Loan 833 – Uplift of Northern Scandinavia – SCANLIPS2

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Abstract Between July 2008 and September 2009 12 SEIS-UK broadband seismometers supplemented with 4 broadband seismometers and 5 semi-permanent seismometers operated by the University of Uppsala were deployed across northern Scandinavia in a 500 km long profile. 5 instruments in remote locations without mains power were deployed with wind turbines to maintain battery charge over the winter. Of these only the turbine placed in clear open ground charging a single large battery powered the instrument throughout the winter. The other instruments shut down between late October and late February. Data recovery was c. 85%, excluding the winter downtime, yielding 84 M_B > 6.0 events for Receiver Function analysis. The data are currently being processed and preliminary results of Receiver Function analysis and SKS splitting are presented here.

Introduction and objectives The results of a recent seismic experiments in southern Scandinavia have cast doubt on models suggesting that the mountainous region of southern Norway is in approximate isostatic equilibrium [1]. The mountains do not appear to be supported by a substantial crustal root which, to a first approximation, mirrors the surface topography. This observation was supported by the presence of a large negative Bouguer gravity anomaly [2,3] but it is likely that much of this feature is due to variations in crustal density (Fig. 1). This experiment is the third of 3 profiles (including the SCANLIPS profile (Loan 783)) designed to increase our knowledge and understanding of the mechanism of support of Scandinavian topography. The southern and central Norway profiles crossed areas of major and low uplift and present day topography whereas the profile reported here crosses a region of intermediate topography.

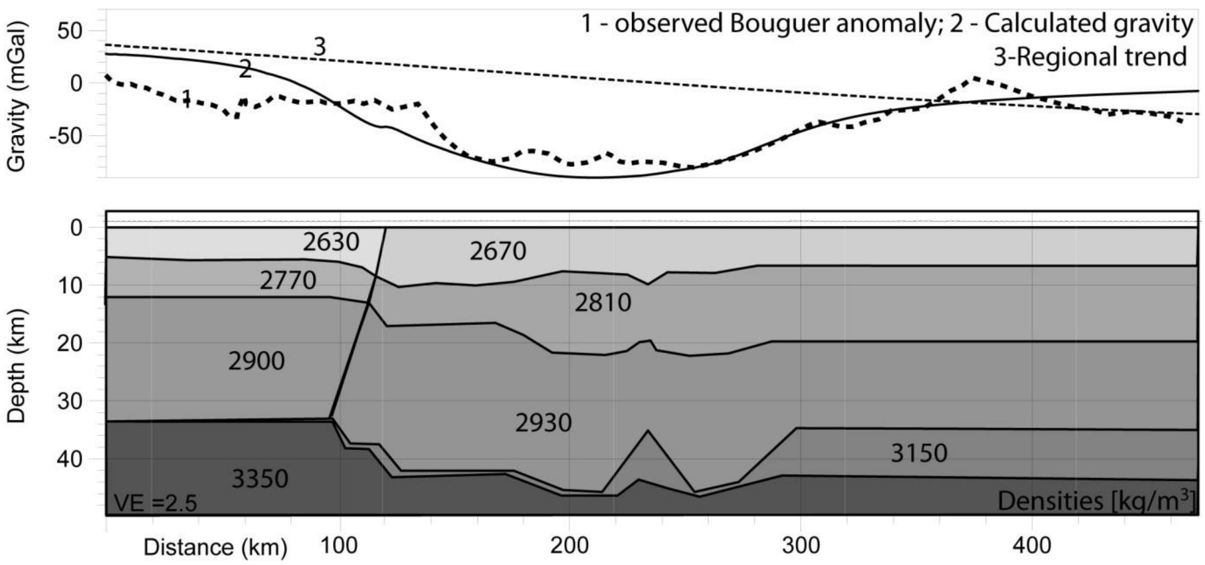

Fig. 1. Crustal density model along the SCANLIPS profile crossing central Scandinavia derived from seismic velocities determined from forward and inverse modelling of receiver functions and the calculated gravity anomaly compared with the anomaly observed along the profile. This model suggests that the topography of the Scandes mountains is not supported by a substantial crustal root. Instead the crust thickens from 32 km at the Norwegian coast to a maximum of c. 42 km and remains at around 40 km thick beneath Sweden (From [1]).

