Notes from ISC Data Users

Using ISC Data

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Excerpt from the
Summary of the Bulletin of the International Seismological Centre:

Havskov, J. and Lieser, K. (2021), Using ISC Data, *Summ. Bull. Internatl. Seismol. Cent.*, January – June 2019, *56*(I), pp. 30–46, `https://doi.org/10.31905/L2IR6ZNA`.

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5.1 Using ISC Data

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It is well known the ISC has the most complete database of seismic event parameter data available anywhere and it also has the most complete catalogue of epicenters. The ISC will receive and store any data that is submitted so the ISC can also function as a useful backup for individual agencies. All that data is available online. Currently there are more than 27000 stations registered in the International Seismograph Station Registry and there has been a large increase in data received by ISC since it was founded in 1964 (see Figs. 7.3 and 7.7). To review all data available today would be too time-consuming and therefore, currently only events larger than magnitude 3.5 and a few others smaller than 3.5 under specific conditions (see Chapter 10.1 ISC Operational Procedures in Appendix, p. 110) are reviewed and/or relocated and magnitudes recalculated. For unreviewed events, only the hypocentres and magnitudes from the submitting agencies are given while for reviewed events ISC magnitudes and hypocentres are given in addition, if available. This of course is mostly the case for distant events. In addition, not all data is used in the reprocessing such as some amplitudes and back azimuths. While the hypocentres and magnitudes calculated by the ISC are very uniform, some associated data is less so (e.g., amplitudes that are reported by different agencies with different standards). Therefore, extracting a data set comprised of reviewed and unreviewed events will result in a non uniform data set and reprocessing it to make it uniform requires some filtering. In this note we will give some guidelines on how this can be done and give some examples.

The user can take out data from the ISC Bulletin in two formats: ISF (see Example 1) (`http://www.isc.ac.uk/standards/isf/`) and QuakeMl (`https://quake.ethz.ch/quakeml/`). The extracted ISC data will be illustrated using the most used ISF format. Some of the converted data is tested with SEISAN (*Havskov et al.*, 2020) which has software to convert ISF format to SEISAN (`http://seisan.info`).

5.1.1 Hypocentres

How the ISC is processing: The ISC reviews all events above M3.5 and certain events between 2.5 and 3.5 dependent on azimuthal gap, number of reported phases and number of reporting agencies. However, during review, tiny local events can also become reviewed events, e.g., when it is needed to move phases out into larger events. But not all reviewed events have an ISC hypocentre. At least two different agencies must report phases and an azimuthal gap of less than 315 degrees is required for an event to qualify for an ISC solution. If the event does not meet the criteria for an ISC solution the event is fixed to an agency hypocentre, i.e. residuals are calculated with the ak135 velocity model (*Kennett et al.*, 1995) where the hypocentre parameter of an agency are used (origin time, RMS, latitude, longitude, depth etc.) and the phase names are changed according to ak135. If several hypocentres are available one will be designated the prime hypocentre. If an ISC solution is available this will usually be the prime hypocentre (see Example 1), except for some rare cases where the IASPEI solution for reference events was set as prime for nuclear explosions. If there is no ISC solution the prime is found by a score based on the network coverage. Should this not be available it is essentially random.

There are some exceptions to these rules regarding IDC (International Data Center of CTBTO). All events reported by IDC are reviewed and unless IDC is the only hypocentre author with less than six associated seismic phases in an event, the ISC will try to calculate an ISC hypocentre.

In short: every ISC solution is reviewed but not all reviewed events have an ISC solution. Reviewed events will show residuals according to ak135 while unreviewed events are not relocated and will not show residuals even if the reporting agency has reported any residuals. For more details see ISC Operational Procedures (Appendix).

If, for a particular area, the user takes out a mixture of reviewed and unreviewed events, the data set will not be uniform since different programs and earth models might have been used by the several reporting agencies. To create a uniform data set it must be relocated as not all reported hypocentres have been calculated with ak135 and unreviewed events do not show any residuals. That can lead to problems with phase names, see next section. Note that when searching the ISC Bulletin for a particular area and an event has several hypocentres, the event will be selected if any of the hypocentres are within the selected area. Similarly, if any of the magnitudes are within the given range, the event will be selected. However, there is an option to only take magnitudes determined by a specific author into account.

Recommendation: Use the prime solution. However be aware that the prime hypocentre in an unreviewed event with several reporting agencies might not always be the best fitting solution and the quality can only be judged by reviewing it after relocation. It should also be mentioned that not all agencies send all of their station data to the ISC and an agency's hypocentre might have been calculated with more stations available to the local agency than is shown in the ISC Bulletin.

5.1.2 Seismic Phases

The IASPEI Commission on Seismological Observation and Interpretation (*Storchak et al.*, 2003, `http://www.isc.ac.uk/standards/phases/`) has given a recommended list of official phases that should be used in reporting. The identification of phases varies a great deal between the currently 150 reporting agencies. The ISC location program, ISCloc (*Bondar and Storchak*, 2011) will reinterpret the phase type so it best fits the ak135 model used for location which will make the phase identification more uniform for reviewed events. The original phase names provided by the agencies are stored and the user can get them by extracting data in QuakeMl format but not in the ISF format. The original data files submitted to the ISC can be found online on the agency web pages of the ISC web site: `http://www.isc.ac.uk/iscbulletin/agencies/`.

The ISC uses a relative weighting scheme to ensure that arrivals picked less reliably or prone to phase identification errors are down-weighted in the location algorithm (see *Bondar and Storchak*, 2011; ISCloc manual (`http://www.isc.ac.uk/iscbulletin/iscloc/`) and ISC Operational Procedures (Appendix)). Reported weights and weights calculated by ISCloc are not provided and the only indication on a high or low weight is if the phase is flagged as time defining or not. Note that phase weights reported by the agencies are not used.

ISCloc is allowed to re-interpret phases in every distance range, e.g., P phases can become Pn, Pb, Pg, PP, PnPn, PKiKP, Pdif, PcP, PKP(ab/bc/df) etc as well as depth phases, with a similar set up for S phases. There are certain rules to that, e.g., depth phases cannot be set as first arrivals by ISCloc or P phases cannot be renamed as S phases. An analyst can fix a phase to every available phase name manually though. Some agencies report their phases as just P, even if they are actually a PP, PKPbc or PKiKP phase and thus ISCloc needs to be flexible. Obviously, this can go wrong and will be fixed during review by an analyst. Only P and S type phases are used for location and phases like Lg and T are not used. If residuals are larger than 60 s the phase is treated as unidentified. For more details see ISCloc manual (`http://www.isc.ac.uk/iscbulletin/iscloc/`). ISCloc will take all IASPEI phases into account but not all phases necessarily become time defining. This depends on the weighting algorithm in ISCloc, e.g., very large residuals are rejected. Phases not contributing (meaning weighted out) will not have a time defining flag but the residuals will be calculated. Example 1 shows an event where some phases are time-defining while others are not: Pn on station SRK with a residual of -5.1 s was not used in the location, while PETK Pn with -1.5 s residual contributed to the solution as can be seen by the time defining flag T in column Def.

