Tutorial

Fault plane solutions in SEISAN

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Contents

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.

FPFIT: 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:

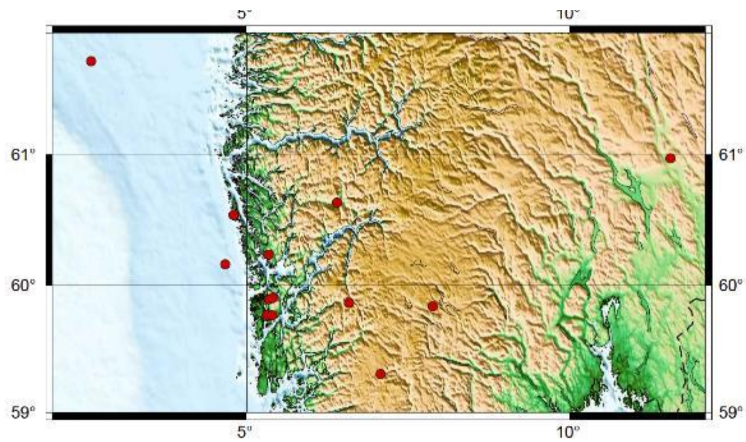
https://seisan.info/fps/fps-test-data.tar.gz

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.

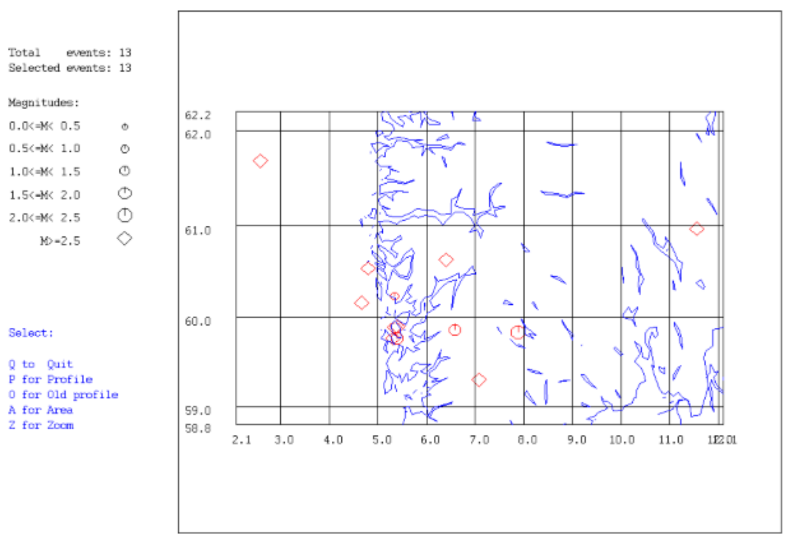
Waveforms and response files, not strictly needed, but nice to have if you want to do other things like checking the polarities or recalculate the amplitudes. Some output files from the testing are also there. All files should be put in the working directory, and you should work there.

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 FPFIT
FPFIT:     -------------------------------------
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

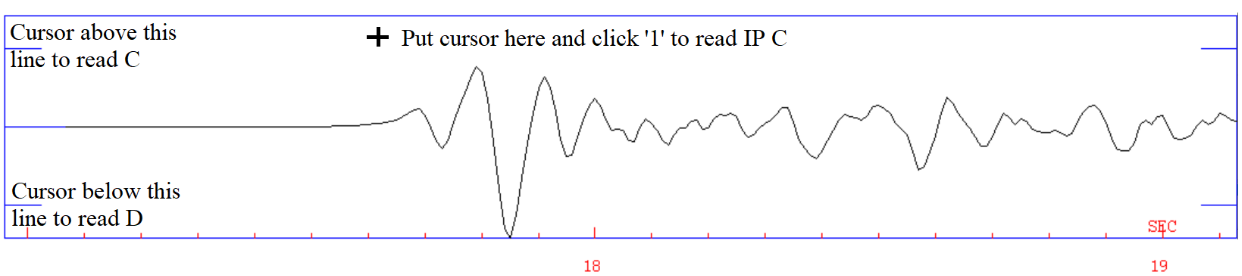
The most common way of making FPS is to use polarities. There is not any really good way of obtaining polarities automatically since the first onset can be quite unclear. So, they must be made manually with MULPLOT (command 'p' or 'pol' in EEV):

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

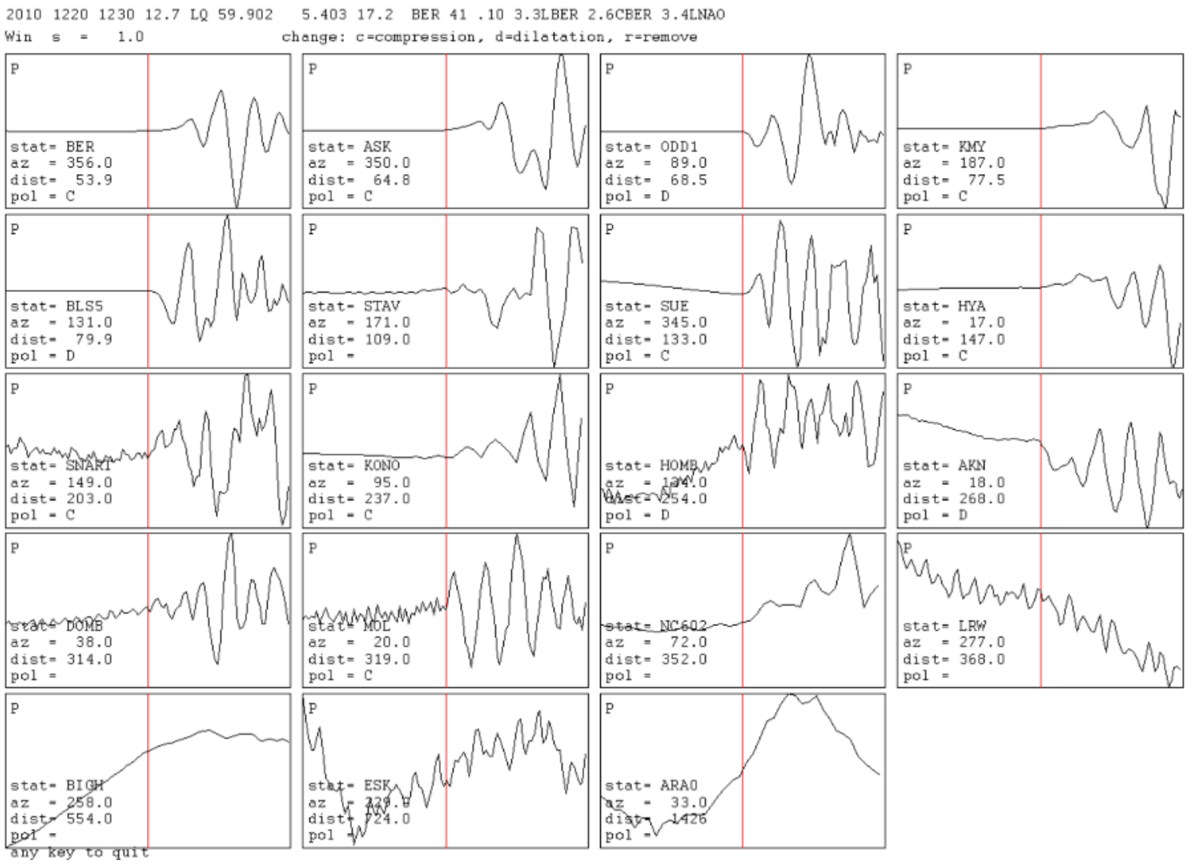
A filter can change the polarity or make it unclear.

