Topic	**HYPOSAT / HYPOMOD**
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User Manual for HYPOSAT (including HYPOMOD)

1 Introduction

HYPOSAT is a program package developed to locate seismic sources. It utilizes travel-time data, backazimuth (*i.e.*, station-to-event azimuth) values, and ray-parameter values. Phases considered are those included in IASP91-type tables, and reflections from the Conrad and from the Mohorovičić discontinuities, if local models are used. The program follows the phase name recommendations of the IASPEI Working Group on Standard Phase Names (see IS 2.1). Additionally, all possible travel-time differences between different onsets at individual stations are estimated and can be included in the location process (*e.g.*, PcP-P as an additional constraint for the source depth). If amplitude and period measurements for P onsets or surface waves are available, station magnitudes and an event magnitude can also be estimated. More details about the general features of the program can be found in Schweitzer (1997, 2001a).

The data files containing the global models (*e.g.*, ***iasp91.tbl*** and ***iasp91.hed***), the list of up to now defined seismo-tectonic units (***REG_L3.DAT***), the attenuation curves for magnitude estimations (***MB_G-R.DAT*** and ***MB_V-C.DAT***), and the ellipticity corrections (***elcordir.tbl***) must all be located in the same directory. The path to this directory must be set by the environment variable **HYPOSAT_DATA**.

The program needs two input files in ASCII format. One file contains the general parameters to steer the inversion process (***hyposat-parameter***) and the other file contains the observed data for the event to be localized (***hyposat-in***). Contents and structure of these files will be explained in the following sections.

The program **HYPOMOD** uses the same input files as **HYPOSAT** but it only calculates all residuals for a given hypocenter without any inversion.

The newest versions of the programs (including source code, this manual, the PDF version of Schweitzer (1997), data files containing travel-time models and station parameters, and several examples) are located in six compressed tar-files (all versions in ***hyposat.****version****.tar.Z*** or ***hyposat.****version****.tar.gz***, the UNIX version in ***hyposat_u.****version****.tar.Z*** or ***hyposat_u.****version****.tar.gz***, and the LINUX version in ***hyposat_l.****version****.tar.Z*** or ***hyposat_l.****version****.tar.gz***) for free download from NORSAR's anonymous ftp-address *ftp.norsar.no* under the directory */pub/outgoing/johannes/ hyposat*. The address when using your web-browser is: ftp://ftp.norsar.no/pub/outgoing/johannes/hyposat. Questions related to program updates and maintenance should be directed to the author.

2 Getting Started

This section describes how some simple examples for **HYPOSAT** can be started and executed. The simplest way to use the program for own locations is to start from one of the following examples and modify input data and parameters for your needs. The meaning and format of the input is described in the following sections.

Installation of **HYPOSAT**:

1) Make a sub-directory for **HYPOSAT,** copy the compressed tar-file containing the ***hyposat-software package*** from the NORSAR's ftp site (*ftp.norsar.no*), decompress it, and run:

tar -xvf hyposat.version.tar or
tar -xvf hyposat_u.version.tar or
tar -xvf hyposat_l.version.tar,
depending on the module you have downloaded.

Then you will have a directory containing the following files and subdirectories in the UNIX Solaris) case:
bin/ data/ examples/ man/ README_u src/
or in the LINUX:
bin_l/ data_l/ examples_l/ man/ README_l src_l/
or all together if you had downloaded the full version.

The file *README_u* (or *README_l*) contains a complete list of all files following with the installed ***hyposat-software package*** and a explanation of these files.

2) If needed re-compile the software in the */src* (or */src_l*) subdirectory by running:
make and/or *make -f Makefile.hypomod*

Executing **HYPOSAT**:

Change to the subdirectory *examples/* (or *examples_l*).
Here you will find input file examples for four different cases: an event observed with a network of stations (*.net*), a single array (*.single_array*), a set of local and regional stations (*.regional*), and a teleseismically observed event (*.tele*). **HYPOSAT** runs with two input files. To check your installation, try the following:

cp hyposat-in.net hyposat-in
cp hyposat-parameter.net hyposat-parameter
*setenv HYPOSAT_DATA $**path**/hyposat/data*
(or *setenv HYPOSAT_DATA $**path**/hyposat/data_l*)
(where ***$path*** is the actual path to the subdirectory hyposat)
and run:
../bin/hyposat (or *../bin_l/hyposat*)
You will then get an output file *hyposat-out*, which should be identical to the file *hyposat-out.net* distributed with the ***hyposat-software package.***

3 The File hyposat-parameter

The file containing the inversion-steering parameters must (!) have the name ***hyposat-parameter*** and must reside in the actual directory where the program is executed. The structure and contents of ***hyposat-parameter*** is as follows:

-----start of the example for a ***hyposat-parameter*** file ---

```
     hyposat-parameter file for hyposat 4.4

GLOBAL MODEL                           : ak135
GLOBAL MODEL 2                         : iasp91
GLOBAL MODEL 3                         : _
GLOBAL MODEL 4                         : _

LOCAL OR REGIONAL MODEL                : _
PHASE INDEX FOR LOCAL MODEL            : 0000

CRUST 5.1 PATH                         : ./
CRUST 5.1                              : 0
OUTPUT OF REGIONAL MODEL (DEF 0)       : 1

STATION FILE                           : ../data/stations.dat
P-VELOCITY TO CORRECT ELEVATION        : 4.5
S-VELOCITY TO CORRECT ELEVATION        : 3.3
STATION CORRECTION FILE                : stations.cor

LG GROUP-VELOCITY (DEF 3.5 [km/s]) : 3.5752
RG GROUP-VELOCITY (DEF 2.5 [km/s]) : 2.5

LQ GROUP-VELOCITY (DEF 4.4 [km/s]) : 4.4
LR GROUP-VELOCITY (DEF 3.95 [km/s]): 2.85

STARTING SOURCE LATITUDE [deg]     : 999.
STARTING LATITUDE ERROR [deg]      : 10.

STARTING SOURCE LONGITUDE [deg]    : 999.
STARTING LONGITUDE ERROR [deg]     : 10.

STARTING SOURCE DEPTH [km]         : 0.
STARTING DEPTH ERROR [km]          : 50.
DEPTH FLAG (f,b,d,F,B,D)           : b

STARTING SOURCE TIME (epochal time): 0.
STARTING TIME ERROR [s]            : 600.0

MAXIMUM # OF ITERATIONS            : 80
# TO SEARCH OSCILLATION (DEF 4)    : 6

LOCATION ACCURACY [km] (DEFAULT 1.): 1.
CONSTRAIN SOLUTION (0/1)           : 1

CONFIDENCE LEVEL (68.3 - 99.99%)   : 0.
EPICENTER ERROR ELLIPSE (DEF 1)    : 1

SLOWNESS [S/DEG] (0 = APP. VEL)    : 1
```

```
MAXIMUM AZIMUTH ERROR [deg]         : 30.
MAXIMUM SLOWNESS ERROR [s/deg]      : 5.

FLAG USING TRAVEL-TIME DIFFERENCES : 1

MAGNITUDE CALCULATION (DEF 0)       : 1
P-ATTENUATION MODEL (G-R or V-C)    : G-R
S-ATTENUATION MODEL (IASPEI or R-P): R-P

INPUT FILE NAME (DEF hyposat-in)    : _

OUTPUT SWITCH (YES = 1, DEFAULT)    : 1
OUTPUT FILE NAME (DEF hyposat-out) : _
OUTPUT LEVEL                        : 4
```