Example 1: Event where some phases are time-defining while others are not (ISF format). The abbreviations and units in this and the following (ISF) examples are: Err - origin time error, Smaj and Smin - semi major and minor axis of the epicenter error ellipse in km, Az - azimuth of error ellipse (degree), Depth (km), f for fixed, Ndef - number of defining phases, Nsta - number of defining stations, Gap - azimuthal gap (degree), Mdist - distance to closest station (degree), Qual (hypocentre) - analysis type and location method, Author - author of origin, Sta - station, Dist - epicentral distance (degree), EvAz - azimuth from event to station (degree), Tres - travel time residual (s), Azim - back azimuth (degree), Slow - slowness (s/degree), Sres - slowness residual (s/degree), Def - T is time defining flag, SNR - signal to noise ratio, Amp - amplitude (nm), Per - period of amplitude (s), Qual (phases) - direction of motion, manual (m) or automatic (a), onset quality, Magnitude - showing both the type and the value. Standards and formats can be found here: `http://www.isc.ac.uk/standards/`

```
Event 13918462 Kuril Islands
Date       Time        Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author
2009/10/01 00:23:28.90                46.3900  153.3400                 49.0
     SKHL
2009/10/01 00:23:29.50  0.70          46.8400  152.8900   8.9   8.4  -1  30.0                                        JMA
2009/10/01 00:23:32.00  1.06          46.6490  152.7380  13.6   8.2  53  53.0              28                        MOS
2009/10/01 00:23:33.83  0.60 0.740    46.6669  152.6732  18.9  10.8 155  49.4    4.7   31       136   7.22  78.40     uk IDC
2009/10/01 00:23:31.67  0.55 2.580    46.2097  153.0627 11.81 6.113 144  48.0   4.49  102    86 136   3.77  78.93 m i ke ISC
 (#PRIME)

Magnitude  Err Nsta Author      OrigID
MPVA    5.0           SKHL      00764866
MSH     5.2           SKHL      00764866
MMM     5.1           JMA       15072871
mb      4.2        10 MOS       14469069
mb      3.7 0.1    18 IDC       16645279
mb1     4.0 0.1    21 IDC       16645279
mb1mx   3.9 0.1    30 IDC       16645279
mbtmp   4.0 0.1    21 IDC       16645279
MS      3.3 0.1     8 IDC       16645279
Ms1     3.3 0.1     8 IDC       16645279
ms1mx   3.1 0.1    47 IDC       16645279
mb      4.0 0.1    18 ISC       16764113
MS      3.5 0.1     5 ISC       16764113

Sta      Dist  EvAz Phase        Time      TRes  Azim AzRes   Slow   SRes Def   SNR       Amp   Per Qual Magnitude
KUR      3.77 256.8 Pn       00:24:28.9     1.7                          T__                          ci
KUR      3.77 256.8 Sn       00:25:14.6     4.4                          T__                          _i
SKR      4.92  23.3 Pn       00:24:37.6    -5.3                          ___                          _e
PETK     7.53  21.8 Pn       00:25:17.283  -1.5 185.7         13.00      T__  35.1      2.3  0.33 __
SONM    31.48 290.2 P        00:29:46.6    -2.2  59.5          8.50      T__   2.2      0.4  0.76 __ mb      3.3
SONM    31.48 290.2 LR       00:43:22.117        113.1        38.20      ___           76.5 18.28 __ MS      3.4
```

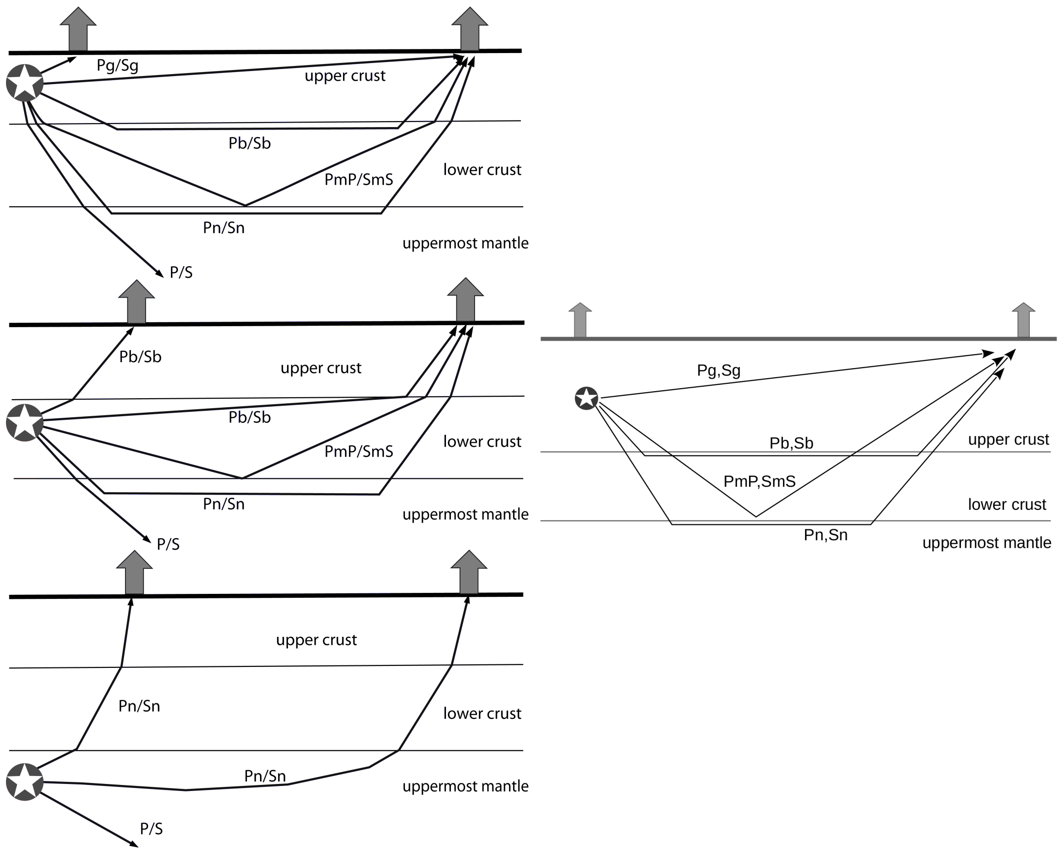

Figure 5.1: *Left: Phase definition in the ak135 model (after* Storchak et al.*, 2003, 2011;* Schweitzer et al.*, 2019), right: traditional phase definitions (e.g.* Aki and Richards*, 2002;* Stein and Wysession*, 2003).*

For some local phases the change of phase names gives an undesirable side effect. At short distances the main phases are Pg, Pb and Pn which traditionally are identified as seen in Figure 5.1 with Pn as a refracted wave along the Moho. However, the IASPEI definition of Pn follows the ak135 notation that includes any P wave bottoming in the uppermost mantle or an up-going P wave from a source in the uppermost mantle (`http://www.isc.ac.uk/standards/phases/`). This implies that for some distance/depths both Pb and Pn, in the ak135 definition, are what most location program would call Pg or P. The Pg phase in ak135 is what is traditionally called Pg. This change of definition from earlier practice was decided by the IASPEI Working Group on Standard Phase Names because the corresponding ak135 code did not differentiate between the classic Pn travelling as a headwave alongside the Moho and the branch of direct P that leaves a source in the uppermost mantle (Dmitry Storchak, personal communication).

For local earthquakes, the user will mostly use a standard location program (such as *Hypoinverse* (*Klein*, 2002) or *Hypocenter* used in SEISAN (*Lienert and Havskov*, 1995)) using a flat layer velocity model. Having the phases identified as Pb or Pn will then imply an identification which might not be in accordance with the local model or which cannot be calculated (Pn if the source is below Moho, Pb if the source is below Conrad). The Pb phase is rarely observed in practice and the corresponding Conrad layer might not be present in all models. So for local use Pb and Pn should be relabelled as P in order to get reliable locations (see Examples 2-4). The same is the case for the corresponding S-phases.

