Users Guide for Early-est

EArthquake Rapid Location sYstem with EStimation of Tsunamigenesis

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Introduction

Early-est (Bernardi et al., 2015) is a software package for rapid location and seismic / tsunamigenic characterization of earthquakes. The **Early-est** software package operates on offline-event or continuous-realtime seismic waveform data to perform trace processing and picking, and, at a regular ***report interval***, phase association, event detection, hypocenter location, and event characterization. This characterization (Table 1) includes m_b and M_{wp} magnitudes, the determination of apparent rupture duration, T_0, large earthquake magnitude, M_{wpd}, and assessment of tsunamigenic potential using T_d and T50Ex, as described in Lomax and Michelini (2009ab, 2011).

This distribution includes two **Early-est** time-domain processing programs that operate on mini-SEED data packets:

miniseed_process - Runs **Early-est** time-domain processing on Mini-SEED event files, e.g. downloaded from IRIS-Wilbur http://www.iris.edu/cgi-bin/wilberII_page1.pl).
seedlink_monitor - Runs **Early-est** time-domain processing on continuous data returned from one or more SeedLink servers.

The software and examples in this distribution are configured for global (teleseismic to regional scale) monitoring of events of about M4 and larger, using up to 200-500 stations and the ak135 model (Kennett et al., 1995). This configuration uses a sliding analysis window of 1 hour, an association/location/reporting interval of 1 min, and a maximum of 10 events located each report interval. These settings may limit application to the local scale, though the software is stable and robust for processing events recorded only at nearby stations. Program application properties files allow changing the configuration settings for use on a regional or local scale.

This distribution also includes a set of bash, GMT and Python extension scripts to perform focal mechanism determinations and generate html and graphical output showing extensive system and event information.

The core Early-est software consists of a set of time-domain processing modules written in C and distributed under the GNU General Public License. The core software uses libslink (http://www.iris.edu/pub/programs/SeedLink) and libmseed (http://www.iris.edu/software/libraries) for managing SeedLink connections and reading mini-SEED data, and the libxml2 XML parser and toolkit.

The **Early-est** extension scripts make use of: the HASH program (Hardebeck and Shearer, 2002; http://quake.wr.usgs.gov/research/software/#HASH) for computing focal mechanisms; and bash, Python and the GMT package (GMT4 required, GMT5 is too slow) (http://gmt.soest.hawaii.edu) for plotting maps, histograms and alphanumeric information.

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Program Requirements

Early-est has been developed and tested on Mac OS X 10.9.5 (BSD UNIX). **Early-est** should compile and run correctly in a command-line shell on all Linux/UNIX based systems with gcc 4.2 or higher, or equivalent C compiler and linking support.

Compilation of of **Early-est** requires that libslink, libmseed and libxml2 are installed and available on the gcc library search path. Use of the HASH program requires gfortran of equivalent FORTRAN compiler and linking support. Use of the **Early-est** extension scripts requires that bash, ghostscript and Python (e.g. v2.7.5 or later) are installed. For graphical output, the executables from the plotting package GMT (GMT4 required, GMT5 is too slow) must be installed and available on the system executable path.

The ***seedlink_monitor*** program generates output files in a new directory for each report interval (e.g. 1 min). The number and total size on disk of these directories and files can become large if ***seedlink_monitor*** is run for an extended period; periodic archiving and cleanup of these files is recommended.

Installing Early-est

Note: You may need root permission to perform some of the following.

1. Download, unpack and install (make) the following required libraries:

   libslink - http://www.iris.edu/software/libraries

   libmseed - http://www.iris.edu/software/libraries

   libxml2 and libxml2-dev – your package manager, or http://xmlsoft.org/ or http://www.macports.org/

   - Copy libslink.a and libmseed.a to your default library directory or a directory on your LD_LIBRARY_PATH, e.g. '/usr/local/lib'
   - Copy libslink.h, slplatform.h and libmseed.h to your default include directory, e.g. '/usr/local/include'
   - Example (after download and unpacking):

```
cd libslink
make
sudo cp -p libslink.a /usr/local/lib
sudo cp -p libslink.h /usr/local/include
sudo cp -p slplatform.h /usr/local/include
cd ../libmseed-2.19.5
make
sudo cp -p libmseed.a /usr/local/lib
sudo cp -p libmseed.h /usr/local/include
```

2. Set the MYBIN environment variable to a convenient binary executable directory on your PATH. Example:

```
export MYBIN=/home/<my_login>/bin
```

3. Download and unpack early-est-<version>.tgz from early-est.alomax.net/software in a convenient installation directory.

4. A simple 'make clean' and then 'make' in the early-est-<version>/ directory should build the Early-est programs on most Unix-like systems. You may need to adjust some options and settings in the Makefile in the early-est-<version>/ directory.

5. For report generation and graphical output using plot_warning_report_seedlink_runtime.bash, the following must be installed on your system and available on your PATH.:

   - bash
   - ghostscript, or ImageMagick (http://www.imagemagick.org) or GraphicsMagick (http://www.graphicsmagick.org)
     Adjust the following in plot_warning_report_seedlink_runtime.bash:

     # choose here if you want to use gs (ghostscript) or convert (ImageMagick/GraphicsMagick command) for ps to jpg conversion
     #USE_CONVERT_FOR_PS2JPG=NO
     USE_CONVERT_FOR_PS2JPG=YES

   - the GNU bc arbitrary precision calculator language: package: bc

- the GMT software package (GMT4 required, GMT5 is too slow) http://gmt.soest.hawaii.edu; including GSHHG (from ftp://ftp.soest.hawaii.edu/gshhg/) and psmeca from the GMT supplemental library (may require installing libgmt-dev on Linux systems).

- Python 2.7
  Some advanced Python packages are also required: Pandas http://pandas.pydata.org/pandas-docs/stable/install.html; and scikit-learn http://scikit-learn.org/stable/install.html Python and these packages can be easily installed with www.anaconda.com/download

- Verify settings in the event processing (python/processEvents.py) properties file: process_events.prop

- If using HASH: build HASH, cd to early-est-<version>/HASH_v1.2/ and type 'make clean' and then 'make'. Requires that gfortran is installed. Type cd .. to return back to the early-est-<version>/ directory.

6. For uploading report files to a remote site see Running ***seedlink_monitor*** below.

Important Notes:

1. Early-est needs to open simultaneously approximately 15 files for each associated/located event. This number (e.g. about 150 for 10 events) may exceed the limit on number of open file descriptors for each process on some operating systems; this will lead to an "too many open files" error. On Mac OS X 10.6 the default limit is too low; it can be increased by running 'ulimit -n 4096' in the terminal window from which ***miniseed_process*** or ***seedlink_monitor*** will be run, or the command 'ulimit -n 4096' can be placed in the ~/.profile file.

Running Early-est, Examples

The example programs can be run from the early-est-<version>/work directory, which contains necessary helper files.

Run miniseed_process:

For more information on command line options, use 'miniseed_process -h'

```
miniseed_process msprocess_out/Honshu_2011_0_90deg.mseed -g
  miniseed_process_station_coordinates.csv -a -pz gainfile.csv -pz-query-host
  service.iris.edu -pz-query irisws/resp/1/query -pz-query-type IRIS_WS_RESP -sta-
  query-host service.iris.edu -sta-query fdsnws/station/1/query -sta-query-type
  FDSN_WS_STATION -timeseries-query-hosturl http://alomax.net/webtools/sgweb.html?
  http://service.iris.edu -timeseries-query irisws/timeseries/1/query -timeseries-
  query-type IRIS_WS_TIMESERIES -timeseries-query-sladdr
  rtserve.iris.washington.edu:18000 -timeseries-query-hosturl
  http://alomax.net/webtools/sgweb.html?http://service.iris.edu -timeseries-query
  irisws/timeseries/1/query -timeseries-query-type IRIS_WS_TIMESERIES -timeseries-
  query-sladdr 137.227.224.97:18000 -mwp -mb -mwpd -report-delay 1200 -v -alarm -i
  AU_XMIS

python python/processEvents.py MECHANISM msprocess_plots/
  msprocess_out/Honshu_2011_0_90deg.mseed.out/ msprocess_out/
  msprocess_out/Honshu_2011_0_90deg.mseed.out/ Honshu_2011_0_90deg fmamp_polarity

python python/processEvents.py EVENTS msprocess_plots/
  msprocess_out/Honshu_2011_0_90deg.mseed.out/ msprocess_out/
  msprocess_out/Honshu_2011_0_90deg.mseed.out/ Honshu_2011_0_90deg fmamp_polarity

./plot_warning_report_GMT4.gmt msprocess_plots/
  msprocess_out/Honshu_2011_0_90deg.mseed.out/
  msprocess_out/Honshu_2011_0_90deg.mseed.out/ Honshu_2011_0_90deg 0.2
  fmamp_polarity

$PS_VIEWER msprocess_plots/Honshu_2011_0_90deg_Monitor.pdf
```

Open early-est-<version>/work/msprocess_out/Honshu_2011_0_90deg.mseed.out/events/hypo.1299822380908.html in your browser.

Run seedlink_monitor:

For more information on command line options, use 'seedlink_monitor -h'

Extra installation notes for ***seedlink_monitor***:

1. Create the directory `seedlink_out/iris` (or other path corresponding to the -o option argument)
2. To update http server directory with last real-time warning output files (html, jpg, csv, etc.):
   a) Set the variable LOCAL_DIR_WARNING in plot_warning_report_seedlink_runtime.bash (or other file you use for the -c value) to an existing local directory or http server directory to use for last real-time warning output files (html, jpg, csv, etc.)
   b) Copy '*.html' and 'alarm.mp3' to the LOCAL_DIR_WARNING directory on the http server
3. To use FTP to update an http server directory with last real-time warning output files (html, jpg, csv, etc.)
   a) Set FTP_USER_PW_HOST and FTP_DIR_WARNING environment variables, e.g.,
   ```
   export FTP_USER_PW_HOST="ftp://<user>:<password>@<hostname>"
   export FTP_DIR_WARNING="/projects/early-est"
   ```
   or modify the code in plot_warning_report_seedlink_runtime.bash to copy files directly to a www directory on an http server without using ftp.

b) In file plot_warning_report_seedlink_runtime.bash , comment out with '#' the line DO_FTP_TO_REMOTE=NO.
c) Copy '*.html' and 'alarm.mp3' to the FTP_DIR_WARNING directory on the http server

Use a command of the following form:

```
seedlink_monitor rtserve.iris.washington.edu:18000 -S
  AD_*:00BHZ,IU_*:00BHZ,II_*:00BHZ,G_*:00BHZ,JP_*:BHZ,FR_*:BHZ,MN_*:BHZ,TT_*:BHZ,H
  T_*:BHZ,HL_*:BHZ,AT_*:BHZ,PM_*:BHZ,MY_*:BHZ,GT_*:BHZ,CZ_*:BHZ,IC_*:BHZ,BL_*:BHZ
  -t -3600 -nt 120 -locs --,00,10,01 -c
  ./plot_warning_report_seedlink_runtime.bash -g realtime_station_coordinates.csv
  -o seedlink_out/iris -a -v -pz gainfile.csv -pz-query-host service.iris.edu -pz-
  query irisws/resp/1/query -pz-query-type IRIS_WS_RESP -sta-query-host
  service.iris.edu -sta-query fdsnws/station/1/query -sta-query-type
  FDSN_WS_STATION -timeseries-query-hosturl http://alomax.net/webtools/sgweb.html?
  http://service.iris.edu -timeseries-query irisws/timeseries/1/query -timeseries-
  query-type IRIS_WS_TIMESERIES -timeseries-query-sladdr
  rtserve.iris.washington.edu:18000 -timeseries-query-hosturl
  http://alomax.net/webtools/sgweb.html?http://service.iris.edu -timeseries-query
  irisws/timeseries/1/query -timeseries-query-type IRIS_WS_TIMESERIES -timeseries-
  query-sladdr 137.227.224.97:18000 -mwp -mb -mwpd -si -alarm  -agency-id
  my.domain.name
```

Note: Press Ctrl-C to stop program after several 'New report generated' messages.

```
$PS_VIEWER seedlink_plots/t50.pdf
```

and view other files in seedlink_plots/ (Note: these files can be viewed while the above command is running.)

Run seedlink_monitor with multiple SeedLink servers:

Use a command of the following form:

```
seedlink_monitor rtserve.iris.washington.edu:18000 -S
  AD_*:00BHZ,IU_*:00BHZ,II_*:00BHZ,G_*:00BHZ,GE_*:BHZ,JP_*:BHZ,FR_*:BHZ,MN_*:BHZ,T
  T_*:BHZ,HT_*:BHZ,HL_*:BHZ,AT_*:BHZ,PM_*:BHZ,MY_*:BHZ,GT_*:BHZ,CZ_*:BHZ,IC_*:BHZ,
  BL_*:BHZ -t -3600 -nt 120 -locs --,00,10,01 rtserve.iris.washington.edu:18000 -S
  DK_*:BHZ,GB_LRW:BHZ,GB_KPC:BHZ,GB_JSA:BHZ,GB_MCH1:BHZ,SS_SAIP:BHZ,AU_MORW:BHZ,AU
  _ARMA:BHZ,AU_MTSU:BHZ,AU_COEN:BHZ,AU_FITZ:BHZ,AU_GIRL:BHZ,AU_MILA:BHZ,AU_RIV:BHZ
  ,AU_TOO:BHZ,AU_LHI:BHZ,AU_EIDS:BHZ,AU_MCQ:BHZ,AU_MTN:BHZ,AU_NFK:BHZ,AU_XMI:BHZ,A
  U_KDU:BHZ,AU_MOO:BHZ,AU_MANU:BHZ,AU_RABL:BHZ,AU_NIUE:BHZ,AU_MAW:BHZ,NZ_ODZ:BHZ,N
  Z_KHZ:BHZ,NZ_URZ:BHZ,NZ_OUZ:BHZ,BK_CMB:BHZ,CI_PASC:00BHZ,MS_BTDF:BHZ,IM_ATTUB:BH
  Z,PS_PSI:BHZ,AK_GAMB:BHZ,AK_TNA:BHZ -c
  ./plot_warning_report_seedlink_runtime.bash -g realtime_station_coordinates.csv
  -o seedlink_out/iris -a -v -pz gainfile.csv -pz-query-host service.iris.edu -pz-
  query irisws/resp/1/query -pz-query-type IRIS_WS_RESP -sta-query-host
  service.iris.edu -sta-query fdsnws/station/1/query -sta-query-type
  FDSN_WS_STATION -timeseries-query-hosturl http://alomax.net/webtools/sgweb.html?
  http://service.iris.edu -timeseries-query irisws/timeseries/1/query -timeseries-
  query-type IRIS_WS_TIMESERIES -timeseries-query-sladdr
  rtserve.iris.washington.edu:18000 -timeseries-query-hosturl
  http://alomax.net/webtools/sgweb.html?http://service.iris.edu -timeseries-query
  irisws/timeseries/1/query -timeseries-query-type IRIS_WS_TIMESERIES -timeseries-
  query-sladdr 137.227.224.97:18000 -mwp -mb -mwpd -si -alarm  -agency-id
  my.domain.name
```

Notes:

1. All SeedLink server options must follow immediately after the corresponding SeedLink server address, otherwise the last options set for a previous SeedLink server address will be propagated to subsequent server addresses.
2. With multiple SeedLink servers, data retrieval, latencies and processing at start-up may be asynchronous until all streams have been received up to current realtime.
3. To send an e-mail alert messages, append command-line options of the following form:
   `-sendmail "http://my.domain.name/early-est,me@my.domain.name,me@my.domain.name,someone.else@domain.name"`

```
(<base web url>,<from>,<to>[,<to>]...})
```

Early-est properties files

Early-est applications properties file

One startup, miniseed_process and seedlink_monitor read additional application options from a properties file in the current working directory named miniseed_process.prop or seedlink_monitor.prop, respectively. If the properties file is not present, all option values are set to defaults corresponding to the teleseismic monitor mode of Early-est and to the values set in ttimes.c through included header file ttimes/ttimes_*.h.

