Dist_3D: adding Ry0_nga, adding the option of the reference and station locations in Cartesian coordinates, and testing the resulting revised program

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Working in C:\forprogs\develop\test_dist_3d, I revised dist_3d and associated subroutines. These notes document the results.

The test case used these three faults. With the location of the reference point as shown in the stars in Figure 1, I checked the program outputs of rx_nga, ry0_nga, az_nga, r_jb, and a few r_rup by hand, drawing lines on maps printed in CoPlot and measuring distances by hand using a Gerber scale and angles with a protractor. I include scans of the maps (Figures 2, 3, and 4). I compared the results with the dist_3d output files. I found good agreement.

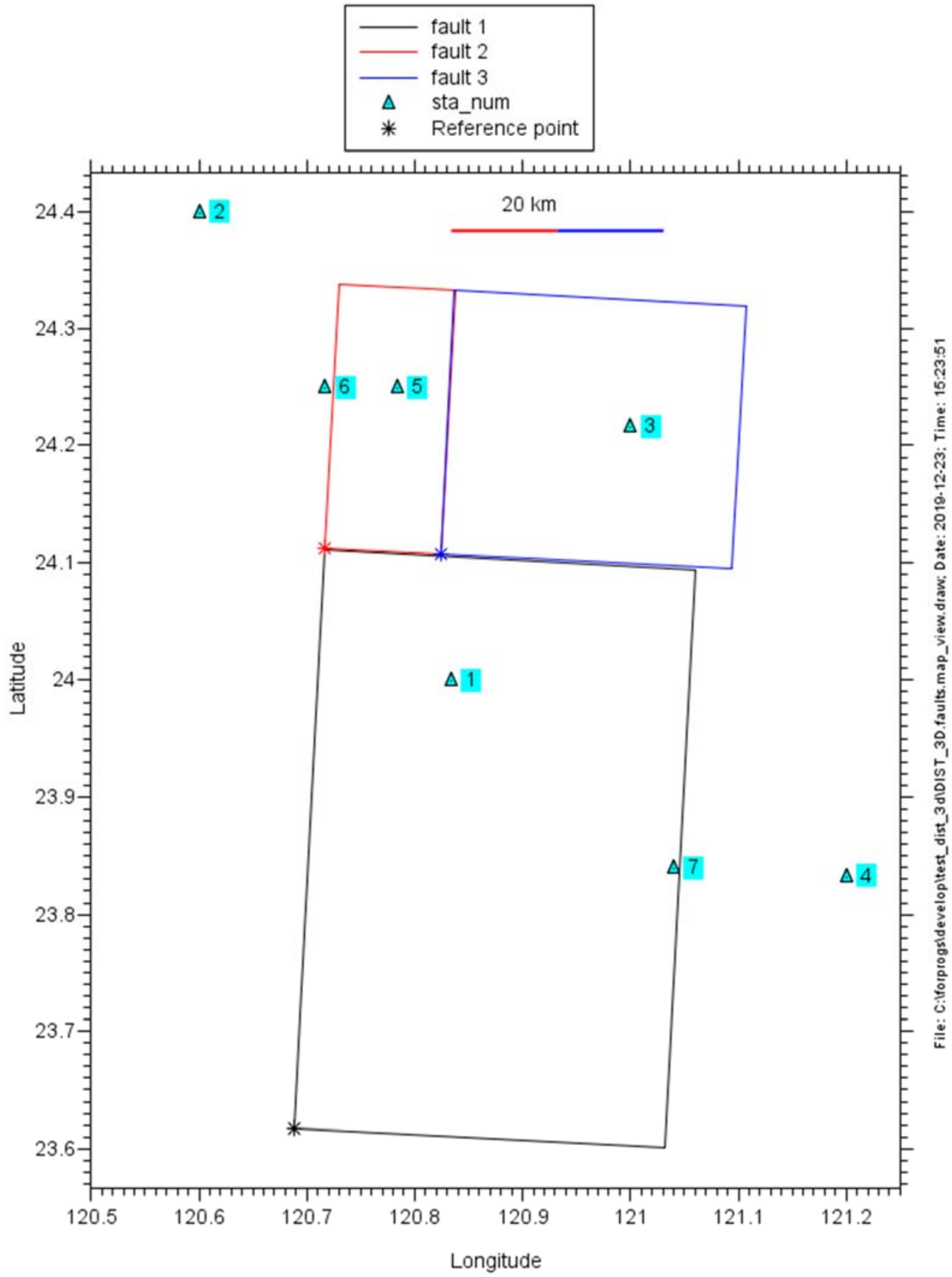

fault 1
fault 2
fault 3
sta_num
Reference point
20 km
Latitude
Longitude
File: C:\forprogs\develop\test_dist_3d\DIST_3D.faults.map_view.draw; Date: 2019-12-23; Time: 15:23:51

Figure 1.