Example 2: The agency identified phases are shown in parenthesis. The agency phase identification is what traditionally would have been expected and the nearest station show Pg and Sg. In this case changing all Pn/Sn-phases to P and S will, when relocating, again identify the first two phases as g-types.

```
Event  14091935 Sichuan
Date        Time        Err    RMS Latitude Longitude   Smaj   Smin   Az   Depth   Err Ndef Nsta Gap   mdist   Mdist Qual    Author
2009/10/01 23:04:55.45    0.97 1.462   31.2363   104.1277 24.69 7.464 139   14.0f          9     7  94    0.45   58.57 m i ke ISC

Sta      Dist  EvAz Phase         Time       TRes  Azim AzRes    Slow    SRes Def
CD2      0.45 224.4 Pn(Pg)    23:05:07.4     -0.2                             T__
CD2      0.45 224.4 Sn(Sg)    23:05:14.5     -1.1                             T__
XAN      4.92  54.1 Pn(Pn)    23:06:09.6      0.6                             T__
XAN      4.92  54.1 Pg(Pg)    23:06:27.1     -2.5                             T__
XAN      4.92  54.1 Sn(Sn)    23:07:06.2      0.5                             T__
```

Example 3: In this event, all phases are labelled as Pn/Sn and a standard location program will put the event above Moho unless the program ignores the n. The original phases reported were all P and S. By removing the n, *Hypocenter* locates the event at 160 km depth. We do not know the local model or program used to get the agency's 86 km depth. Removing station JHO gives a 40 km depth so the depth is not well defined. These phases would traditionally have been called P/S. Note that the time defining flag is not set since the ISC did not locate the event and only calculated the residuals with the location fixed to the JMA solution.

```
Event  15487367
Date        Time          Err    RMS Latitude Longitude   Smaj   Smin   Az Depth    Err Ndef Nsta Gap   mdist   Mdist Qual    Author
2009/10/01 22:36:15.70    0.40          26.0000   140.6600    4.4    4.0   -1   86.0                                                 JMA

Magnitude   Err Nsta Author       OrigID
      4.2            JMA        15073229

Sta      Dist  EvAz Phase         Time       TRes  Azim AzRes    Slow    SRes Def
JHHJ     1.50  65.0 Pn        22:36:41.4      0.2                             ___
JHHJ     1.50  65.0 Sn        22:37:00.9      0.3                             ___
CBIJ     1.75  51.0 Pn        22:36:44.7      0.2                             ___
CBIJ     1.75  51.0 Sn        22:37:07.3      1.0                             ___
BS01     8.63   1.7 Pn        22:38:15.3     -1.9                             ___
BS03     8.77 359.2 Pn        22:38:16.8     -2.7                             ___
JOD2     9.33 352.0 Pn        22:38:26.3     -1.0                             ___
JRY     10.10 351.8 Pn        22:38:35.8     -2.0                             ___
JAG     10.44 354.6 Pn        22:38:38.6     -3.9                             ___
JHO     10.58 359.6 Pn        22:38:39.7     -4.6                             ___
JHO     10.58 359.6 Sn        22:40:30.2    -10.7                             ___
```

Example 4: The nearest station in this example reports Pb (VLS) and a station further away reports Pg (AMT). Trying to relocate this event with *Hypocenter* and the ak135 model will ignore the first station (if flag for enforcing Pb and Pn is set) since it is too close for Pb. When using only P and S, all stations will be used. For more distant stations, Pn will be the first arrival instead of Pb, the phase at the closest station will be Pg and the RMS will be smaller compared to forcing the arrivals to be Pb. This shows that it can be problematic to label first arrivals Pg, Pb and Pn.

```
Event 15069387 Ionian Sea
Date         Time          Err    RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author
2009/10/01 23:04:09.70         0.400  38.0200   19.9700   8.5  11.0  -1  12.0   8.1     6      323                      ATH
2009/10/01 23:04:09.30         1.570  38.0200   19.9600f10000 10000      12.0f          6    5 323   0.52   1.88     uk
     CSEM

Magnitude  Err Nsta Author      OrigID
MD     3.2         5 ATH       14603884
MD     3.2           CSEM      16462702

Sta      Dist  EvAz Phase        Time       TRes  Azim AzRes   Slow   SRes Def
VLS      0.52  72.3 Pb       23:04:19.7                                    ___
VLS      0.52  72.3 Pb       23:04:19.7                                    ___
AMT      1.47 108.8 Pg       23:04:37.0                                    ___
AMT      1.47 108.8 Sb       23:04:57.1                                    ___
AMT      1.47 108.8 Pb       23:04:37.0                                    ___
AMT      1.47 108.8 Sb       23:04:57.1                                    ___
EFP      1.58  74.6 Pb       23:04:39.2                                    ___
EFP      1.58  74.6 Pb       23:04:39.2                                    ___
KLV      1.73  88.5 Pb       23:04:41.2                                    ___
KLV      1.73  88.5 Pn       23:04:41.2                                    ___
GUR      1.88  91.8 Pn       23:04:43.5                                    ___
GUR      1.88  91.8 Pn       23:04:43.5
```

Below is the SEISAN relocation forcing Pb, Sb and Pn. PN2 means refracted from interface 2 (Conrad) and PN3 is refracted from layer 3 (Moho).

Abbreviations are: hrmn - hour and minute, lat - latitude, long - longitude, depth is in km, no - number of stations, m - number of degrees of freedom, damp - damping, errln, errlt, errdp - error (km) in latitude, longitude and depth, respectively, stn - station, dist - distance (km), azm - azimuth(degree), ain - angle of incidence (degree), w - input weight, phas - given phase, calcphs - phase used by program, tsec - second of arrival, t-obs - observed travel time (s), t-cal - calculated travel time (s), res - residual (s), wt - weight used, di - importance of phase.

```
 date hrmn   sec      lat      long depth    no m    rms  damp erln erlt erdp
910 1 23 4 10.35 38 3.84N  19 58.1E  12.0*  10 2   0.87 0.000 27.4 20.4  0.0
stn    dist    azm  ain w phas     calcphs hrmn tsec  t-obs  t-cal    res   wt di
VLS      56  76.8       0 Pb               23 4 19.7    9.4
VLS      56  76.8       0 Pb               23 4 19.7    9.4
AMT     164 110.5 94.3 0 Pg       PG      23 4 37.0  26.65  28.40  -1.75 1.00  8
AMT     164 110.5 64.0 0 Sb       SN2     23 4 57.1  46.75  46.27   0.48 1.00 18
AMT     164 110.5 63.2 0 Pb       PN2     23 4 37.0  26.65  27.49  -0.84 1.00 11
AMT     164 110.5 64.0 0 Sb       SN2     23 4 57.1  46.75  46.27   0.48 1.00 18
EFP     174  76.0 63.2 0 Pb       PN2     23 4 39.2  28.85  29.01  -0.16 1.00 14
EFP     174  76.0 63.2 0 Pb       PN2     23 4 39.2  28.85  29.01  -0.16 1.00 14
KLV     192  90.0 63.2 0 Pb       PN2     23 4 41.2  30.85  31.71  -0.86 1.00  2
KLV     192  90.0 46.2 0 Pn       PN3     23 4 41.2  30.85  29.97   0.88 1.00  4
GUR     209  93.2 46.2 0 Pn       PN3     23 4 43.5  33.15  32.18   0.97 1.00  5
GUR     209  93.2 46.2 0 Pn       PN3     23 4 43.5  33.15  32.18   0.97 1.00  5
```

