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User's Guide to HYPOINVERSE, a program for VAX and Professional 350 Computers to Solve for Earthquake Locations

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INTRODUCTION

HYPOINVERSE was originally written for the Eclipse minicomputer in 1978, and that version is documented in USGS Open File Report 78-694. This report supercedes the earlier document and serves as a detailed user's guide to the version for Digital Equiptment Corporation's VAX and PC350 computers.

HYPOINVERSE will locate any number of events in an input file, which can be in several different formats. Any or all of printout, summary or archive output may be produced. In addition, the PC350 version can plot a color epicenter map either of events as located or of previously located events in a summary file. In addition, the PC350 version can accept phase data from a real-time-picker (RTP) attached to its communications port and produce locations, graphics and other outputs in real time. The files and screen are managed to allow continuous operation for long periods.

The present version of HYPOINVERSE is driven by user commands. The various commands define input and output files, set adjustable parameters, and locate a file of earthquake data using the parameters and files currently set. It is both interactive and "batch" in that commands can be executed either from the keyboard or from a file. The user may either supply parameters on the command line, or omit them and be prompted interactively. The current parameter values are displayed and may be taken as defaults. This makes the program very easy to use. Combining commands with and without their required parameters into a command file permits a variety of customized procedures such as automatic input of crustal model and station data, but prompting for a different phase file each time.

All commands are 3 letters long and most require one or more parameters or file names. Filnames may be up to 40 characters long. Typing just the command name causes prompts for each required parameter. You will see their current values, and pressing RETURN leaves its value unchanged. You can thus examine values and names without changing them. (A few seldom-used commands such as those setting convergence parameters do not generate prompts and must be followed by the parameter list). If they appear on a line with a command, character strings such as filenames must be enclosed in apostrophes. The appendix gives this and other free-format rules for supplying parameters. When several parameters are required following a command, any of them can be omitted by replacing them with null fields (see appendix). A null field leaves that parameter unchanged from its current or default value. When you start HYPOINVERSE, default values are in effect for all parameters except file names.

If a file called "HYPINST." resides in your current directory, it is read as a startup command file by HYPOINVERSE. It can be used to set your own default values, read station or crust model files that you always use, etc. You can then enter commands directly or transfer control to other command files to do specific jobs.

If you are running HYPOINVERSE on the Menlo Park VAX 11/780, put the following line in your LOGIN.COM file:

```
$ HYP :== RUN WE:[KLEIN.HYP]HYP.EXE
```

and run the program anytime by typing HYP. If you are running HYPOINVERSE on one of Digital Equiptment Corporation's PC350 microcomputers, you may either install it on and run it from an application menu, or run it from DCL by typing RUN HYP. When run from DCL, the graphics, FORTRAN and communications libraries must be installed in memory (see the "special file and disk commands" section for DCL installation).

A maximum of 500 stations are allowed in the lookup station list read from station files, but this can be readily increased in both the VAX and PC350 versions. The maximum number of stations which may report a given event is 70 (50 on the PC350), and at most 80 readings (P or S waves) (50 on the PC350) may be used per event. The latter storage arrays can be increased almost without limit on the VAX owing to its virtual memory, but these arrays in the PC350 version can only be increased consistent with the limited 16-bit address space.

SPECIFYING CRUSTAL VELOCITY MODELS

HYPOINVERSE allows a maximum of 3 crustal models. The same model is always used to calculate travel times to a given station, and a model is specified for each station. Models may be of two different types which are stored and calculated differently. The simplest is the homogeneous layer model, which always calculates travel times from the basic model parameters. The second model type uses layers with linear velocity gradients, but requires that a travel time table be generated by the program TTGEN. The table need be generated only once, and HYPOINVERSE uses it very efficiently by merely interpolating from it to get all travel times and derivatives. The two model types may be mixed within the 3 allowed models, and the user assigns a number (1-3) at the time each model is read in. The only restriction is in the PC350 version, in which only one linear gradient model is presently allowed, and if used it must be model number 1. Since the PC350 version stores travel time tables in virtual arrays, the program can be readily modified to add models, but a small reduction in speed may result.

Separate P and S models may be specified for each station. The general rule for S waves is that all model travel times are multiplied by the specified P to S velocity ratio. This is done regardless of whether the S model number is the same as the P model. Thus specifying a model to only be used for S waves requires that S velocities be divided by the P to S ratio before the model is specified. This technique flexibly permits either 3 different P models (which are also used for S), or totally independent P and S models.

Homogeneous layer models

Each model may consist of up to 10 homogeneous layers including the halfspace. Velocity must increase with depth. Use the CRH command to specify the model number (1-3) and the name of the file containing the homogeneous layer model. The CRH command also reads the model into memory. For example:

CRH 2 'CRUST2.'

The format of the crust model file (CRUST2. in the example) is:

Line 1:	(A20)	Model name.
Lines 2 and later:	(2F5.2)	Velocity of layer and depth to its top.

Use one line per layer, top layer first. The depth to the top of first layer must be 0.0, and last layer is the halfspace. Maximum of 10 layers.

Linear gradient models using a travel-time table

An alternative and more computationally efficient way to compute travel times is by interpolation within a table generated prior to running HYPOINVERSE. Use of a table permits more complex travel time calculations, such as linear velocity gradients within layers and capacity for a buried low-velocity zone. The travel time table must be calculated and written to a file prior to locating earthquakes using the program TTGEN. For instructions on using TTGEN, see the appendix.

A travel time table may be calculated for a velocity-depth function consisting of from 2 to 10 points at which the velocity and depth are specified. The velocity is then assumed to be linear between points, ie., with a uniform gradient within layers. Several restrictions apply to the possible models (see also the earlier HYPOINVERSE report). (1) No two velocity-depth points may be at the same depth (a sharp velocity discontinuity is not allowed). Discontinuities may be modeled with thin layers with high gradients, but the transition layer should be thick enough that one or two rays used to generate the travel time table will bottom within the layer and define a reverse branch of the travel time curve. (2) The depth of the first point must be 0.0, and other points must be given in increasing order of depth. (3) The last (deepest) point sets the velocity of the homogeneous half space assumed to underlie the model. (4) The halfspace velocity must be the greatest of any specified to insure that rays can be refracted along the top of the halfspace. (5) One buried low-velocity zone is permitted in each model, ie. velocity may not decrease with depth except for one group of adjacent layers. (6) Homogeneous layers may be specified by assigning the same velocity to two adjacent points.

Use the CRT command to specify the model number and the file name containing the travel time table to be assigned to that model. The allowable model numbers are 1-3 in the VAX version and only model 1 in the PC350 version. The CRT command also reads the model into memory. For example:

```
CRT 1 'TABLE1.CRS'
```

SPECIFYING THE STATION LIST AND USE OF STATION DELAYS

Specify the file to read to get the names, coordinates and other station data using the STA command. For example:

STA '1984.STA'

The station data is read into memory as soon as this command is given, and is kept until another STA command is issued. The file must contain one line per station.

HYPOINVERSE calculates travel times with a single crustal model between source and receiver whose velocity depends only on depth. It does allow some complexity and very simple ability to mimic laterally varying velocity structures, however. The flexibility is two-fold: (1) Up to 3 different crustal models can be specified, and a given model is always used by the stations assigned to it. (2) Two different travel-time delays may be specified for each station, and the choice of which delay to use depends (in a simple way) on the location of the epicenter (see the DLY command below to define the geometry of the two epicenter regions). Thus a crustal model appropriate to a part of a net may be assigned to the stations there, and travel times from earthquakes in a different part of the net may be specially adjusted (using a special set of delays) if the model used is not appropriate to the entire source-receiver path. The two sets of delays are completely independent of the 3 crustal models, although two sub-nets with matching models and delays could of course be used as a special case. S delays are calculated from P delays by multiplying by the P to S velocity ratio.
The relationships used in handling arrival times and delays are as follows:

TOBS = SEC + CCOR - OT
RES = TOBS - TCAL - DLY

where

SEC = observed arrival time
CCOR = clock correction
OT = origin time
TOBS = observed travel time
TCAL = calculated travel time
DLY = station delay
RES = travel time residual

The station data format

Cols.	Format	Data
1-4	A4	Station name. The first character may not be a number.
5	A1	Station weight (in units of 0.1) by which the weights assigned each phase are to be multiplied. Use * or 0 for no weight, 1-9 for the partial weights 0.1 to 0.9, or leave blank for full (1.0) weight.
6-7	I2, 1X	Latitude, degrees.
9-13	F5.2	Latitude, minutes.
14	A1	N or blank for north latitude, S for south.
15-17	I3, 1X	Longitude, degrees.
19-23	F5.2	Longitude, minutes.
24	A1, 4X	W or blank for west longitude, E for east.
29-31	F3.1, 1X	Period (in sec) at which the maximum amplitude will be read for this station. Must be in the range 0.1 to 1.9 inclusive.
33	I1	S wave crust model number (1-3) to always use for this station. If left blank, use the P wave model.
34	I1, 1X	P wave crust model number (1-3) to always use for this station. If left blank, use model number 1.
36-40	F5.2, 1X	P delay (sec) for delay set 1.
42-46	F5.2, 1X	P delay (sec) for delay set 2.
48-52	F5.2, 1X	Amplitude magnitude correction. If in the range ± 2.4, the correction is included (by addition) in the amplitude magnitude, and the result averaged with other stations to get the event magnitude. If you don't want a certain station's magnitude included in the average, use a correction of 5.0 plus the actual correction.
54-58	F5.2, 1X	Duration magnitude correction (see above for range etc.).
60	I1	Instrument type code for this station used to select the appropriate response curve to derive an equivalent Wood Anderson amplitude. Must be either 0, 1 or 2: 0: Standard Wood-Anderson torsion seismograph. 1: USGS standard (1 HZ geophone, .7 critical damping.) 2: Hawaii-type Sprengnether seismometer.
61-66	F6.2	Calibration factor for amplitude magnitudes, equal to the peak-to-peak amplitude of a 10 microvolt RMS signal at 5 hz applied to the VCO and measured in mm on the Develocorder film viewer. For instrument types 0 and 2 this should generally be 1.0. A cal factor of 0.0 signifies an unknown response for which no amplitude magnitudes will be computed. The cal factor must be between 0 and 49.9 inclusive.

PHASE DATA INPUT FORMATS

The name of the input phase data file is specified with the PHS command. The LOC command starts locating events, for example:

```
PHS '1983.PHS'
LOC
```

The file may contain any number of earthquakes. Phase data may be in the traditional USGS format, in condensed format (see below), or raw picker format, but the format must be specified before the LOC command is given (see the COP command). All formats require one line (input record) per station and a terminating line after each event. The terminating record may be all blank or may contain trial hypocenter information. Each station may report any or all of (1) P time, (2) S time, (3) amplitude or (4) coda duration. An arrival time will not be recognized and processing will continue if any of the following are true:

1) The remark field ("IP" or "ES") is blank.
2) The station is not on the list.
3) The phase line is incomprehensible or in a bad format.

In addition, data in traditional USGS format are rejected if:

4) The year, month & day do not agree with the first station read.
5) The arrival time differs by more than 4 minutes from the first station

The traditional USGS phase data input format

This is the default format, but it may be requested with the COP command by requesting format number 1 (i.e. "COP 1").

Cols.	Format	Data
1-4	A4	Station name. Must agree exactly (upper/lower case, position of blanks, etc.) with name in station file. May not be all blank, and may not begin with a number.
5-6	A2	P remark such as "IP". If blank, any P time is ignored.
7	A1	P first motion such as U, D, +, -, C, D. The number of non blank fields in an event are counted and output.
8	I1,1X	Assigned P weight code: 0 or blank = full weight, 1= 3/4 weight, 2= half weight, 3= 1/4 weight, 4-9 = no weight.
10-19	5I2	Year, month, day, hour & minute.
20-24	F5.2, 7X	Second of P arrival.
32-36	F5.2	Second of S arrival.
37-38	A2, 1X	S remark such as "ES". If blank, any S time is ignored.
40	I1, 4X	Assigned weight code for S. See P weight codes.
45-47	F3.0, 7X	Peak-to-peak amplitude in mm on Develocorder viewer screen or paper record.
55-58	I4, 4X	Optional event sequence number which can be used for event bookkeeping. If this field is non-blank and the follwing 4 cols (59-62) are blank, use this number to label the location printout. If this field is blank (sequence numbers not defined), then events are numbered sequentially on the location printout. This sequence number is not output to the summary file.

63-65	A3	Optional event remark. Two 1-letter event remarks may be derived from this 3-letter remark and output to the summary file. The first two 3-letter remarks in the input series of phases will, if they match one on a preset list, have their first letters used for the two final event remarks. The preset remark list now consists of: "FLT" & "F__" (felt); "TRM" & "T__" (tremor associated); "LPC" & "LPD" (long period); and "BLS" (quarry blast). The 3-letter event remark output to the summary file is derived solely from the earthquake location and depth.
66-70	F5.2	Clock correction to be added to both P and S times.
71	A1	Station remark. Unused except as a label on output.
72-75	F4.0	Coda duration in seconds.

Note: if the header (first line of each event) is deleted from each event in a full-format archive file, that file may also be used as full-format phase input. The archive file is basically a phase file with the blanks filled in.

Condensed phase data input format

The condensed format is requested with the command "COP 2". Like the traditional format, the condensed format requires one line per station and a normally blank terminator line. Unlike the traditional format, a header giving the date & time is required, and a separate station line is required for each P time, S time, and amplitude. The coda duration may be on any line, and is right after the time or amplitude. Thus multiple lines with the same station name may be present. If you group all the entries for the same station together, the data will be attributed to one station as if entered on a single line in traditional format. This uses memory most efficiently. If you scatter data for the same station around, they are treated as different stations with the same name. This yields the same results, but uses more memory.