Picking polarities

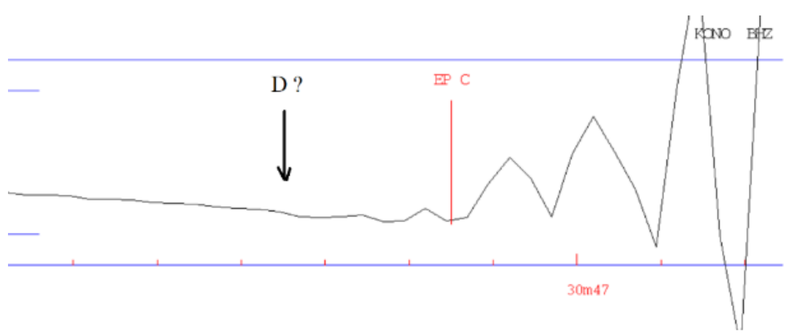
Polarities are mostly picked with MULPLT during routine processing since they can be picked with the same keypress as used for picking the P-arrival:



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):



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’:

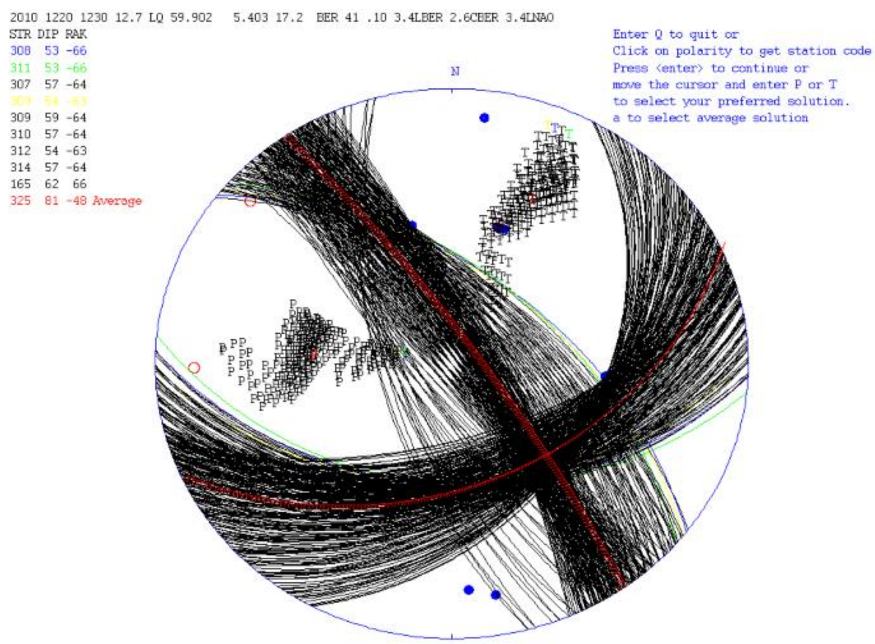
```
Number of polarities:           12
Amplitude types:   Manual:       0   Automatic:   10   Spectral:    10
Automatic amplitude selected
Use amplitudes, (y/n=enter)


 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:

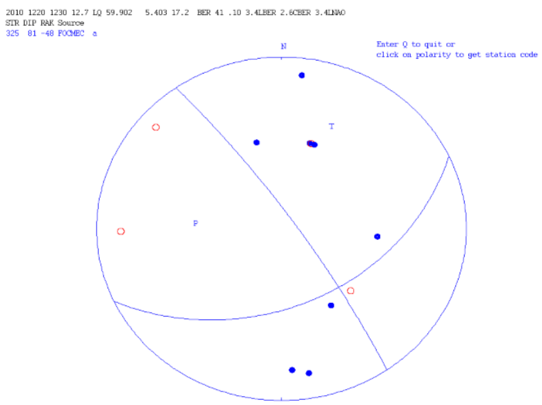
- pol: number of polarities available,
- amp: number of amplitude ratios available,
- err: error accepted in amplitude ratio,
- rms dev: the rms deviation (degrees) of the two normal vectors from the average normal vector of all solutions,

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

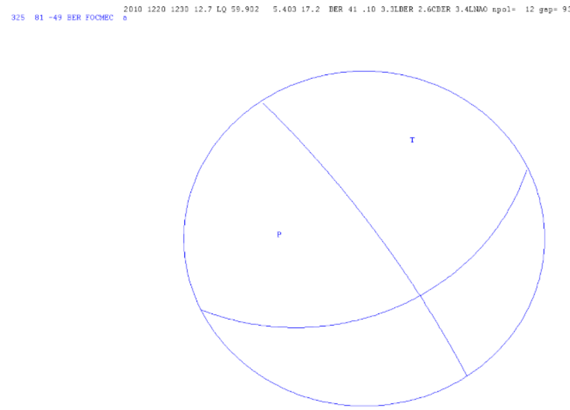
The parameters for each trial are listed as well as the number of solutions (sol). In this case it is simple since there is one polarity error, no amplitudes are used although present (use of amplitudes has not been activated in FOCMEC.DEF), but it gives more than 500 solutions, so the next step is to 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:



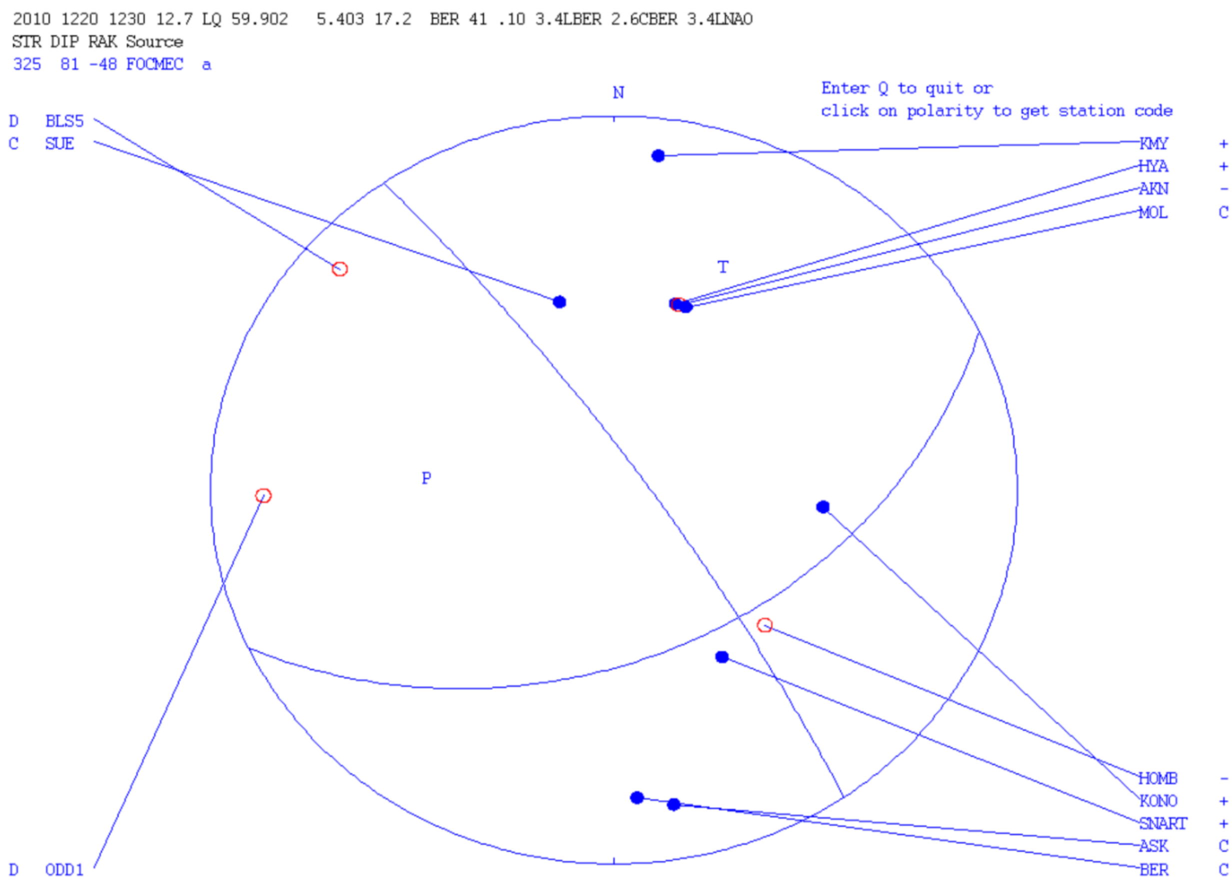
Command fo



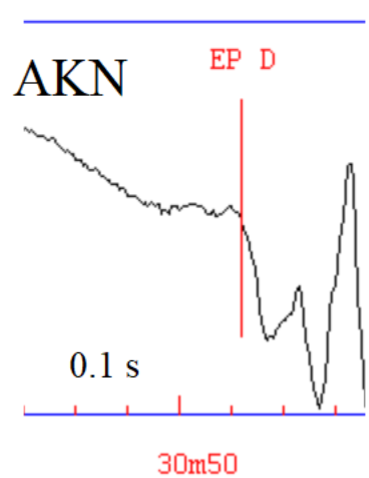
Command foo

The advantage of the foo command is that it can plot FPS without location and polatity data. Somemtimes 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
```