SEISAN output using just P and S:

```
 date hrmn   sec      lat      long depth    no m    rms  damp erln erlt erdp
910 1 23 4 11.59 38 6.32N  20  1.6E  12.0*  12 2   0.55 0.000 16.1 10.2  0.0
stn    dist    azm  ain w phas     calcphs hrmn tsec  t-obs  t-cal    res   wt di
VLS      50  80.7103.9 0 P        PG      23 4 19.7   8.11   8.88  -0.77 1.00 12
VLS      50  80.7103.9 0 P        PG      23 4 19.7   8.11   8.88  -0.77 1.00 12
AMT     161 112.7 46.2 0 P        PN3     23 4 37.0  25.41  26.17  -0.75 1.00 11
AMT     161 112.7 50.6 0 S        SN3     23 4 57.1  45.51  45.19   0.32 1.00 19
AMT     161 112.7 46.2 0 P        PN3     23 4 37.0  25.41  26.17  -0.75 1.00 11
AMT     161 112.7 50.6 0 S        SN3     23 4 57.1  45.51  45.19   0.32 1.00 19
EFP     168  77.2 46.2 0 P        PN3     23 4 39.2  27.61  27.01   0.61 1.00  5
EFP     168  77.2 46.2 0 P        PN3     23 4 39.2  27.61  27.01   0.61 1.00  5
KLV     186  91.5 46.2 0 P        PN3     23 4 41.2  29.61  29.35   0.27 1.00  1
KLV     186  91.5 46.2 0 P        PN3     23 4 41.2  29.61  29.35   0.27 1.00  1
GUR     204  94.6 46.2 0 P        PN3     23 4 43.5  31.91  31.59   0.33 1.00  1
GUR     204  94.6 46.2 0 P        PN3     23 4 43.5  31.91  31.59   0.33 1.00  1
```

To use the most reliable data it is recommended to give a full weight to phases that are time defining in an ISC solution as these phases will have been identified by ISCloc and will show acceptable residuals. However, non-defining phases should not be dismissed because of their larger residuals or no residuals (meaning that ISCloc was not able to identify this phase) as they might be a good fit when using another velocity model. ISCloc imposes hard limits on distance and depth, e.g., Pg phases above around 10 degrees distance will not fit ak135 and show either no or large residuals. Another example for this is PKPbc which can be misidentified outside its defined distance range as a different phase by ISCloc and show large residuals. ISC analysts then fix the phase manually back to PKPbc, which will result in no residual being shown as it cannot be calculated. Also note that depth phases will only be time defining when they are accompanied by a P phase on the same station. Thus, depth phases can be a perfectly good pick whilst being non-defining. In some cases, phases can have good residuals but do not contribute to an ISC solution yet as ISCloc stops after a certain number of iterations. These phases will likely become time defining after another run of ISCloc, which is usually done by ISC analysts during review if necessary. Nevertheless, some phases in the ISC Bulletin might have good residuals while being non-defining due to this effect.

For events that are not reviewed by the ISC there are no residuals in the ISC Bulletin. For these events all phases have to be used for relocation since we have no idea which phases were used by the local agency. However, as there is often not a consistent practice when picking Pg, Pb and Pn and corresponding S it might be necessary to also relabel these phases to just P and S.

Recommendation: For events relocated by the ISC, use all phases with a time defining flag. Other phases, from the same event, without a time defining flag but with a residual, should be included with a low weight. Phases without residuals should be included with zero weight so they can be evaluated after relocation. ISC reviewed events which are fixed to the agency location and reported with ak135 residuals should all be used since there is no time defining flag. For events not reviewed and located by the ISC, use all phases. Consider relabelling all crustal phases to P and S.

5.1.3 Back Azimuth and Slowness

The back azimuth (BAZ) can be useful for improving the epicenter location, particular for small events. The ISC reports the back azimuth determined by an agency but ISCloc does not use it in calculating locations and thus there is no quality check. Back azimuth from arrays are usually OK, at least for P, and could potentially be used. Occasionally, ISC analysts make use of back azimuth and slowness from arrays to confirm the phase association to an event if the phase readings are reported without a hypocentre. Slowness can be converted to apparent velocity and is useful for phase identification. However, currently the back azimuth must be removed or weighted out to not corrupt the relocation. Slowness is not used by many programs and, even for arrays, can be wrong.

Example 5: BAZ from arrays fit within about +/- 20 degrees. For H11S2, the back azimuth fits well but the slowness is completely wrong as a T-wave takes more than 0.7s to travel one degree. So be aware that automatic data from arrays might not always be reliable. Station AFI gives 3 different values for back azimuth where only 227 is correct.

```
Event 17141286 Tonga Islands
Date       Time        Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author
2009/10/01 23:13:04.72   3.41 0.610 -15.2759 -173.6043 184.3  28.9 146   0.0f          5      210  49.68 145.

Magnitude  Err Nsta Author      OrigID
mb      3.7 0.1    4 IDC       16645498

Sta      Dist  EvAz Phase        Time      TRes  Azim AzRes   Slow   SRes Def
AFI      2.23  52.7 Pn       23:13:38.835  -4.2  76.4          9.10        ___
```

AFI	2.23	52.7	Sn	23:13:58.435	-12.9	227.1		22.50		___
AFI	2.23	52.7	LR	23:14:04.0		183.6		26.60		___
H11S2	38.76	329.3	T	00:01:16.715		152.1		0.70		___
WRA	49.68	256.7	P	23:21:58.55	-0.3	89.5		6.90		___
ASAR	49.96	251.8	P	23:22:00.7	-0.3	87.7		7.80		___
TXAR	80.71	56.2	P	23:25:23.15	2.9	224.0		5.20		___
PDAR	82.31	41.9	P	23:25:28.65	0.0	208.1		5.00		___
ILAR	82.36	11.2	P	23:25:27.5	-0.6	209.5		7.10		___
BRTR	145.94	320.9	PKPab	23:32:47.1	-0.2	118.6		1.50		___

Example 6: This event was not relocated by the ISC. Relocating it with SEISAN without using BAZ, gives nearly the same solution as IDC. Including the back azimuth from the most reliable P phases changes the location slightly but also shows that the BAZ values are not very reliable with up to 40 degree residuals on P and up to 98 degrees on other phases.

Abbreviations: IDC - IDC location, SEISAN - SEISAN location without BAZ, - -BAZ - SEISAN location with BAZ.

	Year	moda	hrmn	sec	lat	lon	depth	rms
IDC:	2009	1001	0003	12.4	-4.817	153.350	79.2	0.51
SEISAN:	2009	1001	0003	11.4	-4.818	153.350	70.5	0.52
--BAZ :	2009	1001	0003	11.4	-4.821	153.345	70.7	0.40

Event 17141139 New Ireland region

Date	Time OrigID	Err	RMS	Latitude	Longitude	Smaj	Smin	Az	Depth	Err	Ndef	Nsta	Gap	mdist	Mdist	Qual	Author
2009/10/01	00:03:12.44 16645277	4.83	0.510	-4.8165	153.3501	28.9	19.3	48	79.2	39.6	15		177	7.66	150.83	uk	IDC

Magnitude		Err	Nsta	Author	OrigID
mb	3.7	0.1	10	IDC	16645277
mb1	3.9	0.1	11	IDC	16645277
mb1mx	3.7	0.1	21	IDC	16645277
mbtmp	3.8	0.1	11	IDC	16645277
ML	3.3	0.3	1	IDC	16645277
MS	3.6	0.2	1	IDC	16645277
Ms1	3.5	0.2	1	IDC	16645277
ms1mx	2.7	0.1	26	IDC	16645277

