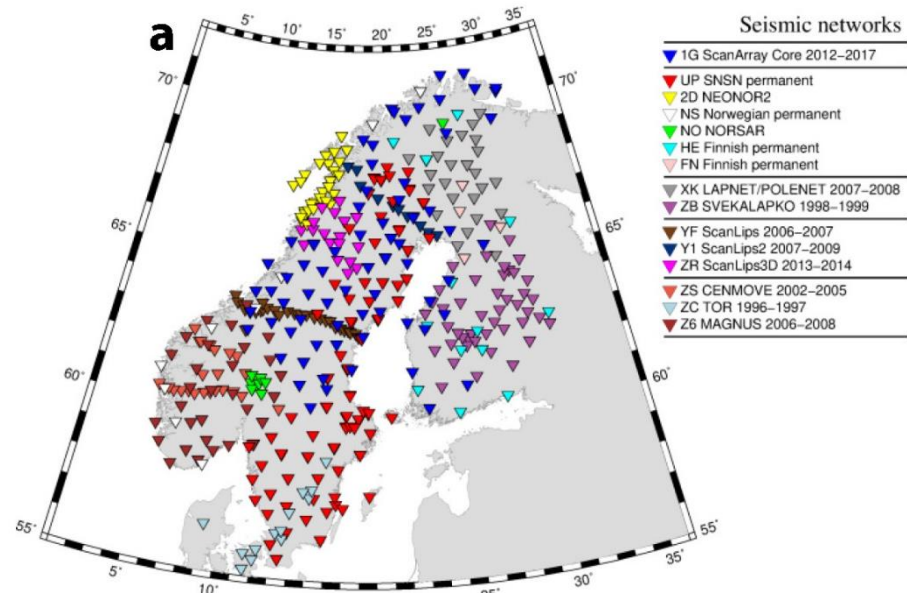
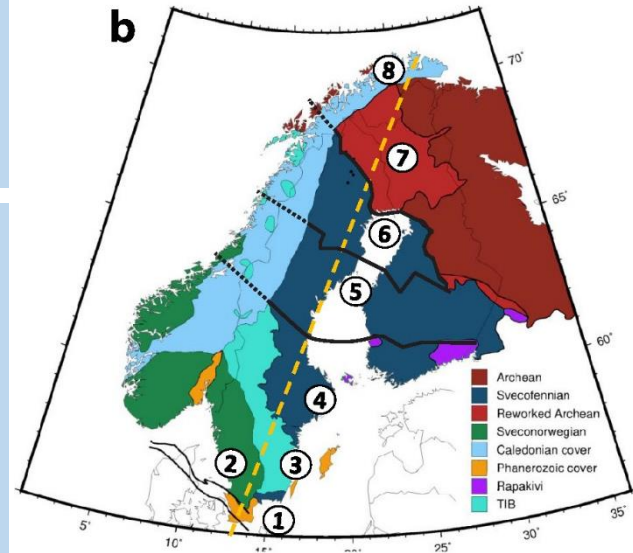
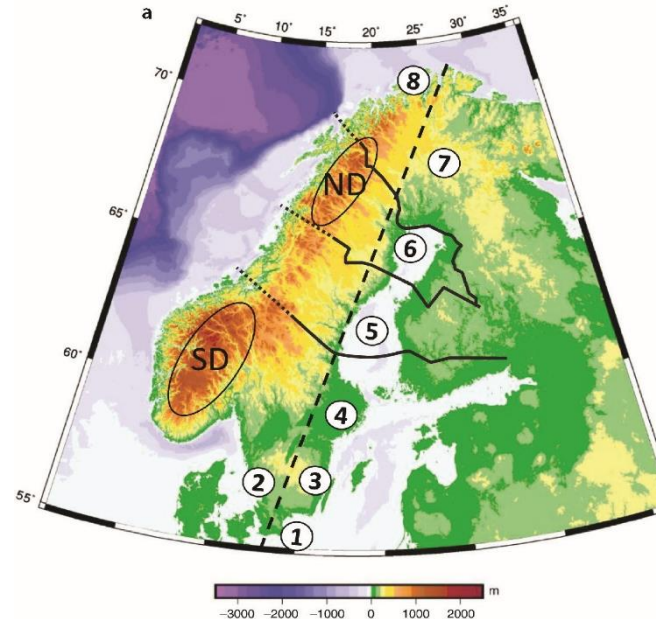
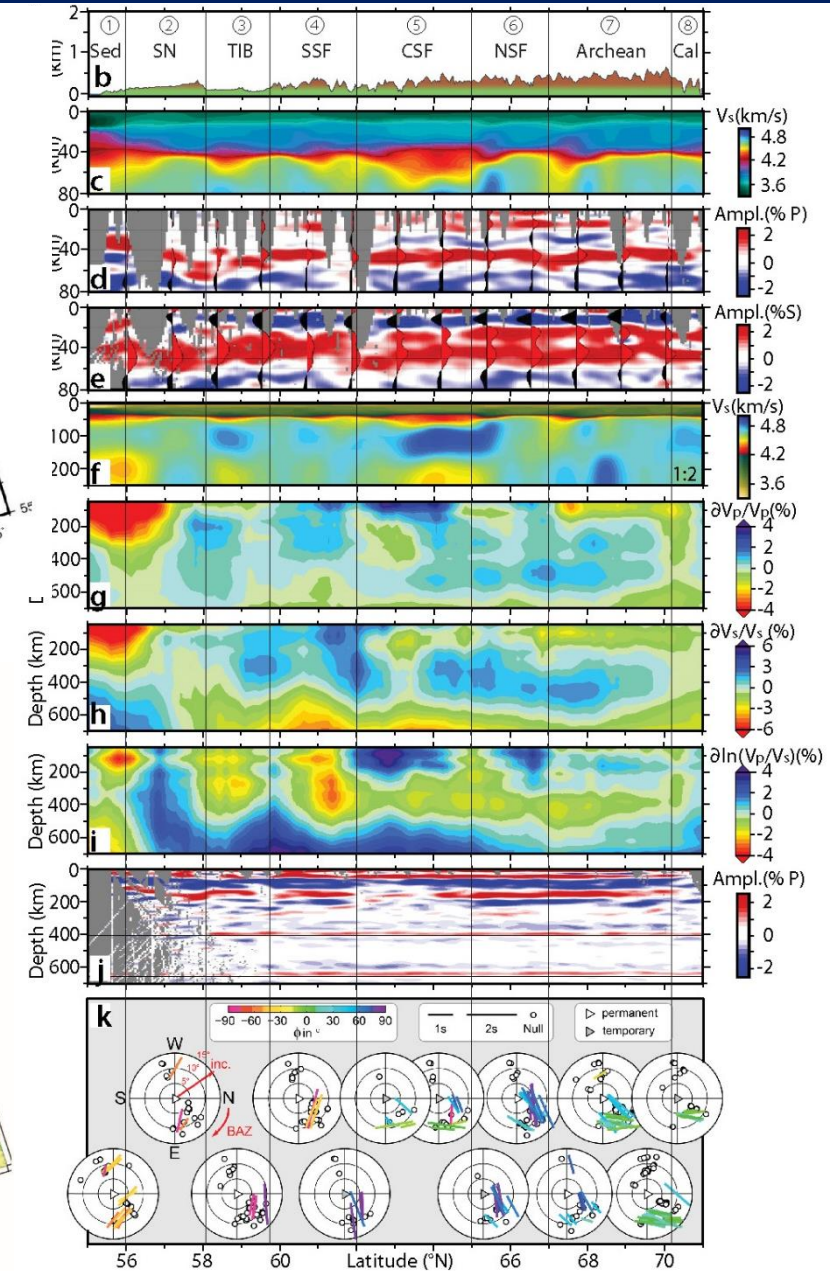


ScanArray - Seismological study of the connection between topographic change and deep structure in Fennoscandia

H. Thybo, N. Bulut, M. Grund, A. Mauerberger,
A. Makushkina, I. Artemieva, N. Balling, O. Gudmundsson,
V. Maupin, L. Ottemøller, J. Ritter & F. Tilmann
Seismological Research Letters, in press

- The ScanArray international collaboration has acquired seismological data at 192 stations in NW Fennoscandia.
- The objective is to link deep and shallow structure and to provide new observation that may explain the enigmatic topography in W Fennoscandia, far from any plate boundary.
- Fennoscandia has now been covered by broad-band seismic data at a nominal station spacing of 50 km.
- Data is being interpreted by a variety of seismic analysis methods.



ScanArray - Seismological study of the connection between topographic change and deep structure in Fennoscandia

Thybo, H.^{1,2}, Bulut, N.¹, Grund, M.³, Mauerberger, A.^{4,5}, Makushkina, A.⁶, Artemieva, I.M.^{7,8}, Balling, N.⁹, Gudmundsson, O.¹⁰, Maupin, V.², Ottemøller, L.¹¹, Ritter, J.³, Tilmann, F.^{4,5}

¹Eurasia Institute of Earth Sciences, Istanbul Technical University, Turkey.

²Center for Earth Evolution and Dynamics (CEED), University of Oslo, Norway.

³Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

⁴Deutsches GeoForschungsZentrum(GFZ), Potsdam, Germany

⁵Freie Universität Berlin, Berlin, Germany

⁶Australian National University, Canberra, ACT, Australia,

⁷Department of Geophysics, Stanford University, California, USA.