HYPOINVERSE may optionally produce archive output in condensed format (see the ARC and CAR commands). The condensed archive format may also be read as condensed phase format. Since input phase and output archive formats are set independently, HYPOINVERSE may be used to condense phase data.

The first line of each event in condensed format must be a header containing date & time. The rule is that the P & S times at individual stations are added to the reference time on the header to get actual arrival times. Thus if the reference seconds field is blank (zero), the individual times refer to seconds within the reference minute. If the reference second is the event origin time, the individual times are actually observed travel time residuals. A HYPOINVERSE summary record is an acceptable header in which only the date & time fields are read.

The format of the header is:

Cols.	Format	Data
1-10	5I2	Reference year, month, day, hour and minute.
11-14	F4.2	Reference second (optional). If blank, second is 0.0.

The format of each station line is:

Cols.	Format	Data
1-4	A4	Station name. Must agree exactly (upper/lower case, position of blanks, etc.) with name in station file. May not be all blank, and may not begin with a number.
14-17	F4.0	Optional coda duration in seconds.

The format of cols 5-13 depends on the letter (P, S, or A) in col 6:

P time:

5-6	A2	P remark such as "IP". An uppercase P must be present in col 6.
7	A1	P first motion such as U, D, +, -, C, D. The number of non blank fields in an event are counted and output.
8	I1	Assigned P weight code: 0 or blank = full weight, 1= 3/4 weight, 2= half weight, 3= 1/4 weight, 4-9 = no weight.
9-13	F5.2	Second of P arrival relative to reference time.

S time:

5-6	A2, 1X	S remark such as "ES". An uppercase S must be present in col 6.
8	I1	Assigned S weight code.
9-13	F5.2	Second of S arrival relative to reference time.

Amplitude:

6	A1	Must be the uppercase letter A.
9-13	F5.2	Peak-to-peak amplitude in mm on Develocorder viewer screen or paper record. Use the form "XXXX." to input a large integer.

The terminator line

One terminator line must follow each event. If the line is blank, a standard trial hypocenter is used: it is at the standard trial depth beneath the station with the earliest time, at an origin time two seconds before the earliest time. Trial values for any or all of depth, latitude, longitude or origin time may be specified on the terminator line. If a trial value is absent, the standard value is used. To specify a trial origin time, you must give hour, minute and second. To specify a trial latitude or longitude, you must give degrees and minutes. The format is that of a HYPOINVERSE summary line, which can be used to set a trial hypocenter to a previous location. A terminator which is a HYPO-71 style instruction card and is blank except for columns 18-19 is a valid terminator, but the instruction parameter will have no effect. To fix the depth for one event only, make the trial depth negative. To fix the depth for all events, set the default trial depth negative.

Terminator (trial hypocenter) format

Columns 1-4 must be blank, or column 1 must contain a numeric character.

Cols.	Format	Data
7-10	2I2	Trial hour and minute.
11-14	F4.2	Trial second.
15-16	F2.0, 1X	Trial latitude (deg).
18-21	F4.2	Trial latitude (min).
22-24	F3.0, 1X	Trial longitude (deg).
26-29	F4.2	Trial longitude (min).
30-34	F5.2	Trial depth (a negative value fixes depth).

Raw picker input format

HYPOINVERSE can handle output from the Allen-Ellis real time picker (RTP). Use format number 4 (i.e. "COP 4") to read picker format from a file. On the PC350 version only, use format 5 to read directly from the communications port and locate events in real time. See the section on running HYPOINVERSE in real time. HYPOINVERSE uses an "XP" in columns 5-6 to recognize phase cards, and an asterisk in column 1 to recognize an event terminator. No trial hypocenter information can be used with picker format, and fields such as S time and remarks are not read. If printer output is being generated, any lines beginning with "PPICKER ALIVE" or "LAT" are output to the printer as an aid in monitoring a real time system. All other lines including station status reports are presently ignored by HYPOINVERSE.

Input of new phase data from the keyboard

If you do not have files of phase data, HYPOINVERSE has a utility to input arrival time data from the keyboard and write a condensed phase file in "basic" format which can subsequently be located. The input utility automatically sets the input format to number 2. The phase data may come from a reading sheet or other external source. The phase data input utility is invoked with the INP command (no arguments). You must be prepared with a small file containing a list of up to 100 station names (see below). You will be prompted for data from these stations, and will not have to enter station names for each event. The input utility is mostly self-explanatory and prompts for the data and decisions it needs. A description of its operation follows.

The input utility first asks for the filename to which phase data will be written. If an existing file is named, any data there is appended to. If a file called "STALIST." is present in the current directory, it is read for the list of station names to prompt for on each event. If the file "STALIST." is not present, another filename is requested and must be given. The prompting list of stations is a convenience: data for other stations may be entered, but the unlisted station name must be given along with each datum. Also, data need not be entered for every station in the prompting list. Responding with just a RETURN goes on to the next station in the list. Stations reporting data for most events should therefore be listed for the most efficient operation. The "STALIST." file also controls whether S-times, amplitudes and durations are routinely requested for certain stations in addition to the P-times for all stations.

The format of the station prompting file is:

Cols.	Format	Data
1-4	A4	Station name. A P-time will be requested for all stations.
5	A1	If non-blank, prompt for an S-time for this station.
6	A1	If non-blank, prompt for an amplitude for this station.
7	A1	If non-blank, prompt for a duration for this station.

Next, the phase data input utility asks whether you want to input full arrival time remarks, first motion and weight ("IPU1", "ES_3", etc.). Pressing RETURN to either this initial question or a remark prompt for an individual station (if you answered "Y" to the initial question) simply produces a remark of "_P__" or "_S__" with full weights.

The following prompts and entries are made for each event you wish to input: (1) Enter the event date and time. For the second and later events, pressing RETURN to a prompt for year, month, day, hour or minute gets the default, which is that of the prior event. (2) Prompts will be made for each station on the prompt list. The P-time is entered first, followed by duration, S-time, and amplitude if you requested prompts for them. If you chose to enter full remarks and weights, prompts for these will precede those for each P and S time. (3) When the preset station list is complete, you will be asked if you want to enter another P or S time. If yes, you must enter station name, full remark (which will determine whether this a P or an S) and weight, and the time. The minimum remark you may enter is either "_P" or "_S". (4) You will then be asked for a duration and amplitude for the previous station. Enter zero if there is none, and input a positive value if there is. (5) When the event is complete, you will be asked whether you want to stop entering data and return to command level. If you answer anything but "Y" or "YES", you will be asked for the date and time of another event which you must complete.

IMPORTANT NOTES: (1) All station names are four letters long. If your station file uses three letter names and right-justifies them, you must include a leading blank in station names you enter. (2) All data identifiers such as P, S, A or C must be uppercase. The case of station names must agree with that in your station files. (3) All numeric data may be entered in free-format (whole numbers may omit a decimal point, leading zeros are optional, etc.). Alphameric input such as station names and remarks, however, is used exactly as entered. (4) Once you press RETURN, the only way to correct mistakes is by leaving HYPOINVERSE, editing the phase file, and returning to locate the corrected file.

SOME SIMPLE COMMAND SEQUENCES

Several examples of command sequences will illustrate the flexibility of HYPOINVERSE. The intent here is to point out some of the most useful commands and how they might be sequenced. The commands which set your default parameters or which read station and crustal model files can be placed in a file called "HYPINST." and will be executed on startup each time HYPOINVERSE is run in that directory.

Example 1.	The simplest possible run (keeps all defaults).
CRH 1 'MOD1.CRU'	Read layer model 1 from the file MOD1.CRU.
STA 'ALL.STA'	Read station list from file ALL.STA.
PRT 'RUN1.OUT'	Send printer output to the file RUN1.OUT.
PHS 'SET1.PHS'	Define the phase file as SET1.PHS.
LOC	Locate the events.

Example 2:	Generates additional output files.
CRT 1 'MOD1.CRU'	Read gradient model 1 from the file MOD1.CRU.
STA 'ALL.STA'	Read station list from file ALL.STA.
PRT 'RUN1.OUT'	Send printer output to the file RUN1.OUT.
SUM 'SET1.SUM'	Write HYPOINVERSE summary data to the file SET1.SUM.
ARC 'ARC1.ARC'	Write archive data to the file ARC1.ARC.
PHS 'SET1.PHS'	Define the phase file as SET1.PHS.
LOC	Locate the events.

Example 3:	Read condensed phase data, write a compact print file, and use HYPO71 format summary output.
CRH 1 'MOD1.CRU'	Read layer model 1 from the file MOD1.CRU.
STA 'ALL.STA'	Read station list from file ALL.STA.
PRT 'RUN1.OUT'	Send printer output to the file RUN1.OUT.
LST F	Don't list available stations or crust model in printout.
KPR 1	List only final solution & station data on printout for each event.
TOP F	Don't begin each new event at the top of a page.
SUM 'SET1.SUM'	Write summary data to SET1.SUM.
H71 T	Use HYPO71 summary format.
PHS 'SET1.PHS'	Define the phase file as SET1.PHS.
LOC	Locate the events.

Example 4:	Locate a set of events with, then without S.
CRH 1 'MOD1.CRU'	Read layer model 1 from the file MOD1.CRU.
STA 'ALL.STA'	Read station list from file ALL.STA.
PRT 'RUN1.OUT'	Send printer output to the file RUN1.OUT.
SUM 'WITHS.SUM'	Put summary data with S in this file.
SWT 1.0	Set S weighting to 1.0 (full weight).
PHS 'SET1.PHS'	Define the phase file as SET1.PHS.
LOC	Locate the events.
SUM 'NOS.SUM'	Put summary data without S in this file.
SWT 0	Set S weighting to 0 (no weight).
PRT 'RUN2.OUT'	Send printer output for the second run to this file.
LOC	Locate the same events as before.

COMMANDS RECOGNIZED BY BOTH VERSIONS OF HYPOINVERSE

The parameters are listed below each command. The parameter defaults, if any, are listed in the examples. Most commands will generate prompts for parameters if you do not supply them on the same line. The commands marked with (*) will generally only be used in startup command files and do not generate prompts.

---- INPUT FILES --

CRT Read a linear gradient crustal model into a travel-time table.
- Model number (1-3). (Model number must be 1 in the PC350 version).
- File name containing the travel-time table.

Example: CRT 2 'TTMOD2.CRU'

CRH Read a homogeneous layer crustal model.
- Model number (1-3).
- File name containing the layer depths and velocities.

Example: CRH 3 'LAYMOD3.CRU'

STA Read a station data file into memory.
- File name containing stations.

Example: STA '1983.STA'

PHS Set the phase data input filename.
- Phase filename.

Example: PHS 'PHASES.PHS'

COP Set the input phase data format.
- Supply the format number as follows:

1 Traditional USGS (full) format.
2 "Basic" condensed format (codas on separate lines).
3 "Picker" condensed format (codas on lines with P times).
4 Raw picker (RTP) format read from a file.
5 Raw picker format read directly from the communications port (PC350 version only, no phase file needed).

Example: COP 1

---- OUTPUT FILES ---

PRT Set the print output filename.
- Supply the filename. Use 'NONE' to skip a printout file.

Example: PRT 'NONE' (the default), or PRT 'PRTFIL.PRT'

SUM Set the HYPOINVERSE summary output filename.
- Supply the filename. Use 'NONE' to skip a HYPOINVERSE summary file.

Example: SUM 'NONE' (the default), or SUM 'OUT.SUM'

ARC Set the archive output filename. This file contains all the data calculated for each station.
- Supply the filename. Use 'NONE' to skip an archive file.

Example: ARC 'NONE' (the default), or ARC 'OUT.ARC'

CAR Set the archive file format. The condensed formats contain only observed travel times, amplitudes, durations, assigned weights & first motions for each station, and the event location. The formats correspond to phase data input formats.
- Supply the format number as follows:

1 Full format with all data.
2 "Basic" condensed format with codas on separate lines.
3 "Picker" condensed format with codas for most stations.

Example: CAR 1 (the default).

H71 Determine the summary format.
- Set a logical flag T for HYPO71 format, F for HYPOINVERSE format.

Example: H71 F (the default).

ERF Error messages (for bad data, station names, etc.) are always written to the print file if one is specified. They may also be sent to the terminal to spot errors during a location run by turning them on.
- Supply a T to send error messages to the terminal, F otherwise.

Example: ERF F (the default).

APP Set the 3 logical flags that indicate whether an existing output file is appended to (T or true), or whether a new one is created (F).
- Supply 3 logical flags for: 1= printout file, 2= summary file, 3= archive file.

Example: APP F T T (the default), or APP F T F to append only to the summary file.

---- LOCATE EVENTS IN A PHASE FILE --------------------------------

LOC Locate events. This is the command that actually locates earthquakes using the files and parameters set by previous commands.

Example: LOC

---- PRINTED OUTPUT FORMAT ---

LST List stations, crust and test parameters at the beginning of the print output file at the time earthquakes are located.
- Set the print code:
0 Print earthquakes only.
1 Add the location parameters & filenames to beginning of printout.
2 Add stations & crust models to parameters & filenames.

Example: LST 2 (the default).

KPR Control the amount of information in the print file for each event.
- Supply KPRINT, which controls print output. Specifying a value also outputs all data output by lower values:

0 Print final location only (2 lines).
1 Add station list for final location.
2 Add the location & adjustments (one line) for each iteration.
3 Add the eigenvalues, covariance matrix & error ellipse.
6 Add the station list at each iteration (VAX version only).

Example: KPR 3 (the default).

TOP Start each earthquake at the top of a page in printout file.
- Set a logical flag (T or F) that controls whether to start each new event with a form-feed.

