Changes made to HYPOCENTER on visit from 6/4/98 to 7/9/98

1. I incorporated all the changes I made to my own version mentioned in my 1997 BSSA paper, including the spherical harmonic station corrections option (disabled by default) and the minute error corrections (enabled by setting test(97)=1: the default is zero), both in hypoloc1. To maintain compatibility with the Bergen version, it was necessary to move the spherical harmonic correction fields in the station data over to the right, as the first of these fields are now used for six magnitude constants. This change should have no effect on existing Bergen stationx.hyp files, only on the ones already containing spherical harmonic corrections, such as the one I gave on my ftp site. The program will crash if one of the old station0.hyp files containing spherical harmonic corrections is used.
2. /no_locate/event1.inp & event2.inp An infinite loop was occurring in hyposub4, line 783 (startloc) caused by one of the latitude/longitude regression start location methods returning an rms of zero. I fixed this problem by limiting the iterations to 30. There was also a problem with distance weighting in startloc. If a starting location was at a distance>xfar from a station, the arrival was weighted to zero, causing an artificially low rms All arrivals were then being weighted to zero by the distance weighting when the start location was >2200 km (the xfar value) away. The program then aborted with a message that there were insufficient non-zero weight arrivals to locate the event. I fixed this problem by temporarily setting xfar=10000 km during startloc, then restoring it to its original value once the starting location was determined. Note that the problem will still occur if the event is REALLY at a distance>xfar from all the stations. However, this can only occur if a distant event is incorrectly labeled as a local event, since distance weighting is not applied to distant events.
3. Changed variable SUM in hyposub4 to double precision. SUM was overflowing in the /no_s/no_s.inp example. This now calculates Sn using IASP91 correctly.
4. /israel/mario.inp. This event locates OK as long as the depth is NOT fixed, HYPOCENTER converges to the correct solution (at zero depth) if the 'E' is removed from the header card. This data is therefore an excellent counter-example to forcing a solution to be at zero depth. I would maintain that a free depth solution is of more value, as it is a very good indicator of how well depth is determined. For example, in my 1997 BSSA paper, the depths of >15 km that I obtained for nuclear explosions in Nevada provided a convincing demonstration that the IASP91 crustal velocities were too high for Nevada. I personally feel that it is bordering on fraudulent to publish a zero depth solution as a valid one, when this is not what is obtained from the data. If people cannot understand this, they do not understand the scientific method. It is a travesty of the method to artificially force mathematical inferences to agree with fact, rather than to admit that the underlying assumptions are imperfect and to address their limitations.
5. I Added a T phase calculation in trtime with the default T phase velocity, test(49), set to 1.48 km/s. Also added L, R & T weights in test(99), test(100) and test(101) with default values of 1, 1 and zero, respectively, to overide the effect of the T phase, while still calculating its residual. To actually use the T phase in location, set test(101)=1.
6. In hypoloc I now calculate the number of different non-zero weight stations in ndiffstat. I then set the error calculation degrees of freedom to 2 if ndiffstat=1. This was causing the error calculation for single-station locations to explode in cases where more than three phases were

present, as in the case in chrash\nevent.inp. I also added some conditions to the start location to stop this event from crashing the program in the apparent velocity regression.