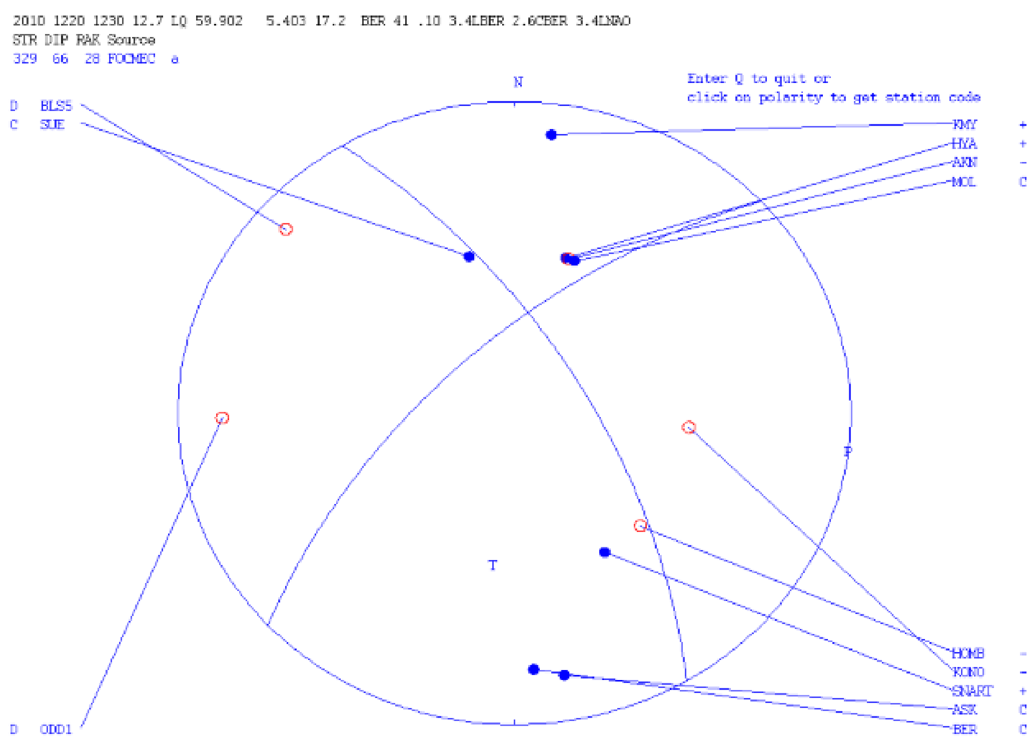
It is now possible to see the polarities of the different stations. The '+' (compression) and '-' (dilatation) indicate that the P was read with emergent onset 'E'. The AKN polarity does not fit so it can be inspected with MULPLT which has options for amplifying the signal. Using MULPLT, single trace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

```
1.0 out of  12 pol,   0 out of  0 amp, err=0.2, # sol= 175, rms dev 30 40, str dip rak 329  66  28, deg 6  New
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  Old
```

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:

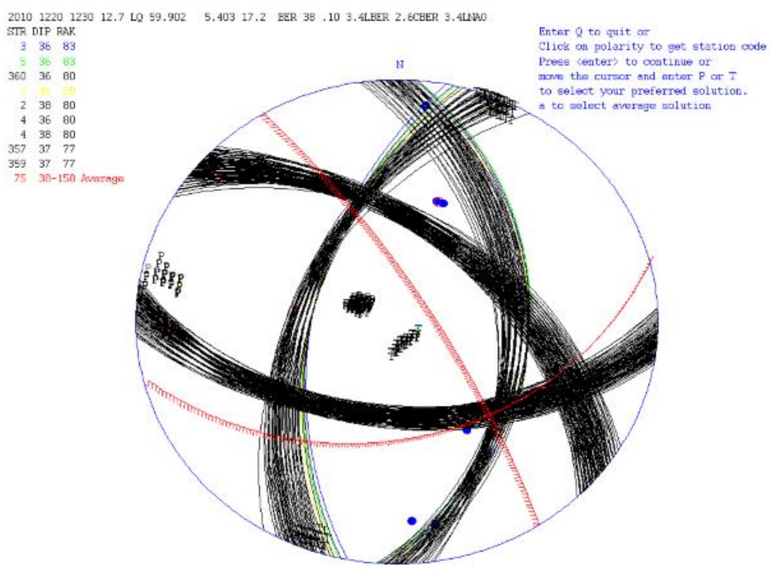


Both examples show that reading polarity is not always easy. The emergent first arrival seen before the pick could come from a refracted arrival from an intermediate layer not present in the location model and therefore the angle of incidence might not be calculated correctly.

In this case relative polarity error has not been used. Relative polarity error means that a polarity error will vary between 0 and 1.0 depending on how close the observations are to the nodal plane. So, it will be 0.0 on the nodal plane. This option can be useful if many observations are close to the nodal plane and maybe then not so clear and in some cases, it might therefore be possible to make a better solution. However, this depends on the data and is this document we have chosen 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

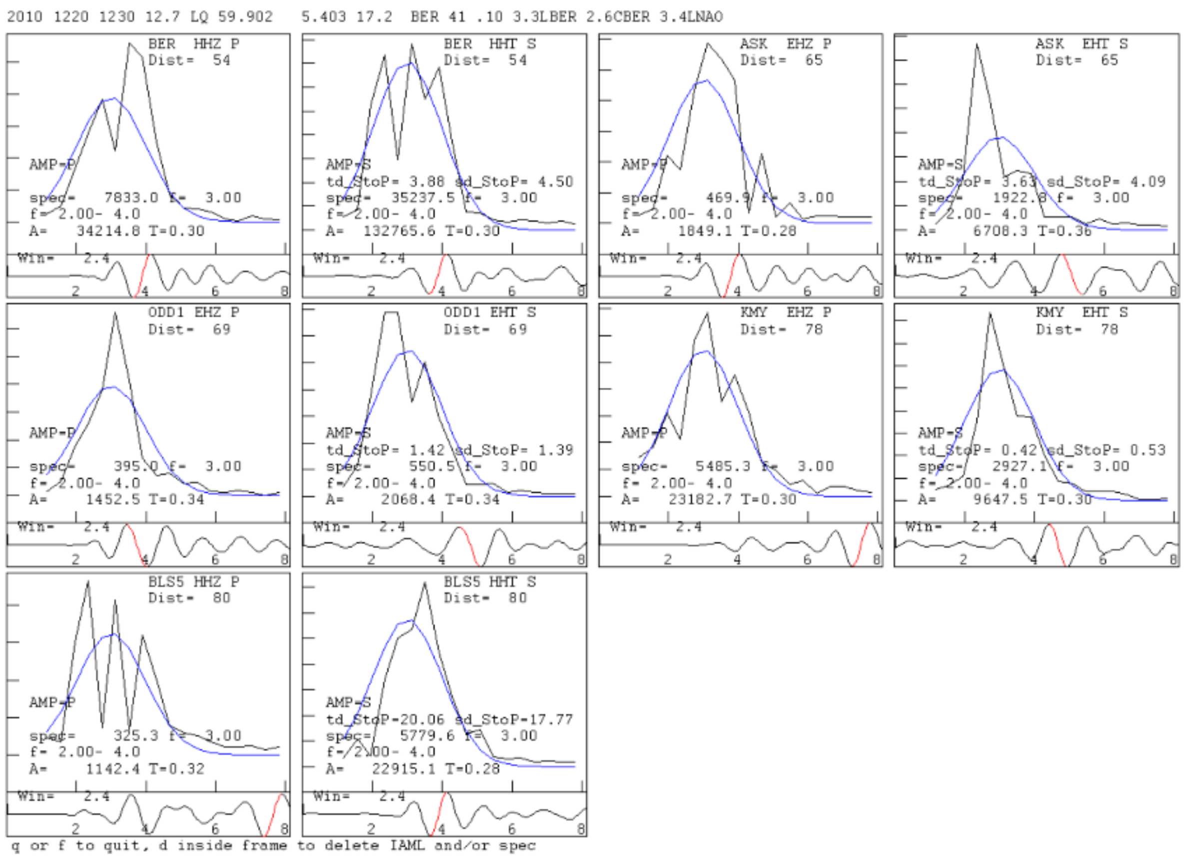
Amplitudes or more correctly, amplitude ratios between P and S can be useful when few or badly distributed polarities are available. It is assumed that the amplitudes are of Pg and Sg phases. Amplitudes should be used with caution since they are often more unreliable than polarities, particularly for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



