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New geomagnetic field observations in the South Atlantic Anomaly region

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Abstract
Three new geomagnetic observatories have been established recently around the South Atlantic geomagnetic Anomaly by GeoForschungsZentrum Potsdam(GFZ), Germany, in collaboration with other institutions. In Bolivia, the collaboration is with Universidad Mayor de San Andres, LaPaz, while Hermanus Magnetic Observatory (HMO) in South Africa has assisted with a new observatory in Namibia. The third observatory was set up on the island of St. Helena with logistical support from the IDA seismological network, University of California at San Diego, USA. All these observatories are operated remotely with a minimum amount of building infrastructure and without permanent staff. People living nearby have been trained to carry out the required absolute measurements for a few hours per week. In this paper we report on our experiences, challenges and solutions in setting up nearly automated observatories in remote locations in order to obtain high quality geomagnetic data. These new data, complemented by annual repeat station surveys in southern Africa, will provide valuable geomagnetic field information on the South Atlantic Anomaly changes in this area of extremely rapid decrease of field intensity.

Key words *geomagnetic observatories – geomagnetic data – South Atlantic*

1. Introduction

The Earth's magnetic field has a distinct dipolar structure. More than 90% of the field strength at the Earth's surface can be attributed to an axial dipole currently tilted by approximately 10.2° with respect to the rotation axis. However, the field is anomalously weak in a region centered in the South Atlantic and covering parts of southern Africa and South America. This area, where the field reaches less than 60% of the field strength at comparable latitudes, is known as the South Atlantic Anomaly (SAA, fig. 1a). It is caused by an increasing patch of opposite magnetic flux compared to the dipole direction at the core-mantle boundary (Bloxham and Gubbins, 1985) and its centre has moved from southern Africa to South America over the last 300 years (Mandea *et al.*, 2007). The local weakening in field intensity allows energetic particles and cosmic rays to penetrate much deeper into the magnetosphere and atmosphere than in other regions, resulting in significant space weather effects such as satellite outages (Heirtzler *et al.*, 2002).

The global dipole strength is currently decreasing at a very high rate (*e.g.* Gubbins, 1987; Hulot *et al.*, 2002), but the intensity change is distributed non-uniformly over the globe. Mapping the long-term global secular variation from ground observations or the difference between magnetic field models derived from

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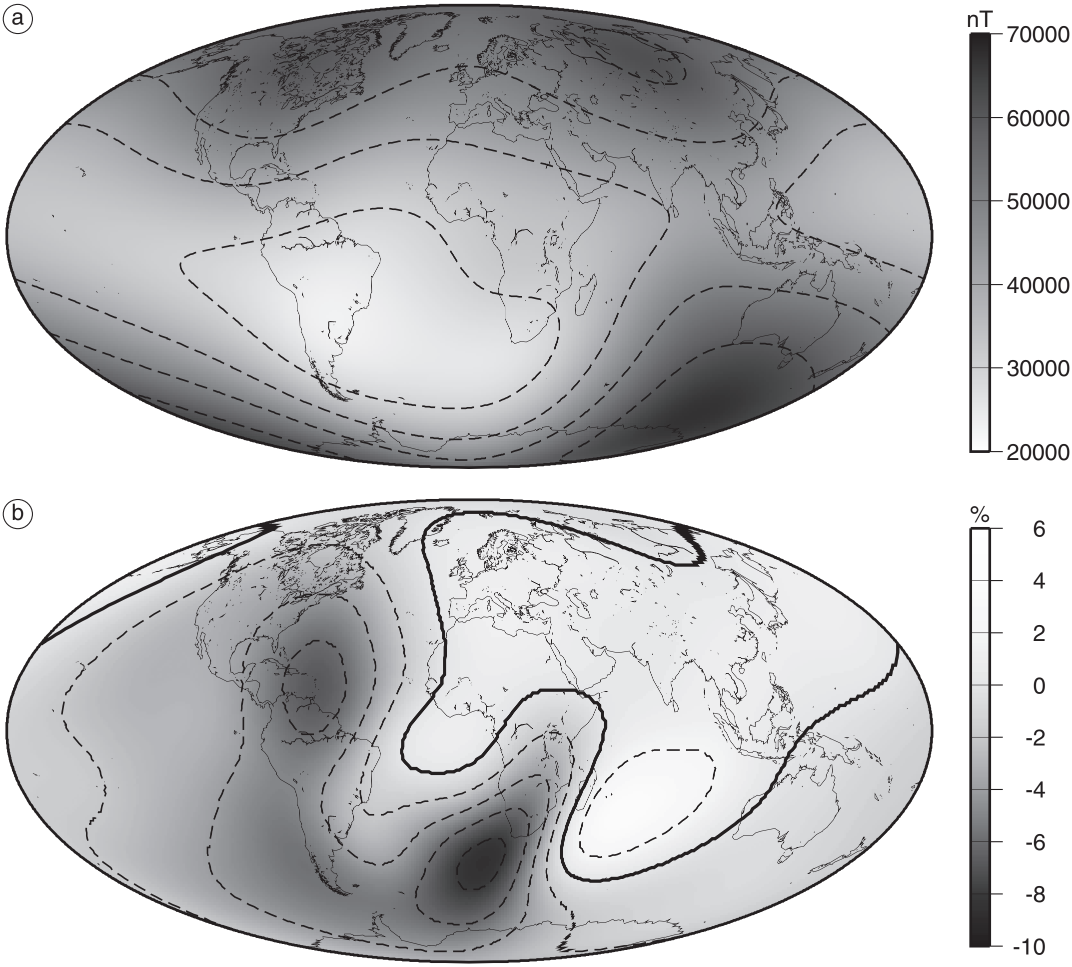

