HS-10 and Develco 8 = Ten-day Recorders 9-17 = User specified calibration curve (See 2.2.10 and Chapter 4) 18 = Use UAGI magnitude calculation (See 4.2.3)				
A1VCO 5-Hz Calibration (mm peak-to-peak) (not used by HYPOELLIPSE)		12	15	F4.0
XMAG calibration constant-C10 (See 4.2.2.2)	0.0	16	20	F5.2
XMAG correction (added to amplitude magnitude) NOTE: If the number typed is the actual magnitude correction plus 10, the magnitude for this station will be computed and listed but not used in computing the average event magnitude. For example, if XMAG correction = 10.2, a correction of +0.2 is applied to all XMAG's for this	0.0	21	24	F4.2

station, but none are used in the average magnitude computed for each event.				
XMAGWT magnitude weight (If zero, exclude XMAG's from this station from event mean and median XMAG magnitude calculations. Print "e" next to XMAG value in output.	1		25	i1
FMAGWT magnitude weight (If zero, exclude FMAG's from this station from event mean and median FMAG magnitude calculations. Print "e" next to FMAG value in output.	1		27	i1
FMAG correction (Multiplies the observed coda).	1.0	28	31	F4.2
P-weight-code replacement. For this station, an ARRIVAL TIME record with P-weight-code of 0, 1, 2, or 3 will be replaced by this code. If blank, use assigned weight.	none		32	i1
S-weight-code replacement. For this station an ARRIVAL TIME record with an S-weight-code of 0, 1, 2, or 3 will be replaced by this code. If blank, use assigned weight.	none		33	i1
Field gain setting (Not used by HYPOELLIPSE).	0	35	36	i2
Palmer attenuator setting of 0, 1, or 2. (Not used by HYPOELLIPSE.)	0		37	i1
Year, month, and day (e.g. 19891231).	99999 999	38	45	i8
Hour of expiration of information in these entries. If another entry with revised time dependent parameters does not follow, then this is time of station expiration.	0	46	47	i4

Two telemetry delays are specified. The primary delay is used unless (1) the source of data is one of those specified for the alternate delay or (2) the source code is "T" or "N", both of which have already been corrected. Certain source codes are equivalent for the purposes of the telemetry delays. For example, the USGS film viewer (source code "V") is equivalent to the USGS one-film digitizer (source code "1"). A complete list of source codes is given in section 4.2.2.2. The following table shows delay-equivalent codes. Only one code from a set of equivalents need be included as an alternate delay code.

Source of data	Equivalent codes
USGS Film	V, *, 1, 4
USGS Tape	S, E, 2
UAGI Film	%, A, F
UAGI Masscomp or SUN Computers	D, J, X,
USGS./UAGI PC's	P, O, U, I, G, K

Primary telemetry time correction	0.0	48	51	F4.2
Source codes of arrival times that will use the alternate telemetry time correction		52	55	4A1
Alternate telemetry time correction	0.0	56	59	F4.2

Polarity indicators may be any of the following:

Indicator	Meaning	Focal Mechanism Symbol:
N	Normal	Same as phase record
R	Reversed	Reverse of phase record
+	Probably normal	Same as phase record
-	Probably reversed	Same as phase record
?	Unknown	Question Mark

Five date-source indicators may be specified, one for each of the following sources of Alaska data:

Item	Default Value	Column Nos.		Format
Source of data				
USGS Film	Source codes effected			
USGS Tape or USGS/UAGI PC's	V, *, 1, 4		60	A1
ATWC Film	S, E, 2, P, O, U, I, G, K		61	A1
UAGI Film	W		62	A1
UAGI Computers	%, A, F		63	A1
Other sources	D, J, X		64	A1
	any other code, including blank		65	A1

The following items allow amplitude measurements for a given station to be made on up to four additional recording systems, each with a different frequency response:

System response code	72	73	i2
A1VCO 5-Hz, Calibration (mm peak-to-peak) (not used by HYPOELLIPSE)	74	77	F4.0
XMAG Calibration constant-C10	78	82	F5.2
System response code	84	85	i2
A1VCO 5-Hz, Calibration (mm peak-to-peak) (not used by HYPOELLIPSE)	86	89	F4.0
XMAG Calibration constant-C10	90	94	F5.2
System response code	96	97	i2

A1VCO 5-Hz, Calibration (mm peak-to-peak) (not used by HYPOELLIPSE)	98	101	F4.0
XMAG Calibration constant-C10	102	106	F5.2
System response code	108	109	i2
A1VCO 5-Hz, Calibration (mm peak-to-peak) (not used by HYPOELLIPSE)	110	113	F4.0
Calibration constant-C10	114	118	F5.2
If station has been moved a small distance, these are the new coordinates:			
New minutes of latitude	119	123	F5.3
New minutes of longitude	124	128	F5.3
New elevation	129	132	i4

- 2.2.5.4) End station list - Format: END STATION LIST

A record with END typed starting in column 1 follows the last STATION record. The record immediately following the BEGIN STATION LIST record may be of the form JUMP FILENAME, where the STATION records are contained in the file 'FILENAME'. In this case, no END record is used in either the original input file or the jump file.

- 2.2.5.5) Additional delays

Delays may be specified for 5 additional models (numbers 6-10). Each set of additional delays begins with a record with DELAY typed in columns 1-5 and an integer delay-model number (6-10) beginning after column 18. This record is followed by a set of records with station code in columns 1-5, followed by P Delay and S Delay (s) in free format. After the last station, a record with END starting in column 1 ends the set of delays. The stations need not be in alphabetical order, and stations not included will be given delays of zero. Note that this must be the extended 5-character station code that ends in either n, e, or z, to correspond to the component specified on the primary station record.

2.2.6 Arrival times

- 2.2.6.1) Arrival-times-next record

A record with ARRIVAL TIMES NEXT starting in column 1 signals the start of the ARRIVAL TIME records. Each earthquake consists of four types of records:

SUMMARY ('/' or '\' in column 83), ARRIVAL TIME, COMMENT ('C*' in columns 1-2) and INSTRUCTION. If any SUMMARY records are present, the first record of the event must be the primary SUMMARY record ('/' in column 83) and this record provides the starting location for the event unless the IGNORE SUMMARY records is in effect (see 2.2.3.14 and 2.2.12). Each event must end with a series of one or more INSTRUCTION records. A maximum of NPA (see 1.3) records may be associated with each event.

- 2.2.6.2) Arrival-time-record format

For each seismograph station recording the earthquake, an ARRIVAL TIME record is typed as follows. A maximum of 256 phases, counting P and S phases, may be used for each earthquake.

Item	Column Numbers		Format
Station code	1	4	A4
Alphanumeric symbol describing P-phase arrival (for example, I or E)		5	A1
P-Phase descriptor		6	A1
P = P arrival read on vertical component N = P arrival read on North-South component E = P arrival read on East-West component If N or E is used, then neither the coda duration nor the maximum amplitude will be used and the first motion direction will not be plotted. The extended 5-character station code is formed from the station code in columns 1-4 (shifted to the right) plus the phase descriptor. If the phase descriptor is not n or e, then z is assumed. This extended name must agree with the extended name in the station list (see 2.2.5.2).			

First-motion direction of P arrival		7	A1
c, C, u, or U	Compression		

d, D	Dilatation		
+	Questionable compression		
-	Poor dilatation		
z, Z	Nodal, and not clearly up or down		
n, N	Noisy		
. or Blank	Not readable		
P-weight-code	8		F1.0
0 or blank	Full weight		
1	Partial weight		
2	Partial weight		
3	Partial weight		
4, 5, 6, 7, 8	No weight		
9	Use S-P interval (see 2.2.9)		
If the P phase is a secondary arrival refracted along the bottom of the ith layer, type the value of I here. If event is in the (i + 1)th layer, direct wave calculation is made. If the event is deeper than the (i + 1)th layer or the distance is too short for this refraction to be possible, then the computed weight is reset to zero. This option only operates with computed layer models with constant velocity (see 2.2.2.1.a).		9	i1
Year, month, day, hour, minute (e.g. 8912312359)	10	19	i10
Seconds of P arrival. If left blank, the assigned weight-code will be set to 8 both during this run and on the ARCHIVE ARRIVAL TIME record.	20	24	F5.2
Seconds of S arrival	32	36	F5.2

S remark (analogous to columns 7-9, e.g. iSN) (Not used by HYPOELLIPSE.)	37	39	A3
S-weight-code		40	F1.0
Maximum peak-to-peak amplitude. Values from .001 to 9,999 are entered as positive. Negative entries are multiplied by -10,000 to allow for values of 10,000 to 9,990,000. Units depend on calibration data (see Chapter 4).	44	47	F4.0
Period of maximum amplitude in hundredths of s. If left blank, 0.1 will be used.	48	50	F3.2
Siemens gain state: 0 = high; 1 = low (gain times 1/4)		61	i1
A1VCO gain-range state. 0 = high; 1 = gain times 1/10; 2 = gain times 1/500.		62	i1
Any remark	63	64	A2
Time correction (s)	66	70	F5.2
F-P time interval (s), for FMAG calculation. In USGS practice, one measures the time between the first P arrival and the point where the peak-to-peak amplitude of the signal drops below 1 cm on a Teledyne Geotech Develocorder film viewer (X 20 magnification). If the F-P time is less than 1.25 times the S-P time, then the FMAG is not calculated.	71	75	F5.0
Polarity source code		105	A1
P-arrival source code		106	A1
S-arrival source code		107	A1
Amplitude source code		108	A1
Coda-duration source code		109	A1

- See 4.2.2.2 for a listing of source codes used in Alaska.

- 2.2.6.3) Instruction record

After each set of ARRIVAL TIME records for a particular earthquake, at least one INSTRUCTION record follows.

<table>
<tr><th>Item</th><th colspan="2">Column Nos.</th><th>Format</th></tr>
<tr><td>MORE Indicator for another INSTRUCTION record following this one. Leave blank if no additional INSTRUCTION records follow. Type MORE if another one follows. The earthquake will be processed once for each INSTRUCTION record.</td><td>1</td><td>4</td><td>A4</td></tr>
<tr><td>Processing Status</td><td></td><td>9</td><td>A1</td></tr>
<tr><td>Event Type. See 2.4.1 for definition of Processing Status and Event type. If a SUMMARY record does not precede an event, then the Processing Status and Event Type from the INSTRUCTION record are placed in columns 74 and 92 of the SUMMARY record generated when HYPOELLIPSE is run. If the event is in Archive Format, and is therefore already preceded by a SUMMARY record, then the event type and processing status on the INSTRUCTION record are ignored.</td><td></td><td>10</td><td>A1</td></tr>
<tr><td>S-data indicator. 0 if S data is not to be used. 1 for use of S data in solution. TEST(38) must be set to 0 for S-data indicator to be used (see 2.2.4).</td><td></td><td>18</td><td>i1</td></tr>
<tr><td>Fixed location indicator</td><td></td><td>19</td><td>i1</td></tr>
<tr><td colspan="4">0 implies nothing fixed.
1 implies depth fixed at trial depth.
7 implies hypocenter fixed but origin time free.
8 implies origin time fixed at trial origin time.
9 implies location fixed at trial latitude, longitude, and depth.

If origin time is entered on this record (cols. 74-80), or on a SUMMARY record, then origin time will also be fixed (see 2.2.12).

If event type is T, R, or N on SUMMARY RECORD, fixed location indicator is ignored (see 2.4.1).</td></tr>
</table>

Trial depth	20	24	F5.2
Trial latitude (Degrees)	41	42	F2.0
N or blank for North, S for South		43	A1
Trial latitude (Minutes)	44	48	F5.2
Trial longitude (Degrees)	54	56	F3.0
W or blank for West and E for East		57	A1
Trial longitude (Minutes)	58	62	F5.2
USGS "CUSP ID" (not used by HYPOELLIPSE)	63	73	A11
Trial origin time (Minutes)	74	75	F2.0
Trial origin time (Seconds)	76	80	F5.2
Sequence Number - will be transferred to columns 94-98 of SUMMARY record.	92	96	A5

- 2.2.6.4) Comment records

Any phase record with C* in columns 1-2 will be printed out during program execution but otherwise will be ignored. There is no limit to the number of COMMENT records per event, except that they count along with SUMMARY records, ARRIVAL TIME records, and the INSTRUCTION record toward the maximum number of records allowed per event - currently set at 256. In this way a comment can be made, for example:

C* Station XYZ may have cross-feed

or

C* these readings may be from two earthquakes.

2.2.6.5) Jump records

If a record with 'JUMP FILENAME' beginning in column 1 is encountered then input is transferred to file 'FILENAME'. When an end-of-file is reached on the subsidiary input file, input resumes from the original file.

- *2.2.7 Station parameter changes during run (see 2.2.5.2 and 2.2.5.3)*

The station list record file may be set up so that station parameter changes will automatically be made as during a single batch run of a set of earthquakes. Each

STATION record has an expiration date and time. If left blank the year is set to 1999. But if, for example, the station calibration changed on 760120 at 1432 from 5.1 to 8.3, then two STATION records would be included in the file. The first would have 5.1 for calibration and an expiration of 7601201432. The second, which must directly follow the first, would be identical except 8.3 would replace 5.1 and the expiration date and time would be updated. As many STATION records as required can be grouped together like this. The expiration date of each station is checked against the current event time before each event is processed.

CAUTION: In order to use this system of automatic updating of station parameters, the earthquake data set must be run in chronological order. All updates for a particular station must also be in chronological order. Note that if the events are rerun, as described in section 2.2.11, then they will not be run in chronological order, so station parameter updating will not operate correctly and errors may result.

2.2.8 Change input items 2.2.1 through 2.2.5 during run

Any or all of these items may be changed as follows:

- 2.2.8.1) Reset record

Type RESET starting in column 1. This record is placed following the last INSTRUCTION record of an event or set of events, and it switches the program to the input mode in which items 2.2.1 through 2.2.5 may be entered. All location parameters will remain in effect except those for which new 2.2.1-2.2.5 records are included. To switch back to reading PHASE records, terminate the 2.2.1-2.2.5 items with an ARRIVAL TIMES NEXT record.

- 2.2.8.2) Reset S record

Type RESET S starting in column 1. This is the same as RESET described above except that (1) a tabulation of average residuals will be printed for the set of events preceding the RESET S record, and (2) a tabulation will begin anew on the events that follow.

- 2.2.8.3) Standard test record

A record with STANDARD TEST starting in column 1 will reset input items 2.2.3 and 2.2.4 to default values. This record is placed after a RESET or RESET S record.

2.2.9 Use of S-P intervals

If the same time base is not available for some stations, it is still possible to use the recorded S-P intervals in the hypocentral solution. To do this, set the weight-code assigned to the P arrival (column 8) to 9, and the weight-code assigned to the S arrival (column 40) to that desired for the S-P interval. This will only work with velocity models that have the same ratio of P-wave to S-wave velocity in each layer.

▪ *2.2.10 How to add your own calibration curve - Format: CALIBRATION Integer*

In addition to the 8 system response tables stored with HYPOELLIPSE, the user may supply tables for up to nine additional seismic systems, corresponding to system numbers 9 through 17. To do this, place a record with CALIBRATION starting in column 1 and the number of additional system calibration tables to be added beginning in column 19 in free format. Each table consists of two records with the values of RSPA for n = 1,20 on the first and n = 21,40 on the second. The format is (20F4.2). The first two records correspond to system number 9, the second two to number 10, etc., up to the total number of tables to be added. See Chapter 4 for the definition of RSPA(n).

▪ *2.2.11 How to run the same data more than once*

A set of ARRIVAL TIME records may be run with a variety of velocity models, station lists, trial depths, or any other of the variable parameters defined in sections 2.2.1 through 2.2.5. First, place the ARRIVAL TIME records in a separate file (named PHDATA in the example below). Then set up the input file as in this example:

Items 2.2.1 through 2.2.5 as desired for 1st run

ARRIVAL TIMES NEXT
JUMP PHDATA
RESET

New items 2.2.1 through 2.2.5 as desired for second run

ARRIVAL TIMES NEXT
JUMP PHDATA

NOTE: HYPOELLIPSE always assumes that the earthquakes being processed are in chronological order when keeping the station parameters up-to-date. Therefore, if the events being rerun span any changes in the station parameters, the station file will have to be included again prior to rerunning the data.