The format and contents of the application properties files is described below, see one of the application properties files for example property settings.

Syntax

Structure of a settings entity: A settings entity is a tree of depth 2. At the top level are the section nodes that represent isolated sections of application settings (e.g. general application properties, font attributes, color attributes, and so on). At the bottom level are the key-value pairs that represent set values for keys inside a particular section.

A settings entity is read from and written to disk using a textual format. The textual format is parsed by sequentially scanning each line. Blank lines are ignored. For all other lines, leading and trailing blanks are ignored. Sections are enclosed by square brackets ("[" and "]") on separate lines. Key-value pairs are written as the key followed by a single equal sign ("="), followed by the value, all of which must be together on one separate line. A key-value pair is associated to the last seen section. A key-value pair is not valid until at least one section has been seen. All lines that start with a hash ("#") are considered comments and are ignored. Empty sections, that is, sections that do not contain any key-value pairs, are not written to disk. Empty sections can be present in the textual format. However, they are ignored when creating a settings entity in memory.

A value can be a single or multi-valued. A multi-valued value is a tuple. Tuples are separated by comma and are singly-typed. This means that a tuple can only contain objects of one kind (e.g. integer tuples, double tuples, etc.).

```
==========================================
[DataInput]
  properties file section with settings for data input
 -------------------------------
 filter.component.accept
   comma separated list of channel component orientations to accept (channel component orientation is
3rd char of channel, e.g. component for BHZ is Z)
  accept only specified channel components, if none specified, accept all channel components
  default: Z
  See also: [TimedomainProcessing] process.orientation.list
 -------------------------------
 filter.ignore_duplicate_net_sta
  ignore streams with same network and station codes as previously accepted stream
  default: 1
 -------------------------------
 filter.ignore_duplicate_sta
  ignore streams with same station code as previously accepted stream
  default: 1
```

==========

[TimedomainProcessing]
properties file section with settings for time-domain processing

---

measures.enable
enable/disable magnitude and tsunami discriminant measures
default: 1

---

process.orientation.list
comma separated list of channel component orientations to be picked and fully processed
default: all channel component orientations picked and processed
Note: superseeds channel component orientations in pick.channel.list
Other components may be processed in certain analyses, e.g. for polarization analysis, horizontal components (N,E,1,2) are used and should be listed in [DataInput] filter.component.accept.
See also: [DataInput] filter.component.accept
default: all inpout channel orientations picked and processed

---

polarization.enable
enable/disable use of P polarization azimuth for location
default: 0

---

polarization.window.start_delay_after_P
start delay after P (sec) of P polarization analysis window
default: 0.0

---

polarization.window.length.min
minimum window length (sec) for P polarization analysis
P polarization analysis is applied in a suite of windows of multiples of 2*polarization.window.length.min and <= polarization.window.length.max
default: 0.25

---

polarization.window.length.max
maximum window length (sec) for P polarization analysis
default: 32.0

---

pick.channel.list
ordered (0-N), comma separated list of channel names for mapping pick parameters.
To apply specific values of a pick parameter to the channels, the number and order of values for the pick parameter must match exactly this list of channel names. If a channel is not present in this list, or the number of values for a parameter is less than the channel index in this list, then the zero (0) index value for the parameter is applied to the channel.
Comma separated list with optional $ separated sub-list of channel names for corresponding pick parameter
default: zero (0) index value for the parameter is applied to all channels
Note: specified channel orientations must be allowed by process.orientation.list

---

pick.raw.enable
enable/disable picking on raw data stream (unfiltered input data)
default: 1

---

pick.raw.filterWindow pick.hf.filterWindow
the filter window (filterWindow) in seconds determines how far back in time the previous samples are examined. The filter window will be adjusted upwards to be an integer N power of 2 times the sample interval (deltaTime). Then numRecursive = N + 1 "filter bands" are created. For each filter

band n = 0,N the data samples are processed through a simple recursive filter backwards from the current sample, and picking statistics and characteristic function are generated. Picks are generated based on the maximum of the characteristic funciton values over all filter bands relative to the threshold values threshold1 and threshold2.

---

pick.raw.longTermWindow pick.hf.longTermWindow

long term window, determines: a) a stabilisation delay time after the beginning of data; before this delay time picks will not be generated. b) the decay constant of a simple recursive filter to accumlate/smooth all picking statistics and characteristic functions for all filter bands.

---

pick.raw.threshold1 pick.hf.threshold1

sets the threshold to trigger a pick event (potential pick). This threshold is reached when the (clipped) characteristic function for any filter band exceeds threshold1.

---

pick.raw.threshold2 pick.hf.threshold1

sets the threshold to declare a pick (pick will be accepted when tUpEvent reached). This threshold is reached when the integral of the (clipped) characteristic function for any filter band over the window tUpEvent exceeds threshold2 * tUpEvent (i.e. the average (clipped) characteristic function over tUpEvent is greater than threshold2)..

---

pick.raw.tUpEvent

determines the maximum time the integral of the (clipped) characteristic function is accumlated after threshold1 is reached (pick event triggered) to check for this integral exceeding threshold2 * tUpEvent (pick declared).

tUpEvent must be less than TIME_DELAY_TAUC_MIN (set in timedomain_processing_data.h)

==========

[WaveformExport]

properties file section with settings for waveform export (miniseed data files)

Exported waveforms are written in a waveforms/<event_id> subdirectory of the -o output directory, e.g., seedlink_out/iris/waveforms/1389094395723/ The waveform files are deleted after the time specified by the parameter file_archive.age_max

---

enable

enable waveform export

default: 0

---

memory.sliding_window.length

length in seconds of sliding window waveform data memory

sliding window ends at last data packet start time for each channel

default: 3600

---

window.start.before.P

earliest start time in seconds before P for waveform window

start time may be later if all waveform data not available

default: 300

---

window.end.after.S

latest end time in seconds after S for waveform window

end time may be earlier if all waveform data not available

default: 600

---

file_archive.age_max

maximum time period in seconds to keep waveform export files on disk

default: 10 days

==========

[Report]

properties file section with settings for report generation

The Early-est reporting module calls the oct-tree associate/locate module with the current pick list, and then the reporting module which determines event characterization results and generates graphical and alpha-numeric reporting output.

---

warning.colors.show

enable or disable HTML and alert message display of warning level colors (grey, green, yellow, red) (1, 0)

default: 0

---

tsunami.evaluation.write

enable or disable output of "Tsunami evaluation" information in the e-mail and in the html event pages (1, 0)

default: 0

---

report.sliding_window.length

length in seconds of the report window, use negative value to deactivate sliding window reports.

default: 3600

---

report.interval

interval in seconds between standard reports.

default: 60

---

report.trigger properties group

properties that control the early triggering of association/location/reporting

---

report.trigger.min_num_picks

minimum number of new picks (that can contribute to association/location) to trigger report.

default: 5

---

report.trigger.pick_window

window in seconds before current data time to count new picks for possible triggered report.

default: 600

---

report.trigger.min_delay_time

minimum data delay time in seconds between possible early triggered reports.

default: 10

---

alert.mb_min

minimum mb magnitude to trigger an alert (e-mail, Twitter, etc).

default: 5.5

---

alert.mwp_min

minimum Mwp magnitude to trigger an alert (e-mail, Twitter, etc).

default: 5.8

---

alert.mwpd_min

minimum Mwpd magnitude to trigger an alert (e-mail, Twitter, etc).

default: 6.95 (rounds to 7.0)

---

alert.tdt50ex_min
  minimum TdT50Ex value to trigger an alert (e-mail, Twitter, etc).
  default: 7.2 (= 0.9 * 8.0, 8.0 is "yellow" cutoff for TdT50Ex)
---
alert.resend_time_delay
  delay in sec after event otime to resend (update) an alert (e-mail, Twitter, etc) if already sent.
  default: -1   (disabled)

==========
[AssociateLocate]
  properties file section with settings for association and location
---
assoc_loc.min_weight_sum_associate
  assoc_loc.min_weight_sum_associate sets the minimum sum of total phase weights for a set of picks to be associated into an event
  default: 4.5 (for teleseismic monitor mode)
---
assoc_loc.min_time_delay_between_picks_for_location
   sets the minimum time delay in seconds between picks on a channel for the succeeding pick to be used for location
  default: 25.0 (same as aref, for teleseismic monitor mode)
---
assoc_loc.gap_primary_critical
  sets the critical primary gap in deg
  default: 270 (for teleseismic monitor mode)
---
assoc_loc.gap_secondary_critical
  sets the critical secondary gap in deg
  default: 315 (for teleseismic monitor mode)
---
phase.names.use
  sets a list of phase names to use in location/association
  This includes all phases that will count in association/location with non-zero weight and other phases that will
  be passively associated.
  Comma separated list with optional $ separated list of required channels for phase
  default: all phases set in ttimes.c through included header file ttimes/ttimes_*.h
---
assoc_loc.*.*
  sets the bounds and step size for the regular grid search that initiates the oct-tree association/location algorithm
  default: e.g. for teleseismic monitor mode:
              depth (km): (DIST_TIME_DEPTH_MAX, 0.0, DIST_TIME_DEPTH_MAX) where DIST_TIME_DEPTH_MAX is set in ttimes.c through included header file ttimes/ttimes_*.h
      lat (deg): (7.2, -90, 90)
      lon (deg): (7.2, -180, 180)
---
assoc_loc.nomimal_critical_oct_tree_node_size
  nominal (approximate) size in km of oct tree node that must be reached before accepting a location
  may be reduced automatically in location.c -> octtreeGlobalAssociationLocation()
  default: 50.0 (for teleseismic monitor mode)
---
assoc_loc.min_critical_oct_tree_node_size
  minimum size in km of nomimal_critical_oct_tree_node_size

default: 1.0 (for teleseismic monitor mode)
---
assoc_loc.nominal_oct_tree_min_node_size
nominal (approximate) minimum size in km of oct tree node to be used for association/location
may be reduced automatically in location.c -> octtreeGlobalAssociationLocation()
default: 5.0 (for teleseismic monitor mode)
---
sta_corr.nmin
minimum number of number of data used to generate time correction to enable correction to be applied
default: 10
---
sta_corr.filename
station time correction file
default: none
---
assoc_loc.upweight_picks_sn_cutoff
S/N cutoff to upweight picks on raw data stream (unfiltered input data) for association/location
if S/N for a pick is greater than this cutoff, then a linear upweight:
upweight = 1.0 + (snr - upweight_picks_sn_cutoff) / upweight_picks_sn_cutoff,
upweight scaled by linear ramp weight (1->0),
is applied so that the pick can have weight > 1, allowing earlier association/location for larger, high S/N events.
Use a negative value to disable upweighting
default: -1
---
assoc_loc.upweight_picks_dist_full
minimum station-epicenter distance to enable full upweighting of picks on raw data stream (unfiltered input data) for association/location
upweighting of picks is scaled by linear ramp weight (1->0) between upweight_picks_dist_full and upweight_picks_dist_max
default: 5.0
---
assoc_loc.upweight_picks_dist_max
maximum station-epicenter distance to enable upweighting of picks on raw data stream (unfiltered input data) for association/location
upweighting of picks is scaled by linear ramp weight (1->0) between upweight_picks_dist_full and upweight_picks_dist_max
default: 10.0
---
assoc_loc.use_amplitude_attenuation
enable or disable amplitude attenuation weighting for event association (1, 0)
calculation and weighting during association of the fit of the P amplitudes attenuation to a power law decay follows a theoretical decay power
default: 0
---
assoc_loc.use_magnitude_amp_atten_check
enable or disable validation of P pick magnitude based on amplitude attenuation error ratio (1, 0)
Mwp, mB and mb magnitudes for a P pick are not used if the ratio between observed and predicted amplitudes
for best fit, event amplitude attenuation is too high or too low
Note: requires assoc_loc.use_amplitude_attenuation = 1
default: 1
---

assoc_loc.persistence.min_num_def_phases
minimun number of defining phases (tot_wt > 0) for an event to be tested for persistence
Use a negative value to disable event persistence
default: 20
---
assoc_loc.persistence.frac_poss_assoc_cutoff
maximum ratio (n_poss_assoc/wt_assoc_full) of picks that could be associated to defining phases to previous association weight
for an event to declared persistent
ratio is [n_poss_assoc = number possible defining phases not already used for full assoc/loc] to [wt_assoc_full = total weight of fully associated defining phases]
NOTE: this ratio is conservative (will overestimate true ratio of weights, since number and not eventual weights used for possible associated phases)
default: 0.05 (=1/20)
---
assoc_loc.persistence.event_persistence_tt_err_fact
scale factor that is multiplied by the phase travel time error to determine if unassociated data might be associated
the scaled error defines a time tolerance to match predicted and observed arrival time of unassociated data
default: 2.0
---
assoc_loc.existing_event_assoc.min_num_def_phases
minimun number of defining phases (tot_wt > 0) for an event to be have existing event association (association/location in a limited region around previous hypocenter), if minimun delay time since event origin time not reached
Use a negative value to disable existing event association
default: 20
---
assoc_loc.existing_event_assoc.delay_otime.min
minimun delay time in seconds since event origin time for an event to be have existing event association (association/location in a limited region around previous hypocenter), if minimun number of defining phases not associated
default: 720 (=12min)
---
assoc_loc.use_mwp_distance_correction
enable or disable correcting the computed Mwp and Mwpd based on epicentral distance (1, 0)
Uses Mwp correction from Bernardi et al. (2015)
Appraising the Early-est earthquake monitoring system for tsunami alerting at the Italian candidate Tsunami Service Provider,
Nat. Hazards Earth Syst. Sci. Discuss., 15, 1–40, 2015 www.nat-hazards-ear th-syst-sci-discuss.net/15/1/2015/ doi:10.5194/nhessd-15-1-2015
default: 1
---
assoc_loc.use_mb_correction
enable or disable correcting the computed mB based on a linear fit to NEIC mb (1, 0)
Uses mb correction from Bernardi et al. (2015)
Appraising the Early-est earthquake monitoring system for tsunami alerting at the Italian candidate Tsunami Service Provider,
Nat. Hazards Earth Syst. Sci. Discuss., 15, 1–40, 2015 www.nat-hazards-ear th-syst-sci-discuss.net/15/1/2015/ doi:10.5194/nhessd-15-1-2015
default: 1

Event processing properties file

If report generation and event processing are preformed, then the python program python/processEvents.py reads additional application options from a properties file in the current working directory named process_events.prop. If the properties file is not present, all option values are set to default values as documented in the properties file.