Fig. 1a,b. a) Global map of magnetic field intensity. The region of weakest intensity is known as South Atlantic Anomaly. (GRIMM Model, (Lesur *et al.*, 2008) b) Change of field intensity between 1979.85 and 2003.5 in percent (Difference between GRIMM and a model from MAGSAT data (Langel *et al.*, 1980).

Magsat (1980) and CHAMP satellite data (2000 to present) reveal that in some regions the field intensity is even increasing (fig. 1b). The strongest decrease is observed in the southern African – Southern Atlantic region. Studies of magnetic field distribution at the core-mantle boundary (CMB) have shown that a patch of reverse flux with respect to the dominating dipole direction exists (Gubbins and Bloxham, 1985), which has been growing continuously since it appeared around 1695 (Jackson *et al.*, 2000). Secular variation at the CMB is exceptionally strong beneath southern Africa, exhibiting a pattern of propagating wave-like structures (Dormy and Mandea, 2005).

Ground observatories are an important complement to the modern magnetic satellite data, *e.g.* to better constrain secular variation through longer time series, or to fill a possible temporal gap between present and future satellite missions. Due to the complementary information content in the data resulting from different distance to the sources and space-time sampling characteristics, a better characterisation of the field is possible with data from different platforms. In the south Atlantic and southern African region the network of continuously recording geomagnetic observatories is sparse. Only 3 INTERMAGNET (http://www.intermagnet.org) observatories (Hermanus, Hartebeesthoek, Tsumeb) exist in southern Africa, one on Ascension island, and five in all South America (Kourou, Huancayo, Vassouras, Trelew, Port Stanley). In addition, three observatories are in operation in that region which are not (yet) members of the INTERMAGNET programme. Two are located in Mozambique, at Maputo and Nampula, respectively. They fall under the auspices of Direccao Nacional de Geologia, Mozambique, and have recently been upgraded and are now operated in cooperation with the Institut Royal Météorologique de Belgique (IRM) and the British Geological Survey (BGS). The third observatory is Tatuoca in Brazil.

Repeat station surveys, discrete annual or bi-annual vector field measurements at additional locations, were carried out on a relatively sparse network consisting of 8 well-distributed stations in South Africa, Namibia and Botswana from 2000 to 2004 by Hermanus Magnetic Observatory (HMO). In 2005 this number increased to 40, where measurements have been done on anannual basis in a cooperation between HMO and GFZ (Korte *et al.*, 2007). Since 2000 about 15 stations have been surveyed in Mozambique by Direccao Nacional de Geologia, Mozambique, in cooperation with IRM, four repeat station values are reported for 2006 by UK Royal Navy surveyors from the HMS Endurance for southern Atlantic islands and one station on Tristan da Cunha island has been surveyed in 2004 by Ludwig-Maximilians-Universität Munich, Germany(LMU) (see Matzka *et al.*, 2009, this issue).