Specifically the experiments were designed to:
Test if the crust is in isostatic equilibrium or is supported by a strong lithosphere by determining variations in its thickness.
Investigate whether there is a relationship between crustal properties and patterns of variable uplift constrained by fission track data [refs in 4] by determining the detailed velocity structure of the crust. A

correlation between velocity structure and uplift would strongly suggest the topography was the result of modification of the crust.

Survey procedure The SCANLIPS2 project data acquisition was completed over 3 years. In June 2007 a reconnaissance of 22 suitable sites (c. 30 km apart) for the instruments in Norway and Sweden was completed, establishing a 500 km long profile from the Lofoten Islands to Haparanda on the Gulf of Bothnia (Fig. 2). The profile includes 5 semi-permanent stations already deployed by the University of Uppsala in Sweden. At the same time 2 SEIS-UK stations were deployed in Norway, at Lodingen in the Lofoten Islands and in Melkedalen on mainland Norway. These two stations were a pilot exercise to test the use of mains power supply to the instruments and overwintering of the instruments at the very low temperatures (c. -20°) experienced north of the Arctic circle. At the same time concrete pipes to protect the instruments were left at the 4 selected sites in Norway. In June 2008 10 SEIS-UK and 4 Uppsala instruments were installed at the temporary sites, except site 11 which was not occupied (Fig. 2). The instruments are a mixture of Guralp, 3T, 40T sensors supplied by SEIS-UK and ESP sensors supplied by the University of Uppsala, recording onto either Guralp DCMs or Nanometrics Taurus digitisers / dataloggers. The two instruments installed in 2007 had SAMs switched for DCMs when they were serviced in June 2008. All instruments were set to record continuously at 50 or 100 Hz sample rates. The SEIS-UK instruments deployed outdoors with solar and wind power were serviced in September 2008 and again, following the winter, in May 2009. The Uppsala instruments were serviced in October 2008 and March 2009. The instruments were recovered in September 2009. Summary details of the deployments are given in Appendix 1 below.

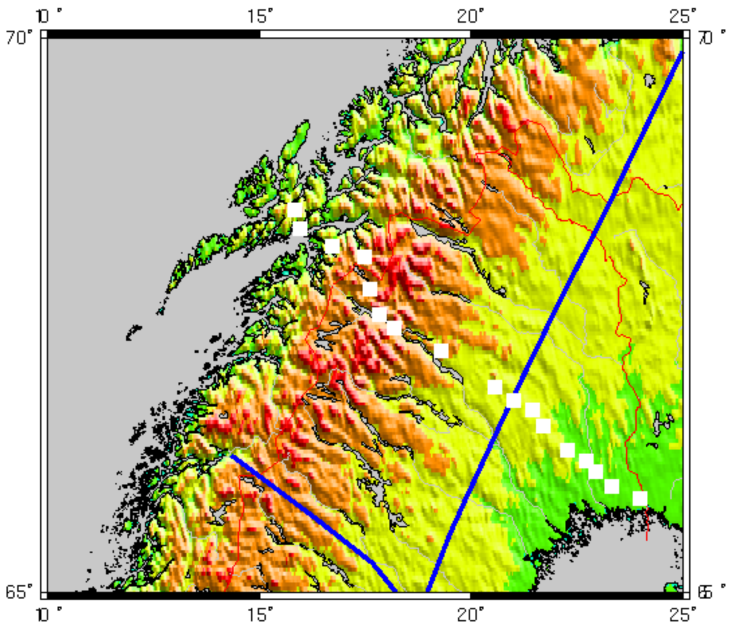

Fig. 2. Location of the Scanlips 2 instruments (White squares) and existing refraction profiles.

All the instruments were deployed either directly on a tile cemented to bedrock or indoors on concrete floors constructed on bedrock. An initial examination of events from the dataset reveals that coupling with the bedrock was good and the signal to noise ratio of the instruments was high.

The instrument at site 2 (Lofoten Islands) failed to write data to the DCM disk correctly. Unfortunately, this was not discovered until after the data were processed and work is ongoing to attempt to recover these data. The 3T sensor at site 10 was damaged by a bear in late August 2008. This damage was discovered at the September 2008 service but could not be fully repaired and the instrument was left to record over winter with the vertical and the N-S horizontal component working. This sensor was then exchanged in June 2009 with the instrument at site 14 in order to have the benefit of 2 summers recording with a good instrument at site 10. This ensured the gap in data coverage (resulting from the non-deployment of site 11) was filled. The instruments at sites 10, 14, 17 and 20 all shut down between late October and late February due to low battery voltages. Of these only site 14 failed to restart normally. Overall the data recovery from the SEIS-UK instruments is about 85%, excluding the winter down time.

