RECOMMENDATIONS FOR EUROPEAN MAGNETIC REPEAT STATION SURVEYS

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Introduction

These recommendations are the result of a European repeat station meeting held at the Niemegk observatory on February 20−21, 2003.
Main aims of geomagnetic repeat station surveys are short scale secular variation studies and updating of high resolution magnetic models and charts. Detailed magnetic anomaly maps provide invaluable insight into the magnetic structure of the Earth’s crust, which is closely connected to its geological structure. The origin of short spatial wavelength secular variations remains puzzling. It may be due to electrical conductivity anomalies and/or to time varying magnetization. The dense magnetic observatory and repeat stations of Europe offers the best opportunity for these kinds of studies, oriented towards the better knowledge of the lithosphere and upper mantle. However, one main difficulty is that the spatial and temporal distribution of repeat station and ground vector surveys has been quite inhomogeneous and that it was almost impossible to obtain a high quality consistent picture of the geomagnetic field and its secular variation for the whole of Europe.
Repeat station surveys traditionally are carried out separately in each country. The spatial wavelengths of measurable secular variation, however, generally are large compared to the dimensions of individual countries. Moreover, spatial extrapolation beyond the actual measurement area is not recommended due to its rapid loss of accuracy. Therefore it is desirable to study a combination of data from several countries. It became very obvious in the discussions at the repeat station meeting that there is a high interest in obtaining more unified results.

Another important point of the discussions had been formulated before by Newitt et al. (1996): "The most important consideration when conducting repeat−station surveys is to achieve a high level of accuracy. Repeat data must be at least good enough to improve the accuracy of SV models produced from observatory data alone. If they are not accurate enough to do this, then the effort expended on repeat measurements is wasted [?]. [?] **It is more valuable to obtain accurate data at a few, well−distributed stations, than to sacrifice accuracy in order to occupy more stations.**"

Comprehensive information on magnetic repeat station surveys and on obtaining high accuracy results of observations may be found in this "Guide for Magnetic Repeat Station Surveys" by L.R. Newitt, C.E. Barton and J. Bitterly. The Guide has been published by the International Association of Geomagnetism and Aeronomy (IAGA), Working Group V−8: Analysis of Global and Regional Geomagnetic Field and its Secular Variation, 1996, and can be obtained from the IAGA Secretary−General.

This report tries to summarize recommendations with respect to the European countries. We want to give a guideline for surveys carried out in the countries participating in the effort to obtain homogeneous European repeat station surveys to obtain results of comparable and high standard. The accuracy of a result at one station can be estimated from the reproducibility of the results of the individual measurements during the occupation of that station. In particular the schedules for doing the measurements are only guidelines, you should judge from your experience how many series of measurements are needed at one station to obtain a high−accuracy result. Newitt et al. (1996) state as typical mid−latitude errors of the individual field elements

20’’ (0.005°)	for D and I
1.5 nT	for H
1.0 nT	for Z
0.5 nT	for F.

Magnetic repeat stations distribution and reoccupation rate

The average distance from one station to another should be no larger than 200 km (Newitt et al., 1996) and a mean distance of about 125 km was considered to be desirable at the Niemegk meeting. While a repeat interval of one year is desirable, an interval of two years is considered to be a good compromise between expense and value of the results. Longer time intervals are not recommended. For secular variation determination, it is more valuable to have denser time series at fewer stations than sparse time series at a larger number of stations. The same is true for accuracy: In case the survey cannot be performed at all repeat stations in a country in one year, it will be more valuable to obtain accurate data at a subset of regularly distributed stations, than to sacrifice accuracy in order to occupy more stations .

Choosing locations for repeat stations

− The magnetic repeat station has to be located in a magnetically undisturbed place, far away from electric railway lines, electric power lines, factories and other sources of magnetic disturbances.

− The magnetic gradient at the chosen site should be less than 3 nT/m. (Check by doing a cross profile across the chosen site with the PPM, also check that the vertical gradient at the site is small.)

− The site of observations should be marked (stabilized) with a permanent nonmagnetic marker. (There are several more or less complicated ways to do this: Sometimes geodetic markers might be directly used, a concrete slab or actual pillar can be installed, or you may just put a nonmagnetic aluminium nail in the ground. Just make sure you and anyone using your description will be able to find the marker again. Note: Hand−held GPS receiver locations are generally considered to be not accurate enough to make a marker dispensable!)