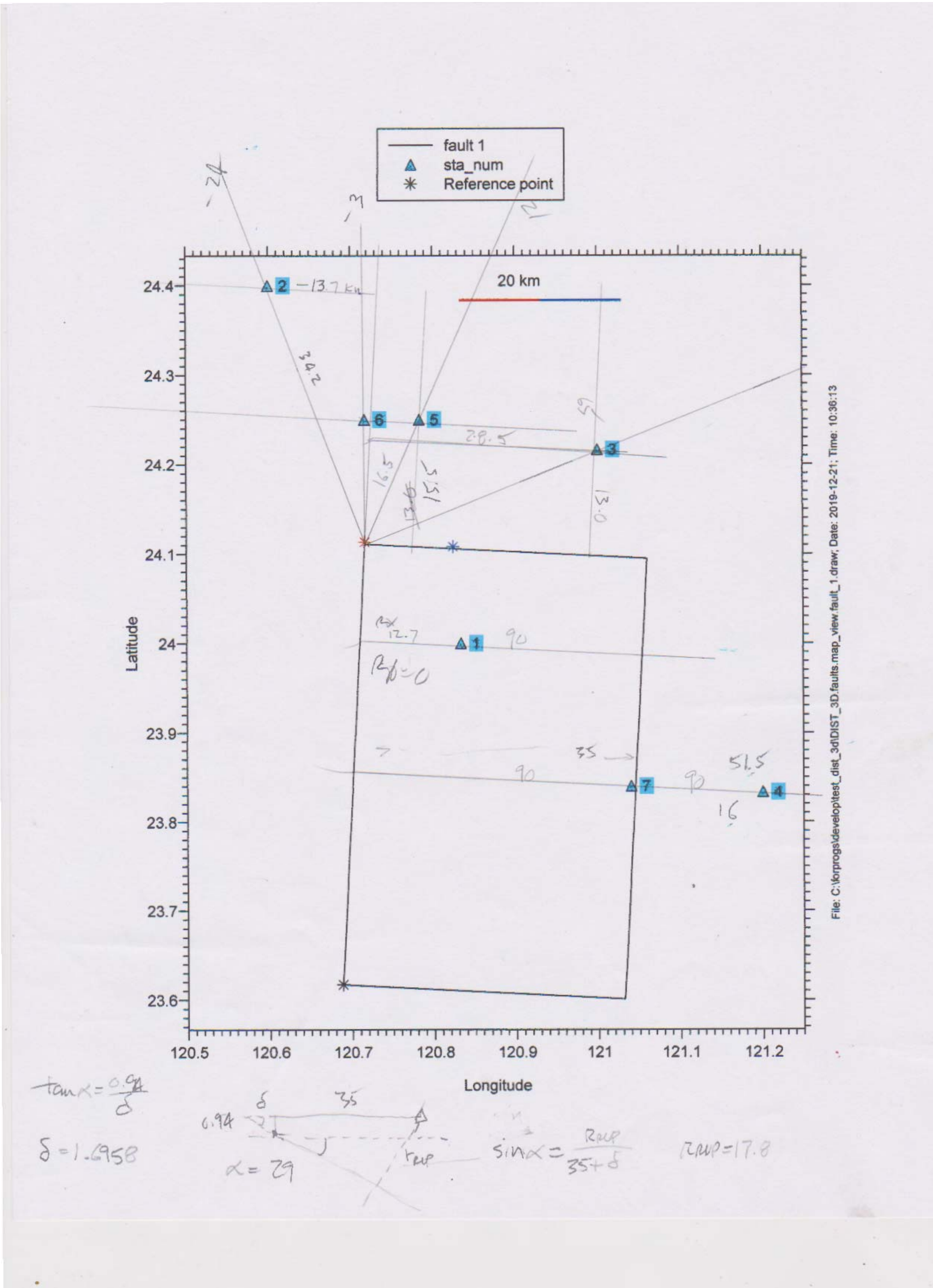
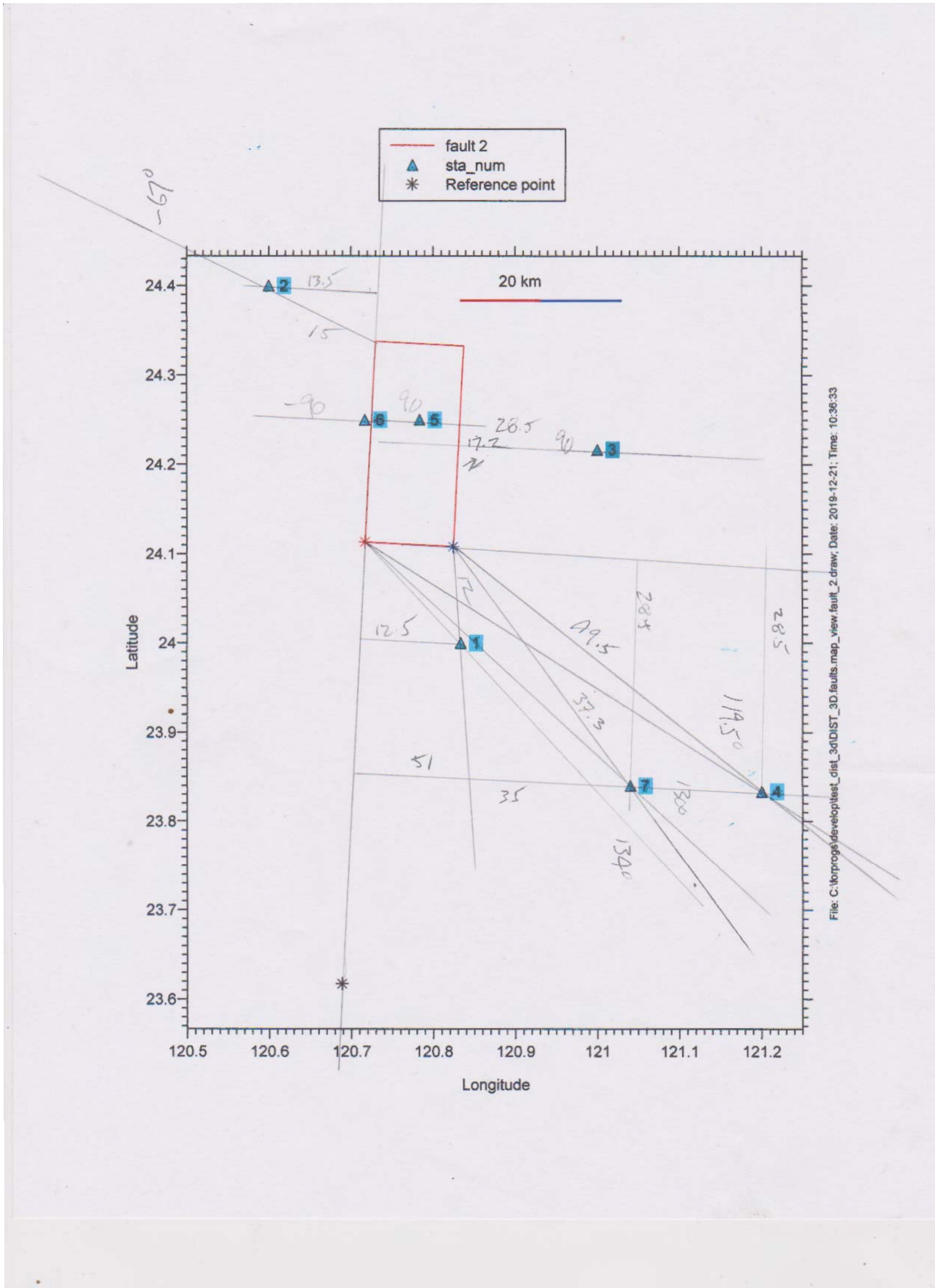

fault 1
sta_num
Reference point
20 km
Latitude
Longitude
File: C:\forprogs\develop\test_dist_3d\DIST_3D.faults.map_view.fault_1.draw; Date: 2019-12-21; Time: 10:36:13