Repeat station measurements are an important source of geomagnetic field information to constrain main field and secular variation models in areas with sparse observatory coverage. However, the quality in terms of elimination of external field influences in repeat station data depends to a large extent on the proximity of a continuously recording observatory or good external field models based on continuous observatory data (illustrated *e.g.* by Matzka *et al.*, 2009 in this issue).

Over the last few years we have further improved monitoring the geomagnetic field around the southern Atlantic by setting up three new, remotely operated observatories. They are located in Bolivia, Namibia and on the island of St. Helena. Installing and operating remote observatories requires substantial efforts. Due to a lack of an immediate possibility to increase the number of observatories even further we therefore increased the number of annually visited repeat stations in South Africa, Namibia and Botswana. This and the new Namibian observatory are collaborative efforts of GeoForschungsZentrum Potsdam (GFZ) and Hermanus Magnetic Observatory (HMO). The Bolivian observatory is a cooperation between GFZ and the Universidad Mayor de San Andres, LaPaz (UMSA).

This paper shares our experiences in setting up and running geomagnetic observatories in remote locations (Section 1) and devising an efficient method to carry out high-accuracy repeat station surveys in large, partly remote areas (Section 2) with limited resources. The availability of the new data is described together with our conclusions.

2. New remote observatories

Traditional geomagnetic observatories are in most cases situated on relatively large properties, with several staff members working in an office building and minimum two extra buildings to record the variations and to carry out the absolute measurements, far enough away to avoid disturbances. With modern digital recording systems, data loggers and data transmission possibilities the in situ infrastructure for new observatories can be significantly reduced, and if the data are transferred to another observatory or institute for data processing, permanent staff are no longer required. The ideal case would be to install a completely automatic observatory, where no manual contribution is needed for a long period of time, say one year. GFZ has made huge efforts in this direction by

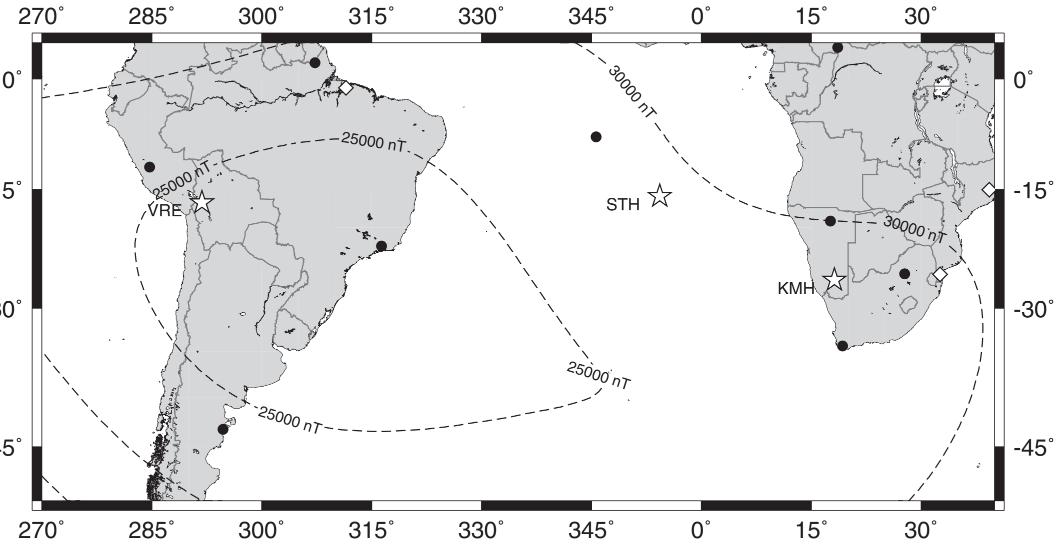

Fig. 2. Location of new observatories in the SAA region (stars): Villa Remedios (VRE), Keetmanshoop (KMH) and St. Helena (STH). Existing observatories that participate in the INTERMAGNET programme (black dots) or not (diamonds) are also shown.

