

Tutorial

Fault plane solutions in SEISAN

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Introduction

SEISAN has many programs to deal with fault plane solutions (FPS) including 4 programs for finding FPS. In this document, the intention is to give examples of using the programs and to get an idea of the possibilities available to work with FPS. The document is made using a set of test data available at our web site <https://seisan.info/>, so the user can reproduce the results shown here. It is assumed that the reader is familiar with the principle of making fault plane solutions, knows how to pick polarity and has some working experience with SEISAN. There is thus no training in picking and locating the events. For details of the different program, see the SEISAN manual.

This tutorial was made using SEISAN version 13.5.

Overview of programs

The list below gives the names (in capital letters) and a short description of the SEISAN programs used in this tutorial.

- FOCMEC: the original FPS Snoke program. It uses polarities and amplitude ratios.
- PPFIT: the original FPS Fpfit program, it uses polarities.
- PINV: a simple FPS program that makes a moment tensor inversion based on assuming that C and D polarities are equivalent to + and -1 amplitudes.
- HASH: the original FPS Hash program modified for SEISAN. It uses polarities and amplitude ratios. The original program can also use multiple models simultaneously to get an idea of the influence of the model on the fault plane solution. This has not been implemented in SEISAN but FOCMEC has a similar option.
- AUTO: can automatically make fault plane solutions of many events. All 4 FPS programs can be used. AUTO also does other things like locating the events and reading amplitudes.
- PLOTFOC: plots FPS for one event, no polarities shown. It plots the FPS' for the first event found in a CAT file.
- FOC: plots many FPS solutions on one page, makes a stress inversion and a Rose diagram of the P and T axis.
- MAP and EPIMAP: plot FPS on a map.
- MAPG: plots FPS on a map using The Generic Mapping Tools (GMT, <https://www.generic-mapping-tools.org/>).
- EEV: event editor for the SEISAN database, used to start the different programs.

MULPLT: manually reads polarities and amplitudes with MULPLT (command 'p' in EEV).

PLOTPOLARITY: reads or modifies polarities for phases where P has been read (command 'qp' in EEV).

AUTORATIO: determine amplitudes automatically, (command 'ar' in EEV). Also used in AUTO.

Note that in the examples below the program names are not given in capital letters, but the way they are typed in the terminal.

Data

The data used in this tutorial is from the Norwegian National Seismic Network. No modification of the data has been made except deleting possible fault plane solutions and adding amplitudes if not there. The events have been relocated using only the station up to 100 km epicentral distance to get the most reliable hypocentral depth (set in STATION0.HYP). The data includes several files, packed in a single file. The file is called fps-test-data.tar.gz and found here:

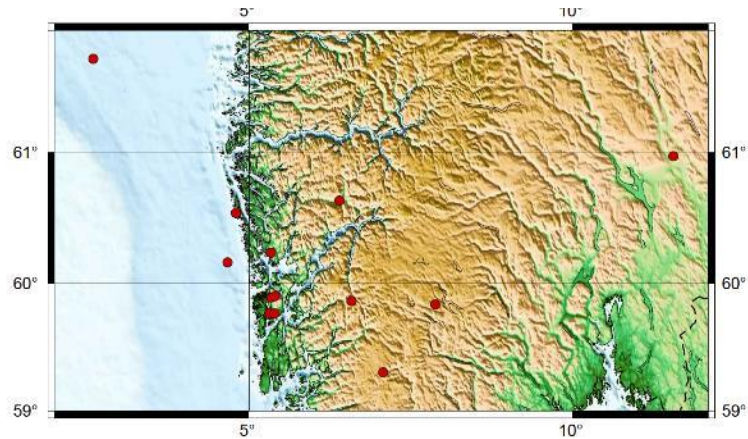
<https://seisan.info/fps/fps-test-data.tar.gz>

List of files included in the data package:

| | |
|-----------------|---|
| fps.inp | 13 events in Nordic2 format. The data contains polarities and amplitudes for stations up to 100 km distance using default parameters. |
| teleseismic.inp | One teleseismic event with polarities. |
| STATION0.HYP | Standard station and model file for Norway. |
| STATION1.HYP | Alternative station and model file for Western Norway. |
| STATION2.HYP | Test model. |
| STATION3.HYP | Test model. |
| STATION4.HYP | Test model. |
| FOCMEC.DEF | Setup of parameters for FOCMEC and HASH. |
| cal.tar.gz | Response files. |
| S-files | S-files of 13 events in a local database. Same as fps.inp. |

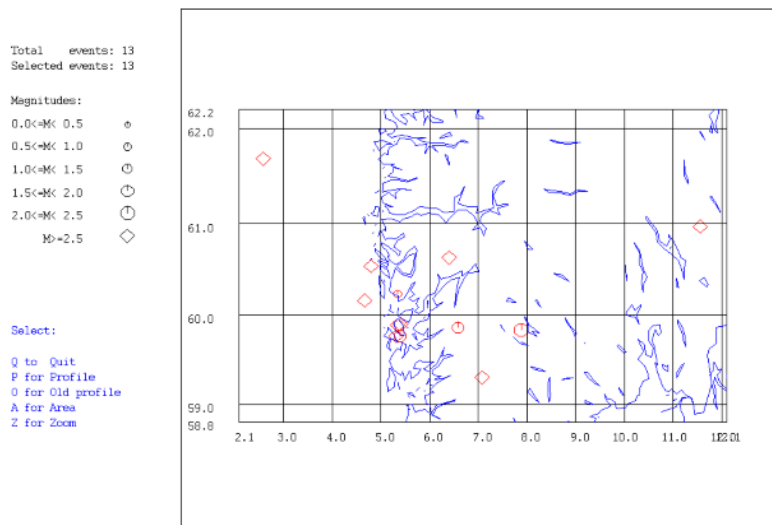
Waveforms and response files, not strictly needed, but nice to have if you want to do other things like checking the polarities or recalculate the amplitudes. Some output files from the testing are also there. All files should be put in the working directory, and you should work there.

The epicenters of the 13 local events are seen here:



They are plotted with equal size of 0.25 cm. The command to make the map is 'mapg fps.inp -m 0.25' followed by your own command to plot the PostScript file mapg.ps. The program requires a contour file and GMT installed. For setup, see SEISAN manual and SEISAN.DEF

A simpler map can be made with EPIMAP using the map command 'map fps.inp m' or just 'map fps.inp' to get symbols proportion to magnitude.



Working with one event in EEV

The most common way to make fault plane solutions is to use the commands in EEV, which can use all 4 programs: FOCMEC, FPFIT, PINV or HASH. Once the selected program is finished, the results will be stored in the S-file. If done twice with the same program, the previous solution is overwritten if the last 8 characters on the line are the same.

In EEV there are many commands to work with fault plane solutions as given by the EEV help command '?' followed by '12':

```
F:      Make a fault plane solution with FOCMEC
FA:      Semiautomatic -----
FAA:     Fully automatic -----
FAAA:    Multimodel  FOCMEC
FH:      Make a fault plane solution with HASH
FHA:     Make a fault plane solution with HASa, no questions
FI:      Make a fault plane solution with PINV
FP:      Make a fault plane solution with PPFIT
PPFIT:   -----
AMPRATIO: Automatic amplitudes for ratio used with fps
AR:      Same as above
FO:      Plot all fault plane solutions, no questions, with polarities
FOO:     Plot all fault plane solutions, no polarities plotted or needed
MAPF:    Makes a map like the MAP command showing fps if there
MAPGF:   Makes a GMT map like the MAP command showing fps if there
FM:      Plot moment tensor solution with mopad
FQ:      Enter quality and position prime fps at top
FD(IF):  Compare P and T axis from two different fps
INPUTFPS: Input complete fault plane solution line
IFP:     Input fault plane solution strike, dip, rake, Ag., Prog, Q.
MAPF:    Makes a map like the MAP command showing fps if there
MAPGF:   Makes a GMT map like the MAP command showing fps if there
POL:     Plot vertical channels P onset with polarities
```

Using only polarities

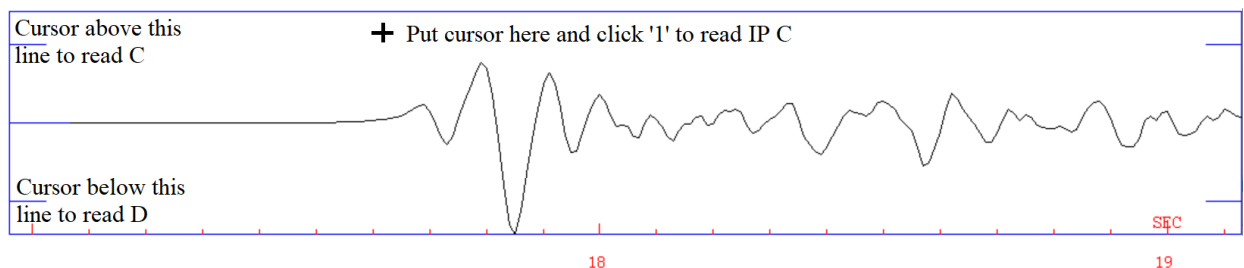
The most common way of making FPS is to use polarities. There is not any really good way of obtaining polarities automatically since the first onset can be quite unclear. So, they must be made manually with MULPLOT (command 'p' or 'pol' in EEV):

*****POLARITIES MUST ALWAYS BE READ WITHOUT FILTER *****

A filter can change the polarity or make it unclear.

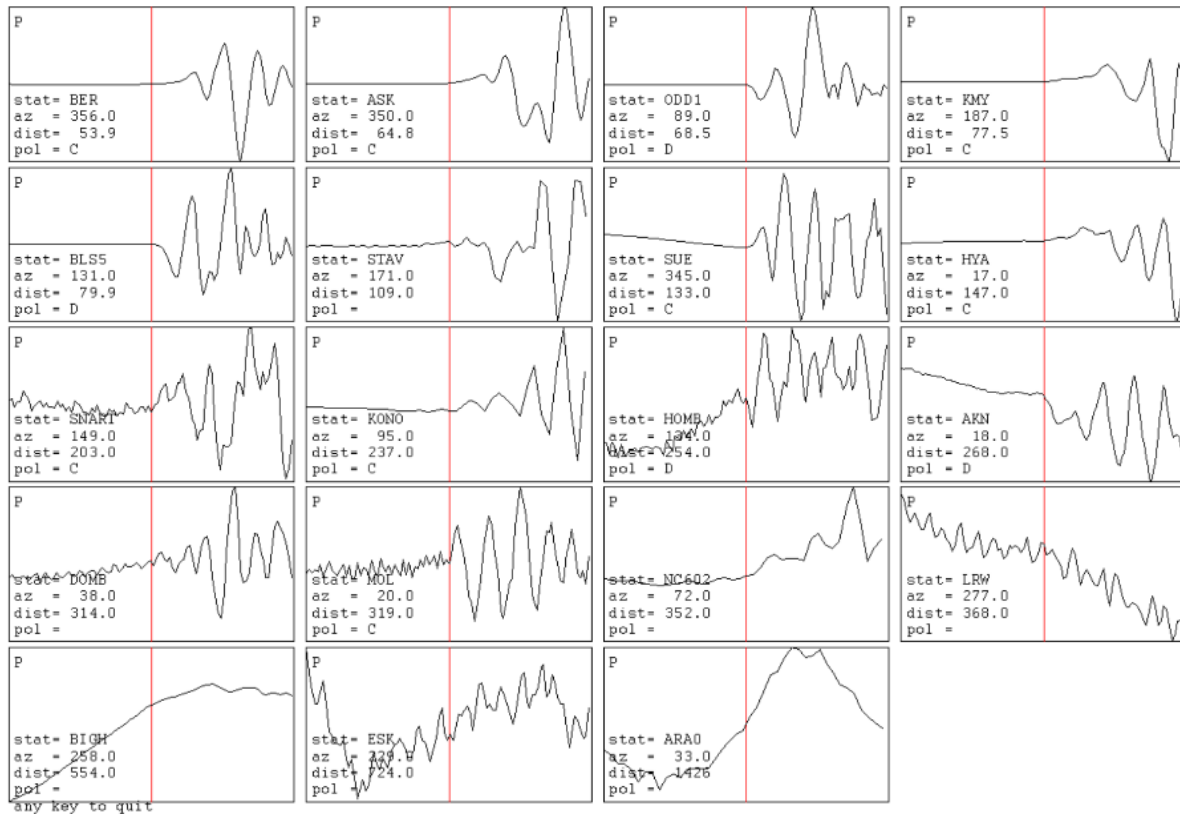
Picking polarities

Polarities are mostly picked with MULPLT during routine processing since they can be picked with the same keypress as used for picking the P-arrival:

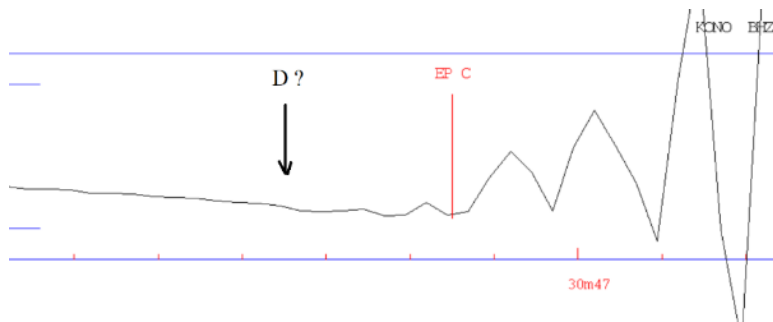


Command 'pol' plots the signal around the P-phase on the Z-component and shows which polarities are made and has a function to change, add or delete polarities (event #6):

2010 1220 1230 12.7 LQ 59.902 5.403 17.2 BER 41 .10 3.3LBER 2.6CBER 3.4LNAO
Win s = 1.0 change: c=compression, d=dilatation, r=remove



It is seen that some polarities are very clear like for station BLS5 while for station KONO, it is rather doubtful. In difficult cases MULPLT can better zoom and amplify the signal like for this example for station KONO made with MULPLT single trace mode:



It is seen that one could maybe have read the first motion as D, however in any case, the polarity is not very clear. The “EP C” marks a reading of a emergent (E) compressional (C) P-phase.

FOCMEC

FOCMEC makes a grid search for all FPS in predefined grid intervals and finds the solutions that fit the given criteria like; no more than 2 polarity errors, one amplitude ratio error with less than a given error. The user will then have to select what is considered the best solution. There are thus several parameters to test for. This can be time consuming but can be a good way of getting an idea of the solutions space with the given data. In FOCMEC this can be done automatically.