7. I corrected an error in startloc that was preventing the iterative search for minimum rms from occurring after the regression on station coordinates for apparent velocity and azimuth. I also increased the number of steps in the search from 10 to 30. I am now able to locate the two Banda Sea events in distan0.inp using the Norwegian network data. However, I was forced to decrease the default azimuth error, test(52), from 10 to 5 degrees to get one of these events within 100 km of the PDE locations.
8. I checked to see that the requested input phase is used for distant events. The only case where a specified phase will not be calculated is when PKP is specified and it does not exist. In this case, the minimum P phase will be used. It is also important that test(72)=0: if this is >0, the closest valid phase will be used.
9. I added a subroutine, find_delta, in hyposub4, to find the delta corresponding to a slowness value p for a given IASP91 phase. I start with an approximate delta obtained using the formula delta=(10.46-p)/0.067, then use iterative linear extrapolations (20 max) to calculate the IASP91 horizontal derivative using the routine trtm, to obtain a match of the specified p to within a settable difference (presently hard-wired to 0.01). If the input phase to find_delta is blank, the routine will take the first phase having a slowness within a factor of 2 of the input p. Otherwise, all non-blank characters of the input phase are matched. If no phase is found, find_delta returns imatch=0 and the located phase is set to ???? with delta left at the starting value.
10. I changed startloc to determine distance from apparent velocity (either from the station coordinate regression, or given in the input data) using find_delta (with a blank phase input).
11. I added a section at the beginning of hypoloc to calculate a location using a single stations arrival time, azimuth and apparent velocity, using find_delta FOR DISTANT EVENTS ONLY. Errors are all set to zero for this location. I was forced to change the minimum number of phases from 3 to 2 in hyp, as well as at the beginning of hypoloc.
12. Put the include files comm1.inc & param.inc both in hypparm.inc.
    Modified all the routines to accept this change (quite a few variable conflicts, esp. in dtdx2).
    Also the f77 compiler now gives a lot of warning messages for unused declarations.
13. I changed hypoloc1, line 116 to weight duplicate phases to –1. Some of the sample input data had two P phases specified at the same station. Although these were valid P's at three-component stations in some cases, in other cases they were clearly mislabeled, causing problems with the location.
14. I added a screen message "Less than three valid phases for this event at its present location: no result" for the cases where less than three valid phases remain in the solution. This can occur when the specified phases do not exist at the present location (e.g. Pdiff phases for distant events or PN phases for local events at less than the critical distance). Previously, no message appeared to indicate why no location was obtained, which was puzzling to the operator when more than three phases were present.
15. I modified the centering algorithm in rmsv (hypoloc1, line 261) which does the centering after the application of the residual weights. I now use up to three, rather than two passes through statement 8700 to calculate the weighted r.m.s., calculating iweightflag on the first pass to indicate whether or nor residual weighting is to be applied.
16. I modified dtdx2 to make the definition of the test(85), test(86) the LOCAL *a priori* error and degrees of freedom, respectively and test(91) and test(92) the DISTANT values. This makes the

program consistent with the manual (at least the hypoman2.tex version that I have - the older hypo.man doesn't mention these test values)

17. I changed line 920 in hyposub2 to correct an error in the error calculation pointed out by Mario Villagran. The quantity kappa_alpha^2 (equation 15 in my 1995 SSRL paper) should have been multiplied by (np+1), the total degrees of freedom in the solution (four for a free depth solution). This effectively means that the calculated hypocentral errors were as much as factor of two low in HYPOCENTER 3.2 (73% low for fuxed depth solutions).

Examples:

1. Distant event previously located as local

Input data:
```
1997  121 0148 27.9 D  47.832  71.955 33.0F BER  2 0.3 4.4BBER         4.9BPDE1
                0.47     999.9   999.9  0.0 -0.2316E+07  0.0000E+00  0.0000E+00E
 ACTION:UPD 97-09-11 13:23 OP:bms  STATUS:               ID:19970121014717     I
 1997  121  147 15.8 D  39.515  76.931 33.0  PDE        4.9BPDE                1
 9701-21-0154-59S.KNN_003                                                      6
 9701-21-0156-10S.KNN_003                                                      6
 1997  121 0147 18.9 D  39.675  76.709 33.0F NAO  1                     4.5BNAO1
     321  SOUTHERN XINJIANG, CHINA                                             3
 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO SNR AR TRES W  DIS CAZ7
 NB2  SZ  P       0155 28.01         5.8  0.7  87.6 14.036.5  5  0.010 4035 314
 KONO BZ EP        155 36.06                                    -0.410 4147 312
 KONO BZ EpP       155 46.88                                     0.410 4147 312
 KONO LN E         210 58.68                                           4147 312
```

Output with version 3.2
```
date   hrmn   sec      lat      long depth   no m    rms  damp erln erlt erdp ic
97 121  153 50.24 5931.06N  24 26.6E  33.0*   4 2   1.30 0.000999.9581.5  0.0  3

 stn   dist   azm  ain w phas    calcphs hrmn tsec  t-obs  t-cal    res   wt di
 NB2    750 288.7 53.4 0 P       Pn       155 28.0   97.8   97.5   0.27 1.00 33
 NB2    750 288.7        AZ                          87.6   97.2  -9.65 0.10 50
 KONO   837 277.4 53.3 0 P       Pn       155 36.1  105.8  107.8  -1.96 1.00  8
 KONO   837 277.4 53.4 0 pP      pPn      155 46.9  116.6  115.0   1.69 1.00  8
 KONO   837 277.4      0                  210 58.7 1028.4
```