− At least two azimuth reference marks should be chosen more or less perpendicular to each other at a distance of at least 200 meters from the site. Keep in mind that you want to be able to see them again every time you re−occupy the station, so pay attention to e.g. vegetation and do not choose marks too far away which might be hard to see in hazy weather.

− A detailed topographic description of the site and reference marks should be made, as well as a description of the access to the site. Photographs can help, too. The determination of the geographical coordinates and elevation using a topographic map and/or GPS technique is also necessary.

− The station should be named with a name recognizable on the topographic map.

This procedure is necessary to ensure that even after some decades the site can be found by the next observers and the measurements will be performed exactly in the same place as previously. In case the station has to be moved to another site, the whole procedure described above should be done from the beginning. The name of the station can stay the same but has to be distinguishable by adding consecutive numbers, roman numbers or letters.

If it can be afforded it might be useful to set up in the neighbourhood of a station a second, spare station no more than one kilometre away. The field difference should be determined upon setup and preferably again from time to time (e.g. every second survey) to ensure constancy. This will allow for an uninterrupted time series in case the main station is destroyed.

Instruments

The absolute measurements are preferably made using a DIM (declination−inclination magnetometer = DI fluxgate magnetometer) and PPM (proton precession magnetometer for intensity). If a DIM is not available, the measurements of D should be performed using a thread declinometer with two magnets, and, instead of inclination, the horizontal component H should be measured using a quartz magnetometer. The instruments should be checked and calibrated at the magnetic observatory before and after the survey. Calibration is also indispensable after any event which might have changed calibration or coefficients of the instruments.

Duration and schedule of observations

If the station is far from an observatory, if it is close to the sea or known to be on a conductivity anomaly it is preferable to use the variometer method with a three−axial variometer recording field variations during the survey near the station.

1) Reference observatory method

If no on−site variometer is available the time needed at each station preferably is about 40 hours. Measurements are done early in the morning and late in the evening to avoid the large amplitudes of diurnal variations. Measurements should not be done under disturbed magnetic conditions. An example schedule of observations is as follows:

First day
- arrival at the site in the afternoon
- approve the station: check that there are no changes (new buildings, power lines etc.) in the surrounding that might influence the measurements, check that the magnetic gradients have not changed significantly since the previous occupation, check that the station marker has not been moved (might even happen to geodetic markers!), verify the geographical coordinates, determine the geographical azimuth of the reference marks, take notes of any changes or any other useful information. Some of this might also be done on the second day between the measurements, but as in some cases a station might not be suitable anymore and will have to be moved it is a good idea to do it first.
- perform the evening measurement − at least two series of observations, with 30 minutes break between them. One series consists of two measurements of three magnetic independent components: D, I and F or D, H and F, depending on the instruments available.

Second day − perform the morning measurement − at least two series of observations,
− perform the evening measurements − at least two series of observations,
− between, do all necessary additional work and documentation that has not been done yet on the first day.

Third day − perform the morning measurements − at least two series of observations,
− after the observations are over, passage to the next station and start with the programme of measurements from the beginning.

2) Variometer method

If a portable variometer with good baseline stability is available it might be sufficient to do fewer series of measurements, although the overall occupation time of the station will not be shorter. The variometer is preferably installed within a few hundred metres of the repeat station, and a PPM is set up to record F during the whole time. Note that after setting up the variometer it will take several hours to equilibrate until stable readings are obtained. The variometer should be buried in the ground and covered with insulation to minimize temperature influence. It is easiest to set it up in D, H, Z orientation, i.e. turning it so that the recording of the Y−sensor reads 0. The Y and X sensor thus record D (in nT) and H respectively. During large magnetic disturbances these horizontal sensors will no longer measure true D and H in that configuration, but this should seldom be a problem except at high latitudes. It is still preferable to do measurements early in the morning and in the evening and under magnetically quiet conditions. However, it is essential to keep the variometer at the site until magnetically really quiet night time conditions have been recorded. Generally two to three nights are sufficient to experience such conditions for a few hours, but activity levels should be checked by a phone call to the observatory and the variometer should be kept at the station for more nights if necessary.