▪ *2.2.12 Summary of first trial-location specifications*

For each parameter, the sources are given in order of decreasing priority.

LATITUDE AND LONGITUDE

INSTRUCTION record, if specified (columns 41-44 contain some non-blank characters), else

SUMMARY* record, if specified (columns 17-20 contain some non-blank characters) - (See 2.2.3.14 to ignore SUMMARY records), else

TEST(3) and (4) values, if both not equal zero, else

Inversion* of up to the first 10 P-arrival times.

DEPTH

If Global Option is in effect, then use multiple starting depths as described in 2.2.3.11.

Use INSTRUCTION record, if depth is specified (columns 21-24 contain some non-blank characters), else

SUMMARY* record, if specified (columns 33-36 contain some non-blank characters) - (See 2.2.3.14 to ignore SUMMARY records), else

Trial depth specified in SUBROUTINE USEDLY if the SELECT DELAY code is not zero and USEDLY sets a depth not equal to 99999. (See 2.2.3.6), else

TEST(5), if not equal -99.0, else

Inversion* of up to the first 10 P-arrival times, rounded to nearest 5 km and not less than 15 km or greater than TEST(36).

ORIGIN TIME

Computed from distribution of S vs P if TEST(49) equals -1 or -2 and the number of pairs of S and P times is greater than 2.

INSTRUCTION record, if specified (columns 74-77 contain some non-blank characters), else

SUMMARY* record, if specified (columns 11-14 contain some non-blank characters) - (See 2.2.3.14 to ignore SUMMARY records), else

Computed from distribution of S vs P if TEST(49) equals 1 or 2 and the number of pairs of S and P times is greater than 2.

Define TO(i) = TP(i) - (TS(i) - TP(i))/(TEST(1) - 1.0) where

TP(i) is the P-arrival time at the i^{th} station,
TS(i) is the S-arrival time at the i^{th} station,
TEST(1) is the Vp/Vs ratio

Use the average value of TO(i) if at least one station has both P- and S- arrivals, else

Inversion of up to the first 10 P-arrival times based on a halfspace with velocity = TEST(48).

NOTE: If TEST(38) is negative, then the origin time will be fixed at the average value of TO(i), unless TEST(49) is negative, in which case it will be fixed at the value determined by the Wadati plot (extrapolation of the (TS - TP) vs TP curve to the point where (TS - TP) equals zero).

*NOTE: Starting parameters will not be taken from the SUMMARY record if the IGNORE SUMMARY RECORD is in effect (See 2.2.3.14).

- *2.2.13 Run data with random errors added*

In order to study the effectiveness of this inversion program for varying station distributions or earthquake distributions, the following method may be used:

a) Generate a "fake" set of perfect phase data for the desired earthquake distribution. This can be done by setting up a group of ARRIVAL TIME records with the stations of interest and including arbitrary P- and S-phase data for each station. Then use a series of INSTRUCTION records, each with a fixed location indicator and one of the desired test earthquake locations (See 2.2.6.3). Run this data with SUMMARY OPTION 4 in order to generate the "fake" set of arrival time data. If these data were fed back into the program, the result should be the desired test earthquake locations, each with a zero RMS residual.

b) In order to have random errors added to each arrival time each time the "fake" data are relocated, type a control record with SCATTER starting in column 1, P-standard error starting in column 20 (F5.2), and S-standard error starting in column 32 (F5.2). Note that this format is fixed. These should be the standard errors for readings with a weight-code of zero. For readings with weight-codes of 1, 2, and 3, larger deviations will be added, based on the WEIGHT parameters (see 2.2.3.13). Place this record directly before the first ARRIVAL TIME record of the fake data set. If an archive phase file is being generated, the arrival times will reflect the added random errors. Each time this job is run a new series of random numbers will be generated because the random number seed is initialized by the time, month, and year of the run.

If the velocity model is also changed, then one can also simulate the systematic errors introduced by not knowing the true earth structure.

Note that an archive file written when SCATTER is in effect will have all of the original arrival times perturbed by random errors.

c) To simulate a non-Gaussian distribution, add a record with NONGAUS starting in column 1, fraction of readings with larger error starting in column 20 (f5.2), and factor by which to increase P & S standard errors starting in column 32 (f5.2). for example, to randomly increase P & S standard errors by a factor of 5 10% of the time, use:

NONGAUS 0.1 5.0

▪ *2.2.14 Define a MASTER event for a random location study*

This option may be used to test the hypothesis that all of the events in a set of locations are located at the same hypocenter, and are only apparently shifted due to random reading errors and variations in which phases were read for each event. Set up a "perfect" event (an event with zero RMS residual) located at the hypothesized hypocenter. Place this as the first of a set of earthquakes and precede it with a record that has MASTER starting in column 1. Specify the reading errors with a SCATTER record next (see 2.2.13). All events following the first will have their minutes and seconds of P and S replaced with the "master" values. Due to the SCATTER option, the computed locations will vary randomly. The spatial distribution of the resulting random distribution and the summary statistics at the end of the run can be compared with the actual data set to test the hypothesis.

▪ *2.2.15 How to generate an ARCHIVE-PHASE FILE*

HYPOELLIPSE can be used in a mode that utilizes and generates data in a data base that combines the raw data measurements of the PHASE records, the SUMMARY record, and certain derived parameters for each station such as the distance, the azimuth, and the angle of incidence (see Data Base Organization table below). To set up HYPOELLIPSE to generate this file, named the ARCHIVE-PHASE FILE, set the SUMMARY OPTION code equal to 2 or 3 (see 2.2.3.2). The file is generated by the following steps:

Write out SUMMARY record(s).

Case 1. The input event included either zero or one SUMMARY records. (Note that the first (primary) summary record will have a "/" in column 83. Any additional summary records will have a "\" in column 83.)

> Case 1a. A new earthquake solution was generated. Then: Write a SUMMARY record for the new solution and discard the previous SUMMARY record, if there was one.
>
> Case 1b. A new solution was not generated. This could happen, for example, if all of the arrivals are weighted out. Then: Write out a FAKE SUMMARY record followed by the SUMMARY record that was previously associated with the event, if there was one.
>
> Case 2. The input event included two or more SUMMARY records.
>
> Case 2a. A new earthquake solution was generated. Then: Write out the new SUMMARY record followed by all but the first of the SUMMARY records previously associated with the event.

Case 2b. A new solution was not generated. Then: Write out a FAKE SUMMARY record followed by all of the SUMMARY records previously associated with the event. A "FAKE" summary record is just a placeholder, with the earthquake location and depth fields left blank.

For each station, write out an augmented PHASE record with original phase data and computed data.

Write out the original INSTRUCTION record.

The generation of archive-phase files is not compatible with option of running events with more than one INSTRUCTION record (see 2.2.6.3, 'MORE').

Data Base Organization

<table>
<tr><td colspan="2">Organization of the old and new data base structures. Raw and derived data that were previously stored in three files are now combined into a single ARCHIVE-PHASE FILE</td></tr>
<tr><td>OLD DATA BASE</td><td>NEW DATA BASE</td></tr>
<tr><td>PHASE records with raw data measurements in one file.</td><td rowspan="3">One archive-phase file with raw and derived information for each station as well as the derived earthquake solution parameters.</td></tr>
<tr><td>SUMMARY records with: derived earthquake solution parameters, such as location depth, origin time and magnitude in another file.</td></tr>
<tr><td>Printed listings with: derived station information, such as distance, azimuth, angle of incidence, and magnitude.</td></tr>
</table>

The ARCHIVE-PHASE FILE may be used as a HYPOELLIPSE input phase file. In that case, the starting location, depth, and origin time will be taken from the first SUMMARY record associated with the event unless overridden by a location, depth, or origin time on the INSTRUCTION record (section 2.2.6.3). The format specification for reading an ARCHIVE ARRIVAL TIME record is as follows:

Item	Col. Nos.		Format
Station code	1	4	A4

Any two alphanumeric symbols to describe P phases. See 2.2.6.2)	5	6	A2
First motion direction of P arrival		7	A1
c, C, u, or U	Compression		
d, D	Dilatation		
+	Questionable compression		
-	Questionable dilatation		
n, N	Noisy		
.or Blank	Not readable		
z, Z	Nodal, and not clearly up or down		
P-weight-code		8	F1.0
0 or blank	Full weight		
1	Partial weight		
2	Partial weight		
3	Partial weight		
4, 5, 6, 7, 8	No weight		
9	Use S-P interval (see 2.2.9)		
If the P phase is a secondary arrival refracted along the bottom of the Ith layer, type the value of I here. If event is in the (I + 1)th layer, a direct wave calculation will be made. Below that, the weight is reset to zero.		9	i1
Year, month, day, hour, minute (e.g. 9812312358)	10	19	i10
Seconds of P arrival	20	24	F5.2
Distance (km)*	25	28	F4.1
AZM - Azimuth from epicenter to station (degrees)*	29	31	F3.0
Seconds of S arrival	32	36	F5.2

S remark	37	39	A3
S-weight-code		40	F1.0
AIN - Angle of ray leaving hypocenter (degrees)*	41	43	F3.0
Maximum peak-to-peak amplitude. Values from .001 to 9,999 are entered as positive. Negative entries are multiplied by -10,000 to allow for values of 10,000 to 9,990,000.	44	47	F4.0
Period of maximum amplitude (s). If left blank, the standard period as specified in the station list will be used	48	50	F3.2
P travel-time computed*	51	54	F4.2
P standard error*	55	57	F3.2
D, B, M, J, X, R, G, or * weight-code (See 2.3.7 for definition)*		58	A1
Instrument Period (S=short, L=long, B=broad)		59	A1
Instrument Gain (H=high, L=low)		60	A1
Siemens gain state: 0 = high; 1 = low (gain times 1/4)		61	i1
A1VCO gain range state. 0 = high; 1 = gain times 1/10; 2 = gain times 1/500		62	i1
Remark (Recorder location in column 63, e.g. F=Fairbanks)	63	64	A2
Corrected first-motion symbol		65	A1
Time correction (s)	66	70	F5.2
F-P time interval (s) for FMAG	71	75	F5.0
P:RES - Residual of P arrival (s)*	76	80	F5.2
S standard error*	81	83	F3.2
D, B, M, J, X, R, G, or "*" weight-code*		84	A1
S:RES - Residual of S arrival (s)*	85	89	F5.2

P delay*	90	92	F3.1
S delay*	93	95	F3.1
P elevation delay*	96	98	F3.1
System response code*	99	100	i2
XMAG*	101	102	F2.1
FMAG*	103	104	F2.1
Polarity source code**		105	A1
P-arrival source code**		106	A1
S-arrival source code**		107	A1
Amplitude source code**		108	A1
Coda-duration source code**		109	A1
Number of satellite hops (NHOP) in telemetry path, each producing a delay of 0.27 s. (If the P-arrival and S arrival sources are not the same, then NHOP is set according to the P-arrival source.) *		110	i1

* These items are added to the original ARRIVAL TIME record, but are not used in subsequent runs of HYPOELLIPSE

** See 4.2.2.2 for a listing of source codes.

Use of Polarity Source Code by HYPOELLIPSE:

STATION records have two fields for keeping track of station polarity (see 2.2.5), the Polarity-Reversal-Indicator in column 34 and the Tape-Polarity-Reversal-Indicator in column 48, and these two indicators do not always agree. The Polarity-Reversal-Indicator is used in correcting the observed first motion unless the polarity source code is S, in which case the Tape-Polarity-Reversal-Indicator is used.

- *2.2.16 How to close current ARCHIVE-PHASE FILE and open a new one*

In some situations it is desirable to close the archive-phase file specified when the program was started and to open a new file with a different name. To do this, use a record with ARC in columns 1-3 and the new file name in columns 19-68. The ARC record must either be included with the initial input data or follow a RESET record. The following example illustrates a run in which P1.ARC corresponds to P1.PHA and P2.ARC corresponds to P2.PHA.

- {Items 2.2.1 through 2.2.5}

- ARC P1.ARC
  ARRIVAL TIMES NEXT
  JUMP P1.PHA
  RESET
  ARC P2.ARC
  ARRIVAL TIMES NEXT
  JUMP P2.PHA

2.2.17 Use of magnitudes not determined by HYPOELLIPSE

For some earthquakes it is desirable to use a magnitude calculated by another organization, and to enter this magnitude in columns 37-38 of the SUMMARY record as the preferred magnitude. In this situation MAGTYP in column 80 is also set to some code other than F, X, or A. For example, in Alaska we use the following codes:

Mag. Type	Source
B	PDE mb
C	Canadian M_L
G	UAGI M_L
H	Helicorder (approximate M_L)
P	Palmer M_L
L	Lamont-Doherty Earth Observatory
O	Other
S	PDE M_S
W	Moment magnitude (Mw)

When earthquakes are being rerun, if the SUMMARY record precedes the phase data (See 2.2.15) and has MAGTYP not equal to F, X, or A, then the preferred magnitude and MAGTYP on the newly generated SUMMARY record will not be changed. Thus, the preferred magnitude is preserved through repeated runs of HYPOELLIPSE.

➢ *2.3 Printed output*

The line-printer outputs of HYPOELLIPSE are generally self-explanatory. The following explanations may be helpful for first-time users.

- *2.3.1 List of stations available (each station uses two lines in the printout)*

Heading	Explanation
P THK	Preferred variable layer thickness. Either 1 or 2.
VAR LAYER THICKNESS 1 and 2	Two thicknesses may be specified for the variable layer.
P MOD	Number of velocity model to be used with this station.
P DLY	Preferred delay model 1 through 5.
PDLY1, SDLY1	Model 1 time delays for P and S arrivals. Followed by delays for models 2 through 5.
SYS	System response code. See 2.2.5 on station list for code number assignments.
CALR	Standard calibration for XMAG
XMGC	Amplitude magnitude correction
FMWT	Weight for F-P magnitudes
FMGC	F-P magnitude correction. Multiplies observed F-P interval.
WT P	Replace P-weight-code of 0, 1, 2, or 3 with this. Ignored if equal to 10.
WT S	Replace S-weight-code of 0, 1, 2, or 3 with this. Ignored if equal to 10.
POL	Two codes are printed, the first for Develocorder polarity and the second for tape polarity. If 1, then reverse observed polarity before plotting on focal-sphere. If > 1, plot as a question mark.
STAWT	The reading weight is multiplied by STAWT.

TLDLY	Correction to be added to the observed time. Used for satellite delays for USGS Alaska data.
YRMODY	Year, month, and day of expiration of time-dependent station parameters.
HRMN	Hour and minute of expiration of these parameters

- *2.3.2 Program specifications*

The TEST variables and abbreviated definitions are printed out so that each run is well documented. The station list and the velocity models are also printed out.

- *2.3.3 Vp/Vs ratio*

If the Vp/Vs-value is in effect (see TEST(49), section 2.2.4) the computed Vp/Vs ratios are printed out. See Chapter 5 for an explanation of the calculations.

- *2.3.4 Iteration output*

It is recommended that PRINTER 1 be used. One line will then be printed per iteration as follows:

Heading	Explanation
I	Iteration step. If a particular step is repeated, I is not incremented.
LAT	Minutes of latitude
LON	Minutes of longitude
DEPTH	In kilometers
*	If depth is constrained.
RMS	Root-mean-square travel-time residual (s). See equation below
NO	Number of P, S and S-P readings used
PRMS	RMS predicted for after the next step. See 4.4 for discussion.
DAMP	Value of damping constant in use. See 4.

EIGENVALUES	The three eigenvalues of the spatial normal equations.
ADJUSTMENTS COMPUTED DLAT, DLON, DZ	The adjustments in the principal directions are converted into changes in latitude, longitude, and depth.
ADJUSTMENTS TAKEN DLAT, DLON, DZ	This adjustment will be taken to reach the next iterative location. The limits imposed by the TEST variables have been applied.

Equation for root-mean-square travel-time residual (RMS). For i phases, i = 1, N, R_i is the observed minus computed time of the i^{th} phase. W_i is the computed weight of the i^{th} phase.

$$RMS = \left[\frac{\sum_1^n W_i R_i^2}{\sum_1^N W_i} \right]^{1/2}$$

- *2.3.5 Quality*

- 2.3.5.1 Based on error estimates

This quality is based on the values of SEH (the horizontal 68% confidence limit in the least well-constrained direction) and SEZ (the 68% confidence limit for depth). See Chapter 3 for further explanation of SEH and SEZ. Note that the following limits are modified from those used previous to April 1984 to reflect revised definitions of ERH and SEZ.