Figure 2.



fault 2
sta_num
Reference point
20 km
Latitude
Longitude
24.4
24.3
24.2
24.1
24
23.9
23.8
23.7
23.6
120.5
120.6
120.7
120.8
120.9
121
121.1
121.2

Figure 3.

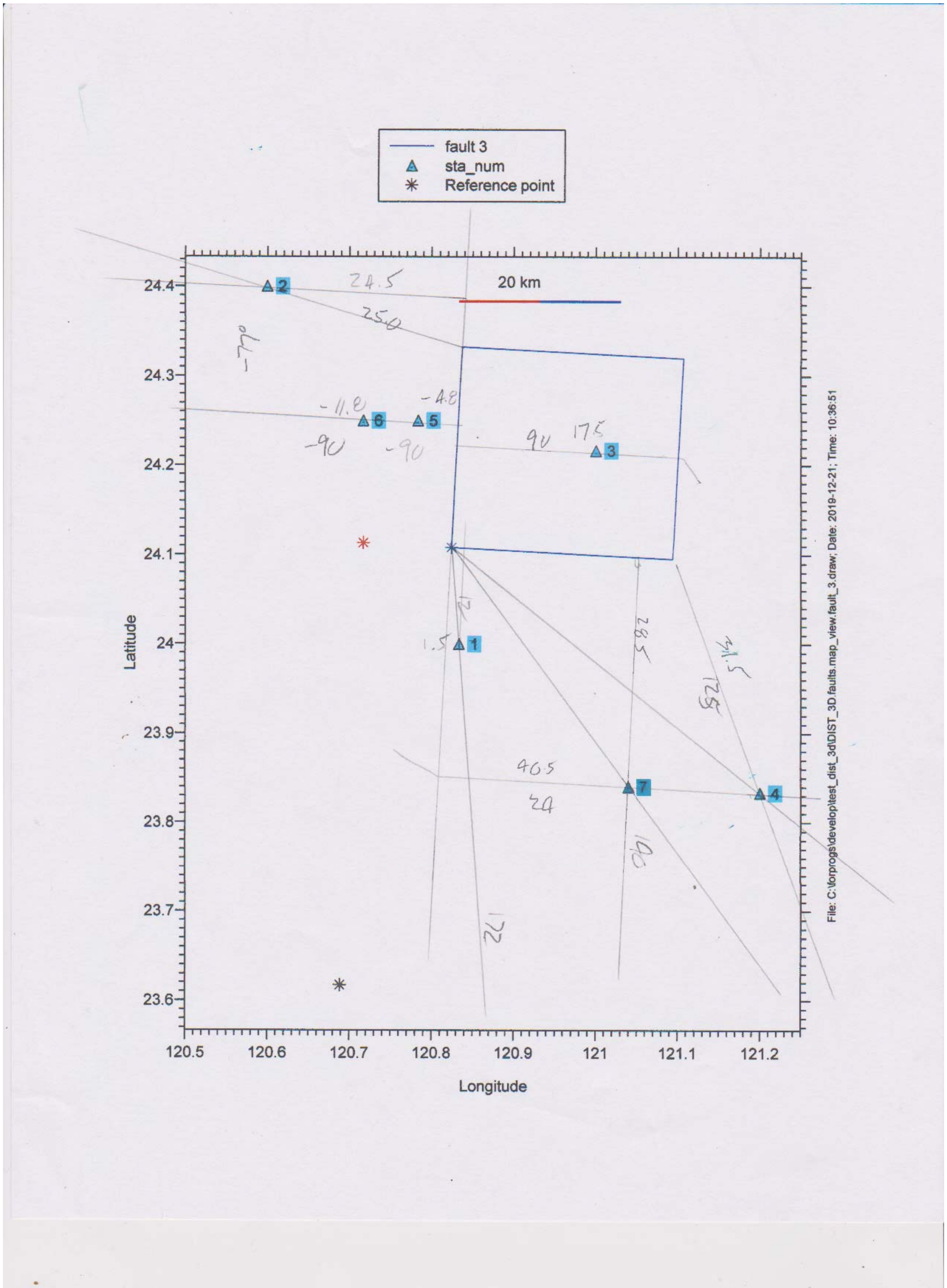

fault 3
sta_num
Reference point
20 km
Latitude
Longitude
24.4
24.3
24.2
24.1
24
23.9
23.8
23.7
23.6
120.5
120.6
120.7
120.8
120.9
121
121.1
121.2
1
2
3
4
5
6
7
File: C:\forprogs\develop\test_dist_3d\DIST_3D.faults.map_view.fault_3.draw; Date: 2019-12-21; Time: 10:36:51

Figure 4.

The results are given in dist_3d.out.geographic_coords.19dec19.reformatted (reformatted to make a landscape mode print more readable). Here is the file:

```
Output of program Dist_3D, using control file dist_3d.ctl

!Minimum Depth for Campbell:

 3.00000000

!Number of Fault Segments:

 3

!Are reference point and station coordinates in Cartesian coordinates (Y/N)?

 N

!  Enter coordinates in this order

!  if Y: N, E coordinates from some arbitrary origin (not necessarily the
refere

!        which can be different for each fault segment)

!  if N: latitude, longitude (positive to the east)

!  NOTE: The coordinates are referred to as "N" and "E" below, even if the
coord

!  are latitude and longitude.  I was going to use "X" and "Y", but those
variab

!  are already used in the programs to mean different things, and I did not
want

!  to add to the confusion.  Besides, "N" and "E" have the same general
meaning

!  direction from an origin to a point for both Cartesian and geographic
coordin

!

!Reference Point and Fault Orientation (ref N, E, elev(m), depth, strike,
dip, s

! depth, s1, s2, w1, w2 have units of kilometers

! NOTE this requirement on the reference point coordinates: it must be on the

!   planar surface containing the rectangular area that is assumed to have
ruptu

!   The reference point need not be on the ruptured surface, although for
simpli

!   I recommend that it be some well defined point on the rupture surface,
such

!   or one of the corners of the rectangle approximating the rupture surface.
```

```
! NOTE this requirement on the fault dimensions: s1<s2, w1<w2

! s1 and s2 are determined by looking along strike from the reference point.

! w1 and w2 are distances updip and downdip from the reference point.