The format and contents of the process_events properties files is described below, see one of the process_events properties files for example property settings.

Syntax

Structure of a settings entity: A settings entity is a tree of depth 2. At the top level are the section nodes that represent isolated sections of application settings (e.g. general application properties, font attributes, color attributes, and so on). At the bottom level are the key-value pairs that represent set values for keys inside a particular section.

A settings entity is read from and written to disk using a textual format. The textual format is parsed by sequentially scanning each line. Blank lines are ignored. For all other lines, leading and trailing blanks are ignored. Sections are enclosed by square brackets ("[" and "]") on separate lines. Key-value pairs are written as the key followed by a single equal sign ("="), followed by the value, all of which must be together on one separate line. A key-value pair is associated to the last seen section. A key-value pair is not valid until at least one section has been seen. All lines that start with a hash ("#") are considered comments and are ignored. Empty sections, that is, sections that do not contain any key-value pairs, are not written to disk. Empty sections can be present in the textual format. However, they are ignored when creating a settings entity in memory.

A value can be a single or multi-valued. A multi-valued value is a tuple. Tuples are separated by comma and are singly-typed. This means that a tuple can only contain objects of one kind (e.g. integer tuples, double tuples, etc.).

Boolean options: accepted values are "1", "yes", "true", and "on", for True, and "0", "no", "false", and "off", for False. These string values are checked in a case-insensitive manner.

==========

[EventInfo]

properties file section with settings for event info generation

---

warning.colors.show

enable or disable display of warning level colors (grey, green, yellow, red) (1, 0)

default: 0

---

location_map.write

enable or disable HTML output of event location map (1, 0)

default: 1

---

tsunami.write

enable or disable HTML output of Tsunamigeneic Assesment (1, 0)

default: 1

---

tsunami.evaluation.write

enable or disable HTML output of Tsunamigeneic Assesment -> Tsunami evaluation (1, 0)

default: 0

---

tsunami.decision_table.write

enable or disable HTML output of Tsunamigeneic Assesment -> Decision table (1, 0)

default: 0

---

tsunami.decision_table.colors.show

enable or disable warning level colors in HTML output of Tsunamigeneic Assesment -> Decision table (1, 0)

default: 1

---

first_motion_mech.run.hash

enable or disable running of HASH First-motion Focal Mechanism (1, 0)

default: 0

---

first_motion_mech.run.fmamp.polarity

enable or disable running of fmamp First-motion Focal Mechanism using first-motion and waveform polarities (1, 0)

default: 1

---

first_motion_mech.run.fmamp.polarity.waveform

enable or disable running of fmamp First-motion Focal Mechanism using waveform polarities only (1, 0)

default: 0

---

first_motion_mech.run.fmamp.amplitude

enable or disable running of fmamp First-motion Focal Mechanism using amplitudes (1, 0)

default: 0

---

first_motion_mech.write

enable or disable HTML output of First-motion Focal Mechanism (1, 0)

default: first_motion_mech.run

---

tsunami.tsunami_rupture_predicitions.write

enable or disable HTML output of predicted tsunami and rupture parameters (1, 0)

default: 0

---

tsunami.tsunami_rupture_predicitions.ff_duration.pkl_file_root

root path and name for saved prediction file set

default: None

---

tsunami.tsunami_rupture_predicitions.ff_rupture_area.pkl_file_root

root path and name for saved prediction file set

default: None

---

tsunami.tsunami_rupture_predicitions.at.pkl_file_root

root path and name for saved prediction file set

default: None

---

tsunami.tsunami_rupture_predicitions.it.pkl_file_root

root path and name for saved prediction file set

default: None

Station/Channel Metadata Files

Early-est uses metadata files to read and write station/channel coordinates and gain metadata. These files are read at start-up when data for a station/channel first becomes available. Missing metadata can be added to the files while Early-est is running, and, if the appropriate FDSN or IRIS web-services are available, Early-est can automatically find meta data for new station/channel data (see below). In the future it is planned that Early-est will intermittently check for changes to station/channel metadata using these web-services.

Station coordinates file (e.g. realtime_station_coordinates.csv)

The station coordinates file can be created off-line, the format is:

MN VLC 44.159400 10.386400 555.000000 2014 3 13

<net> <sta> <lat> <lon> <elev (meters)> <year> <month> <day>

where

<year> <month> <day> are the date when the station coordinates file entry was set, e.g. the date for which the gain is valid. The idea is that in the future Early-est will re-check gains every now and then, if a web-service providing station coordinates is available.

Channel gain file (e.g. gainfile.csv)

The channel gain file can be created off-line, the format is:

AK ATKA -- BHZ 2014 14 4.887423e+08 0.150000 3

<net> <sta> <loc> <chan> <year> <day of year> <gain> <freq> <type>

where

<year> <day of year> are the date when the gain file entry was set, e.g. the date for which the gain is valid. The idea is that in the future Early-est will re-check gains every now and then, if a web-service providing gains is available. Currently, Early-est only checks that the data year is greater than the gain file entry year.

<gain> is gain in <data count units> / <physical ground motion units>

<freq> is frequency for gain (should be 0.15Hz for Early-est, but can differ if response is flat around 0.15Hz)

<type> is type of physical ground motion represented by data relative to ground displacement:

```
#define ERROR_TYPE -1

#define UNKNOWN_TYPE 0

#define SCALING_TYPE 1

#define INTEGRAL_TYPE 2

#define DERIVATIVE_TYPE 3
```

#define DOUBLE_DERIVATIVE_TYPE 4

#define OTHER_CONVERSION_TYPE 5

#define NO_CONVERSION_TYPE 6

so, for example, velocity data has type DERIVATIVE_TYPE 3

Early-est currently only accepts velocity data with DERIVATIVE_TYPE 3 for all magnitude and other processing that requires true ground motion scaling.

Station/Channel Metadata from web-services

Station meta-data for coordinates and gain can be read at start-up and dynamically from FDSN Station and IRIS Station and Response web-services. The parameters for accessing these web-services are specified on the command-line:

```
-g geogfile    file with geographic coordinates of stations (Network Station
 Latitude Longitude Elevation(m))
-sta-query-type type of query station web service (e.g. FDSN_WS_STATION,
 IRIS_WS_STATION)
-sta-query-host host name for station web service (e.g. www.iris.edu)
-sta-query      query root for station web service (e.g. ws/station/query)
     -sta-query-type, -sta-query-host and -sta-query can be repeated in
 corresponding triplets

-pz gainfile   file with gain info for channels (Network Station Location Channel
 Year, DayOfYear, Gain, Freq, Type)
-pz-query-type type of pole-zero response (SEED-RESP format) web service (e.g.
 FDSN_WS_STATION, IRIS_WS_RESP)
-pz-query-host host name for pole-zero response (SEED-RESP format) web service
 (e.g. www.iris.edu)
-pz-query      query root for pole-zero response (SEED-RESP format) web service
 (e.g. ws/resp/query)
      -pz-query-type, -pz-query-host and -pz-query can be repeated in
 corresponding triplets
```

Station time correction file (e.g. residuals_P_TEST.csv)

The station time correction file (application property [AssociateLocate]:sta_corr.filename) defines station/phase time corrections that are subtracted from the observed pick time for association/location for the specified phase type. The time correction in seconds is defined by a minimum and maximum distanced of applicability, between which the time correction is given by a 3rd order polynomial as a function of distance. This file is created outside of Early-est.

The format is:

MN VLC -- BHZ P 0.24 97.54 166 0.4045783 1.119627 -0.1931056 0.04262729 -0.0005226042 1.274545e-06 2015 05 19

<network> <station> <location> <channel> <phase> <dist_min_res> <dist_max_res> <n_data> <mean> <std_dev> <coeff0> <coeff1> <coeff2> <coeff3> <year> <month> <day>

where

<phase> is the phase type to which the correction applies

<dist_min_res> <dist_max_res> minimum and maximum distanced of applicability

<n_data> number of (residual) data used to generate time correction polynomial (correction is applied if n_data >= [AssociateLocate]:sta_corr.nmin).

<mean> <std_dev> mean and standard-deviation of residual data (not used by Early-est).

<coeff0> <coeff1> <coeff2> <coeff3> 3rd order polynomial defining correction, time correction = coeff0 + coeff1*dist coeff2*dist^2 coeff3*dist^3. For constant correction, set coeff0 = correction, and coeff1, coeff2, coeff3 = 0.

<year> <month> <day> is the date when the station correction file entry was set (not currently used by Early-est).

Output Files

All output for ***miniseed_process*** is written in sub-directories under the base directory <file>.out/, where <file> is the Mini-SEED file argument to ***miniseed_process***.

All output for ***seedlink_monitor*** is written in sub-directories under the base directory

<outpath>/<year>/<month>/<day>/<year>.<month>.<day>.<hour>.<min>.<sec>/

where <outpath> is specified by the -o argument to ***seedlink_monitor*** and <year>, <month>, etc. are the time of generation of a report (generated every 1 min).

The directory <base_directory>/ contains csv, html, xml and other files describing the picks, hypocenters, magnitudes and tsunamigenic indicators, station health, and miscellaneous plotting information.

The subdirectory <base_directory>/plots contains GMT format data files for psimage, psxy, pshistogram and other plotting.

If plot_warning_report_seedlink_runtime.bash is run unmodified, the directories specified by SAVE_DIR and LOCAL_DIR_WARNING will each contain many of the files from <base_directory>/ along with jpg and/or pdf files generated by GMT; the directory specified by SAVE_DIR/events and LOCAL_DIR_WARNING/events will each contain, for each associated event, data files for mechanism determination, event html an with jpg and/or pdf files generated by GMT.

IMPORTANT NOTE: the *seedlink_monitor* output can total around 1Gb/day – you are responsible for regular monitoring and managing (archived, moved, deleted, …) of the output directories to avoid using excessive space on the output file system or device.

Algorithm Description

The Early-est programs ***miniseed_process*** and ***seedlink_monitor*** read mini-seed data packets from file or a SeedLink server, respectively, and pass each packet to a ***trace-processing*** module. These programs also call an ***associate/locate - reporting*** module at regular ***reporting intervals*** (e.g. after all data is read for ***miniseed_process***; every 1 min for ***seedlink_monitor***), and perform general initialization, quality control and cleanup operations. Figures 1 and 2 show schematic diagrams of for the two programs and the main modules.

The Early-est software maintains a persistent ***pick list*** for the current ***reporting window*** (e.g. a specified time window for for ***miniseed_process***; the last hour before real-time for ***seedlink_monitor***) and an ***event list*** for a specified archive interval (e.g. the last 10 days). The ***pick list*** is updated continuously as picking and trace processing are applied to new data packets. The ***event list*** is updated at each ***reporting interval*** as new event locations are found or previous locations are deleted. At each ***reporting interval*** the ***associate/locate*** module processes the current ***pick list*** from scratch, without making use of previous associations or location information from the ***event list***; this memory-less procedure simplifies the ***associate/locate*** module and makes it very robust with respect to changes in the ***pick list***, but increases the computational load.

Trace-processing module

The ***trace-processing*** module (Figure 1) processes each new data packet passed by ***miniseed_process*** or ***seedlink_monitor***. This processing includes channel identification, quality control, filtering for picking, picking using ***FilterPicker*** and further filtering and pre-processing as required for seismic and tsunamigenic event characterization (Table 1).

FilterPicker (Lomax et al., 2011; Vassallo et al., 2011) is a general purpose, broad-band, phase detector and picker which is applicable to real-time seismic monitoring and earthquake early-warning. ***FilterPicker*** uses an efficient algorithm which operates stably on continuous, real-time, broadband signals, avoids excessive picking during large events, and produces onset timing, realistic timing uncertainty, onset polarity and amplitude information. In practice, it operates on a pre-defined number of frequency bands by generating a set of band-passed time-series with different center frequencies. Characteristic functions are determined for each frequency band and a pick is declared if and when, within a window of predefined time width, the integral of the maximum of the characteristic functions exceeds a pre-defined threshold.

After picking on each new data packet, for each pick in the ***pick list*** for the current packet channel, the ***trace-processing*** module applies various analyses on the channel data and updates values needed for event characterization. Recursive, time-domain algorithms are used for all filtering and other time-series processing.

Optional ***polarization analysis*** and determination of an azimuth weight is applied to picks that may be used for association/location and for which orthogonal, 3-component data is available. This analysis is performed using real covariance analysis (Hendrick and Hearn, 1999); Nguyen et al. 1989) in multiple windows W_n, starting at the pick time, with length $2^n \Delta T$, n=(0, 1, 2, …). A weighted-mean polarization azimuth and uncertainty is determined from the W_n for which the degree of linearity exceeds a cutoff (e.g. 0.8), weighted by the mean vector amplitude of the 3-component data in each W_n. Polarization analysis is enabled by: 1) providing 3-component data through SeedLink or in miniseed data files, 2) processing 3-component data (see Application properties file → [DataInput] filter.component.accept), 3) enabling and configuring polarization analysis (see Application properties file → [TimedomainProcessing] polarization.*), 3)

Associate/locate - reporting module

The Early-est ***associate/locate - reporting*** module (Figure 1) calls the ***oct-tree associate/locate*** module with the current ***pick list***, and then the ***reporting*** module which determines event characterization results and generates graphical and alpha-numeric reporting output.

