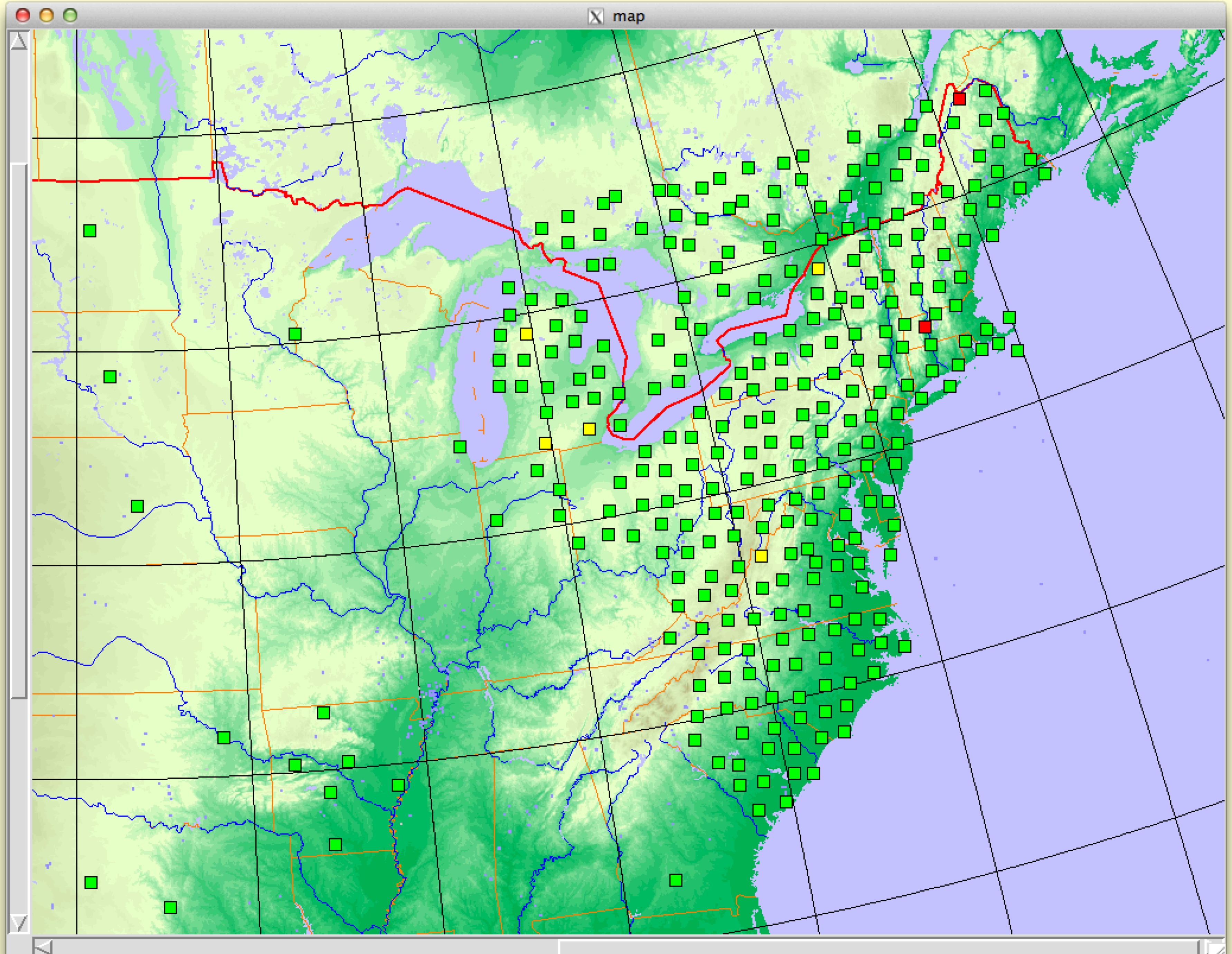
Automatic Event Location with ***Antelope***

May, 2014

Antelope User Group Meeting

Baku, Azerbaijan

BOULDER REAL TIME TECHNOLOGIES, INC.


map

dlmon

File Views Windows

dlname	comt	comp	gp24	gp1	nr24	pmp	SLT	dltncy	runtm	tp	cme	bufr	nl24	np24	ni24	dr	br24	bw24	meme	ade	cals	cltncy	lcq	cldrf	m0-2	m3-5	temp	volt	amp	gpss	gps	pll	lat	lon	el
TA_109C	rint	I	0s	0s	0	I	21s	02s	19h19m52s	1.00	100%	0.0%	1	1	0	2.6k	29m	728k	0			00s	100%	1us	42	20	29C	12.0V	72mA		3D	L	32.889	-117.105	17
TA_121A	cell	VZ	0s	0s	0	I	21s	03s	19h19m27s	1.00	100%	0.0%	2	1	0	3.4k	39m	730k	0			00s	100%	0us			27C	12.0V	61mA		3D	L	32.532	-107.785	164
TA_157A	cell	VZ	0s	0s	0	I	21s	03s	19h19m38s	1.00	100%	0.0%	2	1	0	4.1k	45m	743k	0			00s	100%	0us	-12	20	26C	12.4V	66mA		3D	L	32.678	-80.997	
TA_158A	cell	VZ	0s	0s	0	I	21s	03s	19h19m44s	1.00	100%	0.0%	2	2	0	4.1k	44m	735k	0			00s	100%	0us	15		26C	12.0V	79mA		3D	L	32.736	-80.194	-1
TA_214A	vsat	WB	0s	0s	0	I	21s	03s	15h02m29s	1.00	100%	0.0%	4	7	2	5.9k	66m	1.2m	0			00s	100%	0us	8	21	38C	11.8V	200mA		3D	L	31.956	-112.812	53
TA_435B	cell	VZ	0s	0s	0	I	21s	03s	03h40m12s	1.00	100%	0.0%	2	2	0	3.2k	35m	755k	0			00s	100%	0us	-13	20	27C	12.2V	64mA		3D	L	30.783	-97.585	24
TA_833A	cell	VZ	0s	0s	0	I	21s	03s	19h19m34s	1.00	100%	0.0%	1	1	0	2.3k	25m	727k	0			00s	100%	0us	33		33C	12.2V	62mA		3D	L	28.324	-99.394	16
TA_A04D	cell	VZ	0s	0s	0	I	33s	03s	12h19m23s	1.00	100%	0.0%	2	1	0	6.7k	70m	1.2m	0			00s	100%	0us	-11	20	18C	12.2V	74mA		3D	L	48.720	-122.706	2
TA_A36M	dsl	nwte	0s	0s	0	I	20s	03s	19h19m28s	0.99	100%	0.0%	1	2	0	4.4k	48m	748k	0			00s	100%	-2us	7		6C	13.5V	62mA		3D	L	71.987	-125.247	6
TA_ABTX	cell	ATT	0s	0s	0	I	20s	03s	02h39m09s	1.00	100%	0.0%	2	2	0	3.5k	39m	730k	0			00s	100%	0us	-17	20	28C	12.2V	62mA		3D	L	32.624	-99.643	49
TA_B05D	cell	VZ	0s	0s	0	I	33s	03s	07h17m48s	1.00	100%	0.0%	2	2	0	5.9k	65m	1.2m	0			00s	100%	0us	10	20	18C	12.2V	74mA		3D	L	48.264	-122.096	14
TA_BGNE	cell	VZ	0s	0s	0	I	20s	03s	05h24m41s	1.00	100%	0.0%	2	7	0	4.3k	45m	727k	0			00s	100%	-2us	-26	20	27C	12.2V	148mA		3D	L	41.408	-98.150	56
TA_C06D	vsat	WB	0s	0s	0	I	33s	01h39m38s	18m26s	1.97	92%	20%	130	26	0	19k	73m	1.3m	0			00s	100%	0us	7	20	16C	12.2V	76mA		3D	L	47.923	-120.894	62
TA_C36M	none	none	0s	0s	0	I	20s	03s	19h19m46s	1.00	100%	0.0%	1	1	0	4.2k	45m	747k	0			00s	100%	0us	-15		9C	13.5V	62mA		3D	L	69.348	-124.070	5
TA_D03D	cell	VZ	0s	0s	0	I	33s	03s	19h19m31s	1.00	100%	0.0%	2	22	0	5.9k	64m	1.2m	0			00s	100%	0us	-11	20	19C	12.2V	76mA		3D	L	47.535	-123.089	26
TA_D04E	cell	ATT	0s	0s	0	I	33s	03s	19h19m19s	0.99	100%	0.0%	1	2	0	6.3k	69m	1.2m	0			00s	100%	0us	-12	20	20C	12.2V	76mA		3D	L	47.179	-122.772	3
TA_D46A	vsat	xplo	0s	0s	0	I	20s	03s	06h41m26s	1.00	95%	0.0%	3	3	0	3.8k	40m	727k	0			00s	100%	0us	20		17C	12.8V	56mA		3D	L	46.891	-84.036	33
TA_D47A	vsat	xplo	0s	0s	0	I	20s	04s	19h19m25s	1.00	100%	0.0%	2	3	0	3.2k	36m	740k	0			00s	100%	0us	-17		21C	12.8V	64mA		3D	L	47.056	-83.104	47
TA_D48A	vsat	xplo	0s	0s	0	I	20s	04s	19h19m30s	1.00	100%	0.0%	2	4	0	3.4k	36m	738k	0			00s	100%	0us	15	20	16C	12.9V	64mA		3D	L	47.174	-81.807	41
TA_D49A			0s	0s	0	I	20s	03s	13h09m39s	1.00	100%	0.0%	2	3	0	3.7k	42m	755k	0			00s	100%	0us	4		17C	13.7V	52mA		3D	L	47.273	-81.356	40
TA_D50A	cell	bell	0s	0s	0	I	20s	03s	11h58m04s	1.00	100%	0.0%	2	1	0	3.2k	35m	732k	0			00s	100%	-2us	24	20	22C	12.4V	62mA		3D	L	47.167	-79.841	31
TA_D51A	cell	Bell	0s	0s	0	I	20s	03s	04h11m54s	1.00	100%	0.0%	7	7	0	4.0k	43m	750k	0			00s	100%	-2us	14		20C	12.8V	58mA		3D	L	47.090	-79.373	26
TA_D52A	vsat	xplo	0s	0s	0	I	20s	03s	19h19m42s	1.00	100%	0.0%	1	2	0	3.4k	38m	743k	0			00s	100%	0us	16		18C	13.8V	53mA		3D	L	46.976	-78.412	34
TA_D53A	vsat	xplo	0s	0s	0	I	20s	03s	02h57m35s	1.00	99%	0.0%	2	3	0	3.3k	36m	738k	0			00s	100%	0us	-21		16C	13.7V	53mA		3D	L	47.080	-77.700	33
TA_D54A	cell	bell	0s	0s	0	I	20s	03s	15h16m58s	1.00	100%	0.0%	2	2	0	3.5k	38m	728k	0			00s	100%	0us	34		17C	13.5V	54mA		3D	L	47.152	-76.657	41
TA_D55A	cell	bell	0s	0s	0	I	20s	03s	14h33m31s	1.00	100%	0.0%	3	24	0	3.4k	37m	736k	0			00s	100%	0us	-10		18C	12.8V	57mA		3D	L	47.019	-75.473	33
TA_D56A	vsat	xplo	0s	0s	0	I	20s	03s	03h27m31s	1.00	100%	0.0%	6	5	0	3.5k	37m	725k	0			00s	100%	-2us	-12		14C	12.9V	59mA		3D	L	47.049	-74.757	41
TA_D57A	vsat	xplo	0s	0s	0	I	20s	03s	03h07m02s	1.00	100%	0.0%	12	25	0	3.5k	39m	760k	0			00s	100%	0us	-28		17C	13.1V	58mA		3D	L	47.017	-73.888	41
TA_D58A	cell	bell	0s	0s	0	I	20s	03s	12h36m37s	1.00	100%	0.0%	2	1	0	3.4k	38m	743k	0			00s	100%	0us	40		16C	12.3V	61mA		3D	L	47.096	-72.883	39
TA_D59A	cell	roge	0s	0s	0	I	20s	03s	19h19m46s	1.00	100%	0.0%	2	3	1	3.8k	44m	732k	0			00s	100%	0us	33		17C	12.8V	58mA		3D	L	47.007	-71.836	19
TA_D60A	cell	roge	0s	0s	0	I	20s	03s	19h19m33s	1.00	100%	0.0%	2	3	1	3.5k	40m	727k	0			00s	100%	0us	12		14C	12.9V	56mA		3D	L	46.914	-70.924	5
TA_D61A	cell	roge	0s	0s	0	I	20s	03s	19h19m48s	1.00	100%	0.0%	2	3	1	3.5k	38m	726k	0			00s	100%	0us	-9		15C	13.7V	60mA		3D	L	47.202	-70.187	14
TA_D62A			0s	0s	0	I	20s	25m11s	24m34s	0.00			6	17	0	0	39m	746k	0			00s	100%	0us	11	20	17C	13.9V	58mA		3D	L	47.082	-69.050	18
TA_D63A			0s	0s	0	I	20s	03s	10h44m33s	1.00	100%	0.0%	2	1	0	3.4k	38m	741k	0			00s	100%	0us	-4	20	14C	13.7V	62mA		3D	L	47.037	-68.107	25

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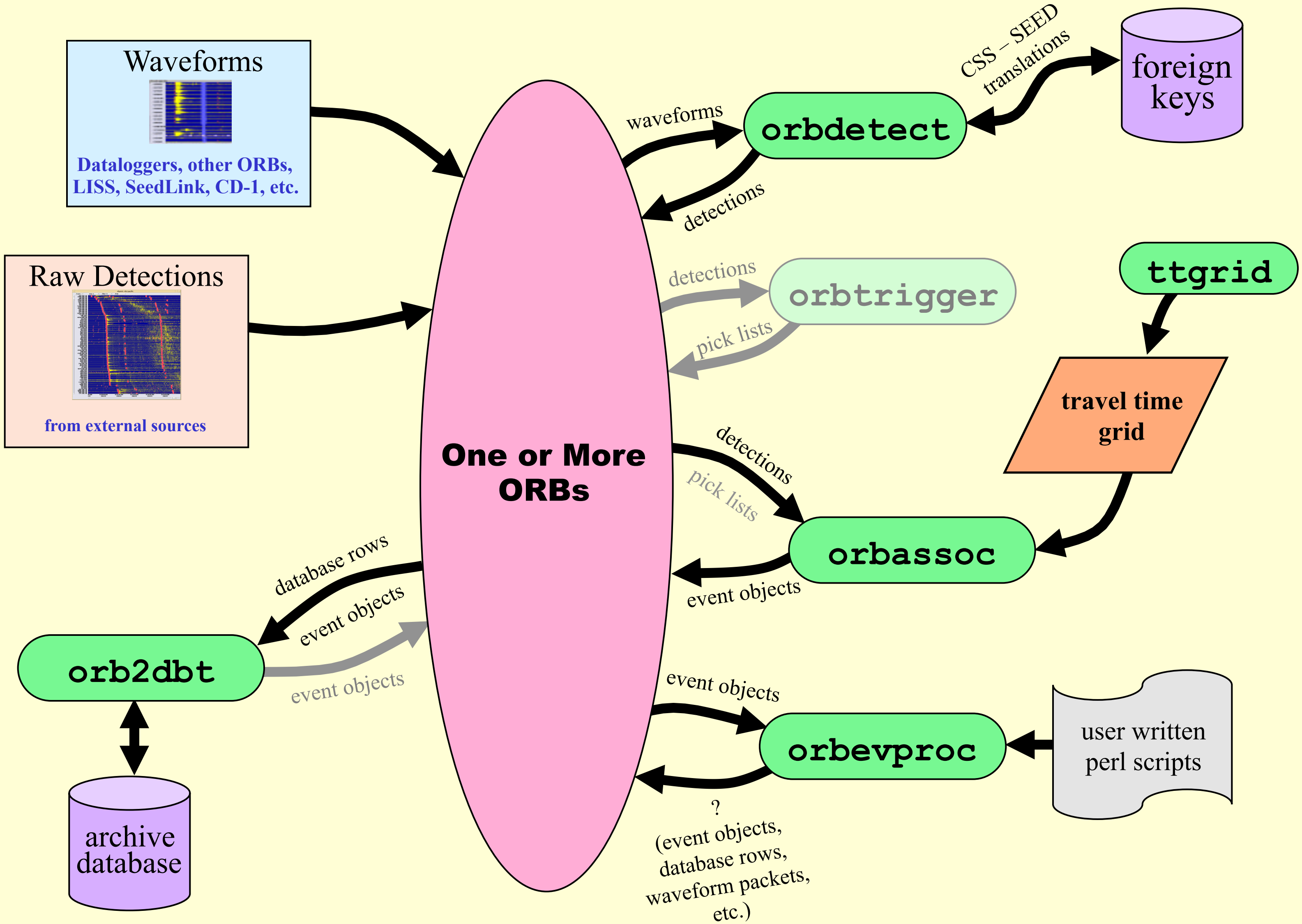
Traditional vs. Automated Event Processing

- Geiger based earthquake location methods
  - We decided to not write another version
  - locsat (UN/CTBTO) and genloc (contributed) included in Antelope distribution
- Automated event location requires a different approach
- There were just a few reliable automated event location algorithms
- These algorithms were neither generally available nor were they documented

Antelope Automated Event Processing



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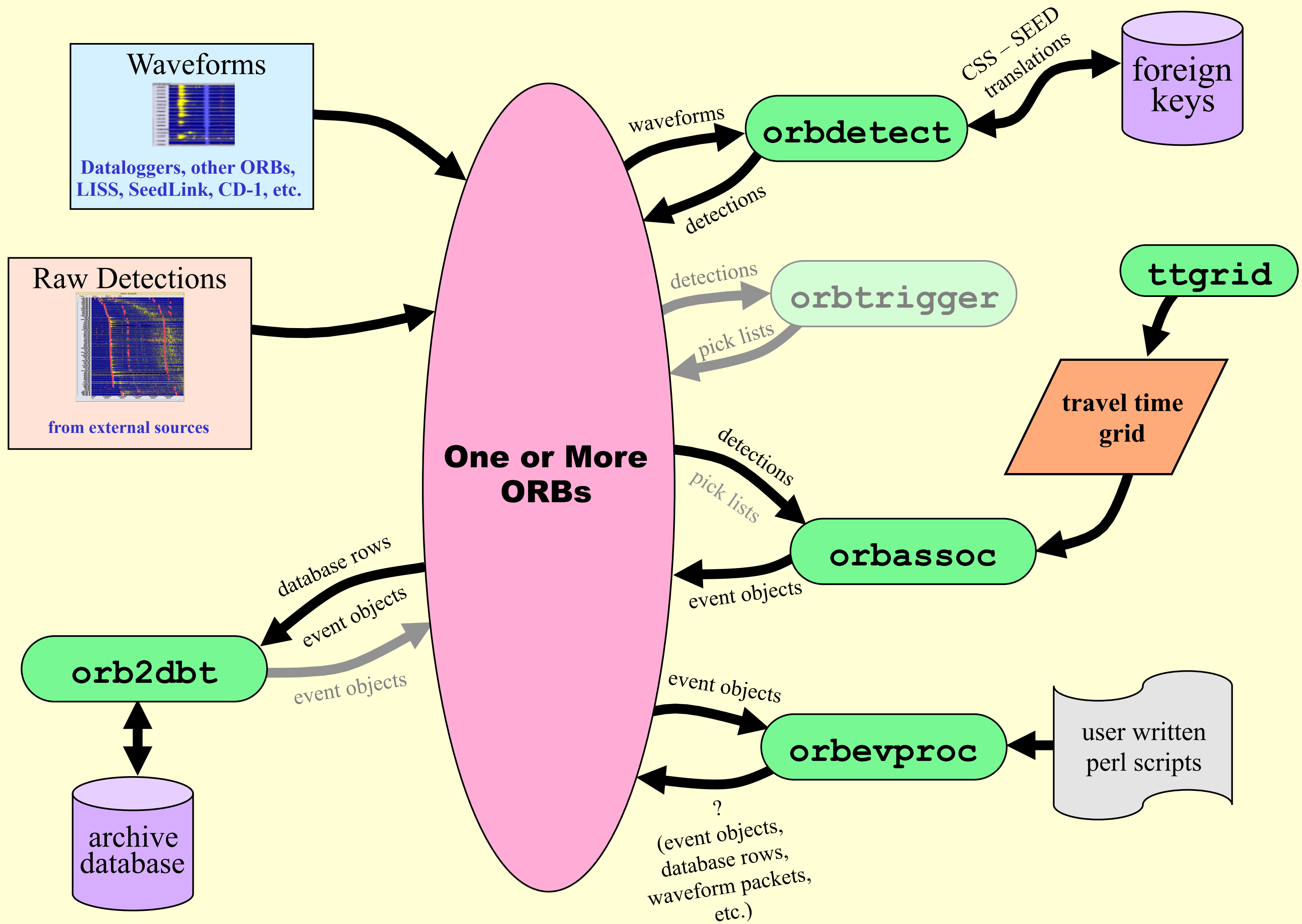
Event Processing

1. Waveforms and detections are imported.
2. **orbdetect** produces arrival detections.
3. **orbtrigger** can be run optionally to group detections into event candidate pick lists.
4. **orbassoc** reads detection picks from **orbdetect** and/or pick lists from **orbtrigger** , searches for event associations through a set of travel time grids, and outputs complete event objects for further processing.
5. **orbevproc** can be run for further event-oriented processing such as magnitude estimation.
6. **orb2dbt** populates an archive database with the event processing results. **orb2dbt** can also output more event objects into the ORB for further processing.