We will now use one event with relatively few observations (12). This is event number 6 in the local data base so write:

```
eev
  Local directory
  Give operator code, max 3 characters
jh
  Reading events from base ,,      13
#   1 12 Aug 2000 14:27 26 L 59.769  5.316  9.1  N .30  3.9CBER  53  ? 6
#   6 20 Dec 2010 12:30 12 LQ 59.902  5.403 17.2  N .10  3.3LBER  41  ?
```

Manual selection of parameters, use command 'f':

```
#   6 20 Dec 2010 12:30 12 LQ 59.902  5.403 17.2  .10  3.3LBER  41  ? f

**** now locating with hyp as a preparation ***

20-1230-12L.S201012
Number of spectra available and number used in average   16   16
#   0 2010 1220 1230 11.3 LQ 59.908  5.362  3.3  BER 41 0.9 3.5LBER 2.6CBER
  If location not ok, result might be unpredictable
  Return to continue (y=return/N)

Number of polarities:      12
Amplitude types:   Manual:    0   Automatic:   10   Spectral:    10
Amplitudes use deselected in FOCMEC.DEF

Total number of polarities and amplitude ratios = 12  gap in az = 91.0  gap in ain = 46.0

Stop              (Q)
Plot saved solution(s)  (1)
Plot new solutions      (2)
Plot selected solution  (3)
Find new solutions      (4)
-1, -2, -3 also plot station

4
There are 12 polarity readings
Use relative weight, y/n=default

Maximum number of allowed polarity errors, enter for 0
1
Degree increment in search, enter for default 2

Fri Jun 14 08:08:21 2024 for program Focmec
-----
Input from a file focmec.dat
  2010 1220 1230 11.3 LQ 59.908  5.362  3.3  BER 41 .90 3.5LBER 2.6CBER 3.4LNAO
Polarities/Errors: P 012/01 SV 000/00 SH 000/00
There are no amplitude ratio data
The minimum, increment and maximum B axis trend:    0.00    2.00  358.00
The limits for the B axis plunge:    0.00    2.00  90.00
The limits for Angle:    0.00    2.00  178.00
```



```

Strike   Dip    Rake    Pol: P    SV    SH
307.26   54.16  -67.59    1.00   0.00  0.00
308.22   52.31  -67.02    1.00   0.00  0.00
309.36   54.16  -67.59    1.00   0.00  0.00
310.33   52.31  -67.02    1.00   0.00  0.00
311.47   54.16  -67.59    1.00   0.00  0.00
.....
330.92   72.41  -45.42    1.00   0.00  0.00
137.01   90.00   48.00    1.00   0.00  0.00
318.35   88.51  -47.98    1.00   0.00  0.00
319.69   87.03  -47.93    1.00   0.00  0.00
321.04   85.54  -47.84    1.00   0.00  0.00
322.39   84.06  -47.72    1.00   0.00  0.00
The maximum of 500 solutions has been reached and the search is stopped

Stop                (Q)
Plot saved solution(s) (1)
Plot new solutions   (2)
Plot selected solution (3)
Find new solutions   (4)
-1, -2, -3 also plot station

```

Since the search stopped at 500 solutions, there will be more solutions that might be different from the first 500, so the user must start again with new selection parameters, command '4'. In some cases, it can take some time to find the best set of parameters to get a reasonable number of solutions. This can now be done in an automatic way, so we use the command 'fa':

```

Number of polarities:      12
Amplitude types:  Manual:   0   Automatic:  10   Spectral:   10
Automatic amplitude selected
Use amplitudes, (y/n=enter)

Total number of polarities and amplitude ratios = 12 gap in az = 93.0 gap in ain = 44.0
0.0 out of 12 pol, 999 out of 0 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
1.0 out of 12 pol, 999 out of 0 amp, err=0.2, # sol= 500, rms dev 18 12, str dip rak 323 82 -52, deg 2
1.0 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 500, rms dev 18 12, str dip rak 323 82 -52, deg 2
Use relative polarity error (y/n=enter)

1.0 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 245, rms dev 15 12, str dip rak 325 81 -48, deg 3
Use relative polarity error (y/n=enter)

Stop                (Q)
Plot saved solution(s) (1)
Plot new solutions   (2)
Plot selected solution (3)
Find new solutions   (4)
-1, -2, -3 also plot station

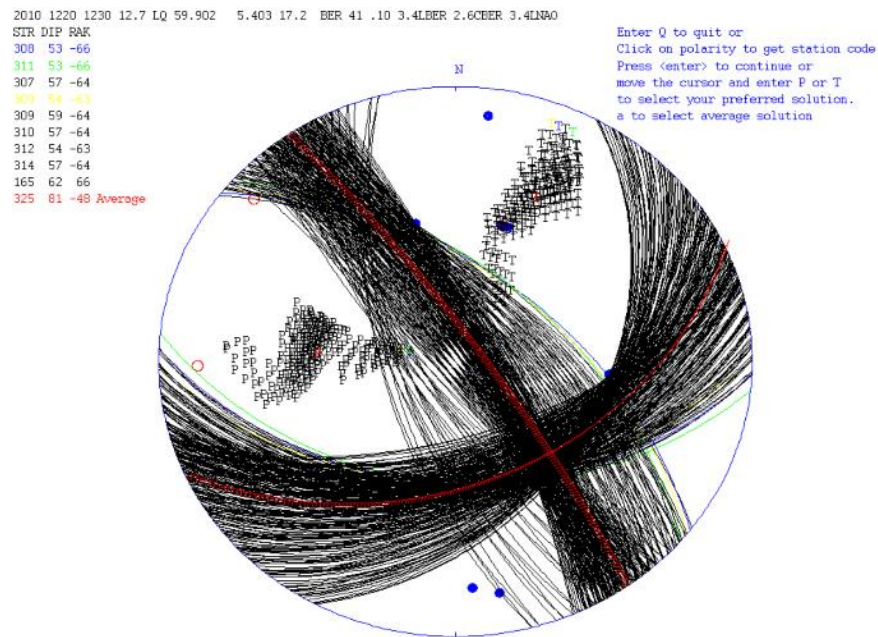
```

The program has now tried different combinations of parameters. For each test there is one output line summarizing the results. The output parameters are:

- pol: number of polarities available,
- amp: number of amplitude ratios available,
- err: error accepted in amplitude ratio,
- rms dev: the rms deviation (degrees) of the two normal vectors from the average normal vector of all solutions,

- strk dip rake: strike, dip and rake of average solution,
- deg: size of the search grid in degrees.

The parameters for each trial are listed as well as the number of solutions (sol). In this case it is simple since there is one polarity error, no amplitudes are used although present (use of amplitudes has not been activated in FOCMEC.DEF), but it gives more than 500 solutions, so the next step is to increase the grid search from 2 to 3 degrees, so the number of solutions is now under the limit of 250 to get an acceptable automatic solution. No amplitudes or relative polarity errors are used in this first search. The solutions can now be seen with option 2:

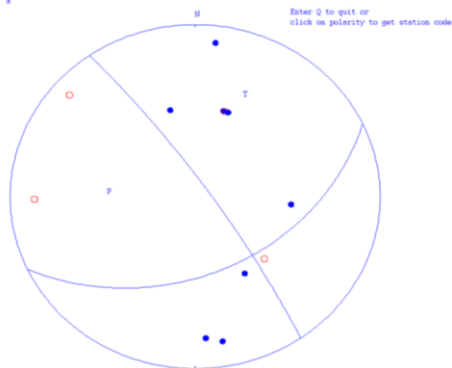


The 245 solutions are shown, and the red solution is the average solution. At the top left is shown the 9 first solutions and the average solution. The average is obtained by averaging the fault plane normal vectors. The user can now select the average solution by pressing 'a' or any other solution by pressing 't' or 'p' near the T or P of the solution desired. In this case the average solution is saved with command 'a'. The solution(s) in the S-file can now be plotted with command 'fo', which shows the polarities or 'foo' which only show the FPS solution:

```

2010 1220 1230 12.7 LQ 59.902 5.403 17.2 BER 41 .10 3.4LBER 2.6CBER 3.4LBAO
OTR DIP NAE Source
325 01 -49 FOCMEC

```

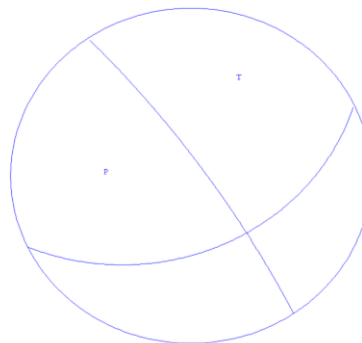


Command fo

```

2010 1220 1230 12.7 LQ 59.902 5.403 17.2 BER 41 .10 3.3LBER 2.6CBER 3.4LBAO apol= 12 gap= 93
325 01 -49 BER FOCMEC

```



Command foo

The advantage of the foo command is that it can plot FPS without location and polarity data. Sometimes it can be useful to also plot the stations to see where the stations used are located on the focal sphere and in particular to see which stations have wrong polarities. This is done with command 'f' and selection -1:

```

# 6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 .10 3.3LBER 41 ? f

```

```

**** now locating with hyp as a preparation ***

```

```

20-1230-12L.S201012

```

```

Number of spectra available and number used in average 16 16

```

```

# 0 2010 1220 1230 11.3 LQ 59.908 5.362 3.3 BER 41 0.9 3.5LBER 2.6CBER

```

```

If location not ok, result might be unpredictable

```

```

Return to continue (y=return/N)

```

```

Number of polarities: 12

```

```

Amplitude types: Manual: 0 Automatic: 10 Spectral: 10

```

```

Amplitudes use deselected in FOCMEC.DEF

```

```

Total number of polarities and amplitude ratios = 12 gap in az = 91.0 gap in ain = 46.0

```

```

Stop (Q)

```

```

Plot saved solution(s) (1)

```

```

Plot new solutions (2)

```

```

Plot selected solution (3)

```

```

Find new solutions (4)

```

```

-1, -2, -3 also plot station

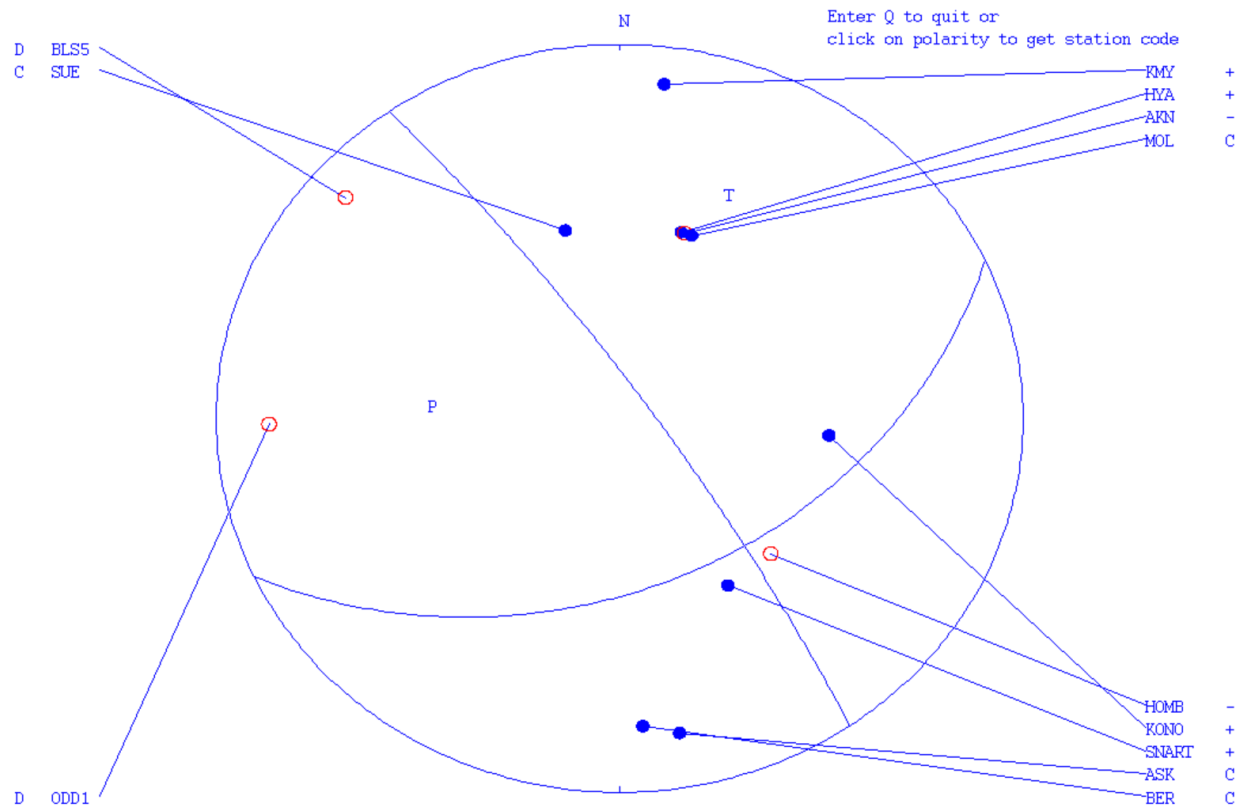
```

```

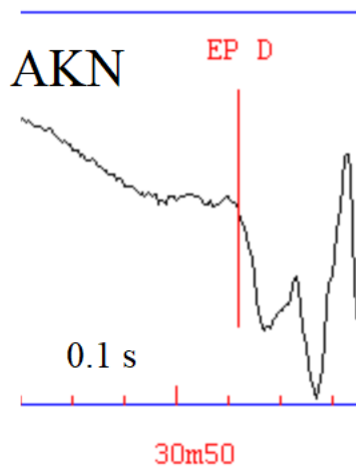
-1

```

2010 1220 1230 12.7 LQ 59.902 5.403 17.2 BER 41 .10 3.4LBER 2.6CBER 3.4LNAO
 STR DIP RAK Source
 325 81 -48 FOCMEC a



It is now possible to see the polarities of the different stations. The '+' (compression) and '-' (dilatation) indicate that the P was read with emergent onset 'E'. The AKN polarity does not fit so it can be inspected with MULPLT which has options for amplifying the signal. Using MULPLT, single trace mode:



The figure above shows that the P-phase first motion was read as “D” (dilatation), but it is also seen that in the downward trend of signal, the polarity could have been read as a compression. It is also seen that the KONO polarity is critical since it is close to the nodal plane. Changing the polarity of KONO to D gives (New below):

