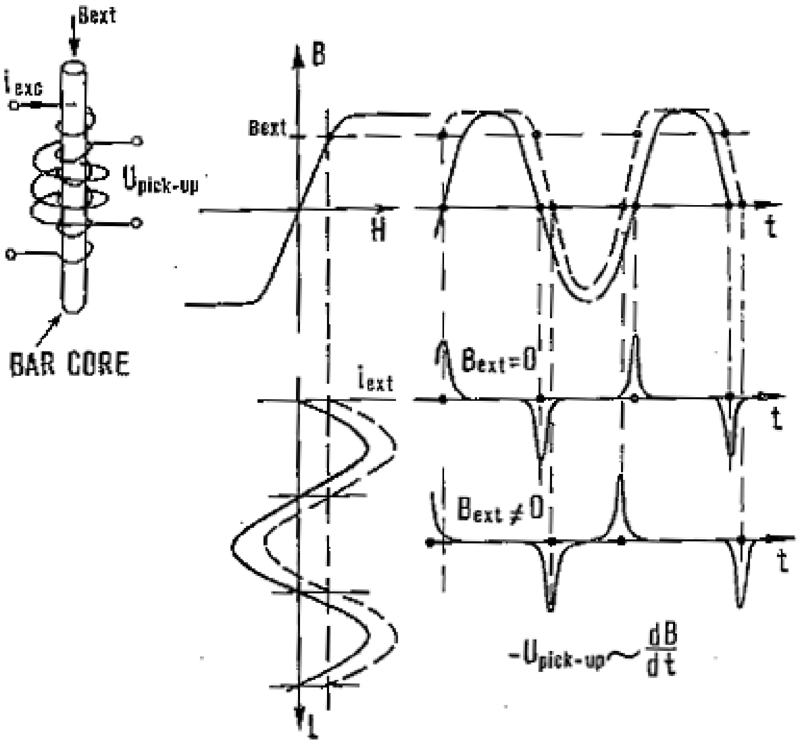
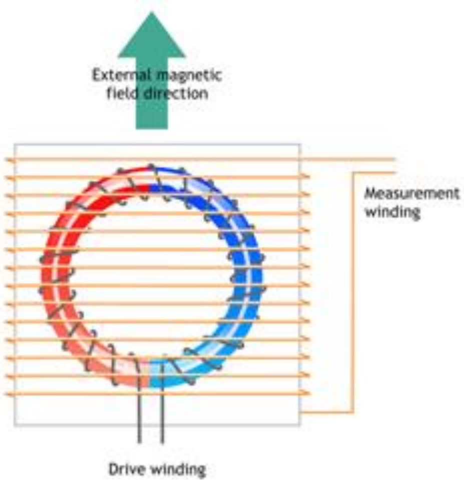
Magnetometers

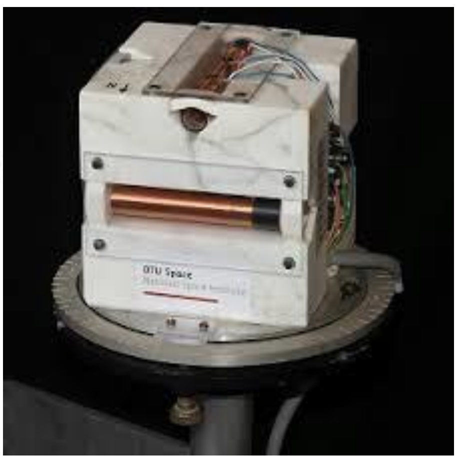
1. Fluxgate magnetometer

The most common type of magnetomers is fluxgate.



Two coils are winded around a ferromagnetic core. An alternating current is fed to the primary coil. If an external magnetic field is present the induced field is limited to one direction by the hysteresis of the core material. The difference between the inducing and the induced fields gives a signal that can be observed. The signal is observed with the pick-up coil.





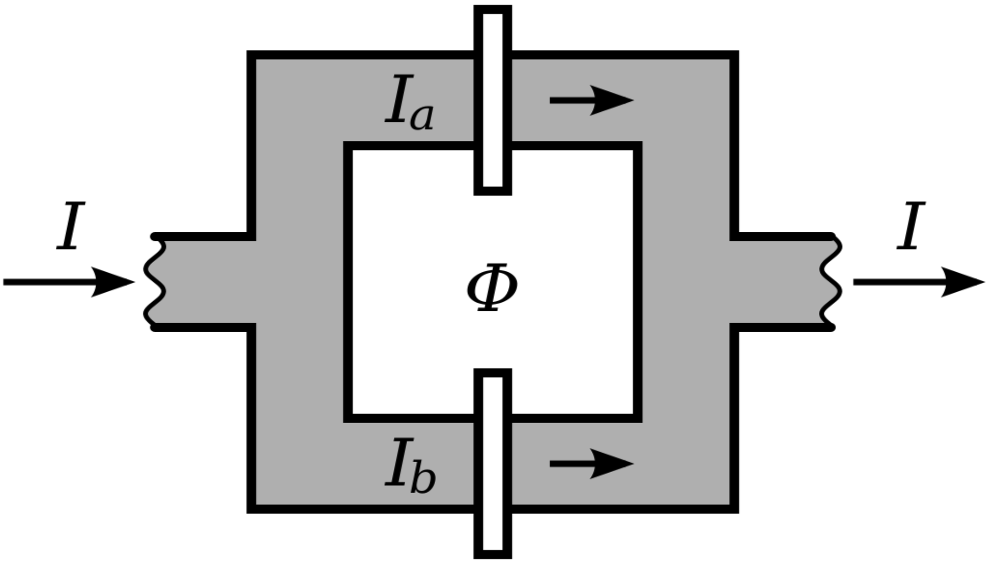
On the left is a ring-core sensor which has lower noise that the bar type. On the right is the sensor made by the Danish Meteorological Institute. Here the sensing elements are set in a marble cube and compensating coils are winded around the fluxgate sensors.

Ukrainian LEMI-025 magnetometer that record correct one-second values.