⁸GEOMAR Helmholtz Center for Ocean Research, Kiel, Germany

⁹Aarhus University, Aarhus, Denmark

¹⁰Uppsala University, Uppsala, Sweden

¹¹University of Bergen, Bergen, Norway

Seismological Research letters, in press

Abstract

The Baltic Shield is located in northern Europe. It was formed by amalgamation of a series of terranes and microcontinents during the Archean to the Paleoproterozoic, followed by significant modification in Neoproterozoic to Paleozoic time. The Baltic Shield includes a high mountain range, the Scandes, along its western North Atlantic coast, despite being a stable craton located far from any active plate boundary.

The ScanArray international collaborative program has acquired broad band seismological data at 192 locations in the Baltic Shield during the period between 2012 and 2017. The main objective of the program is to provide seismological constraints on the structure of the lithospheric crust and mantle as well as the sublithospheric upper mantle. The new information will be applied to studies of how the lithospheric and deep structure affects observed fast topographic change and geological-tectonic evolution of the region. The recordings are of very high quality and are used for analysis by suite of methods, including P- and S-wave receiver functions for the crust and upper mantle, surface wave and ambient noise inversion for seismic velocity, body wave P- and S- wave tomography for upper mantle velocity structure, and shear-wave splitting measurements for obtaining bulk anisotropy of the upper and lower mantle. Here we provide a short overview of the data acquisition and initial analysis of the new data with focus on parameters that constrain the fast topographic change in the Scandes.

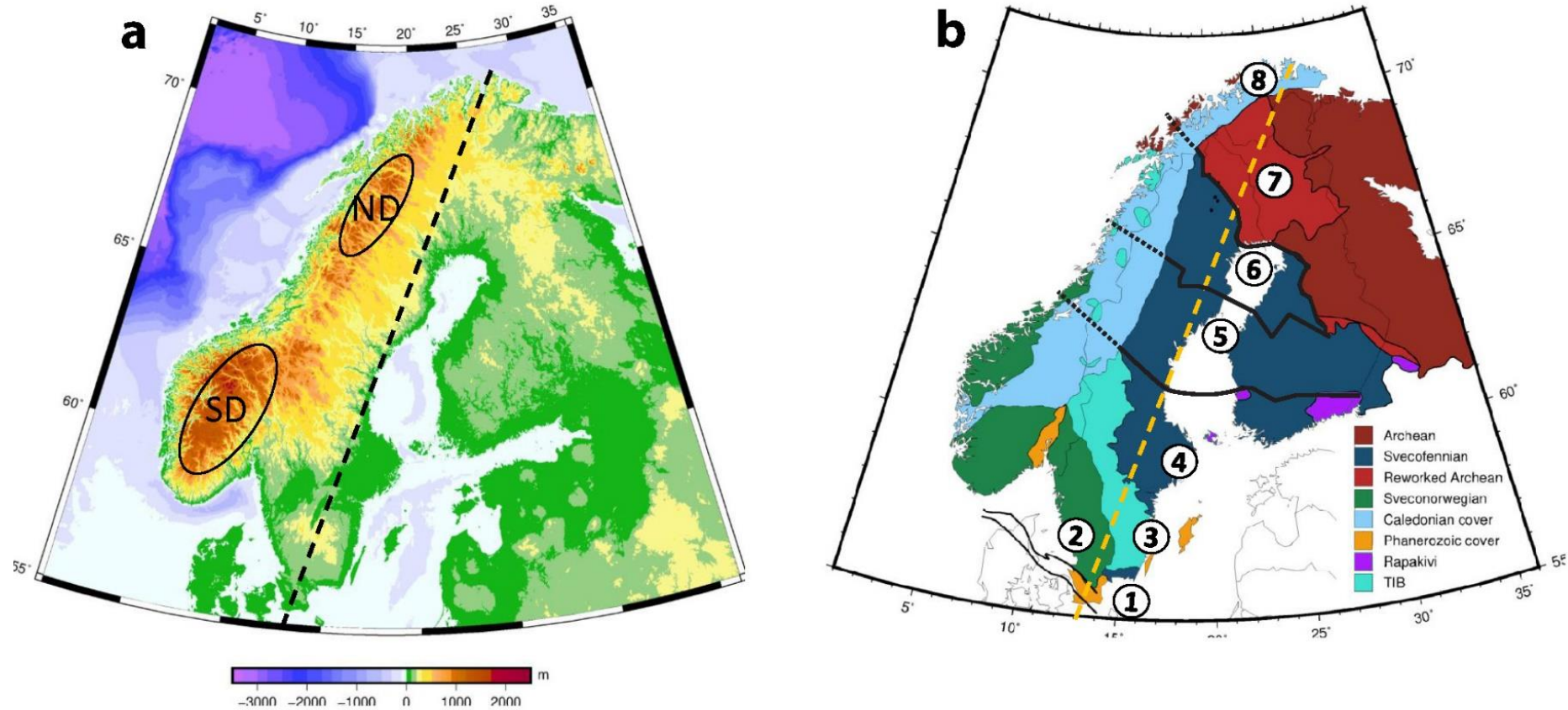


Figure 1. a) Hypsometric map of the Baltic Shield and surrounding areas. The Northern (ND) and Southern (SD) Dome of the Scandes mountain range are indicated.

b) Tectonic sketch map of the Baltic Shield [after *Gaal and Gorbatshev, 1987*]. Full and dotted straight lines divide the southern (4), central (5) and northern (6) domains of the Svecofennian province.

Stippled line (black in a and yellow in b) shows location of profile illustrated in Figure 4. Encircled numbers refer to segments of the profile as explained by color code in the legend and the three Svecofennian domains.