!Reference Point and Fault orientation

     ref_N      ref_E ref_elev ref_depth  strike     dip      s1      s2
w1      w2

  23.61719  120.68854      0.0      0.94    3.00   29.00    0.00   55.00
0.00   40.00

  24.11315  120.71685      0.0      0.94    3.00   29.00    0.00   25.00
0.00   12.50

  24.10797  120.82414      0.0      7.00    3.00    5.00    0.00   25.00
0.00   27.50

!

!Results

!

!  The results for one station per line.

!  Following the station information are distances!  for all of the fault
segments, computed as the minimum

!  over all fault segments of the same distance measure for each segment.

!  This is followed by results for each fault segment,

!  including the icase defined in Figure 4 of Kaklamanos

!  et al.,2011, Earthq.Spectra 27, p. 1219-1235.

!  icase can be used to determine if a station is on the hanging or footwall
side of the fault:

!    foot wall: icase = 1, 4, or 7

!    hanging wall: icase = 2, 3, 5, 6, 8, or 9

!  az_jb (defined in Kaklamanos et al., with "alpha" as the variable name),
is an easier way to determine this:

!    foot wall: az_jb < 0

!    hanging wall: az_jb < 0

!  rx_nga is another way to determine this (and useful on some recent GMPEs):

!    foot wall: rx_nga < 0

!    hanging wall: rx_nga < 0

!  az_jb is defined as alpha in Kaklamanos et al.

!  ry0_nga is used to taper the Abrahamson et al. hanging wall effect; see p.
1040 of Abrahamson et al., EqSpectra 30, 1025-1055.

!
```

```
 sta_num                                                     sta_info
sta_N      sta_E sta_elev

      1                                                 above Fault 1
24.00000  120.83333      0.0

      2                                             upper left corner
24.40000  120.60000      0.0

      3                                                 above Fault 3
24.21666  121.00000      0.0

      4                             halfway up and east of Fault 1
23.83333  121.20000      0.0

      5                                                 above Fault 2
24.25000  120.78333      0.0

      6                               hanging wall side of Fault 2
24.25000  120.71666      0.0

      7                                above lower edge of Fault 1
23.84000  121.04000      0.0