Antelope Automated Event Processing



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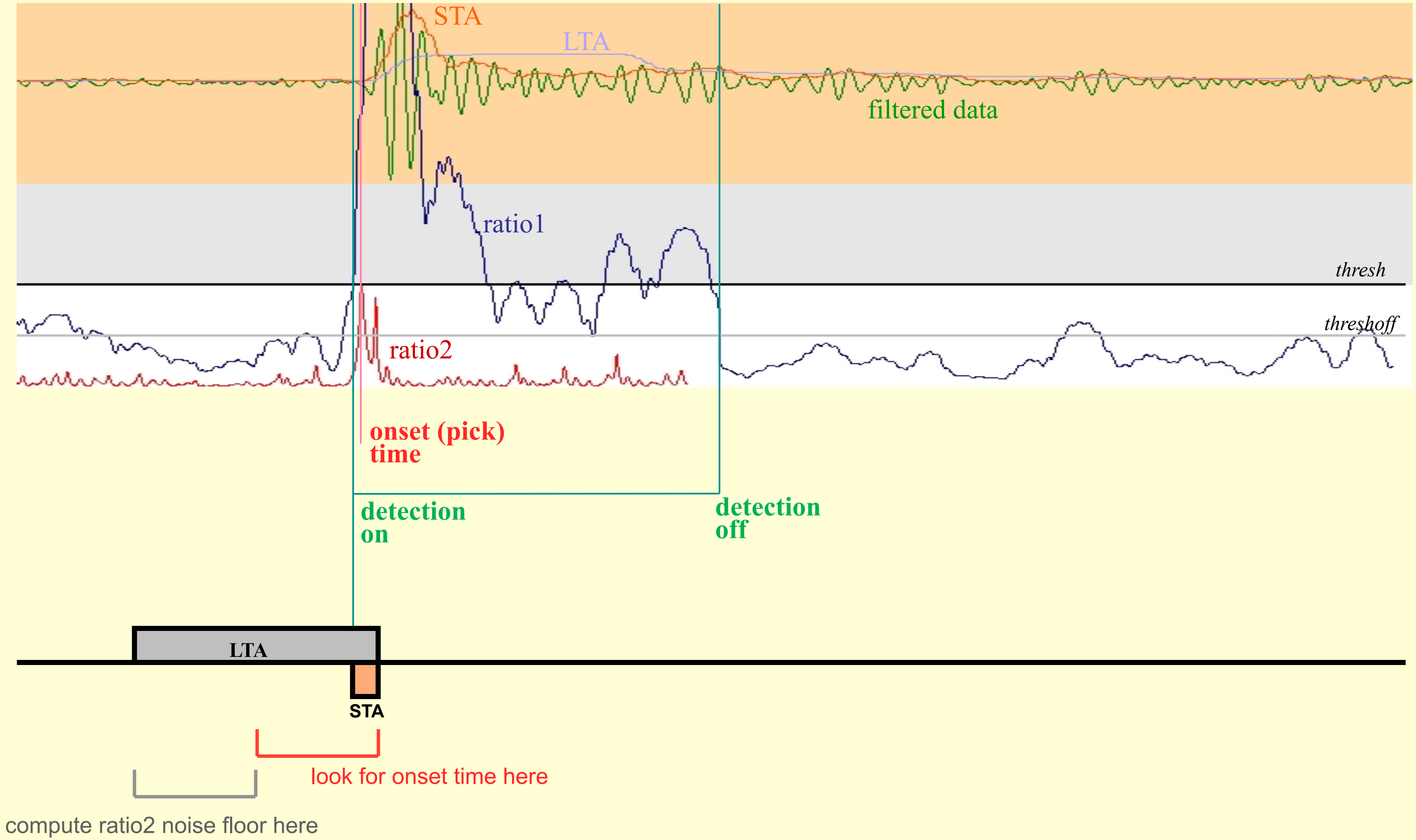
orbdetect – detection processing



orbdetect – output example

scdemo.View53

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0	sta	chan	time	state	filter	snr
	BAR	BHZ	6/08/2002 (159) 21:29:57.836	ON	BW 0.8 4 3.0 4	58.50
	BAR	BHZ	6/08/2002 (159) 21:29:59.486	D	BW 0.8 4 3.0 4	58.50
	BAR	BHZ	6/08/2002 (159) 21:31:18.636	OFF	BW 0.8 4 3.0 4	101.98
	BAR	BHZ	6/08/2002 (159) 21:29:58.736	ON	BW 3.0 4 0 0	68.69
	BAR	BHZ	6/08/2002 (159) 21:29:59.636	D	BW 3.0 4 0 0	68.69
	BAR	BHZ	6/08/2002 (159) 21:30:49.486	OFF	BW 3.0 4 0 0	228.79
	BZN	BHZ	6/08/2002 (159) 21:30:06.275	ON	BW 0.8 4 3.0 4	13.48
	BZN	BHZ	6/08/2002 (159) 21:30:03.700	D	BW 0.8 4 3.0 4	13.48
	BZN	BHZ	6/08/2002 (159) 21:30:54.000	on	BW 0.8 4 3.0 4	18.27
	BZN	BHZ	6/08/2002 (159) 21:30:59.150	OFF	BW 0.8 4 3.0 4	18.27
	BZN	BHZ	6/08/2002 (159) 21:36:54.500	ON	BW 0.8 4 3.0 4	10.03
	BZN	BHZ	6/08/2002 (159) 21:36:55.800	D	BW 0.8 4 3.0 4	10.03
	BZN	BHZ	6/08/2002 (159) 21:37:34.500	OFF	BW 0.8 4 3.0 4	10.03
	CRY	BHZ	6/08/2002 (159) 21:30:08.200	ON	BW 0.8 4 3.0 4	14.88
	CRY	BHZ	6/08/2002 (159) 21:30:09.300	D	BW 0.8 4 3.0 4	18.73
	CRY	BHZ	6/08/2002 (159) 21:30:54.000	on	BW 0.8 4 3.0 4	30.96
	CRY	BHZ	6/08/2002 (159) 21:31:04.250	OFF	BW 0.8 4 3.0 4	30.96
	CWC	BHZ	6/08/2002 (159) 21:36:54.223	ON	BW 0.8 4 3.0 4	13.33
	CWC	BHZ	6/08/2002 (159) 21:36:55.773	D	BW 0.8 4 3.0 4	13.33
	CWC	BHZ	6/08/2002 (159) 21:37:34.223	OFF	BW 0.8 4 3.0 4	13.33
	DGR	BHZ	6/08/2002 (159) 21:30:11.649	ON	BW 0.8 4 3.0 4	29.49
	DGR	BHZ	6/08/2002 (159) 21:30:08.449	D	BW 0.8 4 3.0 4	32.31
	DGR	BHZ	6/08/2002 (159) 21:31:14.499	OFF	BW 0.8 4 3.0 4	32.31

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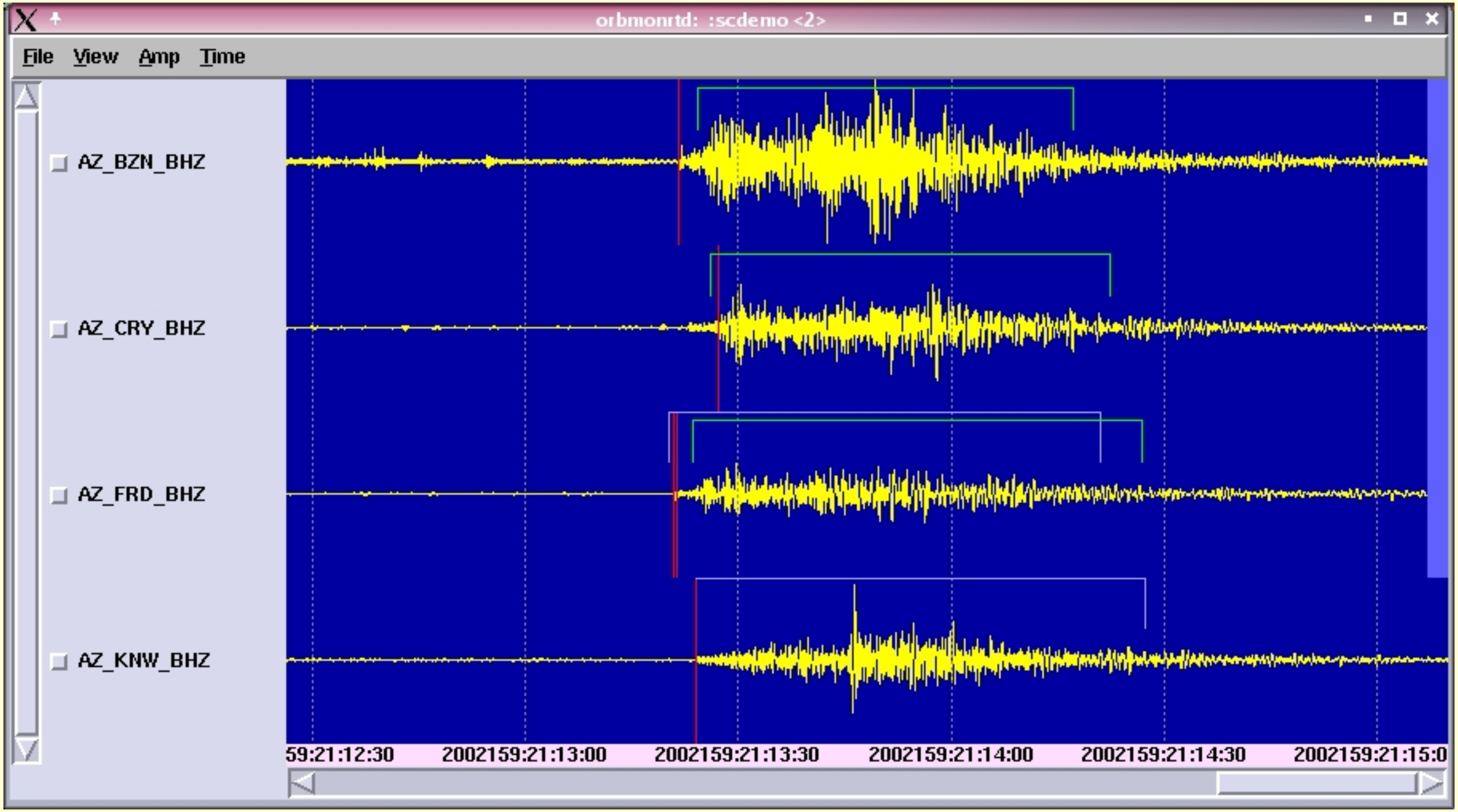
Dismiss

orbdetect – detection glyphs in **orbmonrtd**



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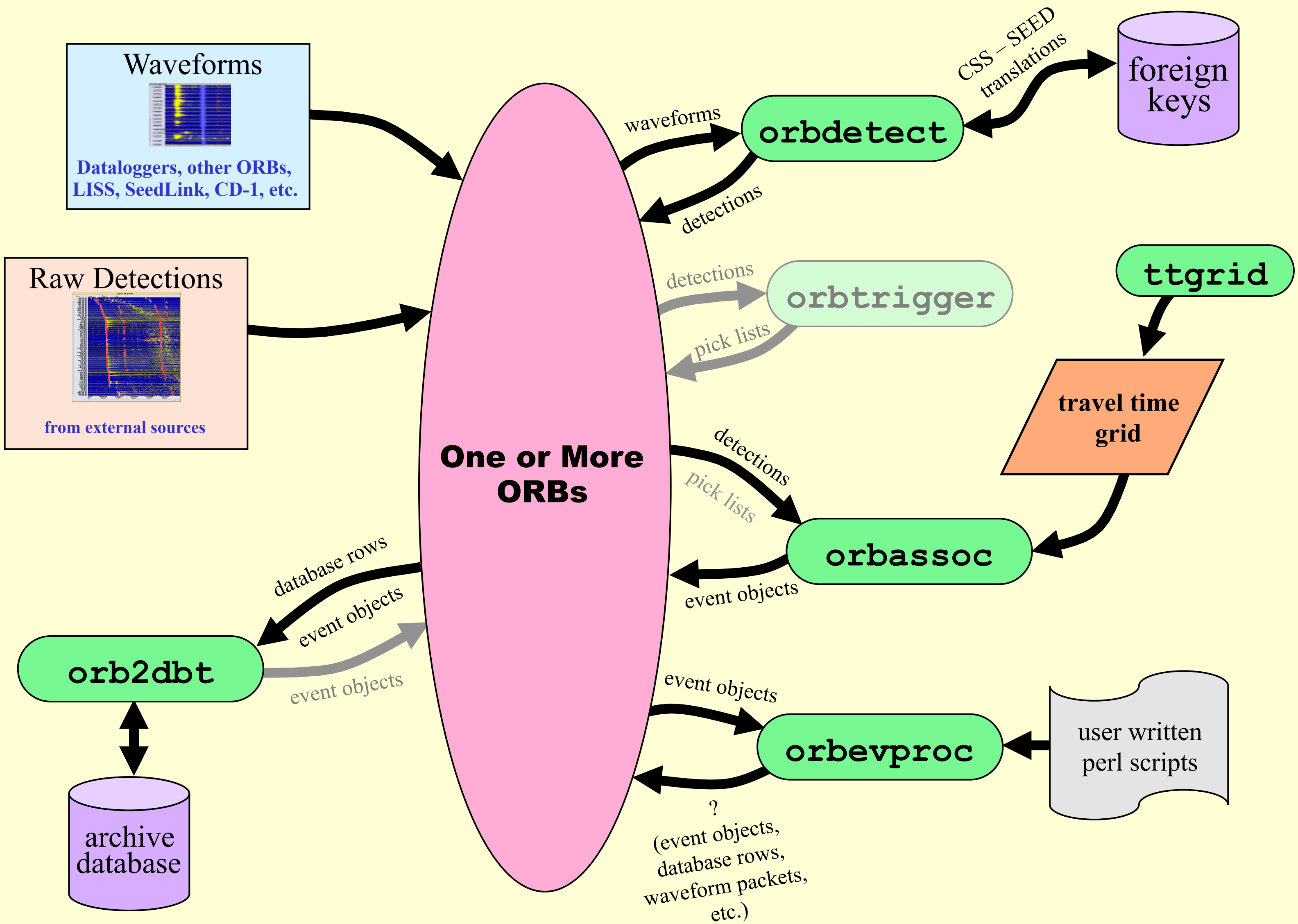

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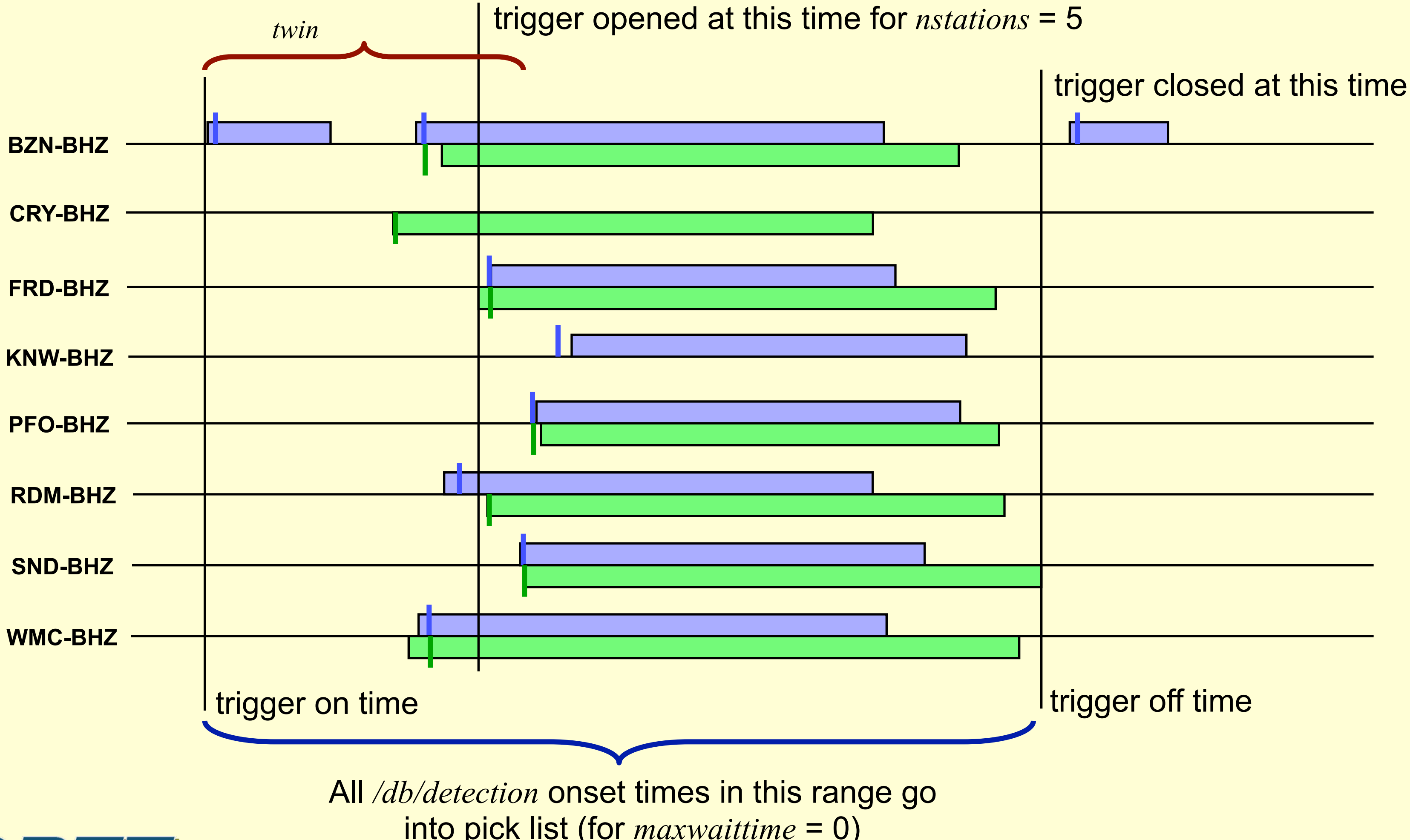
orbtrigger – network trigger processing

Objective: Scan all **orbtrigger** detection buffers to create/modify a network trigger and output an event pick list when appropriate:



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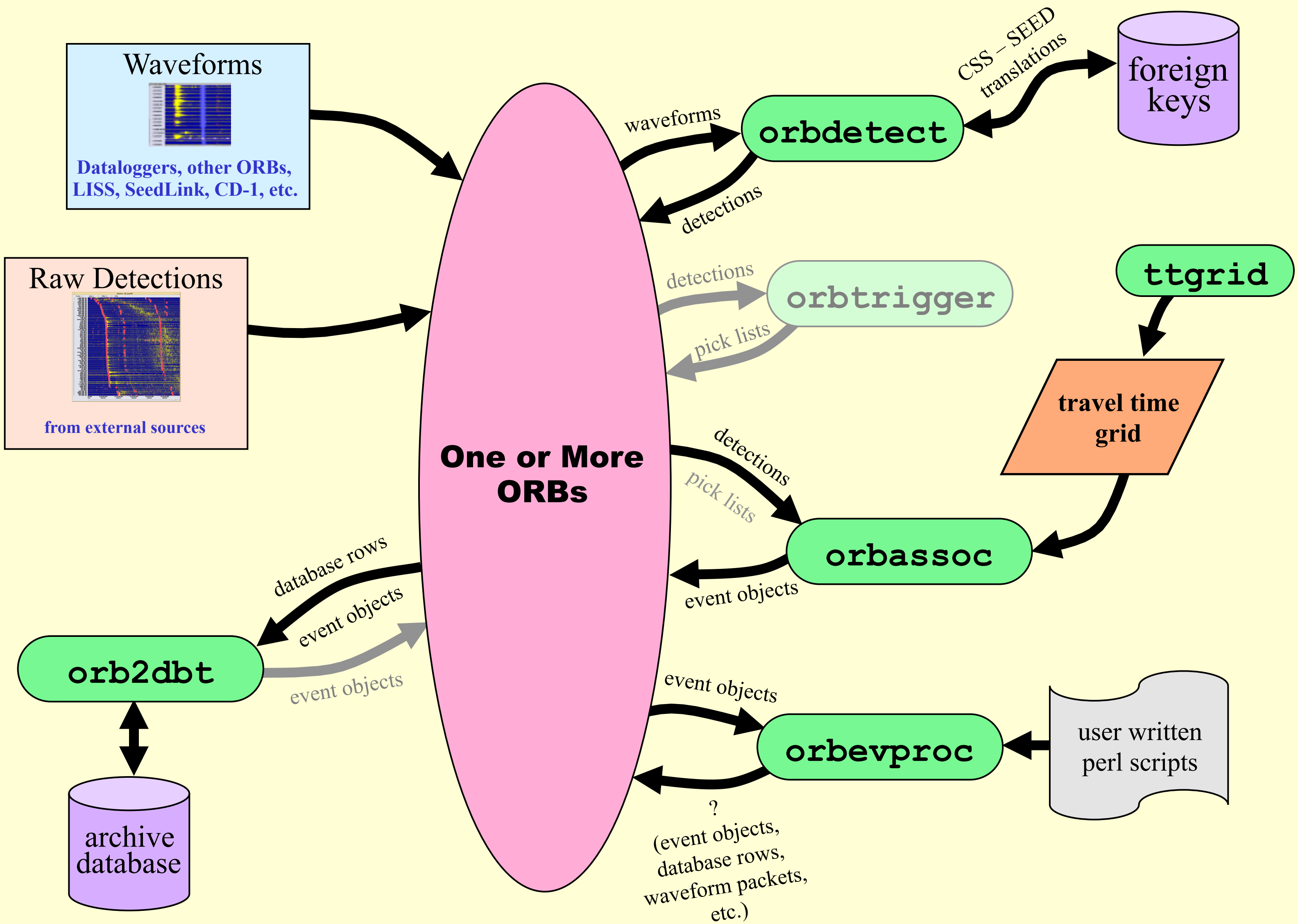
orbtrigger – output */pf/orbassoc* pick list

```
arrivals        &Tbl{
    BAR BHZ Dl 1023647045.63560 68.69000
    BAR BHZ Dt 1023647045.48560 58.50000
    BZN BHZ Dt 1023647049.70000 13.48000
    CRY BHZ Dt 1023647055.30000 18.73000
    DGR BHZ Dl 1023647059.99910 18.19000
    DGR BHZ Dt 1023647054.44910 32.31000
    FRD BHZ Dl 1023647049.02500 10.88000
    FRD BHZ Dt 1023647049.30000 13.22000
    GLA BHZ Dl 1023647037.76060 75.61000
    GLA BHZ Dt 1023647037.81060 119.94000
    JCS BHZ Dl 1023647045.73380 241.03000
    JCS BHZ Dt 1023647047.33380 50.17000
    KNW BHZ Dl 1023647052.12500 8.88000
    LVA2 BHZ Dl 1023647047.42500 30.58000
    LVA2 BHZ Dt 1023647047.40000 24.31000
    MONP BHZ Dl 1023646931.10000 5.12000
    MONP BHZ Dl 1023647043.42500 77.79000
    MONP BHZ Dt 1023647042.70000 102.69000
    PLM BHZ Dl 1023647050.51180 20.99000
    PLM BHZ Dt 1023647054.16180 35.24000
    RDM BHZ Dt 1023647058.02500 16.68000
    SND BHZ Dl 1023647049.95000 16.80000
    SND BHZ Dt 1023647050.10000 6.99000
    SOL BHZ Dt 1023647055.12500 13.14000
    TRO SHZ Dl 1023647048.10000 8.45000
    TRO SHZ Dt 1023647048.00000 12.60000
    WMC BHZ Dt 1023647050.67500 12.71000
}
```

Antelope Automated Event Processing



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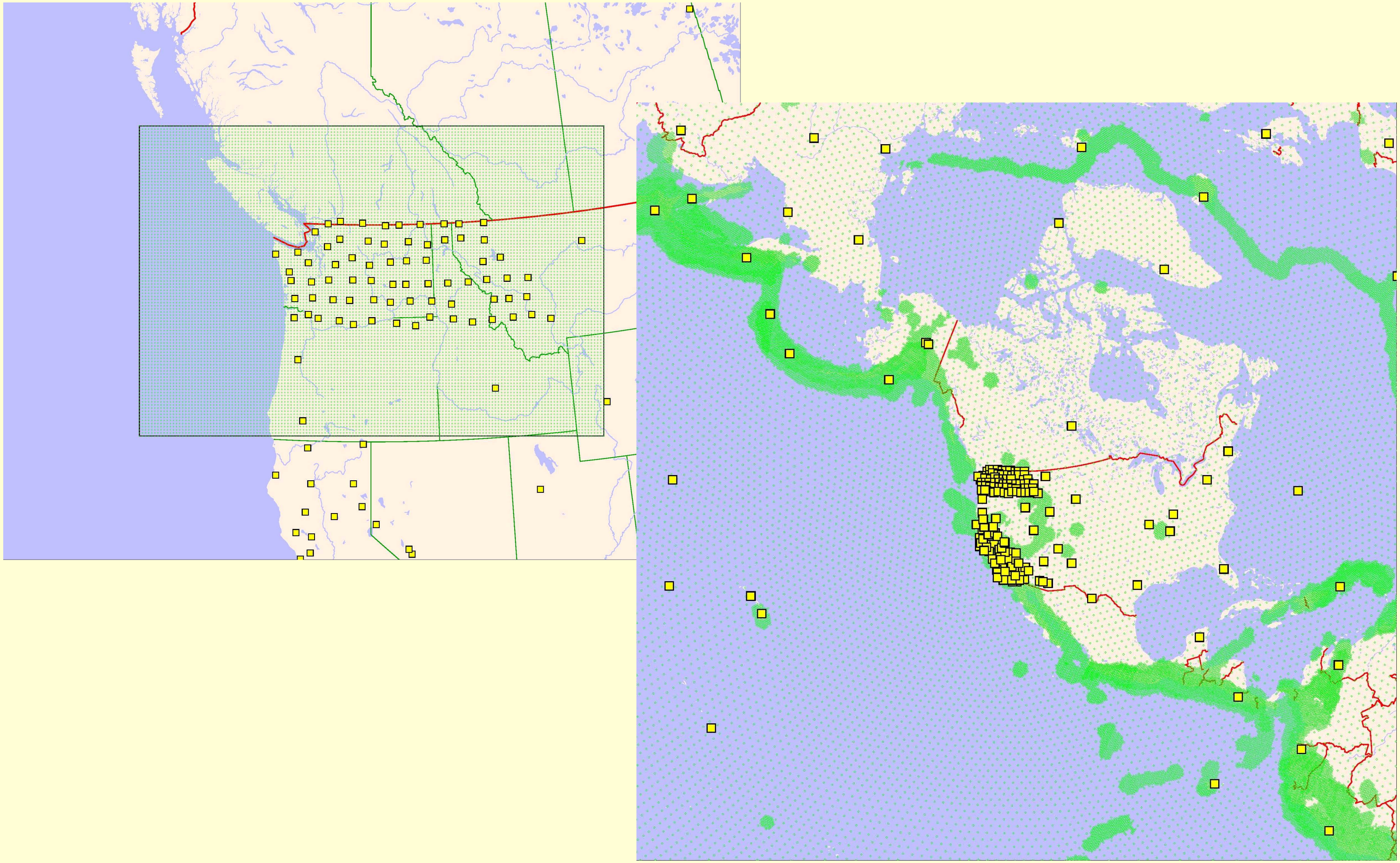
`orbassoc` – travel time grids



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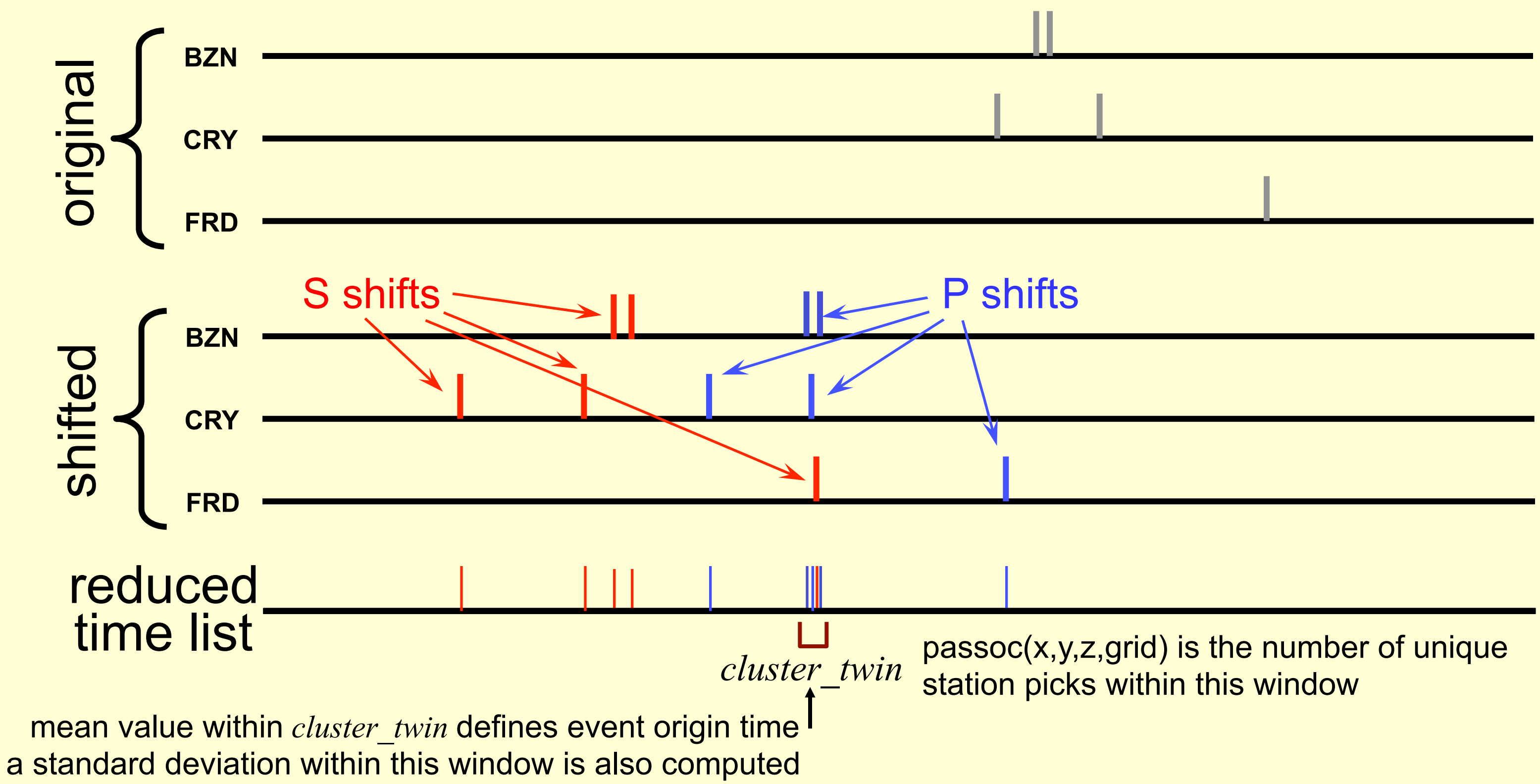
`orbassoc` – passoc processing

For each grid-source location node:

1. All of the times in the pick list are reduced by the phase travel times to an equivalent origin time.
2. These reduced pick times for each travel time phase are put into a reduced time list for subsequent time-clustering analysis:



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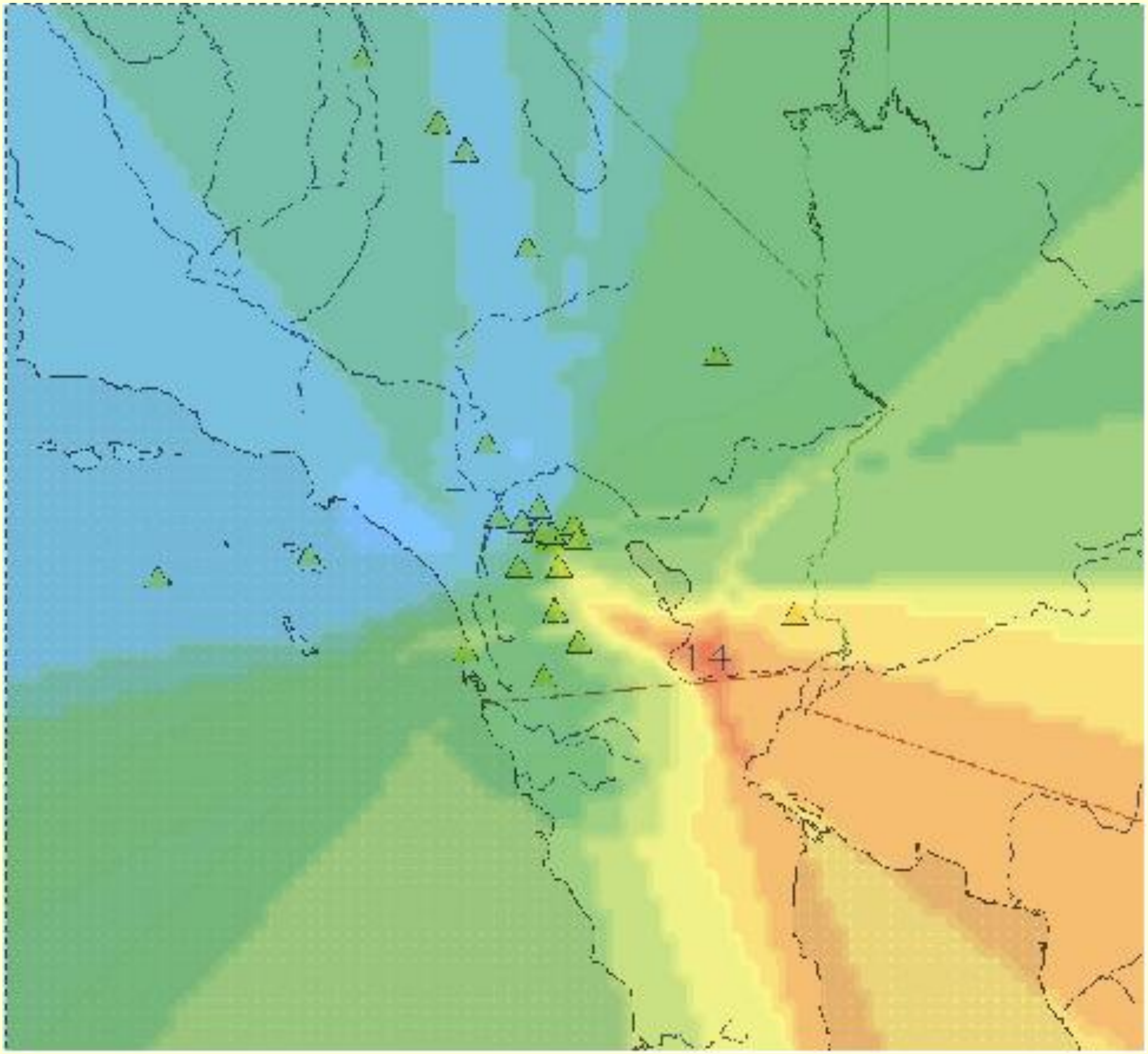
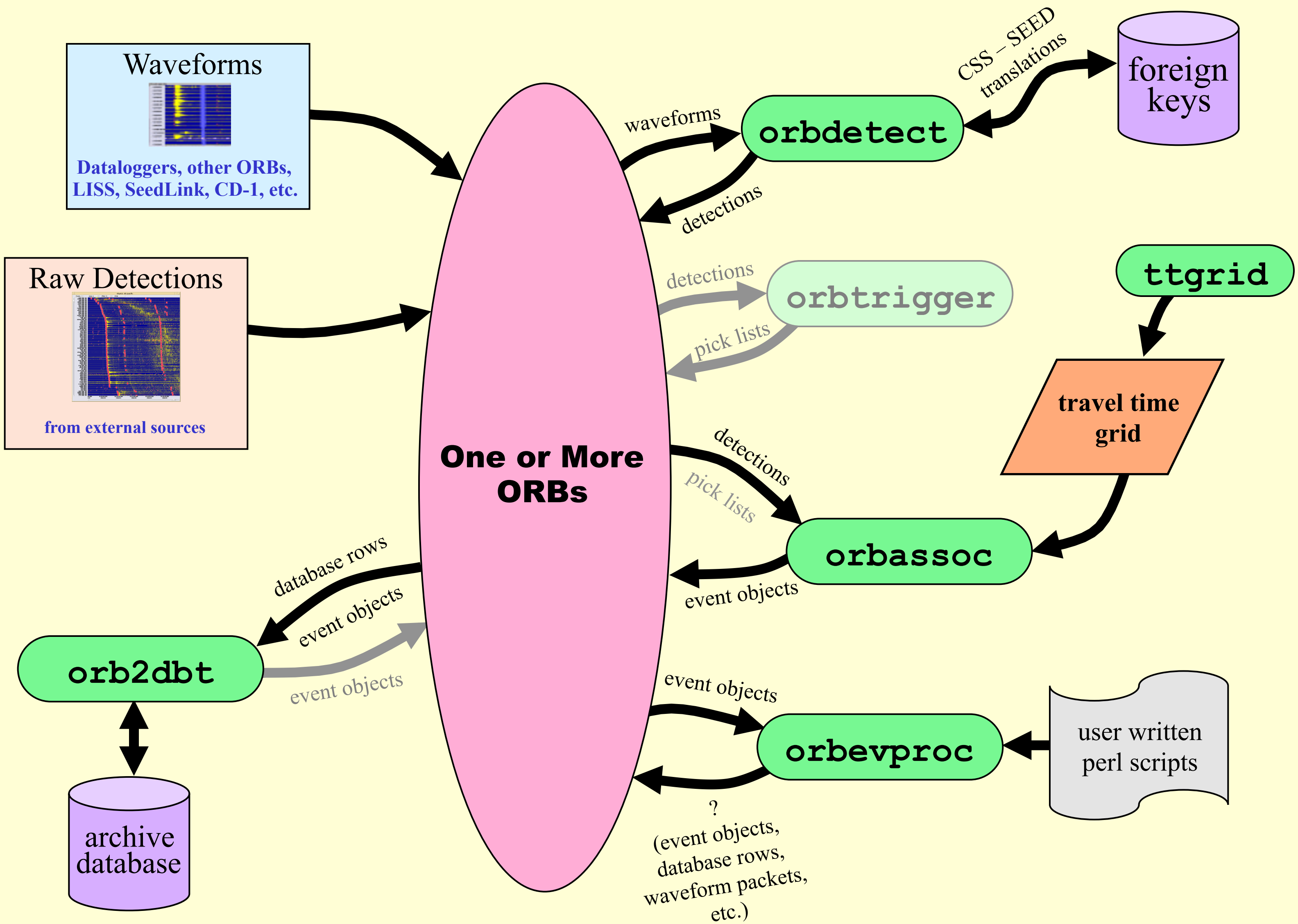
orbassoc – example passoc(x,y,local)