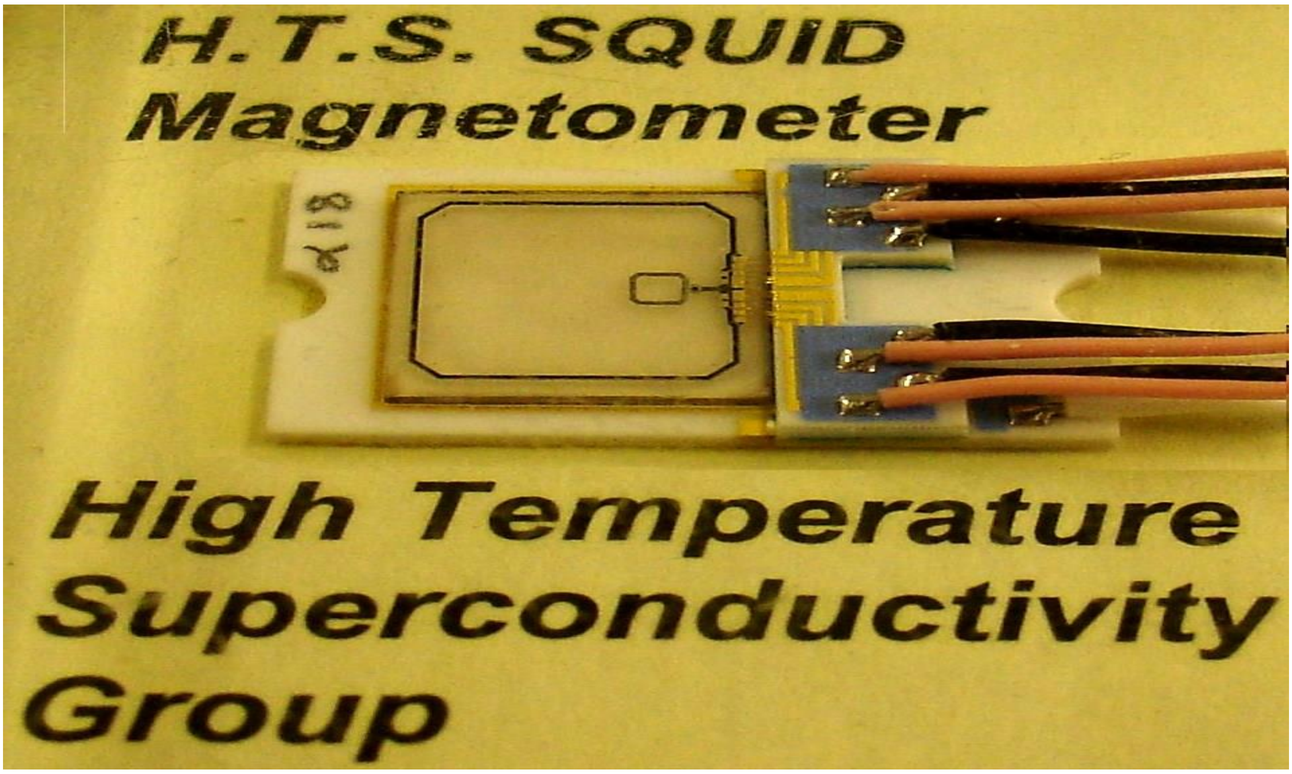
Resolution along each component: **at 0.1-second file and Flash card data**	**0.001 nT**
Temperature drift	**< 0.2 nT/°C**
Noise level at 1 Hz	**< 10 pT rms**
Components orthogonality error	**< 30 min of arc**
Components orthogonality error after calibration	**< 2 min of arc**
Sample rate	**1 per second**
Frequency band for 10 per second data output	**DC – 3.5 Hz**
Digital output	**RS 232**
Power supply	**12 V**

2. SQUID magnetometer

The superconducting quantum interference device (SQUID) consists of two superconductors separated by thin insulating layers to form two parallel Josephson junctions. The device may be configured as a magnetometer to detect incredibly small magnetic fields -- small enough to measure the magnetic fields in living organisms. Squids have been used to measure the magnetic fields in mouse brains to test whether there might be enough magnetism to attribute their navigational ability to an internal compass.

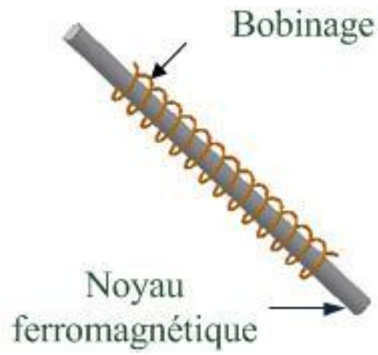


SQUIDs are sensitive enough to measure fields as low as 5 a T (5×10^{-18} T) within a few days of averaged measurements.[1] Their noise levels are as low as 3 fT·Hz$^{-½}$.



3. Induction coils

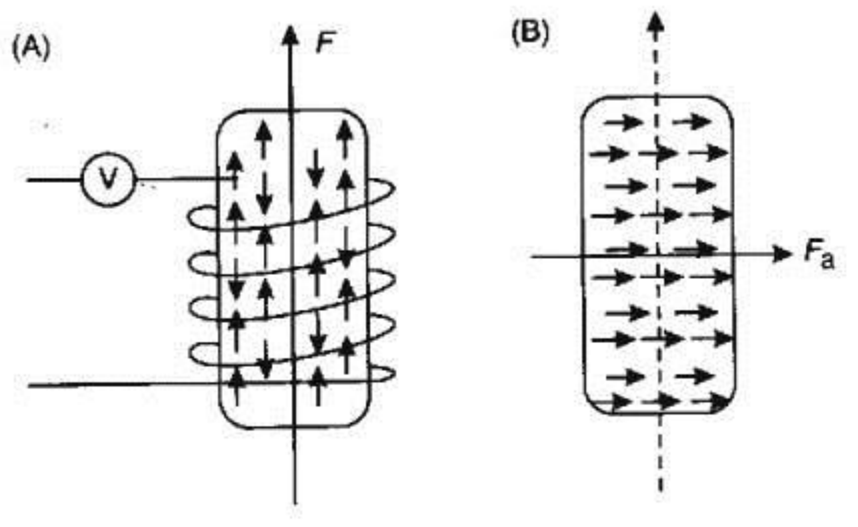
Induction sensors (also known as search coils), because of their measuring principle, are dedicated to varying magnetic field measurement.



Induction sensor constituting with a winding (orange) surrounding a ferromagnetic core.

Frequency band of received signals	1 –70000 Hz
Shape of transfer function	linear - flat
Transfer function corner frequency	20 Hz
Magnetic noise level, pT·H$^{-1/2}$: at 1 Hz at 10 Hz at 10 kHz at 100 kHz	 ≤ 5 ≤ 0.2 ≤ 0.005 ≤ 0.01
Transformation factor error: at flat part of band pass without edges at full band pass edges and corner frequencies	 ≤ ±0.3 dB ≤ 3 dB
Power supply voltage	±(6...12) V
Mass	1.7 kg