The solution with using polarity D at KONO gives a more uncertain solution since the spread in the solutions increases from 15 and 12 to 30 and 40 degrees. However, the average solution is not so different:

Both examples show that reading polarity is not always easy. The emergent first arrival seen before the pick could come from a refracted arrival from an intermediate layer not present in the location model and therefore the angle of incidence might not be calculated correctly.

not to use it except in the following example of the event above with the original polarity of station KONO:

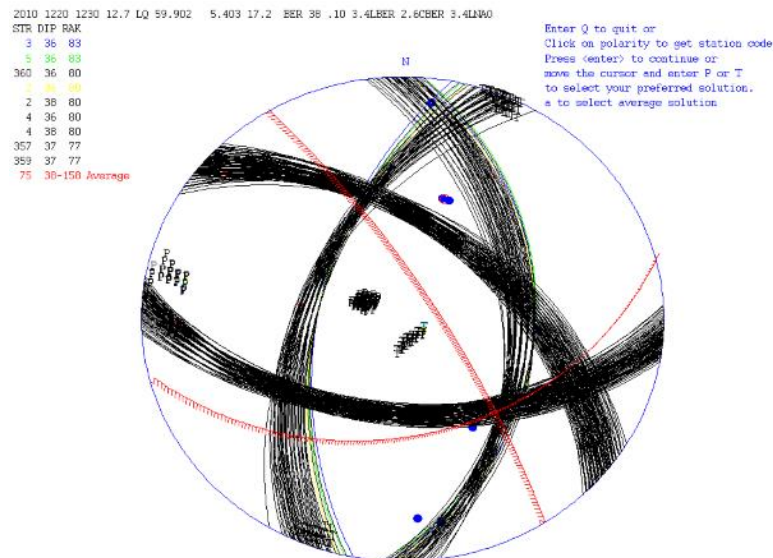
```

Number of polarities:      12
Amplitude types:  Manual:    0   Automatic:  10   Spectral:   10
Automatic amplitude selected
Use amplitudes, (y/n=enter)

Total number of polarities and amplitude ratios = 12 gap in az = 93.0 gap in ain = 44.0
0.0 out of 12 pol, 999 out of 0 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
1.0 out of 12 pol, 999 out of 0 amp, err=0.2, # sol= 500, rms dev 18 12, str dip rak 323 82 -52, deg 2
1.0 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 500, rms dev 18 12, str dip rak 323 82 -52, deg 2
Use relative polarity error (y/n=enter)
Y
0.1 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
0.2 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
0.3 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
0.4 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
0.5 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 122, rms dev 30 50, str dip rak 75 38-158, deg 2

```

In the previous example, where the attempt was to get the number of solutions under 250, the grid size had to be increased from 2 to 3. In this example, a relative weight of 0.5 achieved the same. There are 2 different solutions, however the average solutions are almost the same as before.



Using polarities and amplitudes

Making amplitudes

Amplitudes or more correctly, amplitude ratios between P and S can be useful when few or badly distributed polarities are available. It is assumed that the amplitudes are of Pg and Sg phases. Amplitudes should be used with caution since they are often more unreliable than polarities, particularly for larger distances and the default maximum distance recommended is 100 km. There

are also other parameters used like the filter used. For details, see the SEISAN manual. The amplitudes can be read manually or automatically, or the automatic spectral amplitudes can be used. Since the amplitude ratios are used, there is in general no need for instrument correction assuming all 3 components have the same response. The default is to use automatic amplitudes read on Z and T components, so the data is rotated before reading the amplitudes. The amplitudes are stored in the S-file with specific phase names:

```

ODD1 EHZ      ATPG      1230 24.420 1452.5 0.34
ODD1 E Z      ASPG      1230 23.390 395.0 0.33
ODD1 EHT      ATSG      1230 33.000 2069.9 0.36
ODD1 E T      ASSG      1230 31.660 551.1 0.33

```

where ATPG means amplitude in time domain and ASPG is amplitude in frequency domain. The numbers 1452.5 and 0.34 are amplitude in counts and period in seconds, respectively. The period is used to correct for Q (relation given in FOCMEC.DEF). The amplitudes can be calculated with 'ar' command in EEV, however in the test data set, they are all calculated using default parameters. Using 'ar' gives:

```

#      6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 .10 3.3LBER 41 ? ar
Input S-file 20-1230-12L.S201012
filter frequencies (f1,f2), def=(2,4)

time window for analysis, enter for default 2 s

max distance in km (def=99)

ground motion (0=none (enter), 1=displacement, 2=velocity)

Max deviation in time and spec amp ratios, def 50%

read S amplitudes on Z component (y/n, def=n)?

.....

Station too far, skipSTAV 109.000000
Station too far, skipSUE 133.000000

.....

Components auto selected to use
BER HH Z ASK EH Z ODD1 EH Z KMY EH Z BLS5 HH Z

*****
**** process BER HH Z *****
P time on component HZ
S time on component HE
Channel found: 9 BER HH Z
Time of amplitude 2010 1220 1230 18.2
Amplitude(nm or count) and period(sec) 34214.84 0.30

*** computing spectrum for P***
spectral fit 7832.98389 3.00000000 1.00000000
rotating, baz= 175.425354
Time of amplitude 2010 1220 1230 24.6
Amplitude(nm or count) and period(sec) 132765.59 0.30

*** computing spectrum for S***
spectral fit 35237.5000 3.00000000 1.00000000

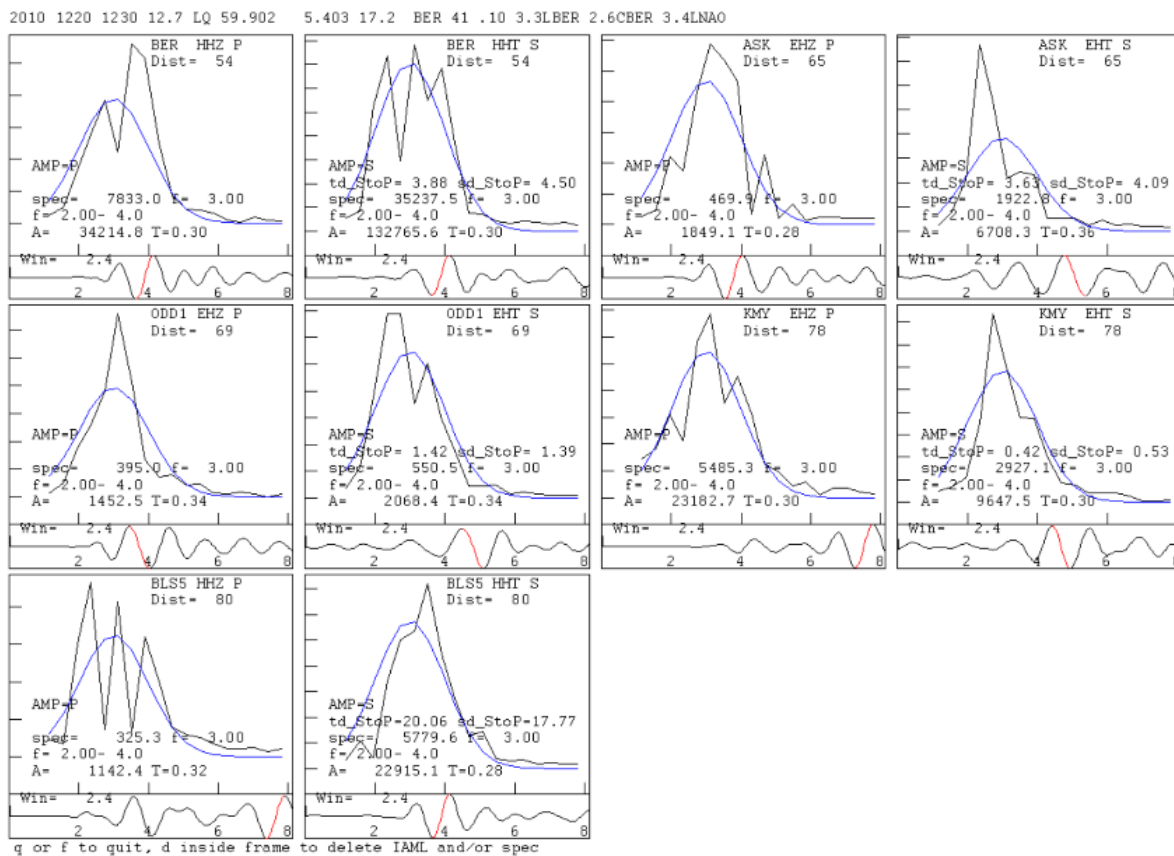
```

| STAT | ATPG | ATSG | ASPG | ASSG | StoPt | StoPs |
|--------|---------|----------|--------|---------|-------|-------|
| BER T | 34214.8 | 132765.6 | 7833.0 | 35237.5 | 3.9 | 4.5 |
| ASK T | 1849.1 | 6708.3 | 469.9 | 1922.8 | 3.6 | 4.1 |
| ODD1 T | 1452.5 | 2068.4 | 395.0 | 550.5 | 1.4 | 1.4 |
| KMY T | 23182.7 | 9647.5 | 5485.3 | 2927.1 | 0.4 | 0.5 |
| BLS5 T | 1142.4 | 22915.1 | 325.3 | 5779.6 | 20.1 | 17.8 |

Save results to sfile (y/n=enter)?
y

Number of events processed 1
Output nordic file is autoratio.nor
Output file with ratios is autoratio.out
Input for plotratio is plotratio.inp.
Parameters used in autoratio.par
Note: The following floating-point exceptions are signalling: IEEE_INVALID_FLAG IEEE_UNDERFLOW_FLAG IEEE_DENORMAL
Plot autoratio results (y/n=enter)?
y

Output plot file is plotspec.eps



The plots show the spectral and amplitude fit so it is possible to control the quality. Bad fits can be deleted interactively. The amplitude values are also checked for deviation between the spectral and time domain amplitudes and the default is that there should be less than 50 % difference in the ratios. In the table above the difference is much smaller (StoPt and SToPs: time domain and spectral domain ratios, respectively). Since in general, the time domain and spectral domain ratios are very close, time domain ratios are generally used.

Using amplitudes

Using amplitudes with command 'fa' for event # 6 gives:

```
Number of polarities:      12
Amplitude types:  Manual:      0  Automatic:  10  Spectral:  10
Automatic amplitude selected
Use amplitudes, (y/n=enter)
y

Q: Local: Qp= 470.0**0.70  Qs= 470.0** 0.7   Global: t*(P)=1.10  t*(S)=4.20

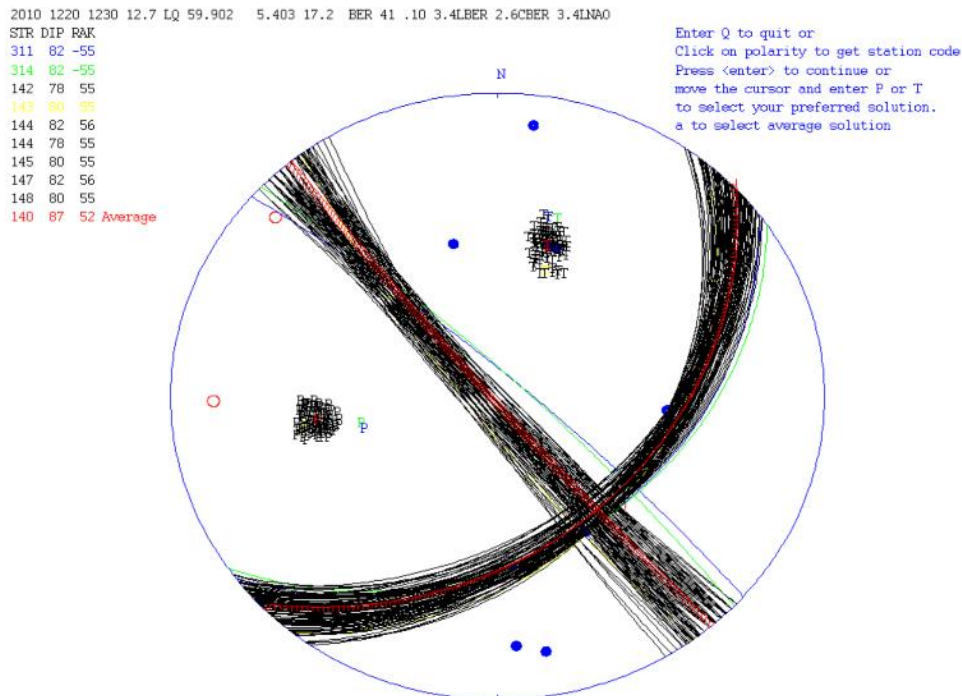
STAT  C PH      AMP      PER TRTIME  QCOR ANGINC ANGEMG Fcor  AZ  DIST
BER   Z PG      34214    0.30   8.9    1.1  101    67  0.8  356   53
BER   T SG     132000    0.30   6.6    1.1  101    67  2.0  356   53
ASK   Z PG      1849    0.28  10.6    1.1   98    68  0.8  350   64
ASK   T SG      6703    0.36   7.8    1.1   98    68  2.0  350   64
ODD1  Z PG      1452    0.34  11.1    1.1   97    68  0.8   89   68
ODD1  T SG      2069    0.36  19.4    1.2   97    68  2.0   89   68
KMY   Z PG     23182    0.30  12.5    1.1   96    68  0.8  187   77
KMY   T SG      9640    0.30  21.7    1.2   96    68  2.0  187   77
BLS5  Z PG      1142    0.32  12.8    1.1   96    69  0.8  131   79
BLS5  T SG     22904    0.28  22.4    1.2   96    69  2.0  131   79

STAT  Ratio type  T      Amp 1      Amp 2  Fcor LogRat
BER   SH(T)/P(Z)  H      132000    34214    0.4   0.20
ASK   SH(T)/P(Z)  H        6703    1849    0.4   0.16
ODD1  SH(T)/P(Z)  H        2069    1452    0.4  -0.21
KMY   SH(T)/P(Z)  H        9640    23182    0.4  -0.74
BLS5  SH(T)/P(Z)  H     22904    1142    0.4   0.95

Total number of polarities and amplitude ratios = 17  gap in az = 93.0  gap in ain = 43.5
0.0 out of 12 pol, 999 out of 5 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
1.0 out of 12 pol, 999 out of 5 amp, err=0.2, # sol= 500, rms dev 16 11, str dip rak 322 83 -51, deg 2
1.0 out of 12 pol, 0 out of 5 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
1.0 out of 12 pol, 1 out of 5 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
1.0 out of 12 pol, 2 out of 5 amp, err=0.2, # sol= 86, rms dev 6 4, str dip rak 140 87 52, deg 2
Use relative polarity error (y/n=enter)

Stop (Q)
Plot saved solution(s) (1)
Plot new solutions (2)
Plot selected solution (3)
Find new solutions (4)
-1, -2, -3 also plot station
```

The solutions are now:



It is seen that the solutions are better defined now with fewer solutions but essentially the same mechanism as for the first test with only polarities. The amplitudes fit relatively well with 2 out of 5 ratios being in error. The solution can now be saved with command 'a'.