-----end of the example--

The order in which these parameters are set is arbitrary. The parameters must be identified with the above given description (bold-faced). The parameters must be written in the file in capital letters! The settings itself must follow after the 37th character of the line (*i.e.*, in this example two characters after the colon). Whenever a line does not comply with this rule, it will be ignored (*e.g.*, blank lines or lines starting with a '*', ...). This file is read only once at the beginning of a location run. Each line can be repeated several times within the file with another setting. In this case, the last set value is used for the location process. For file names, the full path name can be given. In the following all the parameters are explained in more detail:

GLOBAL MODEL: Type of the reference model used to calculate all travel time related theoretical data. This package contains the following models:

ak135	AK135 model (Kennett *et al.*, 1995)
iasp91	IASP91 model (Kennett, 1991; Kennett & Engdahl, 1991)
jb	Jeffreys-Bullen model (Jeffreys & Bullen, 1940 and later)
prem	PREM model (Dziewonski & Anderson, 1981)
sp6	SP6 model (Morelli & Dziewonski, 1993)

The directory where these travel-time tables reside must be specified with the environment variable **HYPOSAT_DATA** before the program is started. The travel-time tables are based on the **libtau**-software package written by Ray Buland and distributed as IASP91-software. If you use an own version of the **libtau**-software, you will have to exchange the ***libtau_h.f*** file (see ***Makefile*** in the source-code directory) and to exchange the corresponding data files (****.hed*** and ****.tbl***) because for the version included here some parameter and dimension settings were changed in the include file ***ttlim.h***.

GLOBAL MODEL 2: Here one can give the name of any other second global model to be used for specific ray paths indicated in the data input file.

GLOBAL MODEL 3: Here one can give the name of any other third global model to be used for specific ray paths indicated in the data input file.

GLOBAL MODEL 4: Here one can give the name of any other fourth global model to be used for specific ray paths indicated in the data input file.

LOCAL OR REGIONAL MODEL: Name of the file with a local (or regional) velocity model. Travel times will be estimated for the following seismic phases (as far as they can be observed with respect to distance and source depth): Pg, Pb, Pn, P, pPg, pPb, pPn, pP, PbP (*i.e.*, in this program upper side reflection from the 'Conrad'), PmP, PgPg, PbPb, PnPn, PP, and the converted phases sPg, sPb, sPn, sP, SbP and SmP. The same phase set is used for S-type phases, respectively.

This parameter (file name) must only be set if a special local or regional model is to be used instead of the global one. The velocity model must contain the following information:

In the first line maxdis = maximum distance in [deg] for which this model shall be used. It is followed by the depth in [km], the P-phase velocity Vp in [km/s], and the S-phase velocity Vs in [km/ s]. The model may contain layers with a constant velocity or with velocity gradients. First order discontinuities must be specified with two lines for the same depth. Additionally, the Conrad- and the Mohorovičić-discontinuities should be marked as shown in the following example. Otherwise, all calculated phases would be called Pg (or Sg).

----------------------example for a file containing a regional velocity-------------------------------

```
 10.                                      | maxdis in free format
     0.000     5.400     3.100            | depth, vp, vs in format (3F10.3)
    10.000     5.800     3.200
    20.000     5.800     3.200CONR        | + mark for the 'Conrad'
    20.000     6.500     3.600            |   in format (3F10.3,A4)
    30.000     6.800     3.900MOHO        | + mark for the 'Moho'
    30.000     8.100     4.500
    77.500     8.050     4.400
   120.000     8.100     4.500
```

----------------------end of example---

PHASE INDEX FOR LOCAL MODEL: This parameter allows the user to specify the set of seismic phases, for which travel times and their partial derivatives will be calculated in the local/regional model:

The parameter is a 4 digit number. The position of a digit defines the phase type for which the value of the digit defines the action for this phase:

- dxxx the digit (d) at this place is the flag for surface reflections (*e.g.*, pP or sS)
- xdxx the digit (d) at this place is the flag for surface multiples (*e.g.*, PP or SS)
- xxdx the digit (d) at this place is the flag for reflections at the Conrad- or the Mohorovičić-discontinuity (*e.g.*, PbP or SmS). Note that the here used name 'PbP', to indicate reflection from the Conrad discontinuity, is not a regular phase name as recommanded by the IASPEI Working Group on Standard Phase Names (see IS 2.1).
- xxxd the digit (d) at this place is the flag for converted phases (*e.g.*, sP or PmS)

d itself can have the following values:

- d = 1 only P-type onsets will be calculated
- d = 2 only S-type onsets will be calculated
- d = 3 both phase types (P and S) will be calculated

e.g.,: 1320 means: the phases pP, PP, SS, SbS and SmS will be calculated but no conversions. 000 or simply 0 means: none of these phases will be calculated.

The direct phases Pg, Pb, Pn, P (or the same for S) will always be calculated as long as the **PHASE INDEX FOR LOCAL MODEL** is not set to a negative value.

CRUST 5.1 PATH: The path to the directory where the CRUST 5.1 data files (Mooney *et al.*, 1998) reside.

CRUST 5.1: This parameter controls the usage of the model CRUST 5.1:

- = 0 CRUST 5.1 is not used at all.
- = 1 CRUST 5.1 is used to calculate station corrections with respect to the local crustal structure below the station.

= 2 CRUST 5.1 is used to define a local/regional velocity model between the source and stations up to a distance of 6 deg.

= 3 CRUST 5.1 is used to define a local/regional velocity and to correct for local crustal structures at the stations and at reflection points at the Earth's surface. If this parameter is set to any value larger than 0 and the model CRUST 5.1 is available, a time correction for the crustal structure at the reflection point of phases reflected at the Earth's surface will be calculated (*e.g.,* PnPn, sS, P'P', ...)

OUTPUT OF REGIONAL MODEL: This flag defines if the local/regional model used for the final inversion is to be printed out in the output file (***hyposat-out***). This option is particularly interesting whenever this velocity model was interpolated from CRUST 5.1:

0 no model output (default)

1 model output

STATION FILE: Name of the file with station coordinates either in NEIC or in CSS 3.0 file format. Only these two formats are currently supported! To get the location results faster, the usage of a file containing only your usually used stations is recommended.