Wind turbines In order to attempt to extend the recording duration of the SEIS-UK instruments placed outdoors (Sites, 5, 10, 14, 17 and 20) 4 Rutland 503 wind turbines and 5 Rutland HRS 503 regulators were purchased by the PI to supplement an existing wind turbine that had been acquired in 2002 by SEIS-UK. These were mounted on 3 m high poles (supplied and modified from old drill rods by the Geological Survey of Norway) supported by steel guy ropes and sited as far as possible from the sensor location (Fig. 3). The regulators (Fig. 4) were connected between the turbine and the battery. Solar panels were also connected to the batteries (2x85 Ah batteries connected in parallel except Site 5 which had a single 85 Ah battery) via a standard SEIS-UK supplied regulator. Site 5 was in a very exposed position on open ground at the head of Nordalen (c. 30 km SE of Narvik) (Fig. 3), the other sites in Sweden were in small clearings in wooded areas.

The instrument at site 5 ran throughout the winter with the battery charge being maintained throughout by the wind turbine. The other sites, as noted above, shut down due to low battery voltage in late October as the sunlight failed. Analysis of the log files obtained from the data loggers in May 2009 revealed that the battery charge in these sites was not maintained at a sufficiently high level by the wind turbines (Figs. 5 & 6). As far as it is possible to determine there are two reasons for this. 1) There was insufficient wind, or too much turbulent air at the Swedish sites. 2) The turbines supplied charge but this was trickled to both batteries so that the voltage never reached the 12.6 V high switch-on threshold set in the SEIS-UK regulator which supplied power direct to the datalogger and sensor.

As a result of this we are able to make two recommendations:
1) If used, the turbines should only be deployed in areas of open ground with smooth airflow.
2) Only 1 low charge battery be connected to the wind turbine so that it is rapidly charged by the turbine. (The turbine regulators only feed charge to the battery when the p.d. from the turbine exceeds the p.d. across the battery terminals.)

These wind turbines and regulators have recently been sold to SEIS-UK because SEIS-UK staff passed them to Prof. R S White for use in Iceland this winter. They will be available for loan on return from Iceland.


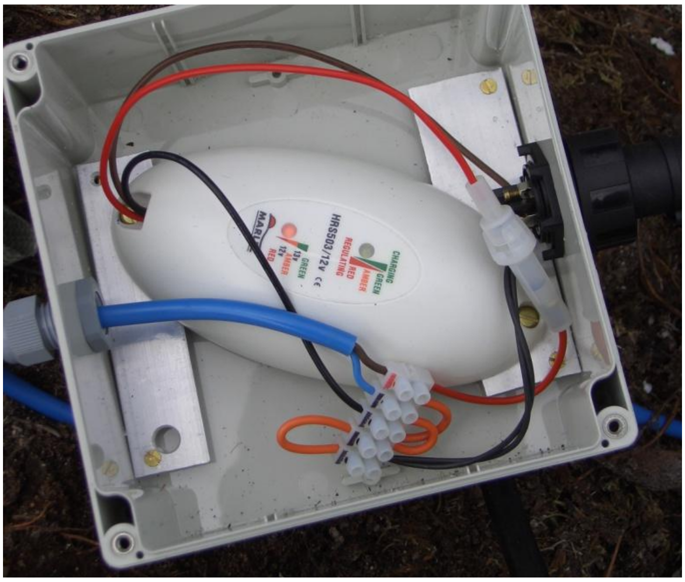

Fig. 4 (Left) The Station at Site 5 in Nordalen, Northern Norway with the wind turbine and the solar panels and sensor (covered with sandbags) in the foreground. Fig. 5 (Right) Wind turbine regulator installed in a protective box. The battery is only charged when the p.d. from the turbine exceeds the p.d. across the battery terminals.