Output with version 4.0

```
date   hrmn   sec      lat      long depth   no m    rms  damp erln erlt erdp ic
97 121  148 27.85 4749.90N  71 57.3E  33.0*   4 2   0.32 0.000999.9999.9  0.0  3

stn   dist   azm  ain w phas    calcphs hrmn tsec  t-obs  t-cal    res   wt di
NB2   4035 314.2 29.9 0 P       P        155 28.0  420.2  420.2   0.01 1.00*31
NB2   4035 314.2        AZ                          87.6   83.0   4.58 0.10 42
KONO  4147 312.1 29.7 0 P       P        155 36.1  428.2  428.6  -0.39 0.99*20
KONO  4147 312.1 29.7 0 pP      pP       155 46.9  439.0  438.6   0.38 1.00* 7
KONO  4147 312.1      0                  210 58.7 1350.8
```

This event was previously located as a local event 5000 km from the PDE solution. However, with a much better start location using the NB2 apparent velocity, it now locates to within 800 km of the PDE solution.

2. Local Event

Input data:

```
1998  1 1 0017 17.8 LP 67.937  20.450   .0F BER  3 1.1 2.5CBER 1.5LBER       1
                2.78      12.7    36.4   .0  -.3056E+03   .0000E+00   .0000E+00E
 ACTION:UPD 98-06-26 10:40 OP:bms  STATUS:               ID:19980101001717     I
 9801-01-0016-45S.NSN_015                                                      6
 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO SNR AR TRES W  DIS CAZ7
 KTK1 SZ EP        017 43.02  143                                 -.810  165  42
 KTK1 SZ ES        018  4.39                                      1.310  165  42
 KTK1 SZ E         018  7.77        7.8  0.2                             165  42
 TRO  SZ EP        017 46.45   95                                -1.510  199 342
 TRO  SZ ES        018 11.00                                       .710  199 342
 TRO  SZ E         018 12.61        8.5  0.5                             199 342
 MOR8 SZ EP        018  0.65  101                                -1.010  309 236
 MOR8 SZ ES        018 35.43                                      1.310  309 236
```

Output with version 3.2

```
date   hrmn   sec      lat      long depth   no m    rms  damp erln erlt erdp ic
98 1 1  017 17.79 6756.25N  20 27.0E   0.0*   6 2   1.15 0.000 21.0  7.3  0.0  3

 stn   dist   azm  ain w phas    calcphs hrmn tsec  t-obs  t-cal    res   wt di
 KTK1   165  42.3 50.4 0 P       PN4      017 43.0   25.2   26.0  -0.80 1.00 11
 KTK1   165  42.3 50.4 0 S       SN4      018  4.4   46.6   45.3   1.31 1.00 21
 KTK1   165  42.3      0                  018  7.8   50.0
 TRO    199 342.5 50.4 0 P       PN4      017 46.5   28.7   30.2  -1.53 1.00  4
 TRO    199 342.5 50.4 0 S       SN4      018 11.0   53.2   52.5   0.67 1.00 31
 TRO    199 342.5      0                  018 12.6   54.8
 MOR8   309 236.1 50.4 0 P       PN4      018  0.7   42.9   43.9  -0.99 1.00 11
 MOR8   309 236.1 50.4 0 S       SN4      018 35.4   77.6   76.3   1.34 1.00 22
```

Output with version 4.0

```
date   hrmn   sec      lat      long depth   no m    rms  damp erln erlt erdp ic
98 1 1  017 17.79 6756.25N  20 27.0E    .0*   6 2   1.15  .000 36.4 12.7   .0  3

 stn   dist   azm  ain w phas    calcphs hrmn tsec  t-obs  t-cal    res   wt di
 KTK1   165  42.3 50.4 0 P       PN4      017 43.0   25.2   26.0   -.80 1.00 11
 KTK1   165  42.3 50.4 0 S       SN4      018  4.4   46.6   45.3   1.31 1.00 21
 KTK1   165  42.3      0                  018  7.8   50.0
 TRO    199 342.5 50.4 0 P       PN4      017 46.5   28.7   30.2  -1.53 1.00  4
 TRO    199 342.5 50.4 0 S       SN4      018 11.0   53.2   52.5    .67 1.00 31
 TRO    199 342.5      0                  018 12.6   54.8
 MOR8   309 236.1 50.4 0 P       PN4      018   .7   42.9   43.9   -.99 1.00 11
 MOR8   309 236.1 50.4 0 S       SN4      018 35.4   77.6   76.3   1.34 1.00 22
```

The locations are identical for the two versions, but the errors have increased 70% in version 4.0 due to the change in the error calculation algorithm described earlier