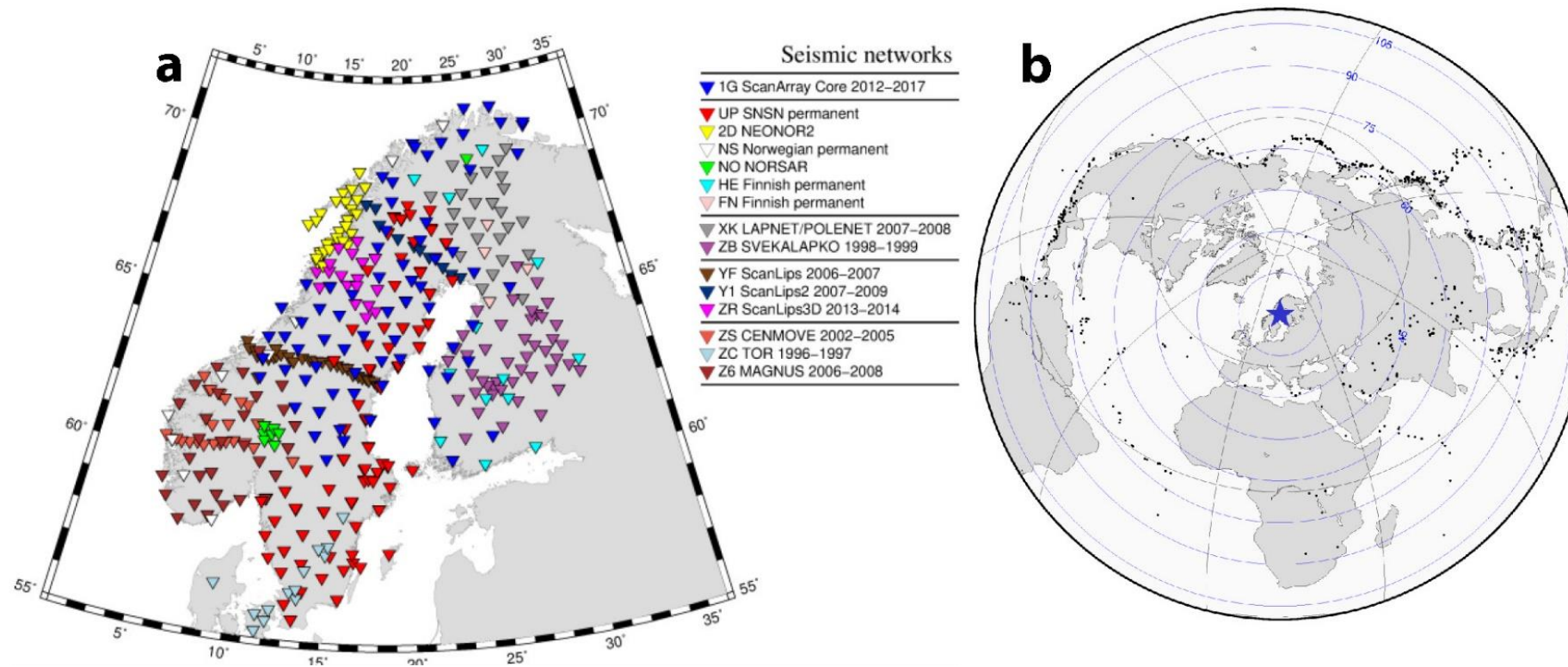
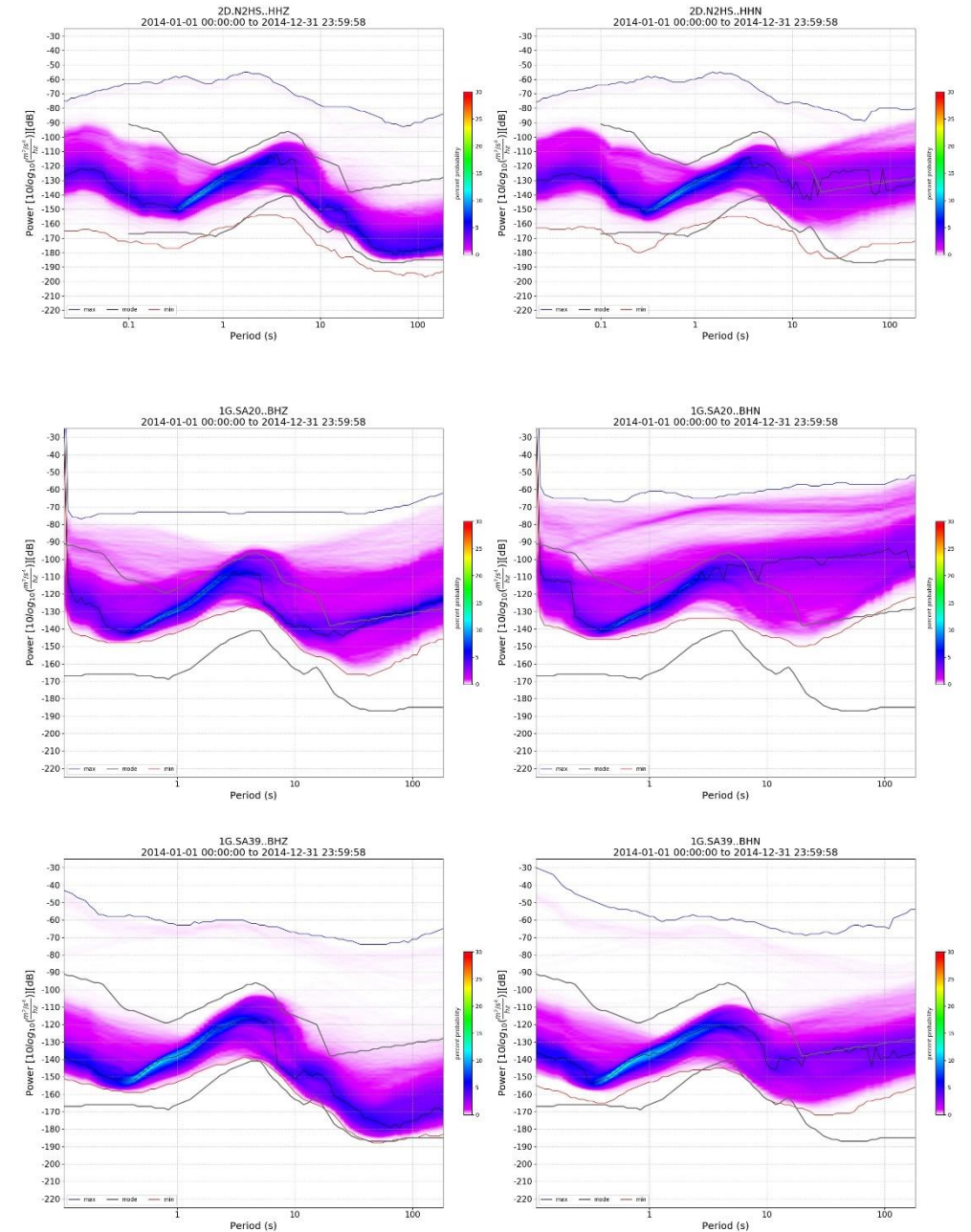


Figure 2. a) Overview map of station locations in the Baltic Shield during temporary deployments. The ScanArray programme includes the ScanArray Core deployment 2012-2017 and the affiliated deployments shown in second box. Earlier deployments are illustrated in the following three boxes. b) Seismic event distribution used for finite frequency tomography, cf. Figure 4f-h. Events in the first quadrangle are dominant, whereas only few events are observed from southerly directions.

Figure 3. Noise power spectral density probability density functions (PSDPDFs) plots for the vertical (left) and North-South components (right) of stations (from top to bottom) H2HS, SA20 and SA39. The plots are computed for one year of data (2014) with the IRIS System for Portable Assessment of Quality (ISPAQ version 2.0.0, provides the Modular Utility for STATistical kNowledgeGathering [MUSTANG] data-quality metrics; Casey et al. 2018). The gray curves are the New High and New Low Noise Model curves after Peterson (1993). The blue and red curves are the maximum and minimum measured noise levels, respectively.



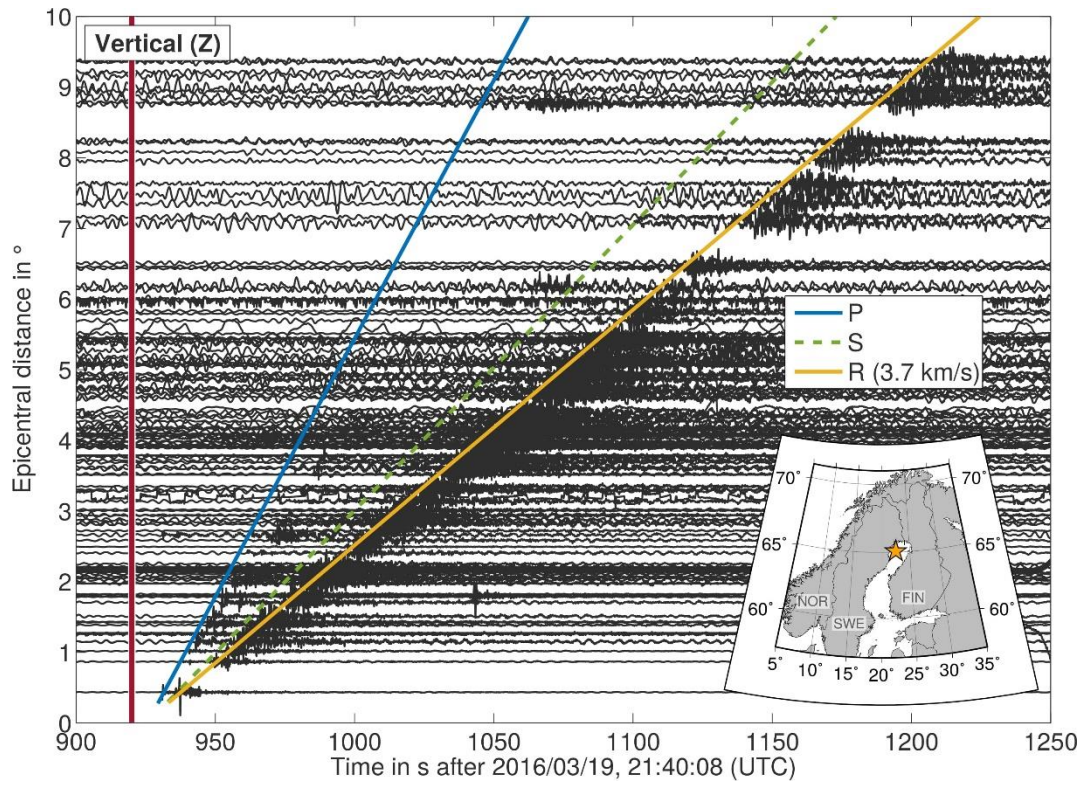
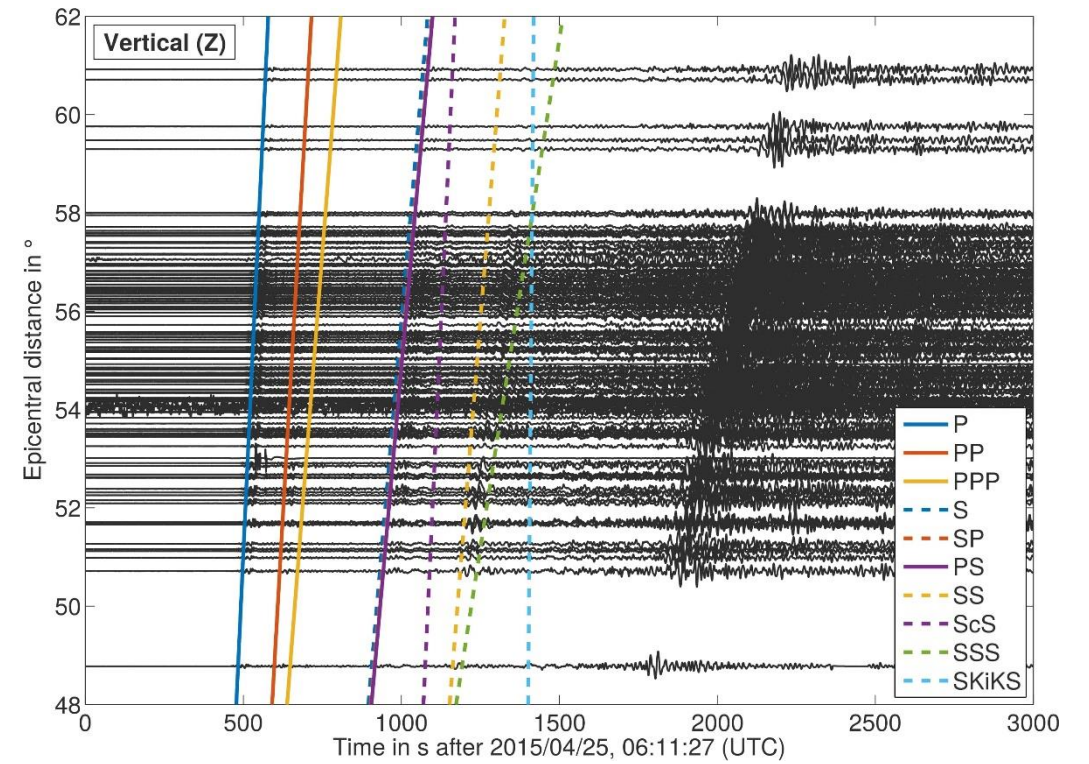


Figure 4. Record sections for a) a local event in the Bothnian Bay on 2016/03/19 with magnitude 4.1, band-pass filtered between 0.04 and 2 Hz, and b) an event in Nepal on 2015/04/25 with magnitude 7.8, band-pass filtered between 0.01 and 0.5 Hz. Theoretical arrival times for all expected phases are highlighted in the sections.