Using 'fa' the user is still asked if amplitudes and relative polarity should be used. This can be avoided by using command 'faa' and the decision whether to use amplitudes and relative polarity is given in the definition file FOCMEC.DEF (in working directory or DAT) with the 2 lines:

```
AMPLITUDES 1: manual, 2: amp, 3: spec 2.0
RELATIVE WEIGHT 0:no, 1: yes 0.0
```

In this case we have chosen to use amplitudes and not use relative weight. Using 'faa' gives:

```
# 6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 N .10 3.3LBER 41 ? faa
**** now locating with hyp as a preparation ****

20-1230-12L.S201012
Number of spectra available and number used in average 16 16
# 0 2010 1220 1230 12.7 LQ 59.902 5.403 17.2 BER 38 0.1 3.4LBER 2.6CBER

Number of polarities: 12
Amplitude types: Manual: 0 Automatic: 10 Spectral: 10
Use automatic amplitude

Q: Local: Qp= 470.0**0.70 Qs= 470.0** 0.7 Global: t*(P)=1.10 t*(S)=4.20

STAT C PH AMP PER TRTIME QCOR ANGINC ANGEMG Fcor AZ DIST
BER Z PG 34214 0.30 8.9 1.1 101 67 0.8 356 53
BER T SG 132000 0.30 6.6 1.1 101 67 2.0 356 53
```

| | | | | | | | | | | |
|------|------|-------|------|------|-----|----|----|-----|-----|----|
| ASK | Z PG | 1849 | 0.28 | 10.6 | 1.1 | 98 | 68 | 0.8 | 350 | 64 |
| ASK | T SG | 6703 | 0.36 | 7.8 | 1.1 | 98 | 68 | 2.0 | 350 | 64 |
| ODD1 | Z PG | 1452 | 0.34 | 11.1 | 1.1 | 97 | 68 | 0.8 | 89 | 68 |
| ODD1 | T SG | 2069 | 0.36 | 19.4 | 1.2 | 97 | 68 | 2.0 | 89 | 68 |
| KMY | Z PG | 23182 | 0.30 | 12.5 | 1.1 | 96 | 68 | 0.8 | 187 | 77 |
| KMY | T SG | 9640 | 0.30 | 21.7 | 1.2 | 96 | 68 | 2.0 | 187 | 77 |
| BLS5 | Z PG | 1142 | 0.32 | 12.8 | 1.1 | 96 | 69 | 0.8 | 131 | 79 |
| BLS5 | T SG | 22904 | 0.28 | 22.4 | 1.2 | 96 | 69 | 2.0 | 131 | 79 |

| STAT | Ratio type | T | Amp 1 | Amp 2 | Fcor | LogRat |
|------|------------|---|--------|-------|------|--------|
| BER | SH(T)/P(Z) | H | 132000 | 34214 | 0.4 | 0.20 |
| ASK | SH(T)/P(Z) | H | 6703 | 1849 | 0.4 | 0.16 |
| ODD1 | SH(T)/P(Z) | H | 2069 | 1452 | 0.4 | -0.21 |
| KMY | SH(T)/P(Z) | H | 9640 | 23182 | 0.4 | -0.74 |
| BLS5 | SH(T)/P(Z) | H | 22904 | 1142 | 0.4 | 0.95 |

```
Total number of polarities and amplitude ratios = 17 gap in az = 93.0 gap in ain = 43.5
0.0 out of 12 pol, 999 out of 5 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
1.0 out of 12 pol, 999 out of 5 amp, err=0.2, # sol= 500, rms dev 16 11, str dip rak 322 83 -51, deg 2
1.0 out of 12 pol, 0 out of 5 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
1.0 out of 12 pol, 1 out of 5 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
1.0 out of 12 pol, 2 out of 5 amp, err=0.2, # sol= 86, rms dev 6 4, str dip rak 140 87 52, deg 2
.... updating event with average fault plane solution
```

which is the same solution as above. But now the average solution is written to the S-file and the user cannot choose an alternative solution from the plot.

Other programs for fault plane solutions

We can now test what the solutions from the other program will give. All 3 remaining programs always write the solution the S-file and the user can only see the results afterwards. In order to compare the solutions, only polarities will be used.

FPFIT:

```
# 6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 N .10 3.3LBER 41 ? fp

**** now locating with hyp as a preparation ***

20-1230-12L.S201012
Number of spectra available and number used in average 16 16
# 0 2010 1220 1230 12.7 LQ 59.902 5.403 17.2 BER 41 0.1 3.4LBER 2.6CBER
If location not ok, result might be unpredictable
Return to continue (y=return/N)
y
Number of phases 45
Number of events used 1
Fpfit uses 3-letter LOWER-CASE commands, which can be followed by
parameters in free-format, or which display current values & generate prompts.
Type "hel" for information on available commands.
yes? # ORIGIN TIME LOCATION DEPTH MAG DDR DIP RAKE CNVRG
-----
1 20101220 1230 12.68 59n54.14 5e 24.2 17.6 1.0 150 48 -172
yes?
Fit 0.080
Errors in strike, dip and rake 5.0 7.0 9.0

60.0 48.0 -172.0 5.0 7.0 9.0 0.1 0.1 FPFIT F
=====

Fit 0.080
Errors in strike, dip and rake 5.0 7.0 9.0

.... updating database with FPFIT fault plane solution
```

```
# 6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 N .10 3.3LBER 41 ?
```

PINV:

```
# 6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 N .10 3.3LBER 41 ? fi

**** now locating with hyp as a preparation ***

20-1230-12L.S201012
Number of spectra available and number used in average 16 16
# 0 2010 1220 1230 12.7 LQ 59.902 5.403 17.2 BER 41 0.1 3.4LBER 2.6CBER
If location not ok, result might be unpredictable
Return to continue (y=return/N)

Number of data used for inversion= 12
Absolute pseudorank tolerance 0.001855 Pseudorank 5
Strike, dip, rake 60.2 71.5 -159.5
Consistent data: 9
Inconsistent data: 3
Number of events 1
=====
.... updating database with PINV fault plane solution
```

HASH:

For HASH there are two options to start the program, 'fh' (questions asked) and 'fha' (all defaults). The all defaults is used here. To deselect using amplitudes automatically, a parameter must be set in FOCMEC.DEF.

```
# 6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 N .10 3.3LBER 41 ? fha

**** now locating with hyp as a preparation ***

20-1230-12L.S201012
Number of spectra available and number used in average 16 16
# 0 2010 1220 1230 12.7 LQ 59.902 5.403 17.2 BER 41 0.1 3.4LBER 2.6CBER

Number of polarities: 12
Amplitude types: Manual: 0 Automatic: 10 Spectral: 10
Amplitudes use deselected in FOCMEC.DEF

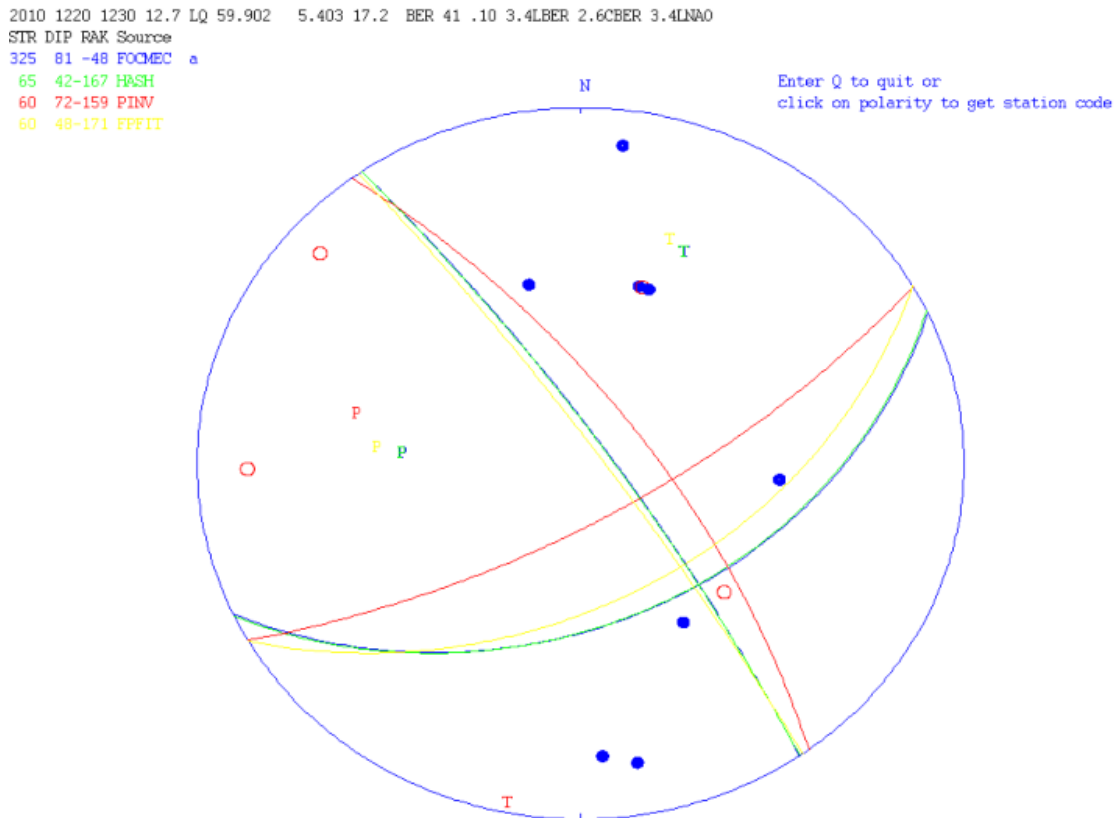
Total number of polarities and amplitude ratios = 12 gap in az = 93.0 gap in ain = 44.0
Number of events 1
vpvs ratio is 0.00
vpvse set to 1.74
Number of polarities is : 12
*** warning - no s/p amplitude ratios for event
Minimum number of polarity misfits overall : 1
New number of pol. misfits inc. extra is : 1
Number of solutions found 832
1 mech = 64.4876785 41.9509239 -167.502640

Strike,dip,rake 64.5 42.0 -167.5
=====

.... updating database with first HASH fault plane solution
# 6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 N .10 3.3LBER 41 ?
```

There were 832 possible solutions, but they were all in one group, so an average was made of all solutions and one final FPS is suggested.

We can now compare the solutions of the 4 programs with command ‘fo’ (showing polarities):



It is seen that the 4 solutions are very similar so that is a good indication that the solution is reliable. The 4 lines with solutions are listed in S-file in the order they are made with the last solution at the top:

| | | | | | | | | | |
|-------|------|--------|------|------|------|------|------|----------------|-------|
| 64.5 | 42.0 | -167.5 | 14.9 | 11.6 | 0.12 | 0.64 | 0.00 | BER HASH | F |
| 325.2 | 81.4 | -48.9 | 15. | 12. | | | | 1 0 BER FOCMEC | f a F |
| 60.2 | 71.5 | -159.5 | | | | | | 3 BER PINV | F |
| 60.0 | 48.0 | -172.0 | 5.0 | 7.0 | 9.0 | 0.1 | 0.1 | BER FPFIT | F |

In addition to the strike, dip and rake (3 first numbers), there are other information and quality measures, see the SEISAN manual. Notice the “aF” at the end of the second line, which indicates it is an automatic FOCMEC solution.

One of the solutions must be chosen as the prime solution for further work when using other programs. The prime solution is the one coming first in the S-file. It is possible to edit the file to move the prime solution to the top, but it is easier and more reliable to use command ‘fq’:

```
# 6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 N .10 3.3LBER 41 ? fq
Fault plane solutions for this event
 64.5 42.0 -167.5 14.9 11.6 0.12 0.64 0.00 BER HASH F
325.2 81.4 -48.9 15. 12. 1 0 BER FOCMEC aF
 60.2 71.5 -159.5 3 BER PINV F
 60.0 48.0 -172.0 5.0 7.0 9.0 0.1 0.1 BER FPFIT F
Give fps number to be prime solution, enter for no change
Give fps number to be prime solution, enter for no change
2
Give quality of prime solution, any one char, e.g. A, B..
B
```

In addition, the ‘fq’ command makes it possible to add the quality. Using A, B .. is a common way of labeling fault plane solution quality, see e.g. the World Stress Map project <https://www.world-stress-map.org/> and [https://datapub.gfz-potsdam.de/download/10.5880.WSM.2016.002/World Stress Map 2016.pdf](https://datapub.gfz-potsdam.de/download/10.5880.WSM.2016.002/World_Stress_Map_2016.pdf). Other programs like FOC and SELECT will now be able to use only given quality solutions. The new first line is now:

```
325.2 81.4 -48.9 15. 12. 1 0 BER FOCMEC BaF
```

When a new solution is made with the same program it overwrites the old solutions if the last 8 characters on the line is the same so if a quality has been added, and a new solution made, the one with the quality is not overwritten:

```
139.8 86.6 51.5 6. 4. 1 2 BER FOCMEC aF
325.2 81.4 -48.9 15. 12. 1 0 BER FOCMEC BaF
 60.2 71.5 -159.5 3 BER PINV F
 60.8 38.0 -171.0 15.2 12.5 0.12 0.64 0.00 BER HASH F
 60.0 48.0 -172.0 5.0 7.0 9.0 0.1 0.1 BER FPFIT F
```