Sta	Dist	EvAz	Phase	Time	TRes	Azim	AzRes	Slow	SRes	Def	SNR	Amp	Per	Qual	Magnitude
PMG	7.65	233.1	Pn	00:05:02.585	1.4	13.3		5.60		___	3.5	2.3	0.33	__	ML 3.3
PMG	7.65	233.1	Sn	00:06:26.335	-0.1	151.7		21.30		___	10.4	11.1	0.33	__	
DZM	21.33	144.7	P	00:07:52.7	-0.5	295.0		16.70		___	3.8	2.8	0.57	__	mb 3.6
WRA	23.85	229.3	P	00:08:18.75	0.1	53.6		9.80		___	17.9	2.2	0.50	__	mb 3.7
ASAR	26.51	223.1	P	00:08:43.05	0.3	57.5		9.20		___	6.8	0.5	0.43	__	mb 3.3
ASAR	26.51	223.1	PcP	00:12:06.119	0.2	112.8		1.70		___	4.4	0.2	0.34	__	
STKA	29.09	200.9	P	00:09:05.475	-0.2	39.7		12.30		___	5.4	1.2	0.58	__	mb 3.7
STKA	29.09	200.9	LR	00:21:17.31		25.7		37.30		___		108.4	19.41	__	MS 3.6
FITZ	30.13	241.8	P	00:09:14.687	-0.3	78.0		9.20		___	12.6	2.8	0.67	__	mb 4.0
RPZ	41.77	160.7	P	00:10:53.917	-0.1	301.0		5.90		___	5.2	9.6	0.71	__	mb 4.4
SONM	66.63	327.6	P	00:13:54.3	-0.4	153.5		5.80		___	2.9	0.3	0.52	__	mb 3.1
VNDA	72.79	178.1	P	00:14:32.2	0.3	341.3		7.30		___	9.1	2.3	0.72	__	mb 4.0
MKAR	80.70	318.8	P	00:15:17.5	0.5	96.9		7.10		___	12.6	0.4	0.43	__	mb 3.4
MKAR	80.70	318.8	pP	00:15:35.875	-1.1	134.1		5.20		___	3.6	0.6	0.83	__	
MAW	85.77	202.6	P	00:15:42.738	0.1	93.5		6.00		___	9.3	2.0	0.61	__	mb 4.1
TORD	150.83	288.4	PKPbc	00:22:56.325	-0.6	67.4		1.40		___	20.2	0.7	0.45	__	
TORD	150.83	288.4	PKPab	00:23:03.475	-0.9	62.5		2.40		___	9.3	0.4	0.45	__	

SEISAN BAZ residuals. *T-obs, t-cal and res are now in degrees.*

stn	dist	azm	ain	w	phas	calcphs	hrmn	tsec	t-obs	t-cal	res
PMG	851	233.1			BAZ-P				13.3	53.8	-40.55
PMG	851	233.1			BAZ-S				151.7	53.8	97.85
DZM	2374	144.7			BAZ-P				295.0	321.6	-26.63
WRA	2654	229.3			BAZ-P				53.6	53.4	0.18
ASAR	2951	223.2			BAZ-P				57.5	48.0	9.48
ASAR	2951	223.2			BAZ-PcP				112.8	48.0	64.78
STKA	3238	200.9			BAZ-P				39.7	24.7	15.02
STKA	3238	200.9			BAZ-LR				25.7	24.7	1.02
FITZ	3354	241.8			BAZ-P				78.0	67.4	10.61
RPZ	4650	160.7			BAZ-P				301.0	332.9	-31.94
SONM	7417	327.6			BAZ-P				153.5	127.5	26.00
VNDA	8103	178.1			BAZ-P				341.3	351.1	-9.83
MKAR	8983	318.8			BAZ-P				96.9	107.2	-10.33
MKAR	8983	318.8			BAZ-pP				134.1	107.2	26.87
MAW	9547	202.6			BAZ-P				93.5	92.3	1.22
TORD	16790	288.4			BAZ-PKPbc				67.4	76.1	-8.72

Recommendation: Weight out back azimuth or calculate residual and include if they fit. Often they do not.

5.1.4 Amplitudes

Amplitudes can cause a lot of confusion since different standards have been used and it is not always clear what correction has been applied by different agencies to produce the amplitude readings. This becomes very complex for magnitudes not calculated by the ISC. Amplitudes can be reported together with the phase reading and in that case there is no information on the time of the observations. Or they can be reported as 'amplitude phases'. Amplitude readings that follow the standard of the IASPEI Working Group on Magnitudes seem to be mostly correct in the ISC Bulletin (*IASPEI*; *Bormann and Dewey*, 2014). The unit is supposed to be nm ground displacement if the names include an A (such as AML) or nm/s if the name has a V (such as IVmBB), see `http://www.isc.ac.uk/standards/phases/#amplitude`. In addition, the ISC accepts amplitudes with the phase names P, pP, sP, AMB and pmax. Ideally only the latest IASPEI recommendation names should be used (it has been the standard for 8 years now) but that would severely limit the available data. The ISC only use amplitudes for mb and MS calculations so these amplitudes are checked and amplitudes that appear to be faulty are not used in the average. This is done by examining the station magnitude distribution (for mb and MS) during review for each event and spotting outliers and patterns. Usually the alpha trimmed median applied by ISCloc will dismiss outliers during magnitude calculations. Currently 39 types of magnitudes are reported to the ISC (see Section 7.5, p.66) and since the ISC is only calculating mb and MS, the input data (mainly amplitudes) for the remaining magnitudes are not checked.

Ml

Ml is not recalculated by the ISC and there seem to be many non standard amplitudes reported. In addition Ml scales for different regions vary so there is no way of calculating correct Ml without using different scales from different regions. The IASPEI standard (*Bormann and Dewey*, 2014) requires to calculate maximum ground displacement in nanometres using a filter that simulates the Wood Anderson (WA) instrument response. The magnitude relation is:

$$Ml_{iasp} = \log(A) + 1.11\log(R) + 0.00189R - 2.09, \tag{5.1}$$

where A is ground displacement in nm and R hypocentral distance in km.

So in order to use amplitudes for Ml calculations some selection must be done. If the standard IASPEI notation IAML is used the amplitudes seem OK in most cases. AML is used for non-standard displacement amplitude measurements and some of these do not fit well. Many amplitudes reported with the S or Sg phases also seem OK, but there are examples where they are off by a factor of e.g., 1000 so there is no guarantee they are correct. In a few cases, the amplitudes have been reported in mm on a Wood Anderson seismogram instead of nm ground displacement (ground displacement = WA displacement/2080). The ISC will convert the reported amplitudes to nm when parsing data into the database as this is the ISF standard unit for amplitudes. However, the ISC does not convert from WA to ground displacement as this cannot be reliably done with the various non-standard reported amplitudes. So be aware that amplitudes for Ml are given in nm but do not necessarily reflect ground displacement but could be the amplitude in nm on a Wood Anderson seismogram. Unfortunately, data are sometimes reported in the wrong unit. In obvious cases, such as values consistently being off by 1000, this will be fixed if spotted by the ISC. Maximum amplitude is often reported on both P and S for short distances but there is no standard magnitude scale which can be used with these P-amplitudes. Amplitudes for Ml are not checked by the ISC, however it seems that amplitudes from trustworthy agencies are OK. IMS (International Monitoring System by CTBTO) arrays may report amplitudes that they use for Ml. However often they cannot be used since they may be non standard, often reported on both P and S beams so they give a wrong Ml if used with the standard scale. Amplitudes reported with AML seem mostly correct, but not always, see Examples 7-11. So in the end, only a fraction of the amplitudes for Ml reported by the ISC can generally be relied upon.