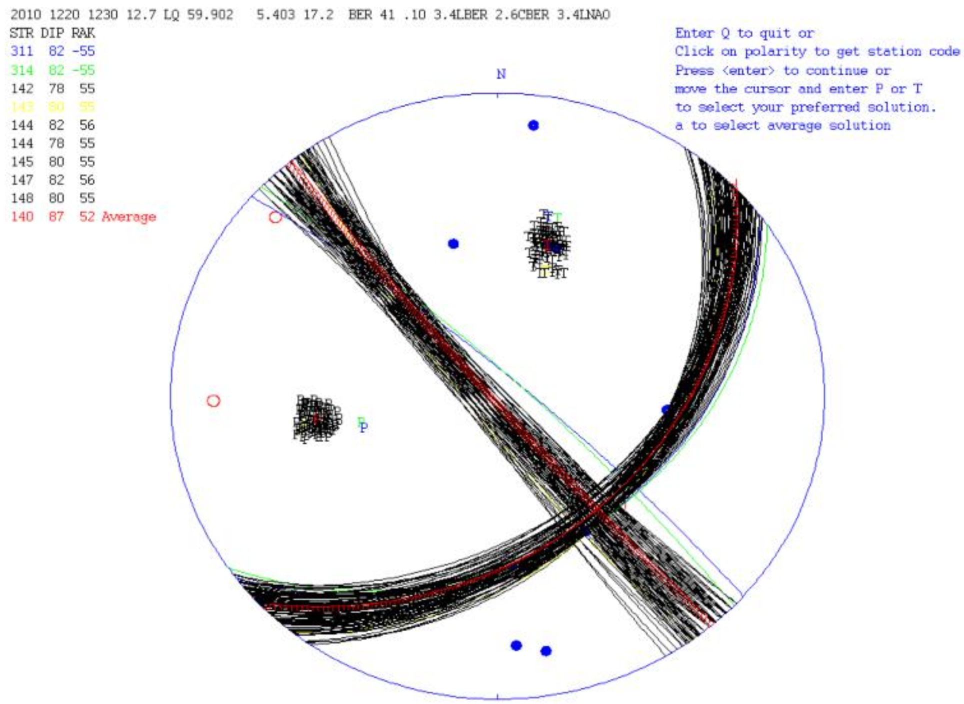
The plots show the spectral and amplitude fit so it is possible to control the quality. Bad fits can be deleted interactively. The amplitude values are also checked for deviation between the spectral and time domain amplitudes and the default is that there should be less than 50 % difference in the ratios. 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
```

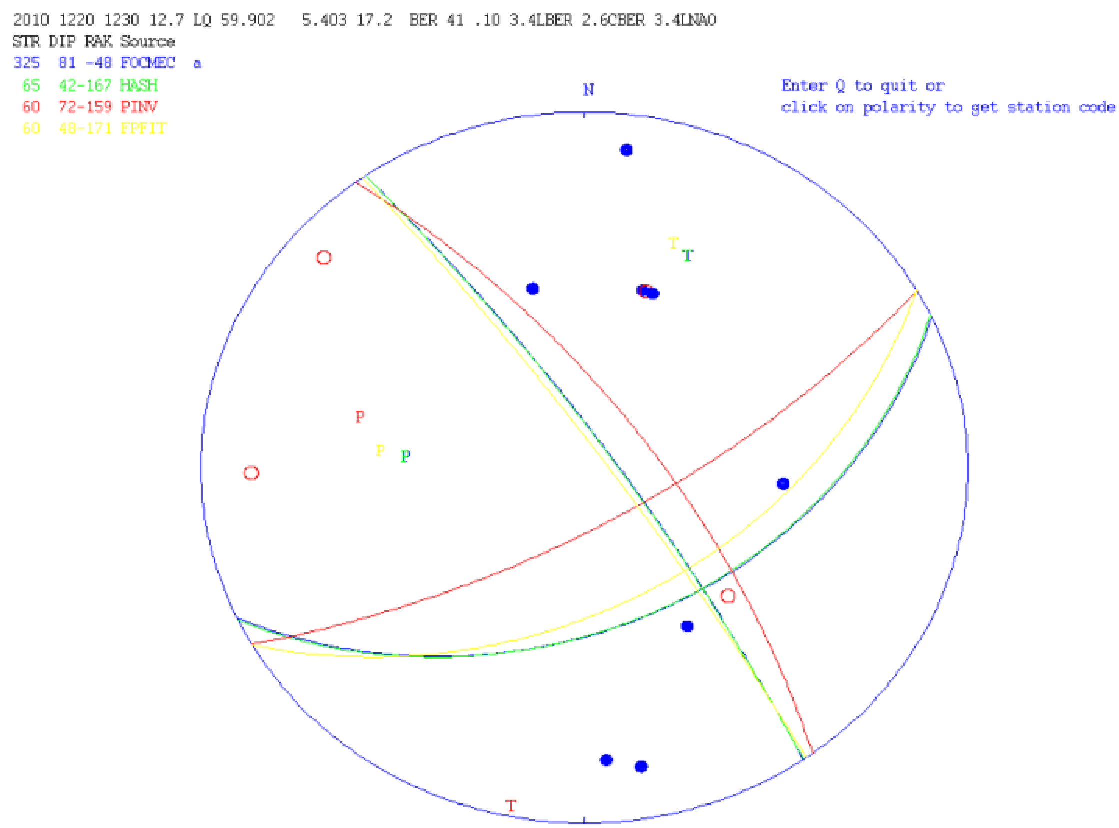
HASH:

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  faF
  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 commend '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. 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
```

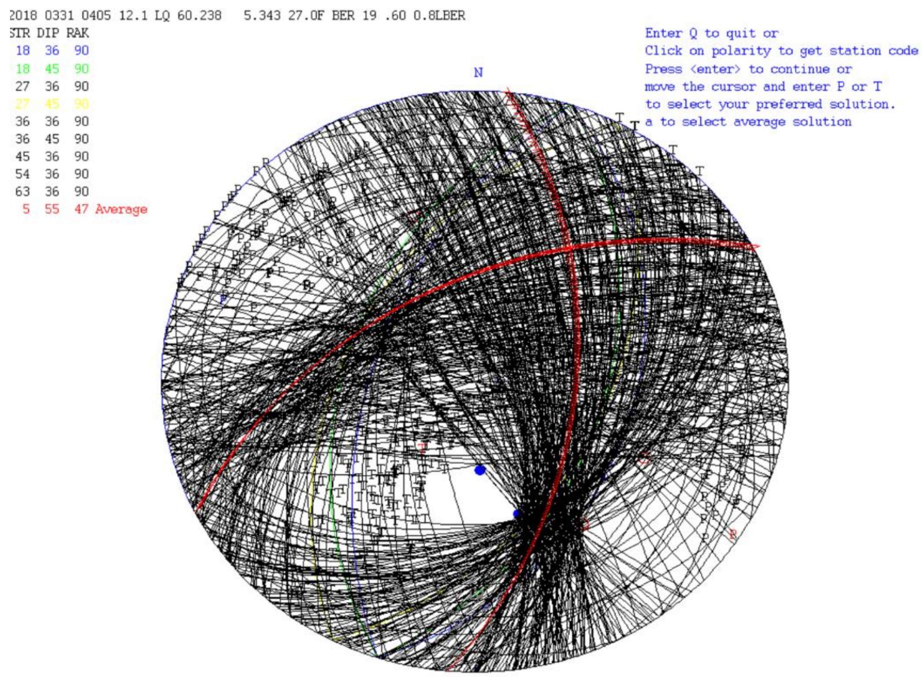
Here is an example of 2 FOCMEC solutions. They have very different slip (-158.9 and -48.9) so from the numbers they look different. This can be evaluated by comparing the P and T vectors with command 'fd':

```
#    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
```

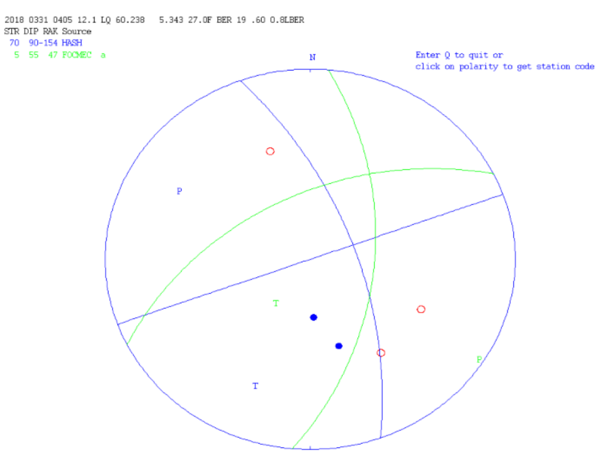
so they are quite similar. This can also be seen by plotting the solutions, but it can be useful to be able to quantify difference in FPS solutions.