the development of a new, automatic, absolute instrument, named GAUSS (Geomagnetic AUtomated System (Auster *et al.*, 2007). However, this instrument is still in an improving and testing phase and not yet available to be installed in remote observatories. At present, two important issues remain a significant challenge in the establishment of new observatories in remote locations. Firstly, the instrument location must be remote enough to ensure no technological and human disturbances, yet electric power supply and data transmission possibilities must exist. Secondly, at least one reliable person must live nearby to carry out the absolute measurements for the calibration of the continuous variation recordings once to twice a week. The manual measurements with a DI-flux theodolite require a substantial amount of care and precision to achieve the required level of accuracy (*e.g.* Jankowski and Sucksdorff, 1996). Over the last years we have gained some experience with different solutions to these challenges by establishing new observatories at Villa Remedios (VRE, Bolivia), Keetmanshoop (KMH, Namibia) and St. Helena island (STH) in the south Atlantic (UK territory). The locations of these stations in the SAA are shown in fig. 2. Note that all three abbreviations are preliminary and not yet official IAGA observatory codes.

2.1. *Villa Remedios*

Our initial plans for a modern observatory in Bolivia near La Paz were to upgrade the existing Patacamaya observatory, run by UMSA, with new instruments. However, in summer 2000, just shortly before the installation was planned, political uprisings prohibited access to the old Patacamaya observatory. The only solution then was to set up a new geomagnetic observatory in a safe area, particularly to ensure its long-term stability. In only two months colleagues from UMSA found suitable new premises at the small village of Villa Remedios and had four small clay buildings erected. The main building is occupied by a new employee of the University, who carries out the absolute measurements and takes care of the premises. The other three huts house the absolute pillar, the variation recording equipment, and the power supply (fig. 3). The geographic coordinates of this observatory are 16.77°S and 98.17°W at an altitude of 3790 m.

The continuous recording equipment consists of a suspended FGE fluxgate variometer, built by the Danish Meteorological Institute (DMI) and a GSM90 Overhauser magnetometer by Gem Systems, both sponsored by GFZ, and the data logger Flare Plus, sponsored and provided by the British Geological Survey (BGS). The time signal is obtained from a GPS receiver. For the absolute measurements a theodolite THEO-MG2KP with a DMI fluxgate sensor bought from MinGeo, Budapest, was provided by GFZ and a proton magnetometer Geometrix G826 was supplied by UMSA. Fluxgate magnetometers are very sensitive to temperature changes. In order to obtain high quality data it is therefore necessary to eliminate temperature fluctuations, even if temperature coefficients are known. However, there is no special insulation or air conditioning for any of the buildings. The clay huts proved to be sufficiently insulated under the prevailing climatic conditions at VRE. There is no significant temperature change inside the huts during a day, only a slow seasonal variation of about 6° C is observed. Its influence is recorded by the absolute measurements (cfr. fig. 4) and is therefore removed from the definitive data by means of the routine data processing.

Solar panels and a wind generator had been planned as power supply for the original Pata-