STATION CORRECTION FILE: Name of the file for station corrections. This file must contain the station name and then the local velocities for P and S waves below this station to calculate the best elevation correction for this station. This value can also be used to correct for a known velocity anomaly below this station. The input is format free. If such information is not available, leave it blank. If one station is not in this list, the default values as defined by the input parameters **P-VELOCITY TO CORRECT ELEVATION** and **S-VELOCITY TO CORRECT ELEVATION** are used!

----------------------example for a file containing station corrections -----------------------------

```
GEC2 5.2 3.2                                  | in free format
```

----------------------end of example--

P-VELOCITY TO CORRECT ELEVATION: Local P velocity (Vpl) to correct for the station elevation (default 5.8 km/s) if this parameter is not set in the **STATION CORRECTION FILE**. If Vpl = 99. a station-elevation correction is <u>not</u> applied and the **STATION CORRECTION FILE** is <u>not</u> used.

S-VELOCITY TO CORRECT ELEVATION: Local S velocity (Vsl) to correct for the station elevation (default Vpl/sqrt(3.)), if not given in **STATION CORRECTION FILE**.

LG GROUP-VELOCITY: A group velocity for Lg can be defined; the default value is 3.5 [km/s].

RG GROUP-VELOCITY: A group velocity for Rg can be defined; the default value is 2.5 [km/s].

LQ GROUP-VELOCITY: A global group velocity for Love wave. (LQ) can be defined; the default value is 4.4 [km/s].

LR GROUP-VELOCITY: A global group velocity for Rayleigh waves (LR) can be defined; the default value is 3.95 [km/s].

STARTING SOURCE LATITUDE: Initial value for event latitude (no default value, an initial latitude will be estimated or chosen from the input data). Valid range: -90 deg<= value <= 90 deg. An initial solution must be set for both latitude and longitude!

STARTING LATITUDE ERROR: Its standard deviation (default 10 deg).

STARTING SOURCE LONGITUDE: Initial value for event longitude (no default value, a start longitude will be estimated or chosen from the given data). Valid range: -180 deg<= value <= 180 deg. An initial solution must be set for both latitude and longitude!

STARTING LONGITUDE ERROR: Its standard deviation (default 10 deg).
STARTING SOURCE DEPTH: Starting value for the event depth (default 0. km).
STARTING DEPTH ERROR: Its standard deviation (default 50 km).
DEPTH FLAG: Flag to handle the source depth:

- f or F the hypocenters depth is fixed for this inversion, as defined by **STARTING SOURCE DEPTH.**
- d or D the depth will be inverted from the beginning.
- b or B means both: *i.e.*, the inversion begins with the fixed depth from **STARTING SOURCE DEPTH** and after reaching a stable solution, the routine also tries to invert for the source depth. Both solutions (fixed and free depth) will be listed in ***hyposat-out*** (see example).

STARTING SOURCE TIME: Initial value for source time in epochal time format. The initial source time can be given in three different formats: as epochal time (*i.e.*, the number of seconds after 01 January 1970 00:00:00), and in two human readable formats yyyy-doy:hh.mm.ss.sss (DOY = day-of-year) and yyyy-mo-dd:hh.mm.ss.sss. For example, the 1 October 2002 at 3 o'clock in the afternoon can be written as 1033484400.0 (epochal time) or as 2002-274:15.00.00.000 or as 2002-10-01:15.00.00.000.

If this value is not set, an initial source time will be estimated from travel-time differences between direct S type and direct P type observations by using Wadati's approach. For this, the program calculates a Vp/Vs relation for each phase type and estimate a source time, respectively. The initial source time is then the mean value of all estimated source times. In the case of only one S-P observation, Vp/Vs is set to sqrt(3.). If no S-P time observation is available, the source time is set to the earliest observed onset time.

STARTING TIME ERROR: its standard deviation (default 120 s).

MAXIMUM # OF ITERATIONS: To avoid indefinite iterations to find a solution, a maximum number of iterations must be defined (default 80).

 # TO SEARCH OSCILLATION: Here the number of solutions from older iterations can be defined with which the newest solution will be compared to identify iterations between very similar solutions (oscillating solutions). The default value is 4 and the maximum number is 10.

LOCATION ACCURACY: If we calculate the distance between the solutions of two consecutive iterations in km, this value gives the maximum vector length to stop the iteration process. The default value is 1 km (also if **LOCATION ACCURACY** is set to 0.).

CONSTRAIN SOLUTION: If this flag is set to 1 (default value), all used observations are checked for their residuals and only the data with relatively small residuals are used for a final inversion.

- 0 no final restriction of data
- 1 final restriction of data (default).

CONFIDENCE LEVEL: Level of confidence for the output of uncertainties in percent, the default uncertainty is +/- one standard deviation (*i.e.,* ca. 68.3%).

EPICENTER ERROR ELLIPSE: The setting of this flag defines whether an error ellipse for the final solution will be calculated or not. The size of the error ellipse corresponds to the chosen confidence level.

- 0 no error ellipses
- 1 error ellipses will be calculated (default).

SLOWNESS [S/DEG]: The slowness of a seismic phase can be given as input value in two different units: apparent velocity or ray parameter. All slowness values must have the same unit in the data input file ***hyposat-in***:

- 0 the slowness input values are apparent velocities in [km/s]

1 the slowness input values are ray parameters in [s/deg]

MAXIMUM AZIMUTH ERROR: Maximum value of a backazimuth-residual to use this observation as a defining phase in [deg].

MAXIMUM SLOWNESS ERROR: Maximum value of a slowness-residual to use this observation as a defining phase in [s/deg].

FLAG USING TRAVEL-TIME DIFFERENCES: By default, the program uses the travel-time differences between all phases observed at one station to estimate a hypocenter. This can be switched off:

0 travel-time differences are not used

1 travel-time differences are used (default)

MAGNITUDE CALCULATION: Flag if body wave (mb) or surface wave (Ms) magnitudes are calculated for this event.

0 magnitudes are not calculated (default)

1 magnitudes are calculated

P-ATTENUATION MODEL: With this parameter the attenuation model used for mb calculations can be chosen. The two possibilities are **G-R** for Gutenberg-Richter (Gutenberg and Richter, 1956a, b) or **V-C** for Veith-Clawson (Veith and Clawson, 1972). No default model is defined!

S-ATTENUATION MODEL: With this parameter the attenuation model used for Ms calculations can be chosen. The two possibilities are **IASPEI** for the IASPEI 1967 formula (often also called Praha formula) or **R-P** for the Rezapour and Pearce (1998) formula. No default model is defined!

INPUT FILE NAME: A file name can be defined at this place if not the standard input-file name (***hyposat-in***) should be used.

OUTPUT SWITCH: This flag determines whether any output file (see also **OUTPUT FILE NAME)** will be written:

0 no output file

1 output file will be written (default)

OUTPUT FILE NAME: A file name can be given at this place if not the standard output-file name (***hyposat-out***) should be used.