Example 7: The amplitudes seem to be too large by a factor of 1000 when initially calculating Ml and might have been reported in nm and not in micrometre as was indicated, but they were likely reported as Wood Anderson amplitudes. The comment says that amplitudes are in micrometres. However, when parsing the data into the ISC database amplitudes are converted into nanometres and comments like these should be ignored. The ISC aims to remove those comments and for the example below (and other events) this has now been done.

```
Event   600896052 Greece-Albania border region
Date        Time          Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual  Author
2011/02/01 01:48:46.50         1.540  39.9775   20.9862f 9999 10000      17.8f         12    7 128   0.27   1.41   ke CSEM
2011/02/01 01:48:46.55         0.460  39.9775   20.9862   6.3   0.9 167  17.8   6.3   12      111   0.27   1.42   ke ATH

(Event not reviewed by the ISC)
(Analyst: Ch.Ventouzi ML Amplitudes are expressed in micrometres All distances are expressed in km)

Magnitude  Err Nsta Author      OrigID
ML     1.2        3 CSEM       601687637
ML     1.2        3 ATH        600844792

Sta      Dist  EvAz Phase        Time      TRes  Azim AzRes   Slow   SRes Def   SNR       Amp   Per Qual Magnitude
MEV      0.27 135.8 P        01:48:52.95                                  ___                          __
MEV      0.27 135.8 P        01:48:53.0                                   ___                          __
JAN      0.34 198.1 AML      01:49:00.83                                  ___        116400.0  0.12 __ ML      1.5
NEST     0.44   6.3 P        01:48:54.89                                  ___                          __
NEST     0.44   6.3 S        01:49:02.3                                   ___                          __
NEST     0.44   6.3 AML      01:49:04.34                                  ___         32200.0  0.34 __ ML      1.1
NEST     0.44   6.3 AML      01:49:04.4                                   ___         22900.0  0.30 __ ML      1.0
```

Table 5.1: *Calculating Ml assuming amplitudes reported as ground displacement (Ml_iasp) gives the wrong magnitudes while assuming Wood Anderson seismogram amplitudes by dividing the amplitude by 2080 (ML_iasp_WA) yields the reported magnitudes. Amp is amplitude and R is hypocentral distance.*

Station	Phase	R (km)	Amp (nm)	Reported Ml	Ml_iasp	Ml_iasp_WA
JAN	AML	42	116,400	1.5	4.9	1.6
NEST	AML	52	32,200	1.1	4.4	1.1
NEST	AML	52	22,900	1.0	4.3	1.0

Example 8: Both AML and IAML amplitudes are reported for the same station by two different agencies and only IAML reported in ground displacement. Although both station magnitudes are a bit high compared to the reported network magnitudes.

```
Event   609928377 Northwestern Balkan Peninsula
Date        Time          Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author
2016/12/23 23:39:23.90   0.40         42.5070   18.5170   0.1   0.0       6.0   1.9   40   22        0.24   3.69     ke BEO
2016/12/23 23:39:24.00   0.50         42.5500   18.4000  6.67 3.336  -1  13.9   3.1    9    9                      MED_RCMT
2016/12/23 23:39:23.99   0.63 2.013   42.5231   18.5002 2.212 1.716  26  15.6  4.07  959  722  19   0.08 124.03 m i ke ISC

Magnitude  Err Nsta Author      OrigID

ML     3.8 0.1   15 IDC        608075296
ML     4.2 0.3  134 ROM        611235664
Ml     4.4          TIR        09993780
ML     4.0 0.2   11 PDG        09127985
ML     4.1       19 BEO        11703260
ML     4.5       18 RHSSO      08424384
Ml     4.3 0.4   37 LDG        08023407
ML     3.8 0.1    5 THE        08488814
ML     4.4          VIE        08401194
```

```
Sta      Dist  EvAz Phase        Time      TRes  Azim AzRes   Slow   SRes Def   SNR       Amp   Per Qual Magnitude
LJU      4.53 322.3 Pn        23:40:34.61   2.7                           T__
LJU      4.53 322.3 Sn        23:41:28.33   4.0                           T__
LJU      4.53 322.3 IAML      23:42:05.37                                 ___          1504.0  1.40
LJU      4.53 322.3 Pn        23:40:34.77   2.8                           T__
LJU      4.53 322.3 AML                                                   ___       7540000.0  1.20  __
```

Table 5.2: *Calculating Ml assuming amplitudes reported as ground displacement (Ml_ iasp) gives the wrong magnitude for the AML phase while assuming Wood Anderson seismogram amplitudes by dividing the amplitude by 2080 (ML_ iasp_ WA) yields the reported magnitude for the AML phase. Amp is amplitude and R is hypocentral distance.*

Station	Phase	R (km)	Amp (nm)	Reported Ml	Ml_iasp	Ml_iasp_WA
LJU	IAML	504	1,504	5.4	5.0	1.7
LJU	AML	504	7,540,000		8.7	5.4

Example 9: Event has wrong IAML amplitudes on BOJS and LJU. Both seem to be 100 times too large.

```
Event   616652085 Albania
Date         Time          Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author
2017/07/03 11:18:18.80    1.19         41.1270   20.8170   0.5   0.5  56  11.0         186                              MOS
2017/07/03 11:18:19.40    0.20         41.0100   20.8000                  12.3   0.5  313  136                          GCMT
2017/07/03 11:18:19.74    0.55 1.722   41.1794   20.8816 1.932 1.635  51   6.9  3.43 1138 1022  11   0.09 122.17 m i ke ISC

Ml      5.2          TIR       09994118
ML      4.1 0.1    10 IDC       13271224
ML      4.9          SKO       11823055
ML      4.8 0.1    13 PDG       13408058
Ml      4.3 0.4    23 LDG       08896013
ML      4.9 0.2    16 THE       09736238
ML      4.7        17 BEO       11783323

Sta      Dist  EvAz Phase        Time      TRes  Azim AzRes   Slow   SRes Def   SNR       Amp   Per Qual Magnitude
BOJS     5.96 318.4 IAML      11:22:07.14                                 ___         17602.0  4.90
LJU      6.70 318.6 IAML      11:22:20.38                                 ___          8779.0  3.90
```

Table 5.3: *Calculating Ml assuming amplitudes reported as ground displacement (Ml_ iasp) gives the wrong magnitude for the two IAML phases while dividing amplitude by 100 (ML_ iasp_ 100) yields the reported magnitudes. Amp is amplitude and R is hypocentral distance.*

Station	Phase	R (km)	Amp (nm)	Reported Ml	Ml_iasp	Ml_iasp_100
BOJS	IAML	663	17,602		6.5	4.5
LJU	IAML	42	8,779		6.5	4.5

Example 10: Stations TTG (phase Sg) and CEME (Phase Sg) report amplitudes with 4476 and 554 nm respectively while PUK (phase AMP) and BCI (phase AMP) report 1.0 and 2.9 nm, respectively. TTG and CEME give a reasonable magnitude (average 2.5) using the Hutton and Boore scale (*Hutton and Boore*, 1987), while PUK and BCO give an average of 0.3. Assuming the amplitudes for PUK and BCO are mm on a Wood Anderson seismogram, we can convert to nm. Now the average magnitude is 2.9 for PUK and BCI. The average Ml reported for this event is 2.4 so 2.9 seems a bit high: Some agencies use the wrong Wood Anderson gain of 2800 instead of 2080, if this is the case, the average magnitude would have been 2.8. In this case the error was easy to spot, but whether the amplitude has been calculated with the correct Wood Anderson gain, or not is still in doubt. This of course is only a problem if the agency reports amplitude in mm on a Wood Anderson seismogram.

```
Event   611449844 Northwestern Balkan Peninsula
Date        Time         Err    RMS Latitude Longitude  Smaj   Smin   Az Depth    Err Ndef Nsta Gap   mdist   Mdist Qual    Author
2015/01/03 22:17:02.34          0.220  42.4562    19.2903    1.4                6.7  20.0                                    TIR
2015/01/03 22:17:03.20    0.03 0.030  42.4391    19.2842    0.0    0.0    0  14.6   0.1    32    16   86   0.02 1.25      ke PDG
2015/01/03 22:17:03.61    0.79 0.814  42.4529    19.3017   2.92 2.534  48  16.9  4.72    69    63   38   0.04 1.28      ke IASPEI
2015/01/03 22:17:04.40    0.20        42.4650    19.3270    0.0    0.0       14.0   2.6    23    15        0.06 2.56      ke BEO
2015/01/03 22:17:03.92    0.76 0.972  42.4563    19.3140   2.57 2.213  52  15.2  4.61   113    63   39   0.05 6.05 m i ke ISC

Magnitude   Err Nsta Author       OrigID
Ml      2.6          TIR         609057730
ML      2.4 0.3    14 PDG         609096920
ML      2.5        12 RHSSO       608421240
ML      2.2        13 BEO         606738973

Sta       Dist   EvAz Phase         Time        TRes   Azim AzRes    Slow    SRes Def    SNR        Amp    Per
TTG       0.05 239.0 Pg         22:17:05.7     -1.1                               T__
TTG       0.05 239.0 Sg         22:17:07.8     -0.8                               T__         4476.2
CEME      0.31 287.3 Pg         22:17:09.1     -1.3                               T__
CEME      0.31 287.3 Sg         22:17:14.1     -0.7                               T__          554.2
BCI       0.56  98.9 Pg         22:17:14.16    -0.9  98.0                         T__
BCI       0.56  98.9 Sb         22:17:22.82    -0.6  98.0                         T__
BCI       0.56  98.9 AMP                             98.0                         ___            2.9   0.28
PUK       0.60 133.7 Pg         22:17:14.67    -1.0 132.0                         T__
PUK       0.60 133.7 Sg         22:17:23.65     0.0 132.0                         T__
PUK       0.60 133.7 AMP                            132.0                         ___            1.0   0.11
```