Oct-tree associate/locate module

The ***oct-tree associate/locate*** module (Figure 2) efficiently and robustly associates picks, and detects and locates seismic events over the whole Earth from 0 to 700km depth using the efficient, non-linearized, probabilistic and global, oct-tree importance-sampling search (Lomax and Curtis, 2001; Lomax et al., 2009). The objective function for the oct-tree search is a probability function, $P(\mathbf{x})$, based on stacking of implicit origin-times for each pick for each potential source $\mathbf{x}_{test}$: given a seismic wave velocity model (currently ak135 (Kennett et al., 1995)), a pick time $\boldsymbol{t_p}$ at a seismic station, and assuming a seismic phase type that may have produced the pick, the phase travel-time from source $\mathbf{x}_{test}$ to station $\boldsymbol{T_x}$ can be calculated and thus the implicit origin-time $\boldsymbol{T_0}$ for the source and phase can be determined by back projection (e.g., $\boldsymbol{T_0} = \boldsymbol{t_p} - \boldsymbol{T_x}$). The set of stacks of $\boldsymbol{T_0}$ for all picks forms a histogram over potential origin-times for a source at $\mathbf{x}_{test}$. If the maximum histogram value exceeds a specified threshold, and if the associated picks for the maximum pass tests on, azimuth gaps, station distributions, and optionally amplitude attenuation, then $P(\mathbf{x}_{test})$ is retained to drive further the oct-tree search to find a maximum $\mathbf{x}_{max} = \max[P(\mathbf{x})]$ and define a seismic event at $\mathbf{x}_{max}$ and associated picks.

The oct-tree search is *direct* and non-linearized – it does not involve linearization of the equations relating the pick times to the source location, and is *global* and *probabilistic* – it samples throughout the prior probability density function (PDF) for the seismic location problem. The search uses an initial, coarse, regular grid-search followed by recursive, octal sub-division and sampling of cells in three-dimensional, latitude/longitude/depth space to generate a cascaded, oct-tree structure of sampled cells. The oct-tree search produces approximate *importance-sampling* - the spatial density of sampled cells follows the objective function *P*.

For each latitude/longitude/depth cell of volume *v* visited by the oct-tree search, a histogram-like stack over implicit origin-times for first-arrival, P phases (currently Pg, P, Pdiff, PKPdf) for all picks in the ***pick list*** is constructed. Each origin-time value $\boldsymbol{T_0}$ is assigned a distance, depth and pick-quality weighted amplitude $\boldsymbol{A}$ between 0 and 1.0, and an uncertainty σ determined by the sum of half the maximum travel-time range across the cell volume with the travel-time and pick uncertainties. $\boldsymbol{A}$ can be further up-weighted by up to a factor of 2 for high signal-to-noise picks at closer distances.

Optionally, a polarization azimuth weight $\boldsymbol{W_p}$ between 0 and 1.0 is *added* to $\boldsymbol{A}$. $\boldsymbol{W_p}$ is based on comparison of the mean and uncertainties of a) the azimuth from polarization analysis (see above for details), and 2) the predicted station-epicenter ray take-off azimuth. $\boldsymbol{W_p}$ is further scaled by the inverse of the station-epicenter distance to compensate for widening of azimuthal arc with distance. For algorithm implementation and details, see timdomain_processing.c->td_doPolarizationAnalysis() and location.c->octtree_core()->"adjust weight for polarization".

Each implicit origin-time is included in the origin-time stack with amplitude $\boldsymbol{A}$ using two step-function time-limits at $\boldsymbol{T_0} \pm \sigma$ inserted in time order. After all picks have been processed, the maximum of the origin-time stack is found by a systematic scan over the available time-limits; the use of step-function time-limits and time ordering makes this scan very fast. All picks whose origin time-limits overlap the stack maximum time are flagged as associated. The stack value, combined with the variance of the implicit origin-times from all associate picks, is converted to a probability, $P(\mathbf{x}, v)$, and additionally weighted based on: tests of the associated picks for amplitude attenuation, and station distance and azimuth distributions. If this value exceeds a specified threshold (currently 4.5),then $P(\mathbf{x}, v)$ is stored for use in the progression of the oct-tree search. If any of these conditions are not met, then the ***oct-tree associate/locate*** module returns, with a flag that no event has been associated. $P(\mathbf{x}, v)$ represents the relative probability that an event is located within a cell of volume *v* at position $\mathbf{x}$.

The oct-tree search to associate / locate is paused when the subdivided cells reach an adaptively determined, minimum size (e.g. <=5km for a location constrained by regional to globally distributed stations, <=1km for a location constrained by locally distributed stations); at this pause uncertainty measures (e.g. PDF scatter samples) on the association stage are generated. The oct-tree search and cell subdivision is then continued for a fixed number of samples (currently about 4600) to obtain a refined, precise location by fixing the associated phases to those corresponding to the maximum of the $P(\mathbf{x}, v)$ found in the association stage. The fixing of the associated phases is necessary for small cell sizes since a decreasing cell volume combined with the step-function limits on origin-time leads to a continuous reduction in $P(\mathbf{x}, v)$ values and eventual instability and non-convergence of the oct-tree search near and at the optimal source location. The precise oct-tree results provide uncertainty measures (e.g. PDF scatter samples, uncertainty ellipsoid) on the location.

When the ***oct-tree associate/locate*** module returns an event, the associated picks for this event are masked in the ***pick list*** and the ***oct-tree associate/locate*** module is called again using the remaining, non-associated picks, until no further events are returned. Thus multiple events can be associated and located within a report interval, and, in general, the events are identified in order of the number of associated picks and better location constraint.

Early-est under ***seedlink_monitor*** with continuous data runs the ***oct-tree associate/locate*** module and ***reporting*** module (see below) at regular report intervals on a sliding window of picks (e.g. every 1 minute using all picks from the past hour), only preserving information from previously established associations and event locations that have a minimum number of defining associated picks or which have origin times before a specified time before current time. This procedure makes Early-est relatively simple algorithmically and robust with regards to changes in the set of available picks and the number of associated picks defining locations. In particular, early stage locations with few associated picks can easily move in space or origin time, or to split into multiple events, or to be absorbed into other events, or to disappear as more pick data becomes available. For established event locations, defined by a minimum number of defining associations (e.g. 20) or which have origin times before a specified time before current time (e.g. 12min, to allow recording of most teleseismic, first P arrivals), association and location is performed only in a limited region around the existing event hypocenter (e.g., for the global case, hypocenter lat/lon +- 1.5 initial, coarse grid cells, depth from 0-800km). The use of a limited region speeds up the association-location processing and helps to guarantee the persistency of established events.

Under ***seedlink_monitor***, in order to reduce the latency of first association/location for significant events, the ***oct-tree associate/locate*** module monitors new picks to determine if a new event association may be possible. The requirements for a possible new event are: 1) there are enough new picks (e.g. 5 new picks) that can contribute with non-zero weight to association; 2) the last available data is more than a specified minimum delay time (e.g. 10sec) after the last report time and before the next report time; 3) the processing latency is small (e.g. less than ½ the report interval). If a new event is possible, then the ***oct-tree associate/locate*** module first processes existing event with their current hypocenter fixed, attempting only to associate more picks, including possibly some of the new picks that defined a possible new event. Next, a full ***oct-tree associate/locate*** processing is run on the remaining, unassociated picks to attempt to detect, associate and locate a new event. If a new event is declared, the ***reporting*** module is run.

Reporting module

The ***reporting*** module (Figure 1) processes the current ***pick list*** and ***event list*** to determine event characterization results (Table 1) and generate graphical, alpha-numeric, XML, HTML and other reporting output for events, picks, stations, etc. An e-mail alert message (Figure 3) is generated (see -sendmail command line option) for each event with magnitudes or tsunamigenic potential exceeding pre-set thresholds (Table 2); the email message body is in file <ALERT_HYPO_FILE> in the output directory. A system call to a script in the working directory './run_action__alert_sent.bash <ALERT_HYPO_FILE> <ALERT_EVENT_PAGE_URL>' (e.g. for Twitter messaging) is also called whenever an e-mail alert is sent.

The module then runs an external script specified by the -c command line option (currently -c ./plot_warning_report_seedlink_runtime.bash) to run HASH, fmamp, generate GMT graphics and final, alpha-numeric, XML, HTML and other reporting output, and to manage output file conversions, copying and cleanup. Figure 4 shows the main graphical display of Early-est, which summarizes the evolving trace-processing, associate/locate and event characterization results in real-time. Figure 5 shows some of the browser-based HTML output of Early-est, which details the evolving Early-est processing and results in real-time.

Computational efficiency

On a 3.33GHz Intel Core 2 Duo iMac with OS X 10.6, the ***oct-tree associate/locate*** module for a single event of around M5-6 (20-100 associated picks) takes about 1sec and the ***reporting*** module about 5-10sec (primarily the GMT graphics and HASH search). For ***seedlink_monitor***, collecting data packets from the SeedLink servers for about 200 stations and processing the data in the ***trace-processing*** module takes very little CPU time, 2-3% CPU on average.

To investigate efficiency for large event sequences, we consider two, hour-long windows of data at stations at 0-180° distance for the 2011.03.11 Mw9 Tohoku, Japan earthquake, one with about 200 stations (run_MED) and a second with about 400 stations (run_BIG). Running ***miniseed_process*** off-line with run_MED or run_BIG associates and locates the mainshock and 9 aftershocks (the association/location is currently limited to 10 events maximum in a report window). On the above iMac the ***oct-tree associate/locate*** module takes about 30 sec for run_MED and about 1.5 min for run_BIG. Additionally, the report and event processing for both runs for 10 events (HASH, event graphics, event HTML, ...) takes about 30 sec (though this runs in a separate process from the data processing and associate/locate).

Thus for run_MED (similar to the current Early-est running at INGV) the processing will approximately keep up with real-time for a mega-event, teleseismic sequence like 2011 Tohoku, Japan, with the latency for display of the results increasing from the usual ~10s to ~1 min. However, the ***associate/locate - reporting*** for run_BIG takes over 2 min, much longer than the reporting interval of 1 min currently used in ***seedlink_monitor***; to avoid that the processing and reporting fall behind realtime in this situation, Early-est will increase the reporting interval. In summary, Early-est in its current form can be used on a standard PC/Mac in real-time for up to around 200-300 channels and up to about 10 events in a report window with report interval 1 min.

Helper Tools

Waveform visualization with SeisGram2K

SeisGram2K (http://alomax.net/seisgram; http://alomax.net/seisgram/beta) includes automatic and interactive tools for selecting events located by Early-est and displaying the waveforms archived using the WaveformExport feature of Early-est. (See [WaveformExport] section of seedlink_monitor.prop or miniseed_process.prop for waveform export options.)

Early-est event waveforms are written under the waveforms/ sub-directory of the program output directory. In SeisGram2K, selecting File → OpenEarly-estWaveforms... will open an event selection dialog which contains:

1. A file choice for selecting the Early-est output directory containing the waveforms/ sub-directory and an XML event listing hypolist.xml;
2. A checkbox for specifying if vertical, z-component traces only should be read;
3. A field for the maximum number of stations to read and display;
4. A list of available events. The available events are listed in a sortable table; double clicking on one of the events will open and display the requested number of stations for the event.

SeisGram2K can be run with a command of the form:

```
java -jar <path_to_jar>/SeisGram2K80.jar
```

allowing interactive opening of Early-est waveform files or other seismogram trace files.

The list of available Early-est events can be immediately displayed on SeisGram2K start-up with a command of the form :

```
java jar <path_to_jar>/SeisGram2K80.jar earlyest.outroot.url <early-
  est_output_directory> -earlyest.open YES
```

To automatically open the latest Early-est event and display waveforms for up to 20 stations, use a command of the form :

```
java -jar <path_to_jar>/SeisGram2K80.jar -earlyest.outroot.url <early-
  est_output_directory> -earlyest.open.latest YES -earlyest.maxnumsta=20
```

All available SeisGram2K command line options related to Early-est waveform reading are :

```
-earlyest.open=<Early-est waveforms: Open Early-est Event Selection dialog at
  startup (YES | NO*)>
-earlyest.open.latest=<Early-est waveforms: Automatically open the latest Early-
  est event and display waveforms at startup (YES | NO*)>
-earlyest.maxnumsta=<Early-est waveforms: Maximum number of stations to read>
-earlyest.outroot.url=<Early-est waveforms: Path to Early-est output root
  directory>
-earlyest.z_comp_only=<Early-est waveforms: Read vertical, Z component traces only
  (YES | NO*)>
```

The default SeisGram2K display of Early-est waveforms is sorted by station distance and shows the Early-est picked phase times in grey and predicted arrival times in blue. To align the traces on the first picked phase, try View → AlignTimeTo… → Phase.