Figure 5. Variation in topography and seismic properties along a NNE-SSW trending transect across the Baltic/Fennoscandian shield (a-j) as shown by stippled line in k). a-j) See next slide

k) Hypsometric map of the study region. Stippled line shows location of profile illustrated in Figure 5. Encircled numbers refer to segments of the profile as given by colour code in the legend. Segments 4, 5 and 6 refer to subdivision of the Svecofennian province into its southern, central and northern domains. The Northern Dome (ND) appears to be located only within the Northern Svecofennian domain and the Southern Dome appears to be located solely within the Southern Svecofennian domain below segments that have been subject to later deformation during the Sveconorwegian and Caledonian orogenies, cf. Figure 1.

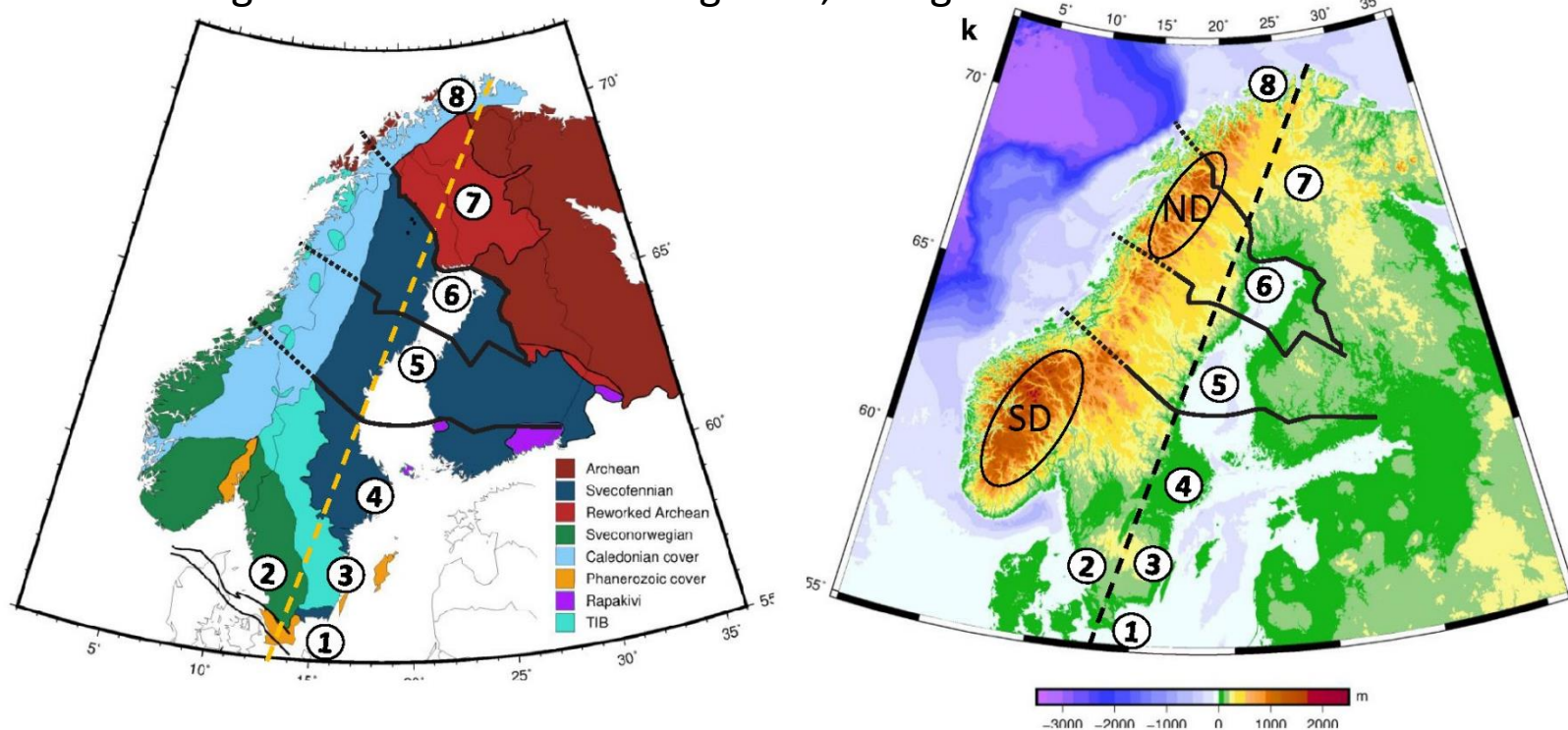
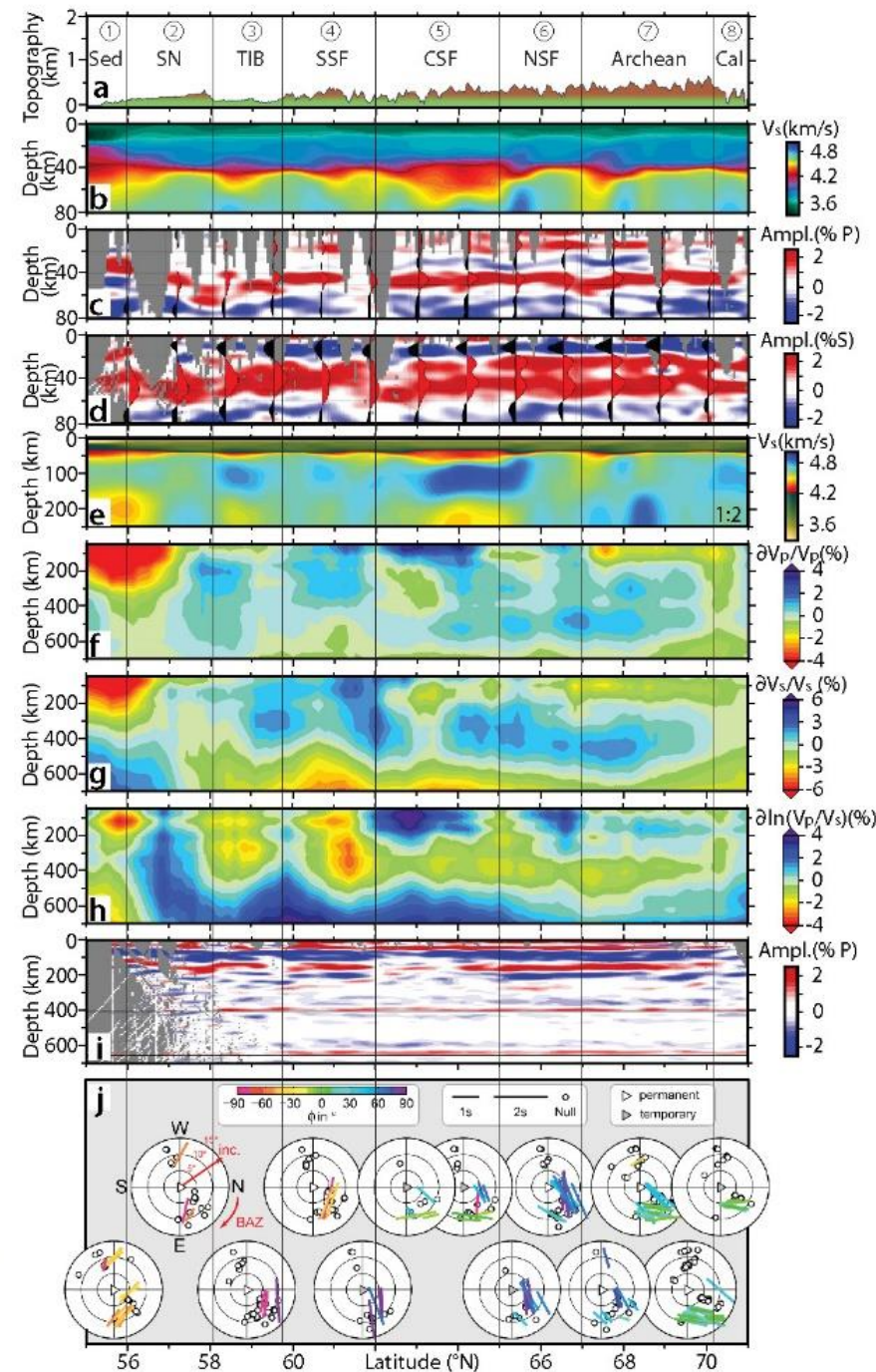
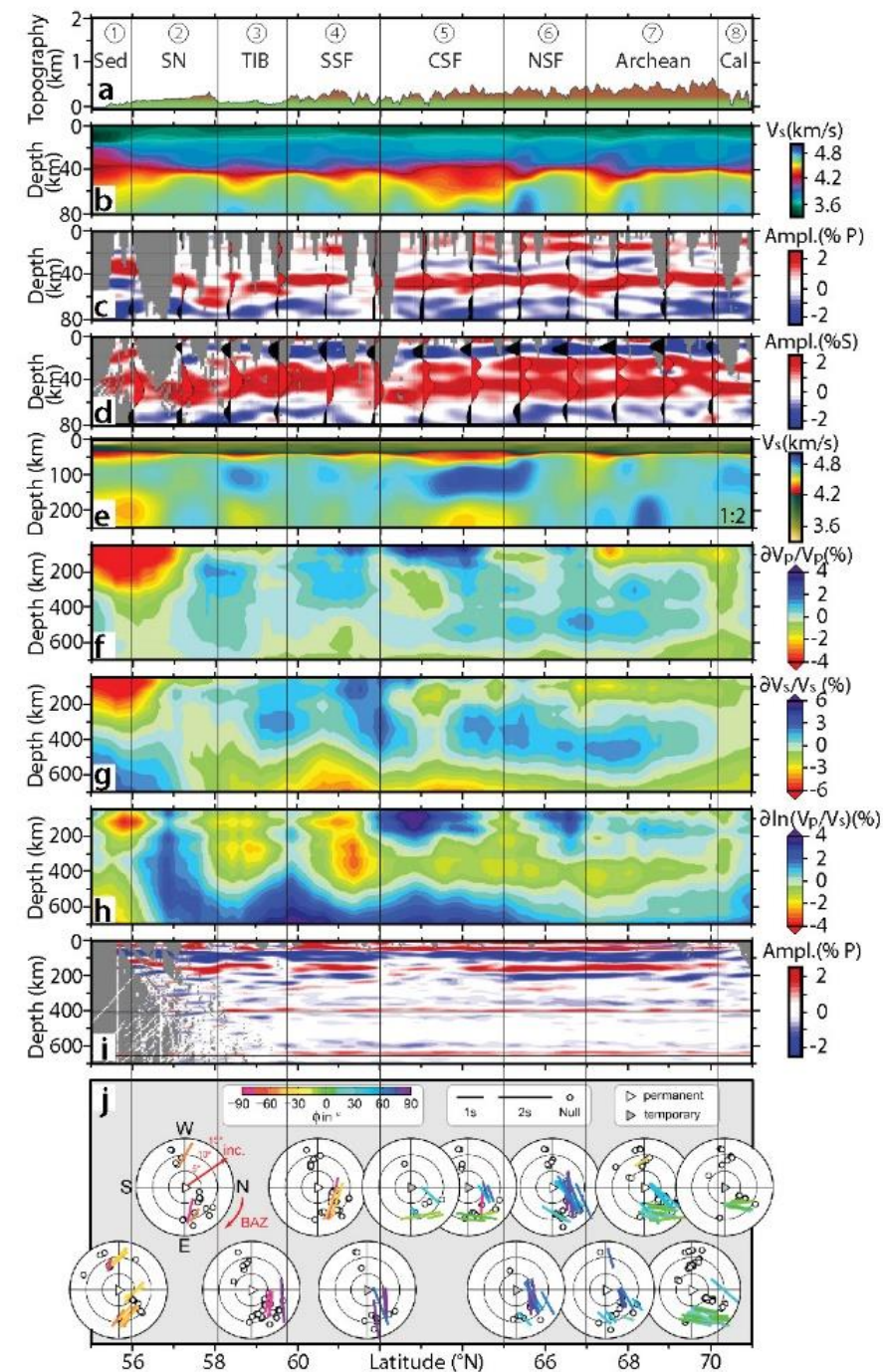