FPS of a small event

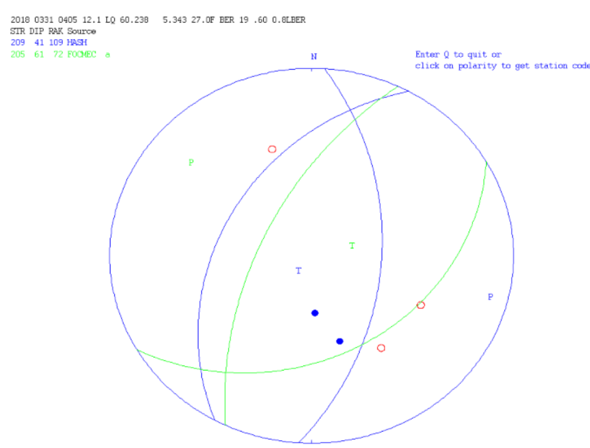
Event # 10 is a Ml 0.8 event with few observations (5 polarities and 4 amplitude ratios). The solution with only polarities is:



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):



Polarities

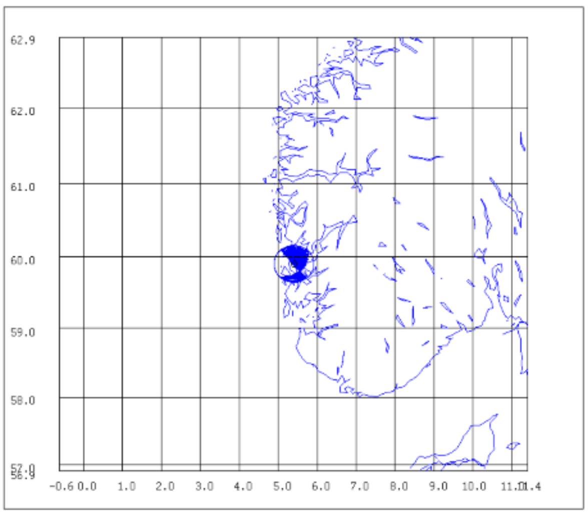


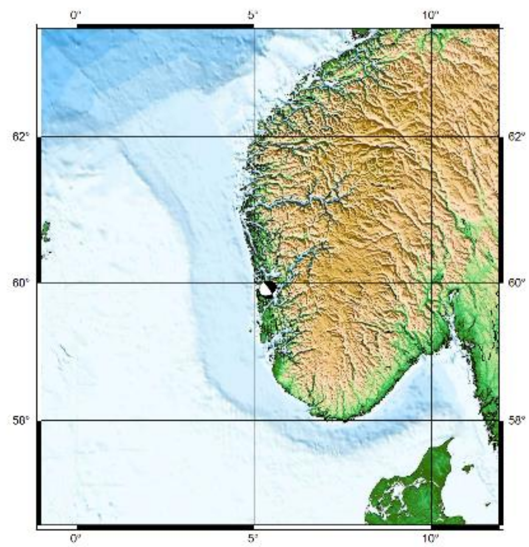
Polarities and amplitudes

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

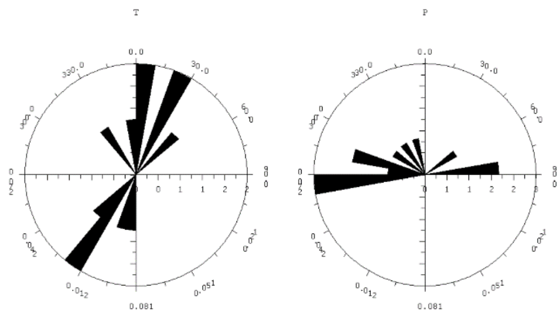
All the FPS programs in SEISAN can be used to calculate fault plane solutions for many events. Program FPFIT and PINV require no setup while FOCMEC and HASH require a FOCMEC.DEF file where it is specified if using amplitudes (both programs) or relative weighting (only FOCMEC) and the attenuation model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

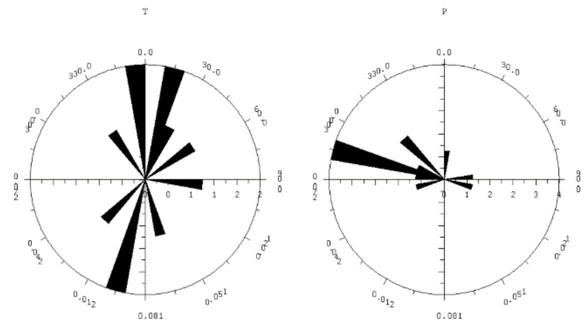
Automatic solutions can be made using all 4 programs with the help of the driver program AUTO. AUTO can run many different SEISAN programs using a database or an input CAT file. Here we will use the fps.inp file and the FOCMEC.DEF is set up to only use polarities and no relative weight is used for FOCMEC.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

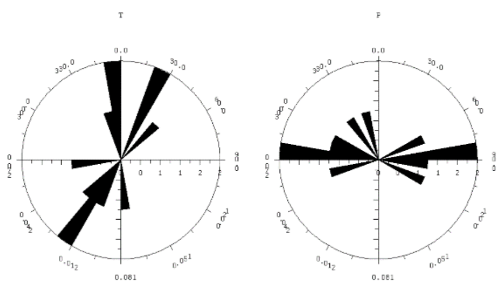
This will now be repeated for all 13 events and the results are given in output file auto.out which now can be used for other kinds of analysis. For the other programs PINV, FPFIT and HASH, the arguments are ‘fi’, ‘fp’ and ‘fh’ respectively. Here we will show the Rose diagrams (program FOC, see later)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



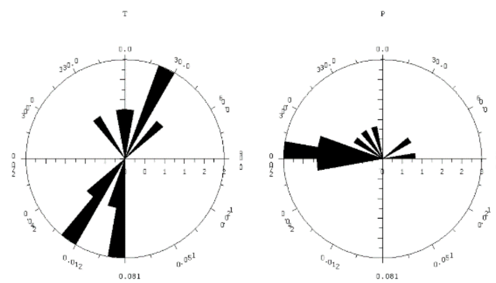
FOCMEC



PINV



FPFIT

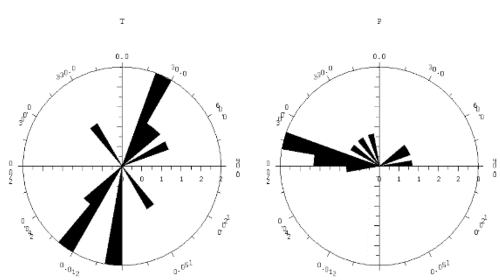


i

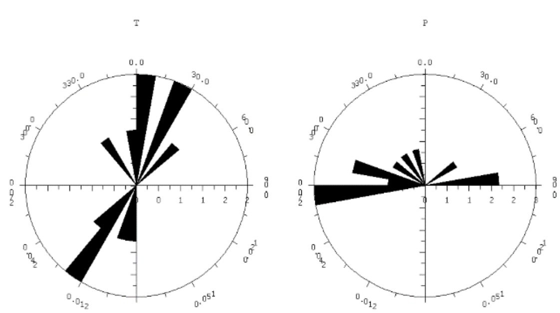
HASH

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:



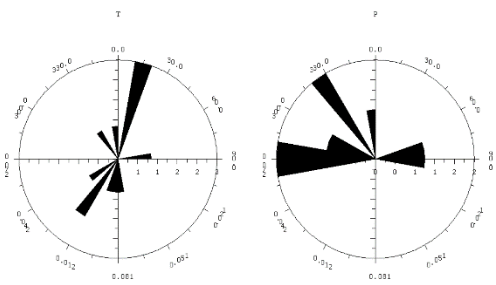
Use relative weight



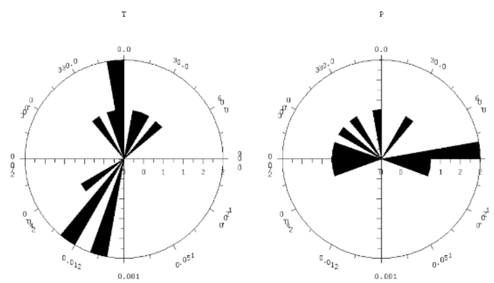
au

Do not use relative weight

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:

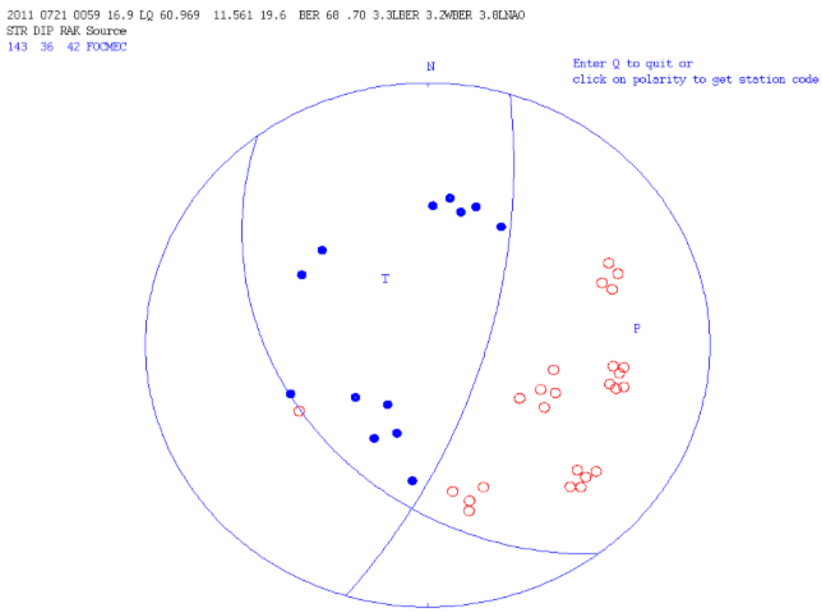


FOCMEC with amplitudes



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:



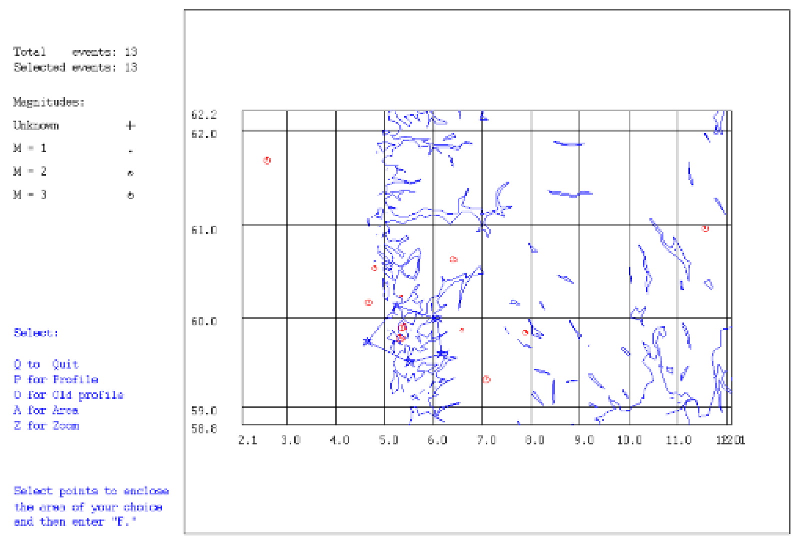
When using amplitudes, it is seen that the amplitude fit is bad (see below, only 3 out of 7 fit the data, 4 do not fit) and the amplitudes therefore do not affect the solution very much, mainly because there are many polarities:

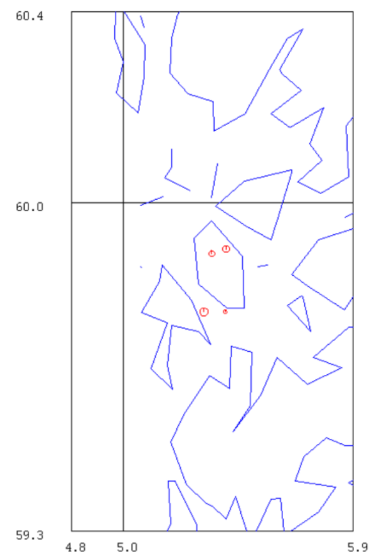
```
Total number of polarities and amplitude ratios =   45  gap in az =  52.0  gap in ain =  30.0
 0.0 out of  38 pol, 999 out of  7 amp, err=0.2, # sol=   9, rms dev  3  3, str dip rak 143  36  42, deg 2
 0.0 out of  38 pol,   0 out of  7 amp, err=0.2, # sol=   0, rms dev      , str dip rak           , 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):



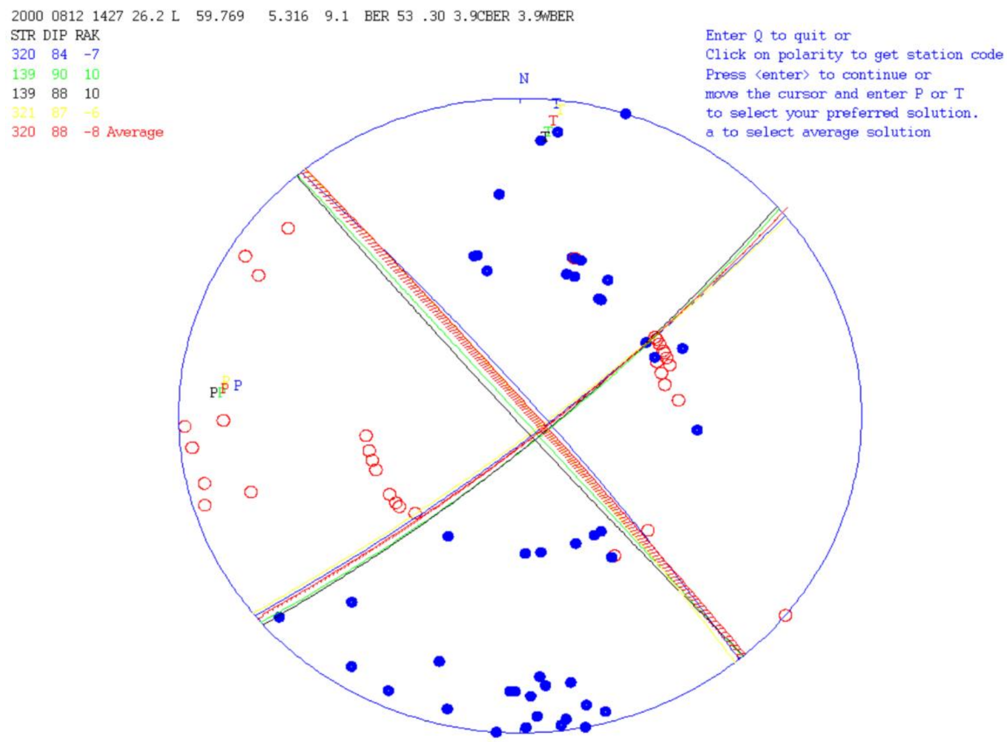


When exiting from MAP, these 4 selected events are in file epimap.are. The next step is to relocate all with HYP to genetrate output files hyp.out and print.out used by the FPS programs. To get a composite FPS with FOCMEC just write:

```
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 soluion 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:



It is seens 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
```

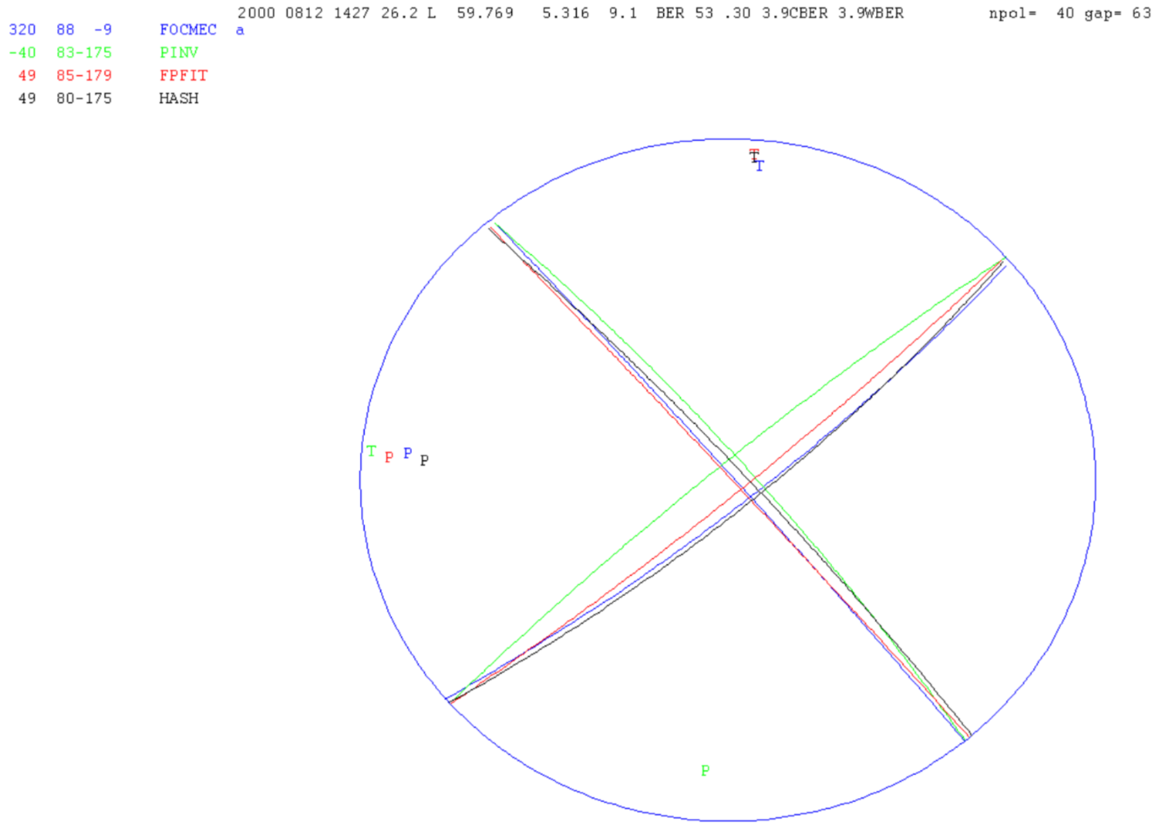
For FPFIT, command is ‘fpfit’:

```
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, defualt 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:’



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         3.2LNAO
 2015 0429 2246 20.7 LQ 59.306   7.076 12.5F BER 62 .90 3.6LBER         3.6LNAO
 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         1.9LNAO
 2021 0524 1802 26.8 LQ 59.837   7.881 12.1F BER 83 .90 2.4LBER 2.7WBER
End of s-file
```

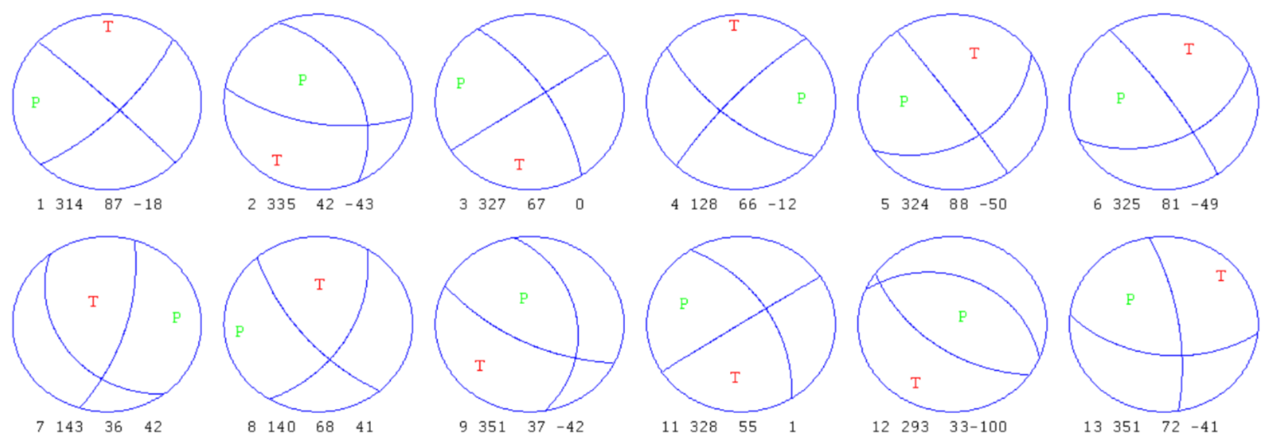
....

Here comes plot seen below.

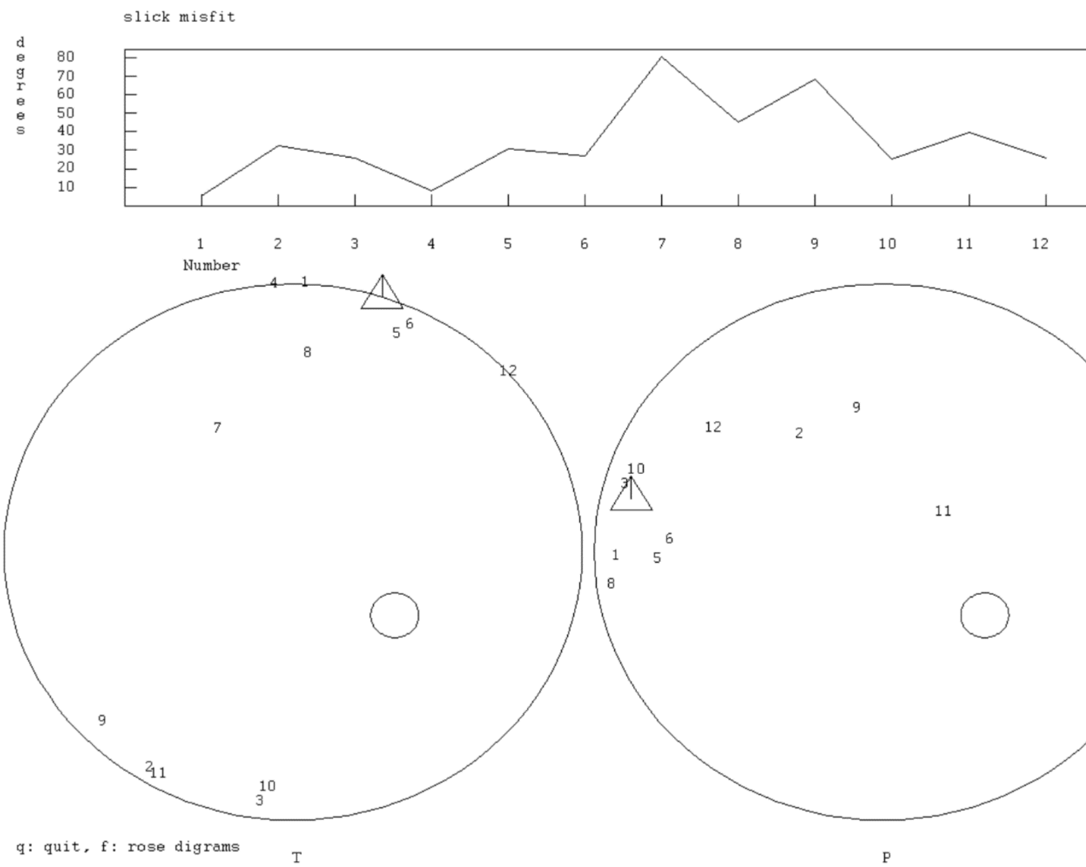
....