Example: TOP T (the default).

REP Report each earthquake located with a brief message on the terminal. This is useful for verifying that the correct file is being located, and for monitoring the progress of long runs.

- Set a logical flag (T or F) that controls whether to report each event located.

Example: REP T (the default).

---- TRIAL DEPTH, VELOCITY RATIO & ERRORS -----------------------------

Note: commands marked with an asterisk (*) do not supply interactive prompts.

ZTR Set the trial depth for the run, which can be overridden for individual events on their terminator/instruction lines.
- Supply the trial depth ZTR.

Example: ZTR 7 (the default).

POS Set the P to S velocity ratio. All S travel times are calculated as POS times the model travel time (which is assumed in P velocities). When S station delays are derived from P delays, the P delays are multiplied by POS.
- Supply the P to S velocity ratio POS.

Example: POS 1.75 (the default).

ERR* Set the assumed net reading and timing error in seconds. This should be the net error from all sources including the reading error and all unmodeled crust and delay time errors. A good value to use is your typical RMS residual after the crust and station delays have been modeled. See the ERC command.

- Supply the reading and timing error RDERR.

Example: ERR .15 (the default).

ERC* Set the coefficient ERCOF of the RMS travel-time residual in the expression for the actual timing error:

ACTUAL TIMING ERROR = /{ (RDERR)2 + (ERCOF*RMS)2 }

Set ERCOF according to the influence you want the fit of your data (the RMS) to play in location error calculation. ERCOF should usually be in the range 0,1 inclusive. The calculated location errors will be proportional to this "actual timing error".

- Supply ERCOF, the error coefficient of RMS.

Example: ERC 1 (the default).

MIN Used to skip events with too few reporting stations. If fewer than MINSTA stations are present for an event, no location is even attempted. This is useful in situations such as real time when small or poor events are to be screened out.

- Supply MINSTA, the minimum number of stations required to attempt a location.

Example: MIN 3 (the default).

---- CONVENIENCE AND CONTROL COMMANDS ---------------------------------

@ Files of commands can be executed as if they were typed at the keyboard by typing @filename.

(VAX version only). Any DCL system command can be executed from within HYPOINVERSE by typing #command. This has no effect on current parameters, and control returns to HYPOINVERSE when the command finishes. This can be used to edit files, check the directory for data files, etc.

STO Stop the program. There are no parameters.

SHO List the current input and output files on your terminal.

---- STATION DELAYS AND EVENT MAGNITUDES & NAMES ------------------------

DLY* Set parameters determining station travel-time delays. Each station may have two delays, and which of them is used may either be fixed or depend on the location of the epicenter.

- Supply KDLY, the delay model choice control:
  1 Always use delay model 1.
  2 Always use delay model 2.
  3 Separate the two delay models by a line of azimuth DLYAZ passing through the point with coordinates DLYLAT & DLYLON. If you look in the direction DLYAZ, delay model 1 applies to stations on your left, model 2 to stations on your right.
  4 Separate the delay models with a circle of radius DLYAZ km centered on DLYLON and DLYLAT. Delay model 1 is inside the circle, delay model 2 is outside.

- If KDLY>2, set DLYAZ, the line azimuth or circle radius.
- If KDLY>2, set DLYWD, the half-width in km of a transition zone separating the two models in which delays become a weighted average of the two models. DLYWD must be positive.

Supply the following in decimal degrees (with fraction).
- If KDLY>2, set DLYLON, the lon of the circle center or line point.
- If KDLY>2, set DLYLAT, the lat of the circle center or line point.

Example: DLY 1 (the default) or DLY 4 20 1 155.32 19.58

DUR* Set constants used to compute magnitude from coda duration. Two formulae can be used spanning different ranges of coda duration. The formulae have the form:

MAG = FMA + FMB*log(DURATION) + FMZ*DEPTH + FMD*DISTANCE

- Supply FMA1, FMB1, FMZ1, and FMD1 for durations shorter than FMBRK.
- Supply FMA2, FMB2, FMZ2, and FMD2 for durations longer than FMBRK.
- Supply FMBRK, the duration above which the second set of constants are used. Set FMBRK=9999 to only use the first set of constants.

Example: DUR -5.2 3.89 .013 .0037, -.9 2.026 .013 .0037, 210.
(for Hawaii, the default), or
DUR -.87 2 0 .0035, 4*0, 9999 (for California)

NET Set the network number for assigning 3-letter names to earthquakes based on their locations. This option requires that prior definition of earthquake regions be coded into the KLASS subroutine. If you do not have a net with defined names, use a NET of 0. Present nets are 1=Hawaii, 2=Long Valley.
- Supply the net number.

Example: NET 0 (the default).

---- WEIGHTING OF ARRIVAL TIMES --

DIS Set the parameters that govern progressive downweighting of more distant stations. DMIN2 is the distance to the second closest seismic station in km. The distance weight is 1.0 for stations closer than DMIN2*DISW1, 0.0 for stations beyond DMIN2*DISW2, and is tapered between those distances. If DMIN2 is smaller (closer) than DISCUT, DISCUT is used in place of DMIN2 in the above distances.
- Supply ITRDIS, the iteration on which distance weighting is to begin. Iteration continues at least until distance weighting begins.
- Supply DISCUT.
- Supply DISW1.
- Supply DISW2.

Example: DIS 0 50 1 3 (the default).

RMS Set the parameters that govern progressive downweighting of stations with larger travel time residuals. RMS is the root-mean-square travel time residual. The residual weight is 1.0 for stations with residuals less than RMS*RMSW1, 0.0 for stations with residuals larger than RMS*RMSW2, and is tapered between these residuals. If the RMS is smaller than RMSCUT, RMSCUT is used in place of the RMS in the above cutoff residuals.
- Supply ITRRES, the iteration on which residual weighting is to begin. Iteration continues at least until residual weighting begins.
- Supply RMSCUT.
- Supply RMSW1.
- Supply RMSW2.

Example: RMS 0 .16 1.5 3 (the default).

SWT Set the S wave weighting factor. Use 1.0 to give all S readings full weight, and 0 to not use any S readings.
- Supply SWT, the factor by which all S weights will be multiplied.

Example: SWT 1.0 (the default).

---- ITERATION AND CONVERGENCE PARAMETERS -----------------------------

CON* Set parameters governing tests for convergence of iterations to a final earthquake solution. The solution is considered final as soon as either the hypocentral adjustment or RMS change falls below set limits or the maximum number of iterations is exceeded.

- Supply ITRLIM, the maximum number of iterations allowed (20). Use an IRTLIM of 0 to fix the hypocenter and calculate an origin time and travel time residuals.
- Supply DQUIT. If the hypocentral adjustment falls below DQUIT km, iteration stops (.04).
- Supply DRQT. If the change in RMS residual falls below DRQT seconds, iteration stops (.001).

Example: CON 20 .04 .001 (the default).

DAM* Set iteration and damping controls affecting hypocenter adjustments.

- Supply DXFIX. Keep the depth fixed until the epicentral adjustment is less than DXFIX km (7).
- Supply DZMAX, the maximum depth adjustment in km allowed without a forced damping of the adjustment vector (30).
- Supply DZAIR. If the depth adjustment would place the hypocenter in the air, move the depth upward by this fraction (0.5).
- Supply DAMP, the mandatory damping factor for all hypocenter adjustments (0.9).
- Supply EIGTOL, the minimum eigenvalue permitted before no hypocentral adjustment is taken in its direction (0.012).
- Supply RBACK (.02). See BACFAC.
- Supply BACFAC (0.6). If the RMS increases by more than RBACK from one iteration to the next, move the hypocenter by the fraction BACFAC back toward the last location and continue iterating.

Example: DAM 7 30 .5 .9 .012 .02 .6

(*) indicates those commands which do not supply interactive prompts.

OUTPUT FILE FORMATS AND PARAMETERS

PRINT OUTPUT

The amount of information in the printed output can be varied somewhat (see the KPR and LST commands). One line of information per iteration is printed when the print control is 2 or larger. The final location data is always written to a print file, and the station list data is written if the print control is 1 or larger.

Iteration output data

I	Iteration number.
ORIGIN	Seconds part of origin time.
LAT N	Latitude.
LON W	Longitude.
Z	Depth.
NWR	Number of P & S readings with weights larger than 0.1.
RMS	The root-mean-square travel time residual using weights.
DT	Origin time adjustment to get to the next iteration location.
DLAT	Latitude adjustment in km, positive north.
DLON	Longitude adjustment in km, positive west.
DZ	Depth adjustment, positive down.
RR	Length of adjustment vector in km.
N	Number of free hypocenter parameters solved for and adjusted. Normally 4, but will be 3 on the first iteration since depth is held fixed. If N is less than 4, it is because the solution is poorly constrained and one or more eigenvalues are less than EIGTOL (see the DAM command).

Final location data

The final hypocenter data consists of two lines. In addition to the date, time, latitude, longitude and depth, this data consists of:

RMS	The root-mean-square travel time residual using all weights.
ERH	The horizontal location error, defined as the length of the largest projection of the three principal errors on a horizontal plane. The principal errors are the major axes of the error ellipsoid, and are mutually perpendicular. ERH thus approximates the major axis of the epicenter's error ellipse.
ERZ	The depth error, defined as the largest projection of the three principal errors on a vertical line.
XMAG	Average amplitude magnitude.
FMAG	Average coda duration magnitude.
RMSWT	The RMS residual value immediately before residual weighting was applied. RMSWT was used to determine which residuals were large enough to down-weight. If much less than the final RMS, then many stations had residuals large compared to RMSWT and were down-weighted.
DMIN	Distance to the nearest station.
GAP	The largest azimuthal gap between azimuthally adjacent stations.
DLYBAL	Equal to 0.0 if delay set 1 was used, 1.0 if delay set 2 was used, and a proportional fraction if the epicenter occurred in the transition zone between the two delay regions.
ITR	Number of iterations required to find the solution.
NFM	Number of P first motions reported for this event.

NWR Number of P & S readings with weights larger than 0.1.
NWS Number of S readings with weights larger than 0.1.
REMARKS The first remark is the 3-letter code based on location and depth as returned from the CLASS subroutine. Two auxiliary 1-letter remarks (F for felt, etc.) may be derived from an optional remark field in the phase data (see phase data input format above). An asterisk (*) indicates convergence problems with the final solution such as running out of iterations, depth held fixed due to poor data, or failure of the hypocenter to reach a minimum in RMS residual.

<u>Station list data</u>

STA Station name.
DIST Epicentral distance.
AZM Azimuth to station in degrees east of north.
AN Angle if emergence at the hypocenter, in degrees up from nadir.
P/S P or S remark code and P first motion.
W Assigned weight code.
SEC Observed arrival time.
TOBS Observed travel time.
TCAL Calculated travel time.
DLY Station delay.
RES Travel time residual. The residual may be flagged (in the following column) by an "X" if that station was given a time but no weight, or an "*" if the residual is larger than 0.50.
WT Actual normalized weight used for this arrival, including assigned weight, distance weight, residual weight, station weight and S weight. S waves are flagged with an "S" following the weight.
R The 1-letter station remark carried from the phase data.
INFO The information or importance contribution of this arrival to the solution. The total importance of all stations equals the number of unknowns (usually 4).
AMP Peak-to-peak amplitude in mm.
DUR Coda duration in seconds.
XMG Amplitude magnitude for this station.
FMG Duration magnitude for this station.

HYPOINVERSE SUMMARY FORMAT

Cols.	Format	Data
1-10	5I2	Year, month, day, hour and minute.
11-14	F4.2	Origin time seconds.
15-16	F2.0	Latitude (deg).
17	A1	S for south, blank otherwise.
18-21	F4.2	Latitude (min).
22-24	F3.0	Longitude (deg).
25	A1	E for east, blank otherwise.
26-29	F4.2	Longitude (min).
30-34	F5.2	Depth (km).
35-36	F2.1	Amplitude magnitude.
37-39	I3	Number of P & S times with weights greater than 0.1.
40-42	I3	Maximum azimuthal gap.
43-45	F3.0	Distance to nearest station (km).
46-49	F4.2	RMS travel time residual.
50-52	F3.0	Azimuth of smallest principal error (deg E of N).
53-54	F2.0	Dip of smallest principal error (deg).
55-58	F4.2	Magnitude of smallest principal error (km).
59-61	F3.0	Azimuth of intermediate principal error.
62-63	F2.0	Dip of intermediate principal error.
64-67	F4.2	Magnitude of intermediate principal error (km).
68-69	F2.1	Duration magnitude.
70-72	A3	Event location remark.
73-76	F4.2	Magnitude of largest principal error (km).
77-78	2A1	Auxiliary remarks (see final hypocenter output above).
79-80	I2	Number of S times with weights greater than 0.1.
81-84	F4.2	Horizontal error (km).
85-88	F4.2	Vertical error (km).
89-90	I2	Number of P first motions.

HYPO71 SUMMARY FORMAT

Cols.	Format	Data
1-6	3I2, 1X	Year, month and day.
8-11	2I2	Hour and minute.
12-17	F6.2	Origin time seconds.
18-20	F3.0	Latitude (deg).
21	A1	S for south, blank otherwise.
22-26	F5.2	Latitude (min).
27-30	F4.0	Longitude (deg).
31	A1	E for east, blank otherwise.
32-36	F5.2	Longitude (min).
37-43	F7.2	Depth (km).
44-50	F7.2	Duration magnitude.
51-53	I3	Number of P & S times with weights greater than 0.1.
54-57	F4.0	Maximum azimuthal gap.
58-62	F5.1	Distance to nearest station (km).
63-67	F5.2	RMS travel time residual.
68-72	F5.1	Horizontal error (km).
73-77	F5.1	Vertical error (km).