Quality	Larger of SEH and SEZ
A	≤ 1.34
B	≤ 2.67
C	≤ 5.35
D	> 5.35

- 2.3.5.2 Quality based on many parameters

SQD-HYPO71 Quality

S is the solution quality as defined in HYPO 71:

S	RMS	SEH *	SEZ* *
A	< 0.15	≤ 1.0	≤ 2.0
B	< 0.30	≤ 2.5	≤ 5.0
C	< 0.50	≤ 5.0	
D	Others		

- SEH is the horizontal 68% confidence limit in the least-well-constrained direction.

** SEZ is 68% confidence limit for depth.

The letter "Q" is used just as a spacer in the string "SQD".

D is the station distribution quality as defined in HYPO71:

D	No.	GAP	DMIN
A	≥ 6	≤ 90	≤ DEPTH or 5 km
B	≥ 6	≤ 135	≤ 2*DEPTH or 10 km
C	≥ 6	≤ 180	≤ 50 km
D	Others		

DMIN is the distance to the nearest station.

- *2.3.6 Final summary output lines*

Heading	Explanation
SE OF ORIG	Standard deviation of origin time.
# OF ITERATIONS	Total number of iterations
DMAX	Distance weighting maximum distance.
SEQUENCE NUMBER	Sequence number from columns 94-98 of SUMMARY record preceding this event.
EVENT TYPE	Column 92 of SUMMARY record (see 2.4.1).
PROCESSING STATUS	Column 74 of SUMMARY record (see 2.4.1).
DMAX	Final value of XFAR, based on TEST(12) and TEST(46).
DATE	If solution based only on S-P data, an * will follow date.
ORIGIN	Hour Minute Second
LAT	Degrees and minutes
LON	Degrees and minutes
DEPTH	Kilometers
MAG	Preferred magnitude. Also entered on SUMMARY record in columns 37-38. See 2.2.3.3, 2.2.17, and 2.4.1.
NO	Number of P, S, and S-P readings used in the solution.
D1	Distance to the closest station used in the solution (km).
GAP	Largest azimuthal separation in degrees between stations as seen from the epicenter.
D	Number of delay-model used (1 to 5).
RMS	If the residuals are R_i and the weights are W_i, i = 1, N, then equation for RMS is as given below.
AVWT	Weights are normalized so that their sum equals NO by dividing each weight by the average weight, AVWT.

SEH	Horizontal 68% confidence-limit for the least-well-constrained direction.
SEZ	68% confidence-limit for depth.
Q - HYPO71	Average of S and D qualities defined in 2.3.5.2. Rounded to lower quality when necessary.
SQD	S and D qualities defined in 2.3.5.2.
ADJ	Length (km) of final adjustment of hypocenter.
I	S-data indicator. 0 - S not used 1 - S is used
N	Fixed location indicator. 0 - nothing fixed, 1 - depth fixed at trial depth, 8 - origin time fixed at trial origin time, 9 - location fixed at trial hypocenter
NR	Total number of P, S, and S-P readings
AVR	Average-weighted residual.
AAR	Average of the absolute value of the weighted residuals.
NM	Number of stations at which amplitude magnitude (XMAG) was calculated.
AVXM	Average XMAG.
MDXM	Median XMAG.
SDXM	Standard deviation of XMAG's calculated, with respect to AVXM.
NF	Number of stations at which F-P magnitude (FMAG) was calculated.
AVFM	Average FMAG.
MDFM	Median FMAG
SDFM	Standard deviation of FMAG's calculated, with respect to AVFM.
VPVS	Computer slope of Tp vs Ts.

Equation for root-mean-square residual:

$$RMS = \left[\frac{\sum_1^n W_i R_i^2}{\sum_1^N W_i} \right]^{1/2}$$

- *2.3.7 Detailed station output: TRAVEL TIMES AND DELAYS:*

Heading	Explanation.
STN	Station code.
C	Component. Z - vertical. N - north-south horizontal. E - east-west horizontal.
PHA	Phase. Blank for P-phase. S for S-phase. SMP for S minus P interval.
REMK	Phase remark (columns 5-8 of PHASE record).
P	First-motion polarity, corrected as per station history.
PSEC	Seconds of P-arrival as typed on ARRIVAL TIME record.
SSEC	Seconds of S-arrival as typed on ARRIVAL TIME record.
RESID	Residual (s).

If a character follows the residual the meaning is: D = Weight reduced to zero by distance weighting. B = Weight reduced to zero by boxcar weighting. M = Weight reduced to zero by truncation weighting. J = Residual is greater than 3 standard deviations from the mean. Used with Jeffrey's weighting. X = Weight reduced to zero during critical station run (see TEST(44)). R = Computed weight less than 0.0005, so set to zero. G = Beyond distance weighting cutoff but included in order to reduce gap (See TEST(46)). * Large residual flagged by RESIDUAL OPTION (See 2.2.3.12).	
STD-ER	Standard error(s) used for this arrival in hypocentral solution. The weight assigned to each phase is proportional to the inverse square of the standard error of the phase.
DIST	Epicentral distance of station (km).
AZM	Azimuth of station from epicenter (degree).
AIN	Angle of ray leaving hypocenter measured with respect to downward vertical (degree).
TC	Station clock correction (s) from ARRIVAL TIME record. Added to observed arrival time.
C	Velocity model used for this travel time.
VTHK	Thickness of the variable layer in km for the velocity model used.
TTOB	Travel time observed (s).
TTCAL	Travel time calculated (s).
DELAY	Station delay (s) for model preferred by closest station.
EDLY	Elevation delay (s).
RMK	Remark from columns 63-64 of PHASE record.
STN	Station code.
SOURCES	Phase data sources followed by number of satellite hops, columns 105-110 of original PHASE record.

MAGNITUDE DATA:	
SOURCE	Amplitude source code from column 108 of ARRIVAL TIME record.
SYS	System response used in computing magnitude.
C10	XMAG calibration constant for USGS magnitude subroutine; For UAGI magnitude subroutine, system magnification in counts per 10^{-6} mm at the period (PER) of wave. Set to -1.0 if calibration data is not available.
AMX	Maximum amplitude from input data, peak-to-peak (mm).
GR	A1VC0 gain range state, 0 = normal; 1 = gain times 1/10; 2 = gain times 1/500.
INK	Siemens playback gain, 0 = high; 1 = low (gain times1/4).
AMF	Maximum amplitude (mm), corrected for gain state and Siemens playback record.
PER	Period (s) of wave where maximum amplitude was read. If PER is not given on ARRIVAL TIME record, then standard period from station archive is used. The default is 0.1s.
UNIT/MM	Station gain at period PER.
GND MOT m	Ground motion (microns), peak-to-peak.
XMGC	XMAG station correction.
XMAG	Amplitude magnitude. An 'e' (for Excluded) follows if XMAGWT = 0; if not, an '*' follows XMAG if XMAG - AVXM > 0.5.
FMP	F-P time interval (s).
FMAG	Coda magnitude. An S follows if the coda was too short with respect to the S-P time for a coda magnitude to be computed; if not, an 'e' (for Excluded) follows the FMAG if FMAGWT = 0; if not, an * follows FMAG if FMAG - AVFM > 0.5.

- *2.3.8 Auxiliary RMS sphere output*

At times there may be a concern that the final iterative earthquake location is not the best one possible. If TEST(6) .NE. 0.0, (see 2.2.4) then the RMS residual is calculated at 14 points on a sphere of radius = TEST(6) centered on the final hypocenter. If the hypocenter is at a minimum of RMS in space, then all the points on the sphere will have larger RMS values than the center point. The DRMS is the RMS on the sphere minus the RMS at the center and will be positive for good locations.

The average DRMS values at the ends of seven diagonals through the sphere are calculated. These are printed in order of poorest to greatest location control and are specified by their down-dip azimuths. If TEST(6) is negative and if a point on the sphere has lower RMS than the center of the sphere, iteration will resume at that point in order to improve the solution. This is allowed only once per earthquake solution to prevent an infinite loop condition from arising.

A tabulation is printed listing the number of readings used, the RMS at the center, the minimum DRMS, the average DRMS, and a quality based upon these values as follows:

Q	NUMBER	RMS	MIN DRMS	AVE DRMS
A	> 6	≤ 0.2	≥ 0.3	
B	≥ 5	≤ 0.4	≥ 0.15	
C	≥ 4	≤ 0.4		≥ 0.5
D	Others			

- *2.3.9 Focal mechanism plot*

If the number of first motions is greater than or equal TEST(7) a focal-mechanism plot will be made on the printer. The diagram is an equal-area projection of the lower hemisphere of the radiation field. The symbol printed is as follows:

+	1 or more +'s
C	1 compression
B	2 compressions
A	3 or more compressions
X	Any combination of compressions and dilatations
-	1 or more -'s

D	1 dilatation
E	2 dilatations
F	3 or more dilatations
?	Indicates that although a first motion was reported,
	the station polarity is uncertain.

A +, -, or ? is printed only if a compression or a dilatation does not occupy the position.

If TEST(7) < 0, a second plot will be made showing station codes on the focal sphere.

Use TEST(45) = .1379 for 8.5-inch paper and TEST(45) = .10106 for 11-inch paper.

▪ *2.3.10 Final Tabulation*

At the end of each run of a set of earthquakes, a table is printed which gives the number of earthquakes within each quality specification. There is also a table which shows for each station the number of times the station was used (N), the average weight (WT), the weighted average residual (AVE), and the standard deviation of the residuals about their mean (SD). The TABULATION option (see 2.2.3.4) controls the quality of the events included in this table.

For P and S arrivals there are sets of two columns in the table. The first bases the weight for the i^{th} residual from the k^{th} event only on the final weight prior to normalization, WT_{ik}, used in locating the k^{th} event. The second also includes an event-weighting factor, F, based upon the number of arrivals and their weights used in locating each event. For the k^{th} event:

$F_k = SUMWT_k * (NRWT - 4)/NRWT_k$, for $NRWT_k > 4$

$F_k = 0.0$, for $NRWT_k \leq 4$

where $NRWT_k$ is the number of readings used in locating the k^{th} event, and SUMWTk is the sum of the weights (WT_{ik}) of the arrivals of the k^{th} event. Inclusion of the factor F in the weights used to compute the average station residual will bring the average residual into closer agreement with the modification in station correction that would be obtained from a joint inversion of all of the events for both location and station correction. Pavlis and Hokanson (1985) suggested using $SUMWT_k$ for this purpose. The addition of the degree of freedom term, (NRWT - 4)/NRWT should further improve the technique, in that the residual pattern for an event with few degrees of freedom will be unlikely to reflect the true station residuals. For data sets consisting of a large number of events, iterative modification of the station corrections using this table of averages and then relocating the earthquakes will give approximately the same results as a joint inversion for both the locations and the station corrections (Pavlis and Booker, 1983; Pavlis and Hokanson, 1985).

If a station is given zero weight on its STATION record (see 2.2.5), it will be included in the tabulation even though it has not been used in any of the solutions. In this case the station code will be proceeded by a 'W'. If a station is assigned a P-weight-code replacement of 4-8 on the TIME-DEPENDENT STATION parameter record (see 2.2.5.3), then the summary will include average P-residual information even though the P arrivals were not used, and the P-residual standard deviation will be followed by a 'P'. The S-residual standard deviation will be followed by an 'S' in analogous situations. In either this case or the case where the station weight is zero, the weight used in the tabulation is based on the P-weight-code on the ARRIVAL TIME record (See 2.2.6).

WARNING: The station weight and the P- and S-weight-replacement codes are time-dependent parameters specified in the station list. The final tabulation assumes, however, that the station weight for a given station was either zero or non-zero during the entire run, and similarly, that the weight-code replacements either were or were not within the range 4-8 during the entire run. If these assumptions are not correct, the tabulation will be in error.

➢ *2.4 Summary record output*

The SUMMARY OPTION record described in 2.2.3.2 controls the SUMMARY record output. The STATION records are generated in the same format as the input STATION records. The other formats are given below.

▪ *2.4.1 Summary record*

To save space no decimal points are used. Use the FORTRAN format for reading the summary record given below.

Item	Column Nos.		Format for Reading
Origin Time:			
KDATE - year, month, day (e.g. 19981231)	1	8	i8
KHRMN - hour, minute (e.g. 2358)	9	12	i4
KSEC - (seconds)	13	16	F4.2
LAT (degrees)	17	18	i2

N or S		19	A1
LAT (minutes)	20	23	F4.2
LON (degrees)	24	26	i3
E or W		27	A1
LON (minutes)	28	31	F4.2
DEPTH (km) [If negative, reset to -00]	32	36	F5.2
PREFERRED MAGNITUDE	37	38	F2.1
NO - Number of P, S, and S-P readings used in the solution	39	41	i3
GAP - Largest azimuthal separation in degrees between stations as seen from the epicenter (deg.)	42	44	i3
D1 - Distance to closest station used in solution (km)	45	47	F3.0
RMS (s)	48	51	F4.2
Azimuth of axis 1 of error ellipsoid (deg)	52	54	i3
Dip of axis 1 (deg)	55	56	i2
SE - length of ellipsoid semi-axis 1 (km)	57	60	F4.2
Azimuth of axis 2 of error ellipsoid (deg)	61	63	i3
Dip of axis 2 (deg)	64	65	i2
SE - length of ellipsoid semi-axis 2 (km)	66	69	F4.2
Average XMAG	70	71	F2.1
Average FMAG	72	73	F2.1
Processing state (not used by HYPOELLIPSE)		74	A1

* - More data available to be added P - Preliminary, but location not finalized F - Final location determine G - National Earthquake Information Center (NEIC) solution A - NEIC solution obtained from USGS/UAGI N - Not of principal interest I - Insufficient data to determine a hypocenter			
SE - length of ellipsoid semi-axis 3 (km)	75	78	F4.2
Quality - either error-ellipsoid quality or HYPO quality depending upon QUALITY OPTION record. (See 2.2.3.4) [In reformatted NEIC data this column contains the depth quality indicator.]		79	A1
MAGTYP - F, X, A, or K to indicate which type of magnitude is entered in columns 37-38. (See 2.2.3.3 and 2.2.17)		80	A1
NSWT - Number of S-phase arrivals used in solution.	81	82	i2
/ or \ The primary SUMMARY record is always first and has a "/" in column 83. If an archive file has more than one SUMMARY record, the second and any subsequent records will have a "\" in column 83.		83	A1
First 4 characters of INSTRUCTION record	84	87	A4
Month earthquake was run	88	89	i2
Year earthquake was run	90	91	i2
Event type		92	A1

E or blank	local or regional earthquake	S	artificial source such as seismic line or shot
T	teleseism	O	other non-earthquake (e.g. sonic boom or lightning)

R	regional (poor coverage; use solution from another organization)	C	calibration signal
N	nuclear explosion	A	volcano tectonic (VT)
G	glacial event	B	volcano long-period (LP)
Q	quarry or mine explosion	X	emergent, low frequency near volcano,
F	false trigger	V	volcano tremor burst or eruption
I	Augustine volcano shore-ice event	H	volcano VT-LP hybrid
+	continuation of previous event		
For type T, R, or N, do not compute the hypocenter location, but instead compute the azimuth and apparent velocity across the network.			
Once the event type has been placed on the SUMMARY record of an earthquake in archive format, it will be transferred to succeeding SUMMARY records generated by later runs of HYPOELLIPSE.			