Example schedule for observations at a site with variometer:

First day: − arrival at station in the afternoon
− approve the station (see above)
− set up the variometer to let it reach equilibrium during the night

Second day: − perform the morning measurements
− do the additional work as above
− perform evening measurements

The variometer now will have to stay at the station for at least one, generally two to three nights more, depending on magnetic conditions. The more morning and evening measurements are done during that time, the higher the accuracy will be. However, if excellent baseline stability has been verified and the variometer has been set up carefully, a second series of measurements in the morning before leaving the station might suffice. It then is possible to do second order (lower accuracy) measurements at surrounding stations in the additional days, using the same variometer for reduction. This is of interest for example if you have by tradition a larger number of stations and do not want to give up some of them completely.

Measurements

Each magnetic measurement series consists of two independent sets. The schedule of one set is as follows:

- observations with PPM − 6 readings during 1 minute (one reading every 10 seconds),
- observation of both reference marks (in both positions of the vertical theodolite circle),
- observations with DIM (magnetic azimuth of reference mark and inclination),
- observations of the reference marks,
- observations with PPM (in the same way as at the beginning).

After the observations, a preliminary calculation of results should be done to ensure that no gross error has been made. Then, the second set is performed.

After a 30 minutes brake, the second series should be performed with the same order of observations as the first. The break is helpful to determine whether magnetic conditions are quiet from the preliminary results.

All individual results of observations in one measurement should be reduced to one (first or average) moment of observation using the standard processes applied to observatories.

The determination of the reference mark geographical azimuth may be done in the break between morning and evening magnetic survey. The method of this determination should ensure the accuracy of geographical azimuth not worse than 12 second of arc. Then, the accuracy of the D determination will depend mostly on the accuracy of the magnetic measurements.

According to the schedule without variometer, one obtains at a repeat station at least 16 individual values of three independent magnetic components measured within 3 days, while in fact only two days are needed at one station including the journey to reach the station.

During the time the PPM is not used for taking the F measurements it should be set up nearby to record F at minute−intervals, synchronized with the variometer records if an on−site variometer was installed, in order to monitor the magnetic activity. Visual comparisons between this record and the record at the variometer site or observatory used for reduction are most helpful in determining discrepancies in the short−period variations which would lower the accuracy in the reduced results.

Documentation

Readings of all observations, as well as the time of observations and other necessary information should be noted in special forms or a journal prepared before the survey.

All observation and recordings should always be done exactly in the same order. This will facilitate determining the results of the survey using computer programs.

Data Processing

This is just a brief outline of standard processing procedures. There are some points that will have to be discussed further, like how to obtain the best final result from the individual measurement series at a station or from the quiet night time values of the variometer and to which epoch to reduce the data. Traditionally the results are reduced to annual means, which makes it easy to model the data for one epoch. However, errors due to secular variation differences at repeat station and observatory are minimised, if the results are merely reduced to quiet night times (considered to provide the undisturbed internal field) close to the time of observation. Modellers working on temporally continuous models would appreciate this kind of results. We suggest to derive and publish results reduced to both, quiet nighttimes and an annual mean. The annual mean preferably is epoch .5. Not only does this seem to be the more widely used epoch now, but as the measurements generally are done in the summer months the error by differing secular variation is smaller compared to epoch .0.

Without on−site variometer:

The values from every set of measurements are reduced to "internal field values" $E_{internal}$ for the components E as follows:

$E_{internal}=E_O + E(t) - E_O(t)$

Where E_O is a quiet night time value or the annual means at the observatory used for reduction, E(t) is the value at the repeat station at the time t of the measurement and $E_0(t)$ is the value recorded at the observatory at the same time.

With on−site variometer

Like at an observatory the baseline of the variometer is determined from the absolute measurements of each set. The variometer records thus become series of absolute values. Now the magnetically most quiet night time period of a few hours is chosen. The absolute values of that time are straightforwardly the quiet night time results. To obtain an annual mean observatory, recordings are required again: the above equation is used with the difference $E(t) - E_0(t)$ now determined from the difference between these quiet night time values at the repeat station and those of the same time span at the observatory.