Swedish National Seismic Network - Status 2020

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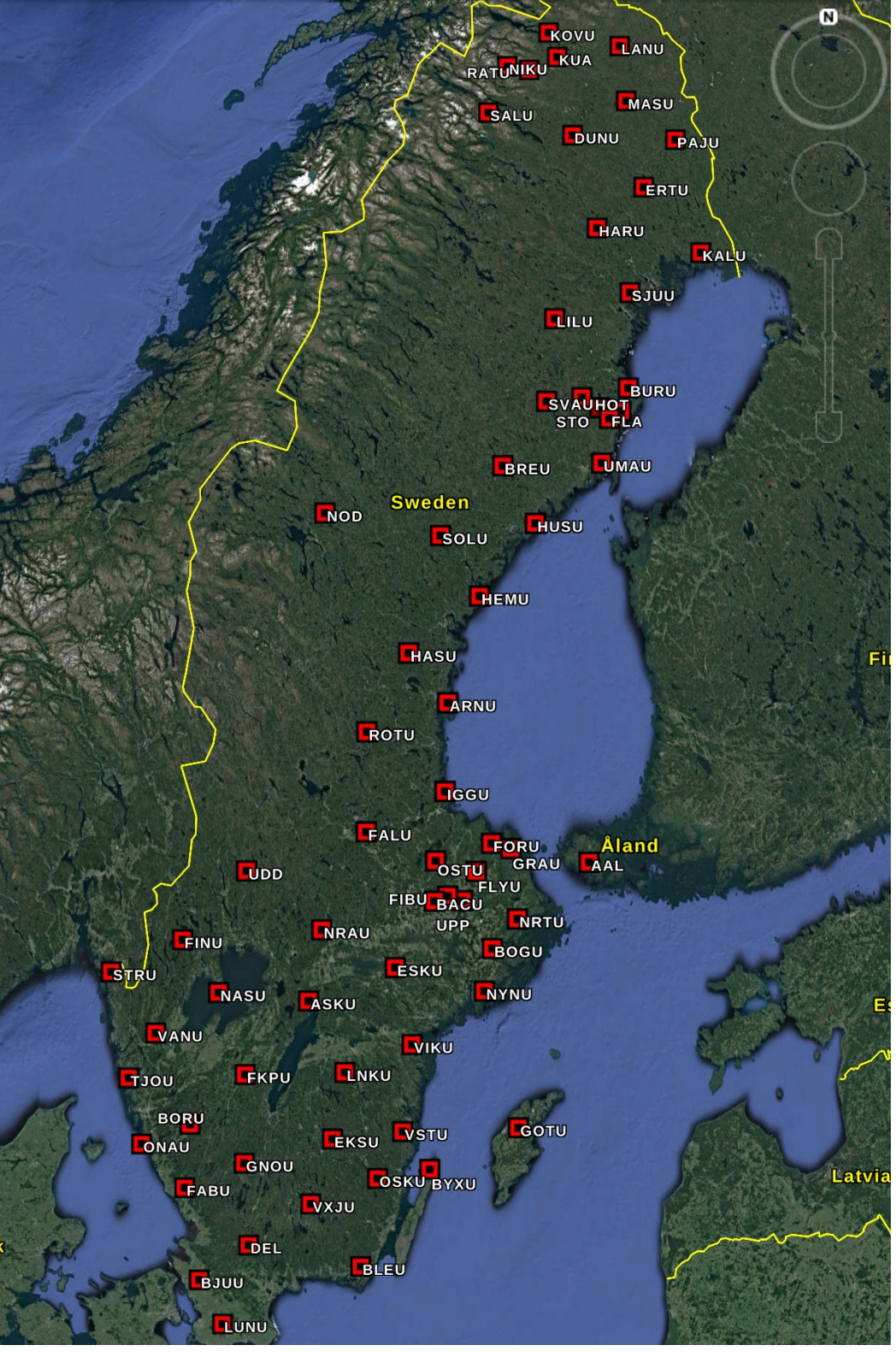
- Network status and updates
- Data/processing flow
- Automatic monitoring processes
- Bulletins and realtime waveforms
- Outlook



- 68 permanent broadband stations
- continuous data 100 sps
- communication via cell network

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aal	AAL	2002	Åland	kov	KOVU	2011	Kortovare
arn	ARNU	2000	Hudiksvall	kur	KUA	1998	Kurravaara
ask	ASKU	2002	Askersund	lan	LANU	2004	Lannavaara
bac	BACU	2001	Vittinge	lil	LILU	2000	Jörn
bju	BJUU	2008	Bjuv	lnk	LNKU	2002	Linköping
ble	BLEU	2002	Karlskrona	lun	LUNU	2008	Lund
bor	BORU	2006	Borås	mas	MASU	2003	Masugnsbyn
bog	BOGU	2019	Bogesund	nas	NASU	2006	Värmlandsnäs
bre	BREU	2000	Bjurholm	nik	NIKU	2003	Nikkaluokta
bur	BURU	2000	Skellefteå	nor	NOD	1998	Norderåsen
byx	BYXU	2002	Öland	nra	NRAU	2002	Nora
del	DEL	1969	Delary	nrt	NRTU	2002	Norrtälje
dun	DUNU	2003	Gällivare	nyn	NYNU	2002	Nynäshamn
eks	EKSU	2002	Eksjö	ode	ODEU	2012	Burträsk
ert	ERTU	2004	Lansjärv	ona	ONAU	2010	Onsala
esk	ESKU	2002	Eskilstuna	osk	OSKU	2002	Oskarshamn
fab	FABU	2006	Falkenberg	ost	OSTU	2001	Horsskog
fal	FALU	2002	Falun	paj	PAJU	2004	Pajala
fib	FIBU	2009	Fiby	rat	RATU	2011	Ratekjokk
fin	FINU	2005	Årjäng	rot	ROTU	2000	Edsbyn
fkp	FKPU	2006	Falköping	sal	SALU	2003	Saltoluokta
fla	FLA	2012	Flarken	sju	SJUU	2000	Luleå
fly	FLYU	2002	Österbybruk	sol	SOLU	2000	Sollefteå
for	FORU	2005	Forsmark	sto	STOU	2012	Storbäcken
gno	GNOU	2006	Gnosjö	str	STRU	2006	Strömstad
got	GOTU	2002	Gotland	sva	SVAU	2000	Svanaliden
gra	GRAU	2001	Öregrund	tjo	TJOU	2006	Tjörn
har	HARU	2006	Harads	udd	UDD	1966	Uddeholm
has	HASU	2000	Hassela	uma	UMAU	2002	Umeå
hem	HEMU	2000	Härnösand	up1	UPP	1904	Uppsala
hot	HOT	2015	Hotjärn	van	VANU	2006	Vänersborg
hus	HUSU	2000	Örnsköldsvik	vik	VIKU	2002	Vikbolandet
igg	IGGU	2000	Gävle	vst	VSTU	2002	Västervik
kal	KALU	2006	Kalix	vxj	VXJU	2001	Växjö

Network maintenance and upgrades

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Upgrade/replacement of station computers

- We phased out sil processing (1990-2020, running on each station computer, locked to a very old Guralp scream version, locked to very old Redhat OS)
- Serial port (data port to digitizer) hangups, data gaps, incomplete backfill, frequent program crashes

- 12 complete new station computers
- ~35 ‘old computers’ upgraded with new OS (Debian 10) and newest Guralp Scream (4.7 beta)
- 9 stations without computer (either EAM or directly connected to modem/router)
- 8 stations still run with an old computer and need to be upgraded

- Stable station computers and increased data timeliness
- Much higher data availability

GPS replacements (Trimble, week roll-over issue)

- 58 done / 10 remain to be done

LILU put into operation after long-term outage
KUA new concrete pillar after groundwater intrusion
HUDU has been closed down (too noisy, station ARNU close by)
UDD is taken out of processing (too much ambient noise) and will be closed down
HFC2 (Hagfors 3C BB station, FOI) has been integrated in SNSN processing as replacement UDD

Conny Holmqvist field engineer and lead/main analyst

Enjoying his retirement after 43 years at the SNSN

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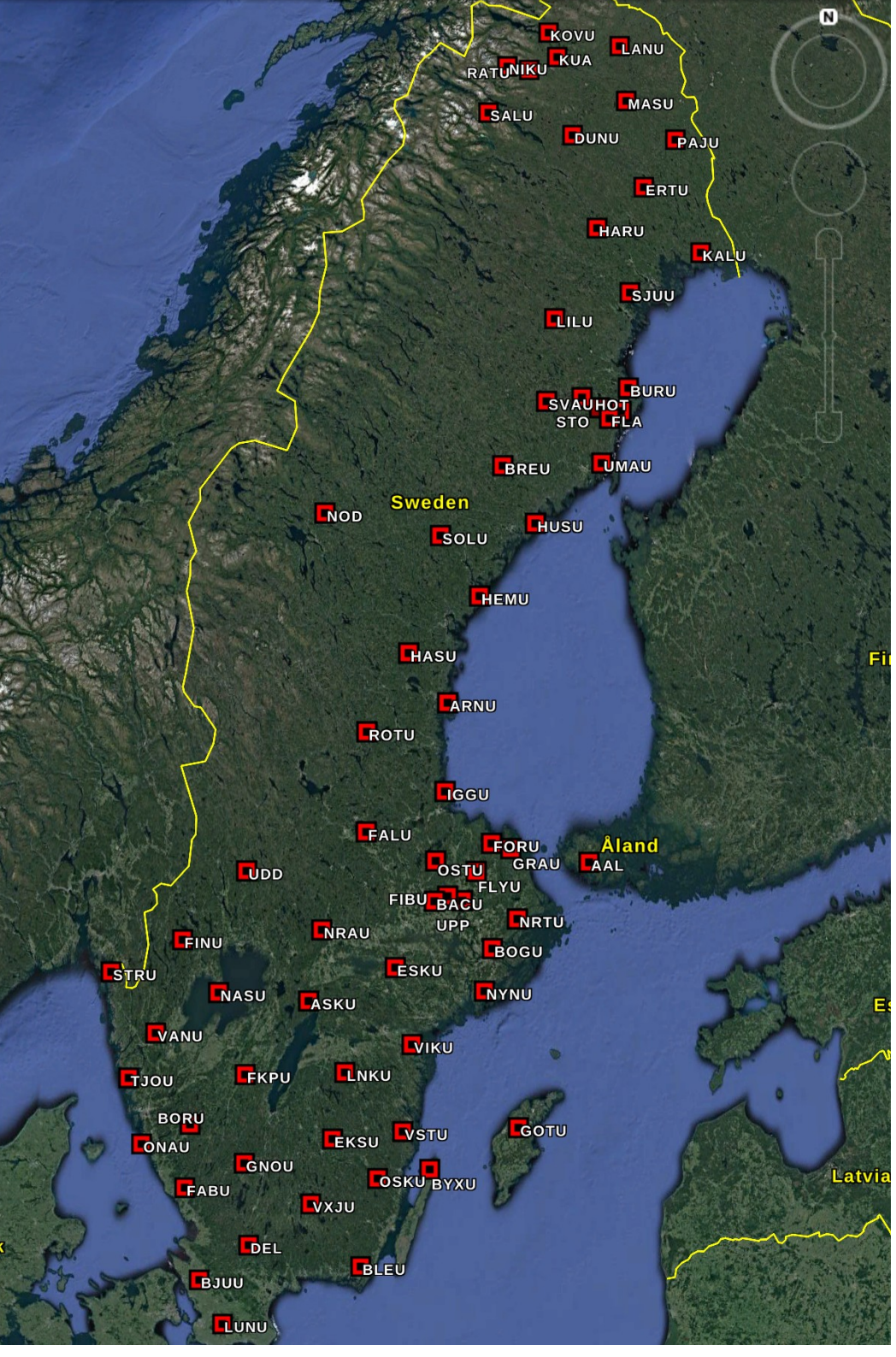