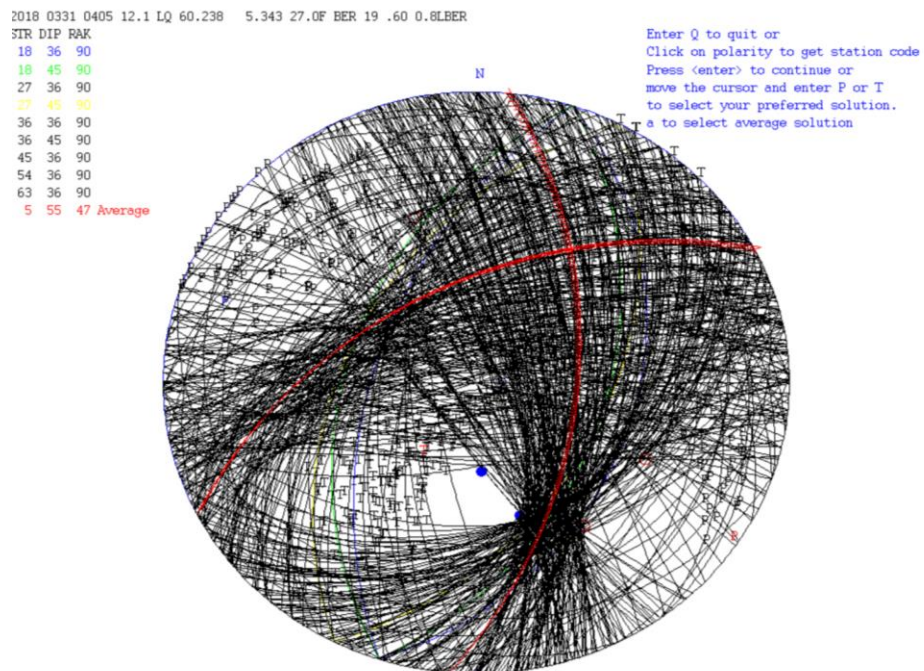
Here is an example of 2 FOCMEC solutions. They have very different slip (-158.9 and -48.9) so from the numbers they look different. This can be evaluated by comparing the P and T vectors with command ‘fd’:

```
# 6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 N .10 3.3LBER 41 ? fd
1 75.1 37.6 -158.9 30. 50. 0 0 BER FOCMEC a
2 325.2 81.4 -48.9 15. 12. 1 0 BER FOCMEC Ba
3 64.5 42.0 -167.5 14.9 11.6 0.12 0.64 0.00 BER HASH
4 60.2 71.5 -159.5 3 BER PINV
5 60.0 48.0 -172.0 5.0 7.0 9.0 0.1 0.1 BER FPFIT
Give two fps numbers to compare P and T
1 2
Difference in P and T, respectively 6.7 6.4
```

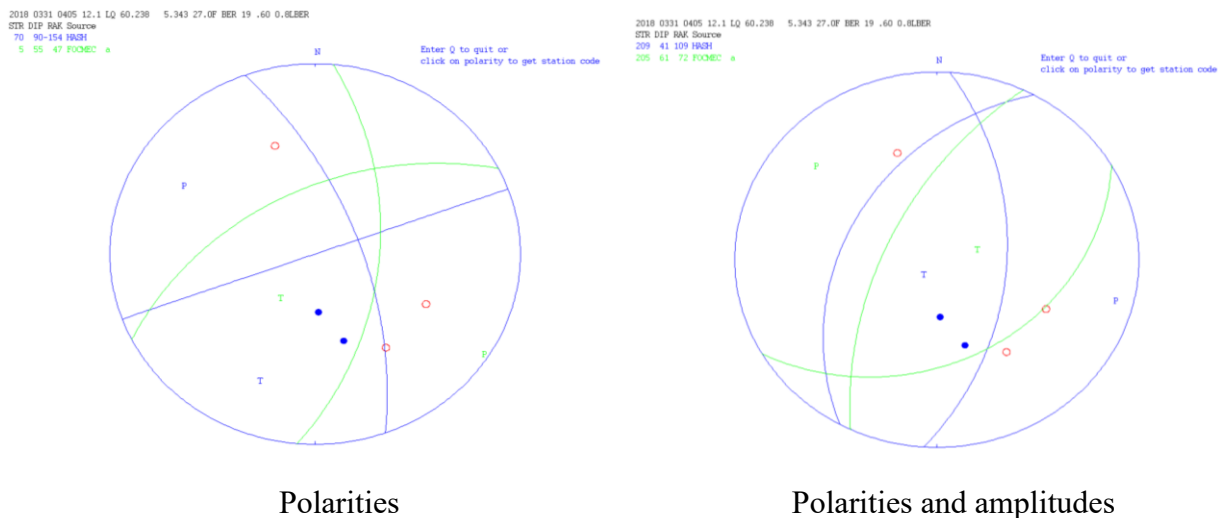
so they are quite similar. This can also be seen by plotting the solutions, but it can be useful to be able to quantify difference in FPS solutions.

FPS of a small event

Event # 10 is a M1 0.8 event with few observations (5 polarities and 4 amplitude ratios). The solution with only polarities is:



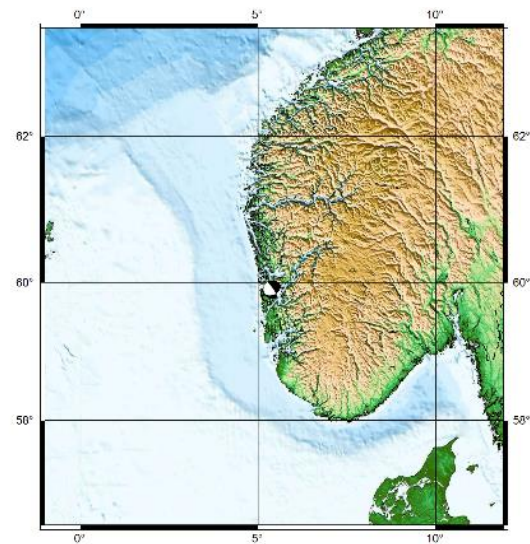
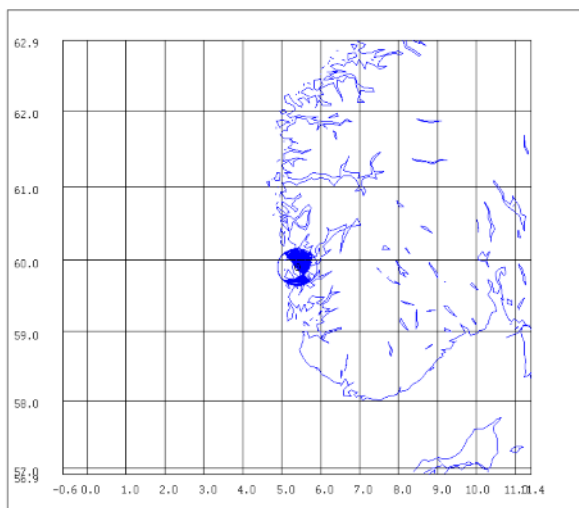
The average solution with only polarities and polarities and amplitude ratios (FOCMEC and HASH) are seen below. The left figure shows all the solutions with polarities, the right figure the solution with polarities and amplitude ratios (blue is Hash and green is FOCMEC):



In this case 3 out of 4 amplitude ratios were ok. It is surprising how consistent the average solutions are, even with only polarities. However, the polarities are well distributed. In this case, amplitudes are important to give confidence in the solution.

Plotting a fault plane solution on a map from EEV

The prime solution (the first one in the S-file) can be plotted on a map with these commands from EEV: The simplest is command ‘mapf’ (using EPIMAP) and the nicest is ‘mapgf’ (using GMT):



The default limits of the map and other parameters are set in SEISAN.DEF.

Making testing easier

When making fault plane solutions it is often desirable to make many different solutions, testing different models etc. So, this requires extensive editing of the S-file and particularly deleting of previous data. This can be done most easily with the ‘dels’ command in EEV:

```
# 6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 .10 3.3LBER 41 ? dels
Give line to delete or keep, terminate with enter
1: Lines with P-phase Not delete
2: Lines with S-phase Not delete
3: Lines with SPEC-phase Not delete
4: Lines with IAML-phase Not delete
5: Lines with IASP-AMP phase Not delete
6: Lines with AM, AT and AS phase Not delete
7: Lines with END phase Not delete
8: Lines with BAZ phase Not delete
9: Lines with any phase Not delete
10: Lines with fp solutions Not delete
11: Phases with given stations Not delete
6
```



```

Give line to delete or keep, terminate with enter
1: Lines with P-phase           Not delete
2: Lines with S-phase           Not delete
3: Lines with SPEC-phase        Not delete
4: Lines with IAML-phase        Not delete
5: Lines with IASP-AMP phase    Not delete
6: Lines with AM, AT and AS phase Delete
7: Lines with END phase        Not delete
8: Lines with BAZ phase         Not delete
9: Lines with any phase         Not delete
10: Lines with fp solutions     Not delete
11: Phases with given stations  Not delete
10
Give line to delete or keep, terminate with enter
1: Lines with P-phase           Not delete
2: Lines with S-phase           Not delete
3: Lines with SPEC-phase        Not delete
4: Lines with IAML-phase        Not delete
5: Lines with IASP-AMP phase    Not delete
6: Lines with AM, AT and AS phase Delete
7: Lines with END phase        Not delete
8: Lines with BAZ phase         Not delete
9: Lines with any phase         Not delete
10: Lines with fp solutions     Delete
11: Phases with given stations  Not delete

2010 1220 1230 12.7 LQ 59.902   5.403 17.2  BER 41 .10 3.3LBER 2.6CBER 3.4LNAO

```

In this case all fault plane solutions and amplitude readings have been deleted. New amplitude readings can then be made, e.g. with a different filter or distance range with the command ‘ar’. If amplitude readings for the same stations and components are made again, the old ones are overwritten.

Processing many events

There are 2 different aspects of processing many events, making fault plane solutions or making analysis and plots.

Making fault plane solutions of many events

All the FPS programs in SEISAN can be used to calculate fault plane solutions for many events. Program FPFIT and PINV require no setup while FOCMEC and HASH require a FOCMEC.DEF file where it is specified if using amplitudes (both programs) or relative weighting (only FOCMEC) and the attenuation model is given to be used with amplitudes, see example below:

```

Def file for focmec and hash, tstar for teleseismic events

*****NEVER USE TABS IN THIS FILE, IT WILL NOT WORK*****

Parameter description           par 1      par 2

QZERO and QALPHA FOR P         124.0      0.91
QZERO and QALPHA FOR S         124.0      0.91
TSTAR for P AND S              1.1        4.2
AMPLITUDES  0:no, 1:man, 2:amp, 3:spec  2.0
RELATIVE WEIGHT  0:no, 1: yes  0.0
MODELS      For multi model, one char each 12

```

Automatic solutions can be made using all 4 programs with the help of the driver program AUTO. AUTO can run many different SEISAN programs using a database or an input CAT file. Here we will use the fps.inp file and the FOCMEC.DEF is set up to only use polarities and no relative weight is used for FOCMEC. Using FOCMEC with AUTO, the option is 'f':

```

auto f
Write auto help to get list of arguments.

Event data input - select one:

SEISAN default data base or          :Enter
Alternative data base, give 1-5 letter code or :
Local index file, name must start with index or :
Local data base, write ,, or         :
Filename for one file, min. 6 chars or with a . :

fps.inp

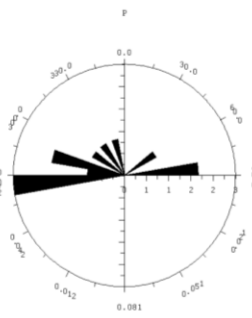
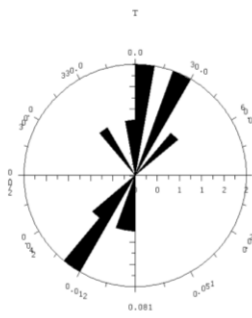
2000 0812 1427 26.2 L 59.769 5.316 9.1 BER 53 .30 3.9CBER 3.9WBER
Number of polarities and gap          40 63.0000000
work.out

date hrnm sec lat long depth no m rms damp erln erlt erdp
0 812 1427 26.21 5946.14N 5 18.9E 9.1 15 3 0.28 0.000 4.7 1.1 7.8
stn dist azm ain w phas calcphs hrnm tsec t-obs t-cal res wt di
EGD 56 354.8 99.2 0 P C PG 1427 35.6 9.40 9.17 0.23 1.00 3
KMY 62 183.7 98.4 0 P C PG 1427 36.2 10.00 10.16 -0.16 1.00 8
KMY 62 183.7 0 1427 37.5
KMY 62 183.7 98.4 0 S SG 1427 44.0 17.83 17.67 0.16 1.00 18
KMY 62 183.7 0 1427 44.8
.
.
.
.
.
Number of polarities: 40
Amplitude types: Manual: 0 Automatic: 6 Spectral: 6
Amplitudes use deselected in FOCMEC.DEF

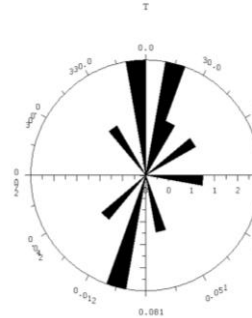
Total number of polarities and amplitude ratios = 40 gap in az = 63.0 gap in ain = 38.0
0.0 out of 40 pol, 999 out of 0 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
1.0 out of 40 pol, 999 out of 0 amp, err=0.2, # sol= 62, rms dev 26 16, str dip rak 313 87 -17, deg 2
1.0 out of 40 pol, 0 out of 0 amp, err=0.2, # sol= 62, rms dev 26 16, str dip rak 313 87 -17, deg 2
2000 1208 0048 06.2 L* 60.163 4.671 16.5F BER 33 .90 3.3CBER 3.6WBER 3.8LNAO

```

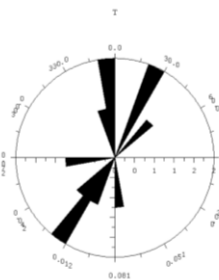
This will now be repeated for all 13 events and the results are given in output file auto.out which now can be used for other kinds of analysis. For the other programs PINV, FPFIT and HASH, the arguments are 'fi', 'fp' and 'fh' respectively. Here we will show the Rose diagrams (program FOC, see later) of P and T axis' for the results from the 4 programs:



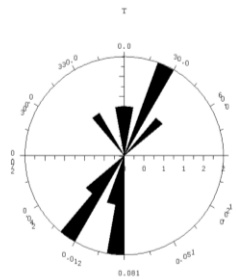
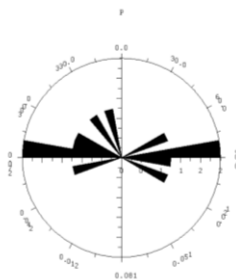
FOCMEC



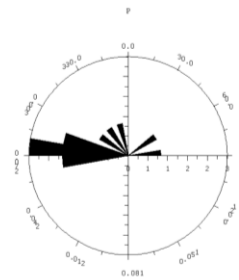
PINV



PPFIT



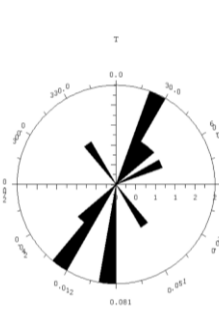
HASH



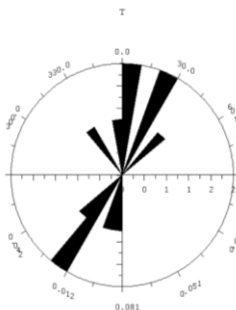
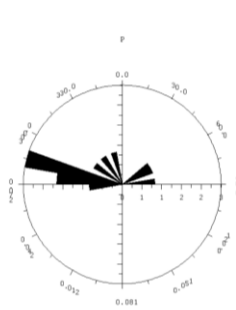
i

It is seen that 4 programs in general indicate similar P and T axis directions. (NB: on Linux the plots do not show numbers).