STATION ARCHIVE OUTPUT FORMAT

Like phase data, archive data is available in both full and condensed formats. The full-format archive output contains all of the information in the printed station list, but in a compact format suitable for archiving. The archive file may be read by a later program to plot first motions on the focal sphere, compile residual summaries, regenerate a printed output file, extract a subset of events, etc.

Both full and condensed archive files have the same structure. The first line of each event is identical with a HYPOINVERSE summary line (see format above), and acts as a header. Next is one line per station, and a blank line terminates each event.

The station lines in full-format archive files are identical in format to phase data with the blanks filled in with additional station data. Thus, deleting the headers from events in full-format archive files allows them to be read back into HYPOINVERSE as phase data. The blank line terminating each event in an archive file is also compatible with phase data input. If you replace the terminating line with the archive header line (HYPOINVERSE summary format) and use the archive file as an input phase file, the previous location will automatically be used as a trial location.

The condensed archive file format is identical to the condensed phase format, and may be directly re-input. HYPOINVERSE may thus be used to condense phase data by reading full-format on input and writing condensed format archive files. Condensed phase files generally use P & S times which are in seconds from the previous whole minute. The reference second on the header line is thus zero. Condensed archive files, however, use the origin time as the reference second on the header line, and observed travel times as P & S times. Either can be used as phase input, since the rule for reading condensed format is to add the reference second to each P & S time to get the actual arrival time.

Full archive file format

The first (header) line for each event is a HYPOINVERSE summary line with the final location and other data. The terminating line for each event is blank. The format of each station line between is:

Cols.	Format	Data
1-4	A4	Station name.
5-6	A2	P remark such as "IP".
7	A1	P first motion.
8	I1, 1X	Assigned P weight code.
10-19	5I2	Year, month, day, hour and minute.
20-24	F5.2	Second of P arrival.
25-28	F4.2	P travel time residual.
29-31	F3.2	P weight actually used.
32-36	F5.2	Second of S arrival.
37-38	A2, 1X	S remark such as "ES".
40	I1	Assigned S weight code.
41-44	F4.2	S travel time residual.
45-47	F3.0	Peak-to-peak amplitude in mm.
48-50	F3.2	S weight actually used.
51-54	F4.2	P delay time.
55-58	F4.2	S delay time.
59-62	F4.1	Epicentral distance (km).
63-65	F3.0, 5X	Emergence angle at source (replaces optional remark on some original phase cards).
71	A1	1-letter station remark.
72-75	F4.0	Coda duration in seconds.
76-78	F3.0	Azimuth to station in degrees E of N.
79-80	F2.1	Duration magnitude for this station.
81-82	F2.1	Amplitude magnitude for this station.
83-86	F4.3	Importance of P arrival.
87-90	F4.3	Importance of S arrival.

Condensed archive file format

The first (header) line for each event is a HYPOINVERSE summary line with the final location and other data. The format and structure of the following station lines are identical to that of condensed phase data (see above). The terminating line for each event is blank.

INTRODUCTION TO MAP PLOTS IN THE PC350 VERSION OF HYPOINVERSE

The PC350 version can make epicenter map plots in color. Plots may be from a summary file of earthquakes located previously, or of earthquakes as they are located. The latter is a key feature of real time operation. Graphics are medium resolution (240 x 960 pixels), but the limited amount of fine detail can partly be offset by using color.

The basic features of the map plots are:
1) The map may have any scale and geographic position.
2) Earthquakes are plotted as symbols, whose size depends on magnitude.
3) Symbols may be of different shapes and colors. Shape can depend on depth and color on event time, or vice versa.
4) Certain magnitudes, depths or times may be left unplotted by assigning a blank symbol or background color to those intervals.
5) Lines (coastlines, faults etc.) and stations may be added to the map.
6) Event counts are displayed by magnitude, depth and time interval as plotted. Unplotted events are also counted.
7) The time intervals (and hence earthquake symbols) can optionally be defined by events as located. Newly located events are plotted with the symbol for the latest time interval until they occur after the end of the interval. Then the intervals are shifted, symbols redrawn for progressively older intervals, and the very oldest events erased.

The first step in setting up a plot is to define the map scale (a large dimensionless number) with the SCA command and the latitude and longitude of the map center with the CTR command. The center may later be shifted by an amount in km with the SHF command or to a new center selected with the cursor using the CUR command. Up to 4 different sets of geographic lines in different colors may be added with the LIN command. The stations used in the locations may be added with the STA and STP commands.

There is a great deal of flexibility in defining earthquake symbols. Use the MAG command to define from 1 to 5 magnitude intervals and the sizes of their corresponding symbols. Use the INT command to set the number of depth intervals (1-7) and number of time intervals (1-7). Also use INT to specify whether symbol type depends on depth and color on time, or whether symbol type depends on time and color on depth. The INT command must be given before any of the other symbol definition commands. Because of limited screen resolution, different symbol types are difficult to distinguish when the symbols are small. It is therefore best to let symbol color depend on depth or time, whichever is more important. Next use the SYM command to define the symbol types, the CLR command to set the symbol colors, and the DEP command to define the depth intervals. Each time interval may be set explicitly with the TIM command, or they may be defined by the date and time of the first interval and some constant interval length using the SET command. The numbers of symbol types and colors, and numbers of depth and time intervals must have been set initially by the INT command.

The actual plots are made in one of two ways. Use the PLT command to plot from a summary file previously defined by the SUM command. Use the LOP command to first plot events (if any) already in the summary file, then locate events, plotting them as you go along. The LOP command functions exactly like the LOC command, but produces graphic output in addition. The top 23 lines of the screen are devoted to graphics and the bottom two lines contain scrolling text. The scrolling lines contain a synopsis of the last event located while locating events. After plotting finishes, the bottom two lines are used for the command dialog. The screen may be erased and full-screen scrolling restored using the RES command.

If your PC350 has a color monitor, 7 different colors are available in addition to the background. The background is color zero, and is black by default. If you have the extended bit map option but no color monitor, you can get shades of gray. Each component of the plot may be assigned a different color number from 0 to 7. The plot components include stations, up to 4 sets of lines, map frame, titles, and from 1 to 7 different earthquake colors made to depend on either depth or time. Thus only 8 colors can be displayed at one time, and you must partition them among all the different plot components. Each of the 8 displayed colors, however, may be redefined in terms of its red, green and blue intensity values using the HUE command. Red and green may each take on 8 intensity values from 0-7, but blue intensities may be only 0, 2, 4, or 6. The 8 default colors were chosen to be easily distinguished from each other, but they can be reset to shades of yellow, for example. Assigning the intensity values 0,0,0 to a color causes it temporarily not to be displayed. (The background color has intensity 0,0,0). The scrolling text always uses color number 4, which is yellow by default.

SYMBOL TYPES AND DEFAULT COLORS

The symbol types available for earthquakes and stations are:

0 No symbol (blank)
1 Square
2 Circle
3 Triangle
4 Diamond
5 +
6 X
7 Solid square
8 Solid circle
9 Solid triangle
10 Solid diamond

The default color definitions with their RGB intensities are:

0	Black (the background color)	0,0,0
1	Dark blue	0,0,6
2	Red	7,0,0
3	Green	0,7,0
4	Yellow	7,7,0
5	Magenta	7,0,6
6	Cyan (looks light blue)	0,7,6
7	White	7,7,6

PLOT AND REAL TIME COMMANDS RECOGNIZED BY THE PC350 VERSION

The parameters required are listed below each command. The parameter defaults, if any, are listed in the examples. All commands supply prompts and defaults if you do not give parameters on the command line.

---- DEFINE THE MAP AREA --

CTR Set the coordinates of the map center. Use positive values for north and west.
- Latitude in degrees and minutes.
- Longitude in degrees and minutes.

Example: CTR 19 20 155 15 (the default is Hawaii)

SCA Set the map scale, which is a large dimensionless number. (If the scale is written "1 to N", "1:N" or "1/N", N is the number to enter here).

Example: SCA 400000. (the default)

SHF Shift the present map center by an amount given in km. The next map plotted will have the new center.
- Supply the latitude shift in km (positive north).
- Supply the longitude shift in km (positive east).

Example: SHF 1 -2.2 (the default is SHF 0 0, or no shift)

CUR Use the graphics cursor to define a new map center within the map presently plotted on the screen. The 4 cursor (arrow) keys each move the cursor by one unit. The corresponding 4 keys just above them in the same inverted T pattern each move the cursor by 10 units (these are the "insert here", "select", "prev screen" and "next screen" keys). When the cursor is in position, press any white key on the main keyboard to register the new center. The next map plotted will have the new center. You can use CUR only once per map: resetting the center twice in immediate succession gives bad results. Be sure to reset the center before setting a new scale if you are doing both. CUR uses the scale of the map on the screen to compute an offset, and resetting the scale first causes an erroneous new center to be computed.

Example: CUR (there are no parameters)

---- EXTRA OUTPUT ON MAPS ---

LIN Plot lines (digitized geology, coastlines, etc.) on the map. The LIN command does not produce any plot output, but sets files and colors for lines on succeeding plots. Lines from up to 4 different files may be plotted. Each record within a line file must contain 6 latitude-longitude pairs. The values must be in decimal degrees with north and west positive. The reading format is 6(F6.4,F7.4). One or more imbedded pairs which are 0,0 (or blank) indicate a pen lift between the previous and following line segments. The line(s) will be automatically plotted on every map until cancelled. Use a file count of 0 to omit all lines.
- Supply the number of files N (0-4).
- Supply N pairs of filenames and color number for that file.

Example: LIN 0 (the default), or LIN 2 'A.LIN' 5 'B.LIN' 6

STP Plot seismic stations on the map. The STP command does not produce any output, but sets parameters for station symbols on succeeding plots. The stations plotted are those used for the locations, and must have been previously read in using the STA command. Use the command "STP F" to disable station plotting.
- Supply a logical flag (T or F) that controls station plotting.
- The symbol type to use.
- The symbol diameter in inches (use a small number such .0001 to turn on a single pixel).
- The symbol color.

Example: STP F (the default) or STP T 1 .0001 7

STA Read a station data file into memory for later locations or plotting.
- File name containing stations.

Example: STA '1983.STA'

TIT Set the title to appear on plots.
- Supply the title, up to 56 characters.

Example: TIT ' ' (no title, the default) or TIT 'JULY 1984 EARTHQUAKES'

---- DEFINE EARTHQUAKE SYMBOLS --

MAG Define from 1 to 5 magnitude intervals and assign a symbol size to each interval. The plot will also display a count of the number of events in each interval. Use a size of 0 to leave an interval unplotted. If a magnitude is equal to or greater than the lower limit specified, it will be plotted with the size for that interval. The total of the number of magnitude, depth and time intervals should not exceed 16.
- Supply the number of magnitude intervals N (1-5).
- N pairs of lower magnitude limit and symbol size in inches for each interval.

Example: MAG 5, 0 .02, 1 .04, 2 .08, 3 .14, 4 .20 (the default)

INT Define the symbol type and color dependence on depth or time. The first parameter is a logical flag as follows:
T: Symbol type or shape depends on depth, color depends on time.
F: Symbol color depends on depth, shape depends on time.
You must also supply the number of depth and time intervals to use. At least one interval for each of depth and time must be used, in which case all events would plot with the same symbol type or color. Important note: the INT command must be given before any of the other symbol definition commands below. That is because the other commands use the dependence flag and number of intervals to define the interval parameters correctly. The total of the number of magnitude, depth and time intervals should not exceed 16.
- Supply the symbol dependence flag (T or F).
- Supply the number of depth intervals NDEP (1-7).
- Supply the number of time intervals NTIM (1-7).

Example: INT F 4 1 [the default is 4 colors depending on depth and 1 symbol type depending on time (which is really no dependence)].

SYM Define the set of symbol types or shapes. The INT command must be given first, since the number of symbol types is either NTIM or NDEP.
- Supply the list of symbol numbers, each 0-10.

Example: SYM 7 (the default is a solid square for all event times)

CLR Define the set of earthquake symbol colors. The INT command must be given first, since the number of symbol colors is either NTIM or NDEP.
- Supply the list of symbol colors, each 1-7.

Example: CLR 2 6 3 4 (the default is red, cyan, green & yellow)

DEP Define the depth intervals, which can be assigned different colors or symbol types. The INT command must be given first, since the number of depth intervals is NDEP. An event is placed in an interval if its depth is greater than or equal to the minimum value given. Events shallower than the first depth interval are not plotted.
- Supply the minimum depths for each interval.

Example: DEP 0 5 13 20 (the default)

TIM Define the time intervals explicitly, which can be assigned to different colors or symbol types. The INT command must be given first, since the number of time intervals is NTIM. An event is placed in a time interval if it is at or after the initial date and time for that interval. Events before the beginning of the first interval are not plotted. Any event after the beginning of the last interval is plotted in that interval. (The exception to this is if you shift intervals in response to new events with the STP command. Events after the last interval then cause intervals to be shifted such that the new event is put in the last interval). You must supply the starting dates and times for each of the NTIM intervals, or can use the SET command (below) if the intervals are of equal length.
- Supply the beginning year, month, day, hour and minute for each of the NTIM intervals.

Example: TIM 60 1 1 0 0 (the default is plotting of all modern events in the same time interval) or
TIM 82 2*1 2*0, 83 2*1 2*0, 84 2*1 2*0 for 3 intervals consisting of those entire years.