Table 1 - Event characterization measures used in Early-est

Measure	*References*	*Description, modifications*
Td	Lomax and Michelini (2011)	Maximum dominant period (smoothed over 5s) in window from P arrival time (Tp) to Tp + 55s.
T50Ex	Lomax and Michelini (2011)	T50 Exceedance, modified as follows: 1) Reduced T50Ex minimum distance to 5deg.
Td*T50Ex	Lomax and Michelini (2011)	Period-duration discriminant for tsunami potential, modified as follows: 1) Reduced Td*T50Ex minimum distance to 5deg.
To	Lomax and Michelini (2009ab, 2011)	High-frequency, apparent source-duration, modified as follows: 1) Removed smoothing window width of 10s from To for short durations; applied with a linear ramp from 10 → 0s for initial durations of 20 → 60s, minimum duration is highest frequency in HF stream (0.2s). 2) Reduced To minimum distance to 5deg. 3) Added reference of To duration to S arrival time (Ts) if raw duration end time (To_end) is after Ts (e.g. if To_end > Ts+(Ts-Tp)/3 then To=To_end-Ts).
mb(Vmax)	Bormann and Saul (2008, 2009)	mb body wave magnitude using Vmax formulation: 1) Apply to BRB velocity a recursive, time-domain filter that implements the WWSSN-SP displacement response: * WWSSN-SP displacement response from Working Group on Magnitudes (Magnitude WG) of the International Association of Seismology and Physics of the Earth's Interior (IASPEI) Commission on Seismological Observation and Interpretation (CoSOI) 2011 ZEROS 3 POLES 5 -3.72500 -6.22000 -3.72500 6.22000 -5.61200 0.00000 -13.2400 0.00000 -21.0800 0.00000 CONSTANT 1.0 This filter is applied to the BRB velocity, so effectively gives: integrate → simulate the WWSSN-SP response → differentiate, without doing the integration and differentiation. 2) Measure Vmax - the peak from Tp to the lesser of Tp+To or Tp+30s, 3) Apply: mb(Vmax) = log10 (Vmax/2π)+ Q(Δ, h)

Measure	*References*	*Description, modifications*
Mwp	Tusboi et al. (1995, 1999)	Mwp magnitude, modified as follows: 1) Applied from Tp to the lesser of Tp+To or Tp+120s.
Mwpd(RT)	Lomax and Michelini (2009a)	Mwpd duration-amplitude, large earthquake magnitude, modified as follows to allow simple and robust real-time application without event type determination: 1) Use constant from Tusboi et al. (1995, 1999) = 4.213e19. Use PREM depth correction; no geometrical spreading or attenuation corrections. 2) Moment correction of Lomax and Michelini (2009a) applied to all event types if To>80s. 3) Reduced Mwpd minimum distance to 5deg (Stable since added reference of To duration to Ts).
Focal mechanism	(Hardebeck and Shearer, 2002)	P-arrival, first-motion focal mechanism using the HASH program.
Focal mechanism	(Lomax, 20XX)	Probabilistic, P-arrival, first-motion and amplitude focal mechanism algorithm (fmamp). Uses oct-tree search; solution quality based on wighted distribution (quasi-pdf) of P and T axes. (Note: Under development; included for information in Early-est distribution.)

Table 2 – Default alert message thresholds

Measure	*Min num readings for alert*	*Min value for alert**	*Min change in value for new alert***
mb(Vmax)	4	5.5	+0.5
Mwp	4	5.8	+0.5
Mwpd(RT)	4	6.95 and Mwp≥6.95	+0.5
Td*T50Ex	4	7.2	+8.0 or change from >8.8 (RED) to <7.2 (GREEN)

* can be set in application properties file
** if an alert has been sent, a new alert is also sent 10min after event origin-time

Figure 1. Early-est Schematic Flow-Diagram

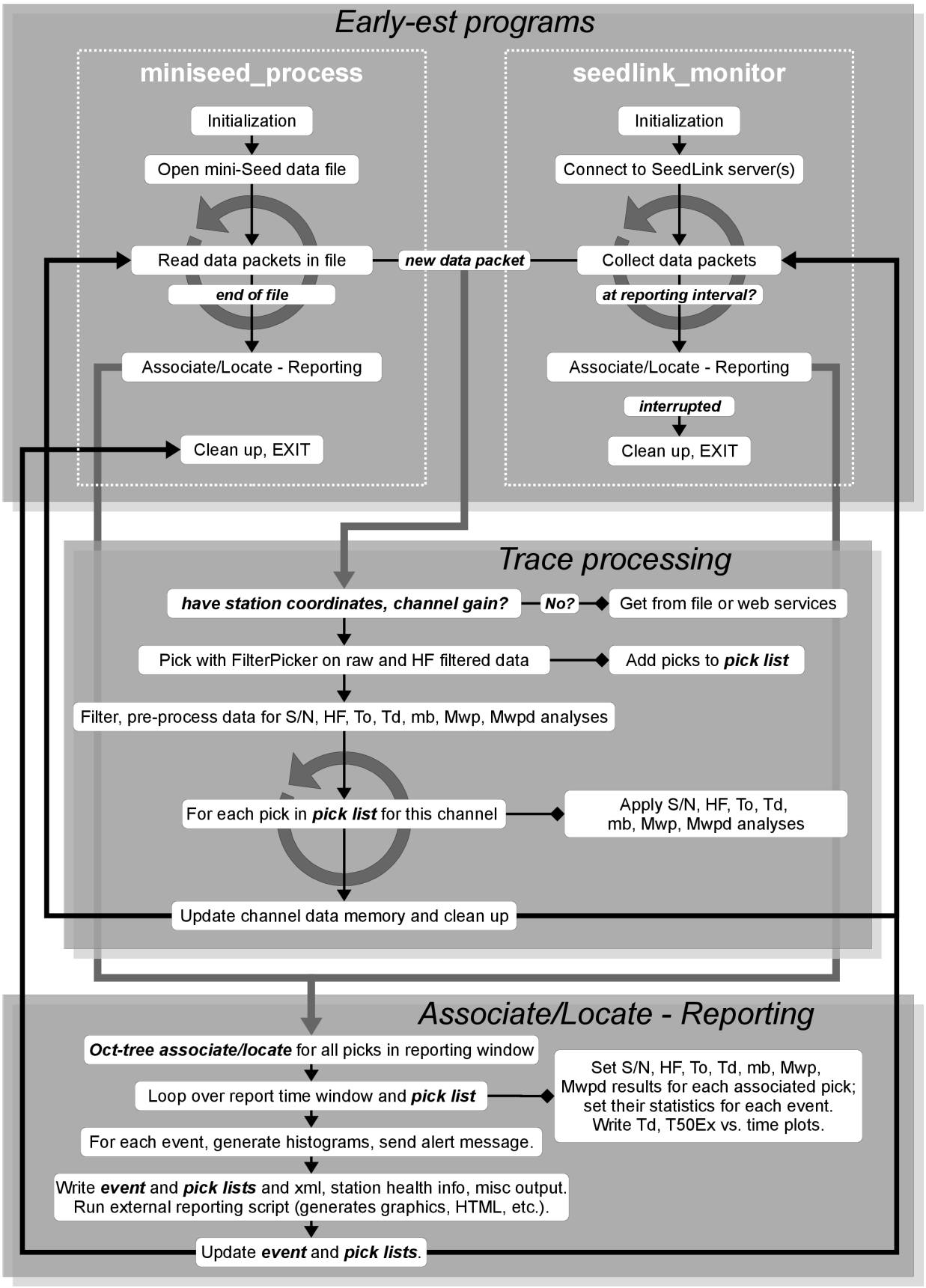
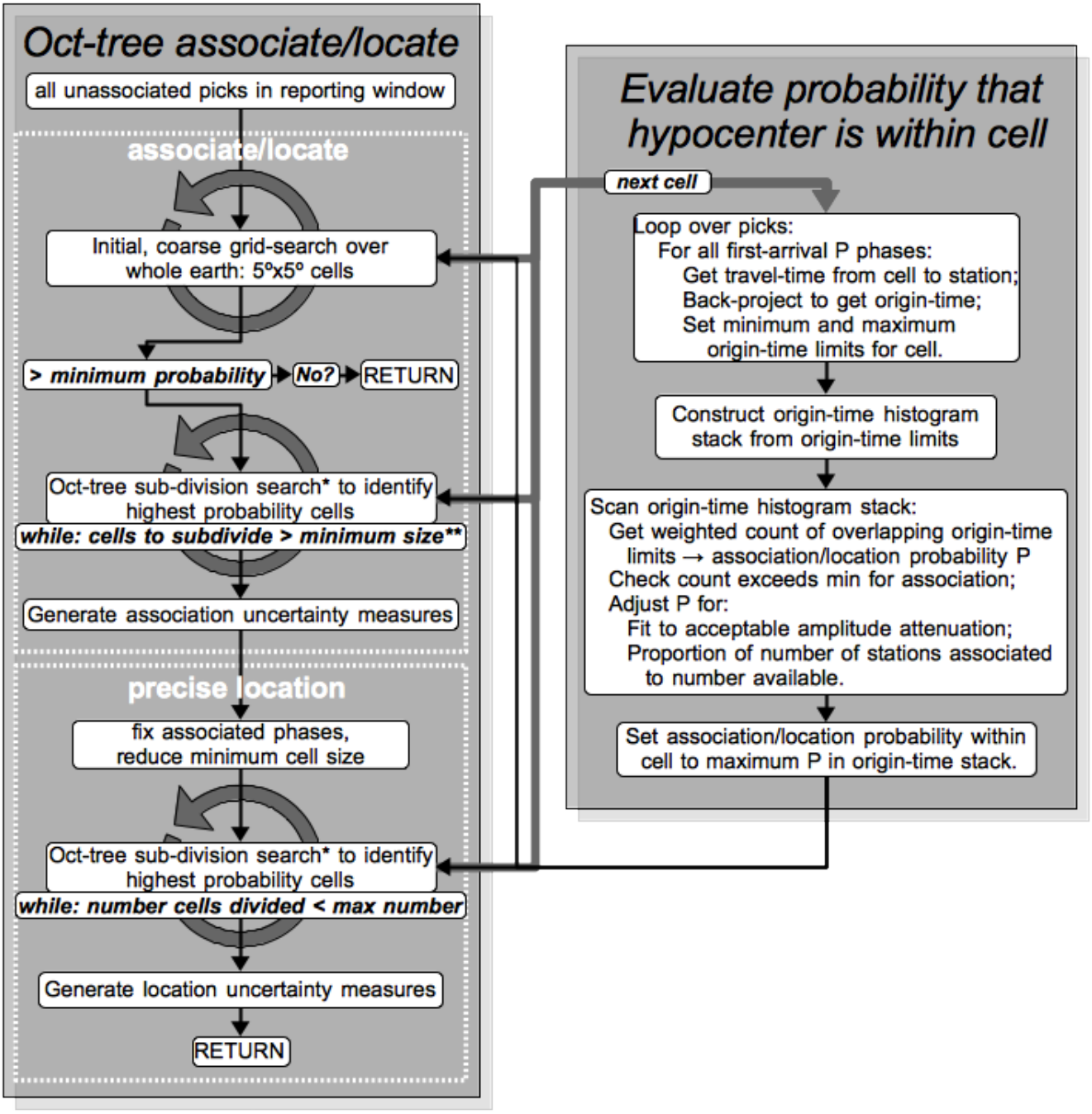


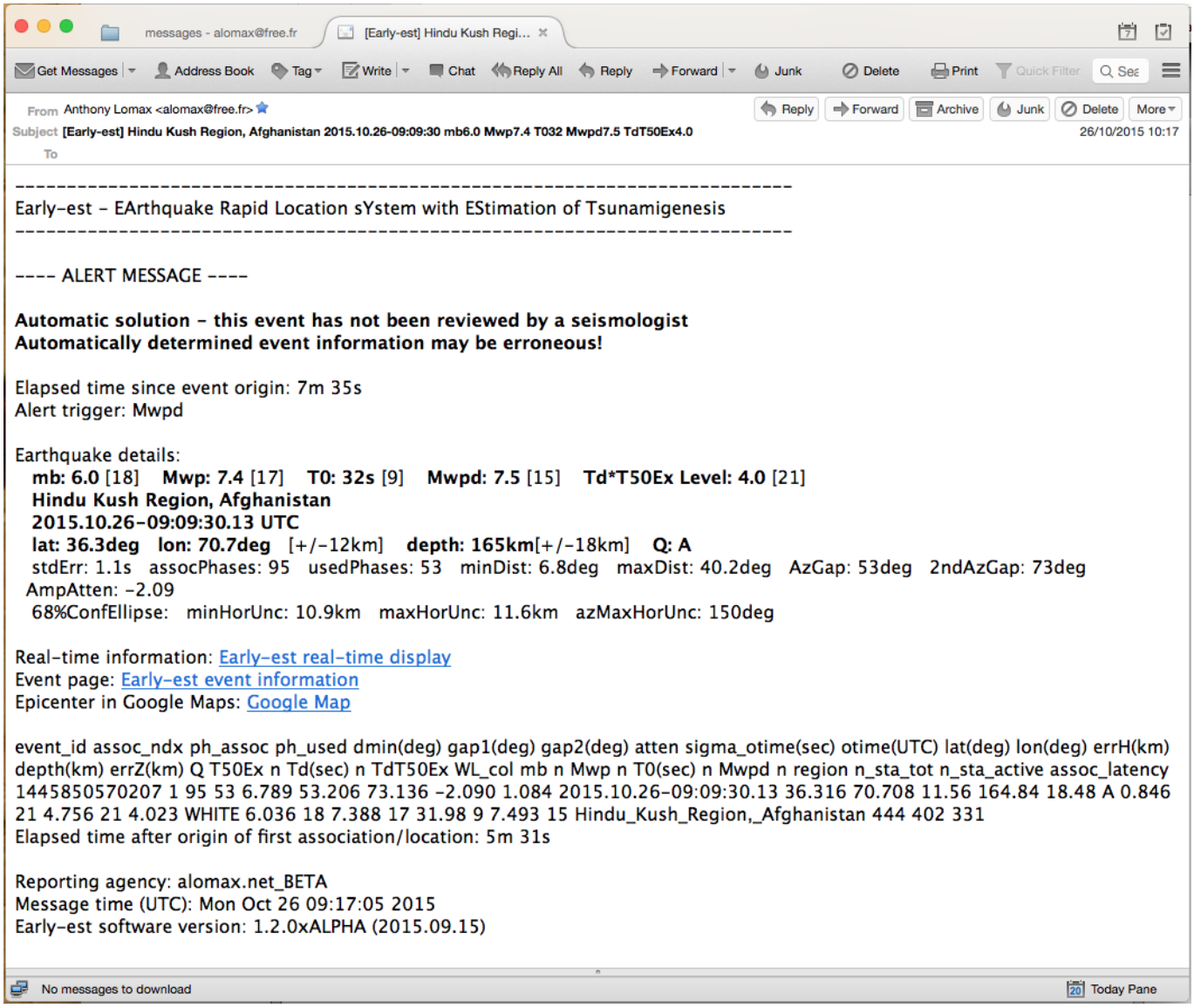
Figure 2. Early-est Associate/Locate Flow-Diagram



* cell division is performed at a fixed cell size for a specified number of cells or until no cell available to divide; the fixed cell size is then reduced and cell division continued