An evaluation of **`orbassoc`**

- Original edition:
  - Worked well for networks with apertures up to 1000 km
  - Could usually discriminate teleseisms (although locations not necessarily good, especially in depth)
  - Reliable for time-separated, "sufficient size" (~10 or more stations) events with "clean" seismic waveform data
  - Fast
- Problems with original edition:
  - Could not properly handle continental to global scale networks
  - Could not properly handle time-overlapping events (becomes important for large aperture networks)
  - Lots of spurious mis-locations when trying to associate with small numbers of stations (< 6) and especially with "dirty" seismic waveform data
  - S associations usually resulted in lots of spurious mis-locations
  - Final solutions were on a grid with no error estimates
  - Because of downstream database processing, could only use one **`orbtrigger-orbassoc`** processing pair at a time
  - Required **`orbtrigger`** – this means only a single hypocenter estimate per event

Antelope Automated Event Processing



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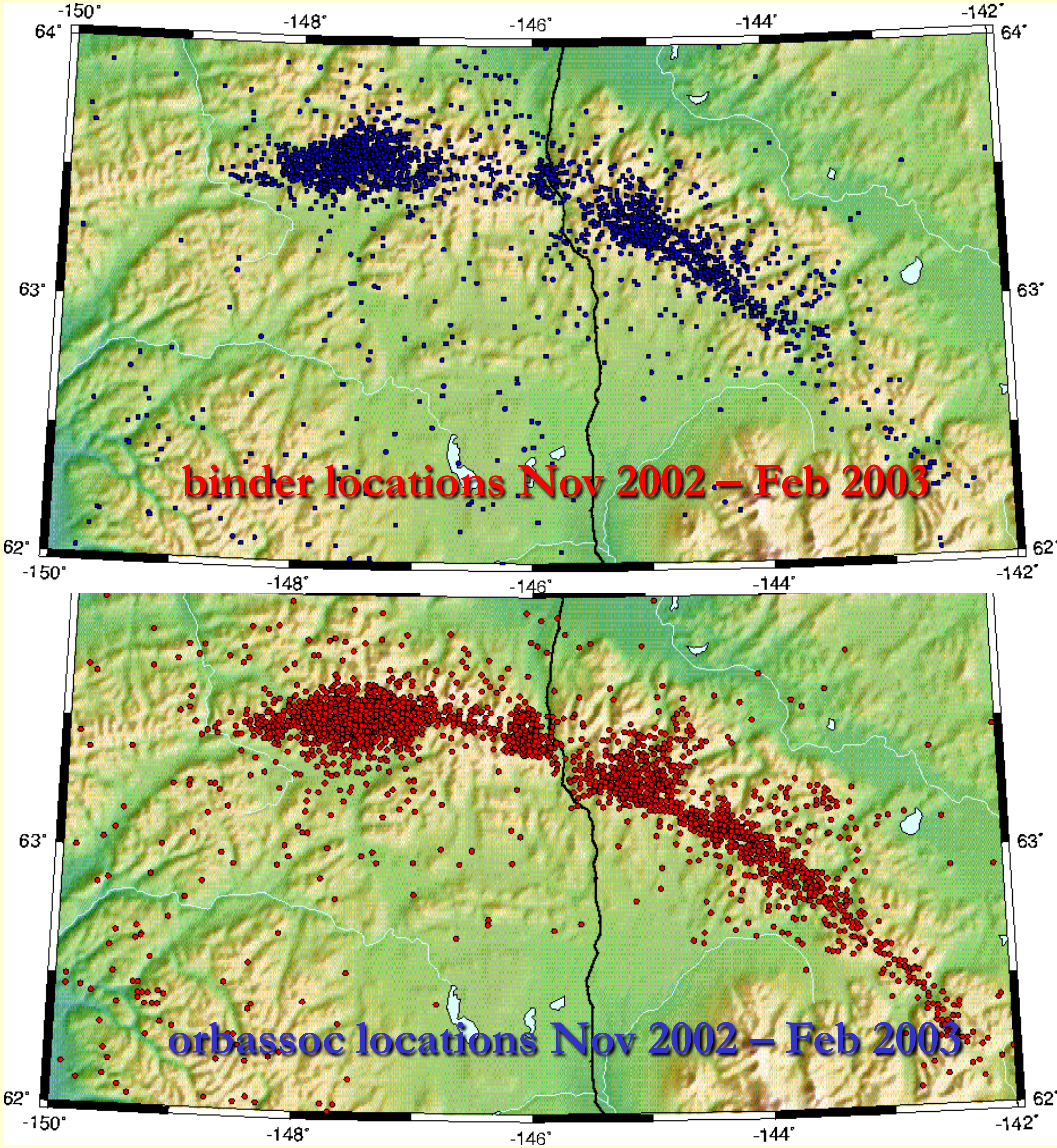
binder locations Nov 2002 – Feb 2003
orbassoc locations Nov 2002 – Feb 2003
-150°
-148°
-146°
-144°
-142°
64°
63°
62°

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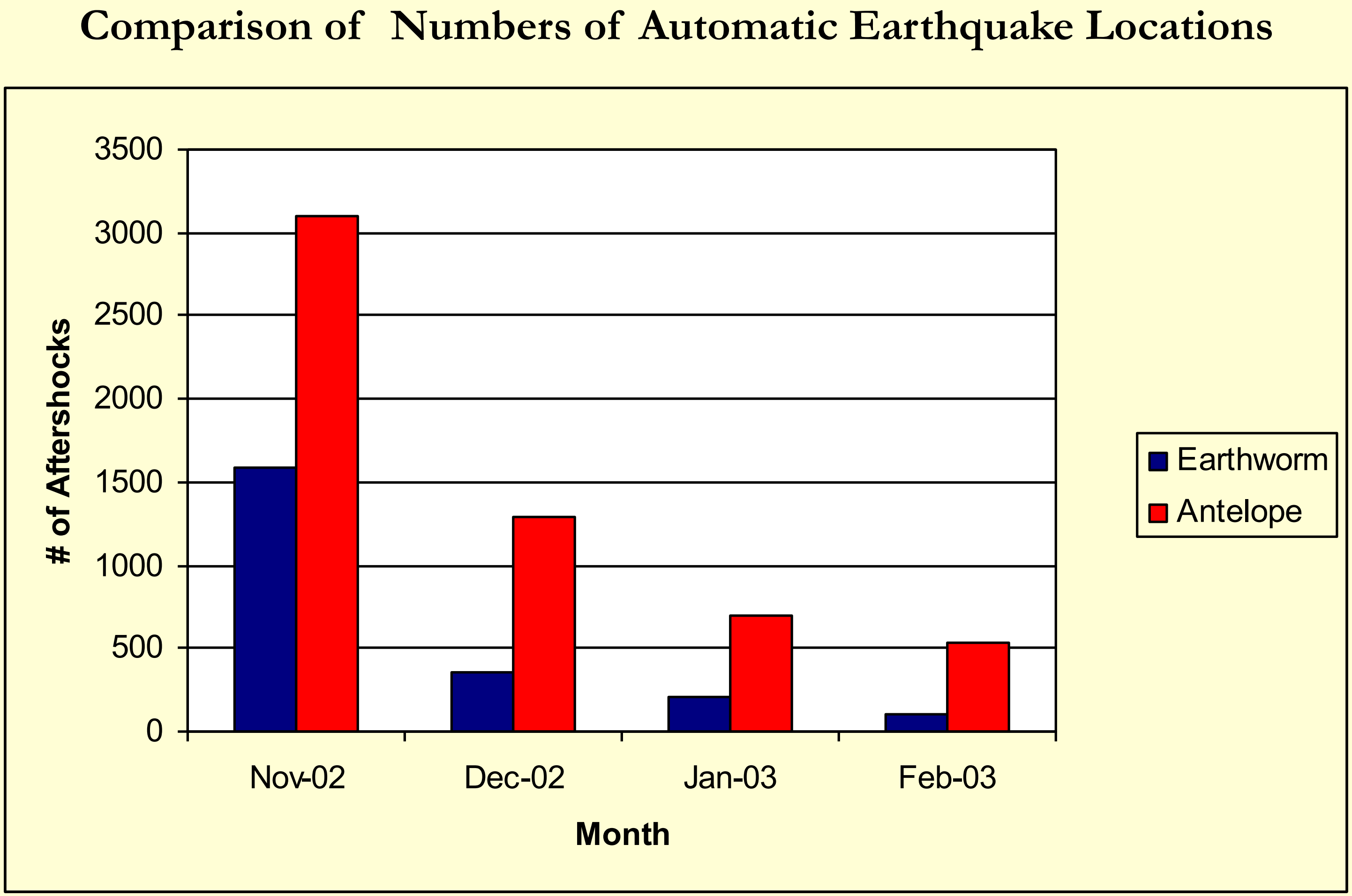
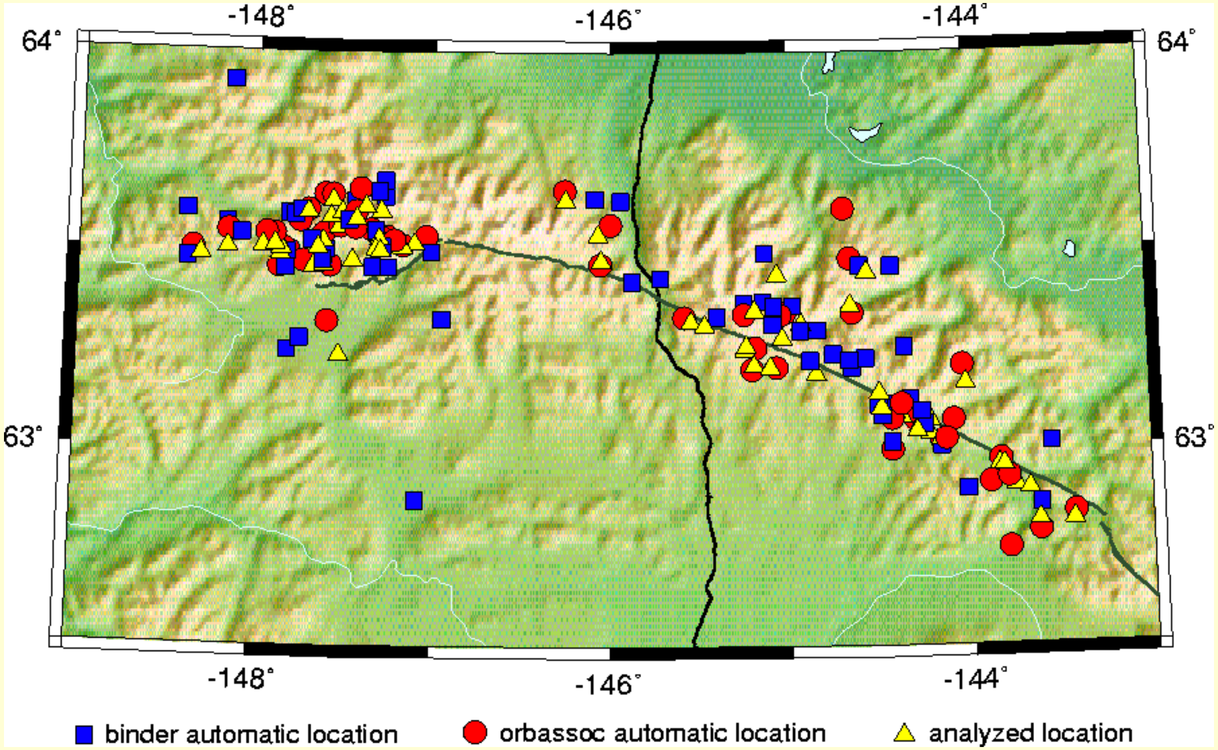
Automatic Aftershock Locations



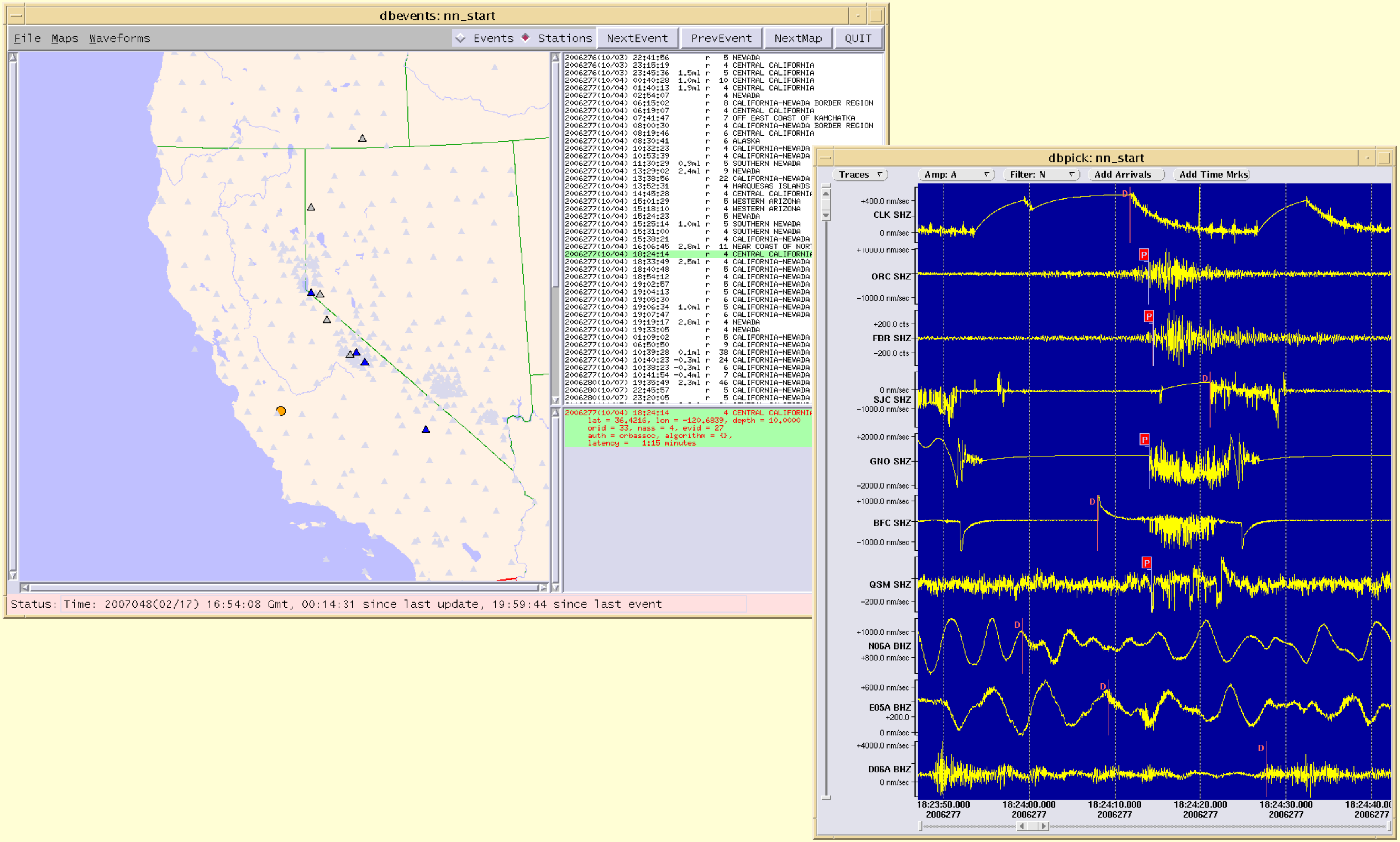
Automatic Aftershock Locations Compared to Analyzed Locations

orbassoc (red) and binder (blue) locations vs. analyzed (yellow) locations
(55 selected events) Nov 18 - 19, 2002



	Average Distance
Earthworm ***binder***	**13.5 km**
Antelope ***orbassoc***	**4.4 km**

Mis-locations with small numbers of stations



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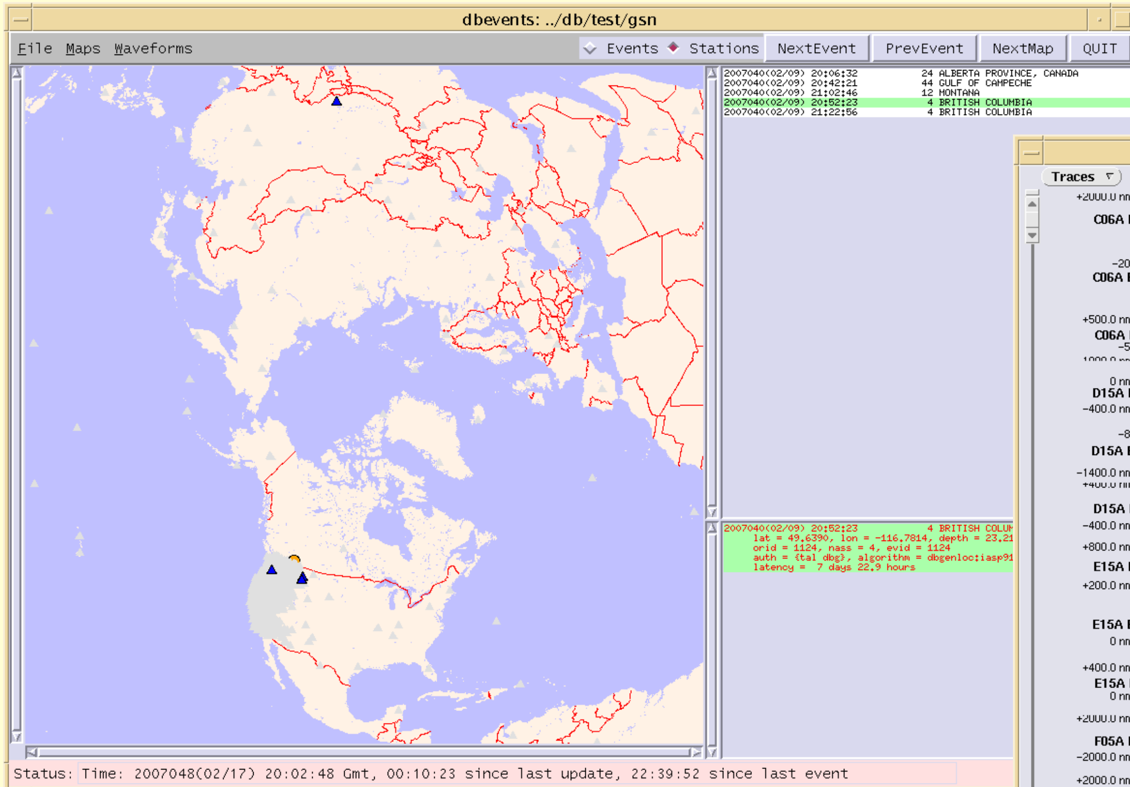
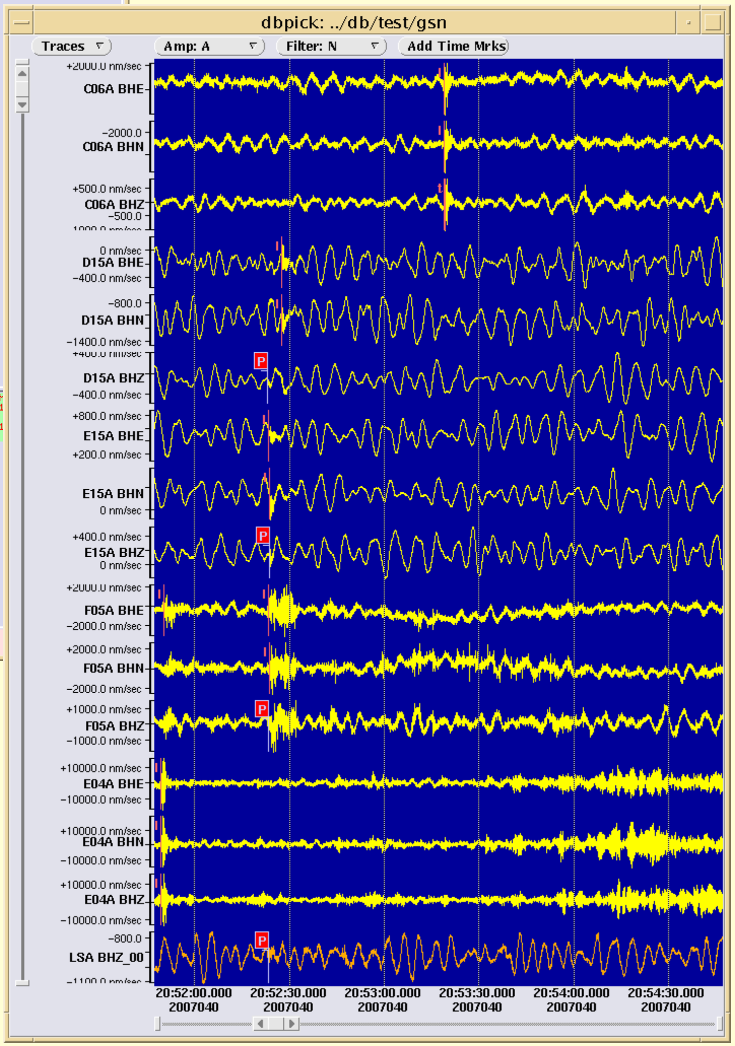
Mis-locations with small numbers of stations