SET Define the time intervals to all be of the same length by giving the start date of the first interval and the interval length. The intervals will be assigned to different colors or symbol types. The INT command must be given first, since the number of time intervals NTIM is set by INT. An event is placed in a time interval if it is at or after the initial date and time for that interval. Events before the beginning of the first interval are not plotted. Any event after the beginning of the last interval is plotted in that interval. If your intervals are of unequal length, you must assign their starting dates explicitly using the TIM command (above).
- Supply the beginning year, month, day, hour and minute for the first interval.
- Supply the length of each interval in days and hours. The length can only be set to the nearest hour. The sum of days and hours is used: for example a length of 1 day and 12 hours is the same as 0 days and

36 hours.

Example: (there is no default)
SET 84 1 1 0 0, 2 0 (for 2 day intervals beginning on 1/1/84.

CLK Reset the equal-length time intervals (previously set with the SET command) from the computer's system clock. The current time will fall in the last time interval. Use CLK in real-time applications when doing a cold start using the LOX command. The SET command must appear before the CLK command.

Example: CLK (there are no parameters)

BAD Set the location error cutoffs above which events will not be plotted.
- Supply the maximum horizontal error for plotting.
- Supply the maximum vertical error for plotting.

Example: BAD 99 99 (the default)

---- COMMANDS TO MAKE PLOTS --

SUM If you are plotting existing locations from a summary file, you must first specify the filename if you have not already done so for a previous location run. The file must be in HYPOINVERSE format, but only the time, location, depth and magnitude(s) are used for plotting.
- Supply the summary input filename.

Example: SUM '1983.SUM' (there is no default)

PLT Plot earthquakes from the specified summary file using all of the current plot options. Events may be plotted from an old file, or plotted immediately after a location run. Thus the command sequence SUM 'file'; LOC; PLT is valid and specifies a summary file, locates events into it, then plots events from it.

Example: PLT (there are no parameters)

PLR Like the PLT command, but superimposes additional data over the plot already on the screen. The PLR command does not erase the screen or initialize a new plot. A typical use is to add earthquake summary or line files. Many changes prior to a PLR command such as changing map scale or resetting time intervals when doing automatic interval shifting will produce meaningless results.

Example: PLR (there are no parameters)

LOP Locate and plot events. The function of LOP is identical to that of LOC, except that events are plotted as located. The LOP command finishes with the same display as the sequence LOC; PLT, except that in the former case plotting occurs after each location and no summary file is required. The LOP command first plots any events already in the summary file, if one is specified.

Example: LOP (there are no parameters)

---- GRAPHICS CONTROL AND COLOR DEFINITION ----------------------------------

RES Restore the screen after plotting by erasing the plot and setting the text scrolling region back to the full screen. It is not necessary to do this between plots.

Example: RES (there are no parameters)

HUE Define one of the 8 displayable colors in terms of the red, green and blue intensity values. This command takes immediate effect on any colors currently on the screen and affects future plots until changed. The red and green intensity values must be integers in the range 0-7, but blue intensities may only take the values 0, 2, 4 or 6. A color may be temporarily blacked out by assigning it intensities of 0,0,0.
- Specify the color number to change (0-7).
- The red, green and blue intensity values.

Example: HUE 0 0 0 0 or
HUE 2 7 0 0 (these are two of the eight defaults)

FRM Define the color numbers of the map frame and titles. These colors will be used on the next and later plots made.
- Color number of the map frame.
- Color number of plot titles.

Example: FRM 7 4 (the default colors are white and yellow)

---- OPTIONS FOR REAL-TIME LOCATION AND PLOTTING -----------------------

RTP Set several flags which govern the automatic or real-time operation of HYPOINVERSE. See the section "Notes on running HYPOINVERSE in real-time" for further discussion. The purpose of these options is to keep a real-time system from drowning in events as they are located. The screen can display only the most current events, erase old ones and replot events as they age. New output files can be created for each day to simplify data management. It is a good idea to try these options out and locate events from a file before using them in real-time. There are 4 flags which are logical (T or F):

- Flag whether (T of F) the events plotted (either with PLT or LOP) establish the time intervals. If this option is used, you must have set a constant interval length with the SET command. The current starting date of the first (and all later) intervals are ignored and reset when the first event is plotted. The first event plotted falls in the last (the current) time interval. When a new event occurs after the last constant-length interval, all the time intervals are shifted back in time and the earthquakes on the screen are replotted with a new color. If this option is selected, the program replots all the events and the symbol key each time the first event falls in a new time interval.

- Flag whether (T or F) new summary and archive output files are to be used for each calendar day. The old files are closed and new ones opened right after the first event in a new day occurs. The filenames are of the form YYMMDD.SUM and YYMMDD.ARC so that no two will have the same name. Once closed, a file can be copied or deleted without interfering with HYPOINVERSE. Any events in the initial summary file set by the SUM command will be plotted before locations begin. For writing out newly located events, however, only the files incorporating the current date will be used.

- Flag whether (T or F) the lines and stations within the map area are to be replotted each day. If earthquake symbols eventually cover (and therefore obliterate) a large area of the screen, some lines and stations will be permanently erased. Replotting lines and stations each day is time consuming, but insures they will be visible after several weeks of operation.

- Flag whether (T or F) to make a screen copy on the dot-matrix printer before replotting the earthquakes when the time intervals are shifted. The frequency of plots will thus match the constant time interval for defining earthquake symbols. If location printout is sent directly to the printer, the plots will be imbedded within it.

Example: RTP 4*F

DEV Specify the device and directory into which daily summary and archive files will be written. This specifier is only used for daily files, and the second RTP flag (above) must be true. This option can be used, for example, to collect real-time data directly on floppy disk, or in any directory different from the one in which HYPOINVERSE is run. If daily files are not used, the directory specifier should be given along with the file names.

Example: DEV ' ' (the default is the current device and directory)
or DEV 'DZ1:[USERFILES]' to use the main directory on the first floppy disk.

---- TEMPORARILY INTERRUPTING REAL-TIME LOCATIONS --------------------------

When locating events from a phase file, reaching the end of the file returns HYPOINVERSE to its own command mode. When locating events in real time (using the COP 5 command), pressing the "1" numeral key on the main keyboard once has a similar effect and causes the program to return to HYPOINVERSE command level at the first opportunity. Stopping locations in this way will not interrupt any current location calculations until they are finished. All output files will also be closed before returning to command level. HYPOINVERSE could also be killed with control-C, but this aborts the whole task, and does not close files so that the most recent data will be lost or difficult to recover. The control-C termination is messy, requires that HYPOINVERSE be restarted from scratch, and may require some special file operations. Be sure to press the "1" key just once and carefully. It may take a few seconds to respond, particularly if computations are in progress. It is possible to confuse the program by pressing too many wrong keys or keys in too rapid succession, so that it will only respond to a control-C abort.

Stopping HYPOINVERSE by pressing the "1" key once allows any command to be entered, then locations restarted cleanly. You can thus change the convergence parameters, the display colors, the map area, or make other adjustments "on the fly". If you are not plotting events as they are located, you should restart with the LOC command like you used to begin the run. If you are plotting the earthquakes, however, you will normally use one of the special commands LOR or LOX to restart locations. In some cases, however, you may need to restart with the LOP command. The restart functions of these three commands are explained below. LOP is the least restrictive in terms of the possible prior operations, but LOR will restart the fastest.

LOP Start or restart locations and plotting, making no assumptions or requirements about what plot is already on the screen, the definition of automatically-shifting time intervals, or the storage of summary data in daily files. The screen is erased, new time intervals will be defined, any earthquakes already counted into time intervals are not kept, and the single file specified in the SUM command is used to plot recent events prior to starting new locations. Events cannot be plotted from the daily YMD.SUM summary files, since the time intervals are assumed to be undefined, and there is no way to tell which summary files to plot from. If automatic time interval shifting is enabled, events plotted from the summary file are always placed in the last time interval, and the intervals are shifted as necessary, which of course takes extra execution time. The LOP command should be used to restart locations after making major changes such as leaving and re-running HYPOINVERSE entirely or resetting the length of the time intervals.

LOX Restart locations and plotting, using the time intervals defined in the previous plot. The screen is erased, and the time intervals will be kept but not the earthquakes counted into them. LOX is thus the best command to restart locations after changing the map area, error cutoffs for plotting, or other change affecting the counting of events into the same time intervals. When events are plotted from the summary file to start the plot, they will be placed in the correct time interval right away, without the need to shift time intervals each time the last interval fills up. LOX will thus restart a plot faster than LOP. New events will begin the automatic time interval shifting when it is necessary to do so. LOX will plot summary events from either the single summary file named in the SUM command or the daily YMD.SUM files (if the second RTP flag is true). The correct YMD.SUM files will be automatically used since the time intervals are defined. LOX rather than LOP may be used to start real-time locations from scratch (for example after a system reboot) if two conditions are met. You must be using daily YYMMDD.SUM files to store summary data, and you must have just defined time intervals from the system clock using the CLK command.

LOR Restart locations and plotting without having made changes to any plot parameters. The screen is not erased, and the plot is assumed to carry on where it left off. Of these three restart commands, LOR is most restrictive in terms of the changes which may precede it, but is the fastest because nothing need be replotted. Use the LOR command after making changes which do not affect plotting, such as resetting the trial depth, changing the print format, or inquiring about disk space. You may also use the LOR command after making cosmetic changes to the color map with the HUE command.

---- SPECIAL FILE AND DISK COMMANDS --

The VAX version of HYPOINVERSE has the ability to execute any DCL (Digital Command Language) command from the HYPOINVERSE command level by preceding the command with #. The PC350 version lacks this capability because of operating system differences, but can be made to do some primitive file maintenance directly from command level. When running HYPOINVERSE interactively, one can always exit, do file maintenance using DCL, and run HYPOINVERSE again. This procedure may be impractical in a real-time context because locations will have to be completely restarted. A common real-time operation, for example, is to merely display the available diskette space to see if an empty one should be inserted for data collection, then resume locations.

Doing file maintenance from within HYPOINVERSE involves internally spawning a task called PIP, and requires that it be run on a computer with the "toolkit" (program development utilities). If the two file maintenance commands PIP and DSK (see below) will not be used, the toolkit is not required, and HYPOINVERSE can be run from a menu, from "application" DCL, or from "toolkit" DCL. If these two commands are to be used, you must select the toolkit from a menu and run HYPOINVERSE from the DCL indirect file given below. These commands install libraries into memory and install PIP under a different task name whose output is directed to the printer. Sending output to the printer is essential to avoid disrupting the graphics display.

You must first locate and copy PIP, giving it a new name. Use the command

```
        DIR [*]PIP.TSK
```

to determine PIP's directory name, then

```
        COPY [directory name]PIP.TSK [ZZSYS]XYZ.TSK
```

This need only be done once, not each time HYPOINVERSE is run. Then execute the following indirect command file from DCL to run HYPOINVERSE. If the commands are placed in a file called HY.CMD, they are executed by typing @HY.

```
$ INSTALL [ZZSYS]COMLIB
$ INSTALL [ZZSYS]PROF77
$ INSTALL [ZZSYS]CGLFPU
$ INSTALL/TASK:...XYZ [ZZSYS]XYZ
$ ASSIGN/TASK:...XYZ TT2: 1
$ ASSIGN/TASK:...XYZ TT2: 2
$ RUN HYP
```

The two HYPOINVERSE file maintenance commands are:

PIP Issue a PIP-format file directive. The output, such as a directory listing, will be sent to the printer so as not to interfere with the graphics display. If you do not supply a command string, you will be prompted for one. There is no default command string.

- Supply the PIP command, the first character of which must be a blank space. A full description of PIP commands can be found in DEC's RSX operating system manuals. PIP commands can copy, delete, list, rename and do other file operations.

Examples:

```
PIP ' DZ1:/FR'               Show the free space on floppy disk 1.
PIP ' /LI'                   List all files in the current directory.
PIP ' DZ1:[USERFILES]*.SUM/LI'  List all summary files on diskette 1.
PIP ' LP:=HYPINST.'          Copy the file HYPINST. to the printer.
PIP ' OUT.=IN1.,IN2.'        Concatenate two files into OUT.
PIP ' 8408*.SUM/DE'          Delete all 8/84 summary files.
```

DSK Print out the available disk space left on the PC350's hard disk (DW1) and two floppy diskettes (DZ1 and DZ2). The messages will appear on the printer This command is for checking space when HYPOINVERSE does real-time data gathering, and spawns PIP with three /FR commands.

Example: DSK (There are no parameters.)

SOME NOTES ON RUNNING HYPOINVERSE IN REAL-TIME

The PC350 version of HYPOINVERSE has several special provisions for locating and plotting earthquakes in real-time when receiving raw picker data directly into the communications port. Treat the notes below, and the RTP command described above as a preliminary checklist for setting up real-time operation. Real-time testing of HYPOINVERSE continues as of this writing, and improvements and enhancements will likely be made in the future.

HYPOINVERSE is told to read raw picker data directly from the communications port with the "COP 5" command. No phase file need be identified. First set the port characteristics (Baud rate etc.) with the DEC communications software. XON/XOFF should be enabled since the 512 byte hardware buffer of the PC350 can easily fill while the previous earthquake is being located. Phase and event terminator records are interpreted by HYPOINVERSE in the usual way. Lines beginning with "PPICKER ALIVE" or "LAT" are copied to the printer as real-time status messages. All other input lines are ignored.

A key feature of real-time operation is the ability to shift time intervals, replot events on the screen and erase the oldest events so that only the most recent period of time is displayed. The first RTP command flag should be T, and the length of the time intervals should be set using the SET command. Normally, any event occurring after the beginning of the last time interval is plotted in that interval. When automatic interval shifting is invoked, however, the last interval is assumed to have the same length as the others. When the first event after the last interval occurs, earthquakes from the oldest interval are erased (replotted in the background color). Then each interval is replotted in the color appropriate to it. The old symbol is not erased, just plotted over by the new symbol. This means that different symbol types may not be used for different time periods, since erasure would not be complete. HYPOINVERSE uses scratch files to store each symbol location, size, type and color. If symbol color depends on time, the symbols are replotted in the new color. If symbol color depends on depth, all symbols are replotted in the original type and color. This insures that newer events will always plot on top of old events, and that erasing old events will not obliterate any new events.