Fixed location indicator, from column 19 of INSTRUCTION record or imposed by SELECT DELAY option (2.2.3.6)		93	i1
Sequence number	94	98	A5
S-P time at closest station used in solution. Blank if either P or S is not used. Set to 9999 if S-P .GE. 100.	99	102	F4.2
ZUP - Computed with GLOBAL OPTION.	103	104	F2.0
ZDN - Computed with GLOBAL OPTION.	105	106	F2.0
Vp/Vs - Computed slope of Ts vs Tp. Only computed if TEST(49) is not equal 0.	107	110	F4.2
Number of readings weighted out due to Jeffrey's, truncation, or boxcar weighting.	111	112	i2
DEPTH (km) [Allowed to be negative]	113	117	F5.2

- *2.4.2 Phase records in input format with corrected arrival times*

This option will create a "perfect" set of data, which then may be used to check the HYPOELLIPSE program. For example, one might want to know how well the program would work on events in some particular region. Fixed solutions specifying this

epicentral region could be run with SUMMARY OPTION 5 and test earthquakes would be generated. The "perfect" data will be generated as follows:

Item	Column Nos.		Format for Reading
Station code	1	4	A4
KDATE	10	15	i6
KHRMN	16	19	i4
SPEC - P-arrival time	20	24	F5.2
SSEC - S-arrival time	32	36	F5.2

Chapter 3. Error Estimates

➢ *3.1 Error ellipsoid*

There are three components that enter into the computation of the hypocentral error ellipsoid:

1. The estimated standard error of arrival times with zero weight code (SEZWC),
2. The weight code assigned to each arrival time, and
3. For each station, the partial derivatives of travel time with respect to latitude, longitude, and depth for the final hypocenter.

There are two options for assigning SEZWC, which is used to scale the ellipsoid. If TEST(29) (see 2.2.4) is positive, then SEZWC is reset for each event to be equal to the RMS residual. This has the disadvantage that the RMS may vary significantly from event to event and usually reflects more than simply random errors in the arrival-time readings. If there are very few readings, the RMS residual may be smaller than the true reading error; or the RMS may be larger due to systematic errors caused by an inappropriate velocity model. As an alternative, SEZWC will be fixed for all events to -TEST(29) if TEST(29) is negative. In this case the error ellipsoid will not reflect any systematic errors or blunders (very large, but rare arrival-time errors), but will give an indication of the relative error between any nearby events located with similar station distributions. If this latter option is used, the RMS residual of each event as well as the size of the error ellipsoid should be monitored for poor hypocentral solutions.

Large error-ellipsoid axes are often the result of partial derivatives with respect to one parameter that are all very small or all nearly equal. For example, for an earthquake near the center of a single ring of stations, the partial derivatives with respect to depth will be nearly the same for all of the stations. This leads to a trade off between depth and origin time because the partial derivative of travel time with respect to origin time is also the same for all stations (always equal to 1.0).

The semi-major principal axes of the 68% joint-confidence ellipsoid are output on the SUMMARY record for each earthquake. The printed output also includes two horizontal single 68% confidence estimates, the larger being called SEH, and the single variable 68 %-confidence estimate for depth, SEZ. The relationship of these error estimates to the error ellipsoid is shown in Figure 3-1. The relationship between a joint two-dimensional probability distribution (Pxy) and a one-dimensional distribution (Px) is illustrated in Figure 3-2. For each value of x, Px is equal to the integral over y of the joint-probability function Pxy. The ratio between s, the 68% confidence limit for x, and m, the maximum deviation of the 68% joint confidence ellipse in the x direction, is equal to the square root of the ratio of the 68% value of chi-square with one degree of freedom to the 68% value of chi-square with two degrees of freedom. Similarly, the scaling relationship between the shadow of the joint hypocentral ellipsoid and the joint-epicentral region is based on chi-square values for two and three degrees of freedom (Figure 3-3).

DEGREES OF FREEDOM	CHI SQUARE VALUE	SQUARE ROOT OF CHI SQUARE
1	1.00	1.00
2	2.30	1.52
3	3.51	1.87

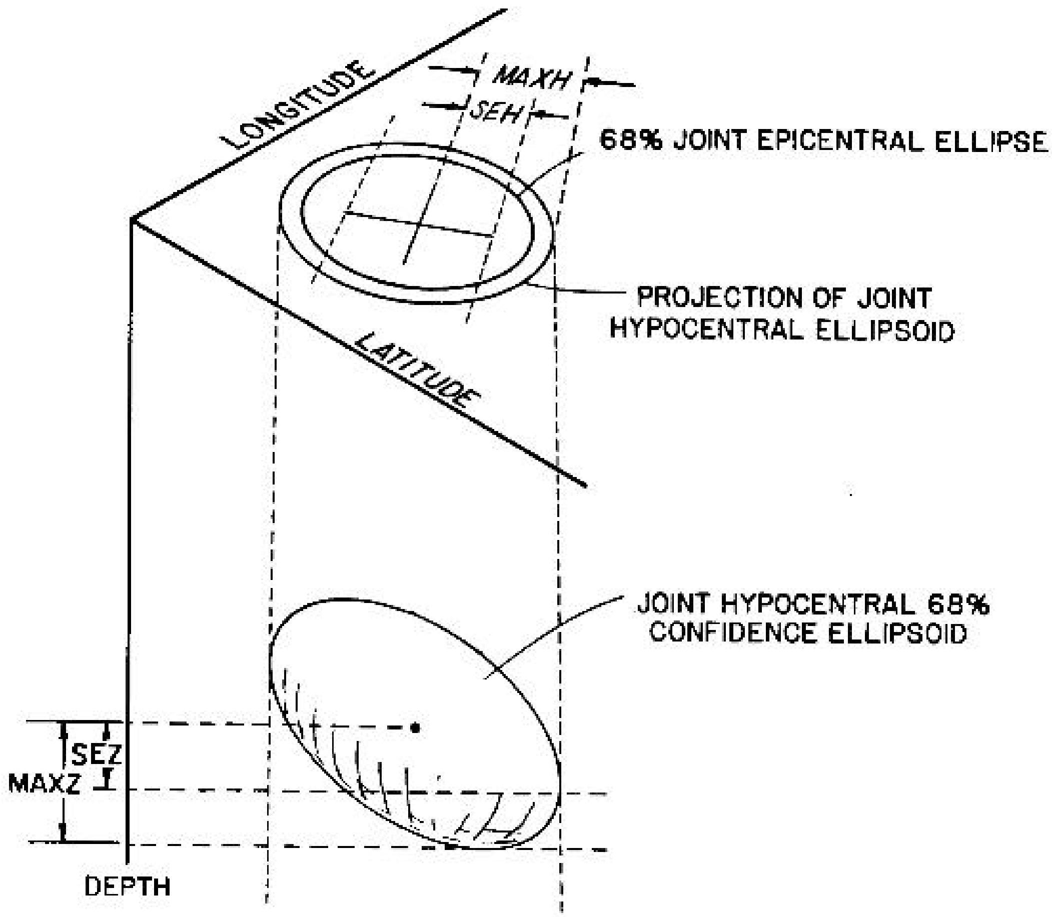


Figure 3-1. Error ellipsoid relationships.

SEH = MAXH/1.87.
SEZ = MAXZ/1.87

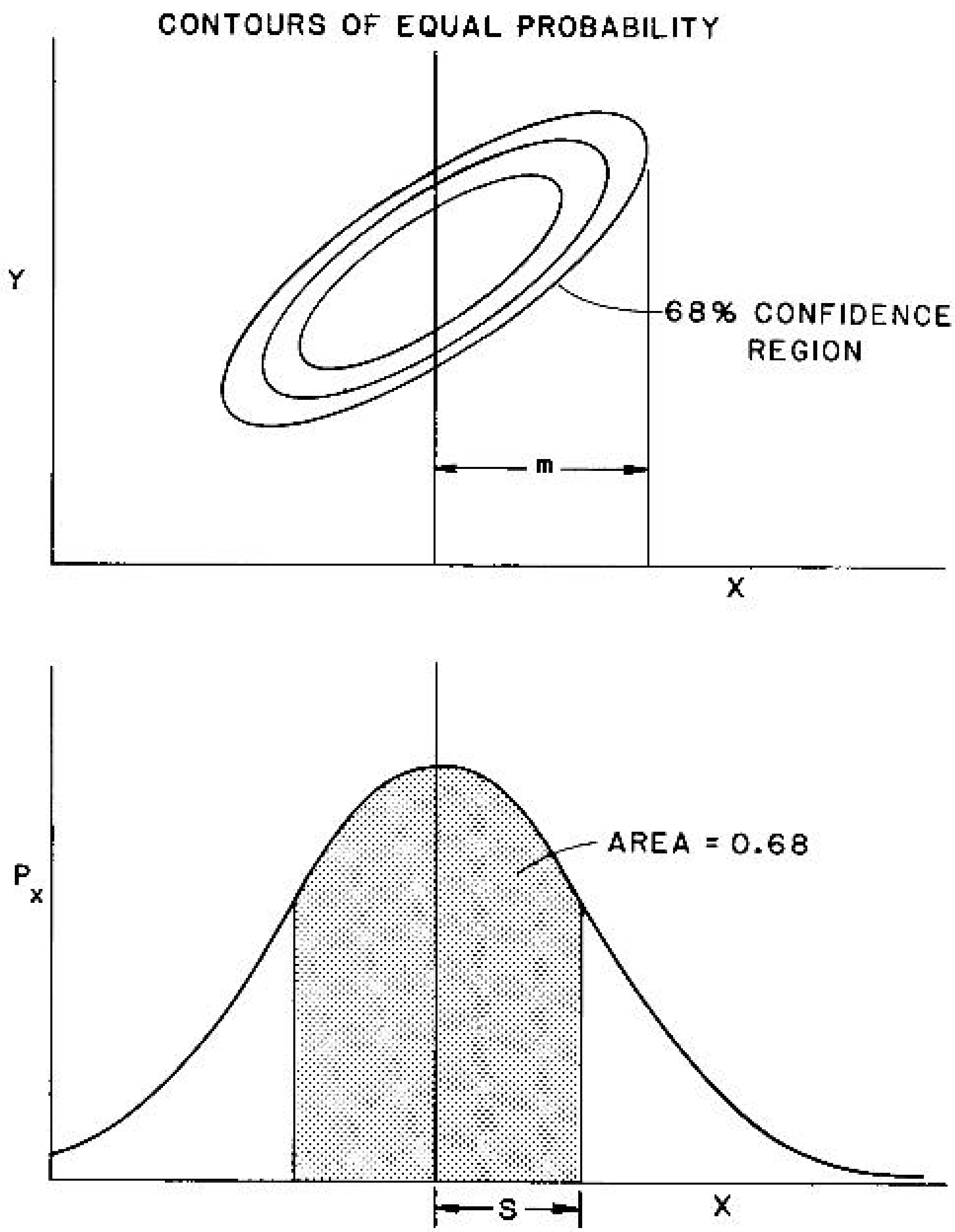


Figure 3-2.

Upper: Contours of equal probability in a two-dimensional probability distribution (Pxy).
Lower: One-dimensional probability distribution (Px) with same x scale as in upper figure.

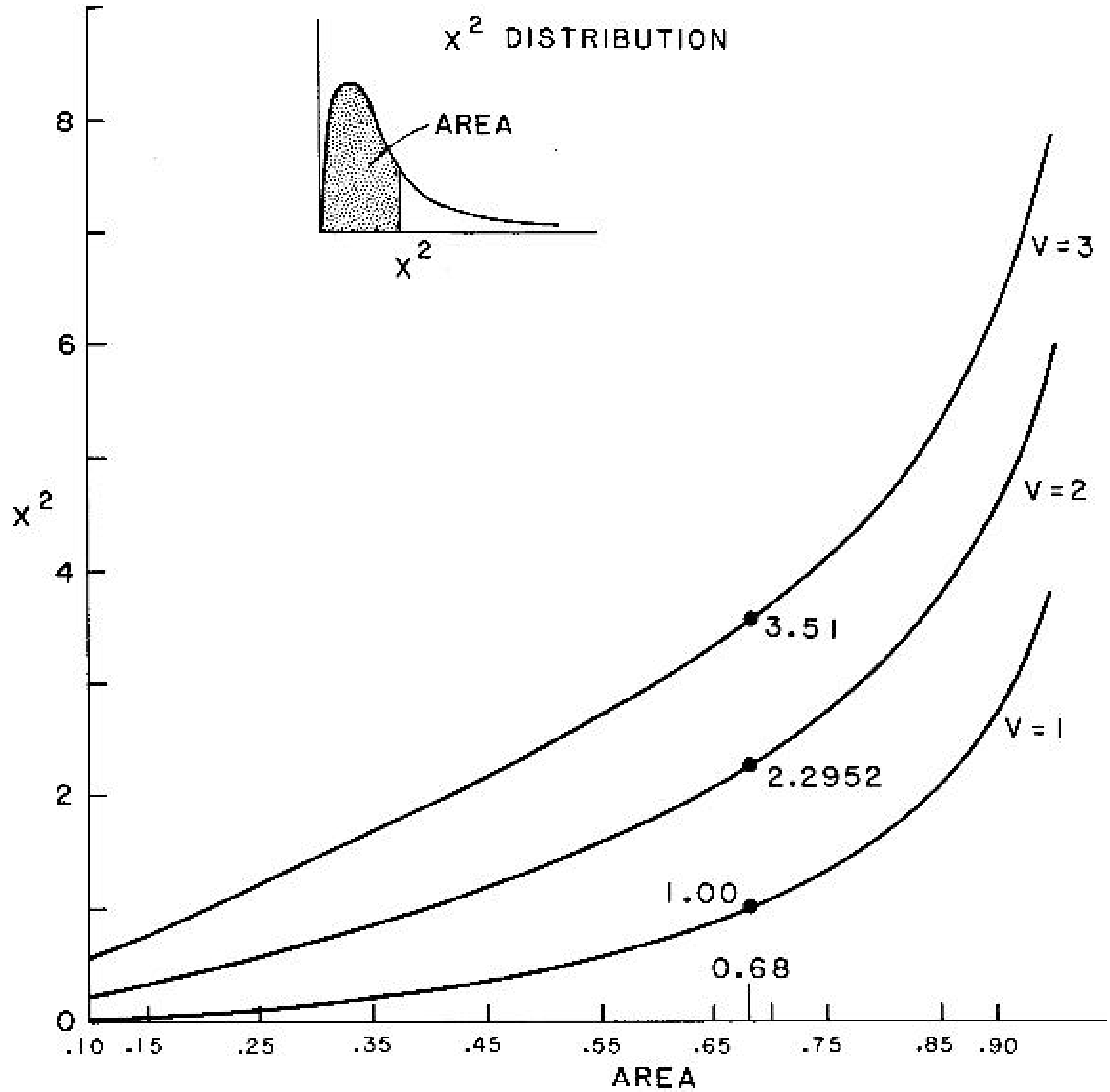


Figure 3-3. Chi-square versus area for 1, 2, and 3 degrees of freedom (V).

➢ *3.2 Global limits on depth*

The error ellipsoid is computed from the partial derivatives of travel times with respect to latitude, longitude and depth, evaluated at the final hypocenter determined for the earthquake. The travel times are not linear. Consequently, the error ellipsoid is an appropriate measure of the errors only to the extent that the partial derivatives are linear in the region nearby the final location and that there is only one spatial minimum of RMS residual. Earthquakes in southern Alaska often have a minimum in RMS residual at two different depths, and sometimes neither minimum is significantly lower than the other is. To help deal with these events, and also as a check on the error ellipsoid, the maximum upward and downward shifts of the depth that still have RMS < RMSLIM are computed and added to each SUMMARY record when the GLOBAL OPTION is used (See 2.2.3.11). RMSLIM is defined so that the depth limits correspond to one-standard-deviation in depth.

$$RMSLIM = SQRT(RMSZERO**2 + (YSE**2)/N)$$

where RMSZERO is the RMS residual of the final solution, YSE is the estimated standard error of the readings, and N is the number of P, S, and S-P observations used.

Nine events from southern Alaska are plotted in cross section in Figure 3-4. The final computed hypocenter, the projected error ellipsoid, and the depth limits computed with the GLOBAL OPTION are all shown. Note that the final hypocenter is not necessarily centered within the range of acceptable depths. In some cases this is due to the depth range spanning a local maximum. In others it is due to the iteration stopping because the minimum is essentially flat over a finite depth range. Also note that the error ellipsoid may indicate either a larger or smaller depth error than is indicated by the computed depth range. Although a vertical line segment indicates the depth range, the epicenter is not fixed during the search for alternative depths; so the true spatial pattern of alternative solutions is not indicated in this plot.