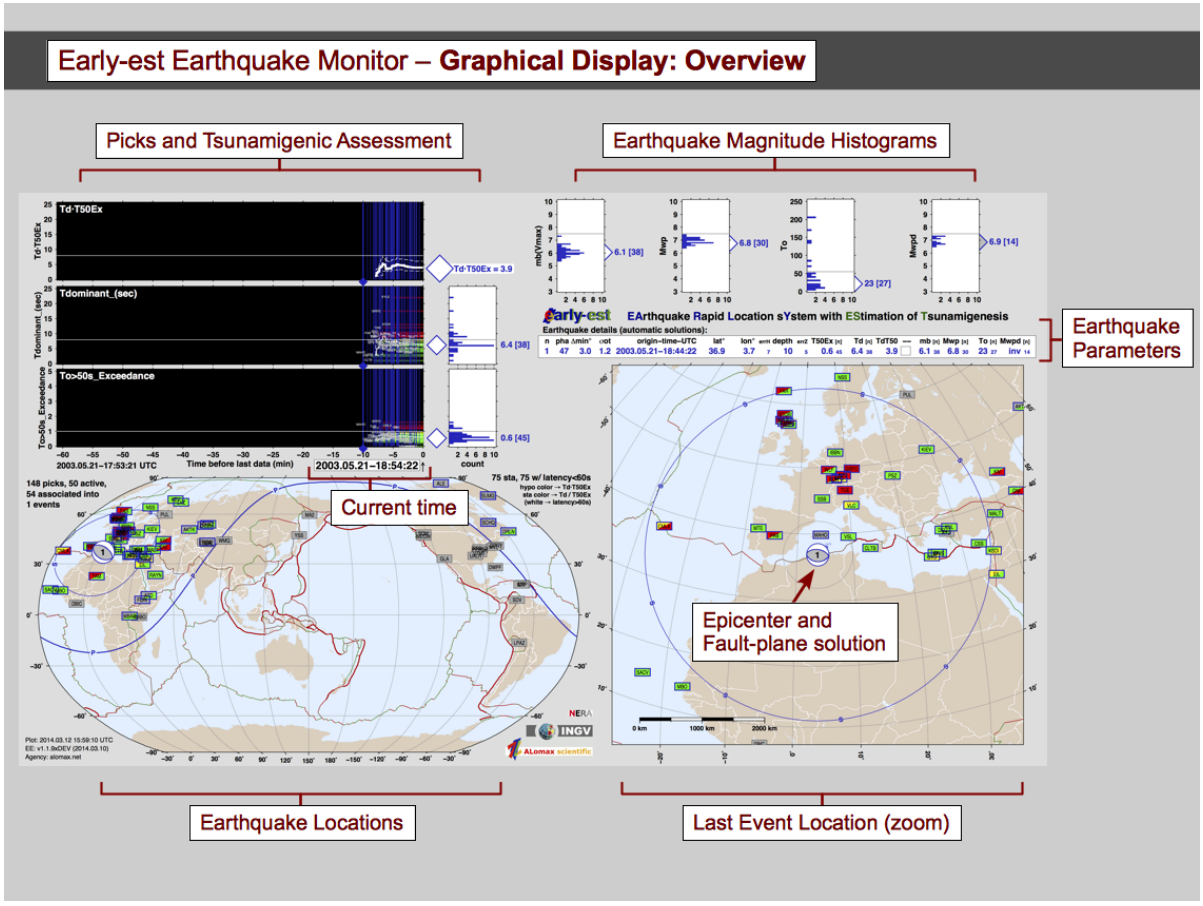
** minimum size is adaptively reduced in proportion to number of associated stations near epicenter

Figure 3


messages - alomax@free.fr
[Early-est] Hindu Kush Regi...
Get Messages
Address Book
Tag
Write
Chat
Reply All
Reply
Forward
Junk
Delete
Print
Quick Filter
From Anthony Lomax <alomax@free.fr>
Subject [Early-est] Hindu Kush Region, Afghanistan 2015.10.26-09:09:30 mb6.0 Mwp7.4 T032 Mwpd7.5 TdT50Ex4.0
26/10/2015 10:17
To
Reply
Forward
Archive
Junk
Delete
More

Early-est - EArthquake Rapid Location sYstem with EStimation of Tsunamigenesis
---
---- ALERT MESSAGE ----
Automatic solution - this event has not been reviewed by a seismologist
Automatically determined event information may be erroneous!
Elapsed time since event origin: 7m 35s
Alert trigger: Mwpd
Earthquake details:
mb: 6.0 [18] Mwp: 7.4 [17] T0: 32s [9] Mwpd: 7.5 [15] Td*T50Ex Level: 4.0 [21]
Hindu Kush Region, Afghanistan
2015.10.26-09:09:30.13 UTC
lat: 36.3deg lon: 70.7deg [+/-12km] depth: 165km[+/-18km] Q: A
stdErr: 1.1s assocPhases: 95 usedPhases: 53 minDist: 6.8deg maxDist: 40.2deg AzGap: 53deg 2ndAzGap: 73deg
AmpAtten: -2.09
68%ConfEllipse: minHorUnc: 10.9km maxHorUnc: 11.6km azMaxHorUnc: 150deg
Real-time information: Early-est real-time display
Event page: Early-est event information
Epicenter in Google Maps: Google Map
event_id assoc_ndx ph_assoc ph_used dmin(deg) gap1(deg) gap2(deg) atten sigma_otime(sec) otime(UTC) lat(deg) lon(deg) errH(km) depth(km) errZ(km) Q T50Ex n Td(sec) n TdT50Ex WL_col mb n Mwp n T0(sec) n Mwpd n region n_sta_tot n_sta_active assoc_latency
1445850570207 1 95 53 6.789 53.206 73.136 -2.090 1.084 2015.10.26-09:09:30.13 36.316 70.708 11.56 164.84 18.48 A 0.846 21 4.756 21 4.023 WHITE 6.036 18 7.388 17 31.98 9 7.493 15 Hindu_Kush_Region,_Afghanistan 444 402 331
Elapsed time after origin of first association/location: 5m 31s
Reporting agency: alomax.net_BETA
Message time (UTC): Mon Oct 26 09:17:05 2015
Early-est software version: 1.2.0xALPHA (2015.09.15)
No messages to download
Today Pane

Figure 4


Early-est Earthquake Monitor – Graphical Display: Overview
Picks and Tsunamigenic Assessment
Earthquake Magnitude Histograms
Earthquake Parameters
Current time
Epicenter and Fault-plane solution
Earthquake Locations
Last Event Location (zoom)

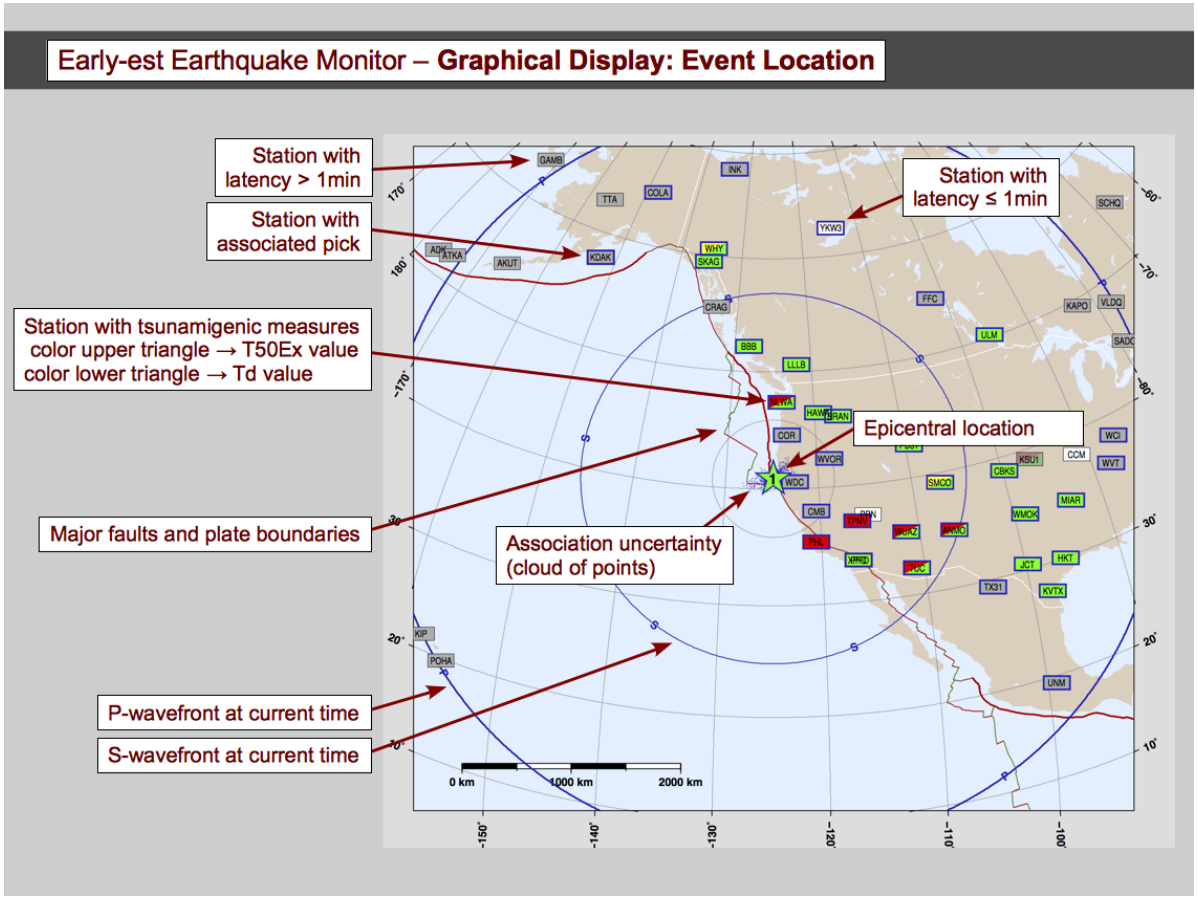
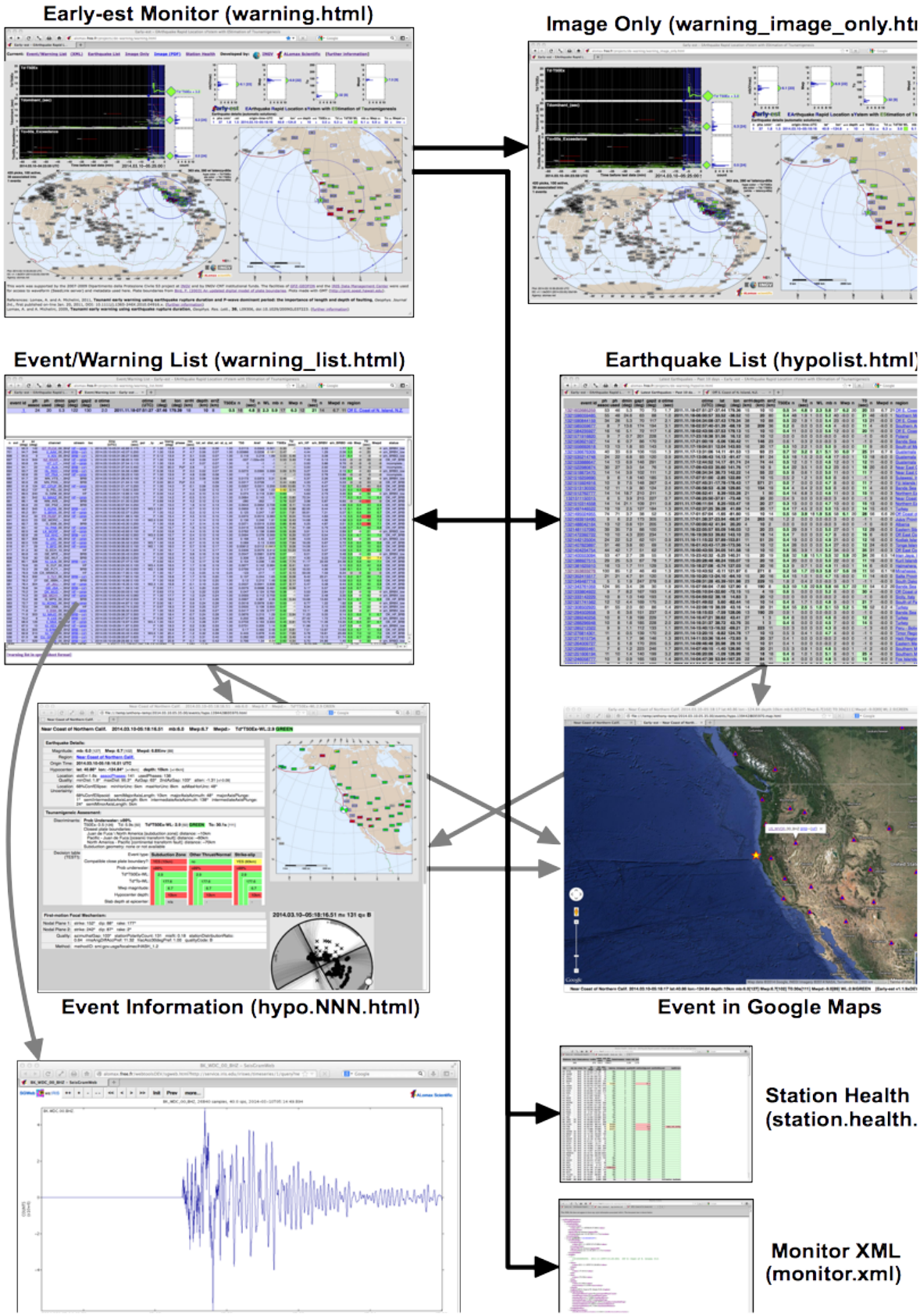

Early-est Earthquake Monitor – Graphical Display: Event Location
Station with latency > 1min
Station with associated pick
Station with tsunamigenic measures
color upper triangle → T50Ex value
color lower triangle → Td value
Major faults and plate boundaries
P-wavefront at current time
S-wavefront at current time
Station with latency ≤ 1min
Epicentral location
Association uncertainty (cloud of points)

Figure 5


Early-est Monitor (warning.html)
Image Only (warning_image_only.ht
Event/Warning List (warning_list.html)
Earthquake List (hypolist.html)
Event Information (hypo.NNN.html)
Event in Google Maps
Station Health
(station.health.
Monitor XML
(monitor.xml)