HYPOINVERSE writes three files which are the permanent records of incoming data. The print output is normally sent directly to the printer, leaving the summary and archive files as the only computer-readable data. The archive file preserves the picks, should be considered a compacted version of the original picker data stream, and can later be input to HYPOINVERSE as a phase file. These output files are kept open by HYPOINVERSE, and only closed when the program is interrupted by pressing the "1" key, or new files opened to begin a new day (see the RTP command). A file which has been closed is more accessible and can be removed from the computer for analysis. Removal can be by a transfer to another DECNET node, or writing output files directly to diskette in the first place.

HYPOINVERSE can be made to start automatically when the system is powered up. This results in the least data loss in case of power failure, though some of the data gathered just before failure will not have filled a block and not been written to disk, and will be lost. The procedure for auto starting of HYPOINVERSE is:

Determine the toolkit application directory ZZAPnnnnn with the command

```
DIR [*]START.CMD
```

Then place this 9 character directory name into the file [ZZSYS]FIRSTAPPL.TTR. This runs the toolkit on powerup. Then put the indirect command @HY (see above and below) at the end of the file START.CMD in the toolkit application directory.

If a task with open files is aborted by a power failure or a control-C, some of the "lost" data can be recovered and the "mess" cleaned up. This can be done manually or automatically (see next paragraph). Determine which output files are locked by doing a directory listing and looking for the "L" attribute. These will usually be the summary and archive files, and one of the H*.SCR plot scratch files. Unlock these, and recover some summary and archive data with commands like these:

```
RUN $PIP
PIP> 840802.SUM/EOF
```

"PIP>" is the prompt, to which you type the filename followed by a switch that writes and end-of-file after the last block. Then exit PIP with a control-Z:

```
PIP> ^Z
ED 840802.SUM
```

Edit the file to delete the last line, which will be corrupted.

If you are saving daily YYMMDD.SUM summary files in the directory DZ1:[USERFILES], you can automatically clean up after a power failure or system crash and restart locations on powerup as follows. Put the following commands in your HY.CMD startup command file:

```
$ DELETE TEMP.SUM;*  (Use the dummy filename from the SUM command.)
$ DELETE *.SCR;*     (After a crash, one of these plot scratch files
                     will also be locked and must be deleted.)
$ RUN REPAIR         (This program performs the UNLOCK and END-OF-
                     FILE operations on the latest YMD.SUM files.)
$ RUN HYP
```

A SAMPLE REAL-TIME COMMAND FILE

HYPOINVERSE contains many real-time options, many of which interact with each other. All combinations of all options have not been tested, and some commands can be contradictory and lead to spurious results if used improperly. For example, giving the command RTP ,T,,, without a SUM or ARC command asks for daily output files without enabling summary or archive output.

The following commands enable the most useful real-time features which have been tested at the USGS in Menlo Park. These should serve as a sample of part of a working HYPINST command file. Deviations from these commands should be considered in light of the options desired and the other commands which interact with them. Your HYPINST file should also contain commands to read station list and crust model, and commands to set the various weighting, format, map, symbol and other parameters.

SUM 'TEMP.SUM'	Enable summary output, and initially plot epicenters from this file as a background against which to locate and plot new events. No events will actually be written to this file, since we will enable daily output files below.
ARC 'TEMP.ARC'	Enable archive output. This file will not be used, since we will enable daily output files below.
CAR 2	Since we will be writing to floppy disk to make data removal easy, use condensed archive format to save space. It is easy to later relocate the events using the archive file as phase input, and then write a full-format archive

	file.
DEV 'DZ1:[USERFILES]'	Write all daily output files in this (diskette) directory. HYPOINVERSE WILL look for daily files here when replotting events after issuing a LOX command.
COP 5	Read picker format phase data directly from the comm port.
PRT 'LP:'	Enable print output and send it to the printer.
INT T 1 5	Let symbol color vary with time interval, and symbol type depend on depth. Use (in this case) one depth interval and 5 time intervals. For real-time applications, you can use any parameters here, but using automatic time interval shifting with only 1 or 2 time intervals is not advised and will erase all or most of the background of previous events at each interval shift. The INT command must precede the CLR, SYM, SET and DEP commands, since these commands use the number of time and depth intervals.
SYM 7	Set the symbol for (in this case) all depths.
DEP 0	Set the top of the (in this case) only depth interval.
CLR 1 6 3 4 2	Set the 5 colors for time intervals.
SET 5* 0 12	The date and time of the first time interval need not be given, but will be subsequently set with the CLK command. Set the lengths of the time intervals to 0 days plus 12 hours.
CLK	Set the time intervals such that the current time from the system clock falls in the last time interval.
RTP T T T F	Set the 4 real-time controls as follows: (1) Enable automatic interval shifting: the first event plotted will define the time intervals, and any event which occurs after the last intervals causes all intervals to be shifted and the screen to be refreshed. (2) Write daily summary and archive files whose names have the form YMD.SUM or YMD.ARC. The daily summary files are used by the LOX command to replot recent events on startup or if a map change is made while HYPOINVERSE is on line. (3) Redraw the geographic lines each day to prevent their eventual disappearance as events are erased. (4) Do not make a screen copy on the printer at the start of each new time interval.
LOX	Begin locations and plotting. This should be the last command in the HYPINST file.

APPENDIX - RULES FOR FREE-FORMAT INPUT OF PARAMETERS

-Supply the parameters in free-format following the command.

-The type and order of parameters is the same as in the command documentation.

-Free-format values may be separated by either spaces or commas.

-Character strings (for filenames, labels etc.) are delimited by apostrophes like 'MYFILE.DAT' .

-The form n*A stands for n occurrences of the value A.

-A null field will leave the existing value unchanged. A null field is specified by two consecutive commas, by one leading comma or by two trailing commas. Thus , 2 ,, 'MYFILE.' ,, changes only the 2nd and 4th of 5 values.

-A slash (/) at the end of a line means all later fields are null.

-The form n* stands for n occurrences of a null field.

GENERATING TRAVEL TIME TABLES WITH PROGRAM TTGEN

Use of a 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. Two grid point spacings are permitted for each 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. The user may generate his own travel time table empirically or with another program (see Appendix 2 for table format) or use the travel time generating program TTGEN to prepare a table from a given velocity-depth function.

Allowable crustal models input to TTGEN

Crustal models consist of from 2 to 15 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 halfspace velocity must be the greatest of any velocities specificed to insure that rays can be refracted along the top of the halfspace.

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

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 reasoable values such as 0.0 or between 0.02 and 8.0 km/sec/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 undersampling a too complicated or irrigular velocity model with too few rays.

Using the program 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 waveguide. 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 halfspace and top of a low velocity zone.

Input to TTGEN on the file TTMOD

All model parameters including depth, distance, and ray intervals at which computations are to be performed are input on the file TTMOD. The program uses reduced travel times for the table to save space. One specifies the inverse of the reducing velocity REDV (in sec/km) to use in calculation. The reduced travel time is the absolute time minus distance times REDV. The values of reduced travel time passed to the location program with the table are limited to the range Ø to 32 seconds, and the user is responsible for choosing a suitable reducing velocity to stay within these limits. Using a reducing velocity equal to the halfspace velocity is a good choice.

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

$$PHI = 2 \cdot TAN^{-1}\left(\frac{Q}{ZH + 1/2}\right)$$

$$P = \frac{SIN\ (PHI)}{VH}$$

where ZH and VH are depth and velocity at the hypocenter, respecively. 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 incrimented 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 downgoing rays begin to penetrate the halfspace, and travel times approriate 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.

Velocity model input format (File TTMOD)

Line	Columns	Format	Explanation
1	1-8	4A2	Printed output filename.
1	9-16	4A2	Travel time table output filename.
1	17-22	F6.1	REDV, one over the reducing velocity used to condense the travel time plots and tables.
2	1-5	F5.2	DQ1 Parameters for incrementing the
2	6-10	I5	NQ1 independent parameter Q governing ray
2	11-15	F5.2	DQ2 spacing (see Text).
2	16-20	I5	NQ2
3	1-5	F5.2	DZ1 Parameters for incrementing the grid
3	6-10	I5	NZ1 spacing in depth (see text).
3	11-15	F5.2	DZ2
3	16-20	I5	NZ2
4	1-5	F5.2	DD1 Parameters for incremenating the grid
4	6-10	I5	ND1 spacing in distance (see text).
4	11-15	F5.2	DD2
4	16-20	I5	ND2
5	1-20	10A2	Title to appear on TTGEN output, and earthquake location output.
6	1-5	F5.2	Velocity of first point (km/sec).
6	6-10	F5.2	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 last point given sets the velocity and depth of the halfspace.

Outputs of TTGEN

The condensed travel time table contains all the information necessary to identify itself and be used by of HYPOINVERSE. The format of the table is transparent to the user, but is given in Appendix for completeness.

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 halfspace. The tabulated data is as follows:

J	The ray index used to reference rays defining the endpoints of a shadow zone or reversed branches.
Q	The 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 sec/km.
DIST	Distance in km at which ray reaches the surface. If DIST = -1, then the ray is trapped in a waveguide and does not reach the surface.
TIME	Travel time in seconds.
REDUCED	Reduced travel time in seconds, given by TTIME - DIST · REDV, where REDV is one over the reducing velocity.
L.BOT	The layer in which downgoing rays bottom.
Z.BOT	The depth at which downgoing rays bottom.
V.BOT	The velocity at which downgoing rays bottom.
DDIF	Distance difference between this and the preceding ray. DD1F is negative on reverse branches.
BR	Branch number. It is incrimented 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*R**2	Amplitude times distance squared. Used to estimate the differences between actual and ideal inverse-square spreading.
REMK	Remark such as RB (reversed branch) or WG (ray in wave guide).

ARRIVAL TIME WEIGHTING

Weighting

The actual weight given an arrival is the product of several factors:

1) Station weight. Will zero-weight a given station for entire run. (Set on station card).
2) S weight (S arrivals only). Will weight all S arrivals for entire run. Any value between 0.0 and 1.0.
3) Assigned weight. Designed to reflect individual arrival quality. May be 0.0, .25, .5, .75 or 1.0 (set on phase card).
4) Distance weight. Can be used to specify a decreasing weight with increasing distance. Will be between 0.0 and 1.0 (see below).
5) Residual weight. Can be used to specify a decreasing weight with increasing travel time residual. Will be between 0.0 and 1.0 (see below).

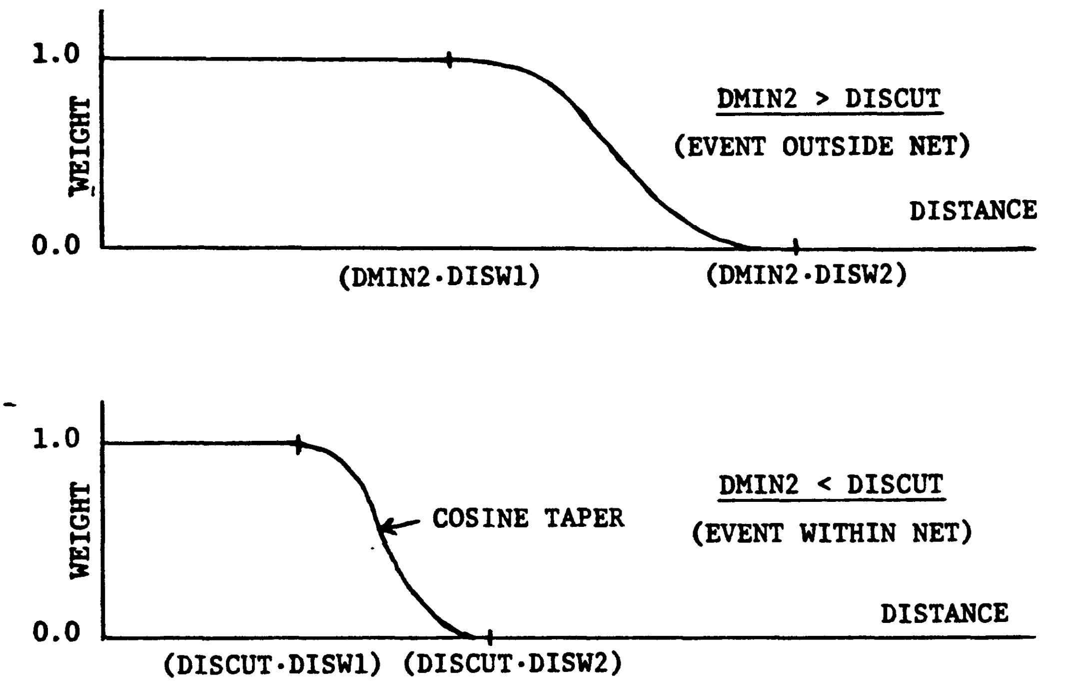

Figure 1 Distance weighting function. DMIN2 is the distance to the second closest station. DISCUT (Km), DISW1, DISW2 are user-defined constants.