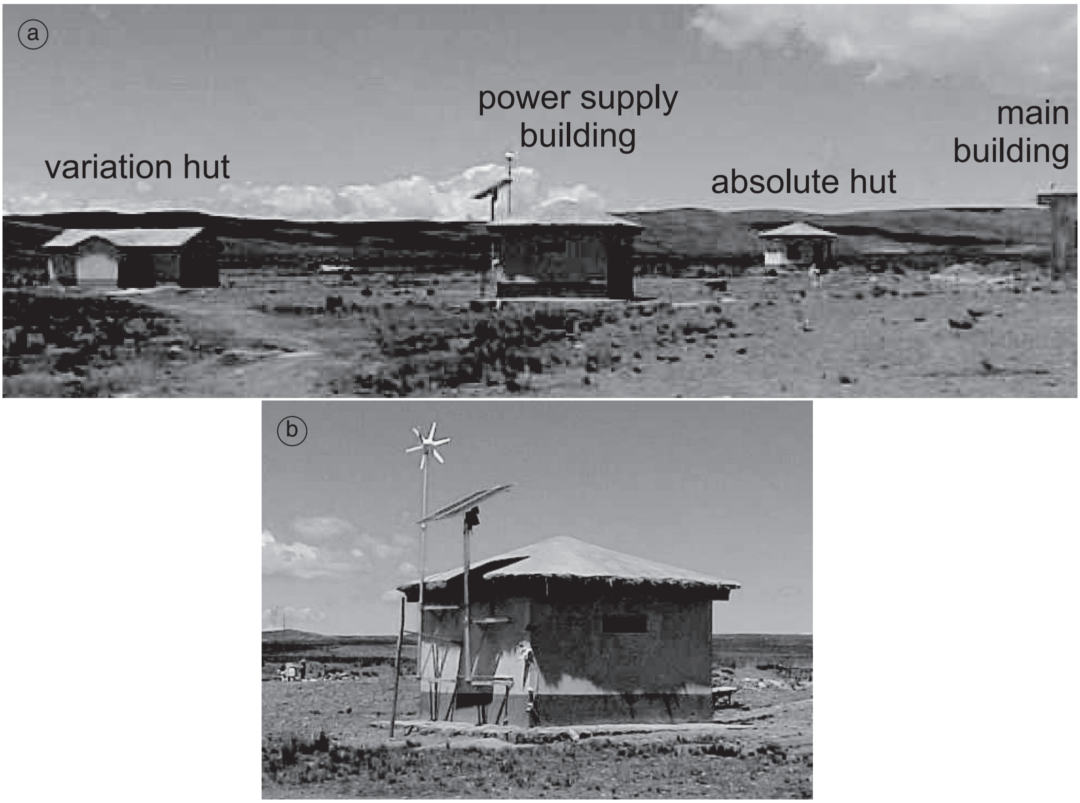

Fig. 3a,b. Observatory buildings at VRE. a) Overview over the observatory premises with a corner of the main building on the right. b) Power supply building with solar panel and wind generator.