Maintenance visits 2020

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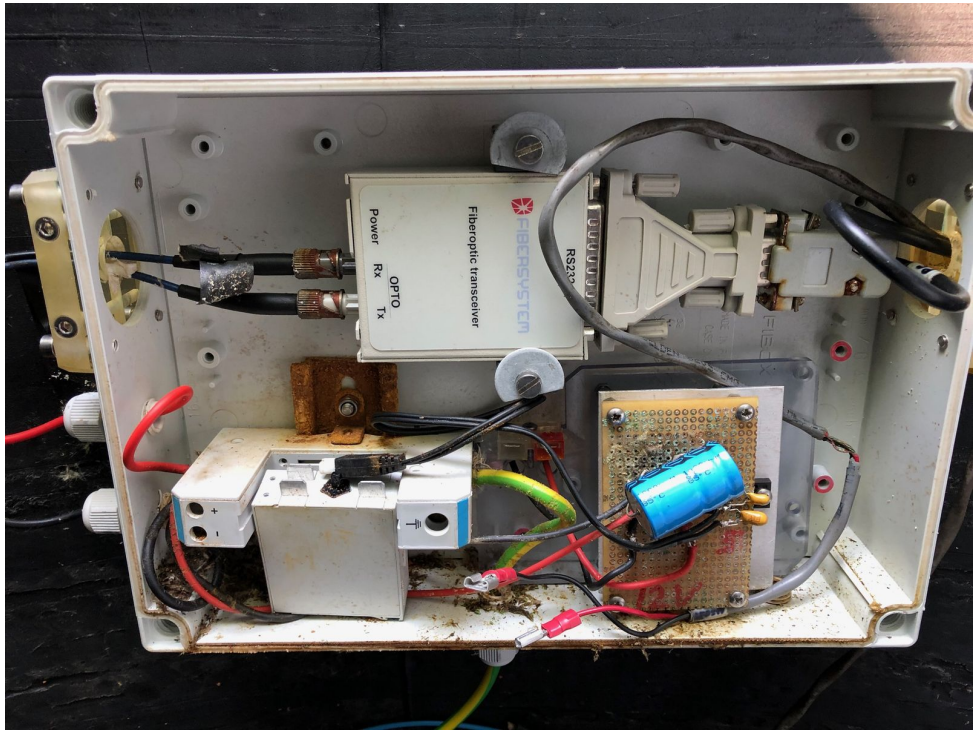
• 23.1.	ASKU	
• 10.2.	OSKU	
• 11.2.	BLEU	
• 12.2.	STRU	
• 13.2.	LNKU	
• 17.2.	BYXU	
• 25.2.	LNKU	
• 28.2.	BOGU	
• 11.3.	FALU	
• 16.3.	FIBU	
• 17.3.	NRAU, ASKU	
• 23.3.	FIBU	
• 24.3.	UPP	
• 26.3.	IGGU	
• 1.4.	GRAU	
• 2.4.	HUDU	**55 field days, 47 stations**
• 3.4.	FIBU	(so far ...)
• 17.4.	BOGU	
• 27.4.	FIBU	
• 25.5.	BOGU	
• 30.5.	FORU	
• 28.5-31.5	KUA	
• 25.6.	NRTU	
• 28.6.	LUNU	
• 8.7.	FALU	
• 16.7.	FALU	
• 22.7.	NRTU	
• 28.7.-31.7.	IGGU, HEMU, HUSU, SOLU, NOD, HASU, ROTU	
• 28.7.	NASU	
• 31.7.	IGGU	
• 5.8.	BOGU	
• 6.8.	FIBU	
• 12.8.	OSTU, IGGU	
• 19.8.	FALU	
• 24.8.-28.8.	BREU, UMAU, FLAU, STOU, HOT, BURU, LILU, SJUU, KALU, PAJU, ERTU, HARU	
• 25.8.	FIBU	
• 10.9.-11.9.	VIKU, VSTU, OSKU	
• 20.9.-25.9.	KUA, KOVU, DUNU	
• 22.9.	FKPU	


Fiberoptic transceiver
Power
Rx
Tx
OPTO
RS232

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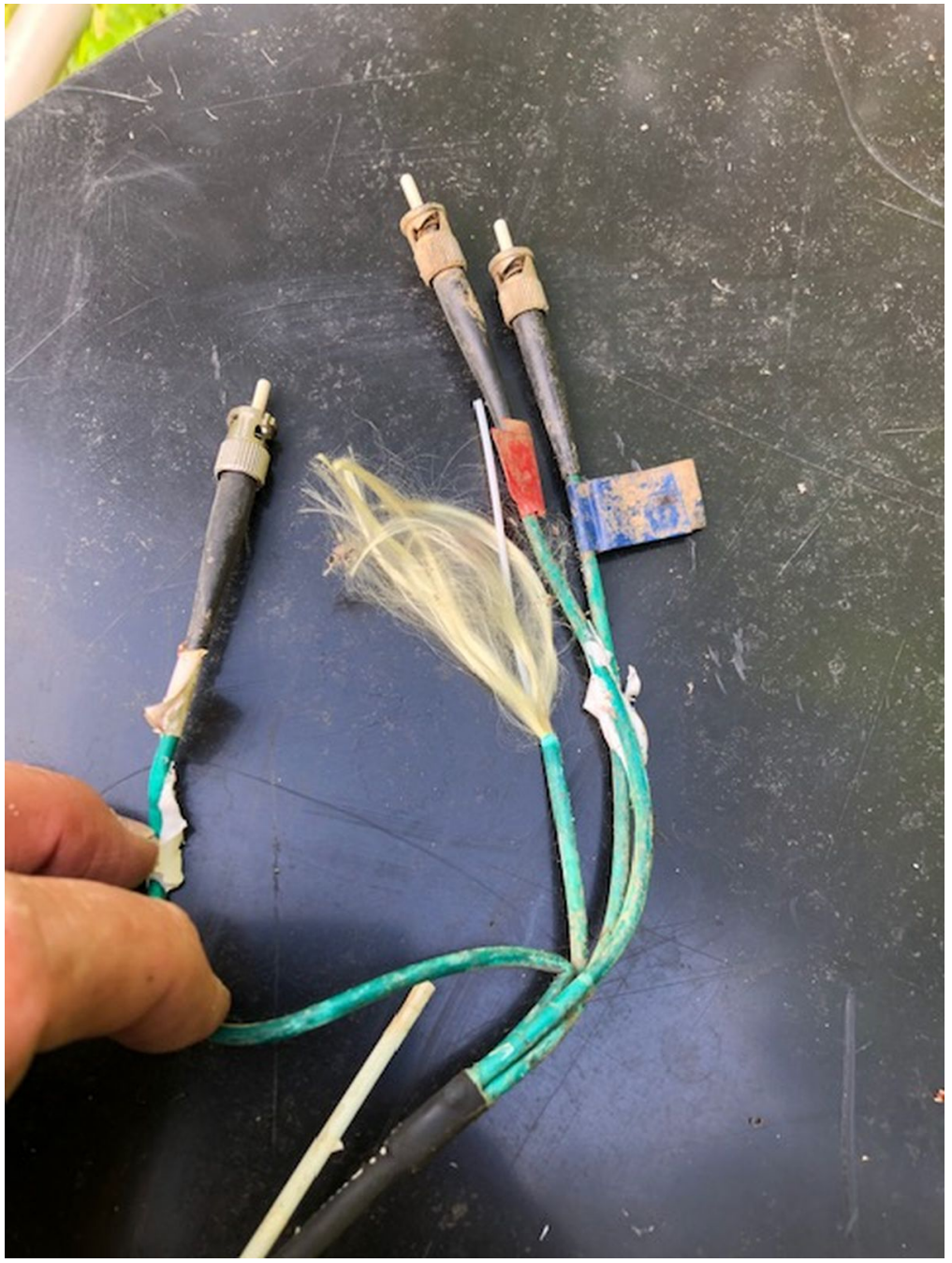