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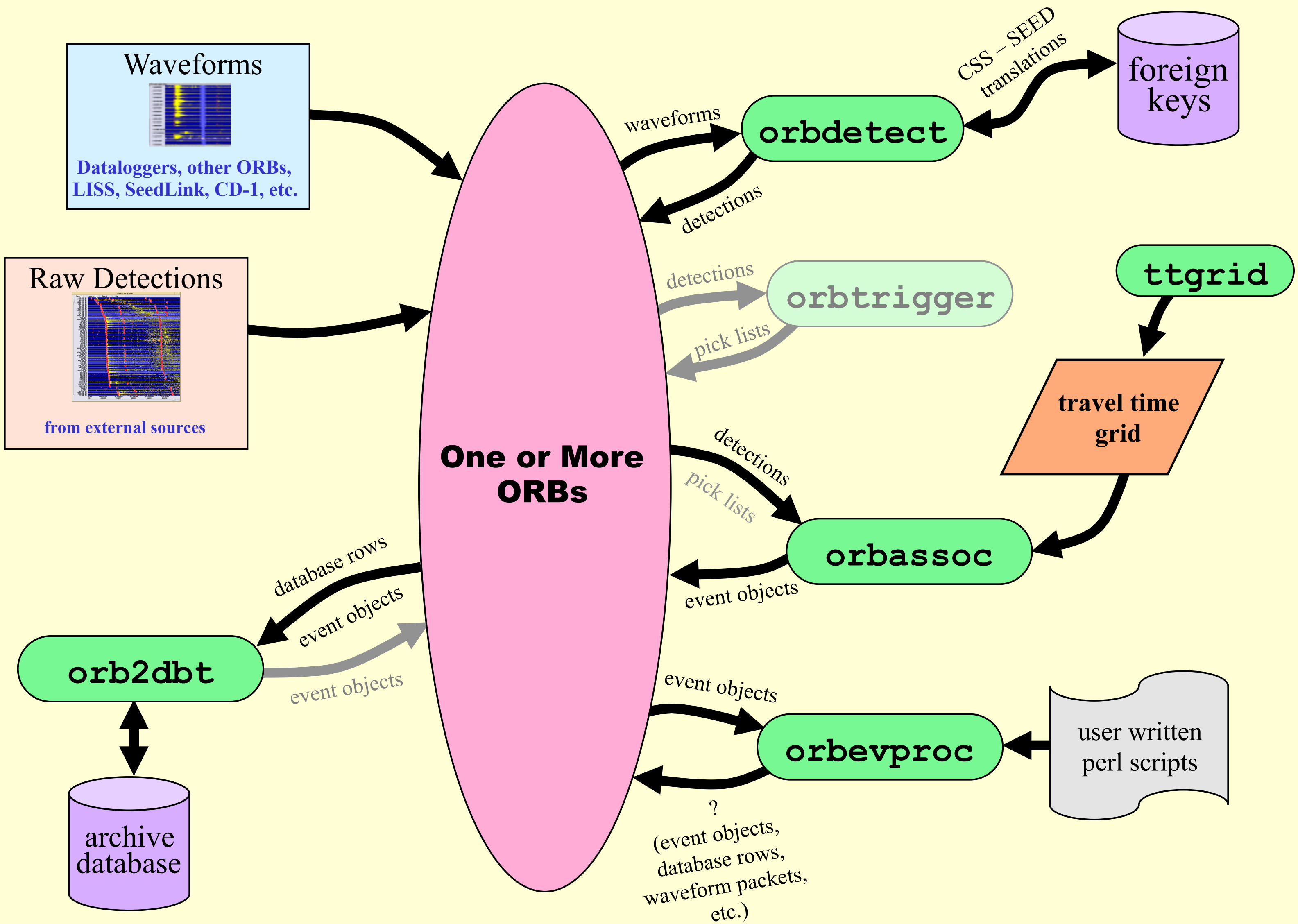
Second edition of **orbassoc**, c. 2002

- Allow multiple **orbtrigger-orbassoc** processes in an attempt to deal with small events with small numbers of associating stations
- Provide a way to subset down regions into subnets to limit the effective source-receiver aperture for small events
- Required doing "smart" origin association in the final archive database so that multiple origins were properly tagged with the same event id and arrivals were not repeated
- **orbassoc** was modified to output encapsulated event ORB "objects", instead of multiple database rows, and **orb2dbt** was modified to implement the "smart" origin association with the archive database
- Major change was actually in **orb2dbt**, not so much **orbassoc**

Antelope Automated Event Processing



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What is an event ORB “object”?

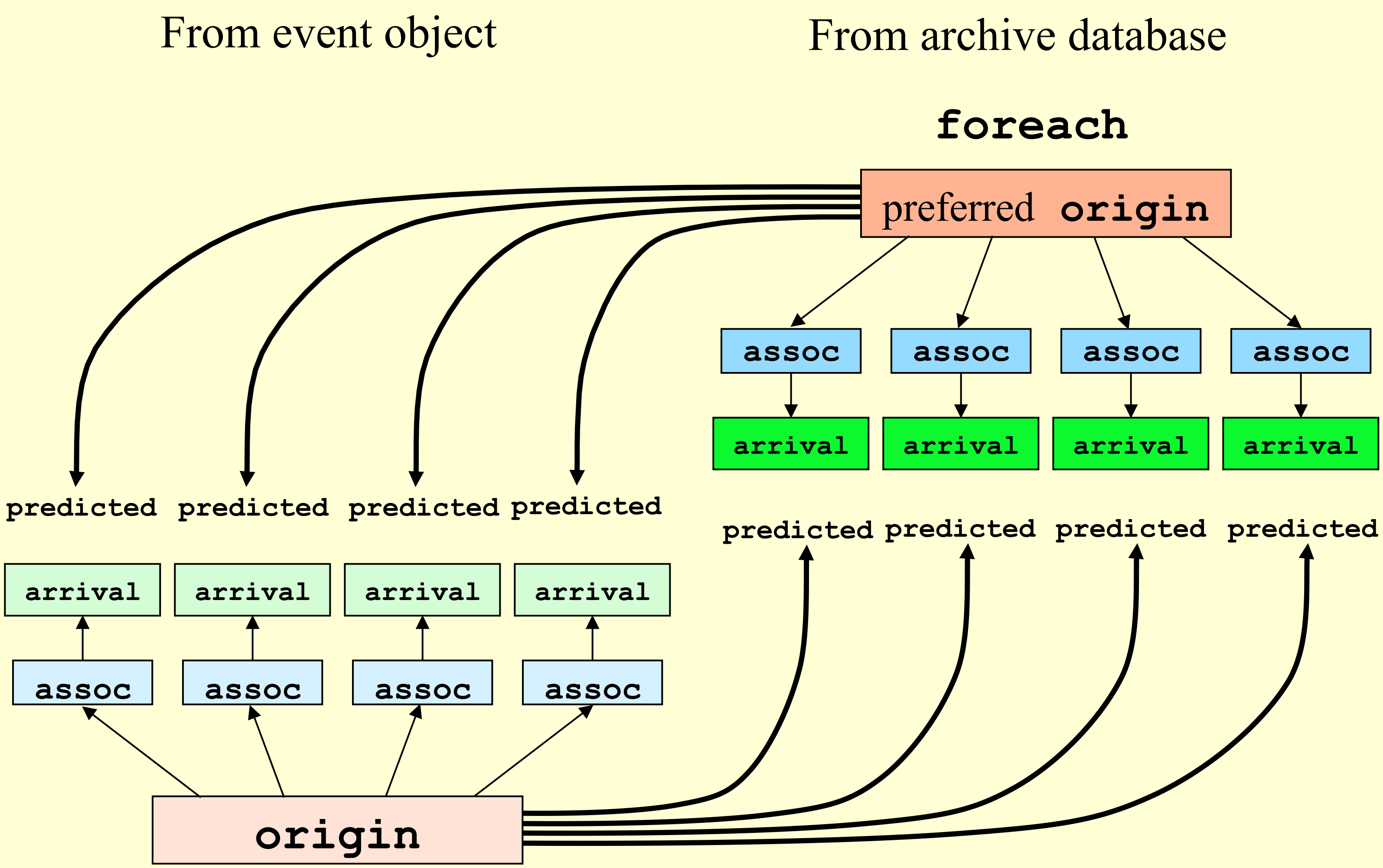
A complete properly indexed temporary database, containing only one origin and all relevant linked other tables, encapsulated into a single parameter file ORB packet usually with srcname **`/pf/orb2dbt`**

```
58 korl%
58 korl%
58 korl%
58 korl%
58 korl% orb2pf -number 1 -start OLDEST -select /pf/orb2dbt ruper:scdemo -

/pf/orb2dbt 1263  2/15/2007  17:32:31.413
arrivals        &Literal{
MONP    1171560724.70000        1  2007046       -1        -1 BHZ      P        -  0.100   -1.00   -1.00   -1.00   -1.00   -1.00  -1.000 2
TRO     1171560730.02500        2  2007046       -1        -1 SHZ      P        -  0.100   -1.00   -1.00   -1.00   -1.00   -1.00  -1.000 2
PFO     1171560731.02500        3  2007046       -1        -1 BHZ      P        -  0.100   -1.00   -1.00   -1.00   -1.00   -1.00  -1.000 2
LVA2    1171560729.47500        4  2007046       -1        -1 BHZ      P        -  0.100   -1.00   -1.00   -1.00   -1.00   -1.00  -1.000 2
SND     1171560732.00000        5  2007046       -1        -1 BHZ      P        -  0.100   -1.00   -1.00   -1.00   -1.00   -1.00  -1.000 2
FRD     1171560731.30000        6  2007046       -1        -1 BHZ      P        -  0.100   -1.00   -1.00   -1.00   -1.00   -1.00  -1.000 2
KNW     1171560734.22500        7  2007046       -1        -1 BHZ      P        -  0.100   -1.00   -1.00   -1.00   -1.00   -1.00  -1.000 2
CRY     1171560733.07500        8  2007046       -1        -1 BHZ      P        -  0.100   -1.00   -1.00   -1.00   -1.00   -1.00  -1.000 2
}
assocs  &Literal{
       1        2 MONP   P        9.99    2.271  121.62  302.84    0.032 d  -999.0 - -999.00 -   -999.0  1.000 taup/iasp91          -1  5
       2        2 TRO    P        9.99    2.658  133.24  314.46    0.029 d  -999.0 - -999.00 -   -999.0  1.000 taup/iasp91          -1  6
       3        2 PFO    P        9.99    2.740  134.16  315.41   -0.089 d  -999.0 - -999.00 -   -999.0  1.000 taup/iasp91          -1  9
       4        2 LVA2   P        9.99    2.631  128.75  310.04   -0.148 d  -999.0 - -999.00 -   -999.0  1.000 taup/iasp91          -1  1
       5        2 SND    P        9.99    2.793  131.37  312.70    0.153 d  -999.0 - -999.00 -   -999.0  1.000 taup/iasp91          -1  3
       6        2 FRD    P        9.99    2.749  130.61  311.93    0.061 d  -999.0 - -999.00 -   -999.0  1.000 taup/iasp91          -1  1
       7        2 KNW    P        9.99    2.963  132.62  314.00    0.043 d  -999.0 - -999.00 -   -999.0  1.000 taup/iasp91          -1  4
       8        2 CRY    P        9.99    2.880  130.14  311.54    0.027 d  -999.0 - -999.00 -   -999.0  1.000 taup/iasp91          -1  6
}
emodel  &Literal{
       2          3.8561         4.38894         4.50075         4.35157  1171560750.67205
}
origerr &Literal{
       2       14214.3916      10134.7653  239474543.8515    3417812.8965     -11951.4452     899262.9430    -854743.4618     105712.57832
}
origin  &Literal{
  31.6814 -114.1501    1.6044  1171560686.10691         2        -1  2007046     8     8   -1       49         4 -  -      -999.0000 f -999.00 8
}
predarrs        &Literal{
       1        2  1171560724.66790   13.75  121.62   -1.00  302.84 -44.2  1171560750.67481
       2        2  1171560729.99630   13.75  133.24   -1.00  314.46 -44.2  1171560750.67567
       3        2  1171560731.11445   13.75  134.16   -1.00  315.41 -44.2  1171560750.67602
       4        2  1171560729.62257   13.75  128.75   -1.00  310.04 -44.2  1171560750.67618
       5        2  1171560731.84727   13.75  131.37   -1.00  312.70 -44.2  1171560750.67636
       6        2  1171560731.23872   13.75  130.61   -1.00  311.93 -44.2  1171560750.67652
       7        2  1171560734.18215   13.75  132.62   -1.00  314.00 -44.2  1171560750.67667
       8        2  1171560733.04835   13.75  130.14   -1.00  311.54 -44.2  1171560750.67683
}

59 korl%
```

What is an event ORB "object"?

- At a minimum there must be a single row of an **origin** table encapsulated into a pf "Literal" string. Event objects with only an origin row are treated by **orb2dbt** as external catalog events to be associated with the existing events in the archive database. These type of event objects are produced by programs like **USGS2orb**.
- In order to promote detections to arrivals for a fully defined origin, such as what we would want to do with **orbassoc** output, the **assoc** and **arrival** tables must also be defined in the event object.
- Additional tables relating to errors and modeling, such as **origerr**, **emodel** and **predarr**, may also be defined, but these are optional.

Orb2dbt event association



Orb2dbt event association

- If a new **origin** exactly matches an existing **origin** in the archive database, then the new event is skipped. A "match" is defined as an exact match in **lat**, **lon**, **depth**, **time**, **ndef** and **nass**.
- If a new **origin** associates with a preferred **origin** in the archive database:
  - A new **orid** is obtained from the archive database
  - The **evid** from the associated preferred **origin** is used
  - The new **origin** is compared against the existing preferred **origin** to see if the new **origin** should become the preferred **origin**
- If a new **origin** does not associate with any preferred **origin**s in the archive database:
  - A new **orid** is obtained from the archive database
  - A new **evid** is obtained from the archive database and a new **event** row is added to the archive database
- **arrival** and **assoc** merging:
  - Each **arrival** associated with the new **origin** is checked against existing **arrival**s in the archive database. If the **arrival** is different from any existing **arrival**s, then it is added to the archive database and a new **arid** is generated. If the **arrival** is the same as an existing **arrival** in the archive database, then the **arrival** is not added and the **arid** from the existing **arrival** is used in the new **assoc** entries.
  - The resulting **orid** and **arid** values are filled into the new **assoc** rows.

`Orb2dbt` event association

- An important capability apart from the associator that allows safe merging of complete events from external sources
- Provides a mechanism for merging origins from external catalogs
- Provides a mechanism for safely modifying existing events, e.g. adding further processing information such as magnitudes
- Allows the associator to make multiple estimates of hypocenters from the same event (e.g. early warning, different subnets, etc.)

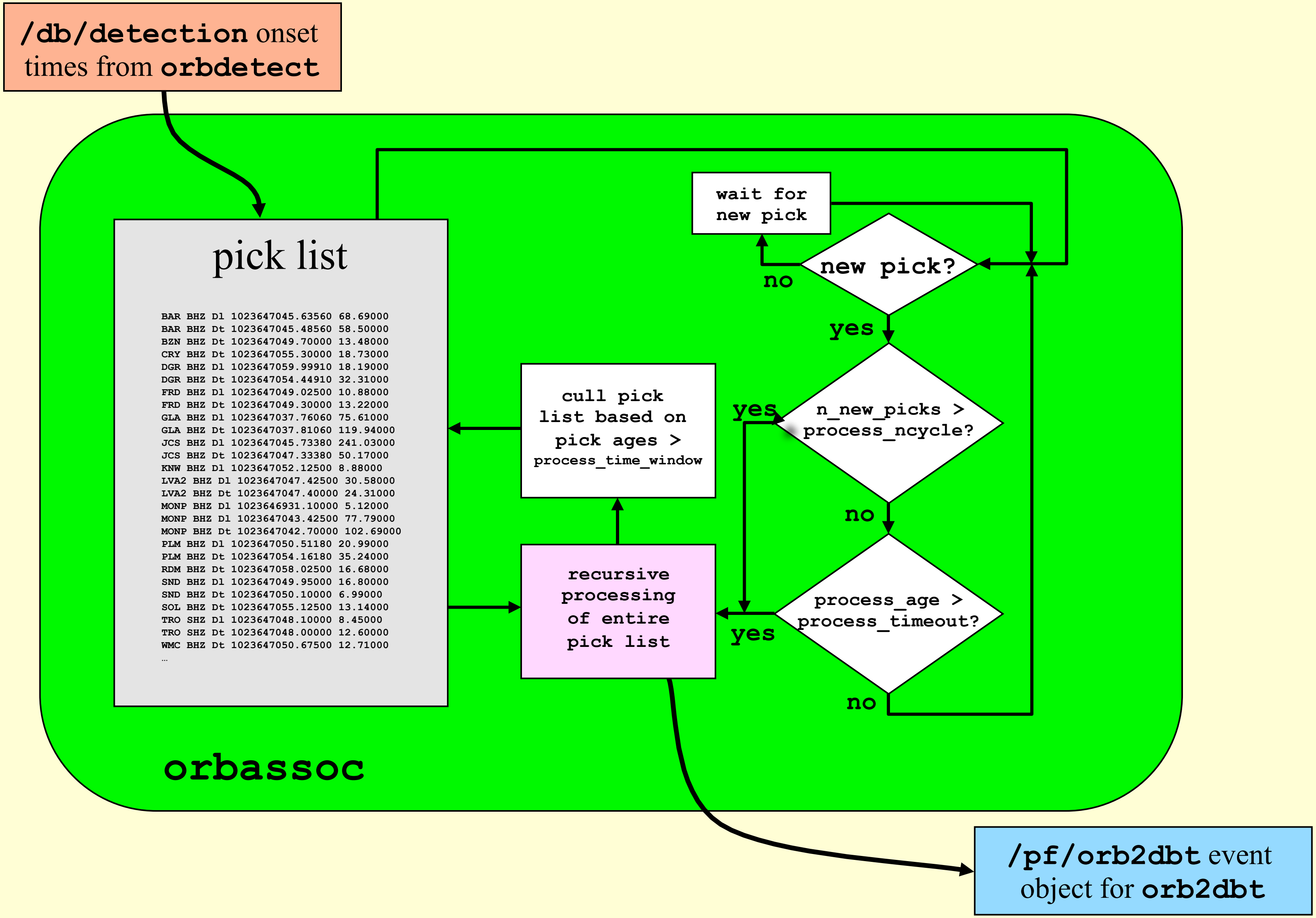
Second edition of **orbassoc**, c. 2002

- Multiple **orbtrigger-orbassoc** processes provided a way to subset down regions into subnets to limit the effective source-receiver aperture for small events
- "smart" event association in the final archive database worked well for providing a generalized method to merge multiple event estimates
- Problems with second edition:
  - Still needed **orbtrigger** which meant no time-overlapping events and no multiple origin estimates from a single **orbtrigger-orbassoc** instance
  - Still could not properly handle large aperture networks
  - Still had problems with very small events and sometime very large events with multiple **orbtrigger-orbassoc** instances (split events, orphan events, events near subnet boundaries)
  - Still produced solutions only on the grid with no error estimates (why is this important? It means that the grid must be sized finely enough to insure reasonable accuracy of solution)
  - Still couldn't handle S-arrivals very well