5 Proton precession magnetometer

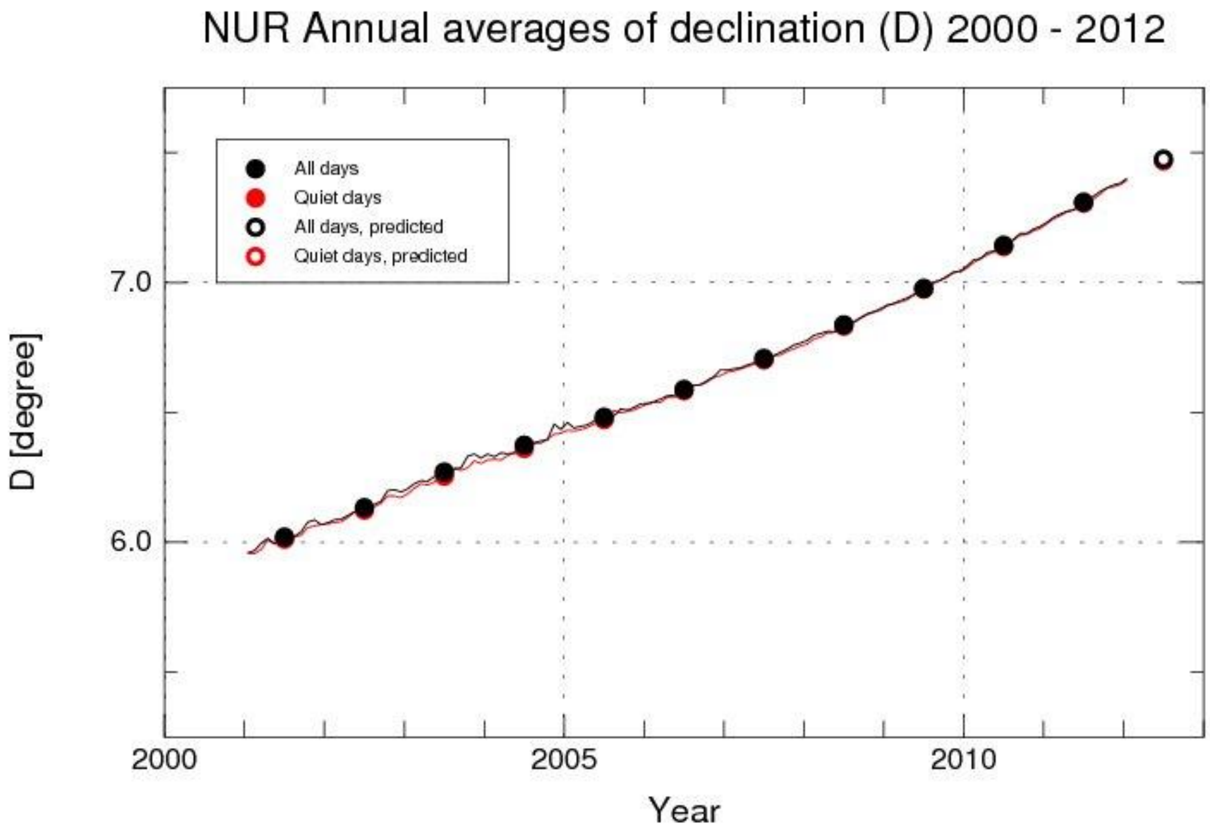


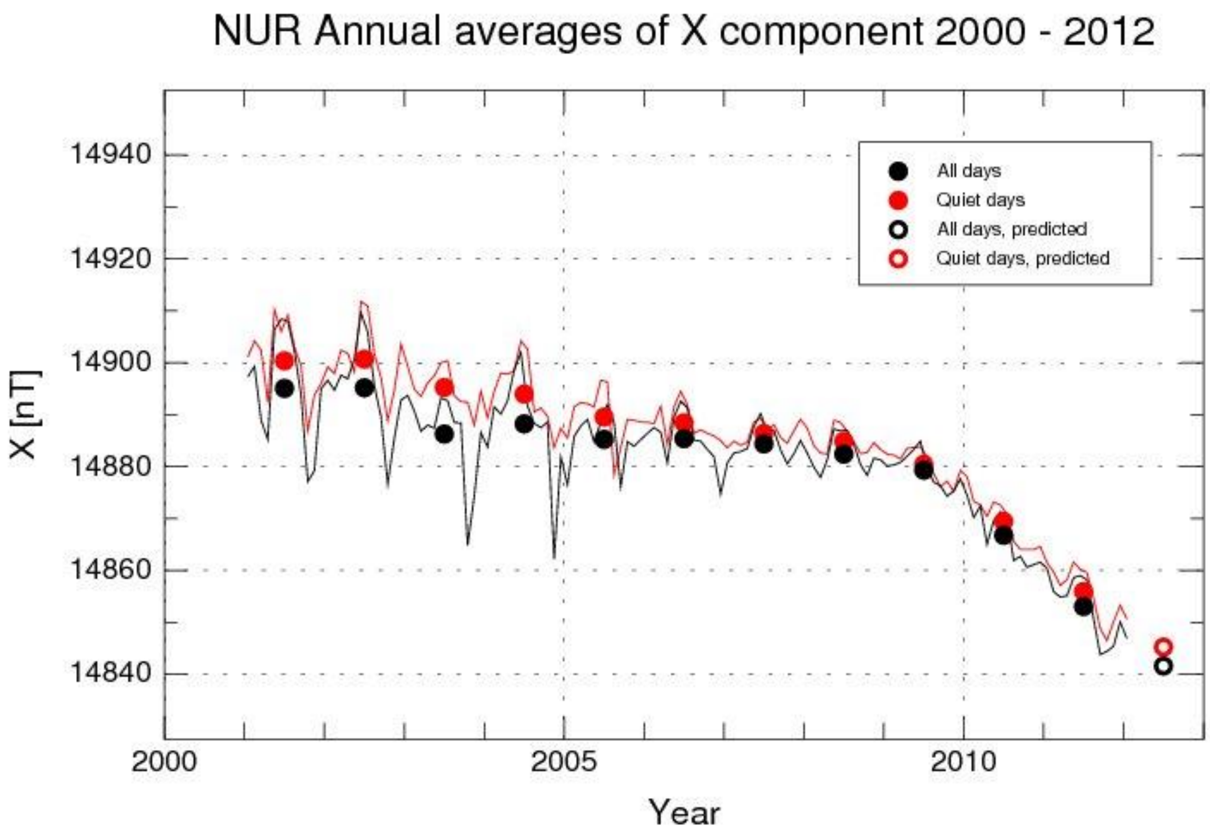
A proton magnetometer measure the total magnetic field strength and is not very sensitive to direction.

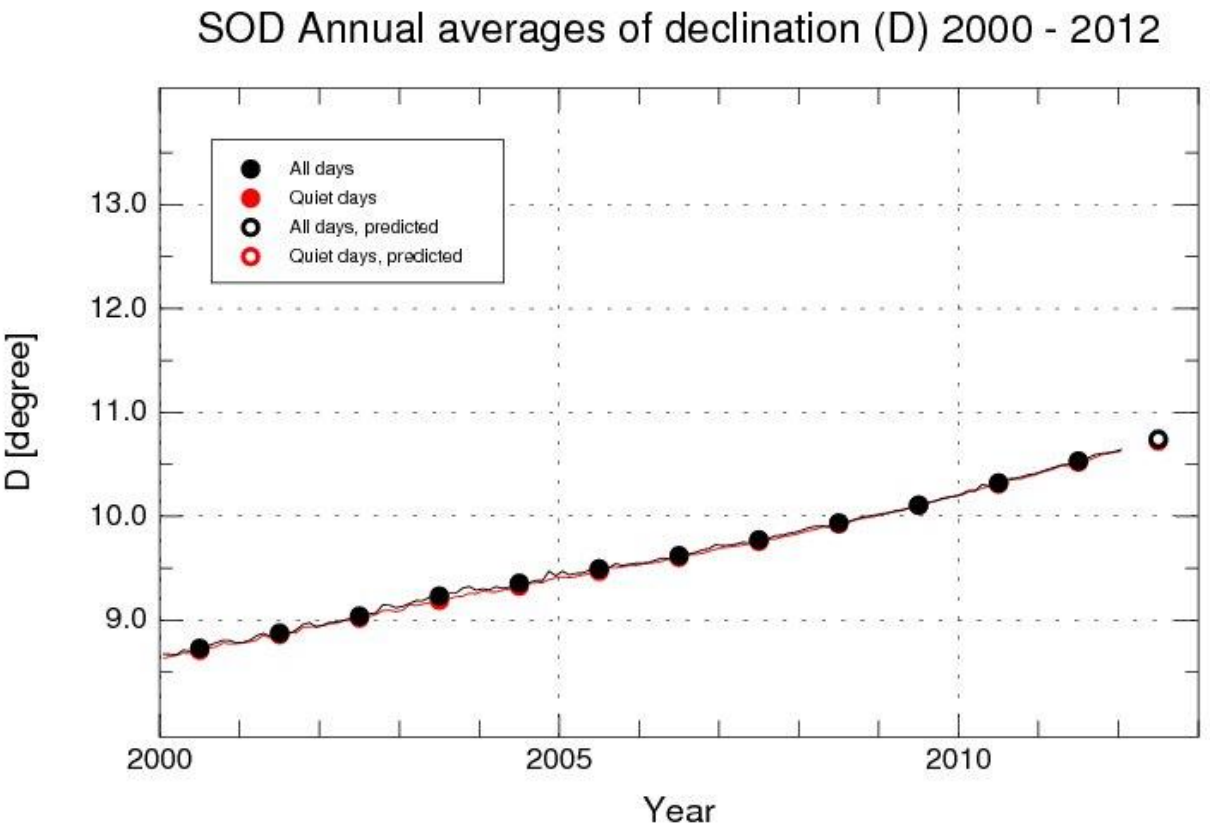
In proton magnetometers a direct current flowing in a solenoid creates strong magnetic field around a hydrogen-rich fluid (kerosine), causing some of the protons to align themselves with that field. The current is then interrupted, and as protons realign themselves with the ambient magnetic field, they precess at a frequency that is directly proportional to the magnetic field. This produces a weak rotating magnetic field that is picked with inductor, amplified electronically, and fed to a digital counter whose output is typically scaled and displayed as field strength.