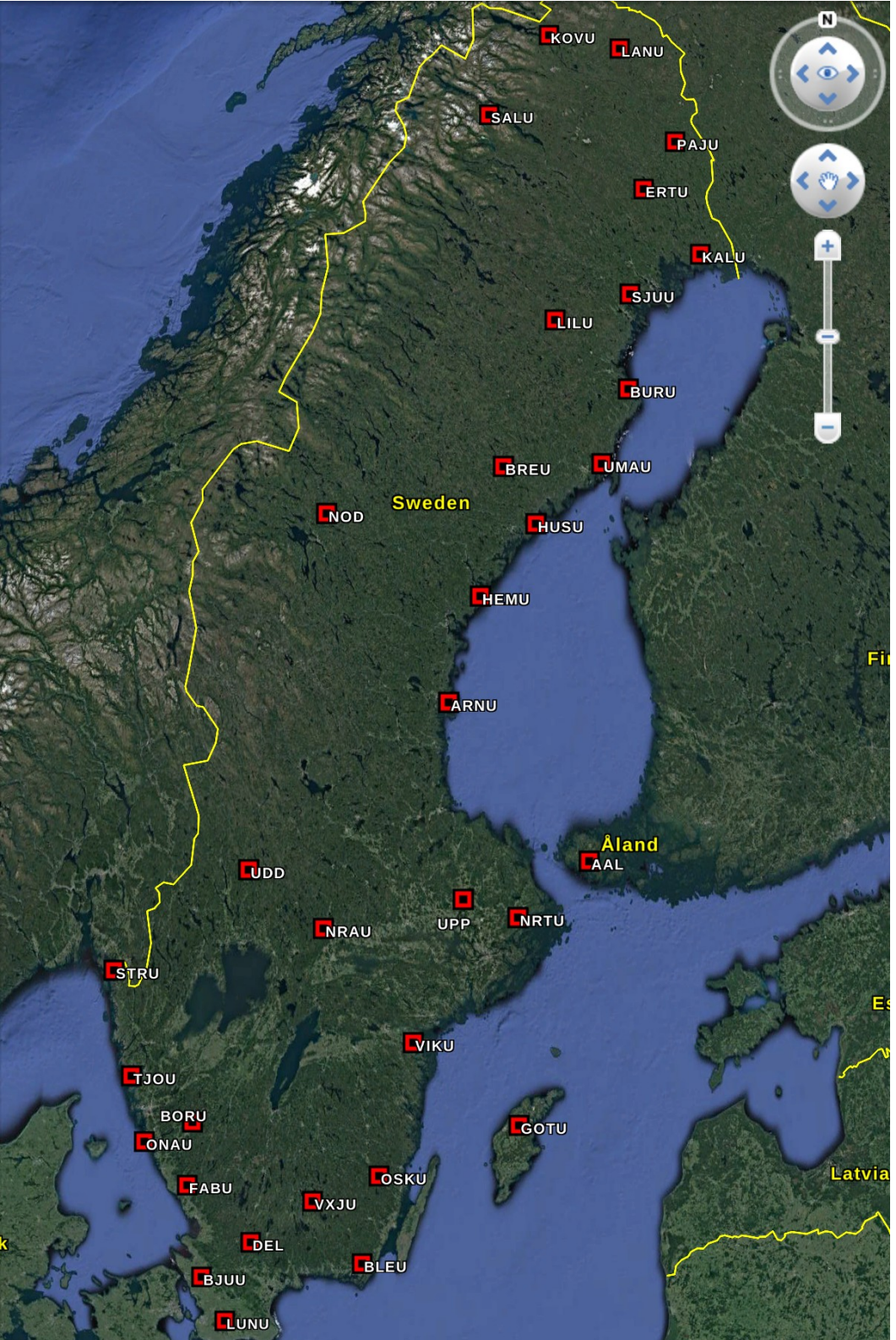

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33 SNSN stations sending realtime data via seedlink to Orfeus (10) and directly to DK (12), NO (8), FI (12) and GE (9)

aal	AAL	2002	Åland
arn	ARNU	2000	Hudiksvall
ask	ASKU	2002	Askersund
bac	BACU	2001	Vittinge
bju	BJUU	2008	Bjuv
ble	BLEU	2002	Karlskrona
bor	BORU	2006	Borås
bog	BOGU	2019	Bogesund
bre	BREU	2000	Bjurholm
bur	BURU	2000	Skellefteå
byx	BYXU	2002	Öland
del	DEL	1969	Delary
dun	DUNU	2003	Gällivare
eks	EKSU	2002	Eksjö
ert	ERTU	2004	Lansjärv
esk	ESKU	2002	Eskilstuna
fab	FABU	2006	Falkenberg
fal	FALU	2002	Falun
fib	FIBU	2009	Fiby
fin	FINU	2005	Årjäng
fkp	FKPU	2006	Falköping
fla	FLA	2012	Flarken
fly	FLYU	2002	Österbybruk
for	FORU	2005	Forsmark
gno	GNOU	2006	Gnosjö
got	GOTU	2002	Gotland
gra	GRAU	2001	Öregrund
har	HARU	2006	Harads
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hus	HUSU	2000	Örnsköldsvik
igg	IGGU	2000	Gävle
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lan	LANU	2004	Lannavaara
lil	LILU	2000	Jörn
lnk	LNKU	2002	Linköping
lun	LUNU	2008	Lund
mas	MASU	2003	Masugnsbyn
nas	NASU	2006	Värmlandsnäs
nik	NIKU	2003	Nikkaluokta
nor	NOD	1998	Norderåsen
nra	NRAU	2002	Nora
nrt	NRTU	2002	Norrtälje
nyn	NYNU	2002	Nynäshamn
ode	ODEU	2012	Burträsk
ona	ONAU	2010	Onsala
osk	OSKU	2002	Oskarshamn
ost	OSTU	2001	Horsskog
paj	PAJU	2004	Pajala
rat	RATU	2011	Ratekjokk
rot	ROTU	2000	Edsbyn
sal	SALU	2003	Saltoluokta
sju	SJUU	2000	Luleå
sol	SOLU	2000	Sollefteå
sto	STOU	2012	Storbäcken
str	STRU	2006	Strömstad
sva	SVAU	2000	Svanaliden
tjo	TJOU	2006	Tjörn
udd	UDD	1966	Uddeholm
uma	UMAU	2002	Umeå
up1	UPP	1904	Uppsala
van	VANU	2006	Vänersborg
vik	VIKU	2002	Vikbolandet
vst	VSTU	2002	Västervik
vxj	VXJU	2001	Växjö

Waveform plots, system responses for SNSN stations

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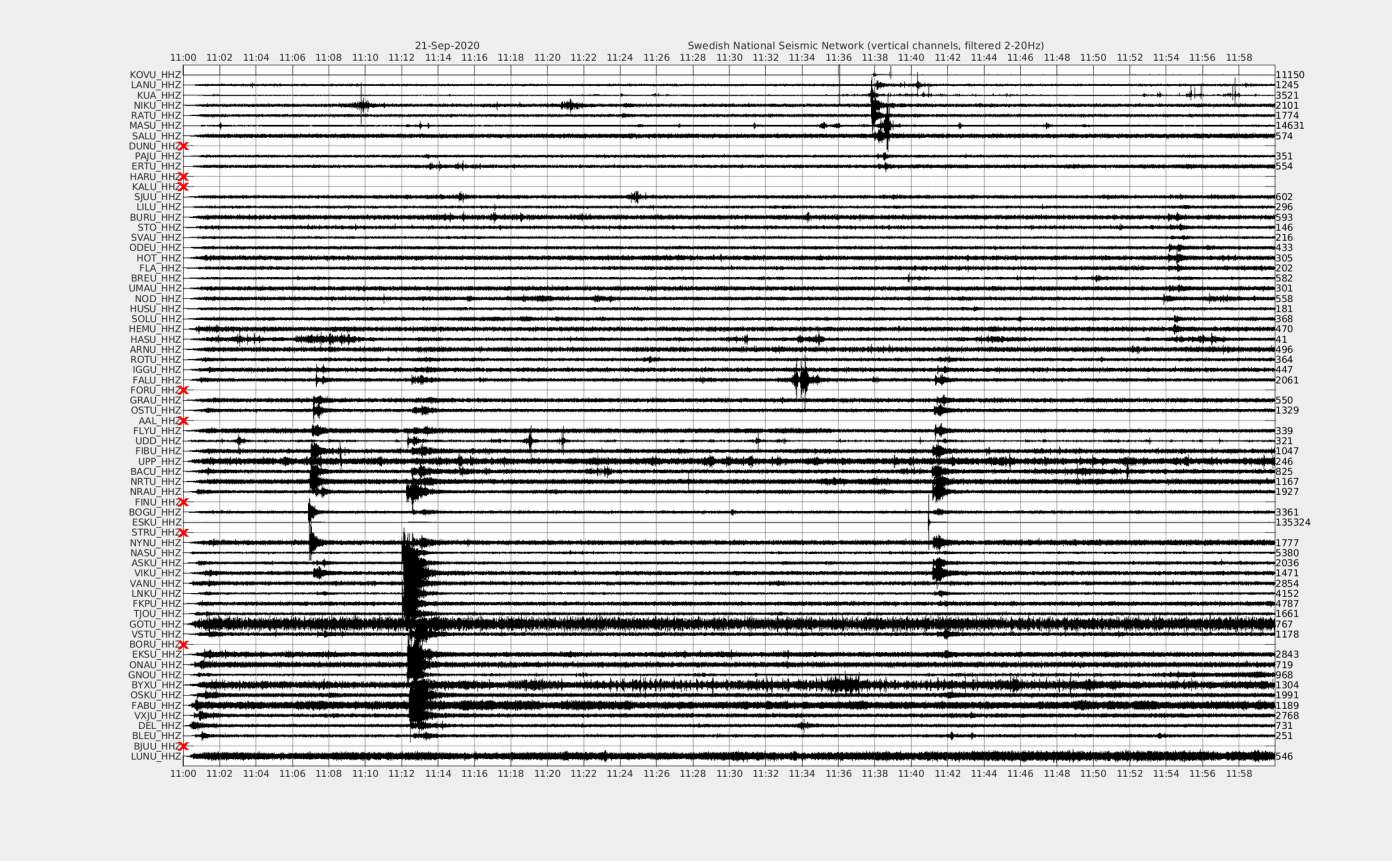
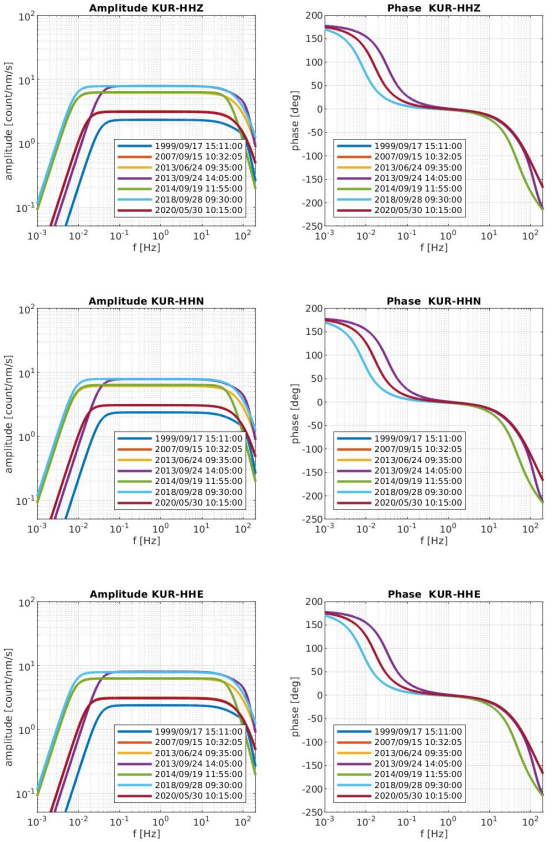
- Daily short- and long-period helicorder plots (instrument-corrected) for the last 2 days
  http://www.snsn.se/mro/helicorder/
- Hourly short and long-period overviews for all z-channels of SNSN stations (current hour updated every 2 min, latest 14 days in subfolders)
  http://www.snsn.se/mro/waveformplots/SP.jpg
  http://www.snsn.se/mro/waveformplots/LP.jpg
- Current and historical system responses (plots, FAP, and PAZ files)
  http://www.snsn.se/mro/resp/