r_ref2sta_horiz r_ref2sta_slant   r_rup r_cmpbl    r_jb   rx_nga ry0_nga

          44.86           44.87    6.90    6.90    0.00    1.56   11.89

          87.12           87.12   14.87   18.54   14.84  -24.45    0.00

          73.53           73.54    8.47    8.47    0.00   17.22    0.00

          57.35           57.36   25.80   25.80   15.89   39.75   28.38

          70.71           70.71    3.71    3.71    0.00   -4.97    0.00

          70.10           70.11    1.24    5.43    0.81  -11.74    0.00

          43.48           43.49   17.56   17.56    0.00   23.47   28.49

fault_1:r_rup r_cmpbl    r_jb rx_nga_segs ry0_nga_segs   az_jb icase

         6.90    6.90    0.00       12.54         0.00   90.00     5

        33.94   35.71   33.93      -13.56         0.00  -23.56     1

        19.47   19.47   12.96       28.27        12.96   65.36     2

        25.80   25.80   15.89       50.87         0.00   90.00     6

        15.94   15.94   15.49        5.99        15.49   21.15     2

        15.19   16.08   15.16       -0.80         0.00   -3.03     1

        17.56   17.56    0.00       34.53         0.00   90.00     5

fault_2:r_rup r_cmpbl    r_jb rx_nga_segs ry0_nga_segs   az_jb icase

        13.74   13.74   12.00       12.48        11.90  133.62     9

        14.87   18.54   14.84      -13.53         0.00  -65.71     1

        18.58   18.58   17.21       28.15         0.00   90.00     6

        49.33   49.33   48.83       50.67        28.38  119.25     9
```

```
         3.71    3.71    0.00        5.96        0.00   90.00     5
         1.24    5.43    0.81       -0.81        0.00  -90.00     4
        37.56   37.56   36.91       34.39       28.49  129.64     9
fault_3:r_rup r_cmpbl    r_jb rx_nga_segs ry0_nga_segs   az_jb icase
        13.86   13.86   11.89        1.56       11.89  172.53     8
        26.16   26.16   25.20      -24.45        0.00  -75.98     1
         8.47    8.47    0.00       17.22        0.00   90.00     5
        32.35   32.35   30.95       39.75       28.38  125.52     9
         8.58    8.58    4.97       -4.97        0.00  -90.00     4
        13.67   13.67   11.74      -11.74        0.00  -90.00     4
        29.88   29.88   28.49       23.47       28.49  140.52     8
```