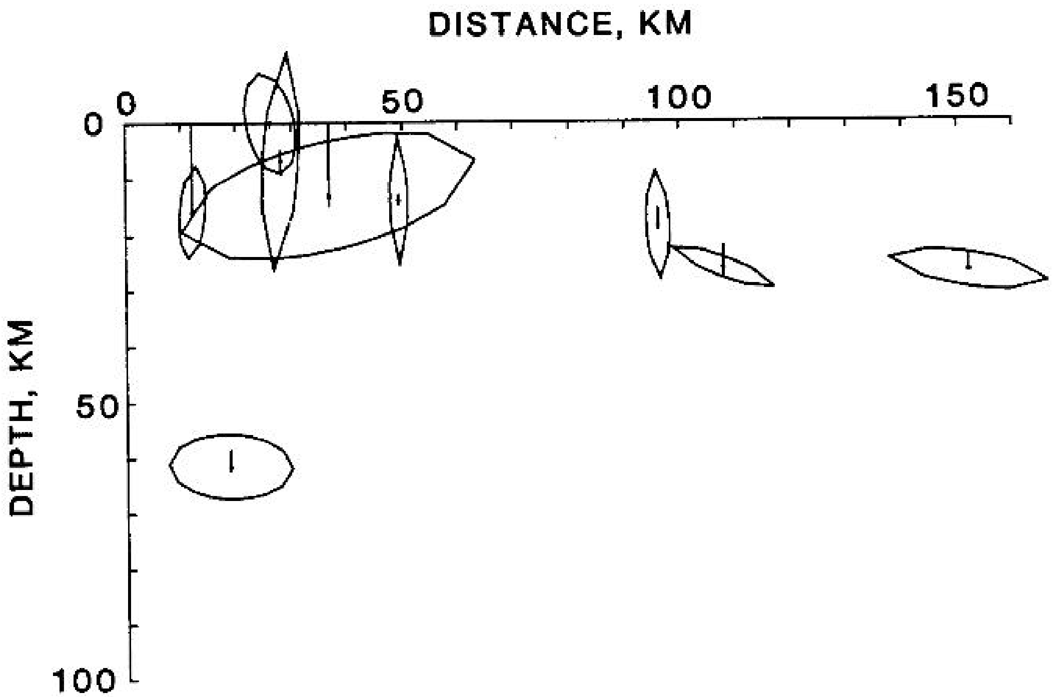


Figure 3-4. Cross section showing relationship between hypocenters, error ellipsoids and depth ranges computed with the GLOBAL OPTION.

Chapter 4. Magnitude Determinations

Both the local Richter magnitude (XMAG) and the coda duration magnitude (FMAG) may be computed by HYPOELLIPSE. The computation of these magnitudes is described below.

➢ *4.1 Coda duration magnitude, FMAG*

FMAG is calculated according to an empirical equation (Lee and others, 1972; Lahr and others, 1975; Bakun and Lindh, 1977) which can be adjusted to agree with the local Richter magnitude scale. The equation for FMAG is

$$FMAG = C_1 + C_2 \log_{10}(F * c) + C_3 D + C_4 Z + C_5 (\log_{10}(F * c))^2$$

where:

C_1, C_2, C_3, C_4, and C_5 are found empirically and correspond to the RESET TEST

variables 31, 32, 33, 40, and 43, respectively (see 2.2.4).

F = F-P time (s), by USGS convention defined to be the time interval between the arrival of the P phase and the time when the envelope of the coda drops to 1 cm peak-to-peak amplitude on a Teledyne Geotech Model-6585 film viewer with 20 x magnification.

D = Epicentral distance in km.

Z = Hypocentral depth in km.

c = Station FMAG correction from TIME DEPENDENT STATION parameter record (see 2.2.5.3)

For California	C_1 = -0.87	for Alaska	C_1 = -1.15
	C_2 = 2.0		C_2 = 2.0
	C_3 = 0.0035		C_3 = 0.0
	C_4 = 0.0		C_4 = 0.007
	C_5 = 0.0		C_5 = 0.0

The station correction (c) is not added to the coda magnitude calculated, but is used as a multiplier of the observed coda. Therefore a station with no FMAG correction should have FMAG correction equal to 1.0. If the STATION record has no entry for FMAG correction, then the correction will be set equal to 1.0. The fifth, C_5, term in the formula can be used to compensate for the nonlinear relationship of log(F) with magnitude (Bakun and Lindh, 1977).

If the MAGNITUDE OPTION code is negative then the F minus P coda length (F-P) from the ARRIVAL TIME record will be converted into the F minus S coda length (F-S) by subtraction of the S-P time. This formulation may be useful for earthquakes with wide depth variations, but is now only experimental.

Coda magnitude will not be computed for a station if the portion of the coda following the S arrival is less than 20% of the total coda duration. This prevents an FMAG from being computed for stations without a significant coda following the S phase.

➢ *4.2 Local Richter magnitude, XMAG*

▪ *4.2.1 Equation used to compute Richter magnitude*

The formula for computing Richter magnitude is:

$$XMAG = \log\left(\frac{A}{2}\right) + \left[-B_1 + B_2 \log X^2\right] + G$$

XMAG	=	Log base 10 of maximum zero-to-peak amplitude in mm as recorded on a standard Wood-Anderson seismograph.	+	Approximation to Richter's $\log A_o$ from Eaton (1970), which accounts for amplitude attenuation with distance. See Figure 4-1.	+	Station Correction
XMAG	=	log(A/2)	+	$(-B_1 + B_2 \log(X^2))$	+	G

where:

A = Maximum peak-to-peak amplitude in mm

For 1 km $\leq$ D < 200 km
$B_1 = 0.15$
$B_2 = 0.80$

For 200 km $\leq$ D $\leq$ 600 km
$B_1 = 3.38$
$B_2 = 1.50$

$$X = \sqrt{D^2 + Z^2}$$

and D is the epicentral distance and Z the focal depth in km.

G = Station XMAG correction, as specified on the TIME DEPENDENT STATION parameter record (see 2.2.5.3).

XMAG is not computed if X is not in the range 0.1 to 1,500 km.

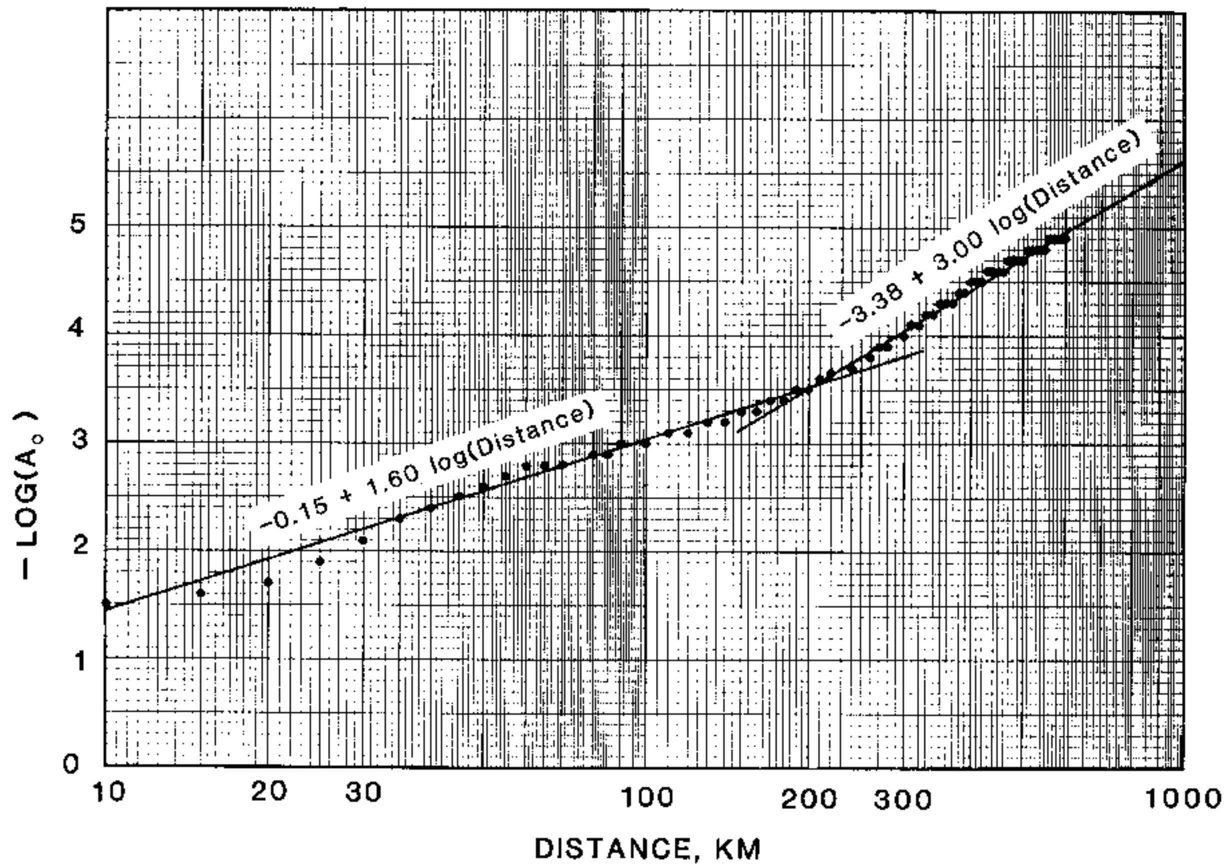


Figure 4-1. Comparison of the term log A_o from Richter (1958) (dots) with the approximation (straight lines) used in HYPOELLIPSE.

- *4.2.2 USGS-style system calibration and XMAG formulation*

A system of station calibration has been developed by the USGS that is based on the assumption that the only difference between the response of stations using the same type of instrumentation is the gain level. On this basis, a series of calibration curves has been developed for use in computing XMAG that only need to be adjusted for an individual station's overall gain. The development of these calibration parameters is summarized below, and follows the method described by Eaton (1970).

At any frequency f, the elements involved in recording ground motion are:

	Seismometer Response	System Response		
Element:	Ground Motion	Geophone Signal	Telemetry	Viewer screen
Amplitude peak-to-peak	2h mm	E_G microVolts(m V)		2A mm

Seismometer Response, $R_S(f)$,

$$R_S(f) = \frac{E_G}{2h} \, microVolts / mm$$

System Response, including telemetry and viewer, V(f),

$$V(f) = \frac{2A}{E_G} \; mm / microVolt$$

Total Harmonic Magnification, MT(f)

$$MT(f) = R_S * V = \frac{A}{h}$$

The system response at some frequency f may be calculated from the response at a particular frequency f_p multiplied by the ratio of the response at f to the response at f_p

$$V(f) = V(fp)\frac{V(f)}{V(fp)}$$

If the viewer amplitude A is measured for input signals E_G of constant amplitude and varying frequency f then the ratio

$$\frac{V(f)}{V(fp)} = \frac{A(f)}{A(fp)}$$

may be calculated as a function of frequency f. Thus

$$V(f) = V(fp)\frac{A(f)}{A(fp)}$$

V(fp) is calculated for f_p = 5 hz for a 10 µV RMS input signal. 10 µV RMS equals 28.28 µV peak-to-peak. Let the amplitude, A(5), for this signal be defined as the value C10.

$$V(f) = \frac{C10}{28.28} \frac{A(f)}{A(5)}$$

The formula for seismometer response is:

$$R_S(f) = \frac{2\pi f^3 G_{LE}}{\sqrt{(F_O^2 - f^2)^2 + 4B^2 F_O^2 f^2}}$$

where:

F_o = natural frequency in Hz

B = damping constant

GLE = motor constant m V/mm/s

Thus the total harmonic magnification is:

$$M_T(f) = R_S V = \frac{2\pi f^3 G_{LE}}{\sqrt{(F_O^2 - f^2)^2 + 4B^2 F_O^2 f^2}} \frac{C10}{28.28} \frac{A(f)}{A(5)}$$

TGN(f) is defined to be Rs(f) divided by 28.28. Using this definition, the total magnification becomes:

$$M_T(f) = C10 \frac{A(f)}{A(5)} TGN(f) \text{ mm(viewer)/mm(ground)}$$

Total Harmonic Magnification	=	Station "Gain"	*	System frequency response	*	Seismometer response divided by 28.28
$M_T(f)$	=	C10	*	A(f)/A(5)	*	TGN(f)

To calculate magnitudes equivalent to the local Richter magnitude it is necessary to calculate the amplitude B(f) that would have been read on the seismogram from a Wood-Anderson seismograph. The magnification of the Wood-Anderson is

$$M_{WA}(f) = \frac{2800\, f^2}{\sqrt{(F_O^2 - f^2)^2 + 4B^2 F_O^2 f^2}} \quad mm(WA\ record)/mm(ground)$$

with F_o = 1.25 and B = 0.8. Urhammer and Collins (1990) found the static magnification to be 2080 rather than 2800. For this reason, TEST(52) is provided to adjust this parameter.

The amplitude that would be measured on a Wood-Anderson record is:

$$B(f) = \frac{A(f)}{M_T(f)} M_{WA}(f)$$

$$B(f) = A(f) \quad * \quad \frac{M_{WA}(f)}{TGN(f)} \frac{A(5)}{A(f)} \quad / \quad C10$$

A(f)	(MWA A(5))/(TGN A(f))	C10
Amplitude (peak-to-peak in mm) as measured on viewer. f is also measured on viewer.	Value is determined by interpolation in the RSPA table corresponding to the system in use.	Station calibration from station record.

It is convenient to carry out the interpolation in terms of a response table (RSPA):

$$RSPA(n) = \log \frac{TGN(f_n)A(f_n)}{M_{WA}(f_n)A(5)} \; vs \; \log(f_n)$$

where $\log(f_n) = -2.0 + 0.1n$

Using the table of RSPA(n), the following formula is used to compute XMAG:

$$XMAG = \log\left(\frac{A}{2C10}\right) - R_{kf} \quad + \quad \left[- B_1 + B_2 \log^2 X\right] \quad + \quad G$$

Log(A/2C10) - Rkf	[-B1 + B2log^{2}X]	G
Log of maximum zero-to-peak amplitude in mm as recorded on a standard Wood-Anderson seismograph	Approximation to Richter's log A_o	Station Correction

where

Rkf = frequency response of system number k for frequency f interpolated from table of RSPA(n).

A = Maximum peak-to-peak amplitude in mm.

C10 = USGS peak-to-peak calibration amplitude for 10-m V rms, 5-hz preamplifier input.

B1 and B2 were defined above.

$$X = \sqrt{D^2 + Z^2}$$

where D = epicentral distance and Z = focal depth in km, and
G = Station XMAG correction.

- 4.2.2.1 Calibration curves for additional systems

For eight systems previously used at the USGS these values are stored in the RSPA table for n = 15 to 34, which corresponds to 0.316 to 25.119 Hz or to periods of 3.162 to 0.040 s. Up to nine additional calibration tables may be used, as described in section 2.2.10. Using this option, five such tables (corresponding to system response codes 9-13) have been defined for use with the USGS A1VCO (Rogers and others, 1980), and are described below. The A1VCO gain is automatically reduced by a factor of 10 or by a factor of 500 when large signals are being recorded. In order to take these gain states into account in computing magnitude, column 62 of the ARRIVAL TIME record (see 2.2.6.2) contains either a 0, 1, or 2, corresponding to normal gain, gain reduced by a factor of 10, or gain reduced by a factor of 500.

System response code 9 has been assigned to an A1VCO recorded on a Develocorder and viewed with a magnification of 20.

$$RSPA(n) = \mathrm{LOG}_{10}\left(\frac{M_T(F_n)}{M_{WA}(F_n)}\right), \text{ where}$$

F_n is the frequency defined by $\log(F_n) = -2.0 + 0.1n$,
$M_T(F_n)$ is the magnification of an ideal A1VCO at frequency F_n and gain zero, &
$M_{WA}(F_n)$ is the magnification of a Wood-Anderson instrument at frequency F_n.

To account for variations in geophone motor constant, gain setting and other factors between different stations, the C10 value is defined to be:

$$C10 = 2^N \frac{MAMP}{PAMP}, \text{ where:}$$

MAMP is the measured peak-to-peak amplitude in mm of the 5-Hz calibration signal,

PAMP is 49.12 mm, the theoretical peak-to-peak 5-Hz calibration signal level for an ideal A1VCO with Develocorder attenuator setting of 2, and
N is the A1VCO field gain minus 2.