OUTPUT LEVEL: Verbosity level for output during the location process on screen (0 – 10) or on file (>10) during the inversion; the default value is 4. If **OUTPUT LEVEL** > 10, the output level for the screen is internally calculated. In addition, the resolution, covariance, correlation, and the information-density matrix will then be written out in a file called ***hyposat-gmi.out***. This file contains always the named matrices for the last inversion. **OUTPUT LEVEL** can be set to the following values:

Input	Matrix Output	Screen Output Level
0 – 10	None	0 – 10
11	the resolution matrix will be written out.	0
12	the covariance matrix will be written out.	1
13	the correlation matrix will be written out.	3
14	all three matrices will be written out.	5
15	"	7
16	"	9
17 – 19	"	10
20	" , plus the diagonal elements of information -density matrix will be written out.	0
21 – 29	"	as for 11 – 19
30	" , plus the whole information-density matrix	0

	will be written out.	
31 – 39	"	as for 11 – 19

4 The File hyposat-in

HYPOSAT then needs a file with all the readings for a specific event: This file has by default the name ***hyposat-in*** but the name can be defined in the parameter file ***hyposat-parameter***. The data-input file must have the following format:

1. line: any title for event identification of maximum 80 characters (used also in the output-file ***hyposat-out***).

2. – (n+1)'th line with the n-observed onsets. This line must (!) be compatible with the following format (FORTRAN):

If we don't wish to calculate magnitudes (see **MAGNITUDE CALCULATION** in the ***hyposat-parameter*** file) this line can contain the following data with the following format:

(a5,1x,a8,1x,i4,4(1x,i2),1x,f6.3,1x,f5.3,1x,f6.2,3(1x,f5.2),1x,a6)

station name, phase name, year, month, day, hour, minute, second, standard deviation of the onset time, backazimuth, standard deviation of the backazimuth observation, either ray parameter [s/deg] or apparent velocity [km/s] (see **SLOWNESS [S/DEG]** in the ***hyposat-parameter*** file), standard deviation of the slowness observation in [s/deg] or [km/s], and a six character long combination of controlling flags. These steering flags (**123456**) have the following meanings and options:

Position **1** the time reading of this onset can be used ('**T**' or '**t**') or not used ('**_**') for the inversion.

Position **2** the backazimuth reading of this onset can be used ('**A**' or '**a**') or not used ('**_**') for the inversion.

Position **3** the slowness reading of this onset can be used ('**S**' or '**s**') or not used ('**_**') for the inversion.

Position **4** the time reading of this onset can be used ('**D**' or '**d**') or not used ('**_**') to calculate travel-time differences and use them in the inversion.

Position **5** the onset-time reading of this onset will be corrected ('**R**' or '**r**') or not corrected ('**_**') for the crustal structure below a reflection point at the Earth's surface by calculating the travel-time difference for the crustal path between the used global model (as set with **GLOBAL MODEL** in ***hyposat-parameter***) and CRUST 5.1.

Position **6** if set to '**2**', '**3**', or '**4**', the other global Earth model (as set with **GLOBAL MODEL 2**, **GLOBAL MODEL 3**, or **GLOBAL MODEL 4** in ***hyposat-parameter***) will be used to calculate the theoretical onset time, the ray parameter, and their partial derivatives for this onset. With any other character at this place the standard global Earth model (see **GLOBAL MODEL** in ***hyposat-parameter***) will be used.

Keeping all positions 1 – 6 blank, the flag combination **TASDR_** will be used as default value.

If one also wishes to calculate magnitudes (see **MAGNITUDE CALCULATION** in ***hyposat-parameter***) this line can contain the following data in the following format:

(a5,1x,a8,1x,i4,4(1x,i2),1x,f6.3,1x,f5.3,1x,f6.2,3(1x,f5.2),1x,a6,1x,f6.3,1x,f12.2)

station name, phase name, year, month, day, hour, minute, second, standard deviation of the onset time, backazimuth, standard deviation of the backazimuth observation, either ray parameter [s/deg] or apparent velocity [km/s] (see **SLOWNESS [S/DEG]** in the ***hyposat-parameter*** file), standard deviation of the slowness observation in [s/deg] or [km/s], the six character long combination of controlling flags (see above), the period of the observed onset, and finally the amplitude of the signal in [nm].

S-type onsets must always be listed after the corresponding P-type onsets – if not, the travel-time difference between these two onsets (S-P) cannot be used for calculating a starting solution for source time and distance from the corresponding station. If it is unknown, of which type the P or S onsets are, you can choose the names P1 or S1 to tell the program that you know it is the first P or the first S onset at this station. Then the program itself chooses the right phase name depending on the distance of the observation.
Onsets with a station name starting with a ***** and lines starting with a blank character are not used.
The values for backazimuth, slowness, period, and amplitude are optional. If backazimuth or slowness values are not available, they must be set to -999. or -1.; the amplitude/period information is only used if both values are larger than 0.
For each phase name not defined by the applied travel-time model(s), the program searches for the best fitting phase. However, onset time and ray parameter of such a phase are not used in the inversion, but eventually the backazimuth information!
When using the correct format, an input file can look like the following example:

------------- example for a ***hyposat-in*** file --

```
NORTHERN MOLUCCA SEA, 1996 29 June, from pIDC’s Reviewed Event Bulletin (REB)
WRA   P        1996 06 29 00 41 44.700 0.300 331.50 20.00 11.10  1.00 TASD__  0.300         4.50
WRA   S        1996 06 29 00 45 48.7   0.600 338.0  20.0  17.0   2.00 TASD__  0.900         2.00
QIS   P1       1996 06 29 00 42 12.8   0.300 -999.   0.0  -999.  0.00 TASD__
QIS   PcP      1996 06 29 00 45 44.8   0.300 -999.   0.0  -999.  0.00 TASD__
ASAR  P        1996 06 29 00 42 16.9   0.300 346.3  20.0    7.1  1.00 TASD__  0.500         3.40
ASAR  PcP      1996 06 29 00 45 45.2   0.300 345.1  20.0    2.3  1.00 TASD__  0.500         2.20
ASAR  S        1996 06 29 00 46 45.3   0.600 347.6  20.0  20.3   2.00 TASD__  0.800         3.90
WARB  P        1996 06 29 00 42 31.2   0.300 339.4  30.0    8.2  2.00 TASD__  0.700         6.50
WARB  PcP      1996 06 29 00 45 49.4   0.300 -999.   0.0  -999.  0.00 TASD__
MEEK  P        1996 06 29 00 42 42.7   0.300 -999.   0.0  -999.  0.00 TASD__
CMAR  P        1996 06 29 00 43 09.0   0.300 109.7  30.0    7.8  2.00 TASD__  0.400         0.60
CMAR  LR       1996 06 29 00 57 48.7  50.000 110.0  30.0  39.5   2.00 _A____ 19.360       188.80
FORT  P        1996 06 29 00 43 11.3   0.300 -999.   0.0  -999.  0.00 TASD__
WOOL  P        1996 06 29 00 43 15.6   0.300   7.9  30.0    9.9  2.00 TASD__  0.600         4.10
SHK   P        1996 06 29 00 43 25.4   0.300 -999.   0.0  -999.  0.00 TASD__
STKA  P        1996 06 29 00 43 46.8   0.300 323.2  20.0    9.0  1.00 TASD__  0.600         7.20
STKA  PcP      1996 06 29 00 46 12.0   0.300 -999.   0.0  -999.  0.00 TASD__
KSAR  P        1996 06 29 00 43 46.7   0.300 177.3  20.0   10.1  2.00 TASD__  0.700         1.70
KSAR  LR       1996 06 29 01 04 25.0  50.000 160.0  20.0   46.0  2.00 _A____ 19.860        40.10
MJAR  P        1996 06 29 00 43 51.9   0.300 357.1  20.0   18.8  1.00 TASD__  0.550         2.00
PDY   P        1996 06 29 00 46 47.0   0.300 111.2  30.0    6.6  2.00 TASD__  0.450         4.30
ZAL   P        1996 06 29 00 47 09.0   0.300 -999.   0.0  -999.  0.00 TASD__
ABKT  P        1996 06 29 00 48 09.5   0.300 -999.   0.0  -999.  0.00 TASD__
*
*NRI   P        1996 06 29 00 48 08.7   0.300 195.9  30.0    3.9  2.00 TASD__  0.750         3.00
* Note, the following phase has an irregular phase name! Therefore we will not use its onset time
* or slowness for inversion.
*
NRI   x        1996 06 29 00 48 08.7   0.300 195.9  30.0    3.9  2.00 _A____  0.750         3.00
MAW   P        1996 06 29 00 49 01.1   0.300 -999.   0.0  -999.  0.00 TASD__
KVAR  P        1996 06 29 00 49 17.2   0.300 -999.   0.0  -999.  0.00 TASD__
NPO   P        1996 06 29 00 49 31.0   0.300 -999.   0.0  -999.  0.00 TASD__
ARCES P        1996 06 29 00 49 51.7   0.300  94.5  20.0    4.1  1.00 TASD__  0.550         0.80
SPITS P        1996 06 29 00 49 55.9   0.300 116.6  30.0    3.5  2.00 TASD__  0.900         3.60
FINES P        1996 06 29 00 50 00.0   0.300 111.2  20.0    5.9  1.00 TASD__  0.550         0.60
HFS   P        1996 06 29 00 50 28.7   0.300 311.3  30.0    1.5  2.00 TASD__  0.750         1.10
TXAR  PKPdf    1996 06 29 00 55 42.7   0.300 -999.   0.0  -999.  0.00 TASD__
SCHQ  PKPdf    1996 06 29 00 55 41.2   0.300 -999.   0.0  -999.  0.00 TASD__
DBIC  PKPdf    1996 06 29 00 55 57.1   0.300 -999.   0.0  -999.  0.00 TASD__
PLCA  PKPdf    1996 06 29 00 56 09.1   0.300 311.9  30.0    6.4  2.00 TASD__  0.900         0.90
LPAZ  PKPdf    1996 06 29 00 56 44.7   0.300 -999.   0.0  -999.  0.00 TASD__
```

-------------- end of the example --

5 The File hyposat-out

With the above example for a ***hyposat-in*** file you will get the following output-file ***hyposat-out***: This example was calculated on a UNIX system, the results on a LINUX system might be slightly different. Explanations are included in [....]:

-----------------example for a ***hyposat-out*** file --------------------------------------

```
HYPOSAT Version 4.4

NORTHERN MOLUCCA SEA, 1996 29 June, from pIDC's Reviewed Event Bulletin (REB)

Parameters of starting solution ( 1 standard deviation):


[ Not all backazimuth-observation pairs are used: if one station is more than 170 deg apart from the crossing point, this crossing point is skipped. ]
Mean epicenter calculated from  165 backazimuth observation pairs
Mean epicenter lat:  29.4748    42.0082 [deg]
Mean epicenter lon: 121.5921     6.0977 [deg]

[ type 1: S - P  or S1 - P1 observation, type 2: Sg - Pg observation, type 3: Sn - Pn observation, type 4: Sb - Pb observation ]
S-P Travel-time difference type 1 with   2 observation(s)
Mean source time:  836008582.700   11.636 [s]
Mean       vp/vs:          1.758    0.035

Iterations        :    7
Number of defining:   58
First reference model   : ak135
Second reference model  : iasp91

The new source parameters

Confidence level of given uncertainties:  68.27 %

Source time  : 1996 06 29 00 36 42.801     0.150 [s]
        or              836008602.801     0.150 [s]
Epicenter lat:                 1.3045    0.0250 [deg]
Epicenter lon:               126.3165    0.0611 [deg]
Source depth :                 0.00   [km] Fixed

Epicenter error ellipse:
Major axes:     5.98 [km]  Minor axes:     3.61 [km]
Azimuth:       62.0  [deg] Area:          67.82 [km**2]

Flinn-Engdahl Region ( 266 ): Northern Molucca Sea

Magnitudes: 4.39 (mb, G-R) 3.57 (Ms, R-P)

 Stat  Delta   Azi   Phase   [used]    Onset time    Res     Baz     Res   Rayp   Res  Used    Amplitude   Period  MAG

WRA    22.534 159.96 P                00 41 44.700   0.167 331.50   -7.15 11.10   0.47 TASD          4.50  0.300 4.43
WRA    22.534 159.96 S                00 45 48.700  -4.364 338.00   -0.65 17.00  -2.34 TA D          2.00  0.900
QIS    25.328 149.77 P1      P        00 42 12.800   1.244                             T  D
QIS    25.328 149.77 PcP              00 45 44.800   0.066                             T  D
ASAR   25.895 163.91 P                00 42 16.900   0.181 346.30    3.89  7.10  -1.96 TA D          3.40  0.500 4.24
ASAR   25.895 163.91 PcP              00 45 45.200  -0.823 345.10    2.69  2.30   0.01 TASD          2.20  0.500
ASAR   25.895 163.91 S                00 46 45.300  -2.629 347.60    5.19 20.30   4.48 TA D          3.90  0.800
WARB   27.329 179.36 P                00 42 31.200   1.588 339.40  -19.89  8.20  -0.78 T SD          6.50  0.700 4.50
WARB   27.329 179.36 PcP              00 45 49.400   0.097                             T  D
MEEK   28.756 194.44 P                00 42 42.700   0.321                             T
CMAR   31.809 304.11 P                00 43  9.000  -0.476 109.70   -9.60  7.80  -0.99 TAS           0.60  0.400 3.88
[ The following LR onset was only used with its backazimuth observation. ]
CMAR   31.809 304.11 LR               00 57 48.700  23.611 110.00   -9.30 39.50   0.45  A          188.80 19.360 3.88
FORT   31.949 177.17 P                00 43 11.300   0.807                             T
WOOL   32.500 187.42 P                00 43 15.600   0.239   7.90   -0.75  9.90   1.13 TAS           4.10  0.600 4.54
SHK    33.587   9.52 P                00 43 25.400   0.573                             T
KSAR   35.990   2.12 P                00 43 46.700   1.176 177.30   -5.37 10.10   1.53 TA            1.70  0.700 3.99
KSAR   35.990   2.12 LR               01 04 25.000 257.097 160.00  -22.67 46.00   6.96              40.10 19.860 3.26
STKA   36.040 157.60 P                00 43 46.800   0.740 323.20  -10.20  9.00   0.43 T SD          7.20  0.600 4.68
STKA   36.040 157.60 PcP              00 46 12.000  -0.606                             T  D
MJAR   36.750  16.10 P                00 43 51.900  -0.210 357.10  156.96 18.80  10.28 T             2.00  0.550 4.09
PDY    59.127 351.99 P                00 46 47.000   1.992 111.20  -52.89  6.60  -0.33 T S           4.30  0.450 4.78
ZAL    62.559 333.79 P                00 47  9.000   0.523                             T
ABKT   72.094 309.51 P                00 48  9.500   0.098                             T
[ The unknown phase x was associated as P and the corresponding residuals were calculated. ]
NRI    72.621 346.75 x       P        00 48  8.700  -3.059 195.90   56.31  3.90  -2.05               3.00  0.750 4.50
MAW    81.351 200.29 P                00 49  1.100   0.155                             T
KVAR   84.499 313.86 P                00 49 17.200  -0.871                             T
NPO    87.457  25.36 P                00 49 31.000  -1.079                             T
[ This P onset does not at all fit in the location with a fixed depth at 0 km. ]
ARCES  92.567 339.77 P                00 49 51.700  -4.215  94.50   15.08  4.10  -0.52   S           0.80  0.550 4.32
SPITS  92.763 348.81 P                00 49 55.900  -0.784 116.60   46.40  3.50  -1.11 T S           3.60  0.900 4.78
FINES  93.759 331.71 P                00 50  0.000  -1.509 111.20   30.82  5.90   1.30 T S           0.60  0.550 4.16
HFS    99.955 332.03 P       Pdif     00 50 28.700  -1.003 311.30 -118.24  1.50  -2.95 T             1.10  0.750 4.57
SCHQ  123.011   9.03 PKPdf            00 55 41.200  -0.098                             T
TXAR  123.387  53.22 PKPdf            00 55 42.700  -0.215                             T
DBIC  130.629 279.87 PKPdf            00 55 57.100   0.161                             T
PLCA  137.880 160.81 PKPdf            00 56  9.100  -0.877 311.90  106.27  6.40   4.56 T             0.90  0.900
```

```
LPAZ  159.401 137.08 PKPdf           00 56 44.700  -0.776                            T

Defining travel-time differences:

 Stat  Delta  Phases           Observed   Res

WRA    22.534 S - P             244.000  -4.530
QIS    25.328 PcP - P1          212.000  -1.178
ASAR   25.895 PcP - P           208.300  -1.005
ASAR   25.895 S - P             268.400  -2.810
ASAR   25.895 S - PcP            60.100  -1.805
WARB   27.329 PcP - P           198.200  -1.490
STKA   36.040 PcP - P           145.200  -1.346
```

[The azimuth range of the maximum gap without any observations is always given in clockwise direction.]

```
Maximum azimuthal gap of defining observations:  53.2 [deg] ->  137.1 [deg] =  83.9 [deg]
```

[RMS is defined as $\sqrt{\frac{\sum Res^2}{N}}$, MEAN-ERROR is defined as $\frac{\sum |Res|}{N}$, and MEAN is defined as $\frac{\sum Res}{N}$; all with the listed residuals *Res* and the number of data *N*.]

```
Residuals of defining data          RMS    MEAN-ERROR      MEAN
    32 onset times            :    1.199       0.826     -0.194  [s]
     9 azimuth values         :    5.858       4.955     -2.336  [deg]
    10 ray parameters         :    0.812       0.709     -0.040  [s/deg]
     7 travel-time differences :   2.333       2.023     -2.023  [s]
```

[The weighted RMS is here defined as $\sqrt{\frac{\sum Res^2 \cdot w}{\sum w}}$ with the listed residuals *Res* and the data weight *w* used for the inversion (*i.e.*, here the standard deviations of the data from ***hyposat-in***) as used at the ISC.]

```
Weighted RMS of onset times (ISC type):    1.455 [s]
```

[The weighted misfit is here defined for the L1-norm as $\frac{\sum \frac{|Res|}{w}}{N}$ and for the L2-norm as $\frac{\sum \left(\frac{Res}{w}\right)^2}{N}$ with *N* the number of data. Input data also means data not used to locate the event. In this case, all backazimuth and ray parameter observations defined as usable by the switches in ***hyposat-in*** were also included.]

```
Weighted misfit of input data         L1      L2
    33 onset times            :    2.744    0.450
    20 azimuth values         :    1.351    2.282
    17 ray parameters         :    1.475    2.736
     7 travel-time differences :   3.637    3.893
    77 misfit over all        :    2.183    2.114

T0                          LAT      LON       Z     VPVS   DLAT     DLON      DZ       DT0    DVPVS DEF    RMS
1996-06-29 00 36 42.801    1.305  126.317    0.00   1.76   0.0250   0.0611  Fixed     0.150   0.04   58    1.199
```

[However, we have still a fixed depth. Let us now try to fit the data better with another depth (see **DEPTH FLAG** is set to **b**!]

```
Iterations        :    4
Number of defining:   58
First reference model   : ak135
Second reference model  : iasp91

The new source parameters

Confidence level of given uncertainties:  68.27 %

Source time  : 1996 06 29 00 36 49.169     0.478 [s]
        or               836008609.169     0.478 [s]
Epicenter lat:                  1.3211    0.0147 [deg]
Epicenter lon:                126.2965    0.0348 [deg]
Source depth :                 44.50      4.28   [km]
```