I then test the dependence of the results on the choice of reference location. I did this only for Fault 1. I chose station 1 as the new reference, and did some hand calculations to determine the depth, s1, s2, w1, and w2 for the reference. Figure 5 shows the map with my calculations.

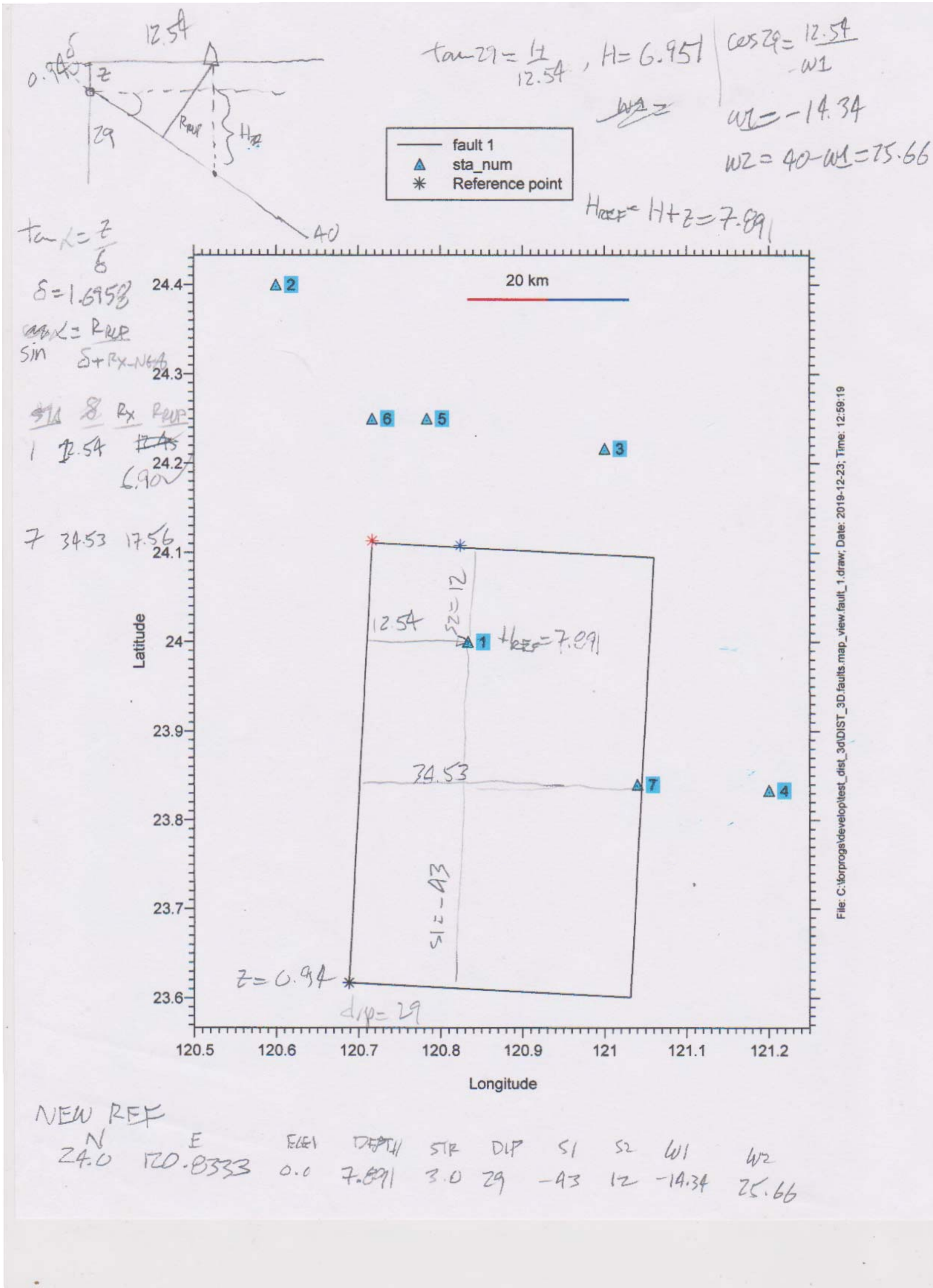


Figure 5. This also includes hand calculations of Rrup for stations 1 and 7.

The results are in dist_3d.out.geographic_coords.fault_1.ref_at_sta_1.reformatted. Here is a comparison of the results for both reference locations:

```
Reference at fault corner:

fault_1:r_rup r_cmpbl    r_jb rx_nga_segs ry0_nga_segs   az_jb icase
         6.90    6.90    0.00       12.54         0.00   90.00     5
        33.94   35.71   33.93      -13.56         0.00  -23.56     1
        19.47   19.47   12.96       28.27        12.96   65.36     2
        25.80   25.80   15.89       50.87         0.00   90.00     6
        15.94   15.94   15.49        5.99        15.49   21.15     2
        15.19   16.08   15.16       -0.80         0.00   -3.03     1
        17.56   17.56    0.00       34.53         0.00   90.00     5

Reference at station 1:

fault_1:r_rup r_cmpbl    r_jb rx_nga_segs ry0_nga_segs   az_jb icase
         6.90    6.90    0.00       12.54         0.00   90.00     5
        33.82   35.58   33.81      -13.49         0.00  -23.51     1
        19.38   19.38   12.85       28.22        12.85   65.52     2
        25.74   25.74   15.78       50.77         0.00   90.00     6
        15.83   15.83   15.38        6.01        15.38   21.35     2
        15.08   15.97   15.05       -0.76         0.00   -2.90     1
        17.53   17.53    0.00       34.47         0.00   90.00     5
```

There are small differences, perhaps due to the precision of the new reference and fault parameters that I determined. But the results are similar enough that I take this as confirming that the results do not depend on the reference location.