System response code 10 has been assigned to an A1VCO recorded on FM tape and processed on the USGS CUSP digital playback system.

$$C10 = 2^N \frac{MAMP}{PAMP},$$ where:

MAMP is the peak-to-peak amplitude of the 5-Hz calibration signal in counts, measured on a high-gain Siemens playback.
PAMP is 2620 counts, the theoretical peak-to-peak 5-Hz calibration signal level for an ideal A1VCO played back on the Siemens, and
N is the A1VCO field gain.

System response code 11 has been assigned to an A1VCO recorded by the PC system.

$$C10 = 2^N \frac{MAMP}{PAMP},$$ where:

MAMP is the peak-to-peak amplitude of the 5-Hz calibration signal in counts, as recorded by the PC,
PAMP is 2620 counts, the theoretical peak-to-peak 5-Hz calibration signal level for an ideal A1VCO recorded by the PC, and
N is the A1VCO field gain.

System response code 12 has been assigned to an A1VCO-Siemens high-gain playback.

$$C10 = 2^N \frac{MAMP}{PAMP},$$ where:

MAMP is the amplitude of the 5-Hz calibration signal in mm, measured on a high-gain Siemens playback.
PAMP is 128 mm, the theoretical 5-Hz calibration signal level for an ideal A1VCO played back on the Siemens, and
N is the A1VCO field gain.

Siemens "ink squirt" playbacks are made at the USGS with one of two gain settings, high or low (reduced by a factor of 4 from high). In order to take the Siemens playback gain into account in computing magnitude, column 61 of the ARRIVAL TIME record (see 2.2.6.2) contains either 0 or 1, corresponding to high or low gain, respectively.

System response code 13 has been assigned to an A1VCO recorded on the UAGI Masscomp computer system.

$$C10 = 2^{N} \frac{MAMP}{PAMP}, \text{ where}$$

MAMP is the amplitude of the 5-Hz calibration signal after conversion to millivolts,

PAMP is 4000 millivolts, the theoretical 5-Hz calibration signal level for an ideal A1VCO recorded on the Masscomp system, and N is the A1VCO field gain.

- 4.2.2.2 Magnitude determination when more than one source is possible

ARRIVAL TIME records include a code in column 108 (see 2.2.6.2) that indicates the source of the amplitude measurement. For example, a given station could be recorded simultaneously on a Develocorder and on a computer system. Interpretation of the amplitude will clearly depend upon the data source being used to make the measurements. The TIME-DEPENDENT STATION records (see 2.2.5.3) allow up to five sources to be used simultaneously for a given station. The magnitude subroutine requires that amplitudes read on certain sources have the appropriate response calibration information available in the station list in order to compute a magnitude.

The source codes used for Alaska data processing are given below. Also shown is the corresponding System Response Code, when a specific code is required for magnitude calculation.

Source Code	Response Function	
V	PRIME	USGS 20x film viewer
1	PRIME	USGS 20x one-film digitizer
4	PRIME	USGS 20x four-film digitizer
*	PRIME	Assumed to be USGS 20x film
H		USGS Helicorder
2	10	USGS FM tape, digitized and processed on CUSP
E	PRIME	USGS FM tape, digitized and processed on Eclipse computer
S	12	USGS FM tape played back into Siemens "ink-squirt"
L		USGS portable RCA/COSMAC ELOG portable digital recorder

P,O,U,I,G,K	11	AEIC PC digital recorder (PCSEIS)
P = Cordova, Petersburg, Yakutat, and Willie1 @ Fairbanks		
O = Willie2 @ Fairbanks		
U = FOCUS		
I = CALIBRATE		
G = EVENT (Willie3) @ Fairbanks		
K = CODA (Willie4) @ Fairbanks		
Z		AEIC Spurr Broad-Band Digital PC recorder (PCSEIS)
5		USGS five-day tape recorder
M		SMA1 and SSA strong-motion recorder
A		UAGI 20x film
%		Assumed to be UAGI 20x film
R		UAGI Helicorder
D	13	UAGI Masscomp digital data from DAQ or DAN
J	13	Same as D, but measured automatically by JadePost
X	13	Same as D, but measured automatically by Xpick
F		UAGI film read by USGS while visiting UAGI
W		Alaska Tsunami Warning Center (ATWC) 20x film
T		ATWC teletype, corrected for satellite delay
B		Published bulletin (EDR, ISC. etc)

C		Canadian data from magnetic tape or digital format
N		NEIS, corrected for satellite delay
Q		PDAS100 portable digital recorder
Y		Field data logger such as Quanterra, K2, or UNIX box

If the amplitude source code on the arrival-time record is blank then the code entered on the BLANK SOURCE option record, which may be any character including a blank (see 2.2.3.21), will be used instead. If the amplitude source code is a blank, "V", "1", "4", or "*", then the primary system response function and the XMAG calibration constant specified in columns 10-20 of the TIME-DEPENDENT STATION record will be used in computing XMAG. If the amplitude source code is not blank, and either does not appear in the above table or does not have a response function associated with it, then an XMAG value will not be computed for that amplitude. Otherwise, a C10 value for the system-response function listed in the table above is sought from the TIME-DEPENDENT STATION records. If the station archive does not have the required C10 value, then XMAG will not be computed for this station.

4.2.3 UAGI computation of XMAG

The University of Alaska Geophysical Institute (UAGI), periodically calibrates each of its seismic stations at a series of periods. These data are maintained in a table that consists of up to 1000 logical records for the SUN version and 100 for the PC version. The data on each record is ordered in the following manner: station_name, source_code, begin_yrmody, end_yrmody, npairs, period(1), sysmag(1), period(2), sysmag(2), ..., period(npairs), sysmag(npairs). Pairs must be in order of increasing period.

Item	Format
Station_name	A4 (columns 1-3 or 1-4)
Source_code	A1 (column 5 or 6)
Begin_yrmody of calibration (eg., 881129)	Free format integer
End_yrmody of calibration	Free format integer
Npairs - number of pairs to follow	Free format integer
Period	Free format real (s)

Sysmag - system magnification	Free format real (counts/mm ground displacement)

The name of this file must be entered on a UOFACAL record included with the input data (see 2.2.3.18). Stations with a primary system-response code equal to 18 (in columns 10-11 of the TIME-DEPENDENT STATION record, see section 2.2.5) will have an amplitude magnitude (XMAG) computed only if calibration data for the corresponding time period is found in the table.

To allow for dates after 1999, years 70-99 are set to 1970-1999; years 00-69 are set to 2000-2069.

➢ *4.3 Summary of parameters that control the magnitude calculations*

The overall preferred magnitude is entered on the SUMMARY record in columns 37-38(see 2.4.1). This magnitude may be either the average XMAG, average FMAG, or the average of XMAG and FMAG, as determined by the MAGNITUDE OPTION code (see 2.2.3.3).

▪ *4.3.1 FMAG*

The computed FMAG for each station is entered on the ARCHIVE ARRIVAL TIME record (columns 103-104; see 2.2.15) and the average FMAG for the event is entered on the SUMMARY record (columns 72-73; see 2.4.1).

The parameters for the FMAG equation are set by TEST variables 31, 32, 33, 40, and 43.

The TIME-DEPENDENT STATION parameter record (see 2.2.5.3) includes:

FMAG weight, which determines how each station's FMAG is weighted in computing the average FMAG for the earthquake.

FMAG correction, a multiplicative correction-factor.

The ARRIVAL TIME record (see 2.2.6.2) includes the measured coda duration (F-P) in seconds and the coda duration source code. The source code is just for documentation and is not used by HYPOELLIPSE.

▪ *4.3.2 XMAG*

The XMAG for each station is entered on the ARCHIVE ARRIVAL TIME record (columns 101-102; see 2.2.15) while the average XMAG for the earthquake is entered on the SUMMARY record (columns 70-71; see 2.4.1).

- 4.3.2.1 USGS XMAG

The TIME DEPENDENT STATION parameter record (see 2.2.5.3) may include up to five system response codes and corresponding calibration constants. This allows magnitude calculations for a station to be based on amplitudes measured on any of five recording systems.

Calibration curves for nominal gain settings may be entered into the program (see 2.2.10)

The ARRIVAL TIME record (see 2.2.6.2) includes the maximum peak-to-peak amplitude, the period of maximum amplitude, the A1VCO gain-state, the Siemens playback gain state, and the amplitude source code.

- 4.3.2.2 UAGI XMAG

The TIME DEPENDENT STATION parameter record must have system response code 18 specified (columns 10-11; see 2.2.5.3).

A table of station calibrations must be specified with a UOFACAL OPTION record (see 4.2.3).

The ARRIVAL TIME record (see 2.2.6.2) includes maximum peak-to-peak amplitude, period of maximum amplitude, A1VCO gain-state, and amplitude source code.

Chapter 5. Determination of the Vp/Vs Ratio

If the P and S phases of an earthquake are read at two or more stations and if the ratio of the P velocity to the S velocity (Vp/Vs) is assumed to be a constant, then the Vp/Vs ratio and origin time can be computed. If P- and S-arrival pairs are available from more than two stations, then in general a plot of S-arrival time versus P-arrival time will not define a single straight line, so some "best fitting" line must be found in order to estimate the slope (Vp/Vs) and the origin time. Since both the P- and the S-arrival times are subject to random errors, it is not appropriate to compute the least-square regression of P on S (which assumes S has no errors) or the regression of S on P (which assumes P has no errors). Instead, errors in both P and S should be taken into account by minimizing (Madansky, 1959)

$$T = \sum_1^n W_i (S_i - A - BP_i)^2 \text{, where}$$

$$B = \frac{Vp}{Vs} \text{, } A \text{ is the } S \text{ axis intercept, and}$$

for the i[th] of n stations:

S_i *is the S arrival time*

P_i *is the P arrival time*

$$W_i = \frac{1}{E_{S_i}^2 + B\,E_{P_i}^2}$$

E_{S_i} = *C times the standard error of the S arrival time*

E_{P_i} = *C times the standard error of the P arrival time*

[The standard errors are computed from the assigned weight codes for P and S. C is an arbitrary constant.]

Although there are closed solutions to this problem if the standard errors (or variances) of S and P are the same for all i (Madansky, 1959), an iterative technique was developed for use with seismic data for which the variance is estimated for each reading. In computing the sum to be minimized for a given value of B, the data are first centered by subtracting the weighted mean of the S arrivals from each S-arrival time and the weighted mean of the P arrivals from each P-arrival time:

$$SC_i = S_i - \frac{\sum W_i S_i}{\sum W_i} \qquad PC_i = P_i - \frac{\sum W_i P_i}{\sum W_i}$$

then the sum (T) to be minimized is computed from:

$$T = \sum W_i \, (SC_i - B \; PC_i)^2$$

To find the value of B that minimizes T, T is initially computed for five values of B defined by:

$$B_k = BL_1 - DB_1(K - 3), \quad k = 1 \text{ to } 5$$

where $DB_1 = 0.6$ and BL_1 is the average of the weighted least squares regression slope of S on P and the inverse of the weighted regression slope of P on S. T is then compared for the five values of B defined by

$$B_k = BL_2 - DB_2(k - 3), \quad k = 1 \text{ to } 5$$

where $DB_2 = 0.4\ DB_1$ and BL_2 is the value of B_k which gave the minimum sum T in the previous step. This process is repeated 6 more times, so that B is resolved to the nearest 0.001 units.

The printed output includes the Vp/Vs ratio and the standard error of the Vp/Vs ratio computed from S regressed on P and also from P regressed on S. The standard error of the slope computed using both P and S weights is estimated from the square root of the sum of squares of the standard deviations computed for S regressed on P and for P regressed on S.

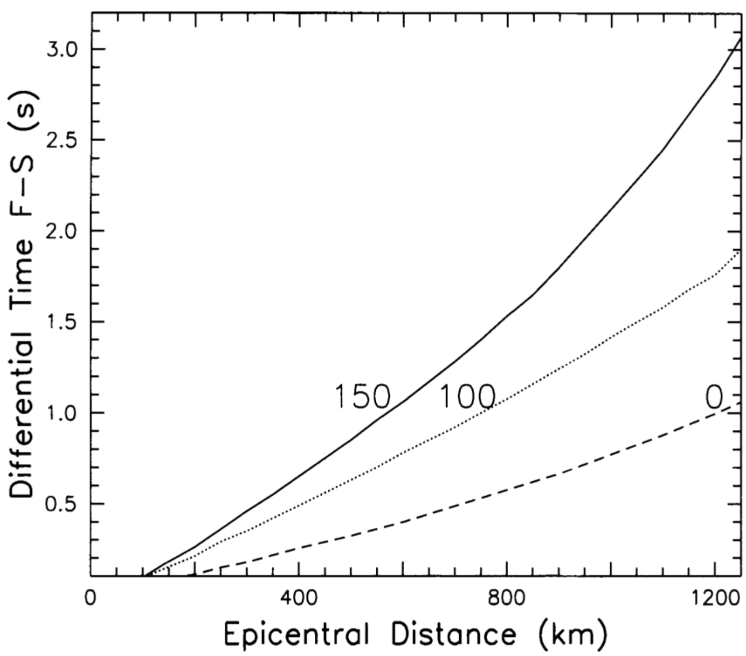
Chapter 6. Generating Travel-Time Tables with Program TTGEN

[This chapter is an excerpt from the HYPOINVERSE manual (Klein, 1985) with only a few minor modifications.]

➢ *6.1 Use of travel-time table*

The program reads a travel-time table generated independently of the location process, and calculates travel time, travel-time derivatives, and emergence angles at the source by interpolation from the table. Three-point (parabolic) interpolation is used within the table, and linear extrapolation is used beyond the table. The table itself is a condensed grid of travel times as a function of distance and depth, so that travel times for shallow nearby sources may be accurately modeled without wasting space on deep or distant grid points where the travel-time curve changes slowly. A user may generate their own travel-time table empirically, with another program, or use the travel-time generating program TTGEN to prepare a table for a flat-earth model from a given velocity-depth function. The source code for TTGEN, along with sample input and output files, is included in the TTGEN directory.

Note that a flat-earth velocity model may be appropriate for locating crustal earthquakes recorded at epicentral distances less than the Pg-Pn crossover distance, but the sphericity of the earth reduces the travel times by as much as a tenth of a second at distances of about 200 km for a surface focus, and 100 km for a 100-km-deep focus (Snoke and Lahr, 2001). The travel-time differences between flat and spherical geometries for the *iasp91* P-wave velocity model of Kennett and Engdahl (1991) are shown below as a function of distance for source depths of 0, 100 and 150 km.



The differential P-wave travel time as a function of epicentral distance for flat (F) and spherical (S) geometries for three different focal depths (from Snoke and Lahr, 2001)

➢ *6.2 Velocity models allowed by TTGEN*

Velocity models consist of from 2 to 20 points at which the user specifies velocity and depth. Linear velocity gradients are assumed to connect the points. The last point fixes the velocity and depth of the homogeneous half-space underlying the model. The half-space velocity must be the greatest of any velocities specified to insure that rays can be refracted along the top of the half space.

The use of linear gradients smoothes out the discontinuities in travel-time derivatives which result from homogeneous layer models, and gives a more realistic spread in emergence angles of down-going rays than is possible with modeling rays as refracted from discontinuities.

One buried low-velocity zone is permitted in the model. This means that velocity may not decrease with depth except for one group of adjacent velocity points. Hypocenters that occur within a low-velocity zone may produce a shadow zone at the surface, and rays in this distance range are calculated as if refracted along the layer above the low-velocity zone.

TTGEN can handle models with homogeneous layers, (zero gradients), but velocity discontinuities (infinite gradients) are not allowed. Velocity gradients should assume reasonable values such as 0.0 or between 0.02 and 8.0 km/s/km in the interest of numerical stability.

TTGEN operates by shooting rays out from the source and calculating time, distance, and other parameters where (and if) they emerge at the surface. Layers with steep gradients (such as might be used to model a Moho transition) can produce reverse branches in the travel-time curve, and such layers should be at least 0.3 km thick to insure that enough rays will bottom in the layer to define the travel-time curve properly. Errors can be introduced in the final travel-time table by under sampling a too complicated or irregular velocity model with too few rays.