Simplified Data Flow and Processing Flow for regional Monitoring

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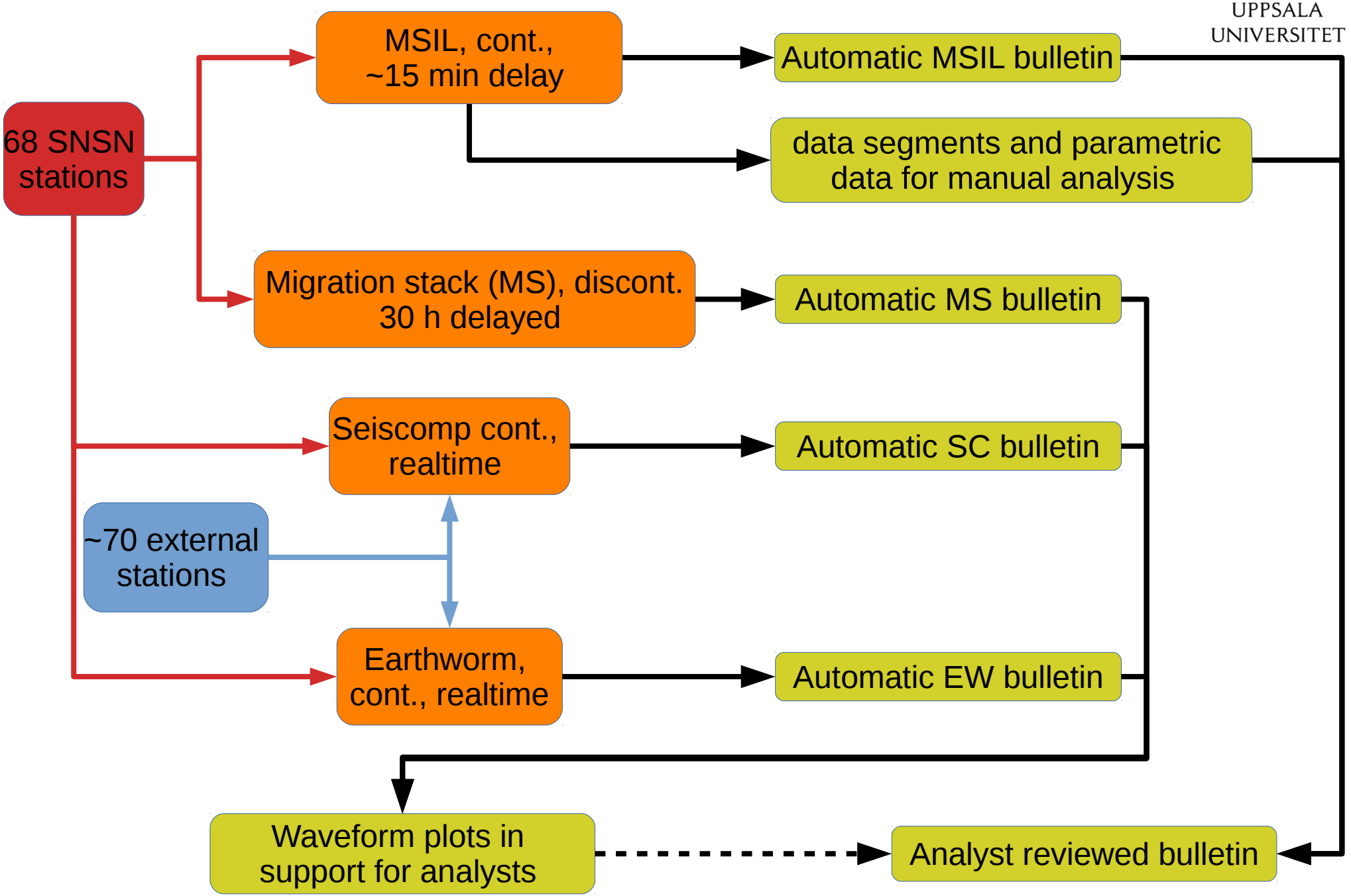

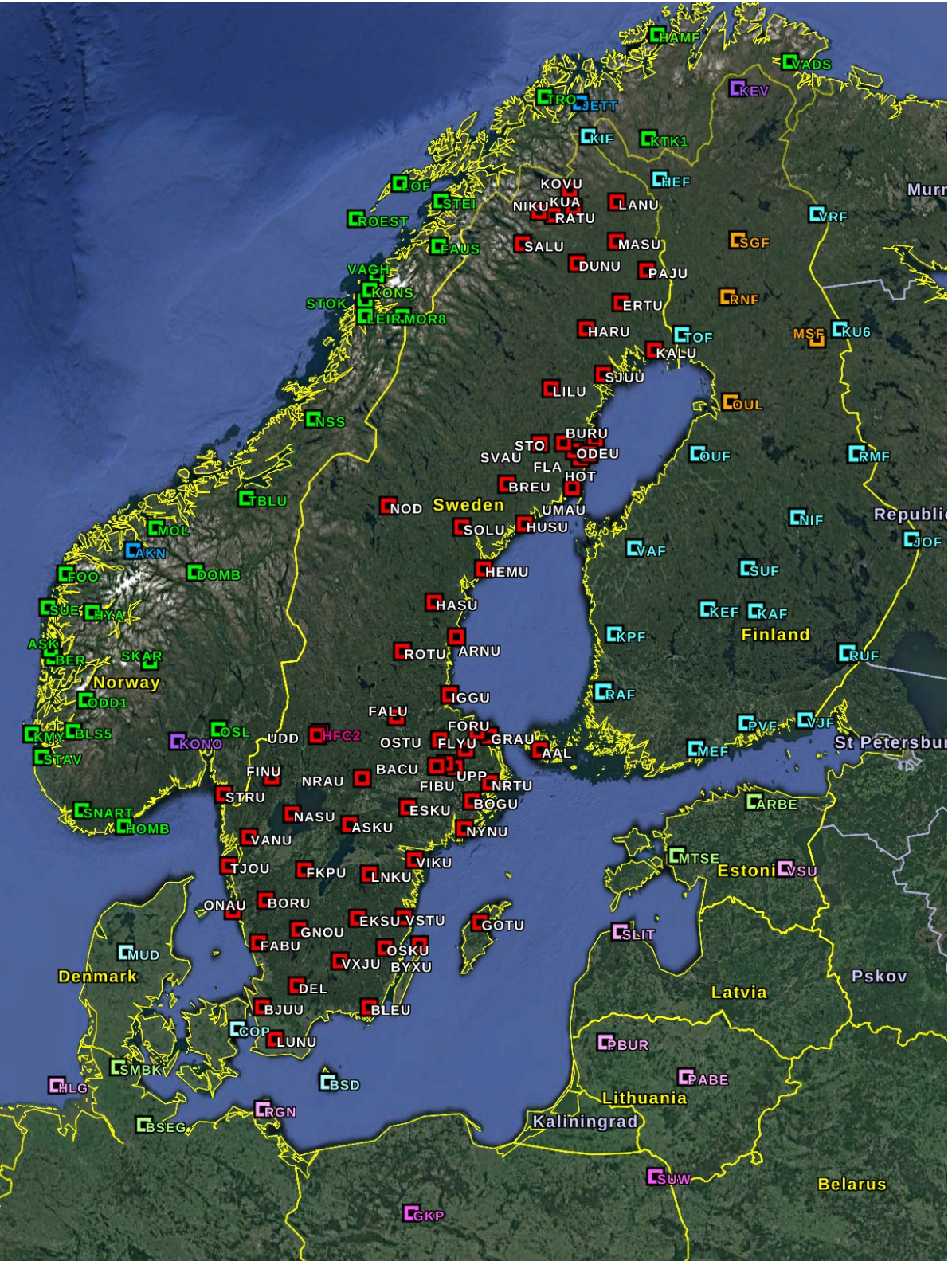

Station network for regional automatic monitoring

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Seiscomp and Earthworm are using SNSN and external stations (~140)

MSIL and MS are using SNSN stations only

Manual analysis only on SNSN data

68	UP	Swedish National Seismic Network
3	DK	Danish Seismological Network
2	EE	Estonian Seismic Network
4	FN	Northern Finland Seismological Network
6	GE	Geofon
3	GR	German Regional Seismic Network
9	HE	Finnish National Seismic Network
1	HF	Hagfors
3	IU	IRIS/USGS
2	NO	Norwegian Seismic Array
32	NS	Norwegian National Seismic Network
7	PL	Polish Seismological Network

140 stations

Compared to 2019 we added about 15 stations

Data processing at SNSN (1)

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Seiscomp3/4
- 2 instances are running in realtime
- Global monitoring of big events (rapid response to Swedish authorities)
- regional monitoring (realtime monitoring of Swedish events)
- requires P-phases from at least 6 stations
- provides automatic bulletins (and alert messages for big global events)

Earthworm
- one instance running in realtime
- realtime regional monitoring
- requires P-phases from at least 4 neighboring (radius 200 km) stations
- provides automatic bulletin

- Both, Seiscomp as well as Earthworm are running very stable and provide reliable near real-time solutions for most events (earthquakes and blasts).
- Independent, sometimes complementary (smaller events might be missed by either SC or EW)
- For any felt event, we have a reasonably good location so that we can respond immediately to calls from press and private persons.
- However, there are problems with very emergent signals typically associated with production in Kiruna mine.