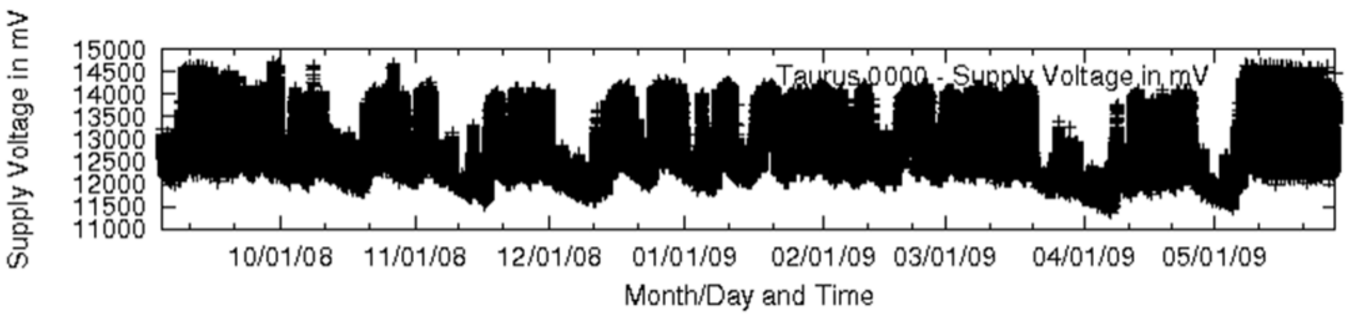

Fig. 5. Battery voltage plotted against time for the station at Site 5. Throughout the winter the wind turbine maintained the battery voltage above the 11.4 V low voltage cut-off.

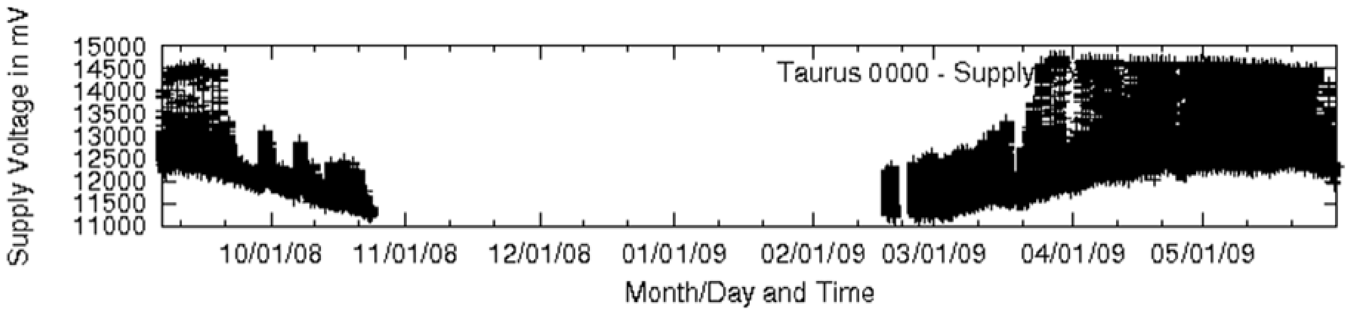

Fig. 6. Battery voltage plotted against time for the station at Site 20. The battery voltage fell below the low voltage cut-off in late October and there was insufficient charge to raise the battery p.d. above the 12.6 V reconnect before late February.

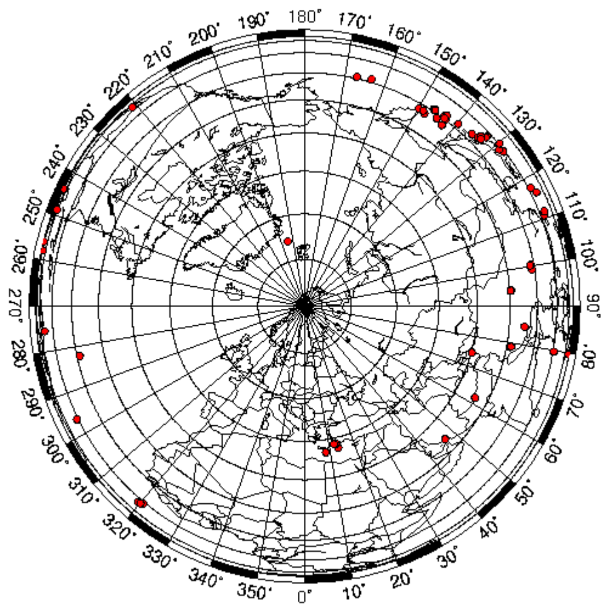

Fig. 7. Map centred on the array illustrating the distribution of the 84 events of M_B > 6.0 recorded by the array (Red dots).