➢ *6.3 Using TTGEN*

At depth intervals specified by the user, the program shoots rays with increasing ray parameter starting with vertically emergent rays, and calculates distance, travel time, and other parameters for each ray (see outputs of TTGEN section). At each depth, a printed listing of these results is produced, noting any reverse branches or rays lost to a low-velocity wave guide. The program then produces the final travel-time table by interpolating travel times at distance intervals specified by the user. Interpolation is done in the first arrival from among the various branches including refractions from the half space and top of a low-velocity zone.

➢ *6.4 Input to TTGEN*

All model parameters including depth, distance, and ray intervals at which computations are to be performed are specified in a velocity model file. The program uses reduced travel times for the table to save space. One specifies the inverse of the reducing velocity REDV (in s/km) to use in calculation. The reduced travel time is the absolute time minus distance multiplied by REDV. Using a reducing velocity equal to the half space velocity is a good choice, but the value is not critical in this version of TTEGN. In the original version, in which INTEGER*2 integers were used, it was important to use REDV to keep the maximum travel time in the table smaller than 32 seconds.

The user specifies the amount by which the independent parameter Q is incremented to calculate the distance and time for rays of various ray parameter and emergence angle. The ray parameter P and the emergence angle PHI are functions of Q as follows:

$$PHI = 2\,\mathrm{TAN}^{-1}\left[\frac{Q}{Z_H + \frac{1}{2}}\right]$$

$$P = \frac{\mathrm{SIN}(PHI)}{V_H}$$

where:
Z_H and V_H are depth and velocity at the hypocenter, respectively.

Q is a better independent parameter than either P or PHI since it gives a greater density of rays for deeper penetrations. This also gives the distant travel-time points a distance spacing comparable to nearby points. The parameter Q is incremented as follows. It takes on the value 0.0 and NQ1 values at increments of DQ1, then NQ2 values at increments of DQ2. The largest value of Q is thus NQ1 * DQ1 + NQ2 * DQ2, and the greatest number of rays (maximum value of NQ1 + NQ2) is 200. Ray calculation stops when down-going rays begin to penetrate the half space, and travel times appropriate to a refracted ray are used beyond this point. Values of DQ1= .08, NQ1 = 100, DQ2 = 0.4, and NQ2 = 100 are a good first try, and generally insure that the entire travel-time curve can be adequately defined by less than 200 rays.

The grid points in distance and depth at which travel times are calculated for output to the final table are determined by eight parameters similar in concept to the Q parameters described above. Travel times are calculated at depths of 0.0 and NZ1 values at increments of DZ1, then NZ2 values at increments of DZ2. This permits a fine-grid spacing for shallow depths and a coarse spacing at greater depths where the travel-time curve will be smoother. Similarly, travel times are calculated at distances of 0.0, DD1, 2DD1, up to ND1 * DD1, and then at ND2 values in increments of DD2. Presently the maximum value of NZ1 + NZ2 is 27, and ND1 + ND2 may be as large as 41.

➢ *6.5 Velocity model input format (TTGEN prompts for name of this file)*

Record #	Columns	Format	Example	Explanation	
1	1-8	A8	TTPR	Name of file with information on run that may be printed.	
1	9-16	A8	TAB	Name of file that will contain the new travel-time table. This is also used to create filenames of the form TABxxx where xxx = DEPTH. One such file is generated for each depth in travel-time table. Each file is designed for plotting a travel-time curve, and contains distance (km), travel time (s) and reduced travel time (s).	
1	17-26	F10.2	0.12	REDV, one over the reducing velocity used to condense the travel-time plots and tables.	
1	27-36	F10.2	1.78	Vp/Vs velocity ratio. (If negative, use this table for P and the next table for S)	
*2	1-5	F5.2	0.08	DQ1	Parameters for incrementing the independent parameter Q governing ray spacing (see Text).
*2	6-10	I5	100	NQ1	
*2	11-15	F5.2	0.04	DQ2	
*2	16-20	I5	100	NQ2	
*3	1-5	F5.2	4.	DZ1	Parameters for incrementing the grid spacing in depth (see text).
*3	6-10	I5	12	NZ1	
*3	11-15	F5.2	10	DZ2	
*3	16-20	I5	15	NZ2	
*4	1-5	F5.2	4.	DD1	Parameters for incrementing the grid spacing in distance (see text).
*4	6-10	I5	26	ND1	
*4	11-15	F5.2	15.	DD2	
*4	16-20	I5	15	ND2	
5	1-20	10A2	Alaska	Title to appear within travel-time table.	
*6	1-5	F5.2	5.6	Velocity of first point in model (km/s).	

*6	6-10	F5.2	0.0	Depth of first point (km). This format is repeated for each velocity-depth point of the model, one line per point, up to a total of 15 points. The first depth must be set to 0.0 km. The last point given sets the velocity and depth of the half space.
*7	1-5	F5.2	5.9	Velocity of second point in model (km/s).
*7	6-10	F5.2	4.0	Depth to second point of mode.
Continue with remaining points of the velocity model.				

* All but records 1 and 5 are read in free format in this implementation.

➢ *6.6 Outputs of TTGEN*

The condensed travel-time table contains all the information necessary to identify itself and be used by HYPOELLIPSE. The printed output of TTGEN contains one tabulation for each depth grid-point. One line is printed for each ray calculation until the deepening rays reach the half space. The tabulated data is as follows:

J	Ray index used to reference rays defining the endpoints of a shadow zone or reversed branches.
Q	User-defined parameterizing variable. Equal increments of Q are designed to give a greater density of deeper rays where they are needed to define the travel-time curve.
EM.ANG	Emergence angle of ray at the source, measured in degrees from zenith.
P	Ray parameter in s/km.
DIST	Distance in km at which ray reaches the surface. If DIST = -1, then the ray is trapped in a wave-guide and does not reach the surface.
TIME	Travel time in s.
REDUCED	Reduced travel time in s, given by TTIME - DIST * REDV, where REDV is one over the reducing velocity.
L.BOT	Layer in which down-going rays bottom.
Z.BOT	Depth at which down-going rays bottom.
V.BOT	Velocity at which down-going rays bottom.
DDIF	Distance difference between this and the preceding ray. DDIF is negative on reverse branches.
BR	Branch number. It is incremented by 1 each time a new forward branch is encountered.
AMP	Relative amplitude of the ray at the surface assuming an isotropic source and geometrical spreading. It is just the ratio of the area of a ring on a unit sphere surrounding the source to the corresponding area at which rays emerge at the earth's surface.
AMP*R2	Amplitude times distance squared. Used to estimate the difference between actual and ideal inverse-square spreading.
REMK	Remark such as RB (reversed branch) or WG (ray in wave guide)

Chapter 7. Use of cylindrical delay regions

A system has been developed for specifying station delays within arbitrarily shaped regions. The strategy for specifying the regions and allowing for smooth transitions on the edges of the regions was suggested by Fred Klein and extended to allow for variations with depth. A region is modeled by one or a combination of vertical cylinders (Figure 7-1), each of which is specified by the coordinates (including depth) of its center, an inner height and an inner radius within which stations delays specific to that region will be used, and an outer height and an outer radius within which station delays will be based on a combination of delay models for this region and adjacent regions.

For each trial location during the earthquake location process, the horizontal and vertical distance to the center of each cylindrical regional is computed. There are three fundamentally different cases to consider:

(Case 1) The location falls within the inner cylinder of one or more of the regions -- in which case the delays specified for the region with the smaller volume are used. If volumes are equal, parameters for the volume with center closest to the epicenter are used.

(Case 2) The location falls outside the outer cylinder of every region -- in which case the default delays are used.

(Case 3) The location falls within the transition zone of one or more of the regions. In this case a three-step procedure is followed:

Step One - A table of weights is generated with one entry for each transitional region that the location falls within. Each entry consists of the delay-model number preferred by the region and the weight, which is computed based on a cosine function that tapers from one at the edge of the inner cylinder to zero at the outer cylinder. Near the corners of each cylinder an elliptical function is used to determine the weight (Figure 7-1). For example, a table with for a location that falls within three transitional regions might be:

Delay Model	Weight
2	.15
4	.40
2	.20

Step Two - If a given delay model appears more than once, then a new combined entry is formed with the sum of the weights for that model. The example table above would become

Delay Model	Weight
2	.35
4	.40

Step Three - The resulting table is sorted by weight, which for this example would result in:

Delay Model	Weight
4	.40
2	.35

Three possibilities must be considered in assigning the final delays:

(a) There is only one entry in the table. If the weight is greater than or equal one, then this delay model is used. Otherwise, the default model is given sufficient weight to bring the total weight up to one, and weighted-average delays are computed for each station.

(b) There are two entries in the table. If the sum of the weights is greater than or equal to one, then the weighted-average delays are computed from these two delay models. If the sum of the weights is less than one, then the default delay-model is given sufficient weight to bring the total up to one, and weighted average delays are computed from the default model combined with the other two models.

(c) There are three or more entries in the table. The weighted-average delays are computed from the three models with the highest weight.

The cylindrical regions are defined in a free-format file, whose name is specified after the SELECT DELAY record (see 2.2.3.6). Each line defines one cylinder, as follows:

Delay Model #	Velocity Model #	Lat (N Pos)	Lon (W Pos)	Inner Radius	Outer Radius	Inner Top-Depth	Outer Top-Depth	Inner Bottom-Depth	Outer Bottom-Depth
integer	integer	real	real	real	real	real	real	real	real
For example:									
2	3	60.0	150.5	100.	150.	0.0	0.0	50.	80.

Lines beginning with C* are ignored and may be used for comments. Up to 10 delay models may be used with this option. Delay model # 1 is the default model, as defined above. Models #' 1-5 are read from the station list (see 2.2.5.2), while models # 6-10 are read in sets following the station list, as described in 2.2.5.5.

The velocity model may also be set by this option. If an event is within one or more of the inner cylindrical regions, then the velocity of the region for which the earthquake is closest to the cylinder's center will be used.

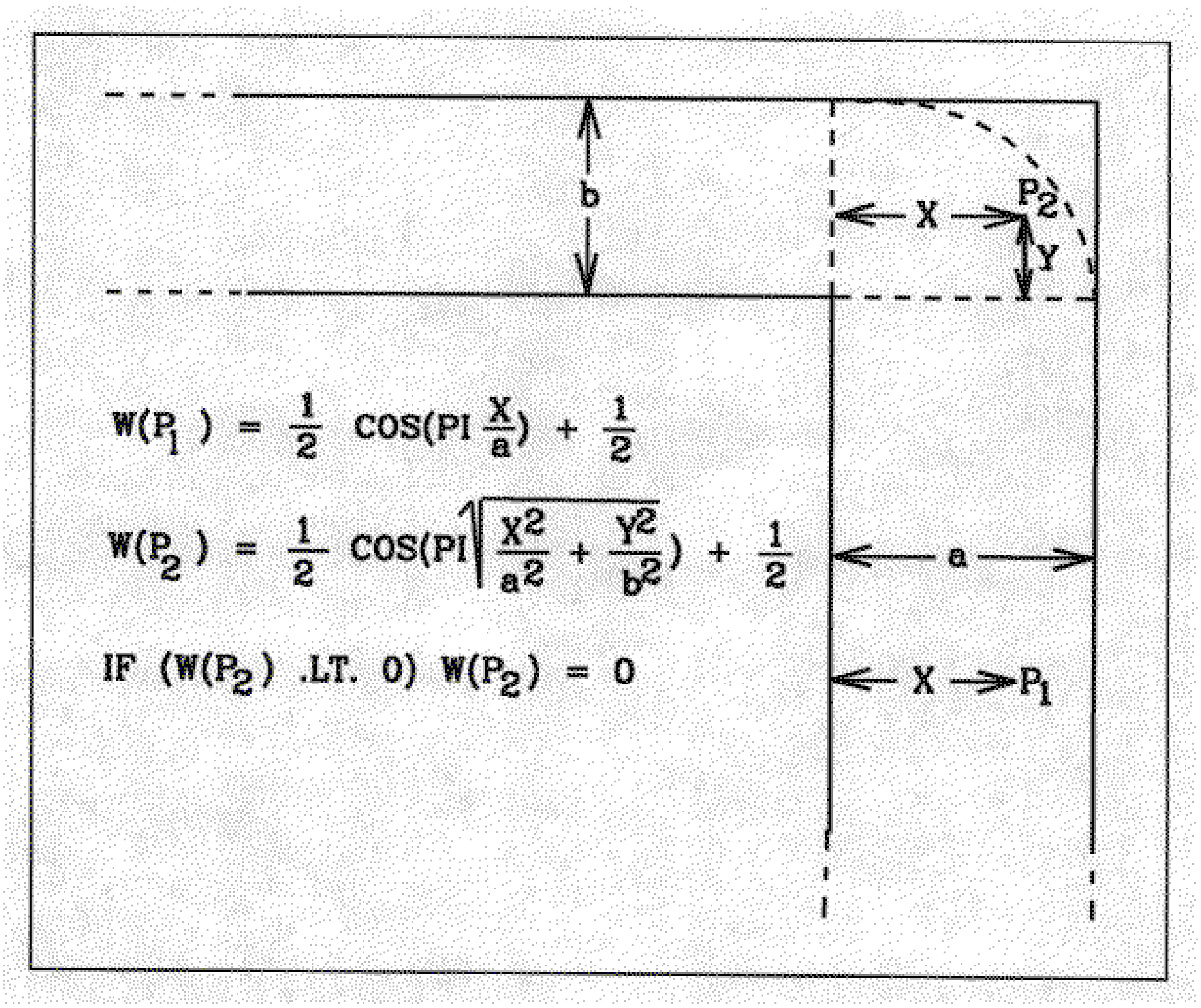


Figure 7-1 A vertical cross-section through the upper-right portion of a cylindrical domain illustrating how weights are computed for points along the edges (e.g. P_1) and for points within the corner regions (e.g. P_2).

Chapter 8. Summary of important formats

Formats are illustrated here for many of the input and output items. Each field includes a typical entry, an abbreviated explanation, and the format for reading the field. For more details, refer to the sections indicated.