Third edition of **`orbassoc`**, c. 2005

- Eliminate **`orbtrigger`** as a required initial processing step for **`orbassoc`** (although it still can be used in a compatibility mode and as a means for rapid initiation of processing in **`orbassoc`**)
- Assimilate a pick list dynamically within **`orbassoc`** directly from **`detection`**s and establish rules for processing and culling the pick list
- Implement recursive pick list processing – will find time-overlapping multiple events
- Implement distance and station density weighting in grid search (attempt to deal with small event problem)
- Include new associate-only mode and iterative reprocessing mode for S-arrivals
- Development of new "universal" teleseismic grid based on observed seismicity for handling large aperture networks

orbassoc pick list processing



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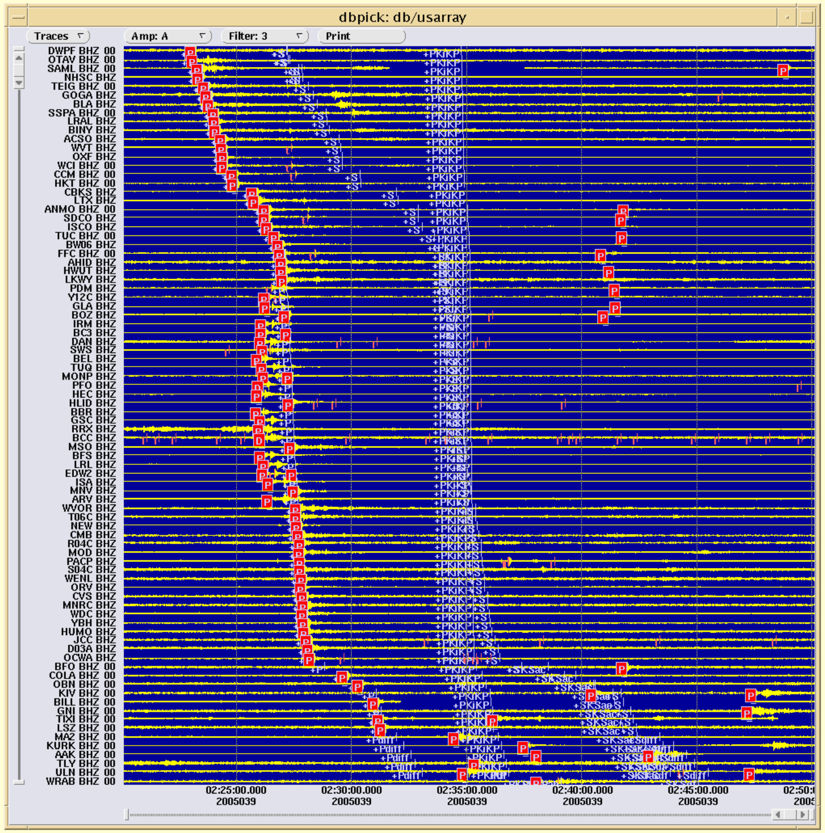
orbassoc pick list processing

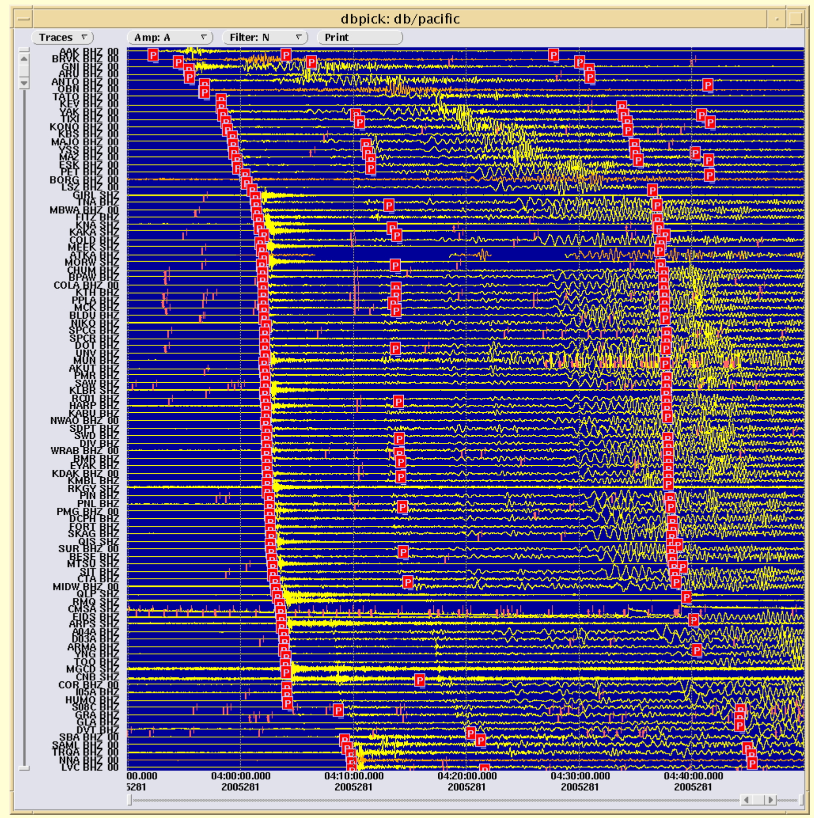
- The internal **orbassoc** pick list is accumulated directly from detection onset times – **orbdetect** can be configured to only produce onset times using the **–onlypicks** command line option flag (don't do this if you plan on using **orbtrigger**) – note that generally picks from every station-channel-filter are put into the list
- The size of the internal **orbassoc** pick list is managed such that the time difference between the oldest and youngest picks stay within the **process_time_window** parameter in **orbassoc.pf** – the moveout for an entire global network can be accommodated by making this time window suitably large (~1200 seconds) - note that this usually results in much larger pick lists than those produce by **orbtrigger**, thereby requiring more CPU time for processing the pick lists
- Each successive pick list processing cycle is completely independent of previous cycles – this means that the same event can be processed many times with multiple hypocenter estimates showing up in the final archive database
- Although it might be desirable to process the internal pick list every time a new pick is received, this is impractical because of the cpu time needed for each processing cycle and the large number of hypocenter estimates for each event that this would produce
- Pick list processing frequency is controlled based on number of new picks received (**process_ncycle** parameter in **orbassoc.pf**) and/or time since the last processing cycle (**process_timeout** parameter in **orbassoc.pf**)

`orbassoc` recursive processing

- The new model now is to form dynamic very large pick lists with all stations, channels, and filter versions over large time windows such that a single snapshot of the pick list can encompass global-scale events with hundreds of stations
- This approach absolutely requires recursive processing in order to separate out the multiple events that will usually be contained in such large pick windows – this was one of the principal improvements to **`orbassoc`** that was necessary to be able to process both continental-global scale events and local-regional scale events at the same time with the same data
- How does this work in **`orbassoc`**?
  - The standard **`orbassoc`** grid search is performed on all grids looking for a single solution that produces the most numbers of defining P-arrivals within the specified cluster time window
  - When a solution is found, Additional P-arrivals are identified as being associated but not defining using a time window larger than the cluster time window.
  - For stations with defining or associating P-arrivals, all detections within a time window around the predicted P-arrival are temporarily removed from the pick list
  - The reduced pick list is reprocessed again in the same way until no more solutions are found

`orbassoc` recursive pick processing





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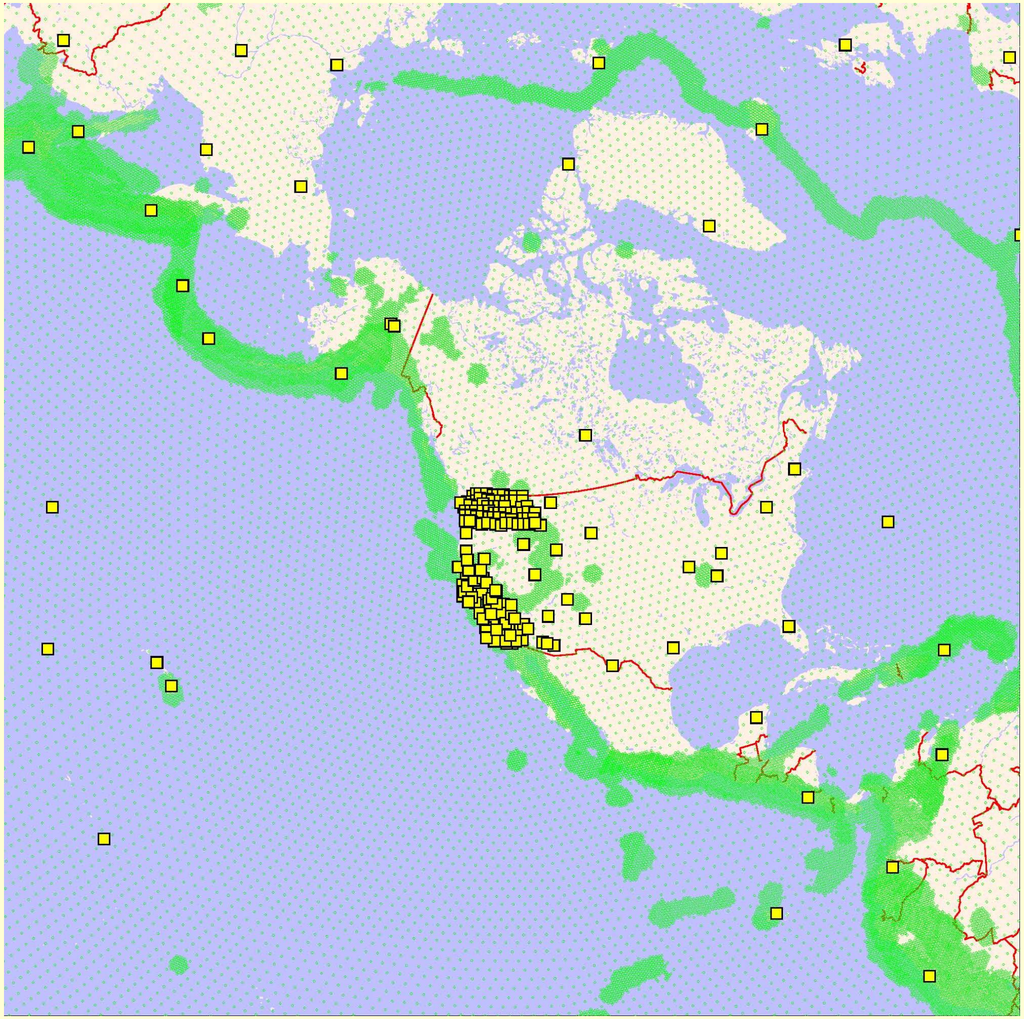
`orbassoc` universal teleseismic grid

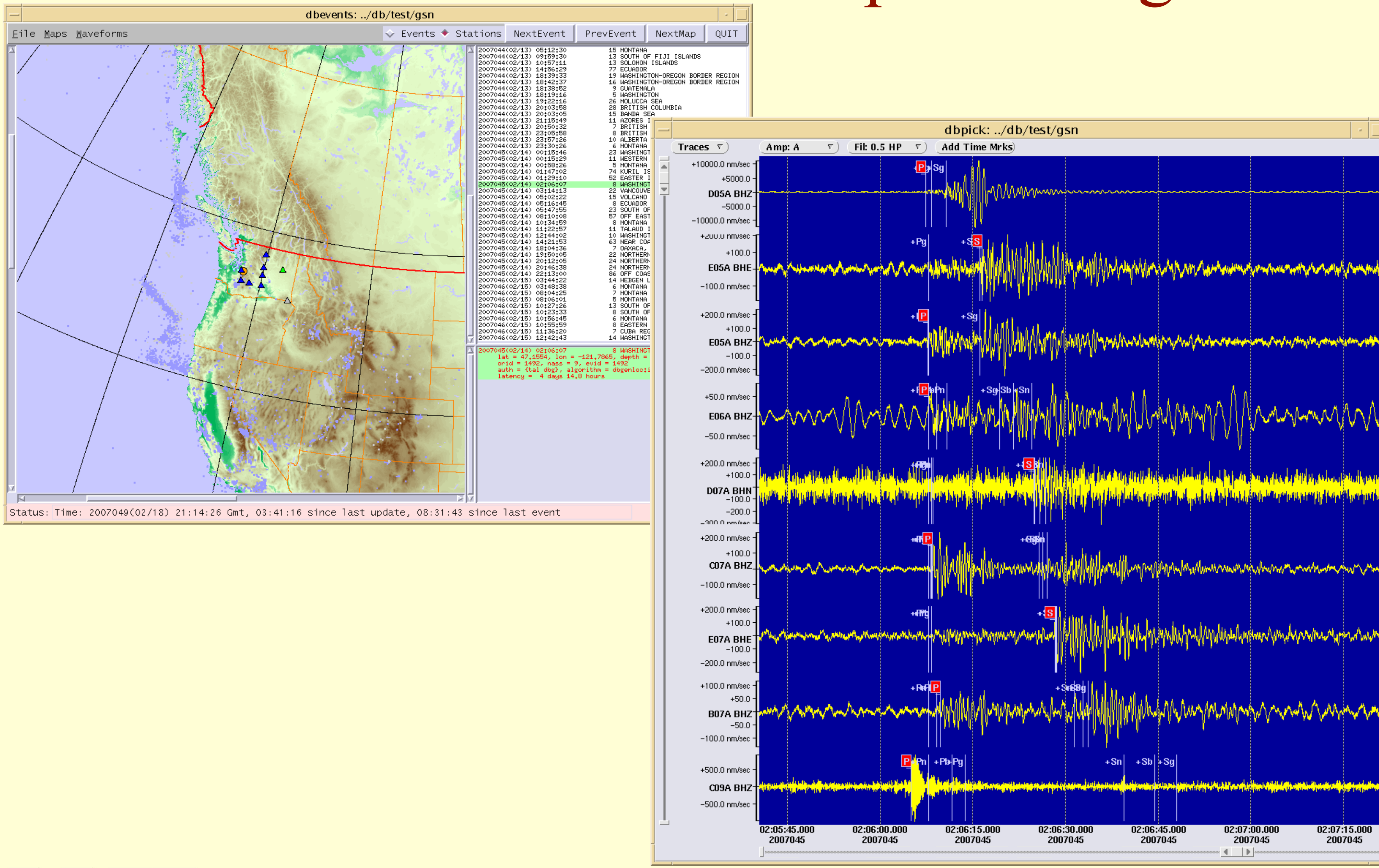
- In order to find events using global distributions of stations it was necessary to develop a travel time grid with a distribution of sources that would work for any distribution of stations.
- Icosahedral-based multi-scale triangular tesselation using USGS PDE events since 1960 to define worldwide seismic zones for grid densification
- Station density weighting was also introduced to minimize the otherwise overpowering effects of high station density within heterogeneous station distributions



orbassoc S-arrival processing

- In the original edition of **`orbassoc`**, S-arrivals were associated by throwing the S travel times into the grid search (using the **`try_S`** parameter in **`orbassoc.pf`**).
- In practice we found that in most cases, trying to use S arrival times in the initial search resulted in many more mis-locations than improvements in locations.
- In edition 3 of **`orbassoc`** we tried a different approach:
  - Always use only P-arrival times in the initial grid searches
  - If an event is found, then look for associated S-arrivals in the pick list by searching for picks around the predicted S-arrival times for all stations.
  - Mark associated S-arrivals if the **`associate_S`** parameter in **`orbassoc.pf`** has been set to **`yes`**.
  - If the **`reprocess_S`** parameter in the **`orbassoc.pf`** has been set to **`yes`**, then using only the detections that associated for P and S arrivals, make another pass through the travel time grid search, this time with **`try_S`** set to **`yes`** so that the S arrivals would be used as defining arrivals in the final solution.

orbassoc S-arrival processing



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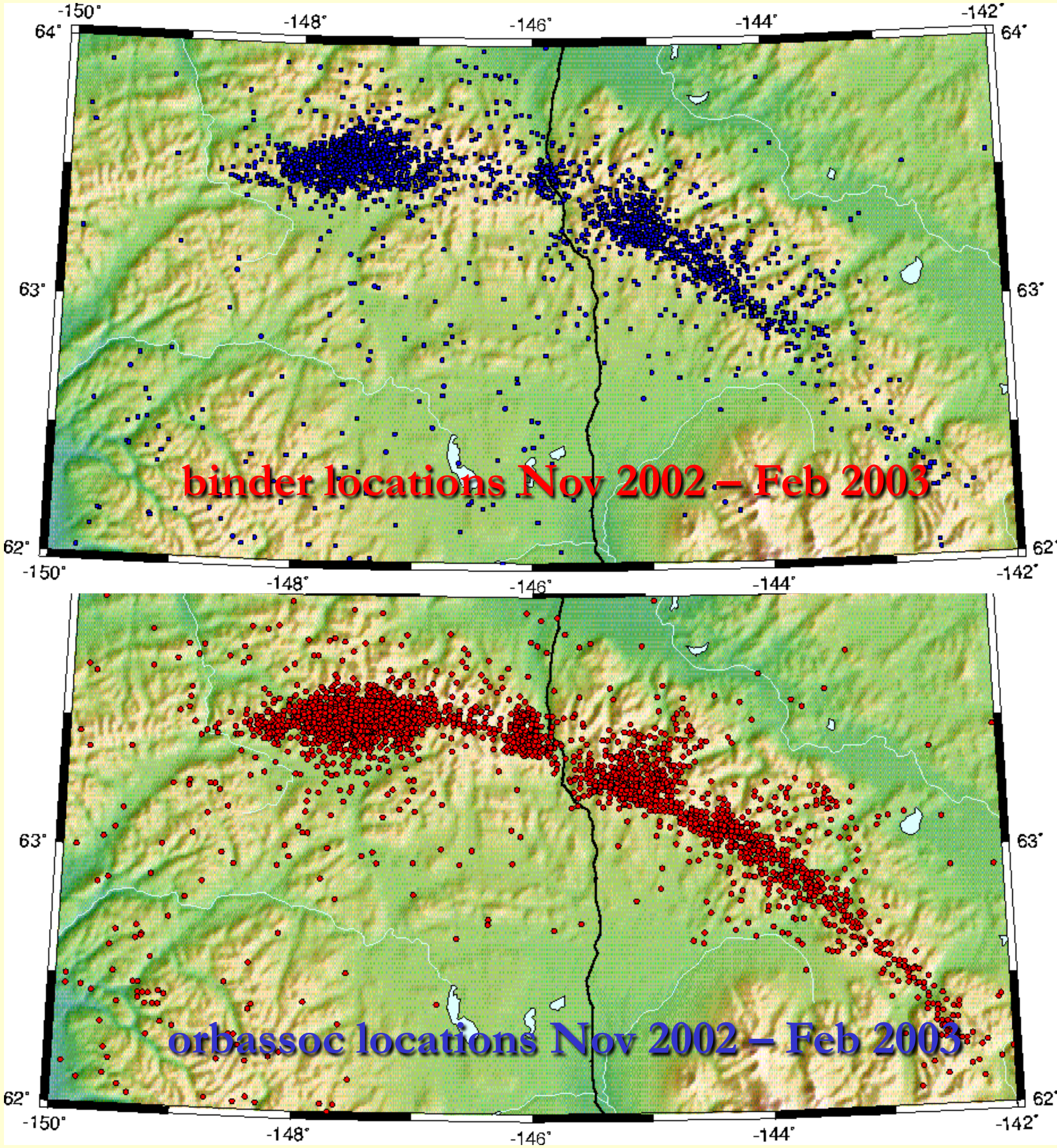
AEIC Alaska Earthquake Information Center
Geophysical Institute, UAF