Data Quality During the period of recording a total of 84 events of Magnitude M_B > 6.0 and from a broad range of back azimuths was recorded at the epicentral distances between 30 and 95 degrees required for the proposed receiver function study (Fig. 7). The data were transcribed into miniSEED using the SEIS-UK processing tools and have been archived at IRIS with the temporary network code Y1. Access to the data is restricted until October 2012.

As noted above, the signal to noise ratio of the data is good (Fig. 8) with considerably quieter records than previously obtained from the SCANLIPS 2 dataset which was recorded using the original configuration of 6TDs. To date a preliminary dataset of large magnitude events M_B > 6.8 has been extracted from the data and some Receiver Functions calculated. Further work is still needed on the raw gcf data supplied by Uppsala and this is ongoing. The following comments relate to data extracted from the SEIS-UK instruments.

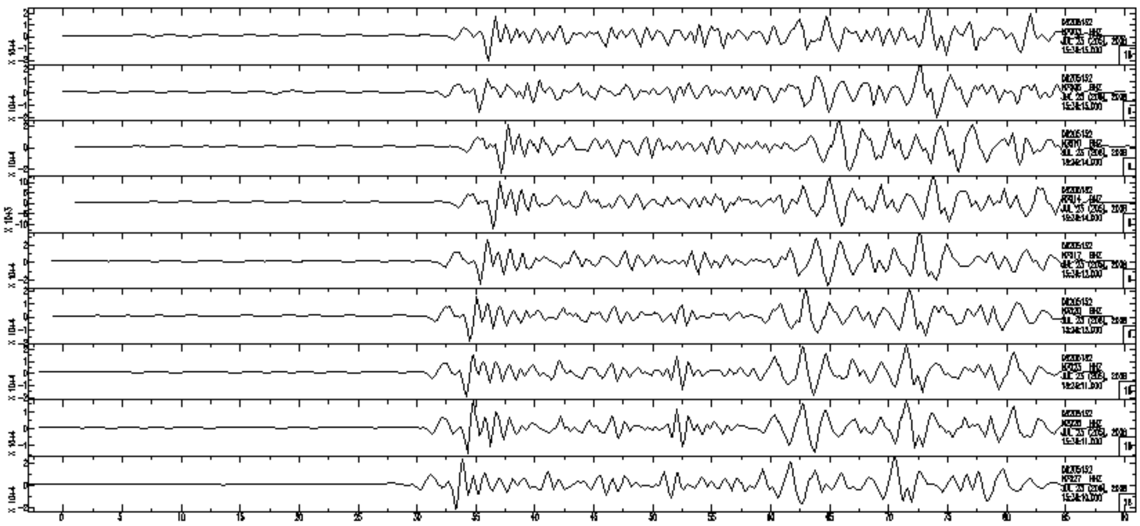

Fig. 8. Example seismic recordings at 9 of the 12 sites occupied with a SEIS-UK instrument of a magnitude 7.0 earthquake from Indonesia on 23rd July 2008. The western most site is the top record. Horizontal scale is from 0 to 90 s.

Interpretation and preliminary conclusions At the time of writing (October 2010) 2 datasets have been extracted from the recordings. The 84 events between 30° and 95° have been extracted for calculation of receiver functions and 8 events suitable for SKS splitting analysis have also been sorted from the continuous miniSEED data.

Receiver Function study At present, receiver functions are being calculated for 84 large magnitude events. An example of receiver functions across the array is shown in Fig. 9. The data show excellent signal to noise ratio and enable a Moho Ps conversion and following crustal multiples to be identified. For most sites the Ps conversion arrives at times greater than 5 seconds after the direct P arrival, corresponding approximately to depths of c. 40 km assuming an average crustal Vp of 6.0 and a Vp/Vs ratio of 1.73 (Fig. 9). There is little clear variation in crustal thickness along the profile from west to east which appears to be consistent the conclusions of the SCANLIPS study [1].Of interest is the lack of a strong conversion at the Moho beneath Sweden which is also consistent with little velocity contrast at the base of the crust in this area as indicated by existing seismic refraction profiles [5,6]. In contrast to the SCANLIPS data preliminary plots for each site show little variation in back azimuth suggesting the structure is relatively homogeneous beneath each site but a lot more of the data need to be processed before this can be confirmed.