➢ *8.1 Velocity model (See section 2.2.2)*

1	2	3	4	5	6	7	8	9	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5
									0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
V	E	L	O	C	I	T	Y											5	.	1		0	.	0		1	.	7	8																									
																		Velocity Depth-to-top Vp/Vs-Ratio																																				
A18																		3 Real numbers with free format in columns 19-80																																				

➢ *8.2 Header (See section 2.2.3.15)*

1	2	3	4	5	6	7	8	9	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5
									0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
H	E	A	D	E	R													A	N	Y		T	I	T	L	E		F	O	R		T	H	I	S		R	U	N															
A18																		A50																																				

➢ *8.3 Reset test (See section 2.2.4)*

1	2	3	4	5	6	7	8	9	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5
									0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
R	E	S	E	T		T	E	S	T									2	1			1	5	.	0																													
A18																		2 Real numbers with free format in columns 19-80																																				

➢ *8.4 Option record (See section 2.2.3) (The PRINTER OPTION record is illustrated below.)*

1	2	3	4	5	6	7	8	9	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5
									0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
P	R	I	N	T	E	R		O	P	T	I	O	N					2																																				
A18																		1 Integer number with free format in columns 19-80																																				

➢ ***8.5 Station - primary (See section 2.2.5)***

1	2	3	4	5	6	7	8	9	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5
									0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
	B	R	K	6	0	N	2	6	.	2	3		1	4	0	W	2	8	.	2	2			2	4	0		2	2		2	0	0		6	0	0	5				0				0				0				0
St Name				LAT			LAT MIN						LON				LON MIN					ELEV					Mod		T	THK1				THK2				D	PDLY 1				SDLY 1				PDLY 2				SDLY 2			
A4				i2			F5.3						i3				F5.3					i5					i2		I	F4.2				F4.2				A	F4.2				F4.2				F4.2				F4.2			

5	5	5	5	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	8
6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0
			0				0			2	0			1	0			3	0		-	3	0	Z
PDLY 3				SDLY 3				PDLY 4				SDLY 4				PDLY 5				SDLY 5				C
F4.2				F4.2				F4.2				F4.2				F4.2				F4.2				A

➢ *8.6 Station - time dependent (See section 2.2.5)*

1	2	3	4	5	6	7	8	9	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5
									0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
	B	R	K	*		1				9			4	9			8	0	0					1		0		1	.	0					3	2	1	9	8	9	1	2	3	1	2	3		-	2	7				
St Code				*	ST WT				SYS		5Hz Cal				Xmag C10					XMg Cor				X		F	FMg Cor				P	S		GN		A	CN YR MO DY								HR		Tel Cor				X	X	X	X
A4				A	F4.2				i2		F4.0				F5.2					F4.2				I		I	F4.1				I	I		i2		I	i8								i2		F4.2				A	A	A	A

5	5	5	5	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8	8	8	9	9	9	9	9	9	9	9	9	9	1	1	1	1	1	1	1	1	1	1
6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	0	0	0	0	0	0	0	0	0
																																												0	1	2	3	4	5	6	7	8	9
			0	N	R	+	-	?	?								0			3	3	1	2	.	2	1		1	1			4	1	1	5	.	3	4		1	2			7	8		8	.	7	6		1	3
Alt Cor				P	P	P	P	P	P							SYS		5Hz Cal				Xmag C10						SYS		5Hz Cal				Xmag C10						SYS		5Hz Cal				Xmag C10						SYS	
F4.2				A	A	A	A	A	A							i2		F4.0				F5.2						i2		F4.0				F5.2						i2		F4.0				F5.2						i2	

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2
	1	5	4		5	.	2	1	2	7	.	2	3	2	9	.	2	2		3	9	0
5Hz Cal				Xmag C10					Revised Lat					Revised Lon					Rev Elev			
F4.0				F5.2					F5.3					F5.3					i4			

➢ *8.7 Arrival time (See section 2.2.6.2)*

1	2	3	4	5	6	7	8	9	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5
									0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
	B	R	K	I	P	U	2		7	9	0	8	0	6	1	0	4	1	1	5	.	3	1								1	9	.	3	8	E	S		3						2	2		1	0					
St Name						M	W		YR MO DY HR MN										SEC.												S-SEC					SRMK			W				Mx AMP				PER			.				
A4				A2		A	I	I	i10										F5.2												F5.2					A3			I				F4.0				F3.2							

5	5	5	5	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8	8	8	9	9	9	9	9	9	9	9	9	9	1	1	1	1	1	1	1	1	1	1
6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	0	0	0	0	0	0	0	0	0
																																												0	1	2	3	4	5	6	7	8	9
					0	0	T	L						0			2	0	0																														E	E	E	E	E
					S	V	Rmk			Tim Cor					F-P Time																																		P	P	S	A	C
					I	I	A2			F5.2					F5.0																																		A	A	A	A	A

➢ *8.8 Instruction (See section 2.2.6.3)*

1	2	3	4	5	6	7	8	9	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5
									0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3
M	O	R	E					*	E								1	0																						6	1	N	3	1	.	5	2					
IPRO								S	T								S	F	TRIAL Z																					LAT			LAT MIN									
A4								A	A								I	I	F5.2																					F2.0		A	F5.2									

5	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	8
4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0
1	4	2	W	5	9	.	0	1												4	2	4	0	.	1	3
LON				LON MIN					CUSP ID											Min		SECONDS				
F3.0			A	F5.2					A10											F2.0		F5.2				

➢ *8.9 Archive arrival time (See section 2.2.15)*

1	2	3	4	5	6	7	8	9	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5
									0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4
	B	R	K	I	P	U	2		7	9	0	8	0	6	1	0	4	1	1	5	.	3	1			6	2		2	9	1	9	.	3	8	E	S		3	1	0	5			2	2		1		2	1	3	8
St Code						M	W	YR MO DY HR MN											Seconds					DIST				AZIM			S-SEC					SRMK			W	A INC			MX Amp				PER			PTT Cal			
A4				A2		A	I	I10											F5.2					F4.1				i3			F5.2					A3			I	i3			F4.0				F3.2			F4.2			

5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8	8	8	9	9	9	9	9	9	9	9	9	9	1	1	1	1	1	1	1	1	1	1	1
5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	0	0	0	0	0	0	0	0	0	1
																																													0	1	2	3	4	5	6	7	8	9	0
	9	0	M	S	H	0	0	T	L	D					0			2	0	0			6	2	1	1	3	1					8	2			0			0		2	9		1	1	6	2	3	E	E	E	E	E	1
P SE			R	INS		S	V	Rmk		M	TIM COR					F-P TIME					P RESIDU					S SE			R	S RESIDU					PDLY			SDLY			EDLY			SYS		xmg		fmg		P	P	S	A	C	H
F3.2			A	A2		I	I	A2		A	F5.2					F5.0					F5.2					F3.2			A	F5.2					F3.1			F3.1			F3.1			i2		F2.1		F2.1		A	A	A	A	A	I

8.10 Summary (See section 2.4.1)

<table>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>3</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>5</td><td>5</td><td>5</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td></tr>
<tr><td>1</td><td>9</td><td>8</td><td>9</td><td>0</td><td>8</td><td>0</td><td>6</td><td>1</td><td>0</td><td>4</td><td>1</td><td>0</td><td>5</td><td>1</td><td>0</td><td>4</td><td>3</td><td>N</td><td>1</td><td>6</td><td>3</td><td>2</td><td>1</td><td>2</td><td>2</td><td>W</td><td>4</td><td>9</td><td>5</td><td>3</td><td></td><td></td><td></td><td>0</td><td>0</td><td>4</td><td>2</td><td></td><td>1</td><td>5</td><td>2</td><td>2</td><td>0</td><td></td><td>8</td><td>2</td><td></td><td></td><td>4</td><td>9</td><td></td><td>3</td><td>1</td><td></td><td>2</td></tr>
<tr><td colspan="8">CN YR MO DY</td><td colspan="4">HR MN</td><td colspan="4">SEC</td><td colspan="2">TLA</td><td></td><td colspan="4">LAT Min</td><td colspan="3">LON</td><td></td><td colspan="4">LON Min</td><td colspan="5">DEPTH</td><td colspan="2">Mag</td><td colspan="3">N Pha</td><td colspan="3">GAP</td><td colspan="3">Dist 1</td><td colspan="4">RMS</td><td colspan="3">AZIM</td><td colspan="2">Dip</td></tr>
<tr><td colspan="8">i8</td><td colspan="4">i4</td><td colspan="4">F4.2</td><td colspan="2">i2</td><td>A</td><td colspan="4">F4.2</td><td colspan="3">i3</td><td>A</td><td colspan="4">F4.2</td><td colspan="5">F5.2</td><td colspan="2">F2.1</td><td colspan="3">i3</td><td colspan="3">i3</td><td colspan="3">F3.0</td><td colspan="4">F4.2</td><td colspan="3">i3</td><td colspan="2">i2</td></tr>
</table>

<table>
<tr><td>5</td><td>5</td><td>5</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>7</td><td>7</td><td>7</td><td>7</td><td>7</td><td>7</td><td>7</td><td>7</td><td>7</td><td>7</td><td>8</td><td>8</td><td>8</td><td>8</td><td>8</td><td>8</td><td>8</td><td>8</td><td>8</td><td>8</td><td>9</td><td>9</td><td>9</td><td>9</td><td>9</td><td>9</td><td>9</td><td>9</td><td>9</td><td>9</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td></td><td>8</td><td>2</td><td>2</td><td>1</td><td>2</td><td>1</td><td></td><td>4</td><td></td><td>6</td><td>3</td><td>8</td><td>2</td><td>0</td><td>2</td><td>2</td><td>F</td><td>1</td><td>2</td><td>5</td><td>7</td><td>C</td><td>F</td><td></td><td>3</td><td>/</td><td>M</td><td>O</td><td>R</td><td>E</td><td>1</td><td>0</td><td>7</td><td>9</td><td>E</td><td>0</td><td>E</td><td>0</td><td>1</td><td>9</td><td>3</td><td></td><td>7</td><td>8</td><td>1</td><td></td><td>5</td><td></td><td>4</td><td></td><td>1</td><td>7</td><td>7</td><td></td><td>3</td><td></td><td>-</td><td>1</td><td>3</td><td>2</td></tr>
<tr><td colspan="4">STD Err</td><td colspan="3">AZIM</td><td colspan="2">Dip</td><td colspan="4">STD Err</td><td colspan="2">xmg</td><td colspan="2">fmg</td><td>P</td><td colspan="4">STD Err</td><td>Q</td><td>M</td><td colspan="2">NS</td><td>/</td><td colspan="4">INST</td><td colspan="4">MO YR</td><td>T</td><td>F</td><td colspan="5">SEQ NUM</td><td colspan="4">S-P TIM</td><td colspan="2">Zup</td><td colspan="2">Zdn</td><td colspan="4">Vp/Vs</td><td colspan="2">WtO</td><td colspan="5">DEPTH</td></tr>
<tr><td colspan="4">F4.2</td><td colspan="3">i3</td><td colspan="2">i2</td><td colspan="4">F4.2</td><td colspan="2">F2.1</td><td colspan="2">F2.1</td><td>A</td><td colspan="4">F4.2</td><td>A</td><td>A</td><td colspan="2">i2</td><td>A</td><td colspan="4">A4</td><td colspan="4">i4</td><td>A</td><td>I</td><td colspan="5">A5</td><td colspan="4">F4.2</td><td colspan="2">F2.0</td><td colspan="2">F2.0</td><td colspan="4">F4.2</td><td colspan="2">i2</td><td colspan="5">F5.2</td></tr>
</table>

Chapter 9. Acknowledgements

This computer program is one of a series of hypocenter programs developed at the U.S. Geological Survey. The program draws heavily on previous location programs. Eaton (1969) wrote the first USGS program based on the principles of Geiger's method (Geiger, 1912), determined how to calculate travel times, magnitudes, etc. Lee made major modifications to Eaton's program to make it computationally more efficient, to use stepwise multiple regression, to use azimuthal weighting and Jeffrey's weighting, and to greatly improve the output format. Lee and Lahr (1972) further modified Lee's program to use S minus P interval time and to facilitate user modification of the iteration controlling parameters.

The first-motion plotting routine is adapted from an unpublished program by M.S. Hamilton. The use of secondary refraction arrivals was suggested and first implemented by P. Papanek. The azimuth and apparent-velocity routine was adapted from an unpublished program by H.M. Iyer. J.C. Lahr developed the method for solving the regression equations and finding the standard error ellipse. P.L. Ward and F.W. Klein considerably modified the travel-time routine, originally written by Eaton. B.R. Lienert's travel-time routine was used as a guide for modifications allowing stations to be embedded within the velocity model (Lienert and others, 1986). The program for generating a travel-time table (TTGEN) and the subroutines for interpolating travel times from the table were modified only slightly from F.W. Klein's HYPOINVERSE location program (Klein, 1985). J.A. Snoke made helpful modifications to the travel-time-table subroutines.

J.C. Lahr and P.L. Ward extensively modified the overall control logic and computational details from the Lee and Lahr (1972) version of HYPO71. W. Gawthrop wrote the linear velocity over a half-space travel-time subroutines. The distance and azimuth are calculated using a subroutine written by B.R. Julian. With this subroutine there is no longer a limit of 70 N. to 70 S. (as in pre-1982 versions of HYPOELLIPSE) and distance and azimuth determinations are more accurate. Correspondence with J.A. Snoke has been instrumental in clarifying the relationship between the error ellipsoid and other error estimates. The program has benefited from many discussions with C.D. Stephens and A.G. Lindh and early manual reviews by W.H. Bakun and R.A. White. Many corrections and revisions to the current version were made at the suggestion of C.D. Stephens.

A thorough and detailed review of this manual by K.A. Fogleman caught many problems and is greatly appreciated. I am indebted to J.S. Gomberg and K.A. Fogleman for reviewing the Y2K version of the manual.

Chapter 10. References

Bakun, W. H., and Lindh, A. G., 1977, Local magnitudes, seismic moments and coda durations for earthquakes near Oroville, California: Bulletin of the Seismological Society of America, v. 67, p. 615-629.

Draper, N. R., and Smith, H., 1966, Applied regression analysis: New York, John Wiley and Sons, 407 p.

Eaton, J. P., 1969, HYPOLAYR, a computer program for determining hypocenters of local earthquakes in an earth consisting of uniform flat layers over a half space: U.S. Geological Survey Open-File Report, 155 p. *http://pubs.usgs.gov/of/1969/0085/report.pdf*

Eaton, J. P., 1970, Harmonic magnification of the complete telemetered seismic system, from seismometer to film viewer screen: U.S. Geological Survey Open File Report, 23 p.

Geiger, L., 1912, Probability method for the determination of earthquake epicenters from the arrival time only (translated from Geiger's 1910 German article): Bulletin of St. Louis University, v. 8 (1), p. 56-71.

Jeffreys, H., 1961, Theory of probability (3rd ed.): London, Oxford at the Clarendon Press, p. 214-216.

Kennett, B.L.N., and Engdahl, E.R., 1991, Travel times for global earthquake location and phase identification: Geophysical Journal International, v. 105, p. 429-465.

Klein, F. W., 1985, User's guide to HYPOINVERSE, a program for VAX and Professional 350 computers to solve for earthquake locations: U.S. Geological Survey Open-File Report 85-515, 53 p. *http://pubs.usgs.gov/of/1985/0515/report.pdf*

Lahr, J. C., Page, R. A., and Thomas, J. A., 1975, Catalog of earthquakes in south central Alaska, April-June 1972: U.S. Geological Survey, Open-File Report, 30 p.

Lahr, J. C., 1979, HYPOELLIPSE: A computer program for determining local earthquake hypocentral parameters, magnitude, and first motion pattern: U.S. Geological Survey Open-File Report 79-431, 310 p.

Lahr, J. C., 1980, HYPOELLIPSE/MULTICS: A computer program for determining local earthquake hypocentral parameters, magnitude, and first motion pattern: U.S. Geological Survey Open-File Report 80-59, 59 p.

Lahr, J. C., 1980, SQUASH/MULTICS: A computer program to be used in conjunction with HYPOELLIPSE to generate an augmented phase data archive: U.S. Geological Survey Open-File Report 80-375, 11 p. *http://pubs.usgs.gov/of/1980/0375/report.pdf*

Lahr, J. C., 1984, HYPOELLIPSE/VAX: A computer program for determining local earthquake hypocentral parameters, magnitude, and first-motion pattern: U.S. Geological Survey Open-File Report 84-519, 76 p. *http://pubs.usgs.gov/of/1984/0519/report.pdf*

Lahr, J. C., 1989, HYPOELLIPSE/Version 2.0: A computer program for determining local earthquakes hypocentral parameters, magnitude, and first-motion pattern: U.S. Geological Survey Open-File Report 89-116, 92 p. *http://pubs.usgs.gov/of/1989/0116/report.pdf*

Lee, W. H. K., Bennett, R. E., and Meagher, K. L., 1972, A method of estimating magnitude of local earthquakes from signal duration: U.S. Geological Survey Open-File Report, 28 p.

Lee, W. H. K., and Lahr, J. A., 1972, HYPO71: a computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes: U.S. Geological Survey Open-File Report, 100 p.

Lienert, B. R., Berg, E., and Frazer, L. N., 1986, HYPOCENTER: An earthquake location method using centered, scaled, and adaptively damped least squares: Bulletin of the Seismological Society of America, v. 76, p. 771-783.

Madansky, A., 1959, The fitting of straight lines when both variables are subject to error: Journal of the American Statistical Association, v. 54, p. 173-205.

Pavlis, G. L. and Booker, J. R., 1983, Progressive multiple event location (PMEL): Bulletin of the Seismological Society of America, v. 73, p. 1753-1777.

Pavlis, G. L., and Hokanson, N. B., 1985, Separated earthquake location: Journal of Geophysical Research, v. 90, p. 12777-12789.

Richter, C. F., 1958, Elementary seismology: San Francisco, W. H. Freeman and Company, 768 p.

Rogers, J. A., Maslak, S., and Lahr, J. C., 1980, A seismic electronic system with automatic calibration and crystal reference: U. S. Geological Survey Open-File Report 80-324, 130 p. *http://pubs.usgs.gov/of/1980/0324/report.pdf*

Snoke, J.A., and Lahr, J.C., 2001, Locating earthquakes: at what distance can the Earth no longer be treated as flat?: Seismological Research Letters, v. 72, p. 538-541.

Uhrhammer, R. A., and Collins, E. R., 1990, Synthesis of Wood-Anderson seismograms from broadband digital records: Bulletin of the Seismological Society of America, v. 80, p. 702-716.