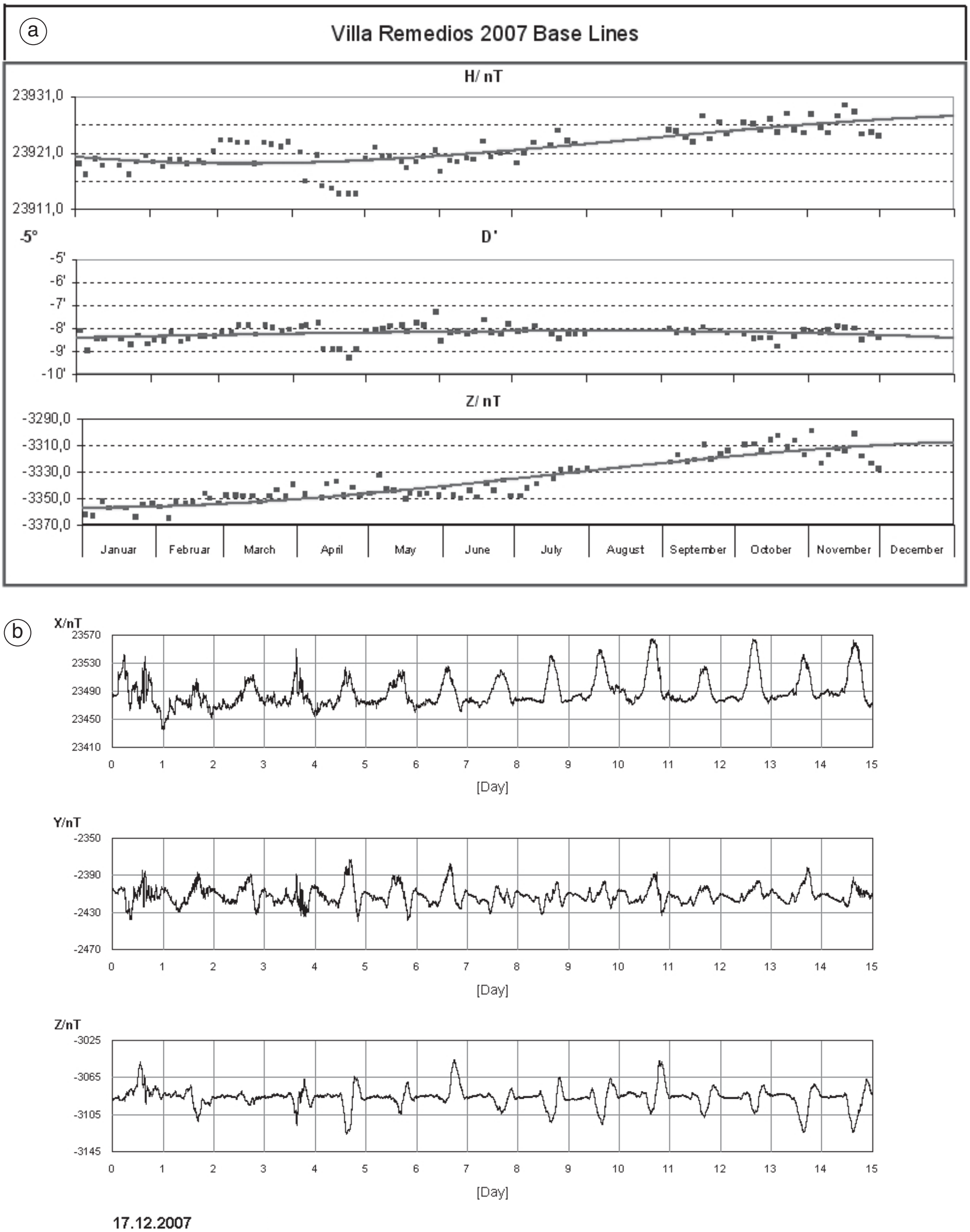

Fig. 4a,b. Expamples for data from VRE observatory. a) Measured (black dots) and adopted (grey line) baselines for 2007. The moderate variation is due to seasonal temperature changes in the variometer hut. b) One minute values of the north (X), east (Y) and vertical (Z) component for the time interval December 17 to 31, 2007.