Sensitivity: 0.022 nT / √Hz
Resolution: 0.01 nT (gamma)
Absolute Accuracy: 0.2 nT
Dynamic range: 20,000 - 120,000 nT
Long term stability: <0.05 nT/year
GSM-90F1: 1 sample /1 sec.
GSM-90F5: 5 samples / 1 sec.
Power: 12V 200mA max., 40mA average
RS232C parameters: programmable

IMAGE magnetometer network


NUR Annual averages of declination (D) 2000 - 2012
All days
Quiet days
All days, predicted
Quiet days, predicted
D [degree]
7.0
6.0
2000
2005
2010
Year


NUR Annual averages of X component 2000 - 2012
All days
Quiet days
All days, predicted
Quiet days, predicted
X [nT]
14940
14920
14900
14880
14860
14840
2000
2005
2010
Year



SOD Annual averages of declination (D) 2000 - 2012
All days
Quiet days
All days, predicted
Quiet days, predicted
D [degree]
13.0
12.0
11.0
10.0
9.0
2000
2005
2010
Year

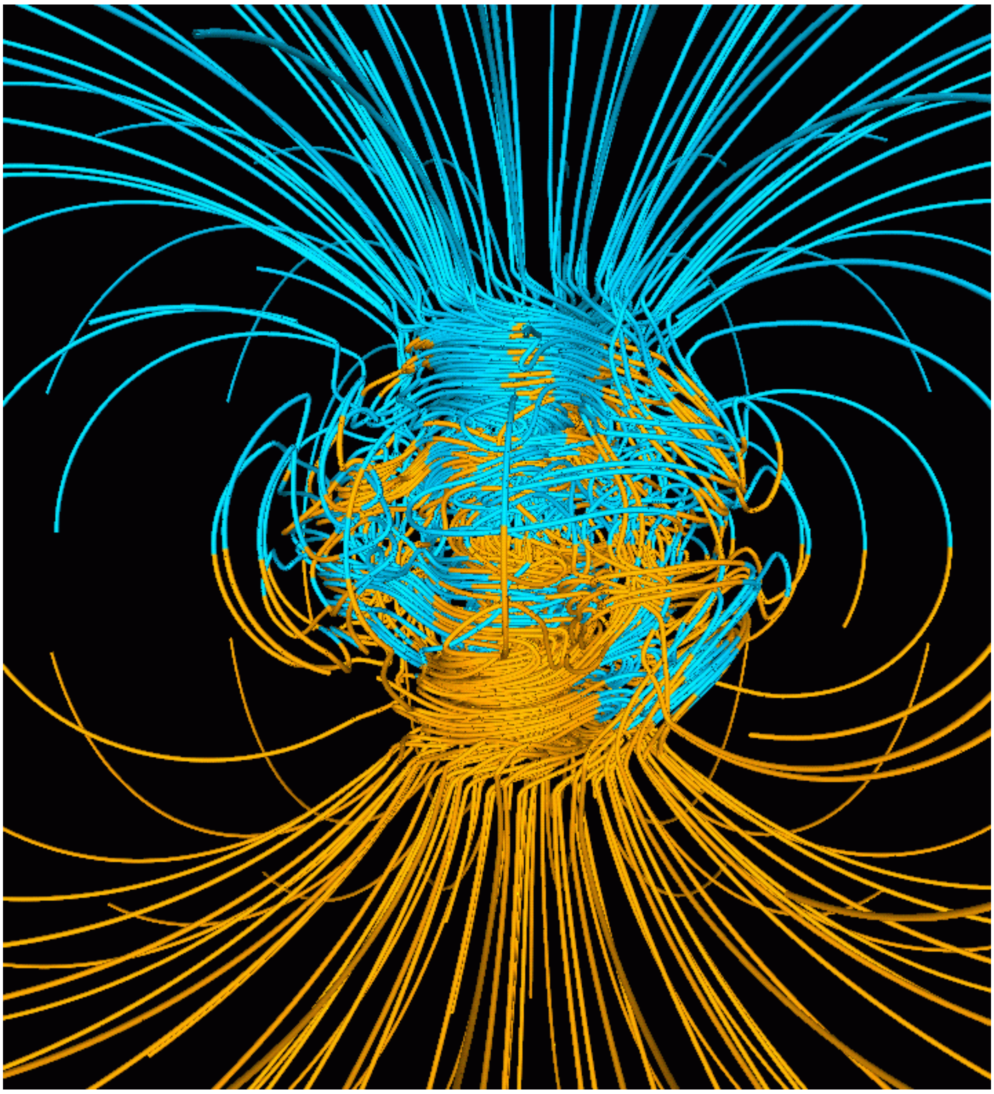


IMAGE magnetometrit + NUR + Gasum

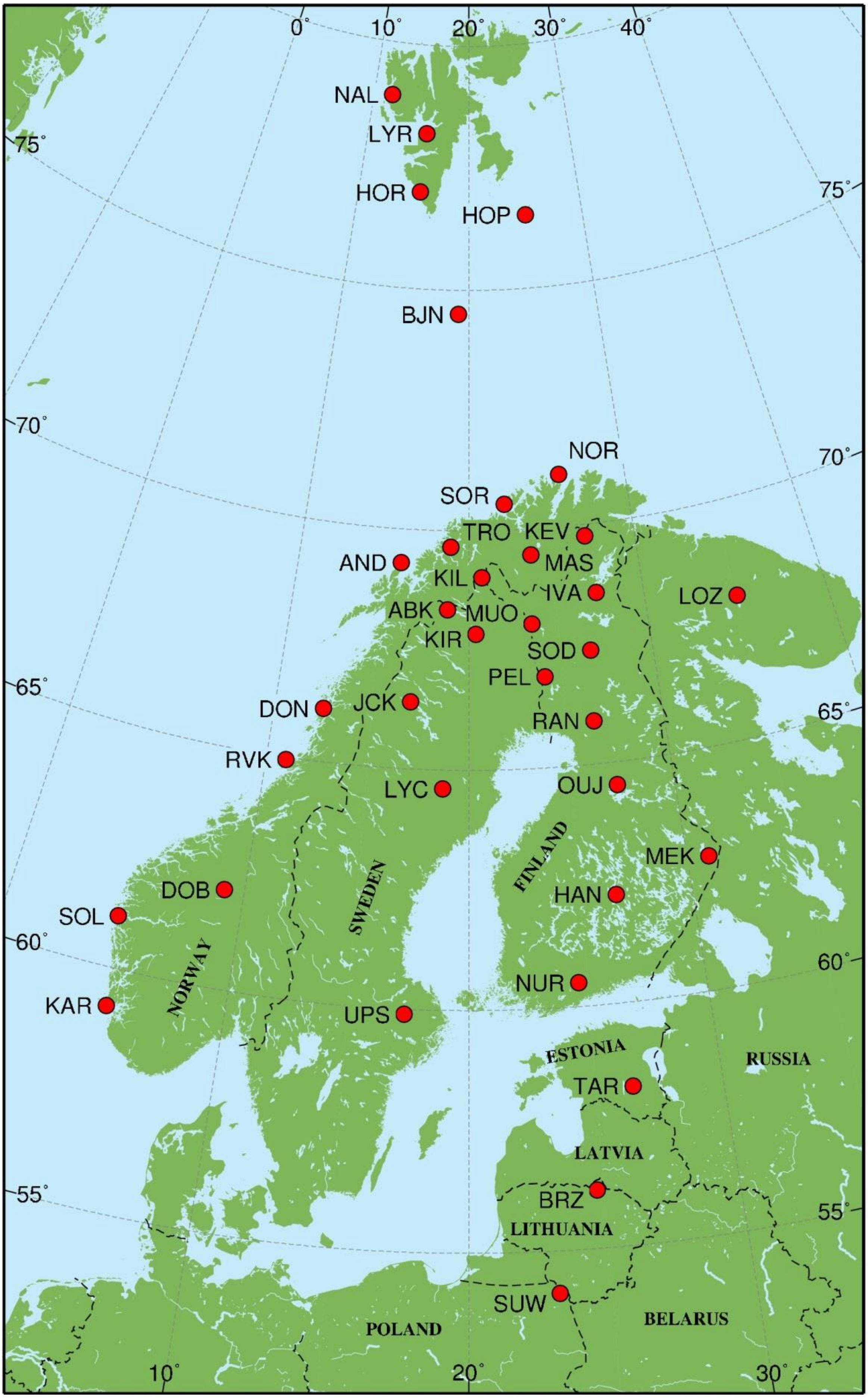
Asema	Malli	Sarja nr.	Asemalla	Sx *	Sy	Sz	X<->Y	X<->Z	Y<->Z
Kevo	Suspended FGE	S0197, E0237	2000 ...	38149 155,1	38593 155,0	38848 154,7			
Masi	LEMI 004F	OUL02	2004 ...	497,5	498,8	498,9	89,63	89,78	90,44
Ivalo	FGE	S102, E102	2000 ...	37636 75.280	37909 75.820	37149 74.300	90.07	89.58	89.51