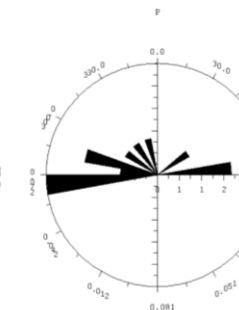
Comparing Rose diagrams is a useful way of seeing the effect of parameter changes in the input like using a different model or using relative weight. Below is seen the effect of using relative weight in FOCMEC:



Use relative weight

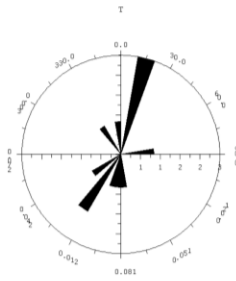


Do not use relative weight

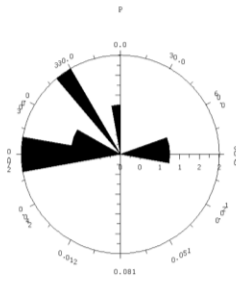


au

It seems that using relative weight does not change the result very much. Now we try using amplitude and we compare FOCMEC and HASH, no relative weighting:



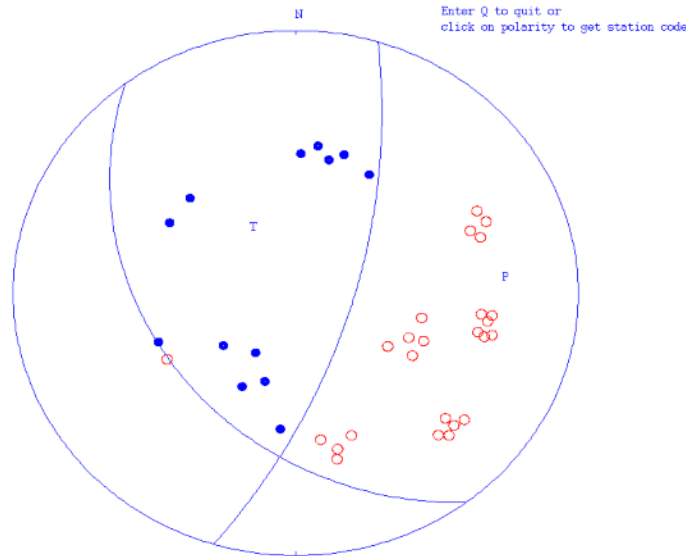
FOCMEC with amplitudes



HASH with amplitudes

In this case, there does not seem to be much change when using amplitudes, maybe there is a bit more scatter in the results. In some cases, the amplitude fit is quite bad, like for event # 7, which has a good solution with polarities:

2011 0721 0059 16.9 LQ 60.969 11.561 19.6 BER 60 .70 3.3LBER 3.2WBER 3.6LNWAO
STR DIP RAK Source
143 36 42 FOCMEC



When using amplitudes, it is seen that the amplitude fit is bad (see below, only 3 out of 7 fit the data, 4 do not fit) and the amplitudes therefore do not affect the solution very much, mainly because there are many polarities:

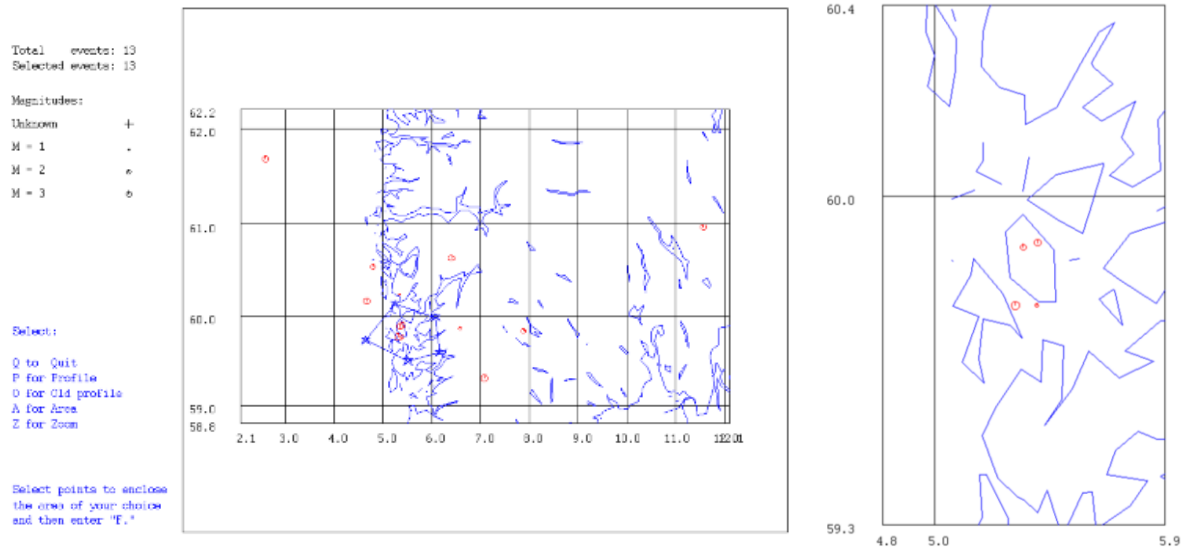
Total number of polarities and amplitude ratios = 45 gap in az = 52.0 gap in ain = 30.0

| | | | | | |
|--------------------|-------------------|-----------------|------------|------------------|------------------|
| 0.0 out of 38 pol, | 999 out of 7 amp, | err=0.2, # sol= | 9, rms dev | 3 3, str dip rak | 143 36 42, deg 2 |
| 0.0 out of 38 pol, | 0 out of 7 amp, | err=0.2, # sol= | 0, rms dev | , str dip rak | , deg 2 |
| 0.0 out of 38 pol, | 1 out of 7 amp, | err=0.2, # sol= | 0, rms dev | , str dip rak | , deg 2 |
| 0.0 out of 38 pol, | 2 out of 7 amp, | err=0.2, # sol= | 0, rms dev | , str dip rak | , deg 2 |
| 0.0 out of 38 pol, | 3 out of 7 amp, | err=0.2, # sol= | 0, rms dev | , str dip rak | , deg 2 |
| 0.0 out of 38 pol, | 4 out of 7 amp, | err=0.2, # sol= | 1, rms dev | 0 0, str dip rak | 150 35 49, deg 2 |
| 0.0 out of 38 pol, | 0 out of 7 amp, | err=0.3, # sol= | 0, rms dev | , str dip rak | , deg 2 |
| 0.0 out of 38 pol, | 1 out of 7 amp, | err=0.3, # sol= | 0, rms dev | , str dip rak | , deg 2 |
| 0.0 out of 38 pol, | 2 out of 7 amp, | err=0.3, # sol= | 0, rms dev | , str dip rak | , deg 2 |
| 0.0 out of 38 pol, | 3 out of 7 amp, | err=0.3, # sol= | 0, rms dev | , str dip rak | , deg 2 |
| 0.0 out of 38 pol, | 4 out of 7 amp, | err=0.3, # sol= | 3, rms dev | 1 2, str dip rak | 150 35 49, deg 2 |

So, amplitudes must be used with care.

Composite fault plane solution

Sometimes there are not enough polarities to make a reliable FPS. If a group of events are in the same area, it is to be expected that they have a similar FPS, and it is then possible to use many events for one FPS. Plotting the data with command 'map fps.inp' (left) and then selecting an area around a cluster of events (command 'a') gives (right):



When exiting from MAP, these 4 selected events are in file epimap.are. The next step is to relocate all with HYP to generate output files hyp.out and print.out used by the FPS programs. To get a composite FPS with FOCMEC just write:

```
focmec
```

```
Number of polarities:      40
Amplitude types:  Manual:    0  Automatic:    6  Spectral:    6
                   0         6  2.00000000
Automatic amplitude selected
Use amplitudes, (y/n=enter)
n

Number of polarities:      53
Amplitude types:  Manual:    0  Automatic:   10  Spectral:   10
                   0        10  2.00000000
Automatic amplitude selected

Number of polarities:      65
Amplitude types:  Manual:    0  Automatic:   10  Spectral:   10
                   0        10  2.00000000
Automatic amplitude selected

Number of polarities:      80
Amplitude types:  Manual:    0  Automatic:   47  Spectral:   47
                   0        47  2.00000000
Automatic amplitude selected

Total number of polarities and amplitude ratios = 80  gap in az = 34.0  gap in ain = 32.0
```

```

Stop (Q)
Plot saved solution(s) (1)
Plot new solutions (2)
Plot selected solution (3)
Find new solutions (4)
-1, -2, -3 also plot station
4
There are 80 polarity readings
Use relative weight, y/n=default

Maximum number of allowed polarity errors, enter for 0
6
Degree increment in search, enter for default 2

Wed Jun 19 15:21:49 2024 for program Focmec
-----
Input from a file focmec.dat
2000 0812 1427 26.2 L 59.769 5.316 9.1 BER 53 .30 3.9CBER 3.9WBER
Polarities/Errors: P 080/06 SV 000/00 SH 000/00
There are no amplitude ratio data
The minimum, increment and maximum B axis trend: 0.00 2.00 358.00
The limits for the B axis plunge: 0.00 2.00 90.00
The limits for Angle: 0.00 2.00 178.00
Strike Dip Rake Pol: P SV SH
320.10 84.14 -8.12 6.00 0.00 0.00
139.35 90.00 10.00 6.00 0.00 0.00
139.14 87.93 9.79 6.00 0.00 0.00
320.98 86.50 -7.20 6.00 0.00 0.00
There are 4 acceptable solutions.

Stop (Q)
Plot saved solution(s) (1)
Plot new solutions (2)
Plot selected solution (3)
Find new solutions (4)
-1, -2, -3 also plot station
2

..... show plot

Save solution (y/n)
y

Plot file is called focmec.eps
Input for GMT pspolar is called pspolar.inp

This is a composite solution, number of events is 4
Solution written to hyp.out

```

In this case the parameters for the solution must be found manually. We knew from previous testing that there are 6 errors so that was chosen for the demo. The plot of the solutions:

```

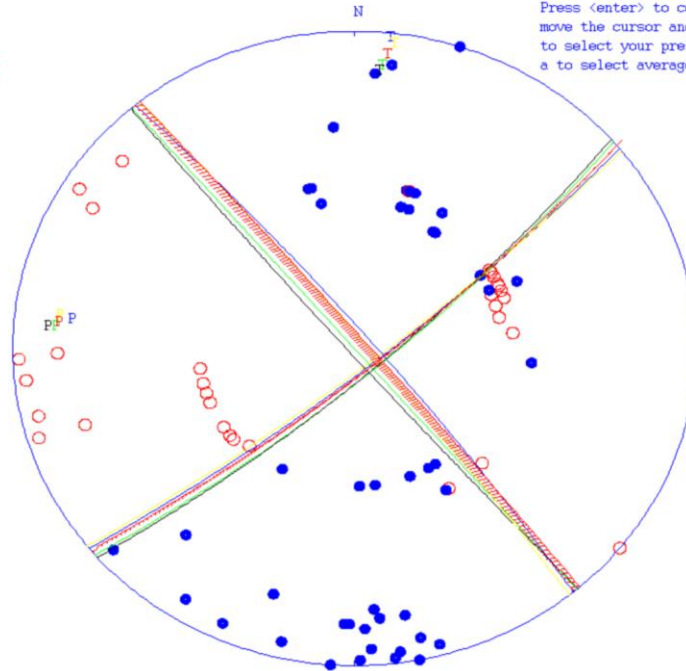
2000 0812 1427 26.2 L 59.769 5.316 9.1 BER 53 .30 3.9CBER 3.9WBER
STR DIP RAK
320 84 -7
139 90 10
139 88 10
321 87 -6
320 88 -8 Average

```

```

Enter Q to quit or
Click on polarity to get station code
Press <enter> to continue or
move the cursor and enter P or T
to select your preferred solution.
a to select average solution

```



It is seen that the 4 events seem to have very similar FPS since the polarities are quite consistent and there were only 6 errors out of 80 polarities.