Figure 5. Variation in topography and seismic properties along a NNE-SSW trending transect across the Baltic/Fennoscandian shield (a-j) as shown by stippled line in k).

- a) Topography along the profile with abbreviations describing the tectonic segments, cf. Figure 1.
- b) Crustal velocity structure obtained by surface wave tomography (after Mauerberger et al., 2020).
- c) P-wave receiver functions.
- d) S-wave receiver functions.
- e) Mantle velocity structure obtained by surface wave tomography (after Mauerberger et al., 2020).
- f) Mantle P-wave velocity structure obtained by finite frequency tomography.
- g) Mantle S-wave velocity structure obtained by finite frequency tomography.
- h) Mantle V_p/V_s ratio obtained by finite frequency tomography.
- i) P-wave Receiver Functions for the mantle structure, showing constant depths to the '410' and '660' discontinuities as well as possible strong converters in the 100-200 km depth range which, however, may be subject to severe interference from multiple arrivals (after Makushkina et al., 2019).
- j) Variation in seismic anisotropy for selected permanent (white triangles) and temporary (gray triangles) recording stations in a 70 km wide corridor around the profile as obtained from shear-wave splitting (after Grund and Ritter, 2020). Splitting parameters (small bars, fast axis direction Φ and delay time δt) are shown in stereoplot-view as a function of backazimuth (BAZ, clockwise direction from North) and incidence angle (inc., radial axis). The orientation of Φ is additionally color-coded.



CONCLUSIONS

The data acquisition by the ScanArray consortium has ensured that the whole Baltic Shield, including the Caledonian deformed crust, now has been fully covered by broad band, passive seismic data at high quality. A series of significant seismological results are already published and results from a variety of other studies are underway.

We demonstrate significantly different seismological properties between eight tectonic segments along a N-S trending profile across the whole Baltic Shield. The velocity model shows strong variation around the Moho along the profile, where intermediate velocities between crust and mantle tend to correlate with the presence of two receiver function converters, possibly representing underplated regions. The lithospheric mantle in the Svecofennian parts of the region has higher velocity than in both the Archean and younger (Sveconorwegian and Caledonian) parts, although the V_p/V_s ratio varies within each of these parts. While the resolution of our seismological methods may be insufficient to identify causes for subtle, long-wavelength changes in topography, our results show that the high topography in the two domes of the Scandes mountain range has developed in two distinct domains of the Svecofennian province of the Baltic Shield which are characterized by significantly different seismic parameters in the crust and upper mantle than the surrounding areas with less topography.

DATA AND RESOURCES

Most data from the ScanArray Core data set has been publicly available since 1 January 2021 within EIDA from the GEOFON data center (FSDN network code 1G2012-2017, doi:10.14470/6T569239). The remaining data from stations operating until September 2017 will become publicly available from the same site by September 2021. Data from UiB are available from <https://doi.org/10.7914/SN/NS> (University of Bergen, 1982); from NORSAR at doi: 10.21348/d.no.0001 (NORSAR, 1971); and from Helsinki from <https://doi.org/10.14470/UR044600> Institute of Seismology, University of Helsinki, 1980). Data from the Northern Finland network is available at <https://www.fdsn.org/networks/detail/FN>. Supplementary Material includes details of the deployment program in Figure S1 and Table S1. Figures were partly prepared using Generic Mapping Tools (GMT and PyGMT, *Wessel et al.*, 2019; *Uieda et al.*, 2021).

Supplementary Material to

ScanArray – A broad band seismological experiment in the Baltic Shield

by H. Thybo et al.