Kilpisjärvi	LEMI 004F	11	2001 ...	671.0	668.1	672.7	89.99	90.25	90.79
Muonio	LEMI 008	N012	2003 ...	666.0	666.7	665.5	89,75	89,47	90,23
Pello	Suspended FGE	S0198, E0221	2000	38249 76.80	38573 76.80	38660 76.80	89.59	90.01	90.00
Ranua	LEMI-025	37	2014-10...22						
Oulujärvi 06.2013 alk.	(FGE) Susp. LEMI-025	S0121, E0121 30	1992-2013 2013	37607 0.9981	37456 0.9981	37525 0.9985	89.95 90.17	90.12 89.64	89.95 89.70
Mekrijärvi 14.8.2013 alk.	(LEMI 004) LEMI 004	01 02	2006-2013 2013	499.3 498.4	498.5 497.8	498.0 497.2	89.59 89.702	90.20 90.259	89.55 89.818
Hankasalmi	FGE	S0122, E0222	2005 ...	37647 76.80	37721 76.80	37465 76.80	90.03	90.02	90.04
Nurmijärvi	Suspended FGE (Lemi 004F) LEMI-025 GSM-90	S0133, E0193 02 12	1995 ... 2010-2013 2013 .... 2013	37520 75.04 498.4 0.9977	37251 74.50 497.7 0.9978	37440 74.88 497.3 0.9972	90.07 89.70 89.75	90.01 90.25 89.52	90.03 89.81 90.17
Tartu	Suspended FGE	S0207, E0256	2001 ...	38765 155.06	38761 155.04	38666 154.66	89.96	90.09	89.99
Birzai	LEMI-025								
Suwalki	LEMI-025								
Mäntsälä	LEMI 004F	03	2004 ...	498.4	498.6	498.0	89.81	90.30	89.74
Varalla	FGE	S0121, E0121	1992	1.0001	1.0000	0.9996	89.98	90.11	89.95