Finally, I checked the program results when the reference and station locations are in Cartesian coordinates. I used deg2km.for to convert the geographic to Cartesian coordinates, with these results:

```
Ref->S1

 Ref. lat, long. =    23.61719  120.68854

 vlat, vlong =    24.00000  120.83333

 Using Richter tables: Distance north, east, dist (km) =    42.39586
14.77637   44.89711

 Using sphere approx : Distance north, east, dist (km) =    42.56660
14.72986   45.04314


Ref->S2

 Ref. lat, long. =    23.61719  120.68854

 vlat, vlong =    24.40000  120.60000

 Using Richter tables: Distance north, east, dist (km) =    86.69539   -
9.03571   87.16499

 Using sphere approx : Distance north, east, dist (km) =    87.04453   -
8.99335   87.50788


Ref->S3

 Ref. lat, long. =    23.61719  120.68854

 vlat, vlong =    24.21666  121.00000

 Using Richter tables: Distance north, east, dist (km) =    66.39067
31.78577   73.60745

 Using sphere approx : Distance north, east, dist (km) =    66.65804
31.65925   73.79432


Ref->S4

 Ref. lat, long. =    23.61719  120.68854

 vlat, vlong =    23.83333  121.20000

 Using Richter tables: Distance north, east, dist (km) =    23.93736
52.19613   57.42328

 Using sphere approx : Distance north, east, dist (km) =    24.03375
52.06519   57.34462
```

```
Ref->S5
 Ref. lat, long. =    23.61719  120.68854
 vlat, vlong =    24.25000  120.78333
 Using Richter tables: Distance north, east, dist (km) =    70.08309
9.67417   70.74765
 Using sphere approx : Distance north, east, dist (km) =    70.36533
9.63441   71.02184


Ref->S6
 Ref. lat, long. =    23.61719  120.68854
 vlat, vlong =    24.25000  120.71666
 Using Richter tables: Distance north, east, dist (km) =    70.08309
2.86994   70.14183
 Using sphere approx : Distance north, east, dist (km) =    70.36533
2.85815   70.42335


Ref->S7
 Ref. lat, long. =    23.61719  120.68854
 vlat, vlong =    23.84000  121.04000
 Using Richter tables: Distance north, east, dist (km) =    24.67605
35.86800   43.53643
 Using sphere approx : Distance north, east, dist (km) =    24.77542
35.77711   43.51808


stop
```

And here is a comparison of the results for Fault 1:

```
Using geographic coordinates:
fault_1:r_rup r_cmpbl    r_jb rx_nga_segs ry0_nga_segs   az_jb icase
         6.90    6.90    0.00       12.54         0.00   90.00     5
        33.94   35.71   33.93      -13.56         0.00  -23.56     1
        19.47   19.47   12.96       28.27        12.96   65.36     2
```

```
        25.80   25.80   15.89       50.87         0.00   90.00     6
        15.94   15.94   15.49        5.99        15.49   21.15     2
        15.19   16.08   15.16       -0.80         0.00   -3.03     1
        17.56   17.56    0.00       34.53         0.00   90.00     5
Using Cartesian coordinates:
fault_1:r_rup r_cmpbl    r_jb rx_nga_segs ry0_nga_segs   az_jb icase
         6.90    6.90    0.00       12.54         0.00   90.00     5
        33.94   35.71   33.93      -13.56         0.00  -23.56     1
        19.47   19.47   12.96       28.27        12.96   65.36     2
        25.80   25.80   15.89       50.87         0.00   90.00     6
        15.94   15.94   15.49        5.99        15.49   21.15     2
        15.19   16.08   15.16       -0.80         0.00   -3.03     1
        17.56   17.56    0.00       34.53         0.00   90.00     5
```

The results are identical.