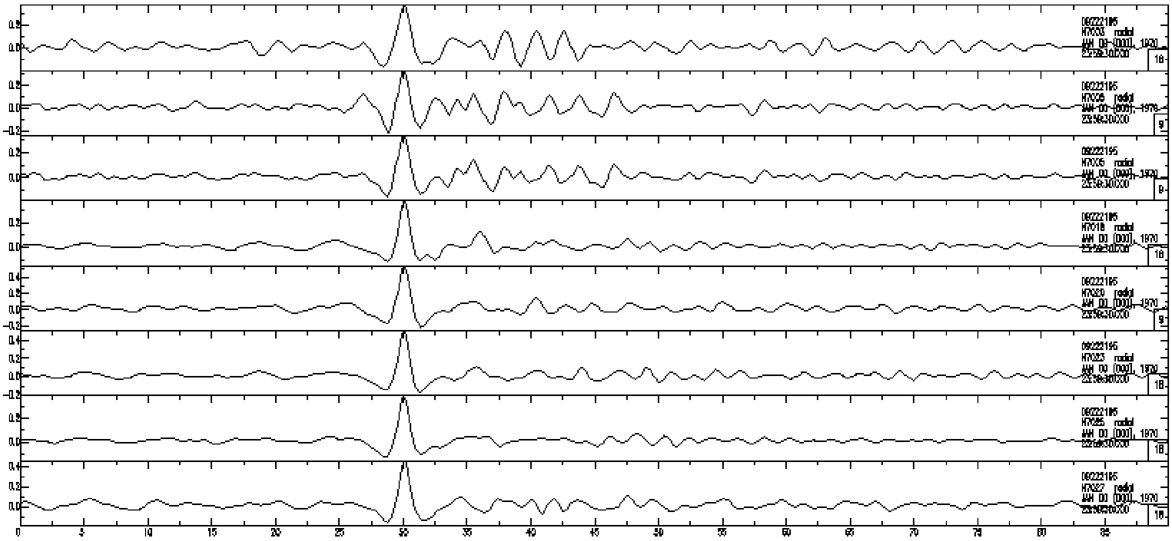

Fig. 9. ZRT receiver functions calculated for an event recorded at 9 of the 12 sites occupied with a SEIS-UK instrument from a magnitude 6.9 earthquake from Indonesia on 10th August 2009. The western most site is the top record. Horizontal scale is from 0 to 90 s. The direct P arrival (peak) is at 30 seconds and the Ps Moho conversion arrives about 5 s later, although this is not clear for the stations in Sweden.

Once calculation of the receiver functions is complete we plan to undertake H-k stacking [7] to determine average Vp/Vs vs depth estimates which will be used as a basis for forward and inverse modelling of crustal velocity structure. LQT functions will be calculated and migrated to provide an image of crustal structure which will then be used as a basis for potential field modelling.

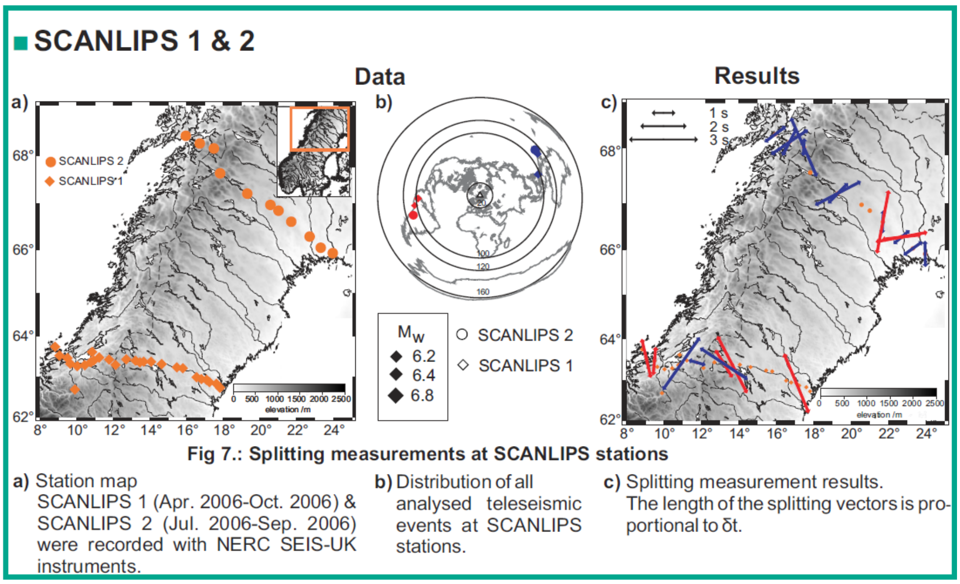

Fig. 10. Preliminary SKS splitting results for the SCANLIPS 1 and 2 data. Note the red and blue arrows in Fig. 10 c relate to back azimuth (Blue - NE), (Red – SW).