* FGE:n yksiköt: nT/mA and kohm

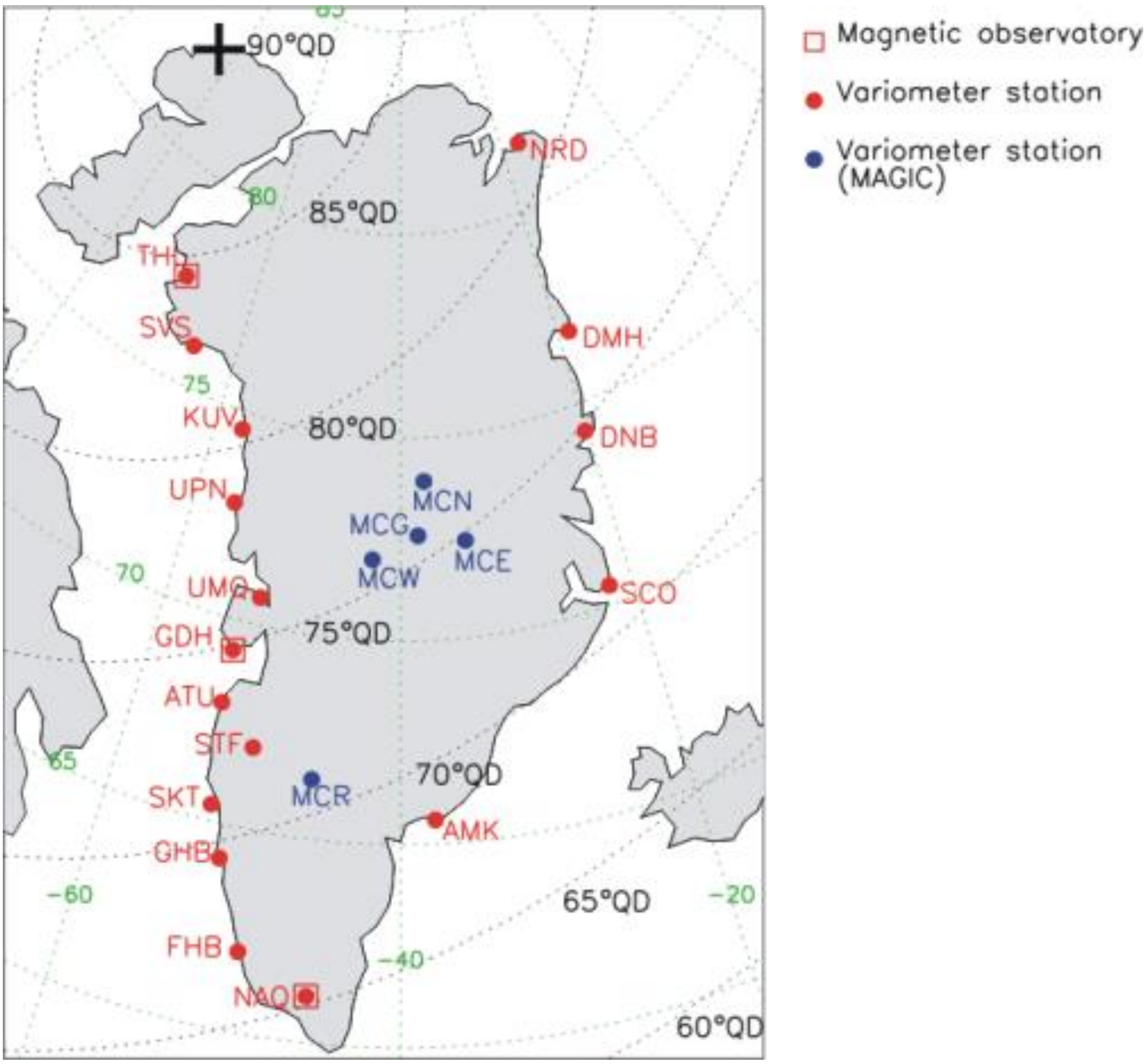
* LEMI:n yksikkö: nT/V

* LEMI-025:n yksikkö nT/nT

Suluissa olevat magnetometrit on poistettu asemilta.



0°
10°
20°
30°
40°
75°
70°
65°
60°
55°
NAL
LYR
HOR
HOP
BJN
NOR
SOR
TRO
KEV
AND
MAS
KIL
IVA
LOZ
ABK
MUO
KIR
SOD
PEL
DON
JCK
RAN
RVK
LYC
OUJ
MEK
FINLAND
DOB
SWEDEN
HAN
SOL
NORWAY
NUR
KAR
UPS
ESTONIA
RUSSIA
TAR
LATVIA
BRZ
LITHUANIA
SUW
BELARUS
POLAND



90°QD
85°QD
80°QD
75°QD
70°QD
65°QD
60°QD
80
75
70
65
-60
-40
-20
THL
SVS
KUV
UPN
UMQ
GDH
ATU
STF
SKT
GHB
FHB
NAQ
NRD
DMH
DNB
SCO
AMK
MCN
MCG
MCE
MCW
MCR
Magnetic observatory
Variometer station
Variometer station (MAGIC)

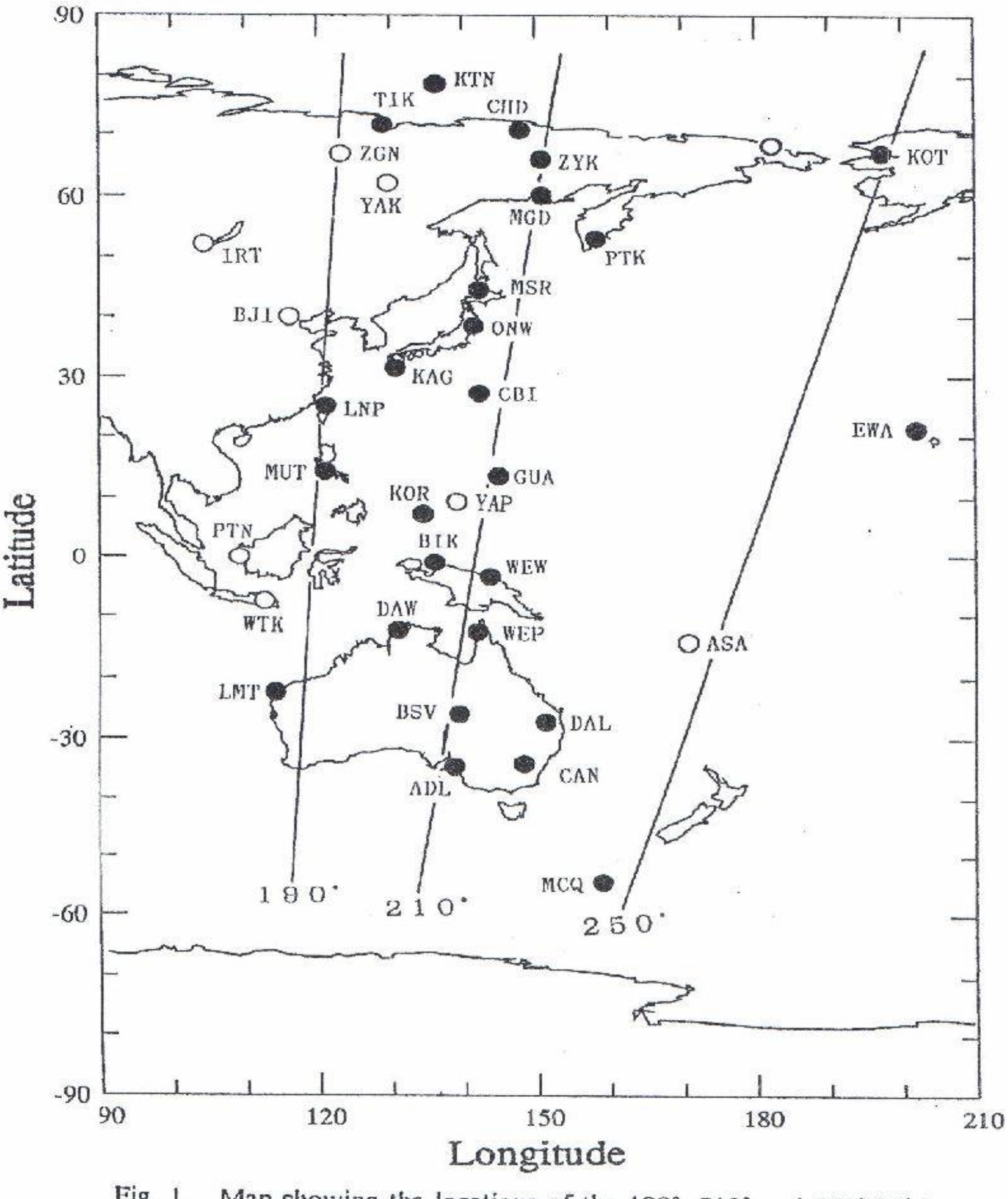


Fig. 1. Map showing the locations of the 190°, 210° and 250° MM chain stations in geographic coordinates (see Table 1).

Calibration system

At the Numijärvi Geophysical Observatory we have an accredited magnetometer calibration system. It is used to calibrate three-component fluxgate magnetometers. I will describe the Nurmijärvi Magnetometer Calibration Facility (abbreviation NuMCF) and present a calibration of one satellite magnetometer of Lusospace, Lisbon Portugal. The NuMCF is part of the magnetic calibration and test laboratory (NuMCTL) of the Nurmijärvi observatory of the Finnish Meteorological Institute, comprising of magnetometer and sight compass calibrations and compass swing base measurements at airfields.

The three axes coil system is shown in Fig. 1 and consists of three sets of four square coils with side lengths from 1.6 to 2.2 meters. The frame is made of aluminum. Two inner coils have 22 turns of 2 mm diameter copper wire and two outer coils have 42 turns of 1 mm wire. The coils are placed on a 70 x 70 cm^2 top of concrete coming up to the floor level of the calibration room. A pillar, made of glass bricks and a marble plate on top of it, is standing on the concrete basement. The pillar serves as a non-magnetic stable base for the tested instruments.