[Note the now much smaller error ellipse.]

```
Epicenter error ellipse:
Major axes:     3.40 [km]  Minor axes:     1.94 [km]
Azimuth:       71.2  [deg] Area:          20.75 [km**2]

Flinn-Engdahl Region ( 266 ): Northern Molucca Sea

Magnitudes: 4.36 (mb, G-R) 3.57 (Ms, R-P)

 Stat  Delta   Azi   Phase   [used]    Onset time    Res     Baz     Res   Rayp   Res  Used    Amplitude   Period  MAG

WRA    22.556 159.93 P                00 41 44.700  -1.002 331.50   -7.11 11.10   0.51 TASD         4.50  0.300 4.36
WRA    22.556 159.93 S                00 45 48.700  -1.916 338.00   -0.61 17.00   0.65 TASD         2.00  0.900
QIS    25.353 149.75 P1      P        00 42 12.800   0.540                             T  D
QIS    25.353 149.75 PcP              00 45 44.800   0.532                             T  D
ASAR   25.916 163.87 P                00 42 16.900  -0.488 346.30    3.93  7.10  -1.95 TA D         3.40  0.500 4.19
ASAR   25.916 163.87 PcP              00 45 45.200  -0.354 345.10    2.73  2.30   0.00 TASD         2.20  0.500
ASAR   25.916 163.87 S                00 46 45.300   0.595 347.60    5.23 20.30   4.49 TA D         3.90  0.800
WARB   27.346 179.32 P                00 42 31.200   0.983 339.40  -19.85  8.20  -0.76 T SD         6.50  0.700 4.41
WARB   27.346 179.32 PcP              00 45 49.400   0.570                             T  D
MEEK   28.767 194.40 P                00 42 42.700  -0.210                             T
CMAR   31.783 304.10 P                00 43  9.000  -0.659 109.70   -9.59  7.80  -0.99 TAS          0.60  0.400 3.79
CMAR   31.783 304.10 LR               00 57 48.700  18.251 110.00   -9.29 39.50   0.45  A         188.80 19.360 3.88
FORT   31.966 177.13 P                00 43 11.300   0.247                             T
WOOL   32.514 187.39 P                00 43 15.600  -0.284   7.90   -0.71  9.90   1.14 TAS          4.10  0.600 4.47
SHK    33.574   9.55 P                00 43 25.400   0.298                             T
KSAR   35.974   2.15 P                00 43 46.700   0.958 177.30   -5.40 10.10   1.54 TA           1.70  0.700 4.03
KSAR   35.974   2.15 LR               01 04 25.000 251.344 160.00  -22.70 46.00   6.96             40.10 19.860 3.26
STKA   36.063 157.58 P                00 43 46.800   0.192 323.20  -10.18  9.00   0.45 T SD         7.20  0.600 4.72
STKA   36.063 157.58 PcP              00 46 12.000  -0.198                             T  D
MJAR   36.740  16.13 P                00 43 51.900  -0.465 357.10  156.92 18.80  10.29 T            2.00  0.550 4.17
```

[This P onset has now a larger residuum than in the first run and is therefore not longer defining for the solution.]

```
PDY    59.108 352.00 P                00 46 47.000   2.113 111.20  -52.91  6.60  -0.32   S          4.30  0.450 4.79
```

```
ZAL    62.536 333.80 P                00 47  9.000   0.712                              T
ABKT   72.068 309.50 P                00 48  9.500   0.395                              T
NRI    72.600 346.76 x       P        00 48  8.700  -2.787 195.90   56.30  3.90  -2.04               3.00  0.750 4.37
MAW    81.360 200.28 P                00 49  1.100   0.351                              T
KVAR   84.474 313.86 P                00 49 17.200  -0.469                              T
NPO    87.451  25.36 P                00 49 31.000  -0.748                              T
[ Note that the following P onset has now a smaller residuum but was still too large to be used as defining. ]
ARCES  92.544 339.77 P                00 49 51.700  -3.787  94.50   15.07  4.10  -0.52   S             0.80  0.550 4.29
SPITS  92.743 348.81 P                00 49 55.900  -0.366 116.60   46.39  3.50  -1.11 T S             3.60  0.900 4.74
FINES  93.735 331.71 P                00 50  0.000  -1.073 111.20   30.81  5.90   1.30 T S             0.60  0.550 4.19
HFS    99.931 332.03 P       Pdif     00 50 28.700  -0.564 311.30 -118.25  1.50  -2.95 T               1.10  0.750 4.57
SCHQ  122.998   9.02 PKPdf            00 55 41.200   0.464                              T
TXAR  123.393  53.20 PKPdf            00 55 42.700   0.310                              T
DBIC  130.607 279.88 PKPdf            00 55 57.100   0.742                              T
PLCA  137.902 160.82 PKPdf            00 56  9.100  -0.377 311.90  106.29  6.40   4.56 T               0.90  0.900
LPAZ  159.427 137.09 PKPdf            00 56 44.700  -0.241                              T

Defining travel-time differences:

 Stat  Delta  Phases           Observed   Res

WRA    22.556 S - P             244.000  -0.914
QIS    25.353 PcP - P1          212.000  -0.008
ASAR   25.916 PcP - P           208.300   0.134
ASAR   25.916 S - P             268.400   1.083
ASAR   25.916 S - PcP            60.100   0.949
WARB   27.346 PcP - P           198.200  -0.413
STKA   36.063 PcP - P           145.200  -0.390

[ Here we get the number of all iterations e.g., also including an earlier solution for fixed depth. ]
Total number of iterations:    18

Maximum azimuthal gap of defining observations:  53.2 [deg] -> 137.1 [deg] =  83.9 [deg]

Residuals of defining data          RMS    MEAN-ERROR      MEAN
    31 onset times              :    0.658       0.558     -0.049  [s]
     9 azimuth values           :    5.862       4.957     -2.316  [deg]
    11 ray parameters           :    0.801       0.706      0.033  [s/deg]
     7 travel-time differences :    0.681       0.556      0.063  [s]

Weighted RMS of onset times (ISC type):    0.727 [s]

Weighted misfit of input data         L1      L2
    33 onset times              :    2.217    0.140
    20 azimuth values           :    1.351    2.282
    17 ray parameters           :    1.429    2.726
     7 travel-time differences :    0.946    1.093
    77 misfit over all          :    1.702    1.763

T0                         LAT      LON       Z     VPVS   DLAT     DLON      DZ       DT0    DVPVS DEF     RMS
1996-06-29 00 36 49.169    1.321  126.297   44.50   1.76   0.0147   0.0348    4.28    0.478   0.04   58     0.658
```

---------------------------end of the example--

6 The Program HYPOMOD and the File hypomod-out

For a given seismic hypocenter solution, the program **HYPOMOD** calculates the residuals for all observed data: the travel times, the backazimuths, and slowness values. With the example given here for a hypocenter inversion with **HYPOSAT**, one has only to modify slightly the ***hyposat-parameter*** file and then one can apply the program **HYPOMOD**. The modifications needed in ***hyposat-parameter*** are to set for the starting source parameters the inversion results. Then you will get an output-file called ***hypomod-out***, which has in principle the same format as ***hyposat-out***.