SKS study Colleagues at Karlsruhr Institute of Technology have been calculating SKS splitting from both SCANLIPS datasets. This study has focussed on potential shear wave splitting in the upper mantle following surface wave studies which indicated the presence of a thermal anomaly in the upper mantle beneath southern and central Norway [8]. The preliminary results (Fig. 10) suggest that the dominant fast propagation direction in central Scandinavia is NW-SE while in the North it is NE-SW suggesting a variation is fast direction in the mantle which may be associated with the mantle anomaly but its origin is still unknown. This work is also being continued.

A poster* describing the preliminary SKS splitting results has been presented at the European Seismological Commission meeting in Montpellier, France. Results of both this and the Receiver Function study will be written up for publication once complete. Both studies contribute to the ESF supported Toposcandes Deep programme which is part of TopoEurope.

* Roy, C., Ritter, J., Schweitzer, J. & England, R. 2010. SKS Splitting analysis to derive mantle anisotropy underneath the Scandinavian Mountains. European Seismological Commission General Assembly, September 6th – 10th, Montpellier, France.

References

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Appendix 1: Station listing.

SCANLIPS 2	Y1										Recording	
Station ID	Site	Dist (km)	Gap (km)	Lat	Lon	Height (m)	X	Y	Instrument	Mains	From	Until
N7002	2	0	0	68.5644	15.8271	8	533732	7606019	SEIS-UK	yes	26/06/2008	13/09/2009
N7001	1	18.97	18.97	68.4	15.9543	15	539166	7587807	SEIS-UK	yes	26/06/2007	14/09/2009
N7003	3	50.74	31.77	68.2468	16.7154	60	570938	7571367	SEIS-UK	yes	28/06/2007	13/09/2009
N7005	5	82.54	31.8	68.1468	17.4881	628	603332	7561313	SEIS-UK	No	27/06/2008	12/09/2009
SL9	9	107.52	24.98	67.8617	17.6122	621	1576400	7535000	Uppsala	No	08/07/2008	11/09/2009
SL10	10	133.02	30.9273	67.6344	17.8271	463	1586300	7505700	SEIS-UK	No	08/07/2008	10/09/2009
SL11		152.82	19.578				1601200	7493000	Uppsala	yes		
SL12	12	173.43	20.6101	67.3801	18.5062		1615985	7478641	SNSN			
N7014	14	212.728	39.2974	67.2083	19.3085	404	1651200	7461200	SEIS-UK	No	29/06/2009	10/09/2009
SL15	15	227.549	14.821	67.1063	19.5214		1661350	7450400	EGF			
SL16	16	273.054	45.505	67.1216	20.5683		1706602	7455192	SNSN			
N7017	17	290.073	17.0195	66.969	20.5703	419	1708000	7438230	SEIS-UK	No	30/06/2008	07/09/2009
N7018	18	313.85	23.7769	66.8439	21.0131	375	1728450	7426100	SEIS-UK	Yes	30/06/2008	09/09/2009
SL19	19	336.348	22.4976	66.7569	21.4517	330	1749400	7417900	Uppsala	Yes	02/07/2008	09/09/2009
N7020	20	355.889	19.5412	66.607	21.7096	396	1762500	7403400	SEIS-UK	Yes	03/07/2008	07/09/2009
SL21	21	377.154	21.2656	66.5541	22.1891		1783191	7398490	SNSN			
SL22	22	396.502	19.3475	66.3863	22.2879	125	1789500	7380200	Uppsala	Yes	03/07/2008	08/09/2009
N7023	23	418.434	21.9317	66.2842	22.7113	100	1809500	7371200	SEIS-UK	Yes	04/07/2008	09/09/2009
SL24	24	434.627	16.1929	66.1726	22.9355	72	1820900	7359700	Uppsala	Yes	04/07/2008	08/09/2009
N7025	25	457.095	22.468	66.0364	23.3126	70	1839400	7346950	SEIS-UK	Yes	05/07/2008	08/09/2009
SL26	26	477.316	20.2219	65.8294	23.945		1844109	7327284	SNSN			
N7027	27	506.229	28.9129	65.9175	23.9737	50	1871250	7337250	SEIS-UK	Yes	05/07/2008	08/09/2009