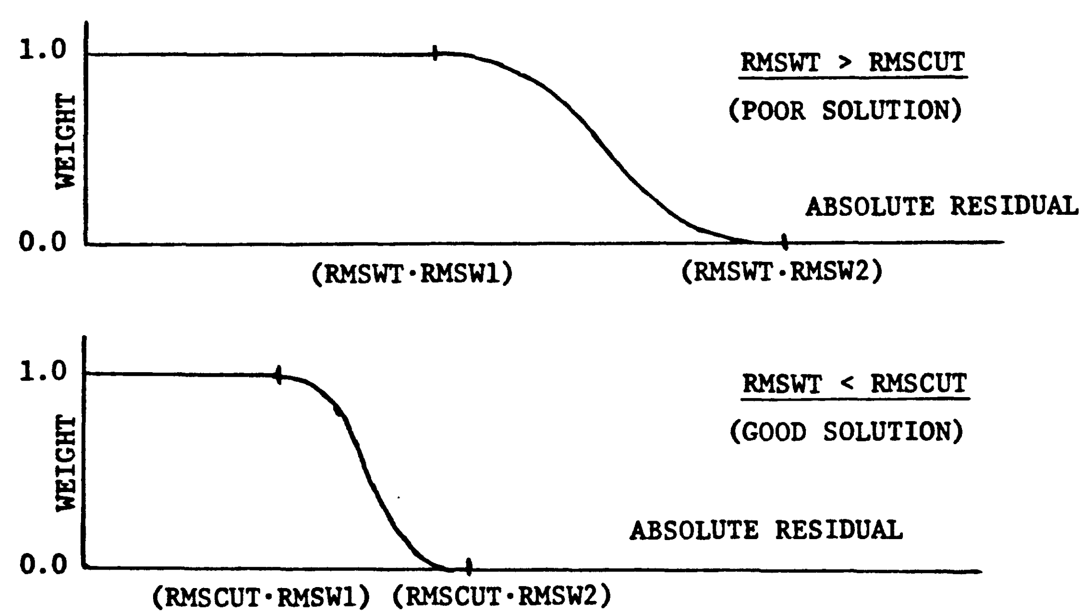

Figure 2. Residual weighting function. RMSWT is the root-mean-square traveltime residual. RMSCUT (sec), RMSW1 and RMSW2 are user-defined constants.

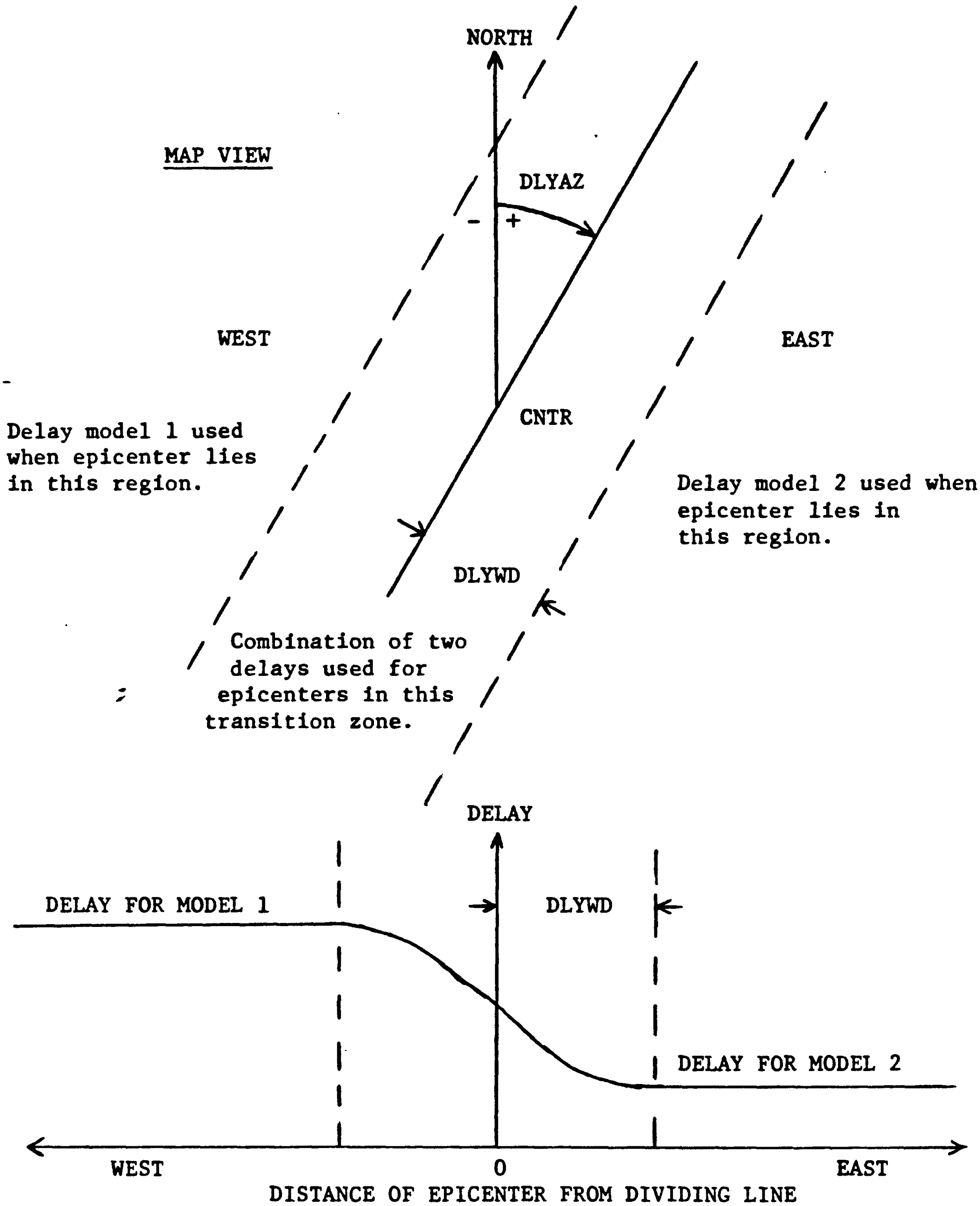

Figure 3. Map view showing delay model geometry. The delay model (or combination of delay models) depends only on the position of the epicenter relative to the dividing line. A cosine taper is used to smooth the transition between delay models.

Distance Weighting

An ideal distance weighting scheme should allow for both down-weighting of distant stations when an event is in the interior of the network, and maximum use of all stations when an event is outside the network. The distance weighting function is 1.0 for near stations, 0.0 for far stations, and follows a cosine taper in between. In this program the distance points at which weight tapering begin and end can be made to stretch out and scale with the distance to the second closest station for events outside the network, if desired. The three parameters which govern distance weighting are (with some sample values), DISCUT (50 km), DISW1 (1.) and DISW2 (3.). The distance at which the taper begins and ends scales with the second closest station distance when it is larger than DISCUT, and are fixed when it is less than DISCUT (see Figure 1). To keep the taper distance fixed at, for example, XNEAR and XFAR, set DISCUT = 1000, DISW1 = XNEAR/1000 and DISW2 = XFAR/1000.

Residual weighting

The purpose of residual weighting is to down-weight arrivals with large residuals which may reflect large timing errors or travel paths for which the velocity model is very poor. The residual weighting function is 1.0 for small residuals, 0.0 for large residuals, and follows a cosine taper in between. In this program, the residual points at which weight tapering begin and end can be made to stretch out and scale with the root-mean-square residual (RMS).

The three parameters which govern residual weighting are (with sample values) RMSCUT (.10 sec), RMSW1 (1.), and RMSW2 (3.). The residuals at which the taper begins and ends scale with the RMS residual when it is larger than RMSCUT, and are fixed when it is less than RMSCUT (see Figure 2). Thus, most stations will be fully weighted when RMS is large, but as iteration and convergence proceed and RMS becomes smaller, large residuals will become down-weighted. RMSCUT prevents an inward spiral in which large residuals are discarded, which then lowers RMS, and which results in more large residuals being discarded, etc.

There are two distinct values of RMS used by the program. RMSWT is the RMS residual computed before residual weights are applied and on which residual weights are based. The output variable labeled RMS is the value of RMS computed after residual weights are applied, and is used for convergence tests (see below). Presently, residual weighting is applied twice, with RMSWT updated each time. This allows two large residuals to be weighted down, since the first value of RMSWT includes the effect of the largest residual and may be too large to have any effect on the second largest residual.

ITERATION AND CONVERGENCE CRITERIA

Where to begin iterations

In absence of a specificed trial origin time, latitude, longitude, or depth on the terminator card, a standard trial hypocenter is assumed. Any one of the four trial hypocenter parameters may be specified independently, however. The trial origin time is two seconds before the first arrival, and the trial epicenter is near the station with the first arrival. Starting depth is at the trial depth ZTR. During the early iterations (usually just the first), depth is held fixed until the horizontal adjustment is less than DXFIX. If the trial depth ZTR is negative, all events in this run are held fixed at this depth (at the positive value), unless ZTR is temporarily overridden by a trial depth set for a particular event on its terminator card.

How iterative steps may be modified

Various parameters can be defined which damp the epicentral adjustments if the adjustment vector becomes large or unstable. DAMP is the damping factor by which all hypocenter adjustments are always multiplied before an iterative step is taken. Damping is automatically cut in half for the last 1/3 of the allowed number of iterations. Thus, if 15 iterations are allowed and convergence has not been reached after 10 iterations, the remaining 5 iterations will be heavily damped. Empirically this appears to improve convergence. If an iterative step would place the hypocenter in the air, the hypocenter is moved up to the fraction (1.-DZAIR) of its present depth. Thus the depth adjustment is -DZAIR * Z. The depth adjustment may be indepently damped if the adjustment is larger than DZMAX. If it is, the depth variation is damped by the factor DZMAX /(DZ + DZMAX) where DZ is the calculated depth adjustment.

If the value of RMS should increase by more than the amount RBACK from one iteration to the next, the hypocenter is moved back by the fraction BACFAC toward the previous hypocenter. This situation often occurs when a poorly constrained hypocenter iterates across a large velocity discontinuity in the crustal model.

The use of a generalized inverse scheme for finding the hypocenter adjustment for each iteration allows great control over the adjustments actually taken. For example we may choose not to make hypocenter adjustments in directions which are poorly constrained by the arrival time data and which are directions in which location errors are large. The parameter EIGTOL does exactly this, and serves as a cut-off below which eigenvalues of inversion are deemed unstable and are suppressed. A very brief description of the matrix equations of the inversion might aid in using this parameter.

Inversion scheme and use of eigenvalue cutoff.

If the solution to the earthquake location problem were linear and if we had exactly as many independent data (arrivals times) as hypocentral unknowns, the answer would be the solution of

$$\underset{n}{T} = \underset{n\times n}{A} \cdot \underset{n}{X} + \underset{n}{G}$$

where T is the n-vector of arrival times, X is the n-vector of hypocenter coordinates and G is constant. A is the n by n partial derivative matrix

$$A_{ij} = \frac{\partial T_i}{\partial X_j}$$

which may be directly calculated from an assumed velocity model. But since the earthquake problem is nonlinear (A is not constant), we must seek successive linearized solutions and iterate toward the true solution until we have converged to the desired accuracy. X and A must also be updated as iteration proceeds. If T_o and X_o are the arrival time and hypocenter vectors calculated at the previous step (or some initial guess on the first iteration) which satisfy

$$T_o = A \cdot X_o + G$$

then subtracting the equations yields

$$T - T_o = A \cdot (X - X_o) \text{ or } \underset{n}{R} = \underset{n\times n}{A} \cdot \underset{n}{DX}$$

where R is the vector of travel time residuals (observed times minus those calculated from the model at the previous step) and DX is the hypocentral adjustment vector, given in this case by $DX = A^{-1} \cdot R$. The number of observations m for the earthquake problem is often in the range 8 to 40, but the number of unknowns is generally only 4. When m exceeds n, however, the true inverse A^{-1} does not exist. We seek the least squares solution which best solves

$$\underset{m}{R} = \underset{m\times n}{A} \cdot \underset{n}{DX}$$

in the sense of minimizing

$$(R - A \cdot DX)^2$$

This is done by premultiplying by A^T to get the least-square condition

$$\underset{n\times m}{A^T} \cdot \underset{m}{R} = \underset{n\times n}{(A^T A)} \cdot \underset{n}{DX}$$

which now only requires inversion of the nxn symmetric matrix $A^T A$.

The solution can be sought in terms of the generalized inverse of A, and in particular the singular value decomposition (SVD) of A. This not only yields the usual least square solution, but permits manipulation of the eigenvalues of $A^T A$, calculation of the errors, and evaluation of the information content of the data. This program uses the SVD subroutine and forms the above matrices from elements of the decomposition.

The decomposition of A is given by

$$\underset{m\times n}{A} = \underset{m\times n}{U} \cdot \underset{n\times n}{S} \cdot \underset{n\times n}{V^T}$$

where U and V are eigenvector matrices and S is the diagonal matrix of eigenvalues of A^TA. Also $U^TU = I$, $V^TV = I$, and assuming that the number of linearly independent arrival time data exceeds the number of unknowns, $VV^T = I$. When the resolution matrix VV^T equals the identity matrix, the unknowns are perfectly resolved which is the usual case for the earthquake problem. Then the least-squares solution can be derived by substitution of A into the least-squares condition and is given by

$$\underset{n}{DX} = \underset{n\times n}{V} \cdot \underset{n\times m}{S^{-1}} \cdot \underset{n\times m}{U^T} \cdot \underset{m}{R}$$

The covariance matrix of the solution DX is given by

$$\underset{n\times n}{C} = w^2 \; \underset{n\times n}{V} \cdot \underset{n\times n}{S^{-2}} \cdot \underset{n\times n}{V^T}$$

where w = constant.