--- example for changes in **hyposat-parameter --------**

```
STARTING SOURCE LATITUDE [deg]      : 1.3211

STARTING SOURCE LONGITUDE [deg]     : 126.2965

STARTING SOURCE DEPTH [km]          : 44.50

STARTING SOURCE TIME (epochal time): 836008609.169
```
or
```
STARTING SOURCE TIME (DOY)          : 1996-181:00.36.49.169
```
or
```
STARTING SOURCE TIME (HUMAN)        : 1996-06-29:00.36.49.169
```

Then run **HYPOMOD** and you will get an output file ***hypomod-out*** which will look like:

------------------example for a ***hypomod-out*** file ---------------------------------------

```
HYPOMOD Version 1.1

NORTHERN MOLUCCA SEA, 1996 29 June, from pIDC's Reviewed Event Bulletin (REB)

The source parameters

Source time  : 1996 06 29 00 36 49.169
        or                 836008609.169
Epicenter lat:                   1.3211 [deg]
Epicenter lon:                 126.2965 [deg]
Source depth :                   44.50   [km]

Flinn-Engdahl Region ( 266 ): Northern Molucca Sea

Magnitudes: 4.21 (mb, V-C) 3.57 (Ms, R-P)

 Stat  Delta   Azi   Phase   [used]    Onset time    Res     Baz     Res   Rayp   Res  Used    Amplitude   Period  MAG

WRA    22.556 159.93 P                00 41 44.700  -1.002 331.50   -7.11 11.10   0.51 TASD          4.50  0.300 4.22
WRA    22.556 159.93 S                00 45 48.700  -1.916 338.00   -0.61 17.00   0.65 TASD          2.00  0.900
QIS    25.353 149.75 P1      P        00 42 12.800   0.540                             T  D
QIS    25.353 149.75 PcP              00 45 44.800   0.532                             T  D
ASAR   25.916 163.87 P                00 42 16.900  -0.488 346.30    3.93  7.10  -1.95 TASD          3.40  0.500 4.18
ASAR   25.916 163.87 PcP              00 45 45.200  -0.354 345.10    2.73  2.30   0.00 TASD          2.20  0.500
ASAR   25.916 163.87 S                00 46 45.300   0.595 347.60    5.23 20.30   4.49 TASD          3.90  0.800
WARB   27.346 179.32 P                00 42 31.200   0.983 339.40  -19.85  8.20  -0.76 TASD          6.50  0.700 4.41
WARB   27.346 179.32 PcP              00 45 49.400   0.570                             T  D
MEEK   28.767 194.40 P                00 42 42.700  -0.210                             T  D
CMAR   31.783 304.10 P                00 43  9.000  -0.659 109.70   -9.59  7.80  -0.99 TASD          0.60  0.400 3.66
CMAR   31.783 304.10 LR               00 57 48.700  18.252 110.00   -9.29 39.50   0.45  A          188.80 19.360 3.88
FORT   31.966 177.13 P                00 43 11.300   0.247                             T  D
WOOL   32.514 187.39 P                00 43 15.600  -0.284   7.90   -0.71  9.90   1.14 TASD          4.10  0.600 4.31
SHK    33.574   9.55 P                00 43 25.400   0.298                             T  D
KSAR   35.974   2.15 P                00 43 46.700   0.958 177.30   -5.40 10.10   1.54 TASD          1.70  0.700 3.82
KSAR   35.974   2.15 LR               01 04 25.000 251.343 160.00  -22.70 46.00   6.96  A           40.10 19.860 3.26
STKA   36.063 157.58 P                00 43 46.800   0.192 323.20  -10.18  9.00   0.45 TASD          7.20  0.600 4.51
STKA   36.063 157.58 PcP              00 46 12.000  -0.198                             T  D
MJAR   36.740  16.13 P                00 43 51.900  -0.465 357.10  156.92 18.80  10.29 TASD          2.00  0.550 3.99
PDY    59.108 352.00 P                00 46 47.000   2.112 111.20  -52.91  6.60  -0.32 TASD          4.30  0.450 4.47
ZAL    62.536 333.80 P                00 47  9.000   0.712                             T  D
ABKT   72.068 309.50 P                00 48  9.500   0.395                             T  D
NRI    72.600 346.76 x       P        00 48  8.700  -2.787 195.90   56.30  3.90  -2.04  A            3.00  0.750 4.17
MAW    81.360 200.28 P                00 49  1.100   0.351                             T  D
KVAR   84.474 313.86 P                00 49 17.200  -0.469                             T  D
NPO    87.451  25.36 P                00 49 31.000  -0.748                             T  D
ARCES  92.544 339.77 P                00 49 51.700  -3.787  94.50   15.07  4.10  -0.52 TASD          0.80  0.550 4.10
SPITS  92.743 348.81 P                00 49 55.900  -0.370 116.60   46.39  3.50  -1.11 TASD          3.60  0.900 4.55
FINES  93.735 331.71 P                00 50  0.000  -1.073 111.20   30.81  5.90   1.30 TASD          0.60  0.550 4.06
HFS    99.931 332.03 P       Pdif     00 50 28.700  -0.564 311.30 -118.25  1.50  -2.95 TASD          1.10  0.750 4.68
SCHQ  122.998   9.02 PKPdf            00 55 41.200   0.464                             T  D
TXAR  123.393  53.20 PKPdf            00 55 42.700   0.310                             T  D
DBIC  130.606 279.88 PKPdf            00 55 57.100   0.742                             T  D
PLCA  137.902 160.82 PKPdf            00 56  9.100  -0.377 311.90  106.29  6.40   4.56 TASD          0.90  0.900 3.96
LPAZ  159.427 137.09 PKPdf            00 56 44.700  -0.241                             T  D

Travel-time differences:

 Stat  Delta  Phases           Observed   Res

WRA    22.556 S - P             244.000  -0.914
QIS    25.353 PcP - P           212.000  -0.008
ASAR   25.916 PcP - P           208.300   0.134
ASAR   25.916 S - P             268.400   1.083
ASAR   25.916 S - PcP            60.100   0.949
WARB   27.346 PcP - P           198.200  -0.413
STKA   36.063 PcP - P           145.200  -0.390

Maximum azimuthal gap of defining observations:  53.2 [deg] -> 137.1 [deg] =  83.9 [deg]

Residuals of data                  RMS    MEAN-ERROR      MEAN
    33 onset times            :    0.988       0.703     -0.097  [s]
    20 backazimuth values     :   55.011      34.014      8.352  [deg]
    17 ray parameters         :    3.151       1.973      0.963  [s/deg]
     7 travel-time differences :    0.681       0.556      0.063  [s]

Weighted RMS of onset times (ISC type):    1.018 [s]

Weighted misfit of input data         L1       L2
    33 onset times            :    2.217    0.140
    20 backazimuth values     :    1.351    2.282
    17 ray parameters         :    1.429    2.726
     7 travel-time differences :    0.946    1.093
    77 misfit over all        :    1.703    1.763
```

------------------------end of the example---

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