Data processing at SNSN (2)

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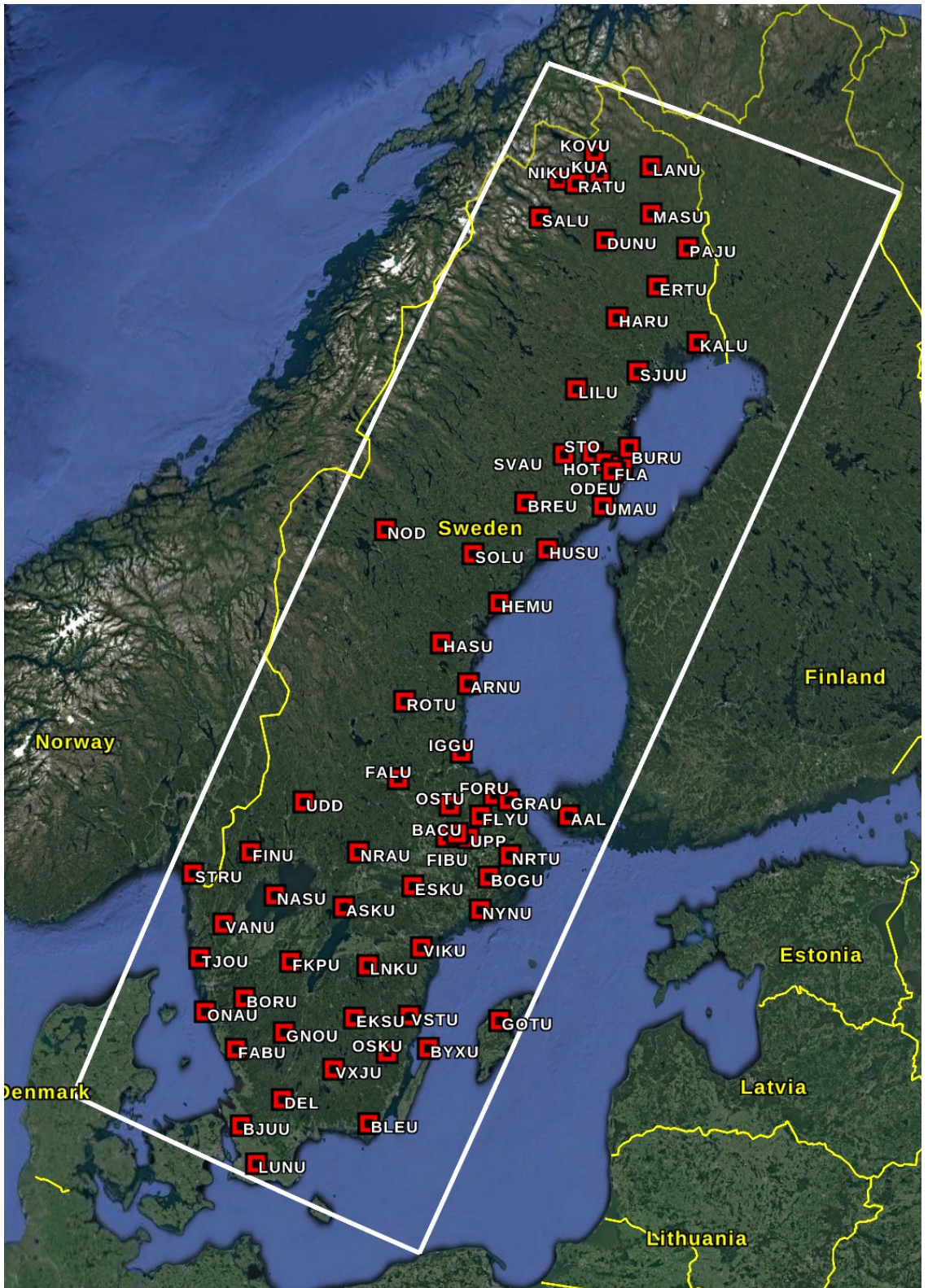
MultiSIL:

- Runs continously with a time lag of 15 min at SNSN
- Detection processing and phase parameter determination (time, amplitude, duration, azimuth, incidence angle) for each SNSN station
- Phase association and localization (2 stations / 4 phases minimum)
- Automatic bulletin
- provides relevant segmented data for analyst software
- provides automatic parametric event data for analyst software

Migration-Stack (*)

- Runs once per day processing the waveform data of the day before
- Computationally expensive (needs about 3.5 h to process 24 hours of data)
- 2x2x2 km traveltime grid for Sweden (1D velocity model)
- Computation of STA/LTA-traces for each channel of the SNSN stations
- STA/LTA-traces are time shifted according to the theoretical P (and S) arrival times from the station to a subsurface grid (32x32x32km) point and stacked.
- The P (and S) stack is evaluated and - in case a threshold is superceeded - the associated gridcells and origin time is flagged
- Then the migration is redone for those cells on a 8x8x8km grid and eventually on a 4x4x4km grid in order to refine the location.
- The location and origin time accuracy is determined from the width of the stack in space and time

(*) Frederic Wagner, Toward fully automatic earthquake detection and processing for tomography in the Hengill area, PhD Thesis, Uppsala University, 2019)



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Station network for regional automatic monitoring with MSIL and MS

MS (Migration Stack)
Computation of STA/LTA for each channel
STA,LTA time windows 1s and 8s, respectively
frequency band: 3-30 Hz

Total monitored volume
520x1550x46km

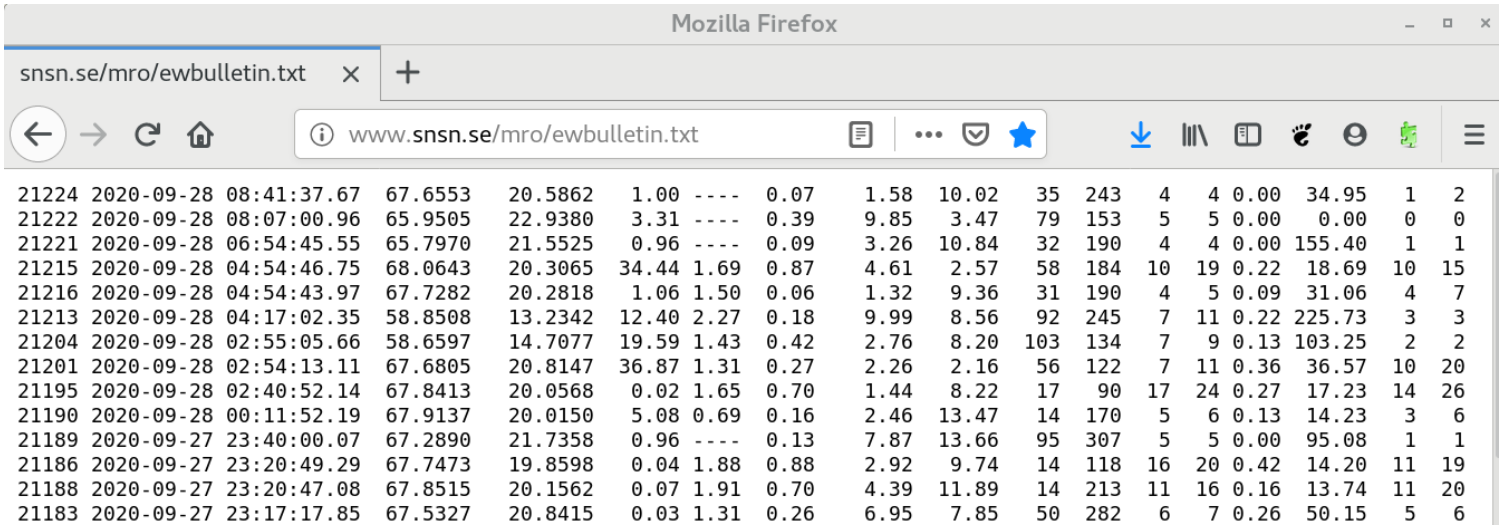
Tabulated P and S traveltimes on a 2 km grid

Stacking cell size 32^3 km, 8^3 km and 4^3 km

maximum stack radius: 100 km
minimum number of stations: 8

numerical intensive: 3.5 hours computation time for 24 hours of data

- Realtime Earthworm bulletin (events of the current 7 days)
  http://www.snsn.se/mro/ewbulletin.txt




```
21224 2020-09-28 08:41:37.67  67.6553   20.5862    1.00 ----  0.07    1.58  10.02   35  243   4   4 0.00  34.95   1   2
21222 2020-09-28 08:07:00.96  65.9505   22.9380    3.31 ----  0.39    9.85   3.47   79  153   5   5 0.00   0.00   0   0
21221 2020-09-28 06:54:45.55  65.7970   21.5525    0.96 ----  0.09    3.26  10.84   32  190   4   4 0.00 155.40   1   1
21215 2020-09-28 04:54:46.75  68.0643   20.3065   34.44 1.69  0.87    4.61   2.57   58  184  10  19 0.22  18.69  10  15
21216 2020-09-28 04:54:43.97  67.7282   20.2818    1.06 1.50  0.06    1.32   9.36   31  190   4   5 0.09  31.06   4   7
21213 2020-09-28 04:17:02.35  58.8508   13.2342   12.40 2.27  0.18    9.99   8.56   92  245   7  11 0.22 225.73   3   3
21204 2020-09-28 02:55:05.66  58.6597   14.7077   19.59 1.43  0.42    2.76   8.20  103  134   7   9 0.13 103.25   2   2
21201 2020-09-28 02:54:13.11  67.6805   20.8147   36.87 1.31  0.27    2.26   2.16   56  122   7  11 0.36  36.57  10  20
21195 2020-09-28 02:40:52.14  67.8413   20.0568    0.02 1.65  0.70    1.44   8.22   17   90  17  24 0.27  17.23  14  26
21190 2020-09-28 00:11:52.19  67.9137   20.0150    5.08 0.69  0.16    2.46  13.47   14  170   5   6 0.13  14.23   3   6
21189 2020-09-27 23:40:00.07  67.2890   21.7358    0.96 ----  0.13    7.87  13.66   95  307   5   5 0.00  95.08   1   1
21186 2020-09-27 23:20:49.29  67.7473   19.8598    0.04 1.88  0.88    2.92   9.74   14  118  16  20 0.42  14.20  11  19
21188 2020-09-27 23:20:47.08  67.8515   20.1562    0.07 1.91  0.70    4.39  11.89   14  213  11  16 0.16  13.74  11  20
21183 2020-09-27 23:17:17.85  67.5327   20.8415    0.03 1.31  0.26    6.95   7.85   50  282   6   7 0.26  50.15   5   6
```