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Revision History Notes

v0.1.0	2009-09-24	First stable version
v0.1.1	2010-01-14	Replaced TestPicker4_1 with FilterPicker5
v0.2.1	2010-03-30	Added Td (dominant period) and Td*T50Ex warning, broadband picking, multi-phase association, event persistence, Mwp, higher precision association/location, and much more.
v0.2.2	2010-06-16	Added to event association checks on gap, secondary gap and percentage of available stations associated within distance of farthest associated station, support for multiple SeedLink servers, and much more.
v0.2.3	2010-06-20	Bug fixes and improvements to association/location reporting and weight count grid.
v0.2.4	2010-06-21	Bug fixes and improvements to association/location reporting and weight count grid.
v0.2.5	2010-07-05	Changed picking from BRB to HF and BRB, with BRB picks used for association/location only if there is an HF pick within the following 30 sec; improvements to association/location reporting and weight count grid.
v0.2.6	2010-11-09	Bug fixes. Changed picking to new version of FP, with changes/improvements to pick uncertainty settings, this may give earlier pick times.
v0.2.7	2010-12-06	Changed -c report command call to background to avoid delays to main trace processing. Changed HF picking tUpEvent from 4 to 2sec.
v0.3.0	2011-03-04	Added oct-tree association/location, mB, T0, Mwpd; extend output and graphics to support previous. Added simple e-mail alert messages, automatic retrieval of station coordinates from web services, XML format output, NLL format phase output for associated phases for each active location. Various bug fixes, improvements and modifications to association/location algorithm and general program functionality.
v0.3.1	2011-03-09	Fixed bug of writing to previously closed file.
v0.3.2	2011-03-31	Modified T0 algorithm to avoid erroneously long T0 durations (and large Mwpd) when P waves from a later event arrive soon after a pick. Changed Mwpd algorithm to use moment correction as in Lomax & Michelini 2008. Modified wavefront sampling algorithm to try to avoid GMT/Postscript plotting failures. Remove plotting of wavefronts and miscellaneous minor changes to plot_warning scripts. Fixed bug in setting start index before P for mB, Mwp, Mwpd calculations. Modified SL collect loop in seedlink_monitor.c to prevent cumulating large delays (multiple sleeps of 0.5s) in sl_collect_nb if a SL conn is down.
v0.3.3	2011-04-01	Fixed bug in setting memory array size. Fixed bug in storing trace data before P for BRB rms and mB, Mwp, Mwpd calculations.
v0.3.4	2011-04-11	Fixed bug in catching SL packet header error: "record header/quality indicator unrecognized". Added check to to avoid processing of same event twice and possible loss of instance with greater associated P phases.
v1.0.0	2011-05-13	Changed check for same event (location.c:isSameEvent()) to use 4*sigma_otime difference and 4*errH epicenter difference, more accurate epicentral distance difference calculation, with smaller otime difference allowing large epicentral difference and vice-versa; merged pickdata from same event with fewer associated P phases into other event, merged phases indicated by new 'M' merged flag to 'loc' column in pick tables. New check to ignore packets that have data

		end earlier than beginning of report window + report interval; prevents creation of duplicate events for events whose OT has passed before report window and whose associated phase data has been removed.
v1.0.1	2011-11-18	Replaced approximate travel-time estimation with accurate travel-time interpolated from table using 2D Lagrange interpolation. Corrected potential problems with mB and Mwp peak amplitude determination, depending on termination packet and timing of To estimation. Fixed minor bugs in T0, mB, Mwp, Mwpd realtime indexing. Added ray take-off angles. Added P first-motion mechanism calculation using USGS-HASHv1.2. Added bash and Python codes to generate event and mechanism information pages, and to generate FocalMechanism QuakeML for mechanisms. Replaced mB magnitude determination with mb(Vmax). Changed Mwpd calculation to report evolving Mwpd magnitude before final To available; limited Mwpd integration window width to S-P time; changed To and Mwpd minimum distance to 15deg. Improved efficiency of inner-loop distance and azimuth checks. Changes to assoc/loc critical node size test algorithm - now compares node size to epicentral distance containing a specified number of associated stations. Changes to oct-tree probability factors (PROB_FACTOR_CONVERGENT, PROB_FACTOR_SAMPLE) for minimum probability to divide; changes to calculation of pdf scatter sample for association and for location.
v1.0.2	2011-11-24	Added audio alert option for warning image-only HTML page.
v1.0.3	2011-12-06	Increases phase uncertainty limits by x2 to avoid missed associations for PKP and other phases. Added check to sendmail parameters to avoid Segmentation Fault crashes. Minor additions and modification to main monitor graphic.
v1.0.4	2011-12-12	Split event processing with processEvents.py into mechanism and events stages; allowed re-ordering of processing in plot_warning_report_seedlink_runtime.bash so that main monitor display with focal mechanism is completed first and rapidly, while slower event processing is done last.
V1.1.0	2011-12-19	Changed PKIKP phase (not supported in iaspei-tau) to PKiKP, added new secondary phases and reduced P error from 4.0s to 1.0s to help avoid false events on PKP, PKiKP, etc. Current supported phase set: P, Pdiff, Pg, PKiKP, PKPab, PKPbc, PKPdf, PKKPab, PKKPbc, PKKPdf, PKPPKPab, PKPPKPbc, PKPPKPdf, PP, S, Sdiff, Sg, SKSac, SKSdf, SKPdf, pP, sP, PcP, ScP, ScS, PKKSab, PKKSbc, PKKSdf, SKKSac, SKKSdf.
V1.1.1	2011-12-21	Fixed bug in S time calculation for limiting Mwpd integration window to S-P time. Added check if total weight of unique associated stations/phases is greater than min_weight_sum_assoc to avoid association on multiple picks from same station.
V1.1.2	2012-03-07	Removed smoothing window width from To for short durations (<60s). Reduced T50Ex, T50Ex*Td, To and Mwpd minimum distance to 5deg; added reference of To duration to S arrival time if duration overlaps S time (e.g. To=HF_duration_end-Ts if Tp+To_est > Ts+(Ts-Tp)/4. Added COUNT_IN_LOCATION | FIRST_ARRIVAL_P for PKPab. Improved checking processing for clip and non-contiguous (gap or overlap) data. Truncated Td estimation to maximum time-window of P+To. Increased P error from 1.0s to 2.0s; set SMALL, MED, LARGE phase errors to 4, 6, 6 sec, respectively (see ttimes.c). Modified monitor.xml formatting to better correspond to QuakeML standard. Added channel links to SeisGramWeb and IRIS Metadata on Event/Pick List HTML page (warning_list.html); the activation of these links depends on the SeedLink server of the channel and is controlled by a new command-line options -timeseries-query*.

V1.1.3 2012-04-16 Added simple broadband, waveform first-motion estimation using sign of Mwp integral at time after P = 1/8 Mwp duration, if Mwp duration > 0.5s; use FilterPicker first-motion otherwise. Fixed bug in setting station quality weight to prevent reduction in quality due to picks that will later be ignored. At dist<20deg, use T0 and Mwpd for report only if T50Ex > 1.0 and tauc > 5.0s; this helps avoid unreasonably large T0 and Mwpd for small events.

V1.1.4 2012-07-17 Changed duration cutoff for Mwpd correction from starting at unique event T0 value (100s) to ramp correction factor from 0 at 90s to 1.0 at 110s; prevents discontinuous change of Mwpd with respect to event T0. Added BRB displacement (BRBD) S/N calculation using 200s RMS window; added BRBV columns in picks.csv and pickmessage.html, added count of picks with low S/N BRBD in picks.log. Changed S/N check for Mwpd from BRB velocity to BRB displacement; avoids overestimate of Mwpd when P waves are in surface wave coda of preceding large event. S/N check for Mwp unchanged on BRB velocity.

V1.1.5 2013-04-16 Fixed bug in calculation of HASH focal mechanism: Nodal Plane 2 strike, dip and rake; were incorrect. Modified HASH inversion parameters (see hash_driver_early_est.bash). Modified HASH solution quality rating algorithm (see hash_driver_early_est.f). Added to pick list fields for: pick type (F – FilterPicker first-motion; W - broadband, waveform first-motion; numeric value is pulse width for W first-motion estimation), and pick weight.

Added additional event evaluation: Probability under-water (considers coastlines and epicentral uncertainty); Identify closest plate boundaries and their tectonic type (using Bird, 2003); Subduction zone analysis and slab depth (using Hayes and Wald, 2009; Hayes et al., 2012).

Added in event page a graphical representation of earthquake parameters, discriminants and derived quantities in a real-time, hybrid decision table/tree.

Added persistent list of associated phases for an event linked from event page.

Fixed problems in GMT plotting (corruption of plots) by setting different GMT_TMPDIR for each main GMT module to prevent overwriting of GMT script data for each module.

Added quality measures to HF FilterPicker and broadband waveform first-motion calculations (Either the broadband, waveform polarity or the FilterPicker polarity is used for mechanism determination, depending on the quality of the polarity measures and signal-to-noise ratios.), modified broadband waveform first-motion parameters.

Changed amplitude at pick (reference for integration) for Mwp and Mwpd integration from trace amplitude to zero; this gives more stable integration and reduces scatter and (upward) bias of station Mwp and Mwpd magnitudes.

Changed BRBV and BRBD S/N calculation to use signal level in window of length To after P instead of fixed window length (was 50s for BRBV S/N and 200s for BRBD S/N); this generally gives higher S/N for short duration P waves and lower S/N for long duration and large event P waves. Modified S/N calculations to use maximum window available after P for provisional S/N estimate until definitive S/N available; this avoids long delay before declaring S/N too low, this delay can allow reporting of temporary, too-high magnitudes which later will be ignored.

Added check to un-associate outlier associated stations (e.g. isolated, very distant stations or late associated with small, local event.); reduces greatly the number of false associations of later arrivals.

		Removed Pdiff as count in location. Fixed bug in ignoring non-contiguous data for location. Improved and fixed minor bugs in comparing times of BRB and HF picks to set use_for_location for BRB picks. Added support for a properties file to allow setting of some program parameters. This change is made primarily to enable microseismic/local/regional scale association, the default values of all properties are appropriate for the global scale. The properties file must be in the working directory with the name seedlink_monitor.prop or miniseed_process.prop for the seedlink_monitor and miniseed_process programs, respectively. Added -no_aref_level_check command-line flag. Disables check of Aref level a means to ignore picks close in time and insure quality (non-overlap) of tsunami discriminants). Instead checks for use_for_location picks less than assoc_loc.min_time_delay_between_picks_for_location seconds (set in properties file, default = 25.0 sec) after another use_for_location pick for same source_id Use this flag to support microseismic/local/regional scale monitoring where tsunami discriminants are not used. Added phase error factor to pick weight to use for association/location. This factor = (reference_phase_ttime_error / time_errors), where reference_phase_ttime_error is the minimum value of the nominal maximum acceptable travel-time error for each phase type used for location/association, and time_errors is the travel-time plus pick error for a pick with specified phase. This change allows more balanced use of non-P phases (e.g. S) with non-zero weight for association/location. This change is made primarily to enable microseismic/local/regional scale association, but it does slightly change the pick weighting for the global scale when only P phases have non-zero weight for association/location. Fixed bug: Calculated hypocenter to station azimuth was incorrect for some azimuth quadrants.
V1.1.6	2013-05-28	Possible fix of segmentation-fault bug (see use_for_location_twin_data in timedomain_processing_data.c->free_TimedomainProcessingData() and timedomain_processing.c->td_process_timedomain_processing(). Changed phase distance weighting (dist_wt) from linear to geometrical decay by using square of previous dist_wt value. Begin modifications to code to support parameter setting with a properties file, robust association/location on a local scale, and easier use of different velocity models. Work in progress to be documented later.
V1.1.7	2014-01.08	Add support for changes to web-services at IRIS: response ws moved to http://service.iris.edu/irisws/resp/1/; station ws (Early-est query type IRIS_WS_STATION) replaced by http://service.iris.edu/fdsnws/station/1/query (Early-est query type FDSN_WS_STATION). Added date stamp to geographic station coordinates file; date stamp is time corresponding to coordinate validity. Added system call to a script run_action__alert_sent.bash (e.g. Twitter messaging) called whenever an e-mail alert is sent. BRB S/N: modified to use maximum window available after P for provisional s/n estimate; bug fix to Mwpd display in phase list. Added properties files (seedlink_monitor.prop for seedlink_monitor,

		miniseed_process.prop for miniseed_process, process_events.prop for processEvents.py. See these properties files for further documentation. Added properties file options to enable/disable alerting and dissemination of tsunamigenic potential warning information and warning color display, and various event reporting options. See [Report] section of seedlink_monitor.prop or miniseed_process.prop and [EventInfo] section of process_events.prop for options. Added export for external processing (e.g. CMT calculation) of waveform segments in miniseed format and waveform header information in SeisGram2K ASCII format. See [WaveformExport] section of seedlink_monitor.prop or miniseed_process.prop for waveform export options. Waveforms are written under the waveforms/ sub-directory of the program output directory. Modifications and bug fixes to date-stamped reading of station meta-data (station coordinates and gain) from file and web-services.
V1.1.8	2014-01-20	Additional bug fix to date-stamped reading of station meta-data (station coordinates and gain) from file and web-services. Bug fix in HASH: gfortran compiler: uncert_subs.f:130.54: Warning: Rank mismatch in argument 'rota' at (1) (scalar and rank-1): call MECH_ROT(norm1_avg,temp1,norm2_avg,temp2,rota)
V1.1.9	2015-04-24	Bug fix: matrix_statistics/matrix_statistics.c: CalcCovarianceSamples*(): new algorithm which subtracts the expectation from each data value before squaring and summing, instead of correcting for expectation after summing and dividing by nSamples. Should prevent precision errors in covariances when expectation is far from coordinates origin. Bug identified by Tobias Megies. Errors in covariance will affect ellipsoid and ellipse, standard-errors (erh, erz, etc.). For teleseismic locations, errors with old algorithm could be large towards longitude +/-180deg. Amplitude attenuation check: Added calculation and weighting during association if the fit of the high-frequency (1-4Hz) P amplitude attenuation to a power law decay follows a theoretical decay power. The weight is related to the cumulative probability of the estimated attenuation power being between -0.5 and -3.5. Magnitude validation based on amplitude attenuation: Added check of channel amplitude error (ratio of observed amplitude to amplitude predicted predicted by attenuation power law); if amplitude error > 5 or < 0.2, do not use channel magnitude estimates. Added persistent storage of (fixed) distance, azimuth and travel-times from each station to each cell of (fixed) initial search grid. This increases slightly program efficiency after first few association-locations. During oct-tree subdivision-search to divide highest probability cells: added subdivision of same-size neighbors of each cell identified to sub-divide. This addition helps to generate a smoother pdf for location and avoids missing optimal maximum likelihood locations for complex pdf's. The subdivision of neighbors has always been used in NonLinLoc. Excluded Pdiff phases from mb, Mwp and Mwpd measures. Changed selection of export waveform to be less strict so as to include all first arrival or direct P phases which can be counted in location. Developed prototype of new probabilistic, grid-search (oct-tree), mechanism determination code, fmamp, using first-motions and, optionally, relative P amplitudes. fmamp can be run and its results displayed along with the HASH

mechanism results in the Early-est HTML event pages. Added fmamp mechanisms: FMAMP_POLARITY, FMAMP_AMP_AREF (high-frequency) and FMAMP_AMP_MWP (broadband) to Early-est HTML event pages, HASH remains definitive (plotted) mechanism.