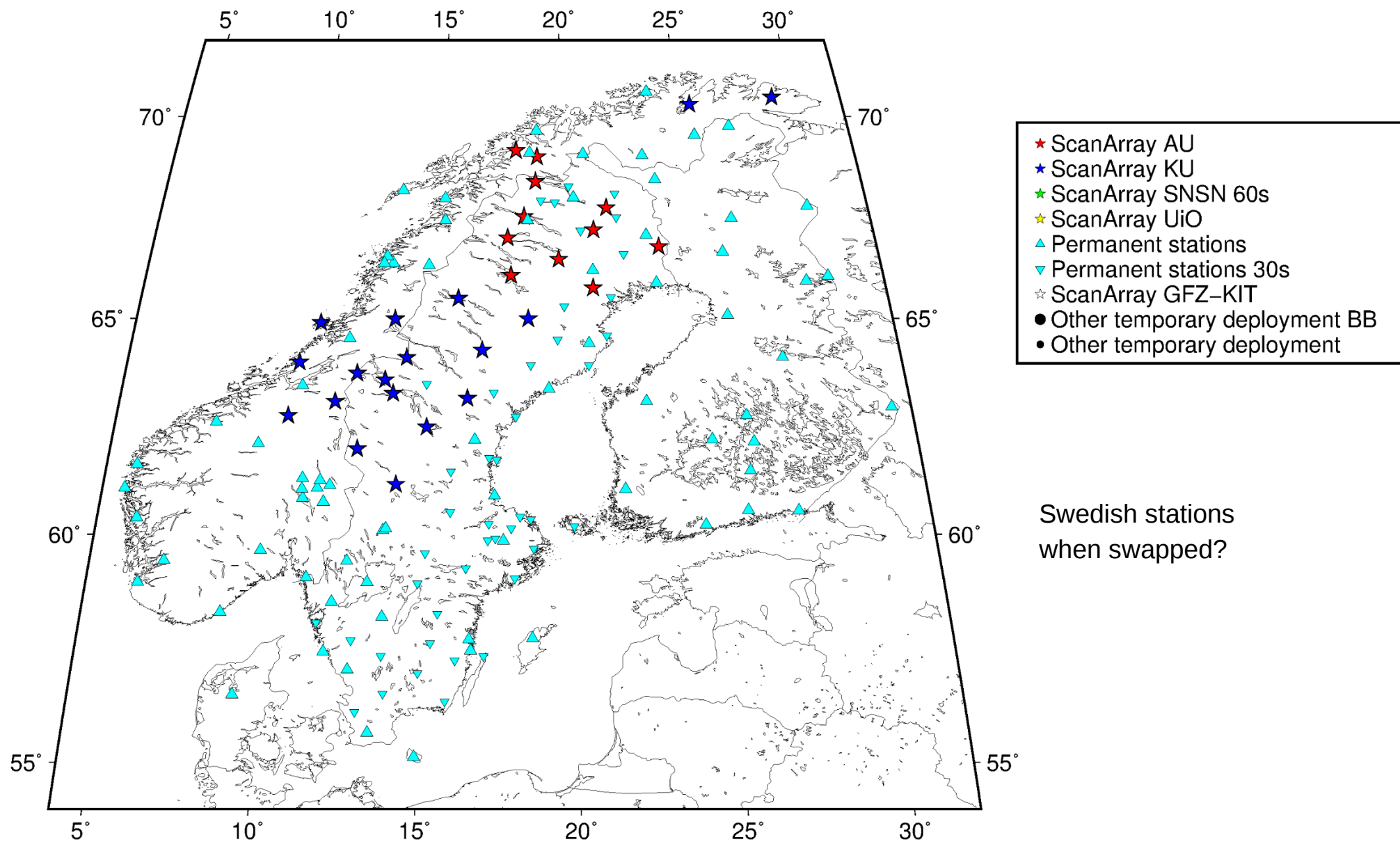
Submitted to Seismological Research Letters on 12 January 2021

Figure S1. Maps illustrating the temporal evolution of the ScanArray deployment in relation to other broad band seismological deployments in Fennoscandia. a) Stations in summer 2012, b) Stations in summer 2013, c) Stations in summer 2014, d) Stations in spring 2015, e) Earlier deployments, f) Total coverage of Fennoscandia at end of the ScanArray deployment.

Table S1. List of stations in the ScanArray 1G core station deployment with operating institution coded in column "Operator". Period refers to seismometer period. Operational refers to the number of years each station was deployed.