Theoretically, the *Alldred and Scollar* (1967) coil system of this size can produce uniform fields with errors less than 0.001 % in a volume with diameter of about 30 cm at the center of the system. A calculation based on real dimensions of the Nurmijärvi coil system, give 18 cm for the corresponding diameter for Y-component, 25 cm for X and 30 cm for Z.

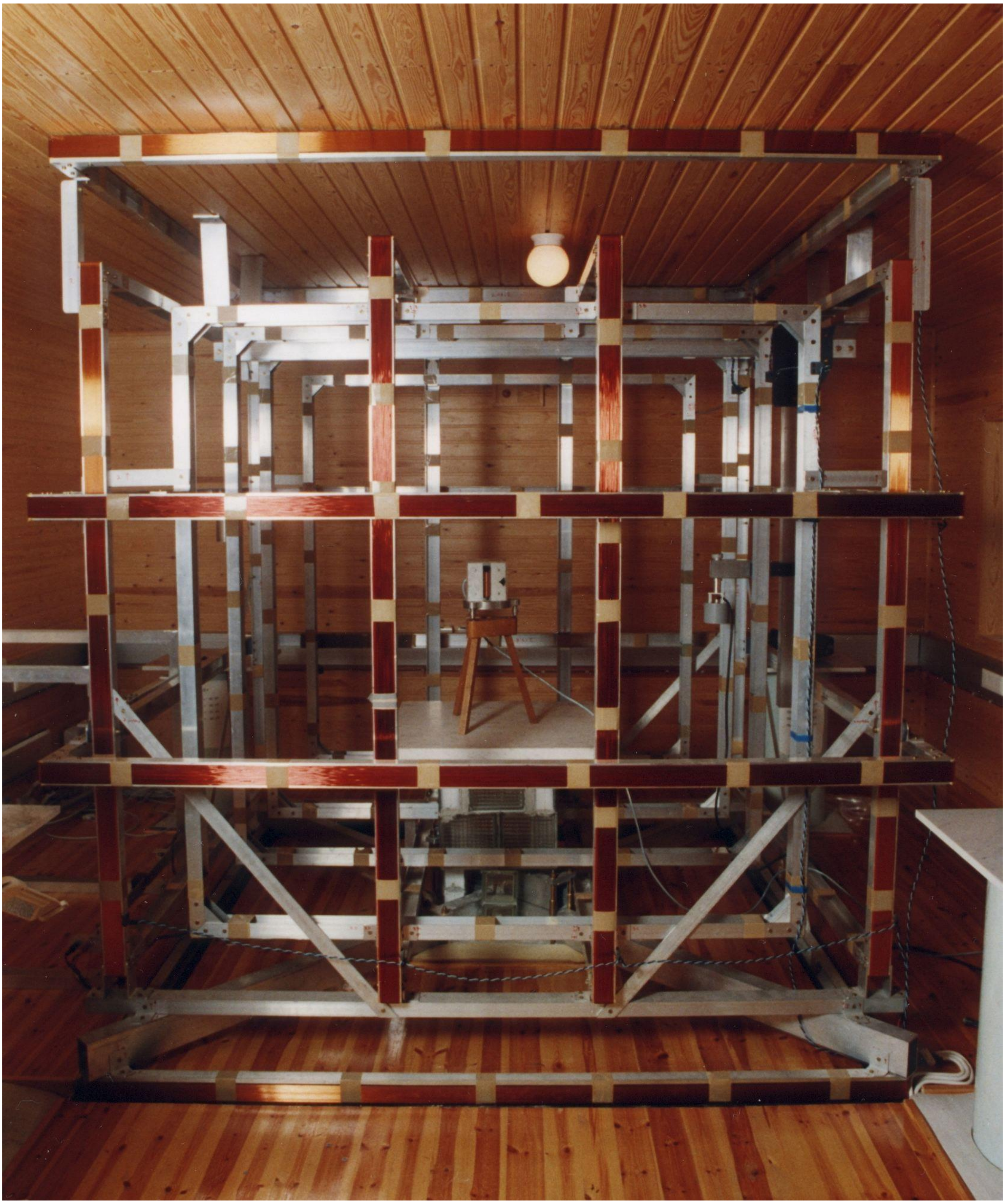


Fig. 1: Calibration coil system of the Nurmijärvi Geophysical Observatory.

The magnetic directions of the coil system were determined with a DI-fluxgate, a non-magnetic theodolite having a fluxgate sensor fastened to its telescope (*Kring-Lauridsen*, 1985).

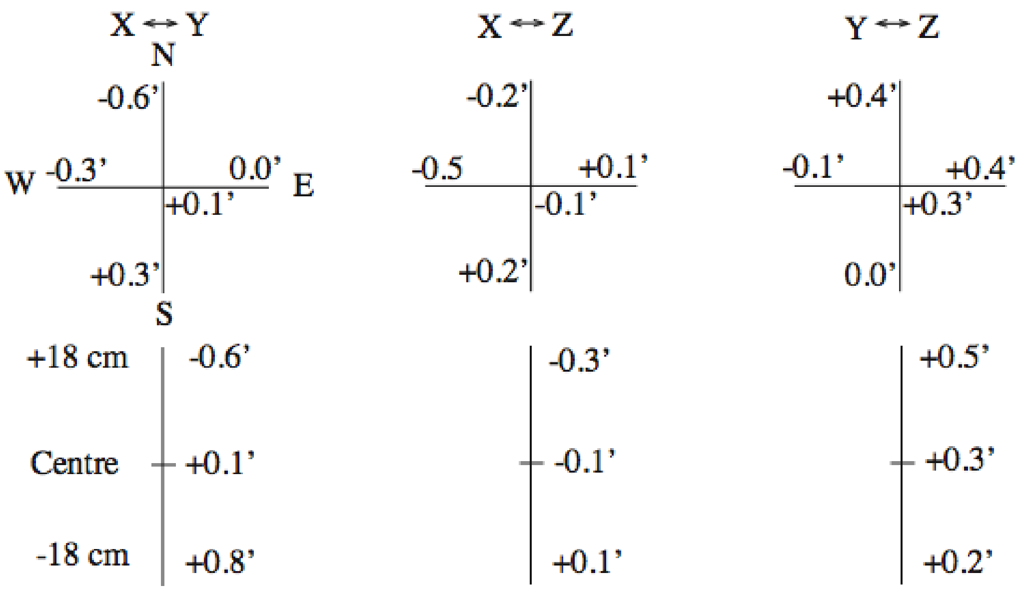


Fig. 2. Angle errors between the orthogonal magnetic fields in the center of the coil system and 15 cm to north, east, south and west (above) and 18 cm above and below the center (below).

The coil constants were measured by using a proton magnetometer in the centre of the coils. The Earth's field of two of the three components was first compensated to a value close to zero. Then large positive and negative fields were generated in the third component and the field in the centre of the coils was measured. With this method the coil constants can be measured with accuracy of ±0.002 %. This measurement is done once in every year and the values (Nov. 2006, 20 °C) were in [nT/mA]: X: 42.401, Y: 48.275 and Z: 36.970. The coil constants have temperature dependencies of -0.0025 %/°C for X component and -0.0020 %/°C for Y and Z components.