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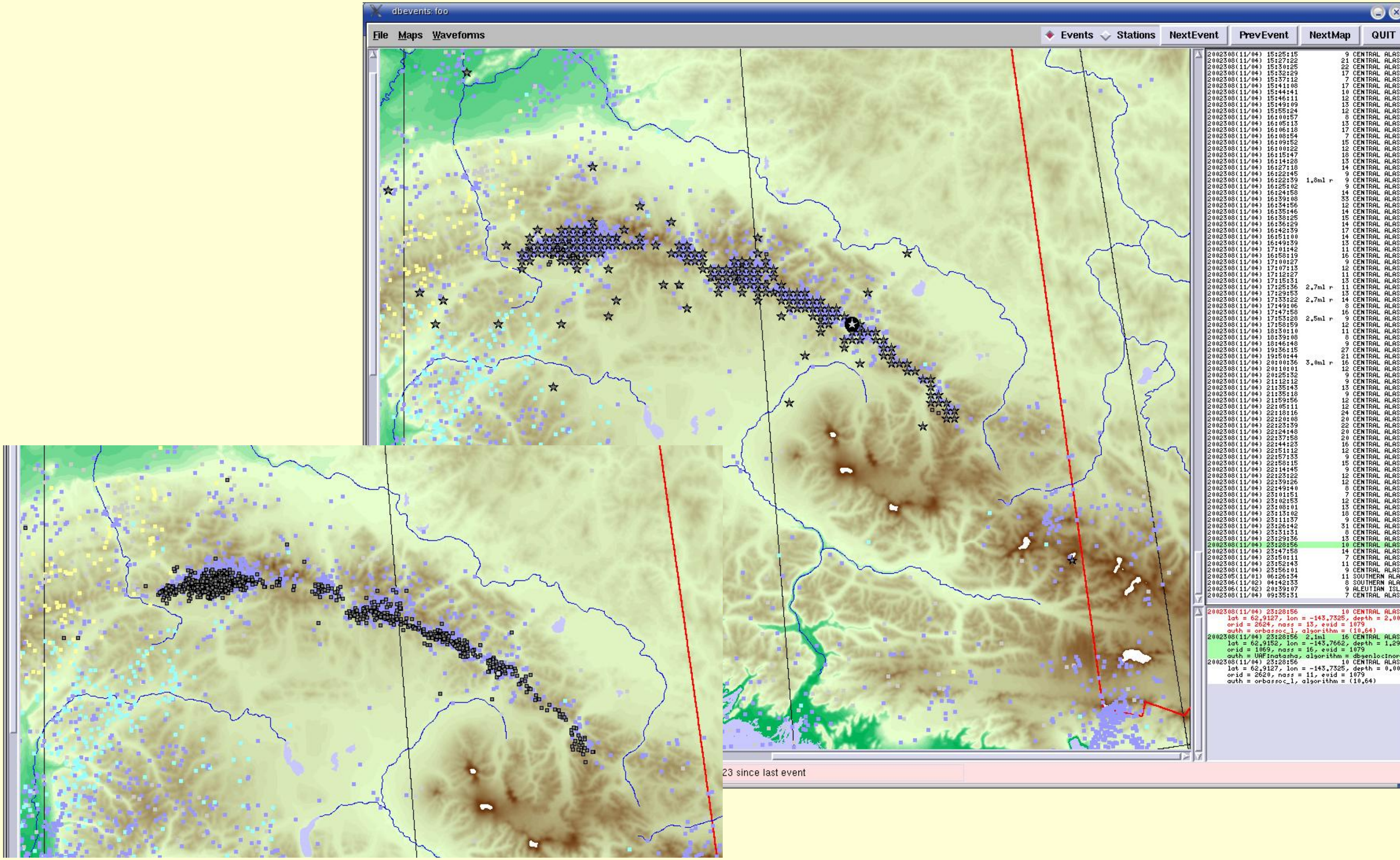
orbassoc: Denali eq test

- Test setup:
  - Used about 30 hours around time of Denali earthquake on 22:12 03 Nov, 2002
  - Transformed analyst picks into detections and processed these with **dbgrassoc**
  - Started with 29564 arrivals. Analyzed database had 1083 events.
  - Used a local grid with about 5 km spacing and depths down to 200 km. Also used utele grid
  - Enabled S-associations
- Summary of results:
  - **dbgrassoc** produced 1042 events:

```
Time   error md=-0.271, 99%=  4.488, 1%=  -5.599, std= 0.562 sec
Depth  error md=-1.000, 99%= 36.404, 1%= -17.015, std= 5.424 km
Distns error md= 0.585, 99%= 10.281, 1%= -38.047, std= 3.559 km
Distew error md= 0.628, 99%= 29.468, 1%= -22.056, std= 3.643 km
```



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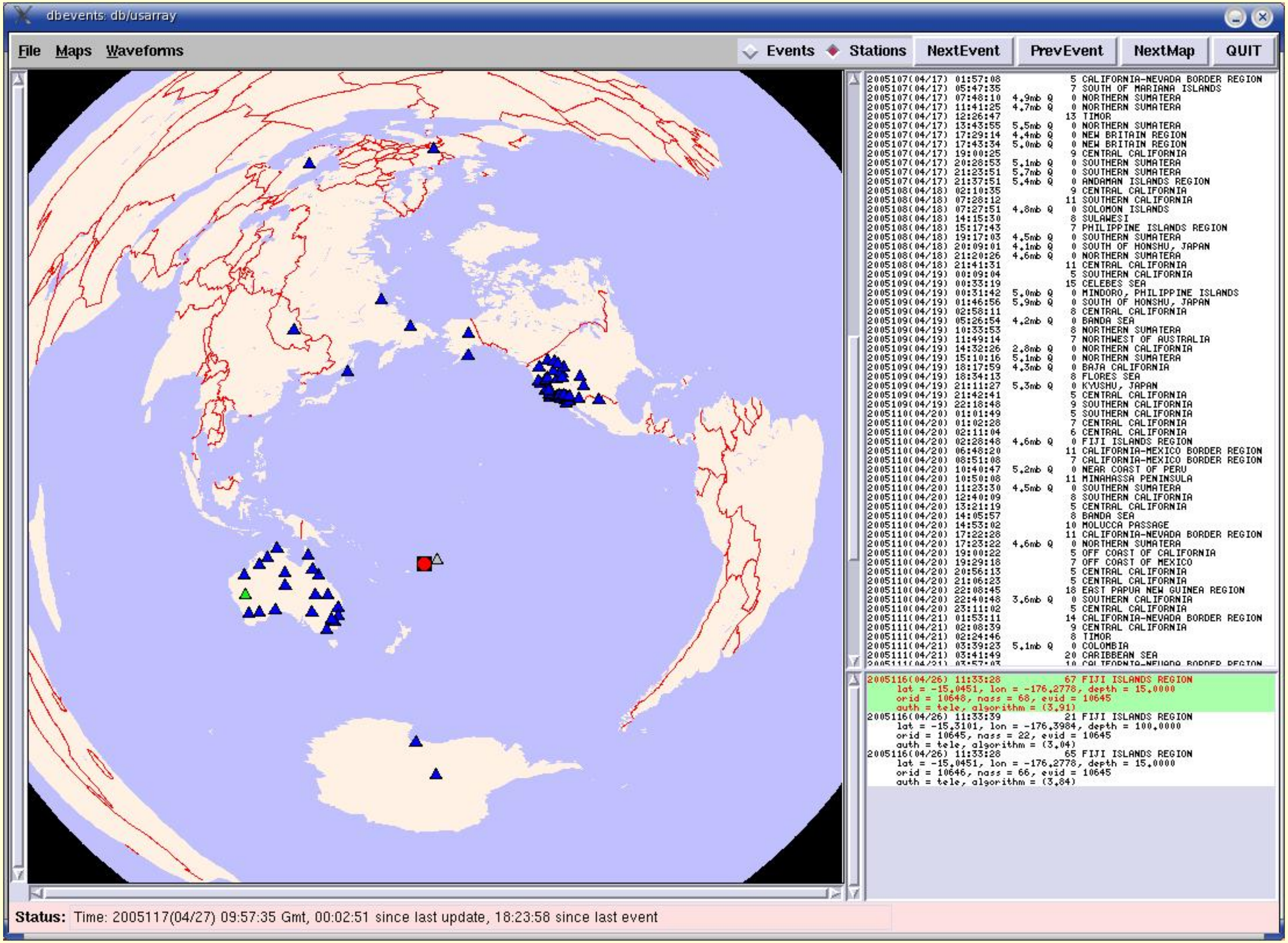
dbevents: db/usarray
File
Maps
Waveforms
Events
Stations
NextEvent
PrevEvent
NextMap
QUIT
2005107(04/17) 01:57:08 5 CALIFORNIA-NEVADA BORDER REGION
2005107(04/17) 05:47:35 7 SOUTH OF MARIANA ISLANDS
2005107(04/17) 07:48:10 4.9mb Q 0 NORTHERN SUMATERA
2005107(04/17) 11:41:25 4.7mb Q 0 NORTHERN SUMATERA
2005107(04/17) 12:26:47 13 TIMOR
2005107(04/17) 13:43:55 5.5mb Q 0 NORTHERN SUMATERA
2005107(04/17) 17:29:14 4.4mb Q 0 NEW BRITAIN REGION
2005107(04/17) 17:43:34 5.0mb Q 0 NEW BRITAIN REGION
2005107(04/17) 19:00:25 9 CENTRAL CALIFORNIA
2005107(04/17) 20:28:53 5.1mb Q 0 SOUTHERN SUMATERA
2005107(04/17) 21:23:51 5.7mb Q 0 SOUTHERN SUMATERA
2005107(04/17) 21:37:51 5.4mb Q 0 ANDAMAN ISLANDS REGION
2005108(04/18) 02:10:35 9 CENTRAL CALIFORNIA
2005108(04/18) 07:28:12 11 SOUTHERN CALIFORNIA
2005108(04/18) 07:27:51 4.8mb Q 0 SOLOMON ISLANDS
2005108(04/18) 14:15:30 8 SULAWESI
2005108(04/18) 15:17:43 7 PHILIPPINE ISLANDS REGION
2005108(04/18) 19:17:03 4.5mb Q 0 SOUTHERN SUMATERA
2005108(04/18) 20:09:01 4.1mb Q 0 SOUTH OF HONSHU, JAPAN
2005108(04/18) 21:20:26 4.6mb Q 0 NORTHERN SUMATERA
2005108(04/18) 21:41:31 11 CENTRAL CALIFORNIA
2005109(04/19) 00:09:04 5 SOUTHERN CALIFORNIA
2005109(04/19) 00:33:19 15 CELEBES SEA
2005109(04/19) 00:31:42 5.0mb Q 0 MINDORO, PHILIPPINE ISLANDS
2005109(04/19) 01:46:56 5.9mb Q 0 SOUTH OF HONSHU, JAPAN
2005109(04/19) 02:58:11 8 CENTRAL CALIFORNIA
2005109(04/19) 05:26:54 4.2mb Q 0 BANDA SEA
2005109(04/19) 10:33:53 8 NORTHERN SUMATERA
2005109(04/19) 11:49:14 7 NORTHWEST OF AUSTRALIA
2005109(04/19) 14:32:26 2.8mb Q 0 NORTHERN CALIFORNIA
2005109(04/19) 15:10:16 5.1mb Q 0 NORTHERN SUMATERA
2005109(04/19) 18:17:59 4.3mb Q 0 BAJA CALIFORNIA
2005109(04/19) 18:34:13 8 FLORES SEA
2005109(04/19) 21:11:27 5.3mb Q 0 KYUSHU, JAPAN
2005109(04/19) 21:42:41 5 CENTRAL CALIFORNIA
2005109(04/19) 22:18:48 9 SOUTHERN CALIFORNIA
2005110(04/20) 01:01:49 5 SOUTHERN CALIFORNIA
2005110(04/20) 01:02:28 7 CENTRAL CALIFORNIA
2005110(04/20) 02:11:04 6 CENTRAL CALIFORNIA
2005110(04/20) 02:28:48 4.6mb Q 0 FIJI ISLANDS REGION
2005110(04/20) 06:48:20 11 CALIFORNIA-MEXICO BORDER REGION
2005110(04/20) 08:51:08 7 CALIFORNIA-MEXICO BORDER REGION
2005110(04/20) 10:40:47 5.2mb Q 0 NEAR COAST OF PERU
2005110(04/20) 10:50:08 11 MINAHASSA PENINSULA
2005110(04/20) 11:23:30 4.5mb Q 0 SOUTHERN SUMATERA
2005110(04/20) 12:40:09 8 SOUTHERN CALIFORNIA
2005110(04/20) 13:21:19 5 CENTRAL CALIFORNIA
2005110(04/20) 14:05:57 8 BANDA SEA
2005110(04/20) 14:53:02 10 MOLUCCA PASSAGE
2005110(04/20) 17:22:28 11 CALIFORNIA-NEVADA BORDER REGION
2005110(04/20) 17:23:22 4.6mb Q 0 NORTHERN SUMATERA
2005110(04/20) 19:00:22 5 OFF COAST OF CALIFORNIA
2005110(04/20) 19:29:18 7 OFF COAST OF MEXICO
2005110(04/20) 20:56:13 5 CENTRAL CALIFORNIA
2005110(04/20) 21:06:23 5 CENTRAL CALIFORNIA
2005110(04/20) 22:08:45 18 EAST PAPUA NEW GUINEA REGION
2005110(04/20) 22:40:48 3.6mb Q 0 SOUTHERN CALIFORNIA
2005110(04/20) 23:11:02 5 CENTRAL CALIFORNIA
2005111(04/21) 01:53:11 14 CALIFORNIA-NEVADA BORDER REGION
2005111(04/21) 02:08:39 9 CENTRAL CALIFORNIA
2005111(04/21) 02:24:46 8 TIMOR
2005111(04/21) 03:39:23 5.1mb Q 0 COLOMBIA
2005111(04/21) 03:41:49 20 CARIBBEAN SEA
2005116(04/26) 11:33:28 67 FIJI ISLANDS REGION
lat = -15.0451, lon = -176.2778, depth = 15.0000
orid = 10648, nass = 68, evid = 10645
auth = tele, algorithm = (3.91)
2005116(04/26) 11:33:39 21 FIJI ISLANDS REGION
lat = -15.3101, lon = -176.3984, depth = 100.0000
orid = 10645, nass = 22, evid = 10645
auth = tele, algorithm = (3.04)
2005116(04/26) 11:33:28 65 FIJI ISLANDS REGION
lat = -15.0451, lon = -176.2778, depth = 15.0000
orid = 10646, nass = 66, evid = 10645
auth = tele, algorithm = (3.84)
Status: Time: 2005117(04/27) 09:57:35 Gmt, 00:02:51 since last update, 18:23:58 since last event

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Third edition of **`orbassoc`**, c. 2005

- For the first time we have the capability of processing any data from any mix and distribution of seismic stations from local to global scales
- Processing has been simplified for the user since we throw everything into a single large buffer instead of trying to make lots of processing subnets
- S-arrival processing is now effective
- Problems with third edition:
  - Still had problems with very small events and sometime very large events (split events, orphan events, events near subnet boundaries). Distance weighting proved not to be very effective.
  - Still produced solutions only on the grid with no error estimates (why is this important? It means that the grid must be sized finely enough to insure reasonable accuracy of solution)
  - Performance problems

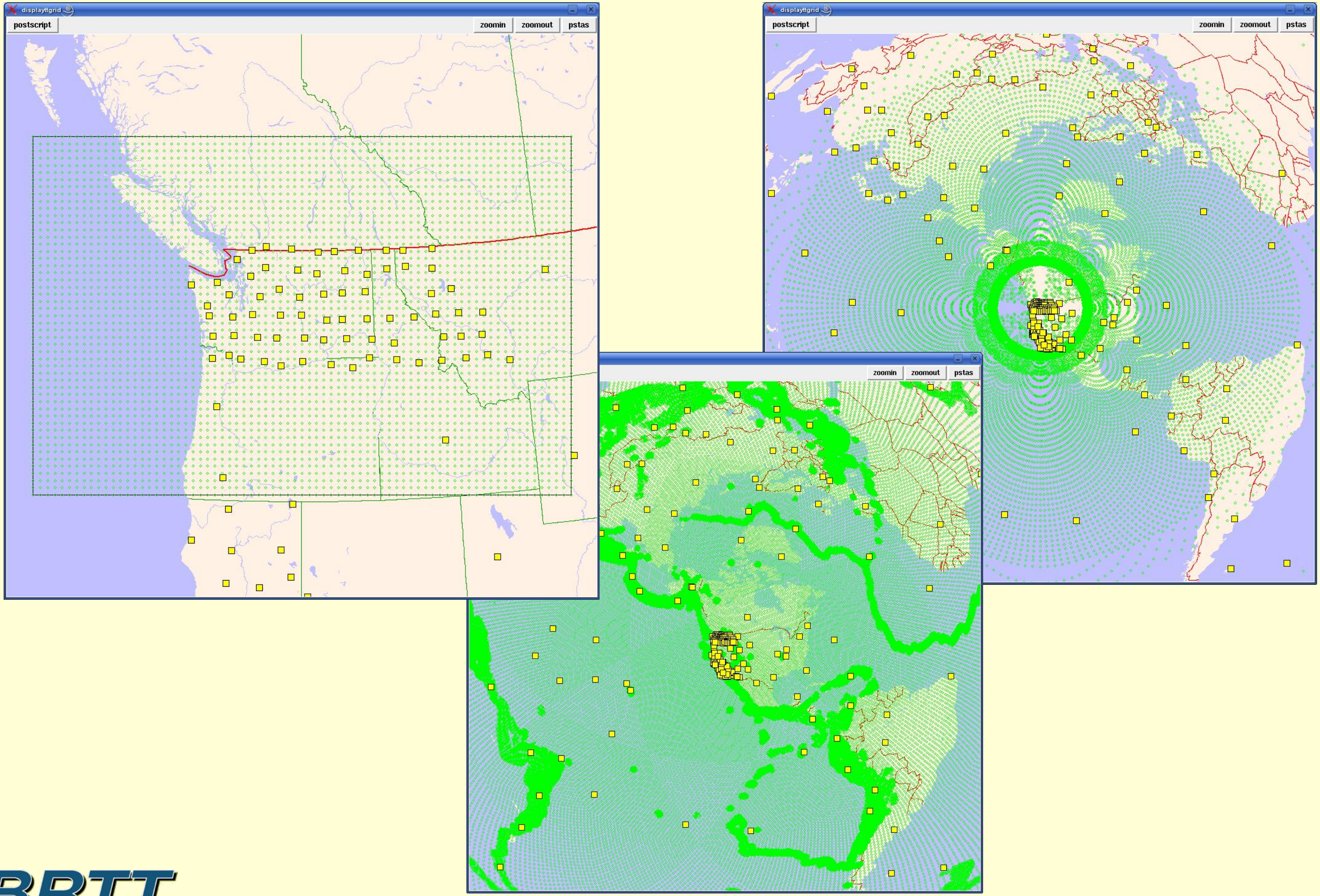
Fourth edition of **`orbassoc`**, c. 2007

- Mainly focus on refinements to the third edition to deal with mis-locations and split events and to improve performance
  - Reduced mis-locations for small events:
    - Added pick reject expressions to remove noisy stations
    - Introduced **`nsta_thresh`** as a function of maximum event-station distance
    - Introduced separate S arrival distance weighting functions
  - Reduced split events
    - Added separate residual thresholds for P and S arrival associations
  - Improve performance
    - Threading
    - Made it so that picks with zero weights were completely eliminated from the grid searches.
    - Added "closest stations" pick list culling during the grid searches.
    - Added ability to run a traditional location code, such as dbgenloc, automatically after finding a grid solution in order to refine the final location and to obtain traditional error estimates. This allows running with much coarser grids and therefore improves overall performance.