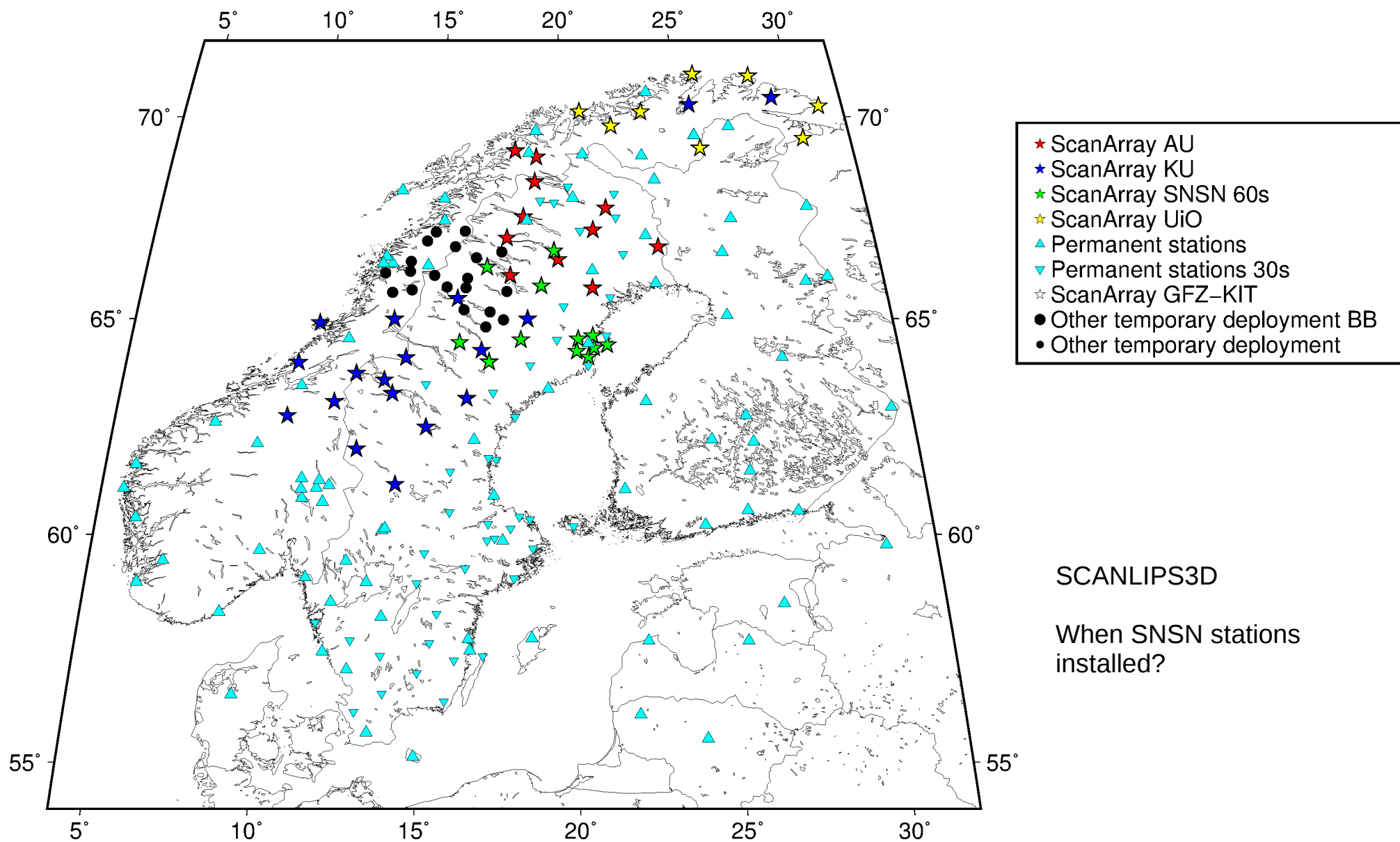
Summer 2012

Figure S1a



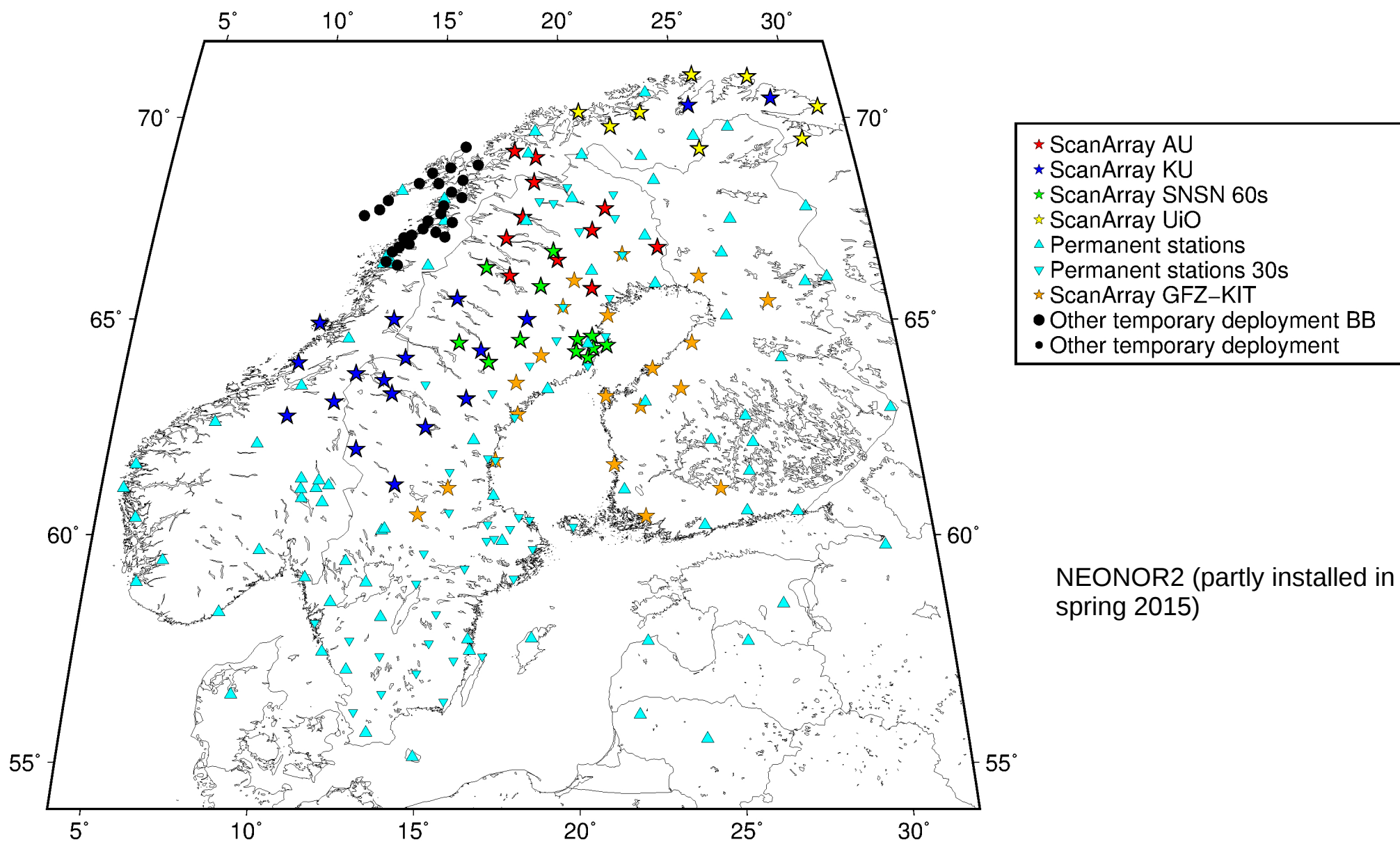
Summer 2013

Figure S1b



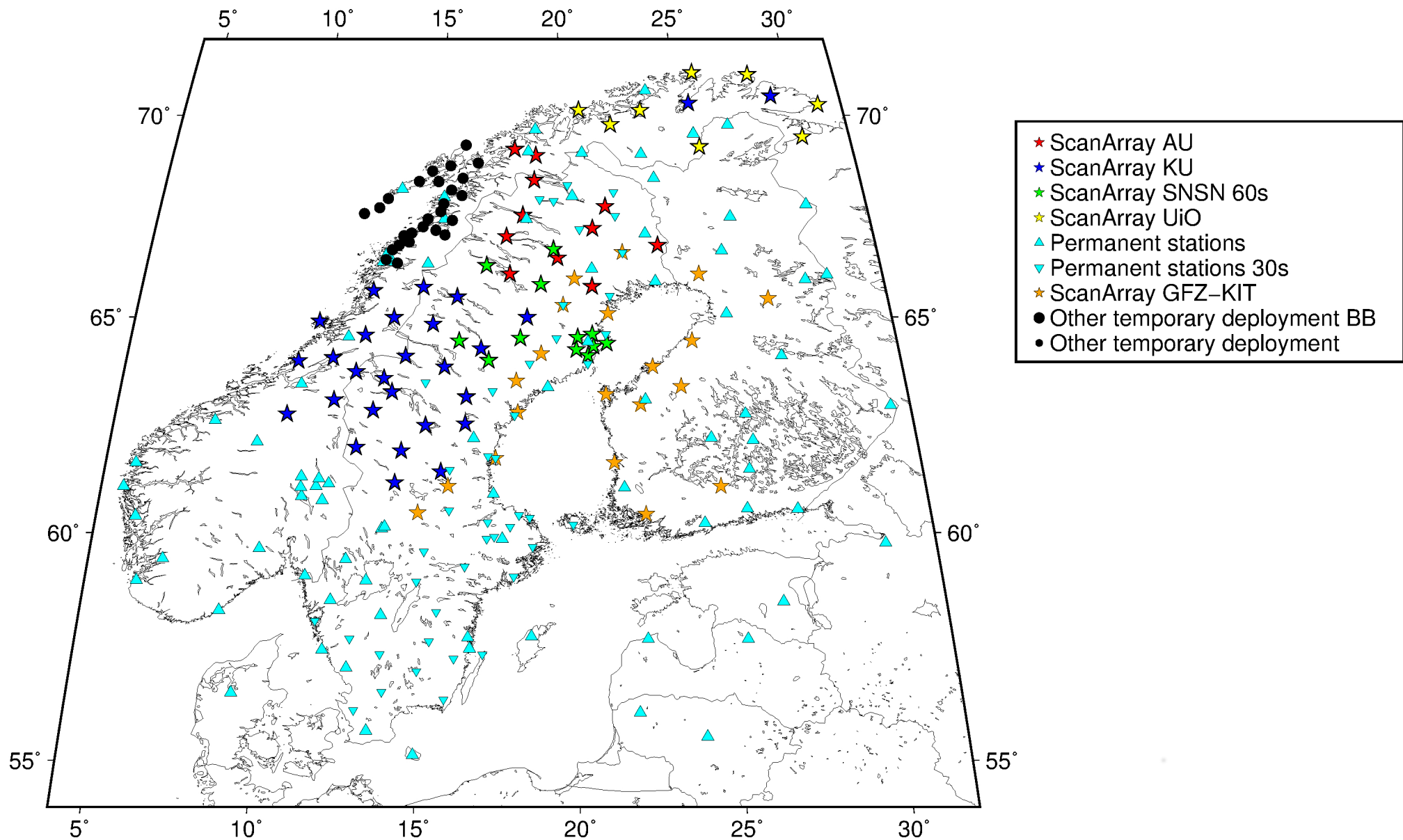
Summer 2014

Figure S1c



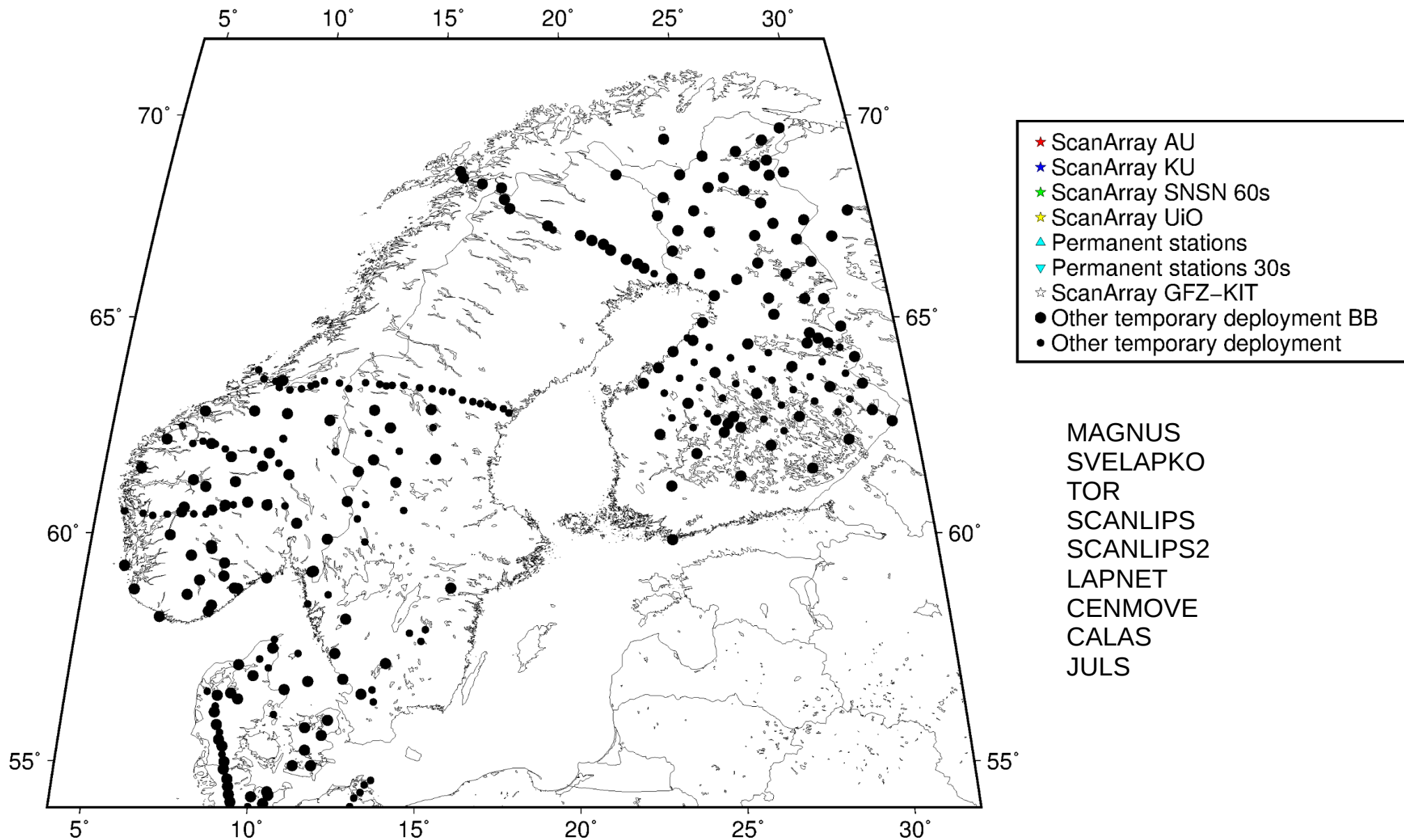
Spring 2015

Figure S1d



Earlier deployments

Figure S1e



Total coverage of Fennoscandia

Figure S1f

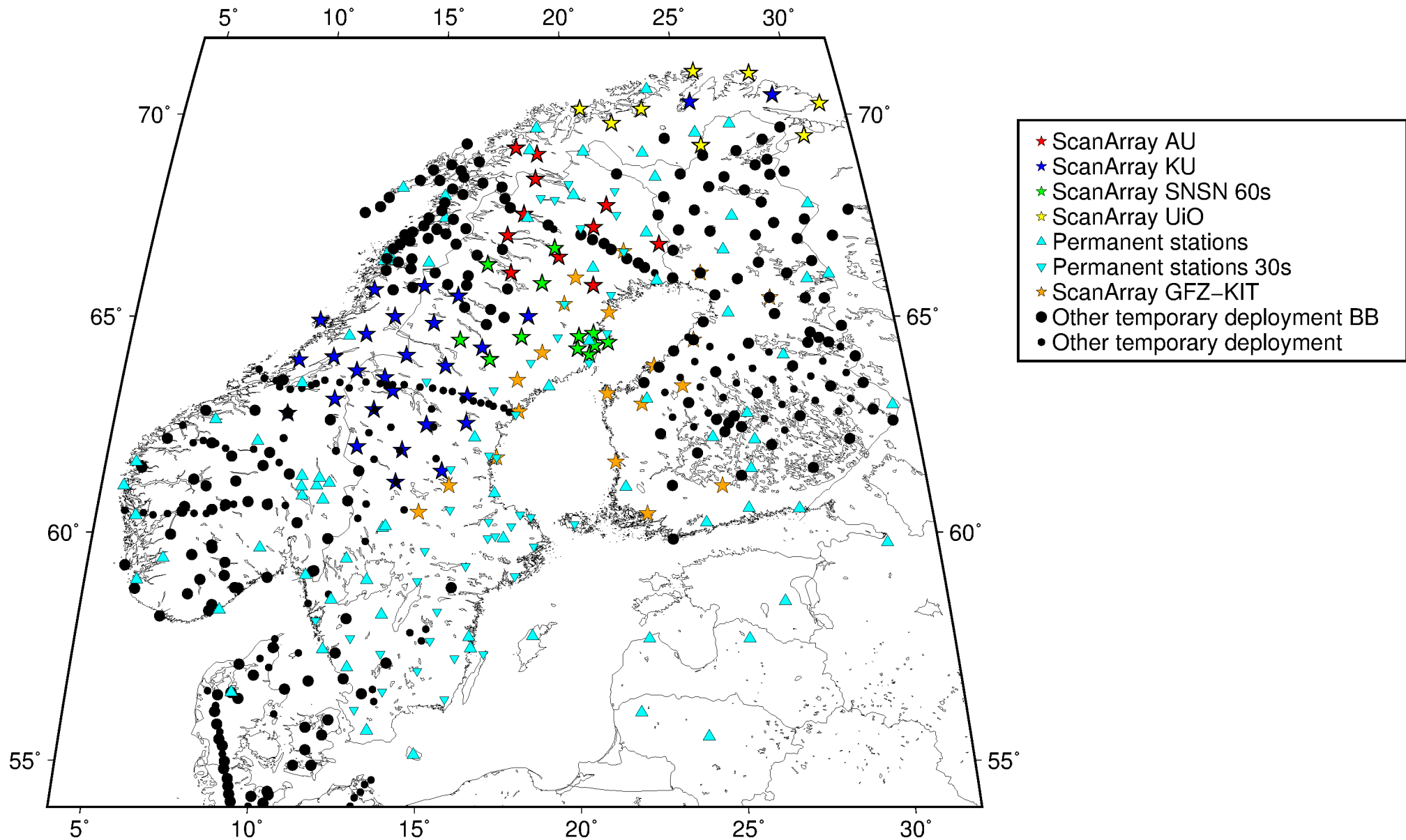


Table S1

Sheet1

Table S1. List of stations in the ScanArray 1G core station deployment with operating institution coded in column "Operator". Period refers to seismometer period. Operational refers to the number of years each station was deployed.

Station	Operator	Latitude (°N)	Longitude (°E)	Elevation (m)	Period (s)	Deployed	Operational (y)
SA01	UiO	71.11106	25.81695	14	120	26/09/2013	3
SA02	UiO	71.06376	28.24166	13	120	25/09/2013	3
SA03	KU	70.50340	29.06682	272	120	03/08/2012	5
SA04	KU	70.31915	25.47692	71	120	31/07/2012	5
SA05	UiO	70.28404	31.00829	33	120	24/09/2013	3
SA06	UiO	70.13431	20.75993	5	120	27/09/2013	3
SA07	UiO	70.12715	23.37370	18	120	26/09/2013	3
SA08	UiO	69.76423	22.06233	13	120	28/09/2013	3
SA09	UiO	69.45361	30.03907	28	120	23/09/2013	3
SA10	UiO	69.20068	25.69157	155	120	25/09/2013	3
SA11	AU	69.13213	18.04955	6	120	06/09/2012	4
SA12	AU	68.97312	18.91437	39	120	07/09/2012	4
SA13	AU	68.34912	18.83685	382	120	06/09/2012	4
SA14	AU	67.69623	21.62417	248	120	05/09/2012	4
SA15	AU	67.47458	18.36473	383	120	08/09/2012	4
SA16	AU	67.15173	21.07752	334	120	05/09/2012	4
SA17	AU	66.95288	17.72637	335	120	09/09/2012	4
SA18	AU	66.73932	23.56422	173	120	04/09/2012	4
SA19	GFZ+KIT	66.56536	22.17883	98	120	18/09/2014	2
SA20	AU	66.42983	19.68620	380	120	09/09/2012	4
SA21	GFZ+KIT	66.04059	25.03044	70	120	01/10/2014	2
SA22	AU	66.03818	17.85910	498	120	10/09/2012	4
SA23	GFZ+KIT	65.92625	20.30078	117	120	20/09/2014	2
SA24	AU	65.73557	20.95423	58	120	10/09/2012	4
SA25	KU	65.67228	14.22488	476	240	01/03/2015	2
SA26	KU	65.69917	12.43827	0	240	03/2015	2
SA27	KU	65.48233	15.89654	444	120	09/2012	5

Sheet1