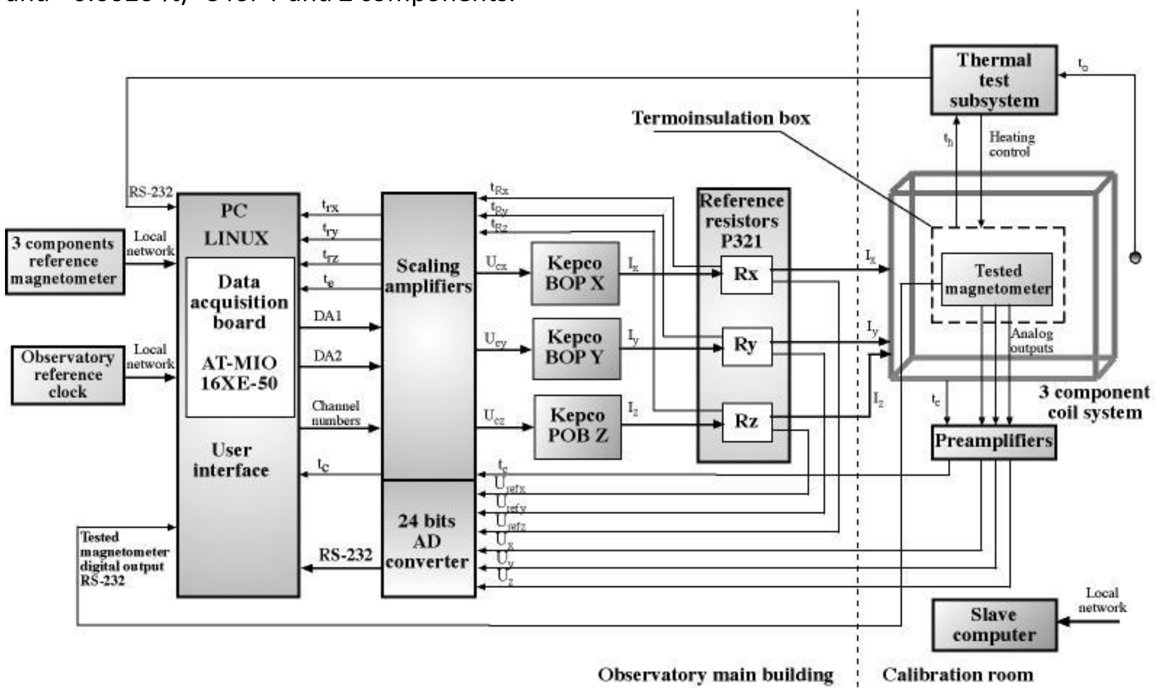
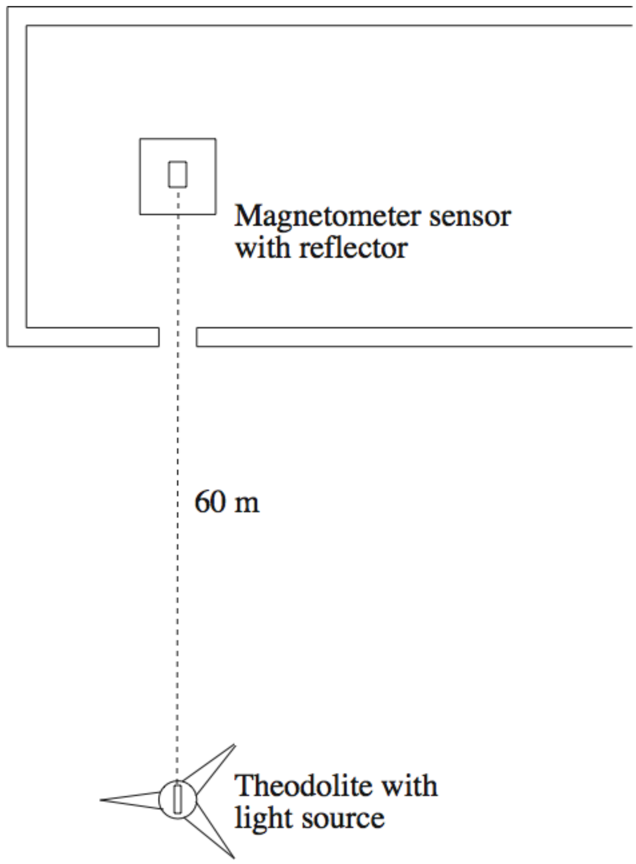


Fig. 3. Funtional diagram of the magnetometer calibration system.

Often the exact knowledge of the orientations of the magnetometer sensor's magnetic axes with respect to the sensor's mechanical axes is needed. With this information the sensor can later be installed e.g. in a satellite so that the true magnetic directions of the magnetometer sensor are known with respect to reference directions of the satellite. At NuMCF a theodolite can be installed on a pillar outdoors 60 m south from the coil system and along the magnetic South axis of the X-coils. By using a light beam from the theodolite (see Fig. 4) and a mirror fixed to the magnetometer sensor (in the centre of the coil system), the orientation of two mechanical axes of the sensor can be measured with accuracy better than ±0.03 °. The third axis is measured with a spirit level.



The temperature variation is generated in a thermally insulated box (Fig. 5) that has a square hole in the bottom for a marble cube. The heating elements are fixed to the marble and the tested magnetometer sensor is standing on the cube. The purpose of this arrangement is to avoid tilting of the underlain pillar due to heating or cooling. The box can be heated up to +60 °C and cooled by using dry ice down to about –30 °C.

The estimation of the uncertainty of the measurements is based on the **EA-4**/02 publication of the *EAL Committee 2* (1999) of the European co-operation for accreditation. The combined standard uncertainties for the current measurement are:

$u(I_X)$= ±0.0036 mA

$u(I_Y)$= ±0.0034 mA

$u(I_Z)$= ±0.0049 mA

And the standard uncertainties of the coil constants:

$u(S_X)$ = ±0.00092 Nt/mA

$u(S_Y)$ = ±0.00099 Nt/mA

$u(S_Z)$ = ±0.00109 Nt/mA

The uncertainty budget for the X-component is as follows:

Quantity X-comp.	Estimate x_i	Standard uncertainty $u(x_i)$	Probability distribution	Sensitivity coefficient c_i	Contribution to stand. uncert. $u_i(y)$
I	80mA	0.0036mA	U-shape	0.0063nT/(mVmA)	0.000023nT/mV
S	42.40nT/mA	0.0009nT/mA	normal	0.012mA/mV	0.000011nT/mV
U	6784mV	0.06mV	normal	-0.00007nT/mV^2	-0.000004nT/mV
B	3392nT	0.16nT	normal	0.00015 /mV	0.000024nT/mV
T	0.5nT/mV				±0.000035nT/mV ±0.007 %

After making an uncertainty budget for all the components we get the standard uncertainties of the sensitivity coefficients:

$u(T_X)$ = ±0.007%

$u(T_Y)$ = ±0.007%

$u(T_Z)$ = ±0.008%

The **EA-4**/02 publication for calibration laboratories states the use of an expanded uncertainty, obtained by multiplying the standard uncertainty u by the coverage factor k = 2. The assigned expanded uncertainty corresponds to a coverage probability of approximately 95 %. Here the multiplication with k = 2 gives the expanded uncertainty of ±0.02 % for the transformation coefficients of all the components.

u(T) = ±0.02 %

For the angles between the components of a three-component magnetometer the corresponding uncertainty is ±0.02 degrees.

Data processing

At the Observation Services of the Finnish Meteorological Institute all 10-second data from the IMAGE-stations is checked manually. Timing errors and external disturbances are removed.

There after the data is transferred to the open database where anyone can fetch it.
https://ilmatieteenlaitos.fi/avoin-data