Fourth edition of **orbassoc.pf**

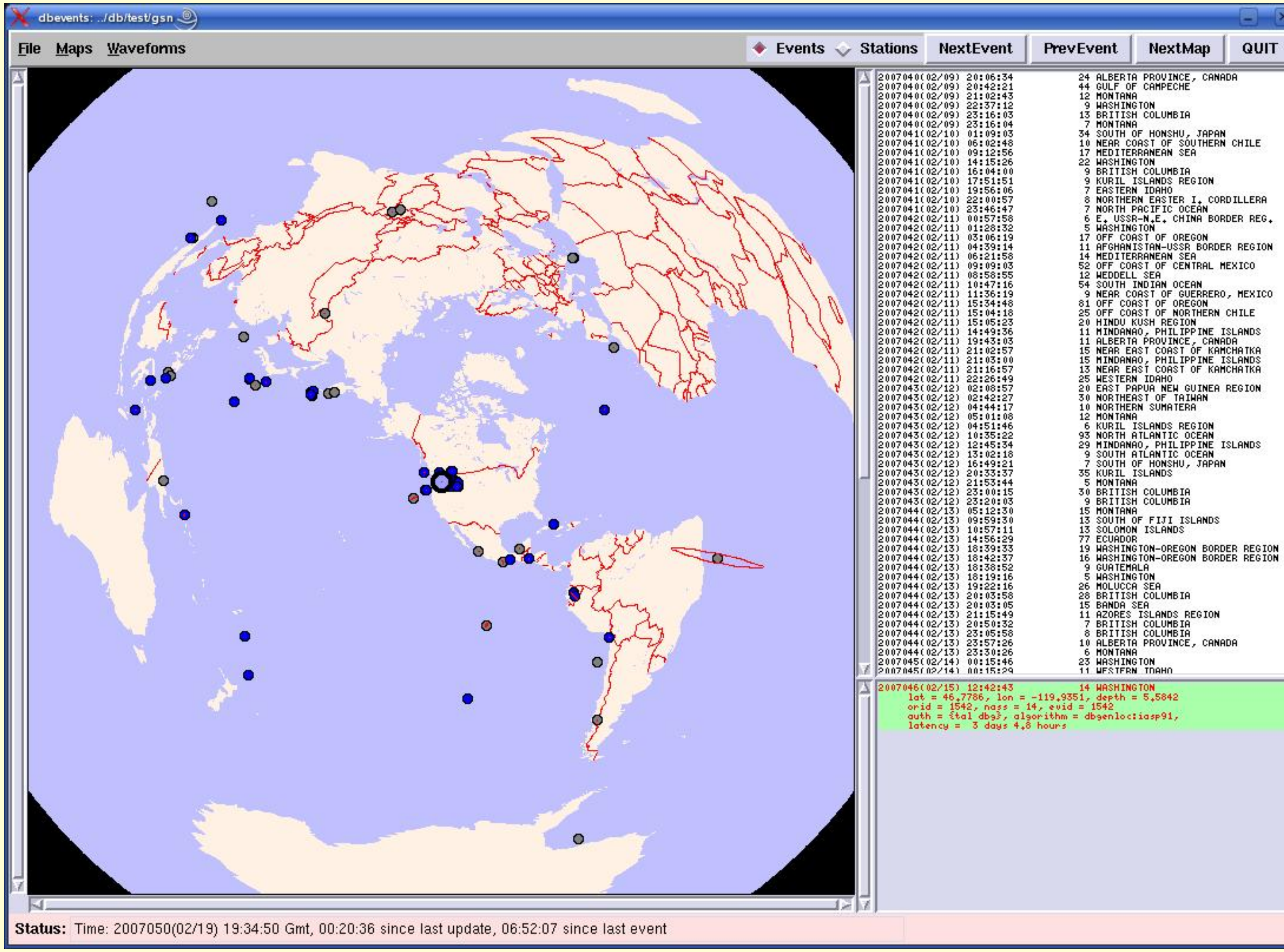
```
#     Parameter file for dbgrassoc

process_time_window     3600.0
process_ncycle          0
process_tcycle          3000.0

detection_reject_expressions &Tbl{      # reject these picks before any processing
sta == "ADH"
sta == "ANT"
sta == "BFC"
}


grid_params &Arr{
        talocal &Arr{
                nxd             11      # Number of east-west grid nodes for depth scans
                nyd             11      # Number of north-south grid nodes for depth scans
                cluster_twin    4.0     # Clustering time window
                nondefining_association_P_maxresid      2.0 # maximum residual for P assocs
                nondefining_association_S_maxresid      3.0 # maximum residual for S assocs
                nsta_thresh     &Tbl{   # Minimum allowable number of stations
                        3.0     4       #    as a function of maximum station distance
                        5.0     5       #    from event
                        180.0   6
                }
                try_S           no      # yes = Try observations as both P and S
                                        # no  = Observations are P only
                associate_S     yes     # yes = Try to associate observations as both P and S
                reprocess_S     yes     # yes = Reprocess when new S-associations found
                drop_if_on_edge yes     # Drop if solution is on the edge of the grid
                P_channel_sifter ..Z|..Z_00     # use only these channels for P arrivals
                S_channel_sifter ..[NEZ]        # use only these channels for S arrivals
                priority        5               # grid priority
                algorithm       talocal         # algorithm field for origin output
                auth            tal             # auth field for origin output
                phase_sifter    .               # sift according to pick phase codes
                closest_stations 0              # only use closest n stations for search
                use_dwt         no              # apply distance weighting to P arrivals?
                dwt_dist_near   10.0
                dwt_wt_near     1.0
                dwt_dist_far    10.0
                dwt_wt_far      0.0
                use_dwts        yes             # apply distance weighting to S arrivals?
                dwts_dist_near  5.0
                dwts_wt_near    1.0
                dwts_dist_far   5.0
                dwts_wt_far     0.0
                relocate rundbgenloc            # relocation script
                use_only_relocation yes         # only output trelocation flag
        }
```

Test using USArray plus GSN data

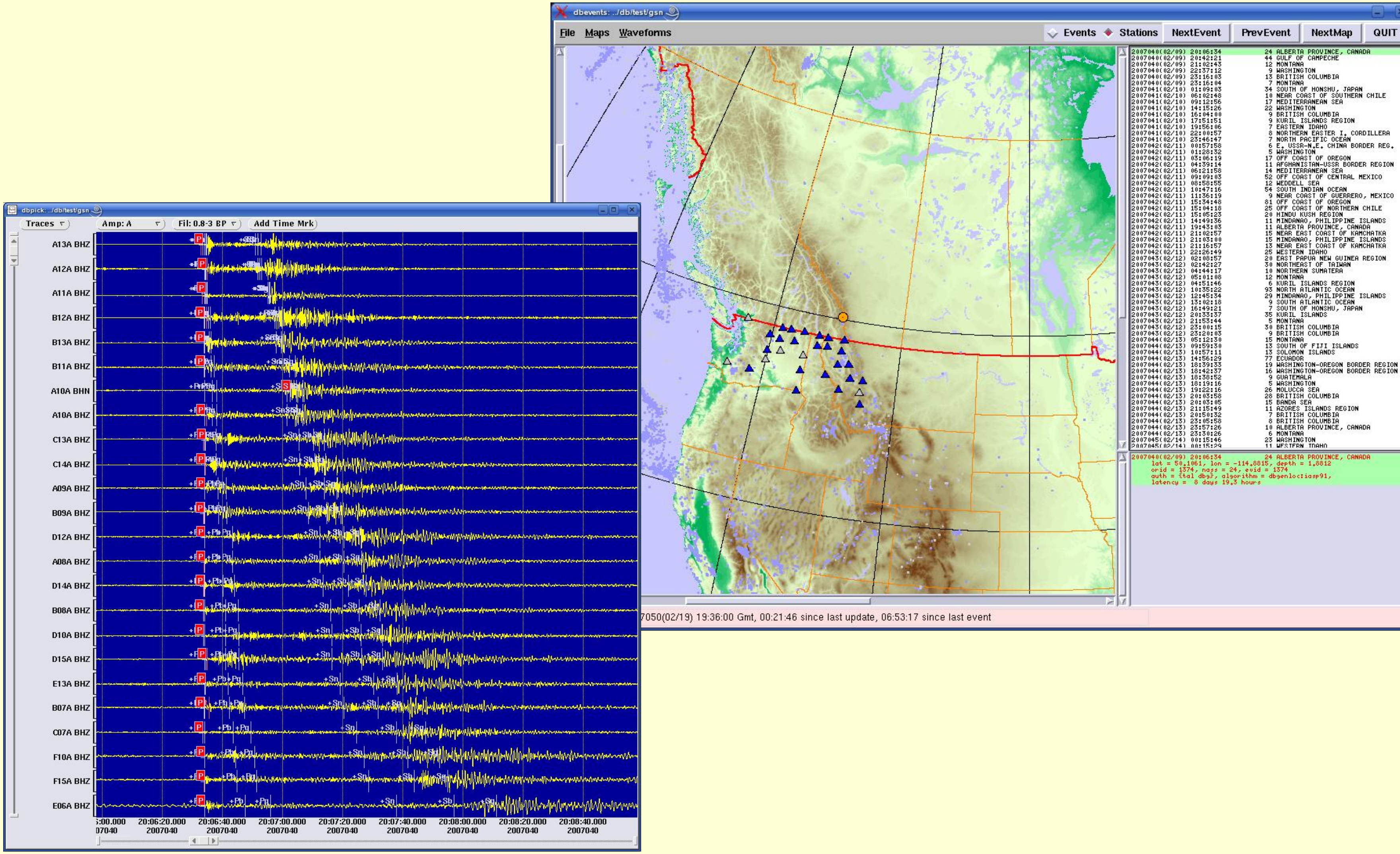


Test using USArray plus GSN data

- ~5.5 days of data from 162 stations.
- 31,393 detections
- 92 events
- 141 stations with arrivals
- ~120 minutes to process using **`dbgrassoc`**



Test using USArray plus GSN data



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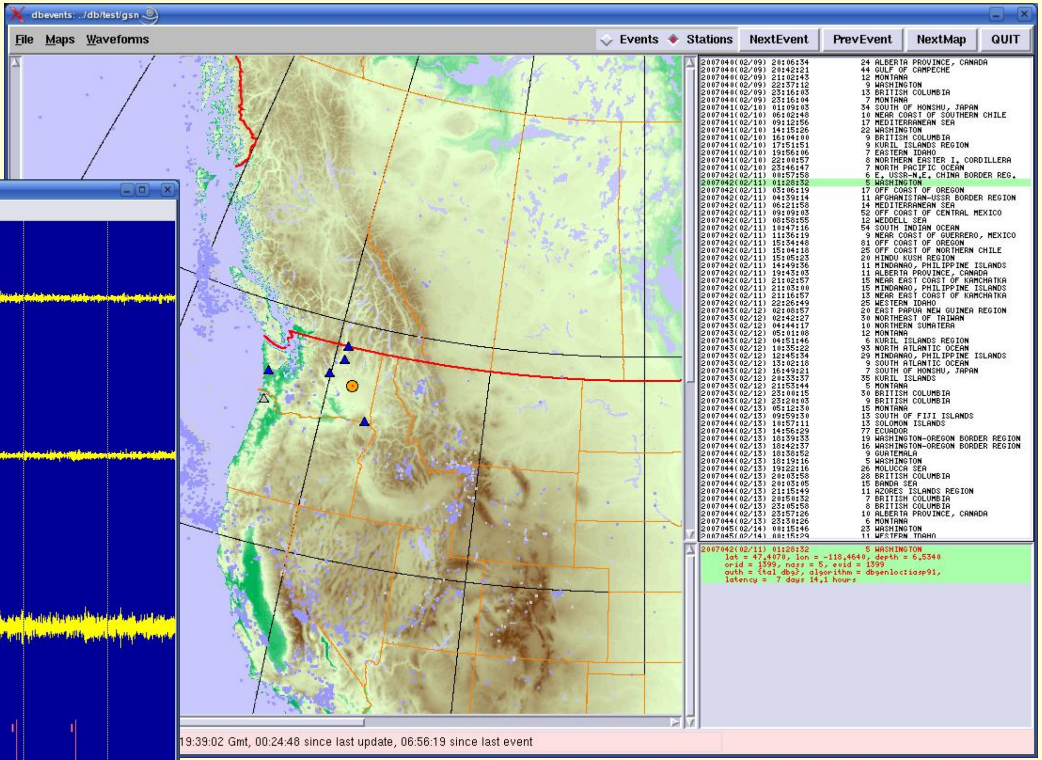
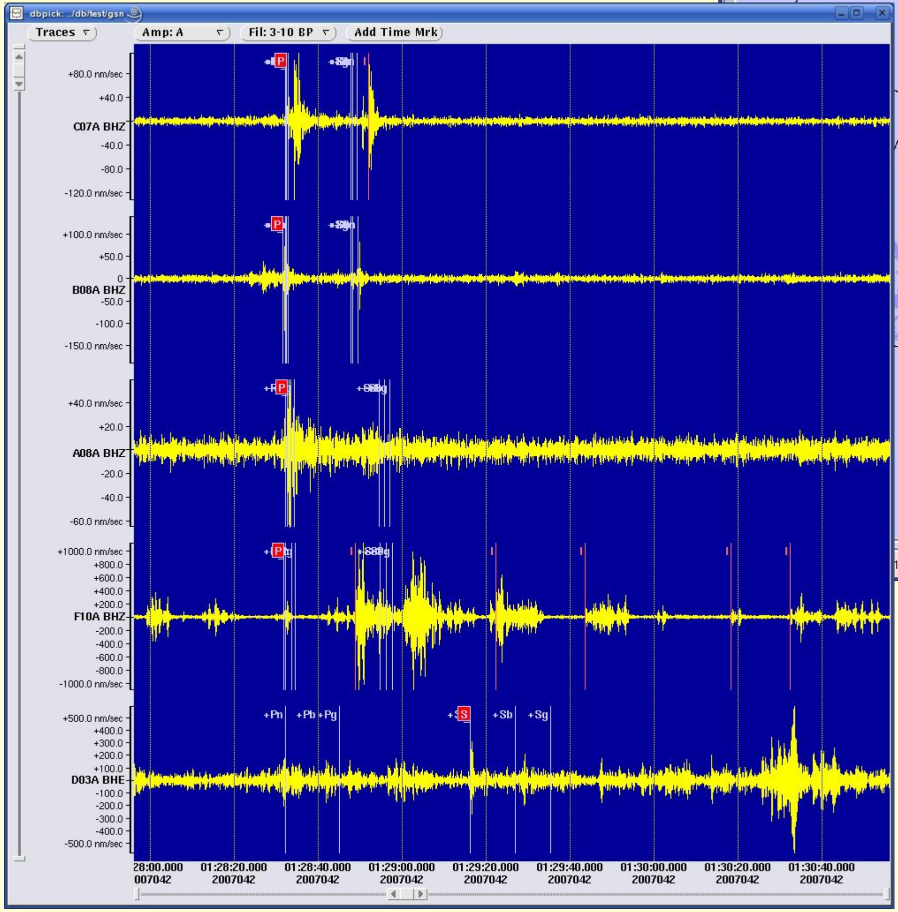
Test using USArray plus GSN data





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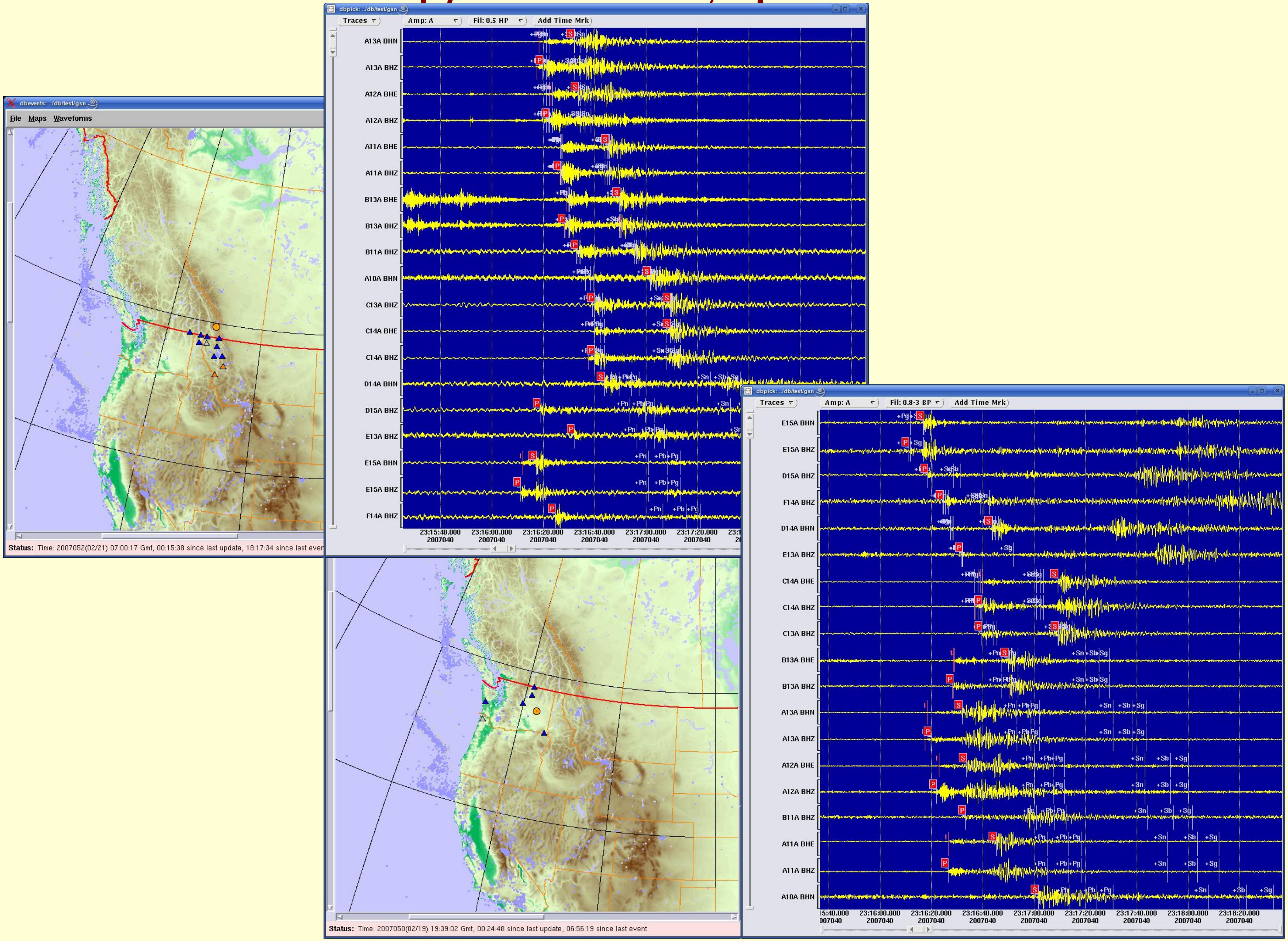
Test using USArray plus GSN data



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Configuration notes

- Preferred approach is to run a single instance of orbassoc with as few grids as possible
- All stations in all grids – "all" stations should include neighboring stations all the way to global scale (GSN)
- Use of utele grids can be computationally expensive – use distance weighting with utele grids to mitigate this
- Continue to use slowness grids for finding teleseisms in local to regional network aperture scales
- Make the local Cartesian grids as coarse as possible and use relocation option to improve the final solutions using a traditional iterative linearized inversion method, such as **`dbgenloc`**
- Use distance (or closest stations) weighting with zero wieghts to improve performance, especially for utele grids
- Use "sequenced" approach for associating S-arrivals