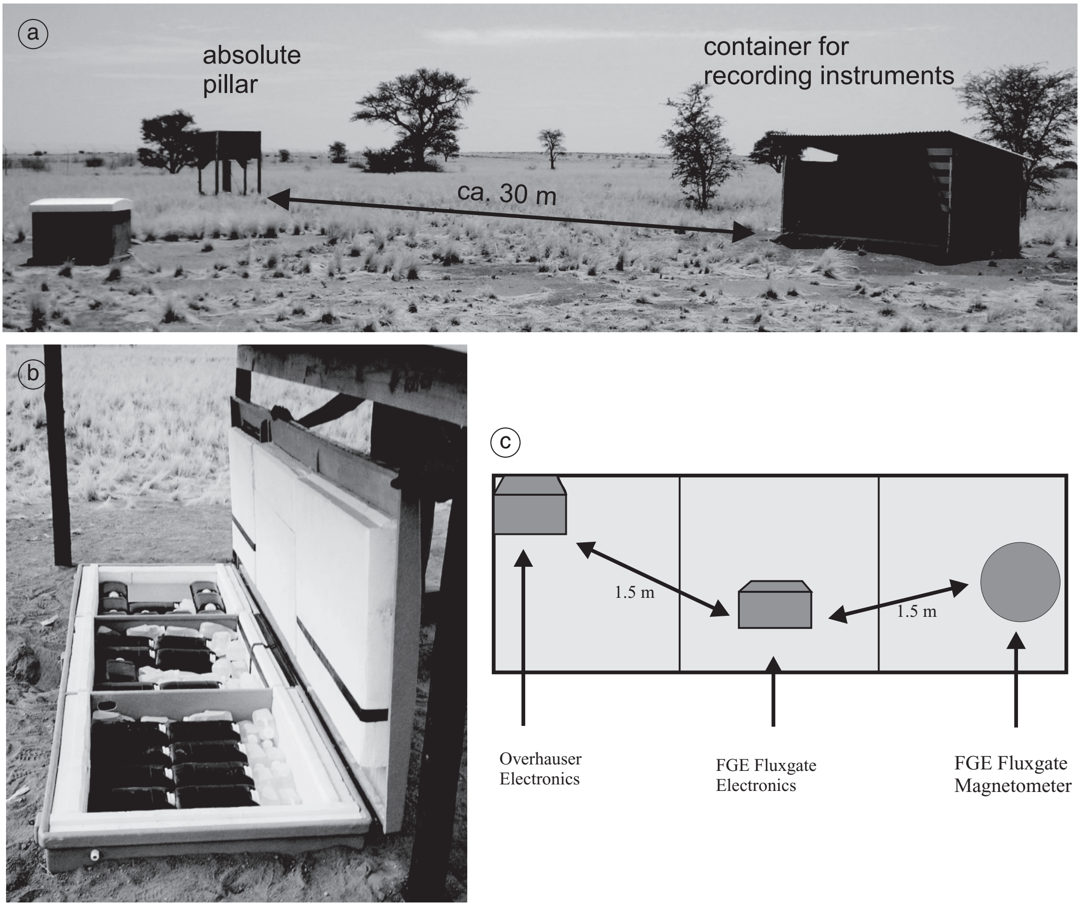

Fig. 5a-c. a) Measurement structures at KMH observatory. b) The container housing the recording equipment with thermal insulation by Styrofoam and water bottles. c) Schematic layout of the instrumentation box showing the respective distances between the different electronics systems and the FGE fluxgate magnetometer. The dimensions of the box are approximately 3 m x 1m x 1.5 m. The average distance between the different electronics configurations is 1.5 m to eliminate disturbing interferences between the different systems.

camaya location. At VRE, electricity supply exists, but it can be rather unreliable with numerous outages taking up to several hours. The solar panels and the wind generator were installed together with powerful rechargeable batteries as an efficient and reliable method to bridge the power outages.

The recording equipment was installed by GFZ staff in December 2000 and an observer was trained in executing the absolute measurements during this visit. Continuous variation recordings have been obtained since December 2000. However, problems with the absolute directional measurements that started just a few weeks after the training of the observer could only be solved in 2005 after a visit of two Bolivian observers to Niemegk observatory, where a problem with the theodolite could be rectified. Since June 2005 good quality complete observatory recordings have been available. Figure 4 shows the measured and adopted baseline of VRE for 2007 and two weeks of variation data.

The adopted baseline is a third degree polynomial over 14 months, including December 2006 and January 2008. The clear gradual drift of the Z component baseline must be an effect of the instrument or instability of the pillar, it is not related to the seasonal temperature variation.

A remaining problem however is the continuous data transfer to GFZ, where data processing is carried out. Due to the remoteness of VRE no telephone/internet connection or cell phone coverage exists, and data are copied from the data logger and sent from La Paz to GFZ by e-mail once every two weeks. The absolute measurement protocols are sent by e-mail only every two months. We are currently working on solutions to improve the data transmission.

2.2. *Keetmanshoop*

An existing airport was chosen as the location for Keetmanshoop observatory in southern Namibia. This choice presents several advantages: a secure environment, existing infrastructure and people from the airport staff to carry out the necessary absolute measurements. The exact location within the airport grounds was chosen to ensure suitable magnetic homogeneity and long-term protection from technical and human disturbances. The latter aspect could be obtained through personal consultation with the airport management. The coordinates of this observatory are 26.32°S and 18.06°E at 1065 m altitude.

Instead of the traditional measurement buildings only essential and functional structures were erected, mainly to minimize the costs. Figure 5a shows a photo of the measurement facilities at the new observatory. The continuous recording instruments are housed in a large container of fibre-reinforced plastic material, custom-built by a boat-construction company. The container is installed about 1 m deep in the ground at a distance of 30 m from the absolute pillar (fig. 5b), containing a low non-magnetic concrete pillar for stable mounting of the vector magnetometer. The different pieces of measurement equipment are positioned at maximum distances within the container to avoid possible disturbances as a result of electronic interferences. The approximate distribution is sketched in fig. 5c. The GSM sensor, not shown in the sketch, is mounted on one of the pillars of the roof construction some 1.5 m above ground.

The recording equipment consists of a suspended FGE three-component variometer and a GSM19 Overhauser magnetometers, all bought by GFZ, with a datalogger that was developed and built at HMO. GPS is used for the time signal. A THEO-MG2KP theodolite with a DMI fluxgate sensor and an additional GSM19 Overhauser magnetometer for the absolute measurements have also been provided by GFZ.

We succeeded in designing a low-cost, but efficient method for thermal insulation of the recording equipment. The container is lined with a thick layer of Styrofoam and in addition the empty spaces around the recording instruments and electronics are filled with plastic cans of different shapes and volumes, filled with water. Together with a roof shielding the container from direct sunlight the annual temperature variation inside the instrument container is damped to a few degrees (taken into account by the absolute measurements), with no significant daily variation. An example of outside temperature variations and how well they are minimised inside the box is shown in fig. 6.