```
 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
```

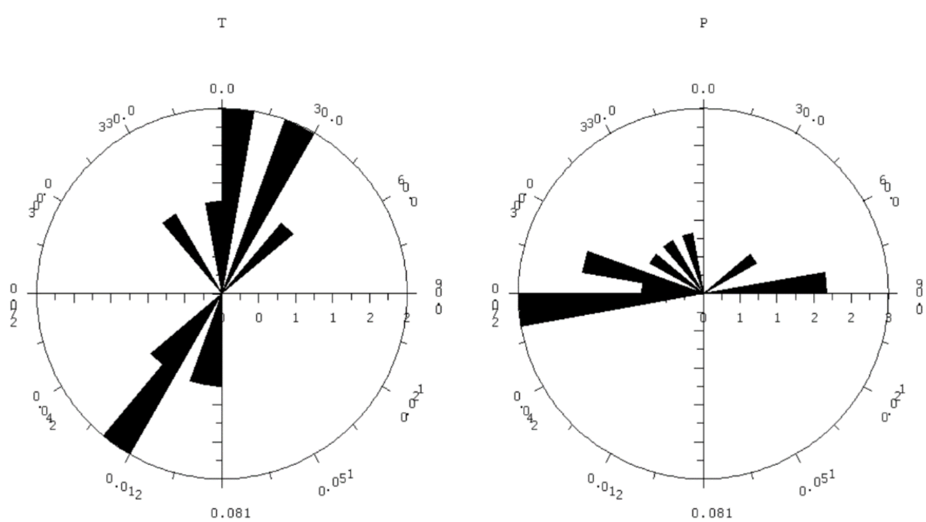
The solutions:



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:

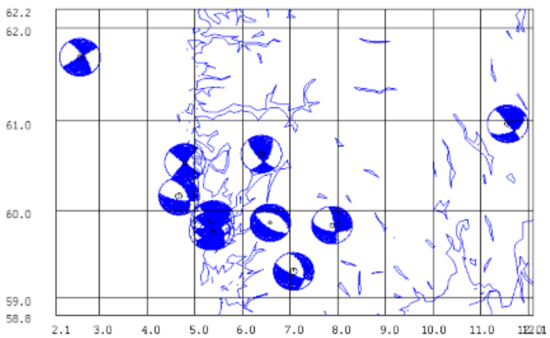


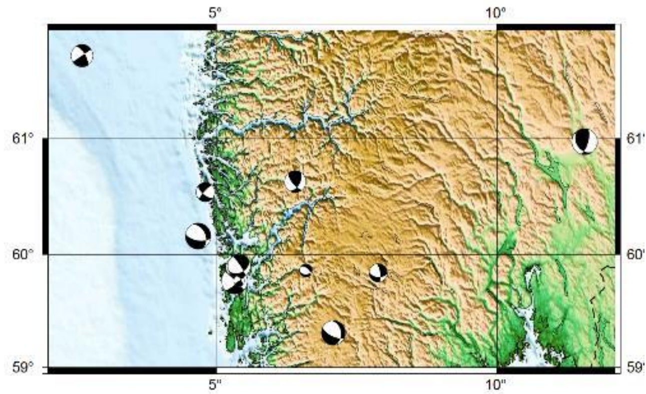
And finally comes the Rose diagram:



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 TimeE L E LatE LonE Dep E F Aga Nsta Rms Gap McA MlA MwA MbA MsA MWA Fp Spec Macro Local MBA MSA
      30  45              20                        10

Date TimeE L E LatE LonE 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				

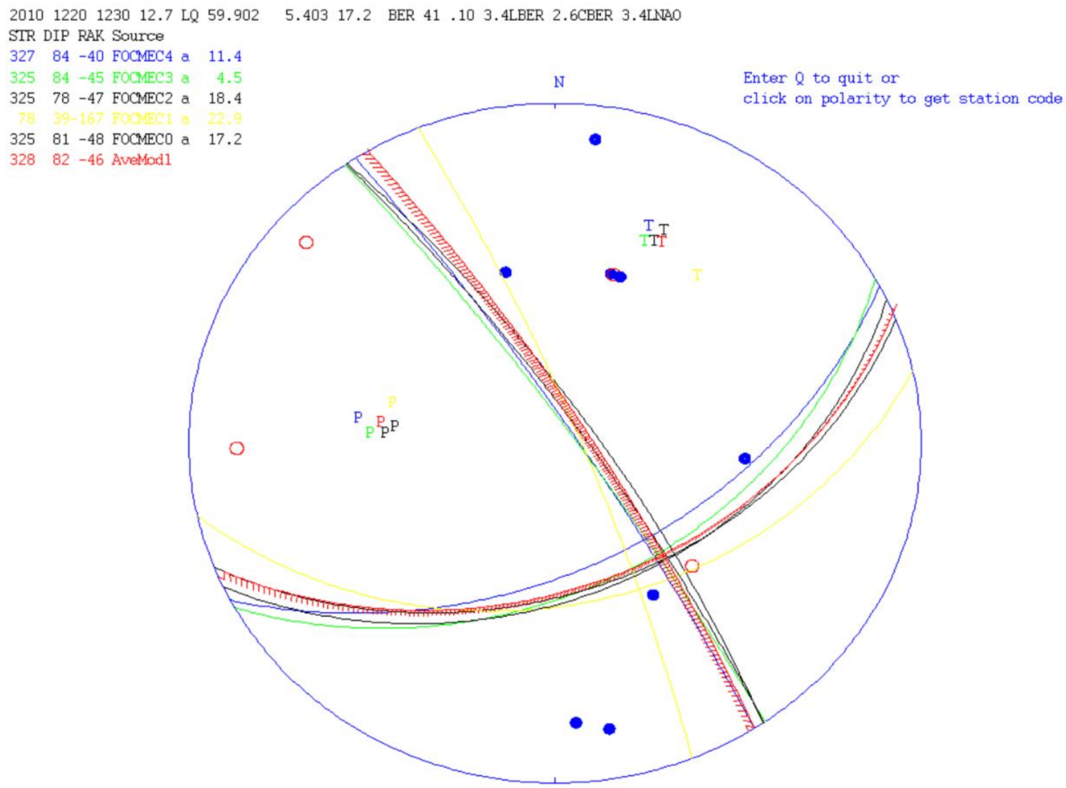
The left column shows P-velocity in (km/s) and the right column the depth (km) to the interface just as they are defined in the SEISAN station file.

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.

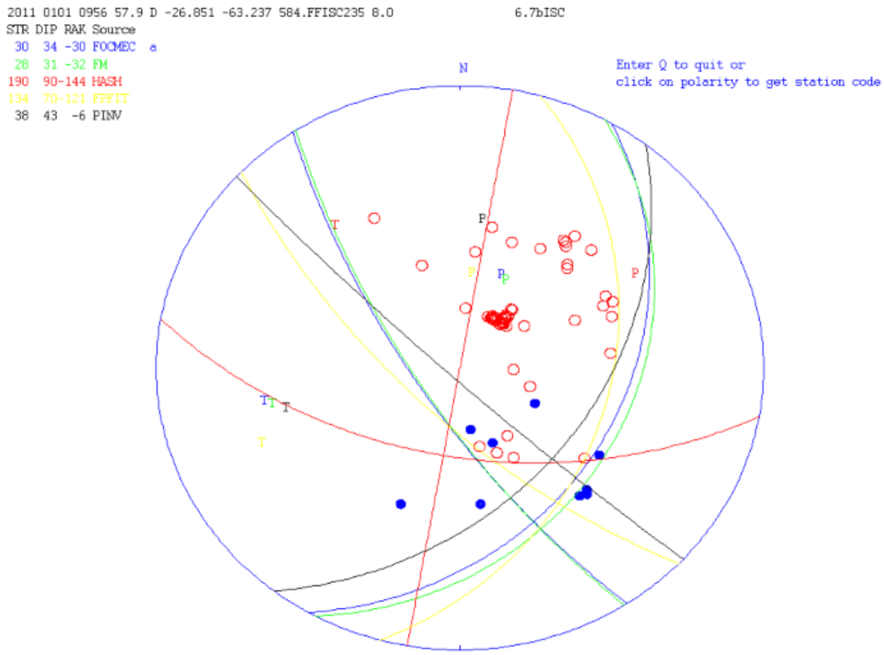
The 5 solutions are now written in the S-file so they can be plotted with 'fo':



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.