Columns:

1 IDnumber
2 oridate
3 oritime
4 lat(deg)
5 lon(deg)
6 depth(km)
7 mag(ML)
8 timeresidual (sec)
9 xerr (formal horizontal error, km)
10 zerr (formal vertical error, km)
11 mindist (distance to the closest station in km)
12 azigap (maximum azimuthal gap in deg)
13 npicks (number of P and S-phases with weight > 0.1)
14 nphase (number of phases)
15 mag_err (magnitude error)
16 mag_mindist (distance to closest station that was used for magnitude estimation)
17 mag_nstat (number of stations for magnitude estimation)
18 mag_nchan (number of horizontal channels for magnitude estimation)

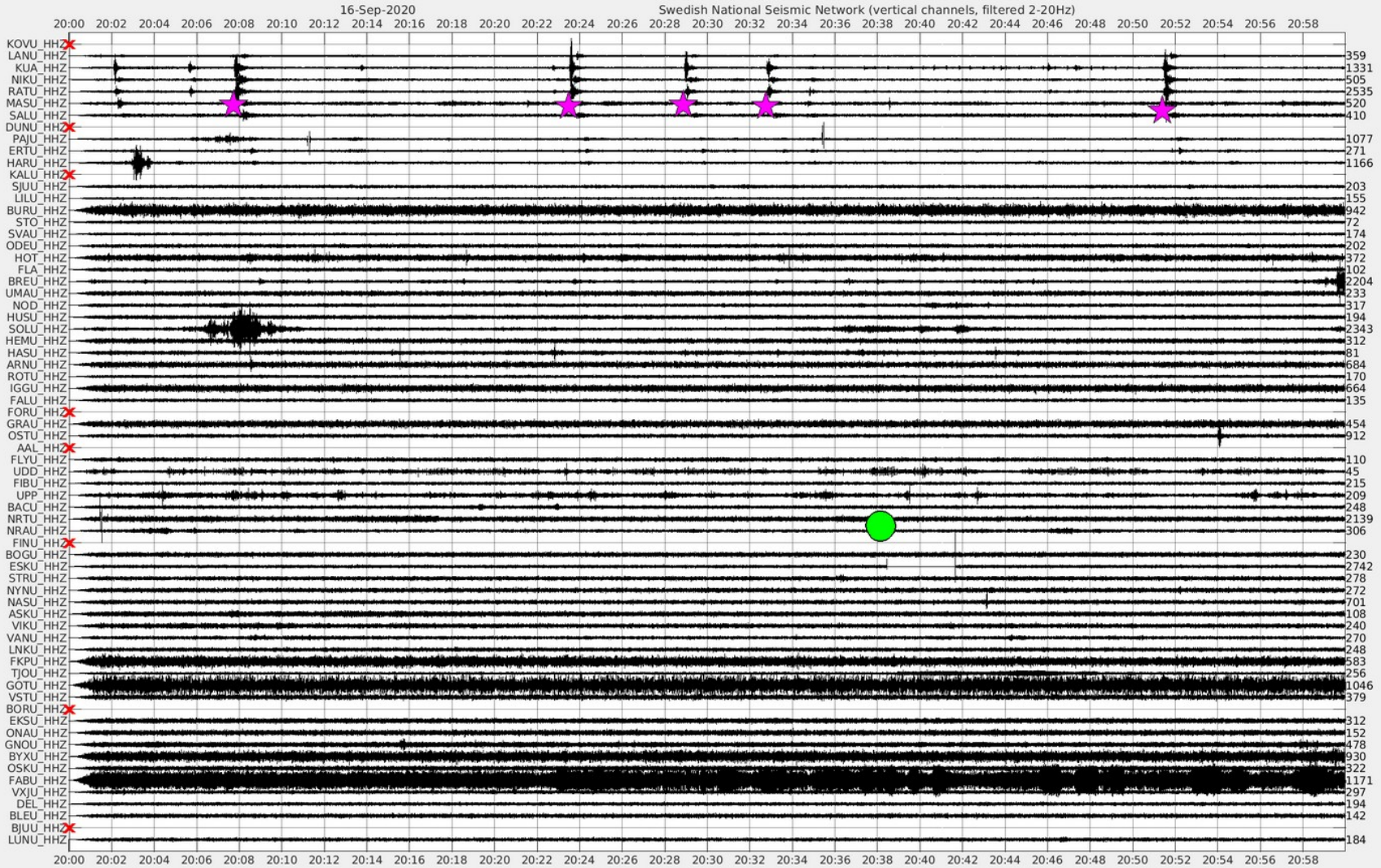
snsn.se/mro/ewbulletin.txt | waveform bulletins of SNSN

www.snsn.se/inni/wavebull/

waveform bulletins of SNSN stations

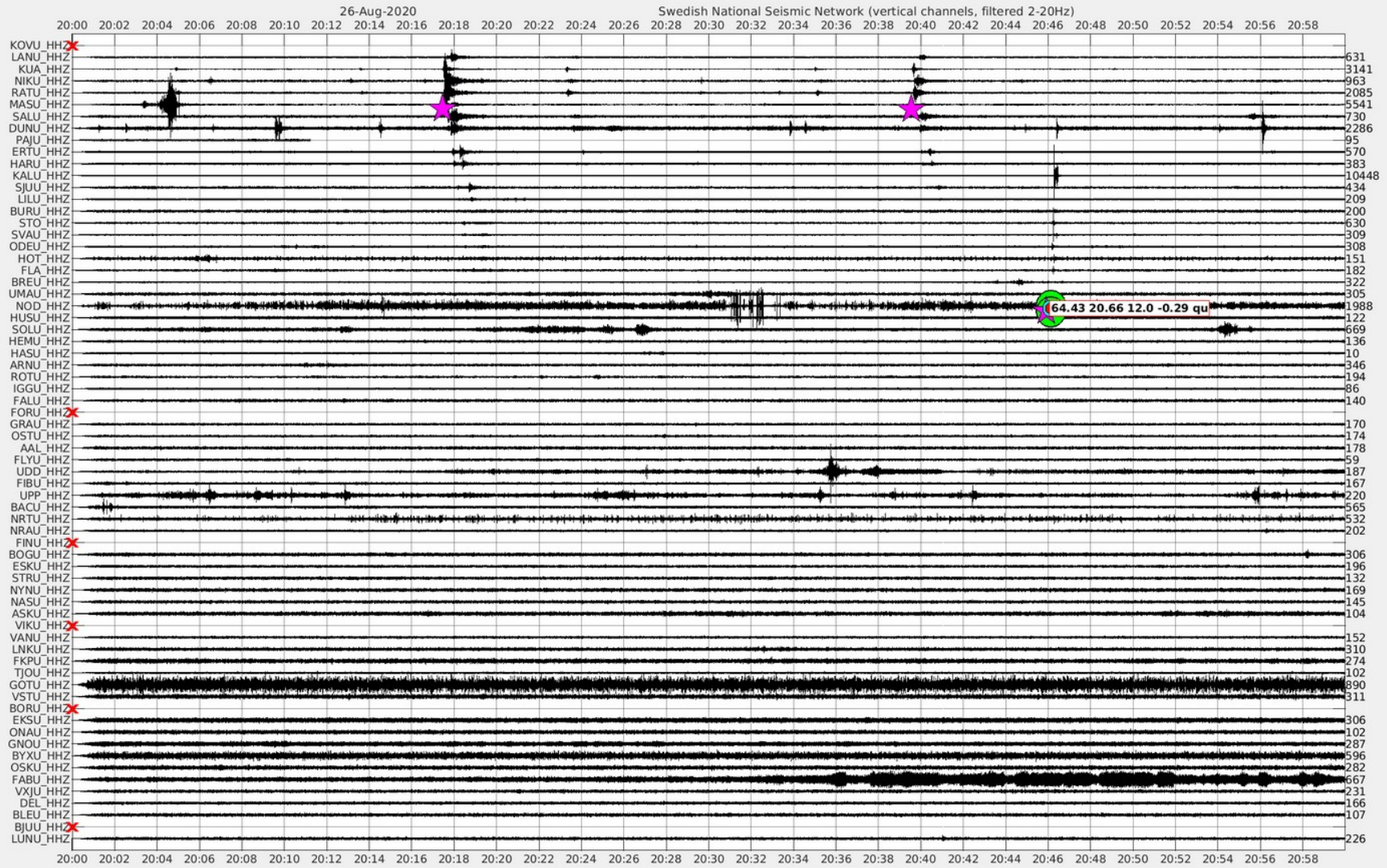
Example – 5 events detected by MS, 1 spurious event by MSIL

Date: - 16 / 09 / 2020 + **Hour:** - 20 + **Legend:** SIL migration-stack seiscomp3 earthworm analyst