Changed broadband, waveform first-motion estimation to sign of peak amplitude of Mwp integral or (moment, "WMO") if S/N of Mwp integral high enough; use FilterPicker first-motion otherwise.

Bug fixes to make requests to multiple response or station web services.

Updated support for displaying event information and epicenter in Google map (launched from Early-est hypocenter region-name links and in alert e-mail) - Google's map service was changed to “new Google Maps” in February 2014, this new service did not display the Early-est epicenter marker. Changed the Google map launching from a URL string (http://...) to Javascript in an event HTML web page (hypo.<event_unique_id>.map.html) to correctly display an epicenter marker. The use of Javascript allows extensive and sophisticated Google map display through the Google Maps JavaScript API (https://developers.google.com/maps/documentation/javascript/basics). To test and demonstrate these display features, added display of epicenter uncertainty ellipsoid and pdf scatter sample, station markers with links to SeisGramWeb waveforms for event.

Added properties file options to set minimum magnitude thresholds (e.g. property [Report] alert.mb_min) for sending alert messages. See [Report] section of seedlink_monitor.prop or miniseed_process.prop.

Removed references to “Warning Level” and “WL” and display warning level colors from all HTML and graphics output and alert messages.

Changed oct-tree target values (node value) from probability in cell to probability density in cell. This makes oct-tree search “standard” importance sampling, as in oct-tree for NonLinLoc, and should give more meaningful scatter samples (location uncertainties). TODO: This change may allow replacing the hierarchical searching by constant levels (oct-tree node size) with “standard”, multi-scale oct-tree search at all levels simultaneously.

Improvements and bug fixes in scatter samples (location uncertainties).

Added persistent list of all hypocenters located (hypolist_persistent.csv). Hypocenters are written once to this list when beginning of report interval slides past hypocenter origin-time (hypocenter origin-time first falls before beginning of report interval). NOTE: this file will grow without limit! Should be archived and deleted each month(?), year(?).

Event persistence: Added check of number of possible new defining picks, Np, (picks with non-zero association weight) for existing events. If Np < Na/20, where Na is the number of existing defining picks, then preserve previous location/hypocenter results for event and only check for association of new picks.

Added support for automatic retrieval of channel gain from FDSN station web-services: FDSNStationXML InstrumentSensitivity Value

Added Mwp distance correction: calculate_Mwp_correction_INGV_EE() from Bernardi et al. (2015) Appraising the Early-est earthquake monitoring system for tsunami alerting at the Italian candidate Tsunami Service Provider. Regression: f(d)=-1.32e-6*d^3 +2.40e-4*d^2 -0.0146*d + 0.314

Changed minimum Mwp distance from 5deg to 1deg since Bernardi et al. (2015) correction based on readings down to about 0deg. Provides more and earlier

Mwp readings.

Added mb magnitude correction: calculate_corrected_mB_INGV_EE() from Bernardi et al. (2015) Appraising the Early-est earthquake monitoring system for tsunami alerting at the Italian candidate Tsunami Service Provider.
Regression:

```
if (mb_uncorr >= 5.125)
  mb_neic = 0.52 * mb_uncorr + 2.46;
```

Standardized and modernized writing of QuakeML XML in C and python:

monitor.xml:

1. Added xmlns:ee="http://net.alomax/earlyest/xmlns/ee" for Early-est specific tags.
2. Added publicID attribute to: <arrival>, <pick>
3. Moved event mb, Mwp, Mwpd <magnitude> from children of <origin> to children of <event>
4. Moved event Td, T50Ex, TdT50Ex, To from <magnitude> children of <origin> to new tag <ee:discriminant> children of <event>
5. Changed <confidenceEllipsoidNLL> to <ee:confidenceEllipsoidNLL>
6. Added <ee:amplitudeAttenuationPower>, <ee:amplitudeAttenuationIntercept> to <origin><quality>
7. Moved unassociated picks to within new <qrt:eventParameters> element under root element <q:quakeml>, to conform to quakeml-rt specifications.
8. <pick>: changed fields to: <ee:stationQualityWeight>, <ee:T50>, <ee:Aref>, <ee:T50Ex>, <ee:Td>, <ee:snHF>, <ee:snBRB>; added <ee:T0>
9. <arrival>: added <timeWeight>, changed fields to: <ee:totalWeight>, <ee:distanceWeight>; removed <T0> (moved to <pick>)
10. TimeQuantity: added <uncertainty> and <confidenceLevel>

hypo.<event_id>.mech.hash|fmamp.xml:

1. Moved <FocalMechanism> element to within <q:quakeml><EventParameters ><Event > elements.
2. Added xmlns:ee="http://net.alomax/earlyest/xmlns/ee" xmlns:hash="http://net.alomax/earlyest/xmlns/hash" for Early-est and method-specific FocalMechanism elements.
3. Changed tags to Early-est and method-specific FocalMechanism elements.
4. Modified publicID's to be a complete smi's.

Format changes:

1. picks.csv, pickmessage.html: added Aerr – ratio of observed Aref amplitude to predicted Aref amplitude when P amplitude attenuation check enabled.
2. hypo*.csv, added:
   n_sta_tot – number of stations for which data has been received in past.
   n_sta_active – number of stations for which data has been received and data_latency < report_interval (e.g. 1min).

assoc_latency – latency in seconds of first association after origin-time of event. May be erroneous (too large) if event de-associated and later re-associated.

V1.2.0 2016-06-08 Added station corrections based on 3rd order polygon fit of residuals with distance. Applied between specified min and max distances, which may depend on distance range of previous association residuals used to generate station corrections. (20150508)

Converted Early-est oct-tree search (over sequential set of decreasing cell sizes / search levels) to standard oct-tree search over all cell sizes / levels simultaneously. Required several changes to target association probability function. (20150728)

Modified gap algorithm so that gap weight goes linearly from one to zero between 180deg and critical gap angles; before weight went to zero from critical gap angles to 360deg. Makes association gap test stronger. (20150730)

Fixed bug in plotting of scatter sample in Google maps after apparent change in Google Maps API that Circles became scaled to true distance. Changed from plotting each scatter point as a Circle to plotting it as a Marker. (20150818)

Added epicenter statistics output "epicenter.diff.csv" to support plotting of epicenter convergence. Epicenter Convergence plot added to main monitor display. (20150812)

Added plotting of un-associated stations (with trace link centered on predicted arrival time), station parameters, station health in Google maps. Added stations map to Station Health page. (20150909)

Added ABCD hypo quality level calculation. See trace_processing/timedomain_processing/location.c→setHypocenterQuality() for algorithm details. Quality level added to main monitor display. (20150904)

At end of association, unassociated, definitive (have non-zero weight for location) picks are assigned increased ttime error (x3). This increase association likelihood and avoid false events due to numerous unassociated picks for large events. The location weight for such picks is set to zero. (20150910)

Changed flagging of picks that count in location so that raw BRB picks will be used even when there is no following HF pick. Effectively enables simultaneous and independent BRB picking and HF picking for location (20150930)

Modified fmamp polarity and amplitude likelihood functions and pick take-off angle distribution weighting to improve mechanism likelihood mapping and solution uncertainty/quality estimation (20151028, 20151104)

Changed preferred and map display FM focal mechanism from HASH to fmamp_polarity.

Bug fix: Added S-P time check for s/n_BRBV, s/n_BRBD and s/n for mb so that signal window cannot end past S arrival time. Also changed (noise, max singal windows) to (20s, 20s) for s/n_BRBD, and (10s, 10s) for s/n_BRBV and s/n for mb. (20151117)

Modifications to amplitude attenuation weighting for association (20160113)

Changed fmamp polarity misfit algorithm and weighting (20160321-20160331)

Only send alerts for acceptable (A or B) quality events (20160304)

Pick distance weighting changed to exact geometrical decay in proportion to distance from source when distance > min distance for distance weighting.

(20160405)

Bug fix: added missing header line for hypo csv files in separate file:<outpath>/hypos.csv.hdr (20160525)

Added global grid based on maximum previous seismicity source depth to help avoid deep locations where not possible or likely. Association probability is multiplied by: weight = 1.0 if event depth <= 100km or previous seismicity depth > 100km, otherwise weight = 0.5 (20160511)

Format changes:

picks.csv: appended "sta_corr" field showing station correction that is subtracted from the listed pick time for association/location (20150716)

hypos.csv: added ABCD hypo quality level field "Q" (20150904)

monitor.xml:

1. Added to <origin>: <ee:qualityIndicators_*>; lists quality measures and weights that contribute to event association validation and ABCD location quality code.
2. Added to <origin>: status indicators: <ee:nstaHasBeenActive>, <ee:nstaIsActive>, <ee:firstAssocLatency>.
3. Added to <pick>: <polarity>, <ee:polarityType>, <ee:polarityWeight>, <ee:stream>, <ee:deltaTime>, <ee:useForLoc>, <ee:stationQualityWeight>, <ee:Avel>, <ee:Adisp>, <ee:staCorr>
4. Added to <arrival>: <ee:takeOffAngleInc>

V1.2.1 2017-03-30 Added support for station corrections for any phase, previously only P phase used. Phase code is specified in the station time correction file. (20160601)

Added azimuth constraint on locations: Configure and read 3-component data streams (e.g. ZNE, Z12); Associate 3-comp, orthogonal channel sets; Apply P polarization analysis to observed, 3-comp data using real, covariance analysis (see alomax_matrix/polarization.c); Up-weight P phases used for location based on comparison of mean/std_devs of estimated observed P azimuth and predicted azimuth for an epicenter (see timedomain_processing/location.c); save 3-comp waveforms. (201608)

Migration to GMT5: extensive changes to *.gmt scripts – GMT5 REQUIRED!, changes to fmamp pspolar output (polarity C/X changed to +/-). (201609)

Modified persistent event location (see V1.1.9, 2015-04-24: Event persistence) so that only a reduced search volume around previous hypocenter is used for oct-tree search. (201609)

Added event location sequence number "seq_num", which counts the number of times the event has been relocated since it's initial association-location (seq_num=0). Note that the sequence number can be reset to 0 if a relocation moves the event in space or time far enough that it is considered a new event. (201609)

Format changes:

picks.csv: Added "paz paz_unc paz_calc paz_wt" (estimated observed P azimuth, its uncertainty, predicted azimuth for epicenter, azimuth upweight value (201608)

hypos.csv: Added “seq_num” (201609)

monitor.xml:

1. Added to <arrival>: <ee:polarizationAzimuth>, <ee:polarizationAzimuthUnc>, <ee:polarizationAzimuthCalc>, <ee:polarizationWeight>
2. Added to <origin>: <ee:seq_num>

V1.2.2 2018-06-01 fmamp: Simplified polarity likelihood algorithm: Changed PERCENT_OUTLIER_ERROR_ALLOWED from 10% to 0%; HASH uses 10% but assume that fmamp probabilistic search is robust against outlier polarities (20170412). Removed MISFIT_NORMALIZATION_CUTOFF, seemed to make little difference (20170411).

fmamp: No longer use PKP polarity readings (may bias solution with large number of readings at very steep dip (20170415)

trace_processing/timedomain_processing/ttimes/ttimes_ak135_0-800_10.h: Changed PP from SMALL_ERROR to LARGE_ERROR (minimax phase); changed ScP from SMALL_ERROR to MED_ERROR (20170303)

Color coded A-D location quality added to event list in main display and in Event pages. Re-arranged order of histogram panels and magnitudes in event list. (201712)

Added support for SeisGram2K reading of archive waveforms: added hypolist.xml list of events with available waveform data; changed waveform file name to include pick time as prefix; added travel-time and residual to NonLinLoc phase format output (201801)

Added writing of event XML files for each location sequence number. Event sequence XML files are written in an event_seq_xml/<event_id>/ subdirectory of the -o output directory, e.g., seedlink_out/iris/event_seq_xml/1517930187844/loc_seq_005.xml The event sequence XML files are deleted after the time specified by the properties file parameter hypocenter_sequence_xml.file_archive.age_max.

Bug fix: WaveformExport: modified waveform start time to correctly export waveform export for non-P picks (e.g. PKP) (20170406).

Bug fix: FDSNStationXML gain: changed “chan” to “channel” (20171212)

Changed (Bug fix?): location.c→dist-range: removed pick_error from range (20180102)

Bug fix: location.c→ amplitude attenuation weight factor: weight was reduced when more outlier amplitudes, corrected to reduce effect of amp_att_weight when many outliers (20180206)

Format changes:

monitor.xml:

1. QuakeML bug fix: Picks made children of Events, not Arrivals (20171219)
2. QuakeML bug fix: Corrected Arrival resourceID to be same as corresponding Pick (20171219)
3. QuakeML bug fix: Pick moved outside Arrival element for associated picks (20171219)

4. QuakeML bug fix: Pick polarity written as one of "positive", "negative" or "undecidable" (20171219)
5. QuakeML bug fix: Magnitude resourceid modified to include Event resourceid (20171219)
6. QuakeML bug fix: Origin depth corrected to be in meters, was kilometers (20180105)
7. QuakeML: Added preferredMagnitudeID element in Event element (20180129)
8. ee:polarizationAzimuthCalc added to Arrival tag (20170309)
9. Bug fix : "ee:seq_num" was not correctly set to loc_seq_num, was set to nassoc (20170309)

V1.2.3 2018-10-03 Bug fix: IMPORTANT:
In timedomain_processing/timedomain_processing.c
Disabled:
#define USE_RAW_PICKS_UNCONDITIONALLY
Likely caused false events due to picking strong, long period arrivals from preceding large events without verification of existence of a corresponding high-frequency pick. Some if these false events had very large Mwp and Mwpd due to large amplitude and long period of picked arrivals. (20180823)

Format changes:

monitor.xml:

1. Bug fix: PickID now includes the stream type (0=HF or 1=BRB) after the channel ID. (20181003)

NLL format phase output:

1. Changed phase label format to NET_STA_LOC (20181203)

V1.2.4 2019-04-12 Bug fix: IMPORTANT:
Revert to GMT4: includes changes to *.gmt scripts – GMT4 REQUIRED! GMT5 runs much too slowly so that report processing does not complete in a timely manner (e.g. << 1min)

Bug fix:
Remove SAVE_DIR in plot_warning_report_seedlink_runtime.bash (20190412)