SA28	GFZ+KIT	65.44692	27.52064	160	120	01/10/2014	2
SA29	GFZ+KIT	65.28787	19.84522	335	240	21/09/2014	2
SA30	GFZ+KIT	65.09228	21.49773	6	120	21/09/2014	2
SA31	KU	64.99111	18.50105	271	120	09/2012	5
SA32	KU	64.98758	13.58130	478	120	09/2012	5
SA33	KU	64.90327	10.84991	9	120	09/2012	5
SA34	KU	64.83179	15.03127	537	240	03/2015	2
SA35	KU	64.53397	12.40071	123	240	03/2015	2
SA36	GFZ+KIT	64.44019	24.51723	50	120	01/10/2014	2
SA37	KU	64.24671	16.81777	414	120	09/2012	5
SA38	GFZ+KIT	64.12913	19.00028	236	120	16/09/2014	2
SA39	KU	64.07180	14.09061	351	120	09/2012	5
SA40	KU	64.04353	11.33531	45	240	03/2015	2
SA41	KU	63.96652	10.23171	18	120	09/2012	5
SA42	GFZ+KIT	63.82646	23.00790	10	120	10-2014	2
SA43	KU	63.81655	15.51477	333	240	03/2015	2
SA44	KU	63.70518	12.34839	462	120	09/2012	5
SA45	KU	63.54918	13.36576	413	120	09/2012	5
SA46	GFZ+KIT	63.48963	18.09452	140	120	15/09/2014	2
SA47	GFZ+KIT	63.35959	23.97327	100	120	01/10/2014	2
SA48	KU	63.23047	13.67801	401	120	09/2012	5
SA49	GFZ+KIT	63.17494	21.27882	40	120	01/10/2014	2
SA50	KU	63.11401	16.32236	153	120	09/2012	5
SA51	KU	63.04408	11.64370	474	120	09/2012	5
SA52	GFZ+KIT	62.93811	22.48778	40	240	01/10/2014	2
SA53	KU	62.80045	13.05265	568	240	03/2015	2
SA54	GFZ+KIT	62.75039	18.14890	13	240	14/09/2014	2
SA55	KU	62.71911	10.03964	533	120	09/2012	5
SA56	KU	62.48589	16.30865	84	240	03/2015	2
SA57	KU	62.44944	14.92132	271	120	09/2012	5
SA58	KU	61.94490	12.55341	562	120	09/2012	5

Sheet1

SA59	KU	61.86536	14.12029	481	240	03/2015	2
SA60	GFZ+KIT	61.69295	17.37935	15	120	13/09/2014	2
SA61	GFZ+KIT	61.59337	21.46223	10	120	01/10/2014	2
SA62	KU	61.38391	15.51161	204	240	03/2015	2
SA63	KU	61.13399	13.95659	449	120	09/2012	5
SA64	GFZ+KIT	61.05372	25.03989	130	240	01/10/2014	2
SA65	GFZ+KIT	61.05349	15.76985	99	120	12/09/2014	2
SA66	GFZ+KIT	60.44683	14.78057	239	120	2014-09-11	2
SA67	GFZ+KIT	60.41585	22.44386	50	120	01/10/2014	2

Operator abbreviations:

AU: Aarhus University

GFZ+KIT: Geoforschungszentrum Potsdam and Karlsruhe Institute of Technology

KU: University of Copenhagen

UiO: University of Oslo