For PINV, command is only 'pinv':

```

pinv
End of s-file
Number of data used for inversion= 80
Absolute pseudorank tolerance 0.004732 Pseudorank 5
Strike, dip, rake 49.8 82.9 -174.9
Consistent data: 73
Inconsistent data: 7
Number of events 4
This is a composite solution, number of events is 4
Solution written to hyp.out

```

For FPFIT, command is 'fpfit':

```

fpfit
Number of phases 183
Number of events used 4
Fpfit uses 3-letter LOWER-CASE commands, which can be followed by
parameters in free-format, or which display current values & generate prompts.
Type "hel" for information on available commands.
yes? # ORIGIN TIME LOCATION DEPTH MAG DDR DIP RAKE CNVRG
-----
1 20 0 812 1427 26.34 59n45.75 5e 18.5 16.7 1.0 139 85 -179
yes?
Fit 0.090
Errors in strike, dip and rake 4.0 8.0 10.0

Following line is composite solution written to hyp.out
49.0 85.0 -179.0 4.0 8.0 10.0 0.1 0.1 FPFIT F

```

For HASH, the command is 'hash_seisan':

```
hash_seisan
hash_seisan
Grid angle for focal mech. search, enter for def 2

Max number of polarity errors, default is 0

Max average error in amp rat, log10, def 0.1

Enter angle for computing mechanisms probability, def is 60

Enter probability threshold for multiples, def is 0.1

Number of polarities:          40
Amplitude types:  Manual:      0  Automatic:   6  Spectral:   6
                   0           6  2.00000000
Automatic amplitude selected
Use amplitudes, (y/n=enter)
n

Number of polarities:          53
Amplitude types:  Manual:      0  Automatic:  10  Spectral:  10
                   0           10  2.00000000
Automatic amplitude selected

Number of polarities:          65
Amplitude types:  Manual:      0  Automatic:  10  Spectral:  10
                   0           10  2.00000000
Automatic amplitude selected

Number of polarities:          80
Amplitude types:  Manual:      0  Automatic:  47  Spectral:  47
                   0           47  2.00000000
Automatic amplitude selected

Total number of polarities and amplitude ratios = 80  gap in az = 34.0  gap in ain = 32.0
Number of events          4
vpvs ratio is 0.00
vpvse set to 1.74
Number of polarities is           : 80
*** warning - no s/p amplitude ratios for event
Minimum number of polarity misfits overall : 6
New number of pol. misfits inc. extra is   : 6
Number of solutions found              7
  1  mech = 49.3220787      80.0000076    -175.000000
  2  mech = 49.3220787      80.0000076    -179.000000
  3  mech = 49.3220787      80.0000076     176.999985
  4  mech = 49.3220787      80.0000076     173.999985

Strike,dip,rake          49.3    80.0   -175.0

Strike,dip,rake          49.3    80.0   -179.0

Strike,dip,rake          49.3    80.0    177.0

Strike,dip,rake          49.3    80.0    174.0

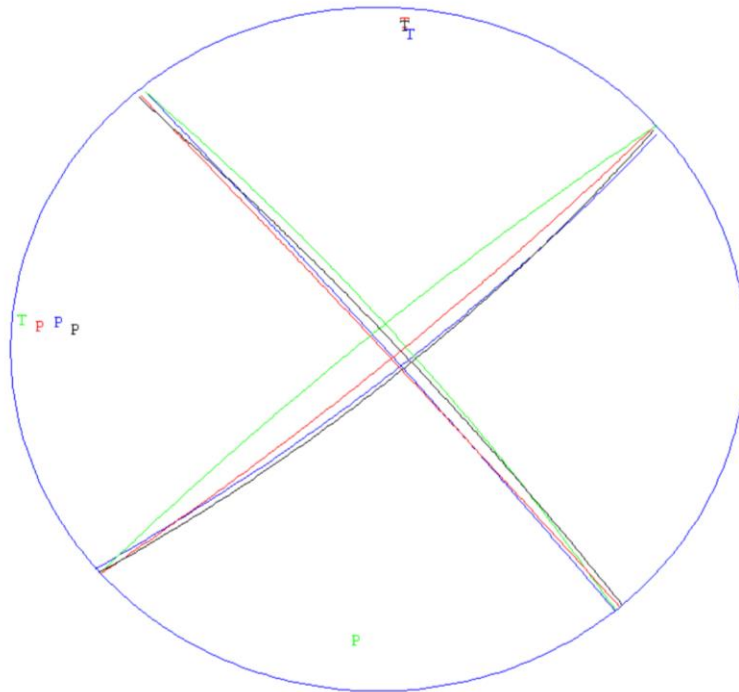
This is a composite solution, number of events is 4
Solution written to hyp.out
```

We now have 4 solutions written to hyp.out. They can be displayed with the command 'plot_foc hyp.out:'


```

320 88 -9 FOCMEC a
-40 83-175 PINV
49 85-179 FPFIT
49 80-175 HASH
2000 0812 1427 26.2 L 59.769 5.316 9.1 BER 53 .30 3.9CBER 3.9WBER npol= 40 gap= 63

```



It is seen that there is a very good consistency between the 4 solutions.

Displaying and analyzing fault plane solutions

Plotting FPS, stress inversion and Rose diagram, program FOC

The FOC program can make a stress inversion and display various parameters. Here we use the output from AUTO for the FOCMEC solutions without amplitude and relative polarity:

```

foc

Give input file
auto.out
Quality, ABC.., up to 5 chars, enter for all

Cumulative(c) or individual misfit(def)

Bin size for rose diagram (def 10 deg)

Plot all solutions selected (Y=enter/n)

2000 0812 1427 26.2 L 59.769 5.316 9.1 BER 53 .30 3.9CBER 3.9WBER
2000 1208 0048 06.2 L* 60.163 4.671 16.5F BER 33 .90 3.3CBER 3.6WBER 3.8LNAO
2003 1215 0428 23.9 L* 61.691 2.595 22.9 BER 47 .10 3.3LBER 2.4CBER 3.1WBER
2004 1101 2226 58.4 L* 60.541 4.799 18.3 BER 21 .50 2.6LBER 2.0CBER 2.8LNAO
2010 1220 0043 23.9 LQ 59.892 5.347 12.4 BER 39 .80 3.0LBER 2.5CBER 3.1LNAO
2010 1220 1230 12.7 LQ 59.902 5.403 17.2 BER 41 .10 3.3LBER 2.6CBER 3.4LNAO
2011 0721 0059 16.9 LQ 60.969 11.561 19.6 BER 68 .70 3.3LBER 3.2WBER 3.8LNAO

```

```

2012 0324 1106 30.5 L 60.635 6.401 15.5 BER 51 .70 3.0LBER 3.2LNLAO
2015 0429 2246 20.7 LQ 59.306 7.076 12.5F BER 62 .90 3.6LBER 3.6LNLAO
2018 0331 0405 12.1 LQ 60.237 5.342 27.0F BER 19 .60 0.8LBER
2019 0517 0122 59.0 LQ 59.769 5.400 13.7 BER 38 .10 1.6LBER
2019 0607 1217 46.9 L 59.877 6.572 1.5 BER 47 .30 1.7LBER 1.9LNLAO
2021 0524 1802 26.8 LQ 59.837 7.881 12.1F BER 83 .90 2.4LBER 2.7WBER
End of s-file

```

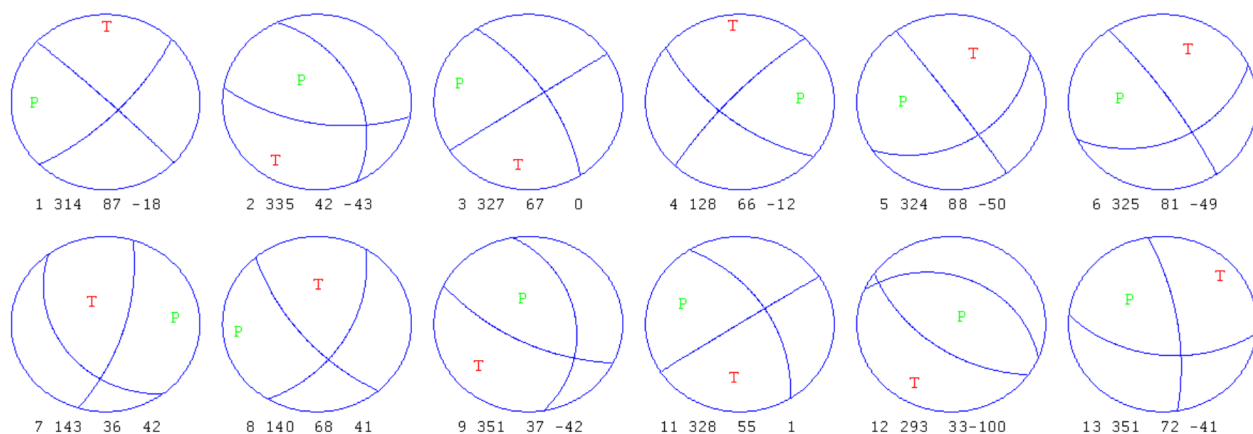
.....
Here comes plot seen below.
.....

```

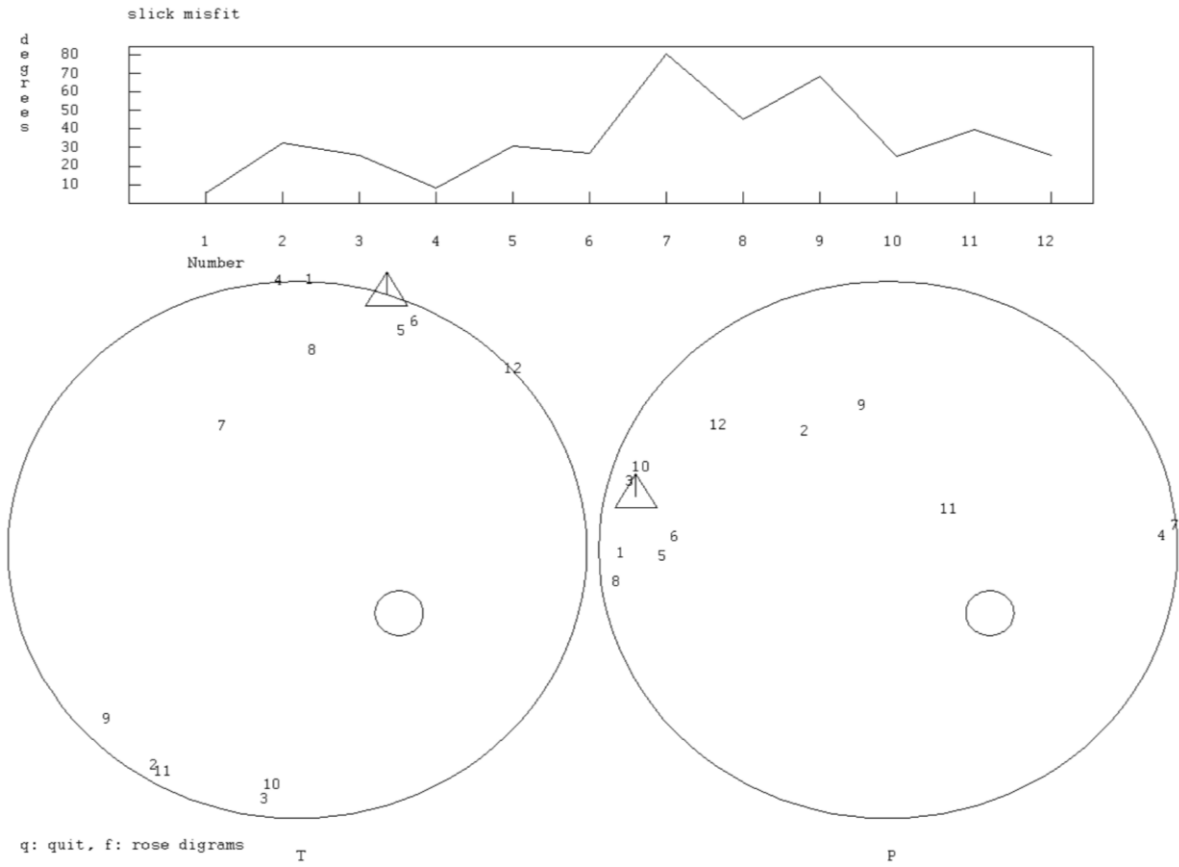
Number of events in input file          13
Number of fault plane solutions converted 12
Number of stations with polarity        114
Output file name with P and T is foc.out
Output file name with polareties is foc_pol.out
Output filename with events is foc_events.out
Output filename for zmap is foc.zmap

```

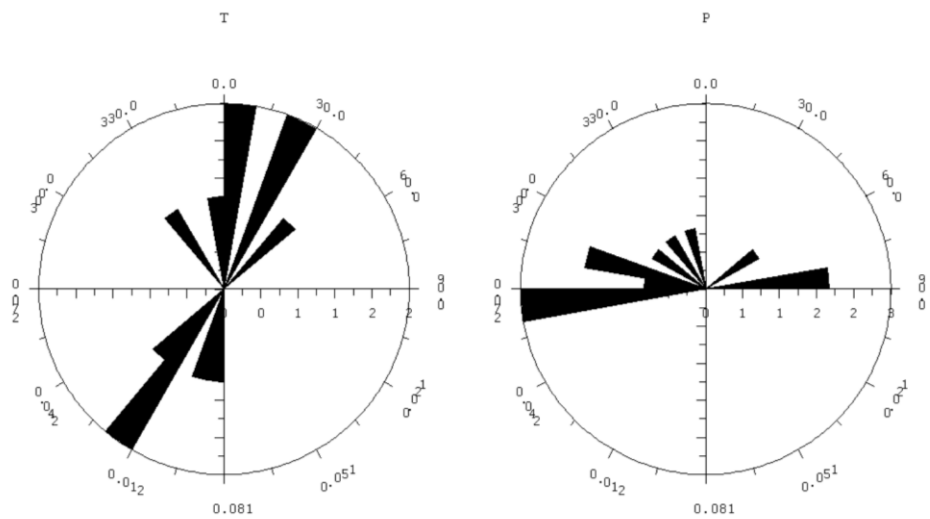
The solutions:



Note, there are only 12 solutions, not 13, since one of the events (#10) did not have enough data to make a solution using only polarities (has 5) due to the default requirement in AUTO to have at least 10 polarities (an argument can change that, write 'auto help to see arguments'). Now follows the stress inversion, see SEISAN manual for more details. The numbers are event numbers:

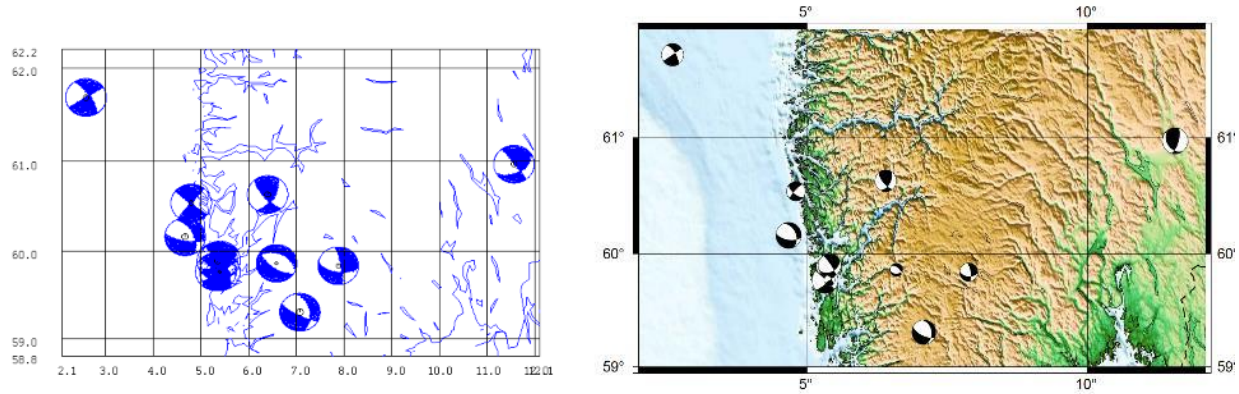


And finally comes the Rose diagram:



Plotting FPS solutions on a map

Many solutions can also be plotted on a map outside EEV, on the command line. The command for using MAP is 'map auto.out f' for EPIMAP and 'mapg auto.out f' for the GMT map:



The GMT map has several additional options, but here all defaults are used, and the size of the solutions is proportional to magnitude.