We see at once that if one or more eigenvalues in S becomes small, both solution and error become large and unstable. Each eigenvalue corresponds to one of the mutually orthogonal principal directions of the solution, and if one eigenvalue becomes small, both the adjustment and standard error in that principal direction become large in proportion to one over that eigenvalue. The principal direction with the small eigenvalue will in general include components of origin time, latitude, longitude, and depth. Most often, however, the smallest eigenvalue has its largest component in depth. If an eigenvalue should become smaller than the parameter EIGTOL, no adjustment is taken in that principal direction for which the error is also large. The program does not add the term to DX originating from the small eigenvalue. In other words, solutions are prevented from becoming unstable and scattering out in the direction in which their error ellipsoids are very long.

In general, the largest eigenvalue is of order 5 (with its dominant component in origin time) and the spatial eigenvalues are of order 0.3 to 0.7. The difference is size between origin time and spatial enigenvalues arises because a change of several km in hypocenter location is required to produce the same change in an arrival time as a one second change in origin time. Unstable or very poorly constrained situations occur when the smallest eigenvalue becomes less than about .02. Looked at another way, instability occurs when the condition number (ratio of largest to smallest eigenvalue) exceeds about 200. The value of EIGTOL should be chosen after attempting to solve for the most marginal events one wishes to locate with a given network, and studying the eigenvalues and iteration history for these events.

When to stop iterating.

Iteration can stop in any of 3 ways: 1) when the number of iterations reaches the maximum allowed, ITRLIM; 2) When the change in the RMS residual between iterations becomes less than DRQT sec; 3) When the hypocenter adjustment vector is less than DQUIT km. The last two tests are only applied after the depth has been freed from its trial value for at least one iteration.

ERROR CALCULATIONS

The covariance or error matrix

The covariance matrix is calculated from elements of the decomposition of the A matrix (see section on inversion scheme) as

$$\underset{n\times n}{C} = w^2 \underset{n\times n}{V} \cdot \underset{n\times n}{S^{-2}} \cdot \underset{n\times n}{V^T}$$

where S and V are matrices composed of eigenvalues and eigenvectors in the "solution space" of the hypocenter. w^2 is the variance (standard error squared) of the arrival time data. The program calculates w^2 as

$$w^2 = RDERR^2 + ERCOF \cdot RMS^2$$

where RDERR and ERCOF are parameters set in BLOCK DATA and RMS is the root mean square travel time residual. RDERR represents the estimated reading error in seconds of the arrival time data. ERCOF is just a weighting factor for including the effects of a poor solution in the error calculations. If you want the calculated errors in the hypocenter to reflect only errors introduced in reading the data, set ERCOF = Ø. This will give objective errors which include the effects of array geometry. If you want to include effects of poorly modeled travel times such as weaknesses in the crustal or delay models, then set ERCOF = 1. ERCOF can be set to any positive value or Ø.

The covariance matrix is a 4 x 4 symmetric matrix whose diagonal elements are the variances (standard errors squared) of origin time (in sec), and latitude, longitude and depth (all in km). The off-diagonal elements are the covariances between these quantities. This allows, for example, a quantitative estimate of origin time error and the tradeoff between origin time and depth. The error ellipsoid is specified by the 3 x 3 sub-matrix with origin time removed.

Error ellipsoid and vertical and horizontal errors.

The error ellipsoid is specificed by the 3 x 3 sub-matrix derived by removing origin time from the covariance matrix. The 3 x 3 covariance matrix must be rotated into the principal coordinates of the solution, whose axes are the major axes of the error ellipsoid. The three principal standard errors are calculated by taking square roots of the eigenvalues (diagonal elements in diagonal form) of the 3 x 3 covariance matrix. The earthquake then has a statistical probability of 32% of lying inside an ellipsoid of error whose major axes are given by the three principal standard errors. An error ellipsoid whose major axes are 2.4 times the standard errors calculated by this program has a 95% chance of containing the "true" hypocenter. The program also calculates the azimuths and dips of the principal axes of the error ellipsoid.

The vertical error ERZ and horizontal error ERH are simplified errors derived from the lengths and directions of the principal axes of the error ellipsoid. Each of the three principal axes (whose lengths are the standard errors) are projected onto a vertical line through the hypocenter, and the largest value is ERZ. ERH is simply the length of the longest of the principal axes when viewed from above (projected onto a horizontal plane).

AMPLITUDE (LOCAL) MAGNITUDES

The method for calculating local magnitudes assumes that maximum peak-to-peak amplitudes are read from a standard Wood-Anderson torsion seismograph. If amplitude is read from another instrument, it is corrected to an equivalent Wood-Anderson response. Richter's original magnitude formula is

$$M_L = \log (A/2) - \log A_o + G$$

where A is the maximum peak-to-peak amplitude on a Wood-Anderson seismograph, $-\log A_o$ is a tabulated function of distance, and G is the station's magnitude correction. The term by term generalization of this formula as used in this program for a particular instrument is:

$$XMAG = \log \frac{AMP}{2 \cdot CAL \cdot R(PER)} + F(D^2) + XCOR$$

where

AMP	is the peak-to-peak amplitude measured in mm on the seismogram or on the Develocorder viewer (or on an equivalent paper record).
CAL	is the calibration factor of the instrument, defined as the peak-to-peak amplitude in mm of a 10 microvolt RMS signal at 5 HZ applied to the VCO. For a Wood-Anderson instrument, CAL should be input as 1.0.
R(PER)	is the response of the instrument at standard gain as a function of period PER relative to the Wood-Anderson instrument. The program assumes that the relative response is completely specified by the product CAL·R(PER). For a Wood-Anderson instrument, the program uses R = 1.
$F(D^2)$	is Richter's distance term $-\log A_o$. It is approximated in the program as an algebraic function of D^2.
XCOR	is the station correction.

The values of CAL, PER and XCOR are constants for the station specified on the station card. AMP is specified on the phase card. The function R(PER) is available for two instrument types beside the Wood-Anderson:

Type Code	Instrument
Ø	Wood-Anderson torsion seismograph
1	NCER standard (1 Hz velocity transducer with 0.7 critical damping).
2	Presently a Hawaii-type sprengnether or HS-10 geophone with Develoco VCO.

In the allowable period range (0.1 to 1.9 sec) R is approximately a linear function in the log-log sense.

For type 1: $\log (1/R) = -1.3 - .95 \log (0.2/PER)$

For type 2: $\log (1/R) = .41 + .56 \log (0.2/PER)$

The constants for type 2 may be reset for another instrument type. Similarly, F is approximately a bilinear function of log (D^2):

For D smaller than 200 km: $F = -.15 + .80 \log (D^2)$
For D larger than 200 km: $F = -3.38 + 1.5 \log (D^2)$

These linear approximations introduce magnitude errors of less than .05 over their useful ranges.

If the calibration factor CAL is found equal to 0.0, no magnitude will be computed for that station. Its allowable range is 0.0 to 49.9 inclusive. The allowable range of PER is 0.1 to 1.9 sec inclusive. The useful range of XCOR is $\pm$ 2.4 inclusive. If you want to compute a magnitude for a station but exclude the result from the average, use a value of XCOR equal to 5.0 plus the actual correction. Thus, the allowable values for XCOR are between -2.4 and 2.4, or between 2.6 and 7.4 inclusive. See the section on station list input for more information.

DURATION OR CODA MAGNITUDES

The second magnitude calculated is based on duration, coda, or F-P time as read on a short period seismogram. The NCER practice is to read the end of coda or "F phase" when the signal decays to 10 mm peak-to-peak on the Develocorder viewer. Amplitude and duration magnitudes are calculated independently, and both appear on all summary outputs. Choosing between or averaging the two must be done by the user outside the program. Magnitude corrections FCOR may be specified for each station. If FMP is the duration time in seconds, D the epicentral distance to the station and Z the depth, the magnitude formulas are for FMP less than FMBRK:

$$FMAG = FMA1 + FMB1 \cdot \log(FMP) + FMD1 \cdot D + FMZ1 \cdot Z + FCOR$$

for FMP larger than FMBRK:

$$FMAG = FMA2 + FMB2 \cdot \log(FMP) + FMD2 \cdot D + FMZ2 \cdot Z + FCOR$$

These are the constants currently in use by the three established networks:

	CALIFORNIA	ALASKA	HAWAII
FMA1	- .87	- 1.16	- 5.0
FMB1	2.0	2.01	3.89
FMZ1	0.0	.007	0.0
FMD1	.0035	.0035	0.0
FMBRK	9000.	9000.	210.
FMA2	0.0	0.0	- .705
FMB2	0.0	0.0	2.026
FMZ2	0.0	0.0	0.0
FMD2	0.0	0.0	0.0

EIGENVALUE AND STATION IMPORTANCE OUTPUTS

Eigenvalue and error output

If KPRINT is 3 or larger, the four eigenvalues of the principal directions of the solution are listed in descending order. These are useful in gauging the relative stability and error of the solution in the four principal directions. Under each eigenvalue are the column eigenvectors corresponding to it. The eigenvectors together make up the matrix V. The elements of the column eigenvectors give the components of origin time, latitude, longitude and depth in the principal direction corresponding to that eigenvalue. In other words, the matrix of eigenvectors accomplishes the "rotation" between the principal and geographic coordinates. The last eigenvector gives the mix of latitude, longitude and depth which are most poorly determined and associated with the smallest eigenvalue.

The covariance matrix gives the variances (diagonal elements) and covariances of origin time, latitude, longitude and depth. The errors listed are the standard errors of origin time (in sec), and latitude, longitude and depth (in km) with the other three variables held fixed. They are the square roots of the diagonal elements of the covariance matrix. The error ellipsoid consists of the lengths of the principal axes SERR and their azimuths AZ and dips DIP in degrees. The principal axes are the standard errors in those directions in units of km. The hypocenter statistically has a 32% chance of lying within the error ellipsoid given. To obtain a 95% confidence ellipsoid, multiply the standard errors by 2.4. See the sections on the inversion scheme and error calculations for more information.

The station importance or information density.

This is a new parameter which is a by-product of the generalized inverse approach and which is not computed by other standard location programs. It is a quantitative measure of the contribution a particular arrival makes to the hypocenter solution, and includes the effect of weight on the arrival data. Computation of the importance may be suppressed and program execution made a bit more efficient by setting KINFO = 0 (in BLOCK DATA). To get the importance set KINFO = 1.

A result of the singular value decomposition of the partial derivative matrix A (see section on inversion scheme) is the information density matrix B = UU^T. This is an m x m matrix, where m is the number of arrival times reported. Each diagonal element b_{jj} of B is thus associated with the ith arrival alone, and is the quantity printed and referred to as the importance of the arrival.

A feeling for what importance means quantitatively may come from realizing that the rows of U are linearly related to the rows of the partial derivative matrix A. In other words, when the partial derivatives of travel time to the ith station with respect to the jth hypocentral coordinate dT_i/dX_j are large for the ith station, (the ith row of A) then the ith row of U and hence the station importance b_{ii} will also be large. Thus a large leverage, through the partial derivative matrix A, of a particular station on the solution is equivalent to a large station importance. This can be seen intuitively from the relation:

$$\underset{m\times n}{A} \cdot \underset{n\times n}{V} = \underset{m\times n}{U} \cdot \underset{n\times n}{S}$$

where the matrices are as defined in the inverison section. When the ith row of A is large (corresponding to the ith station), the ith row of this equation and hence of U will be large. The ith diagonal element s_{ii} of UU^T will also be large.

An illustration of the relation between importance and partial derivatives is the fact that an S reading has a greater importance than a P reading from the same station. The partial derivatives d(travel time)/ d(space coordinate), are larger for S arrivals at the same station by the factor Ts/Tp, and this means that rows of the U matrix and consequently the importance will be larger for the S arrivals. This has an important consequence for assigning weights to arrivals. When and S arrival cannot be read to the same precision as a P arrival, it should be given less weight to compensate for its intrinsically larger importance.

The importance is a measure of the redundancy in the data, and for example is small in distances and azimuths where there are many stations. This can be seen from the following argument. The inversion process for the overdetermined earthquake problem extracts n linearly independent combinations of partial derivatives from the m combinations in the matrix A. One "unit" of importance is attributed to each of these n independent combinations. Hence the sum of importances of all stations for a full earthquake solution is 4. If several data are redundant, i. e. linearly dependent or nearly so, then the unit of importance must be distributed among them and the importance of each redundant datum goes down.

Fred Klein
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25 July, 1985

Dear HYPOINVERSE user:

The present versions of the earthquake location program HYPOINVERSE are written in FORTRAN 77, and run on Digital Equiptment's VAX and Professional 350 computers. The computational function of the program is essentially the same as in the earlier Data General Eclipse computer version. The present HYPOINVERSE is command driven, however, and is thus easier to use and more flexible. A data entry utility and more choice of formats are also new to these versions. The Pro350 version adds map plotting and real-time location of externally picked P times to the basic functions of the VAX version.

The VAX computer is a 32-bit machine, and thus easily accomodates large programs such as HYPOINVERSE without using overlays. Even though the addressable memory of the Pro350 computer is much smaller, overlays can accomodate essentially the same program with graphics and real-time functions added, but with fewer stations per event. The Pro350 computer has the same CPU as a PDP11/23, and runs PDP11 FORTRAN 77 under POS, which is similar to the RSX operating system. The Pro-toolkit is required to recompile or relink the program.

The HYPOINVERSE open file report should adequately document what a user needs to know about the program. The magnetic tape contains FORTRAN source code for both versions, but object and executable files for only the VAX version. The tape also has files used to overlay, link and install both versions of the program that a programmer will need to set them up. Look at the file "README" on the tape to get started. A diskette version of the program is available to those who send three blank RX50 diskettes.

I intend to correct errors in the program and its documentation as they crop up. If you find an error, reread the documentation to be sure it's real, then describe it carefully so I can correct it. Later versions of the program or documentation will carry different dates. I will probably keep a list of corrections to make to the first version as errors are found.

Sincerely,

Fred Klein