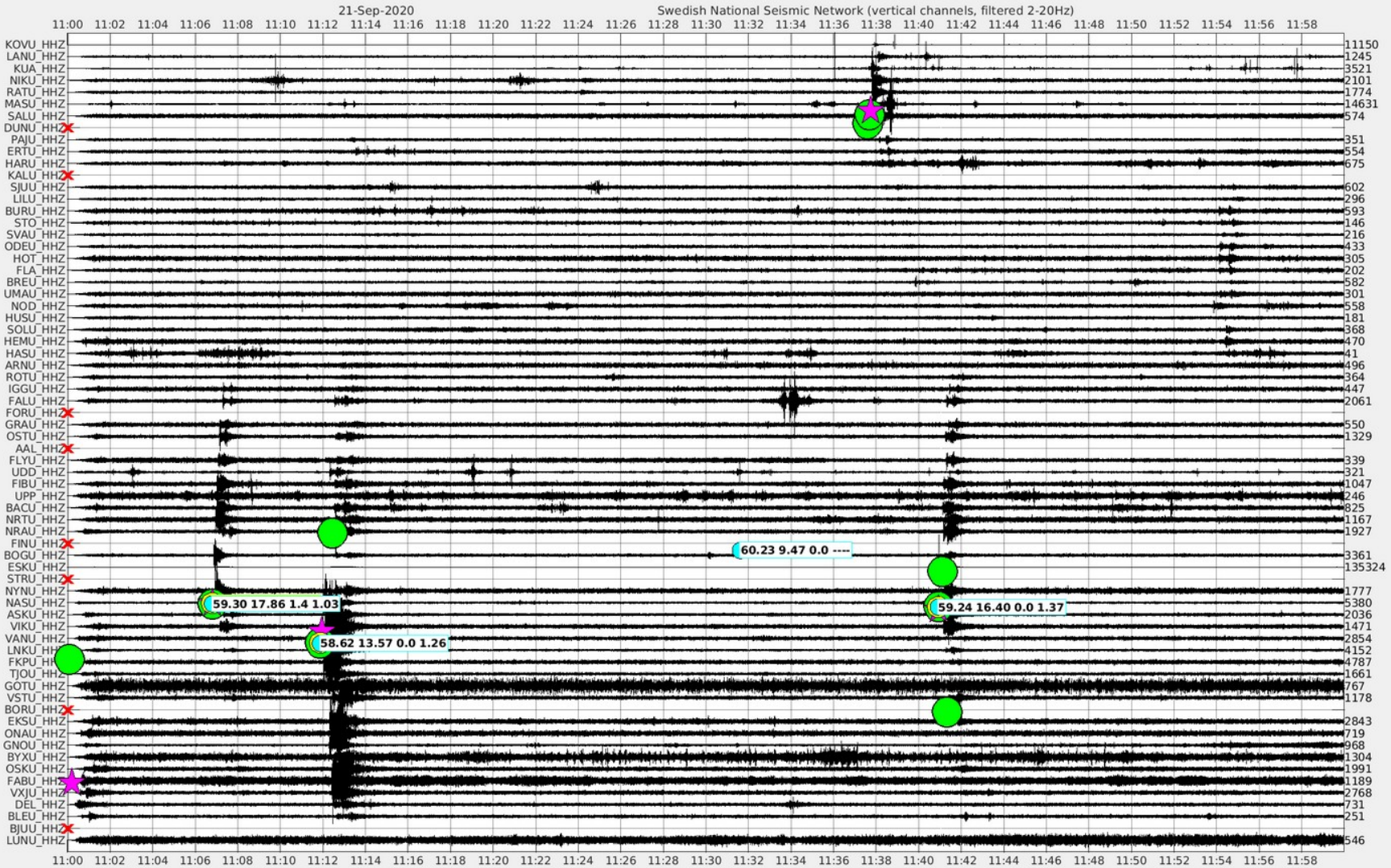
waveform bulletins of SNSN stations Example – 2 events detected by MS, 1 event detected by all methods

Date: - 26 / 08 / 2020 + **Hour:** - 20 + **Legend:** SIL migration-stack seiscomp3 earthworm analyst



waveform bulletins of SNSN stations Example – 4 events

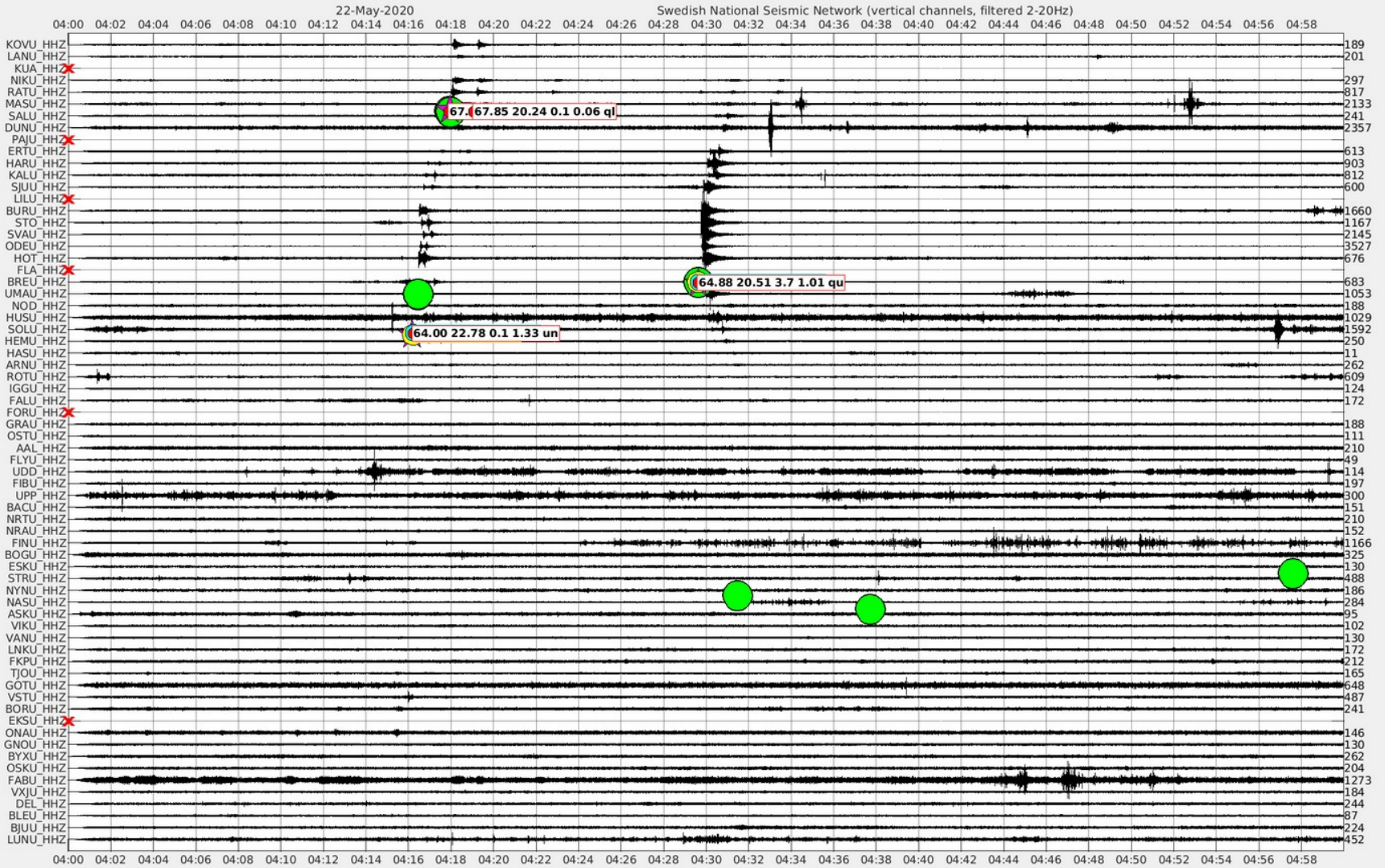
Date: - 21 / 09 / 2020 + **Hour:** - 11 + **Legend:** SIL migration-stack seiscomp3 earthworm analyst



waveform bulletins of SNSN stations

Example – 3 automatic determined events – 4 analyts reviewed events

Date: - 22 / 05 / 2020 + **Hour:** - 04 + **Legend:** SIL migration-stack seiscomp3 earthworm analyst



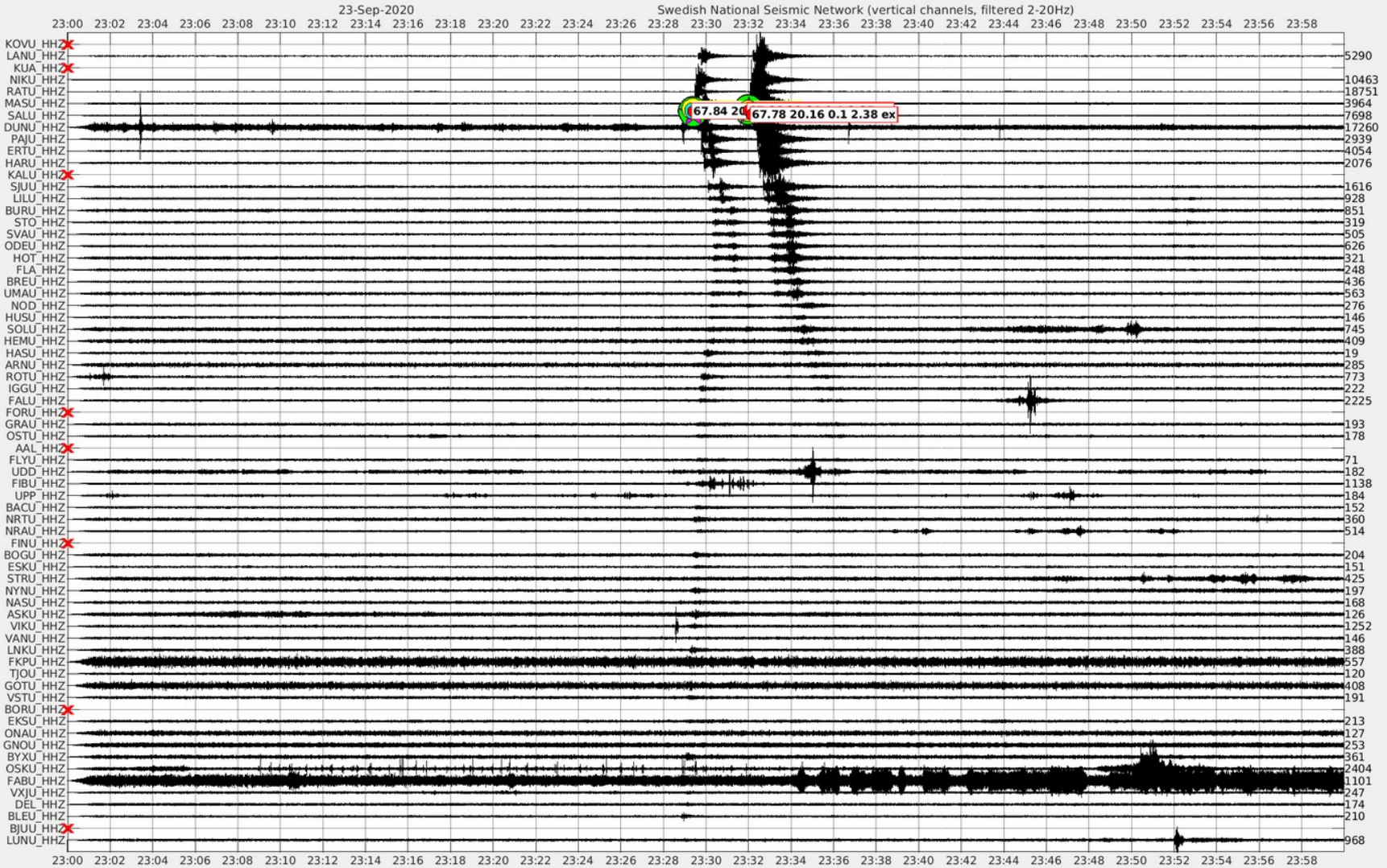
snsn.se/mro/ewbulletin.txt | waveform bulletins of SNSN