Listing FPS

It can sometime be useful to list all FPS of a data set. This can be done with program REPORT:

```
report auto.out
```

Below is shown parameters which can be chosen for output.
A return will chose all, placing any character under a field
will chose that parameter in the output. Each field starts
with a capital letter and ends within the following blank.
The order of the output can be changed by placing a number
under the field and fields will be written out in the order
of the numbers. E after time, lat, lon and dep are errors,
L E is distance and event id s, F is both fix flags and A is
agency for magnitude.

The following example shows that Mc, Depth(Dep) and Time with
error are selected and written out in given order.

| Date | Time | E | L | E | Lat | E | Lon | E | Dep | E | F | Aga | Nsta | Rms | Gap | McA | MlA | MwA | MbA | MsA | MWA | Fp | Spec | Macro | Local | MBA | MSA |
|------|------|---|---|---|-----|---|-----|---|-----|---|---|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|----|------|-------|-------|-----|-----|
| 30 | 45 | | | | | | | | 20 | | | | | | | 10 | | | | | | | | | | | |

| Date | Time | E | L | E | Lat | E | Lon | E | Dep | E | F | Aga | Nsta | Rms | Gap | McA | MlA | MwA | MbA | MsA | MWA | Fp | Spec | Macro | Local | MBA | MSA |
|------|------|---|---|---|-----|---|-----|---|-----|---|---|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|----|------|-------|-------|-----|-----|
| x | x | | | | x | | x | | x | | | | | | | | | | | | | x | | | | | |

Number of output fields 6

| | |
|---|----|
| Number of events | 12 |
| Number of events with spectra: | 8 |
| Number of events with fault plane solution: | 12 |
| Number of events with error estimates: | 12 |
| Number of events with mc | 6 |
| Number of events with ml | 11 |
| Number of events with mw | 0 |
| Number of events with mb | 0 |
| Number of events with mB | 0 |
| Number of events with ms | 0 |
| Number of events with mS | 0 |
| Number of events with mw | 8 |

```

Output report file is report.out
Output nordic file is report_n.out
Output of choises used in report.inp

```

```
more report.out
```

| Year | Date | HRMM | Sec | Latitud | Longitud | Depth | STRIK | DIP | RAKE |
|------|------|------|------|---------|----------|-------|-------|-----|------|
| 2000 | 0812 | 1427 | 26.2 | 59.769 | 5.316 | 9.1 | 314 | 87 | -17 |
| 2000 | 1208 | 0048 | 06.2 | 60.163 | 4.671 | 16.5 | 335 | 42 | -42 |
| 2003 | 1215 | 0428 | 23.9 | 61.691 | 2.595 | 22.9 | 327 | 67 | 0 |
| 2004 | 1101 | 2226 | 58.4 | 60.541 | 4.799 | 18.3 | 128 | 66 | -11 |
| 2010 | 1220 | 0043 | 23.9 | 59.892 | 5.347 | 12.4 | 324 | 88 | -49 |
| 2010 | 1220 | 1230 | 12.7 | 59.902 | 5.403 | 17.2 | 325 | 81 | -48 |
| 2011 | 0721 | 0059 | 16.9 | 60.969 | 11.561 | 19.6 | 143 | 36 | 42 |
| 2012 | 0324 | 1106 | 30.5 | 60.635 | 6.401 | 15.5 | 140 | 68 | 41 |
| 2015 | 0429 | 2246 | 20.7 | 59.306 | 7.076 | 12.5 | 351 | 37 | -41 |
| 2018 | 0331 | 0405 | 12.1 | 60.237 | 5.342 | 27.0 | | | |
| 2019 | 0517 | 0122 | 59.0 | 59.769 | 5.400 | 13.7 | 328 | 55 | 1 |
| 2019 | 0607 | 1217 | 46.9 | 59.877 | 6.572 | 1.5 | 293 | 33 | -99 |
| 2021 | 0524 | 1802 | 26.8 | 59.837 | 7.881 | 12.1 | 351 | 72 | -40 |

Only the prime (first) solution is listed. By ticking off other parameters, they can also be included in the list.

Model dependency of FPS

It is well known that the model can be very critical for the fault plane solution since different models will give different angle of incidence. In addition, the hypocentral depth might change, which also affects the angle of incidence. If a model changes an arrival from direct to refracted, the azimuth will change 180 degrees, so it is particularly the hypocentral depth that is a critical parameter. The original HASH program has an option (not implemented in SEISAN), for one event, to calculate angle of incidence for different models and then use all of this data together to calculate one FPS. The spread of the solutions will then give an indication of the uncertainty of the solutions due to variation in the models. A similar test can be done in SEISAN by making FPS using different models. To automate this, FOCMEC has an option to make automatic solutions for any number of models to compare the solutions and possibly select one solution or more likely an average of the different model solutions. In this data set, there are 5 different models defined in 5 station files STATION0.HYP (the default), STATION1.HYP and STATION2.HYP, STATION3.HYP and STATION4.HYP. The model indicators are defined in FOCMEC.DEF as:

```
MODELS    For multi model, one char    01234
```

The models are

| Model 0 | | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
|---------|------|---------|------|---------|------|---------|------|---------|------|
| 6.2 | 0.0 | 6.0 | 0.0 | 6.2 | 0.0 | 6.2 | 0.0 | 6.0 | 0.0 |
| 6.6 | 12.0 | 6.3 | 8.0 | 6.6 | 12.0 | 7.5 | 18.0 | 7.0 | 23.0 |
| 7.1 | 23.0 | 6.7 | 20.0 | 7.5 | 25.0 | 7.9 | 25.0 | 8.2 | 40.0 |
| 8.05 | 31.0 | 7.7 | 39.0 | 8.1 | 40.0 | 8.25 | 50.0 | 8.4 | 60.0 |
| 8.25 | 50.0 | 8.25 | 50.0 | 8.25 | 50.0 | 8.5 | 80.0 | 8.5 | 80.0 |
| 8.5 | 80.0 | 8.5 | 80.0 | 8.5 | 80.0 | | | | |

The left column shows P-velocity in (km/s) and the right column the depth (km) to the interface just as they are defined in the SEISAN station file.

Using many models for the same event can only be done with one event at a time in EEV. Using again event number 6, (without amplitudes and relative weight), the command is ‘faaa’:

```
# 6 20 Dec 2010 12:30 12 LQ 59.902 5.403 17.2 .10 3.3LBER 41 ? faaa
**** now locating with hyp as a preparation ***

20-1230-12L.S201012
Number of spectra available and number used in average 16 16
# 0 2010 1220 1230 12.7 LQ 59.902 5.403 17.2 BER 41 0.1 3.4LBER 2.6CBER

Number of polarities: 12
Amplitude types: Manual: 0 Automatic: 10 Spectral: 10
Amplitudes use deselected in FOCMEC.DEF

Total number of polarities and amplitude ratios = 12 gap in az = 93.0 gap in ain = 44.0
0.0 out of 12 pol, 999 out of 0 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
1.0 out of 12 pol, 999 out of 0 amp, err=0.2, # sol= 500, rms dev 18 12, str dip rak 323 82 -52, deg 2
1.0 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 500, rms dev 18 12, str dip rak 323 82 -52, deg 2
1.0 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 245, rms dev 15 12, str dip rak 325 81 -48, deg 3
.... updating event with average fault plane solution
**** now locating with hyp as a preparation ***

20-1230-12L.S201012
Number of spectra available and number used in average 16 16
# 0 2010 1220 1230 12.1 LQ 59.905 5.406 22.9 BER 41 0.3 3.4LBER 2.6CBER

Number of polarities: 12
Amplitude types: Manual: 0 Automatic: 10 Spectral: 10
Amplitudes use deselected in FOCMEC.DEF

Total number of polarities and amplitude ratios = 12 gap in az = 75.0 gap in ain = 41.0
0.0 out of 12 pol, 999 out of 0 amp, err=0.2, # sol= 0, rms dev , str dip rak , deg 2
1.0 out of 12 pol, 999 out of 0 amp, err=0.2, # sol= 500, rms dev 30 37, str dip rak 78 25-173, deg 2
1.0 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 500, rms dev 30 37, str dip rak 78 25-173, deg 2
1.0 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 474, rms dev 24 24, str dip rak 76 44-163, deg 3
1.0 out of 12 pol, 0 out of 0 amp, err=0.2, # sol= 195, rms dev 26 26, str dip rak 78 39-167, deg 4
.... updating event with average fault plane solution
```

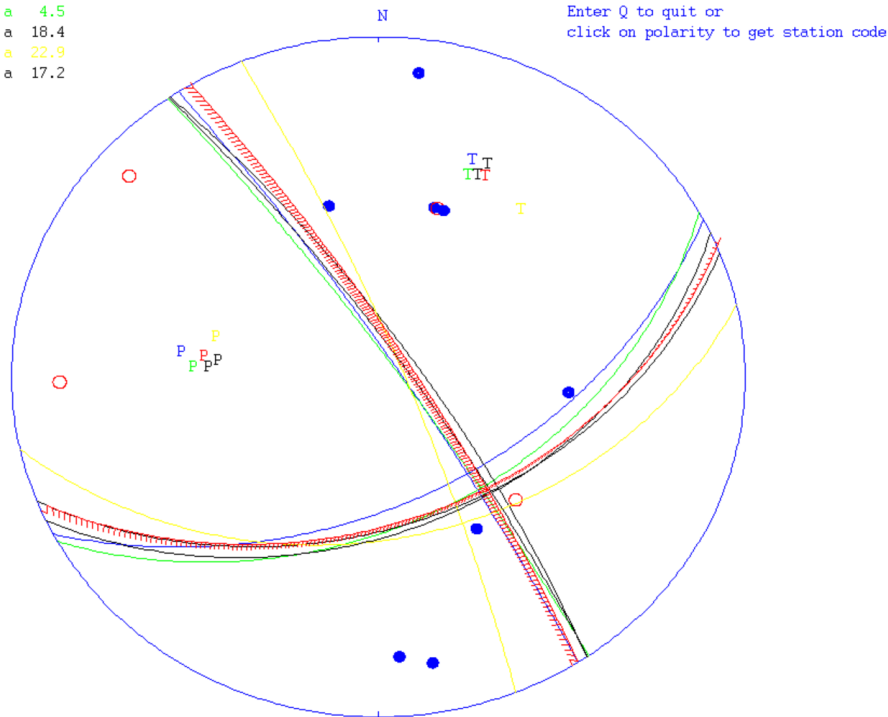
..... etc. for the next models.

The 5 solutions are now written in the S-file so they can be plotted with ‘fo’:

```

2010 1220 1230 12.7 LQ 59.902 5.403 17.2 BER 41 .10 3.4LBER 2.6CBER 3.4LNAO
SIR DIP RAK Source
327 84 -40 FOCMEC4 a 11.4
325 84 -45 FOCMEC3 a 4.5
325 78 -47 FOCMEC2 a 18.4
78 39-167 FOCMEC1 a 22.9
325 81 -48 FOCMEC0 a 17.2
328 82 -46 AveMod1

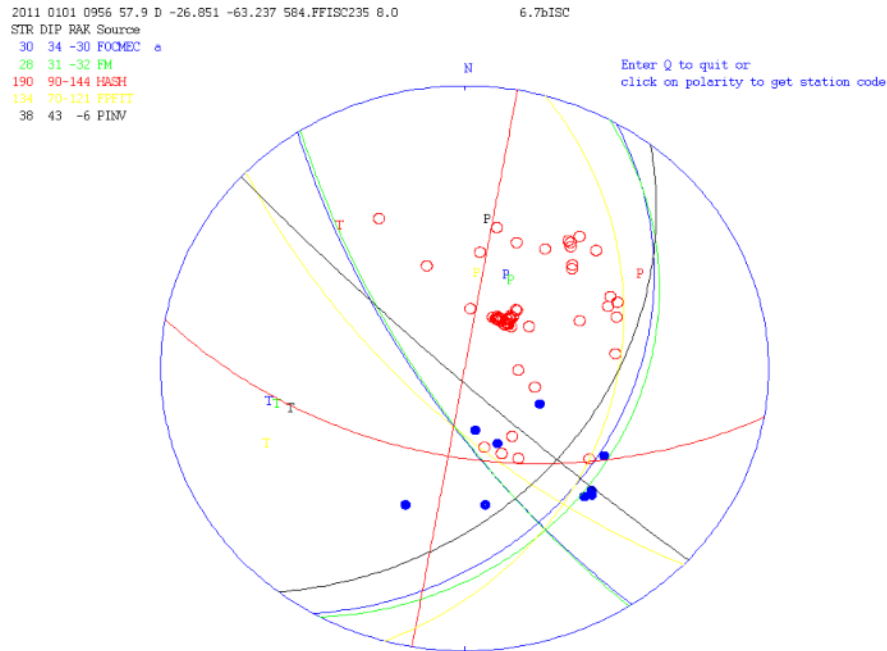
```



In the top left is listed the solutions and the last number is the depth which varies between 4.5 and 22.9 km. The solutions are quite similar so even with such different models, the FPS are quite similar. The average FPS using all models is the red solution which can be chosen when leaving the program. Using the option of multiple models is a simple way of checking the influence of different models without having to change the model for each test. In this case the solutions were only a little dependent on the model.

Teleseismic events

All 4 programs can also calculate FPS of teleseismic events. The test data has one teleseismic event downloaded from ISC in file teleseismic.inp. The event only has stations with polarities. The FPS can be calculated outside EEV like it was done under composite solution or split up in the local database. With teleseismic events, amplitudes can be used but must be made manually. For more details, see the SEISAN manual. Using all 4 programs, the solutions are:



All solutions, except the one made with HASH, are very similar. The green solution is made by ISC using the same first motions and it is almost identical to the solution from FOCMEC.

Summary

- FOCMEC seems the most stable and reliable program and seems to give consistent solutions using the average solution.
- Reading of polarity can in many cases be quite uncertain for emergent arrivals so the first emergent arrival might not be what the program will calculate, and a later arrival should be considered.
- Using amplitudes should be done with caution and some experimentation should be done to get the most reliable results, particularly with respect to distance and filter. If less than 2/3 of the amplitudes fit, amplitudes might not help.
- For small events with little data, amplitudes might be a way to get a solution.
- If there are many small events in the same area with few observations, consider using a composite solution.