Example 11: All 5 stations that report amplitudes (with Sg) give too low Ml station magnitudes (average value 0.1) versus the reported network Ml 1.3. Assuming this to be mm on a Wood Anderson seismogram, the magnitude would be 2.9 which is too high. So it is not clear what amplitude is reported.

```
Event 13826378 France
Date        Time         Err    RMS Latitude Longitude  Smaj   Smin   Az Depth    Err Ndef Nsta Gap   mdist   Mdist Qual    Author
2009/10/01 00:26:51.10    0.06 0.250  45.2844     3.7749    1.5    1.0  67   3.0f                   99    0.24    2.24     ke LDG
2009/10/01 00:26:51.60    0.29 0.400  45.3400     3.8300    0.0    0.0   0   5.0f          10     5 210    0.20    0.87     ke STR
2009/10/01 00:26:50.60    0.14 0.560  45.2685     3.7666    3.2    2.2  64   5.0f          20    10  96    0.25    2.22     ke CSEM
 (Event not reviewed by the ISC)

Magnitude   Err Nsta Author       OrigID
Ml      1.4 0.2     5 LDG         12452567
Ml      1.4 0.0       STR         14928018
ML      1.3 0.2     5 CSEM        16462244

Sta       Dist   EvAz Phase         Time        TRes   Azim AzRes    Slow    SRes Def    SNR        Amp    Per  Qual     ML
VIVF      0.76 122.4 Sg         00:27:15.2                                        ___            1.5   0.22  _e ML   1.6
LASF      1.19 176.9 Sg         00:27:28.9                                        ___            0.3   0.27  _e ML   1.2
CAF       1.25 254.7 Sg         00:27:30.9                                        ___            0.2   0.24  _e ML   1.1
AVF       1.55 349.4 Sg         00:27:39.1                                        ___            0.2   0.24  _e ML   1.3
MTLF      2.23 210.5 Sg         00:28:01.4                                        ___            0.2   0.26  _e ML   1.4
```

Recommendation: Only use amplitudes from IAML phases. In a few cases even IAML can be wrong though. Use AML phases with caution. If the user wants to use other amplitudes, they should be checked by calculating magnitudes for distances around 50-200 km using the standard California scale and compared to what the corresponding agency has reported.

mb

In general amplitudes for mb are correct and are easily selected as the ones used by the ISC. The ISC strictly calculates mb only when the distance is larger than 20 degrees so P amplitudes at shorter distances are not used. The very wide spread SeisComP system (*Hanka et al.*, 2010; `https://geofon.gfz-potsdam.de/software/seiscomp/`) uses a magnitude scale mb extended to shorter distances (J. Saul, personal communication, 2016). The IASPEI standard is to use IAmb while an earlier standard was to use AMB, still used by many. In addition, the ISC accepts amplitudes with the phase names P, pP, sP and pmax. The non standard pmax (not in the IASPEI phase list) is still reported by Russia (MOS) and China (BJI) for mb but was more common in the past. Ideally only the latest IASPEI recommendation IAmb should be used but that would severely limit the available data. Arrays have their own non standard mb scales like mbtmp and the corresponding amplitudes cannot always be used with the standard mb scale.

Example 12: IMS use of mbtmp. The amplitude at station CMAR is associated with a magnitude in the IMS bulletin but in the ISC Bulletin, the distance is too short for ISCloc to calculate the magnitude. So in the ISC Bulletin, we do not know what kind of amplitude it is. For observations with distances larger than 20 degrees, the amplitudes are used for mb.

```
ISC 611831815

CMAR   13.54  12.0 Pn       19:50:18.95   -0.1 198.5         13.60        T__  23.9       1.4  0.33  __
CMAR   13.54  12.0 Lg       19:54:11.852       187.8         32.80        ___   4.1       0.9  0.33  __
CMAR   13.54  12.0 LR       19:55:43.827       195.0         38.60        ___          2514.9 18.14  __
CMAR   13.54  12.0                                                        ___             6.3  0.79  __
KAPI   25.77 112.7 P        19:52:37.619   0.0 259.7          8.40        T__  14.4     128.9  1.02  __ mb     5.5

IDC 14091935

CMAR   13.44  12.1 Pn       19:50:18.950   1.8 198.5   -1.1   13.6   -0.3 T__  23.9       1.4  0.33 a__ ML     4.8
                                                                                          6.3  0.79     mbtmp  4.3
CMAR   13.44  12.1 Lg       19:54:11.852  -0.1 187.8   -7.8   32.8    1.0 T__   4.1       0.9  0.33 ___
CMAR   13.44  12.1 LR       19:55:43.827   1.5 195.0    2.3   38.6    0.1 ___          2514.9 18.14 a__ Ms
KAPI   25.82 112.9 P        19:52:37.619  -0.6 259.7  -33.2    8.4   -0.7 T__  14.4     128.9  1.02 a__ mbtmp  5.6
                                                                                        128.9  1.02     mb     5.6
```

Example 13: Not all mb in the ISC Bulletin are correct. In this event two stations report too high amplitudes. However, they are not contributing to the average as the ISC uses an alpha trimmed median. There is no indication in the ISF file that they have not been used though and the user must also do some checking.

```
Event 13918464 Bougainville-Solomon Islands region
Date       Time        Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author
2009/10/01 07:02:26.00   0.35 1.408  -8.7896  159.4114 8.341 7.490  63 121.5  3.04  267  204  28   0.83 157.71 m i se ISC

Magnitude  Err Nsta Author      OrigID
mb     4.8       18 NEIC      15372161
mb     4.8 0.1   57 ISC       16764170

Sta      Dist  EvAz Phase        Time      TRes  Azim AzRes   Slow   SRes Def   SNR       Amp   Per Qual
ASAR    28.54 235.7 P       07:08:09.35   -1.1  65.3         10.30        T__  48.0       5.0  0.40  __ mb     4.5
AFI     28.69 102.9 P       07:08:08.16   -3.7                            T__           297.2  0.80  _e mb     6.0
BBOO    32.22 218.8 P       07:08:43.02    0.3                            T__           474.3  0.80  _e mb     6.3
```

Recommendation: Use all amplitudes where the ISC or others have calculated mb and use all amplitudes given by the IAmb. For events with an ISC hypocentre, station magnitudes are calculated by ISCloc, while for events with an agency's hypocentre as prime the station magnitudes are those reported by the agency. It is assumed that the user's software automatically does not use data outside the valid distance range. For stations outside the correct station range, accept all amplitudes on phases accepted by the ISC since they are likely correct, but be aware that they have not been checked by the ISC. Consider using an alpha trimmed median (20%) like ISCloc does to sort out any outliers.

mB

Broadband mb, IASPEI name mB_BB, here we use mB: The IASPEI phase name is IVmB_BB indicating that the amplitude is in velocity. There are very few reported to the ISC, probably because it is not implemented in most processing software. For November 2018 there were a total of 545 observations, all from SEISAN users. The ISC is not yet using these amplitudes.