www.snsn.se/inni/wavebull/

waveform bulletins of SNSN stations

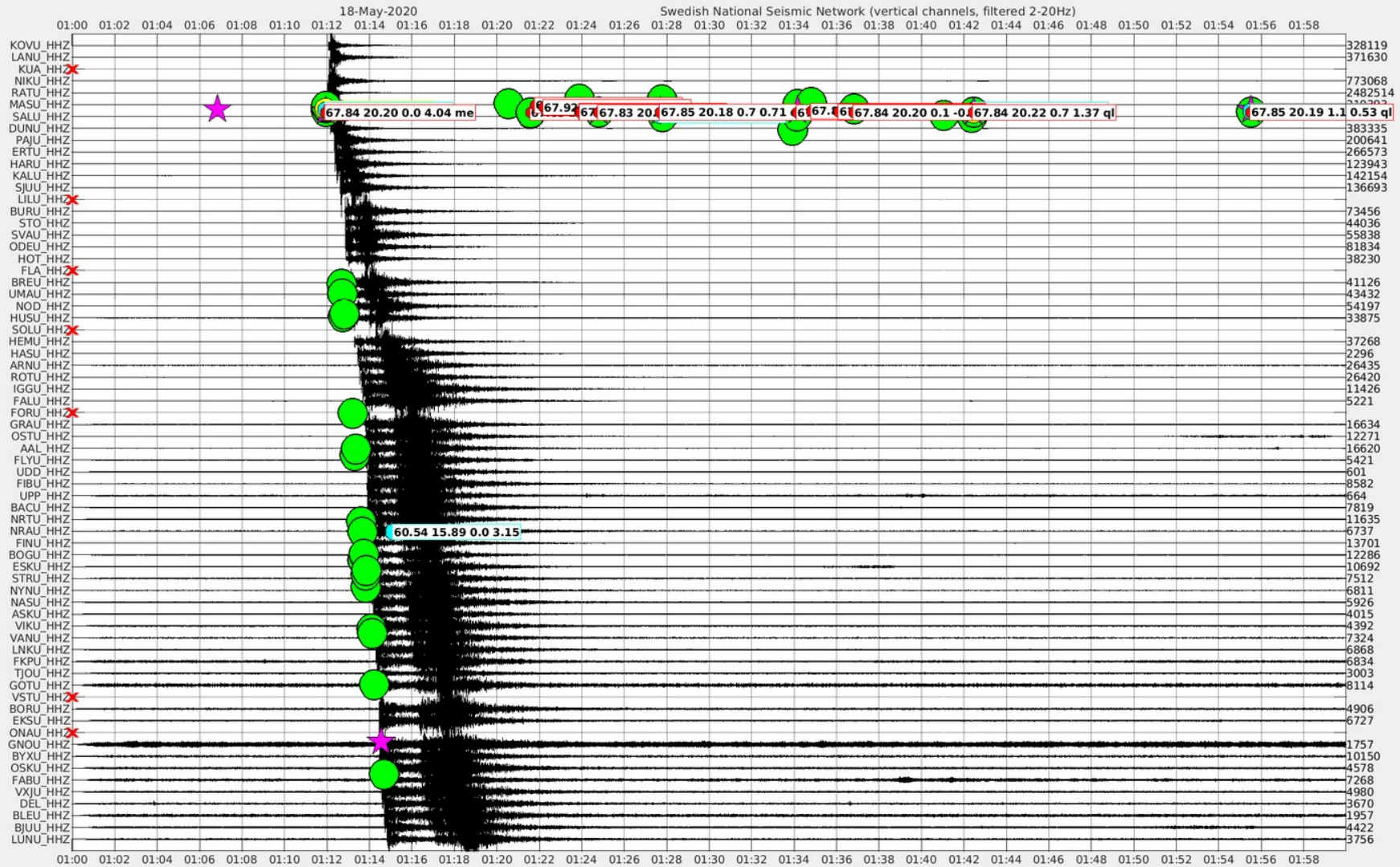
Example – 2 production blasts in Kiruna

Date: - 23 / 09 / 2020 + **Hour:** - 23 + **Legend:** SIL migration-stack seiscomp3 earthworm analyst



waveform bulletins of SNSN stations Example –Kiruna mining-induced earthquake + aftershocks

Date: - 18 / 05 / 2020 + **Hour:** - 01 + **Legend:** SIL migration-stack seiscomp3 earthworm analyst

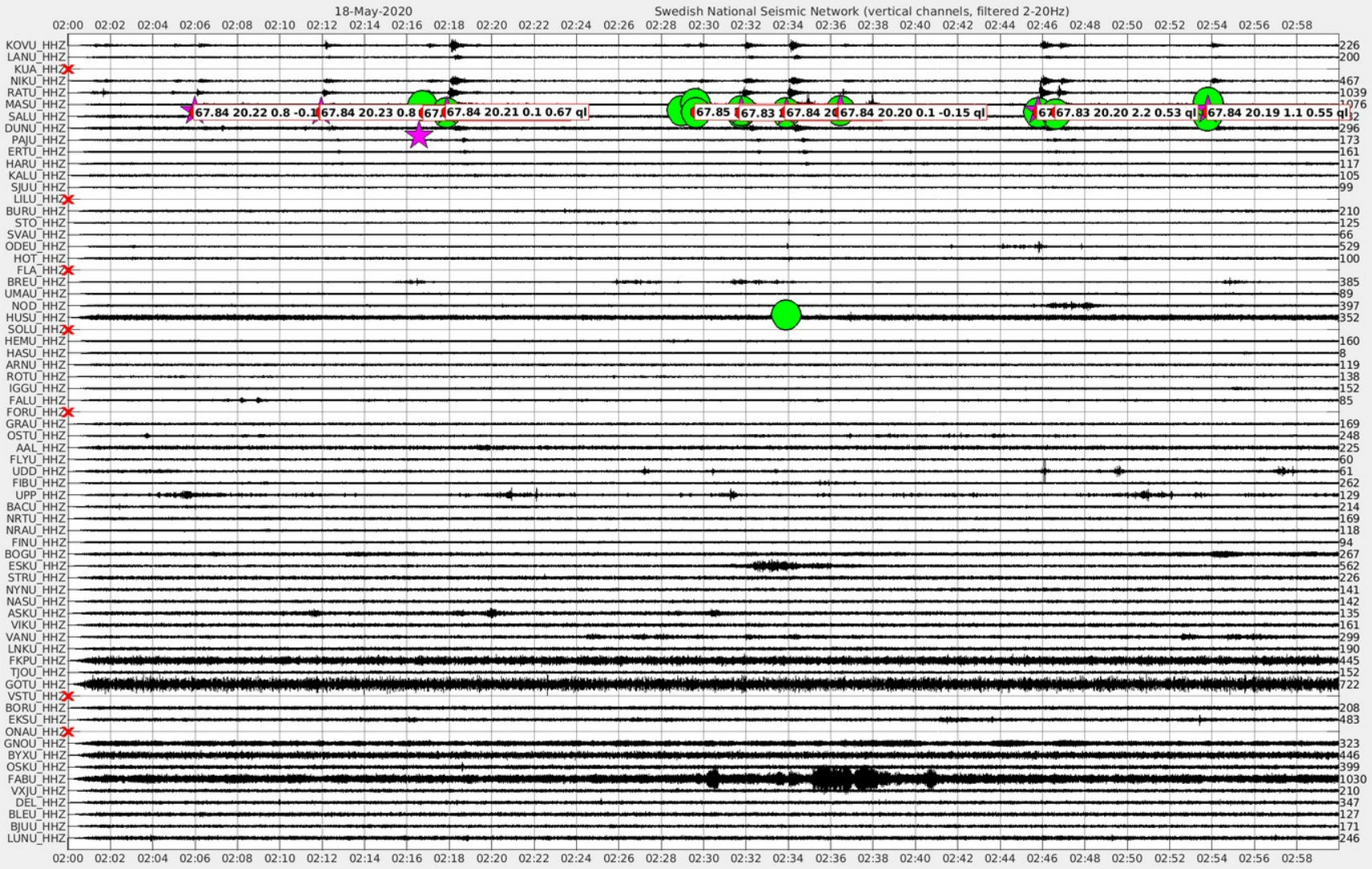


snsn.se/mro/ewbulletin.txt | waveform bulletins of SNSN

www.snsn.se/inni/wavebull/

waveform bulletins of SNSN stations Example – more Kiruna aftershocks

Date: - 18 / 05 / 2020 + **Hour:** - 02 + **Legend:** SIL migration-stack seiscomp3 earthworm analyst



Outlook

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- Upgrade remaining station computers (new hardware or new OS)
- Replace old GPSes
- Merge automatic bulletins
- Interface automatic bulletins with analyst software (Lookimp or equivalent software)
- Automatic discrimination between earthquakes and blasts
- Design and implement new SNSN web pages