Example 14: Agency BJI reports magnitudes mb and mB. We assume mB is broadband mB but the event does not show the corresponding IVmb_BB phases and it seems the amplitude is reported as AMB at station WMQ. The magnitude relation for mB is

$$mB = \log(V_{max}/2\pi) + Q(\Delta, h) - 3.0, \tag{5.2}$$

where V_{max} is ground velocity in nm/s recorded on a broad band sensor proportional to velocity and Q is a correction function dependent on distance Δ and depth h (*Bormann and Dewey*, 2014). In the classic relation, $(V_{max}/2\pi)$ is equivalent to $(A/T)_{max}$.

Strictly speaking the amplitude should be in velocity $V = 410$ nm/s and then $mB = \log(V/2\pi)+$ correction but that is almost the same as assuming displacement $A = 410$ nm and calculating $mB = \log(410\ \text{nm}/5.8\ \text{s})+$correction. So in this example it is hard to know what unit is used unless we assume it to be displacement since IVmb_BB has not been used. The event has several Chinese stations with similar reports but they are not used by the ISC since the period is too high. So ISC data probably contains more data for mB, but they are hard to find as, if not using IVmb_BB amplitudes, there is no way of knowing how the amplitude was picked. If the period is above 3 s it is likely that the amplitude is for mB. China uses the mB magnitude scale regularly (*Bormann et al.*, 2009), but probably reporting displacement and period instead of velocity.

```
Event 13918464 Bougainville-Solomon Islands region
Date         Time          Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author
2009/10/01 07:02:14.80         0.780  -8.6100  159.1900                   31.0          42      323  55.80  88.20      uk BJI
2009/10/01 07:02:26.00    0.35 1.408  -8.7896  159.4114 8.341 7.490  63 121.5  3.04  267  204  28   0.83 157.71 m i se ISC

Magnitude  Err Nsta Author      OrigID
mb      4.9       37 BJI       13450879
mB      5.3       18 BJI       13450879
Ms      5.0       17 BJI       13450879
mb      4.8 0.1   57 ISC       16764170

Sta      Dist  EvAz Phase          Time       TRes  Azim AzRes   Slow   SRes Def   SNR        Amp   Per Qual Magnitude

MCK     82.13  20.6 P          07:14:32.49   -0.4                           T__              30.9  1.00  _e mb      5.1
IMA2    82.13  17.5 P          07:14:32.83   -0.1                           T__                          _e
WMQ     83.12 316.2 P          07:14:38.4    -0.1                           T__                          _e
WMQ     83.12 316.2 AMB                                                     ___              11.0  0.80  __ mb      4.8
WMQ     83.12 316.2 AMB                                                     ___             410.0  5.80  __
WMQ     83.12 316.2 LR                                                      ___             280.0 20.00  __
```

Recommendation: Use all IVmB_BB amplitudes. Amplitudes for mB with period above 3 s are most likely in displacement as reporting amplitudes in velocity instead of a displacement and corresponding period suggests that the reporter uses IASPEI standards and thus would likely report the correct phase names.

MS

Amplitudes for the classic MS are reported with phase names like M, MLR, L, LR and AMS while the IASPEI standard is IAMs_20 indicated that it ideally should be read within the period range 18-22 s. Many amplitudes used by the ISC are not in the 18-22 s range but they are still used as the ISC accepts periods in the range 10 to 60 s.

However, the requirement that the event is shallow (depth < 60 km) and in the distance range of 20 to 160 degrees is followed. So MS calculation does not completely follow the IASPEI standard.

Recommendation: Use all amplitudes for which the ISC calculated a MS magnitude and all of the IAMs_20 amplitudes. It is assumed that the user's software automatically does not use data outside the valid distance range and depth range. Data with the above phase names can still be included with caution. Abnormal magnitudes must be filtered out by the user's software.

MS_BB

Broadband MS, IASPEI name is Ms_BB, here we use MS_BB: The IASPEI phase name is IVMs_BB indicating that the amplitude is in velocity. Since it can be used in distance range 2 to 160 degrees and period 3 to 60 s it should have a much wider use. It is particularly useful for larger regional events where mb and MS cannot be used due to the short distances and Ml being inaccurate. There are very few IVMs_BB reported to the ISC: For November 2018, there are 227, all from SEISAN users. The ISC is not yet using these amplitudes. It seems that BJI calculates MS_BB.

Recommendation: Use all IVMs_BB amplitudes.

Mc or Md

Coda magnitudes from contributing agencies are given but the coda length is not stored. The IASPEI standard is to mark the end of the coda with phase name END from which the coda length and coda magnitude can be calculated. Only if the END phase is used will the ISC store the coda. However they seem not to be reported very often and the ISC has only about 100,000 observations in total, nearly all from Italy (ROM). The END phase has been implemented in SEISAN version 12.0 so there will probably be more in the future although coda magnitudes are used much less than they used to.

Recommendation: Use all END phases.

5.1.5 Summary

Using ISC data presents only a few problems for telseismic phases and magnitudes mb and MS. For local events, where data is often more inhomogeneous, phase names Pg, Pn and Pb should be changed to P and S respectively.

Amplitude data for Ml should be checked before use although most data for IAML phases are OK.

For all phases it is best to use data that is time-defining or has a time residual if relocated by the ISC. Other phases from ISC located events should initially be weighted out. For events not located by the ISC all phases should be used.

5.1.6 Suggestions for Improved ISC Reporting

Jens: Calculate residuals for back azimuth, even if not used, so the user can find reliable observations. Or better, start using back azimuth, then maybe more IDC only events could be located by ISC.

Kathrin/ISC: *The ISC only recently finished the Rebuild project where we recalculated our entire Bulletin between 1964 to 2010 with ISCloc and ak135 to make the Bulletin consistent (ISCloc was implemented in 2009). Changing our location procedure now and introducing another inconsistency is very* *unlikely to happen for some time. This would be a very non-trivial change that would require a lot of staff time.*

Jens: Calculate Ml for reported amplitudes up to 100 km and flag values outside reasonable limits. Up to 100 km there is little difference between different regional scales so the Ml should be reasonable correct. Or better, calculate Ml using Hutton and Boore and report. Indicate large outliers.

Kathrin/ISC: *As described above, Ml amplitudes come in a variety of standards that would require a lot of staff time to sort out and confirm. Unfortunately, it is not viable for us to do so at the moment. Should we decide to calculate a Ml_ISC magnitude this might change. In addition, currently ISF has no way to flag magnitude outliers so this would require some format changes.*

Jens: Calculate magnitude for broadband MS and mb.

Kathrin/ISC: *When time and funding allows we plan to tackle calculating additional magnitudes other than mb and MS.*

Jens: Make available the phases reported to the ISC also in ISF format so the user can see what has changed.

Kathrin/ISC: *As this already is available in QuakeMl format adding it to ISF is not a priority at the moment.*

Jens: Flag events not processed by the ISC.

Kathrin/ISC: *We are in the process of implementing this.*

The ISC is grateful for all feedback. Please contact us for questions, comments and suggestions for improving our data sets and services, or should you find any faults in our data (`http://www.isc.ac.uk/contact/`).

Acknowledgments

We thank James Harris and Domenico Di Giacomo for their help with queries about the ISC database, ISCloc and ISC magnitudes and Natalia Poiata for her helpful comments on the manuscript.

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