The data logging computer is located in a small rented room inside the airport terminal building, some 630 m away. Suitable electricity supply and airconditioning were installed there. A cable trench with 7 inspection manholes has been constructed between the container and the computer room for power supply and data transfer by a fibreoptic cable.

A stable pillar (1.3 m height, asbestos cement pipe filled with non-magnetic concrete) has been installed on a concrete basement for absolute declination and inclination measurements. It is also used occasionally to determine the difference between the total field measured on this pillar and the permanently installed Overhauser magnetometer. The pillar is protected against the weather by a wooden roof and athree-sided canvas windbreak only, a perfectly adequate solution for the climatic conditions of Namibia. Exact coordinates and az-

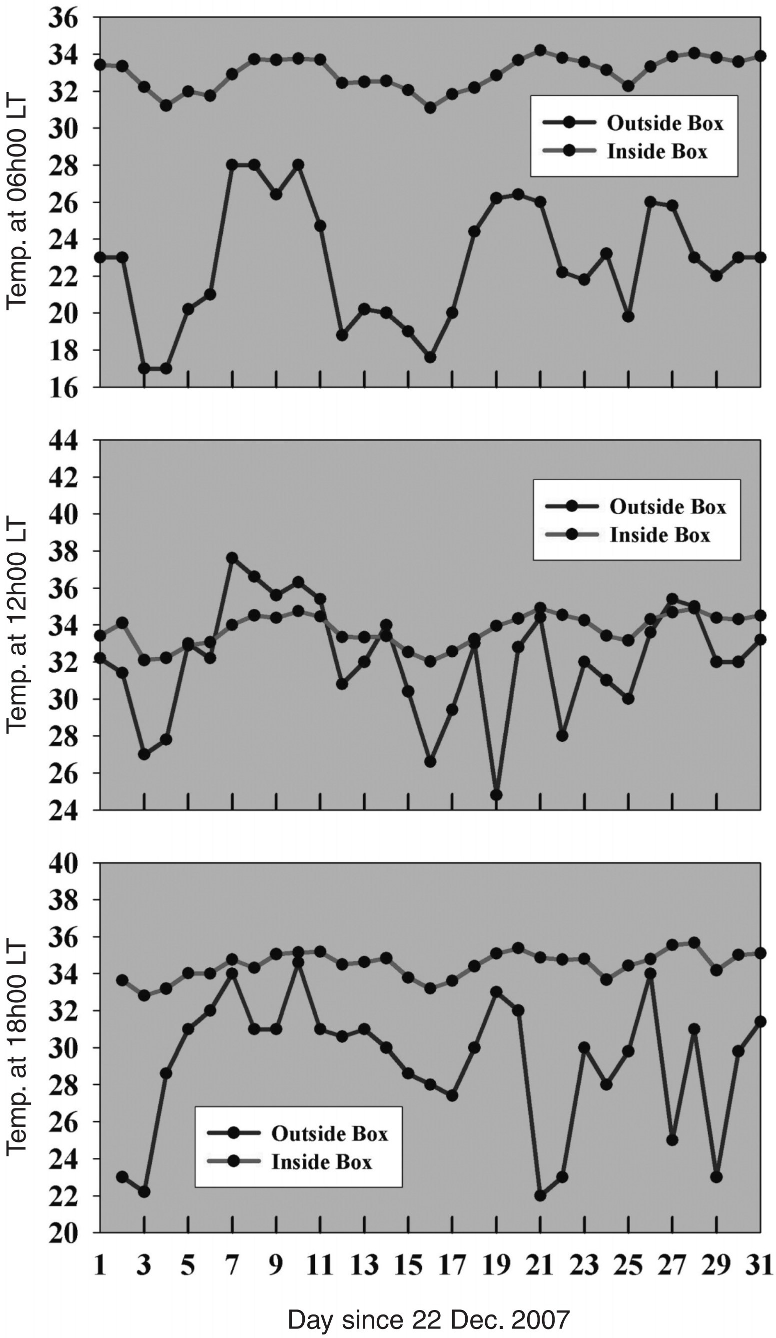

Fig. 6. The temperature variation at KMH Observatory as recorded inside the instrumentation box (grey curves) as well as measured outside by the Meteorological Office at the Keetmanshoop Airport at different times of the day (06h00,12h00, and18h00LT). Data shown are from 23 December 2007 till 22 January 2008.

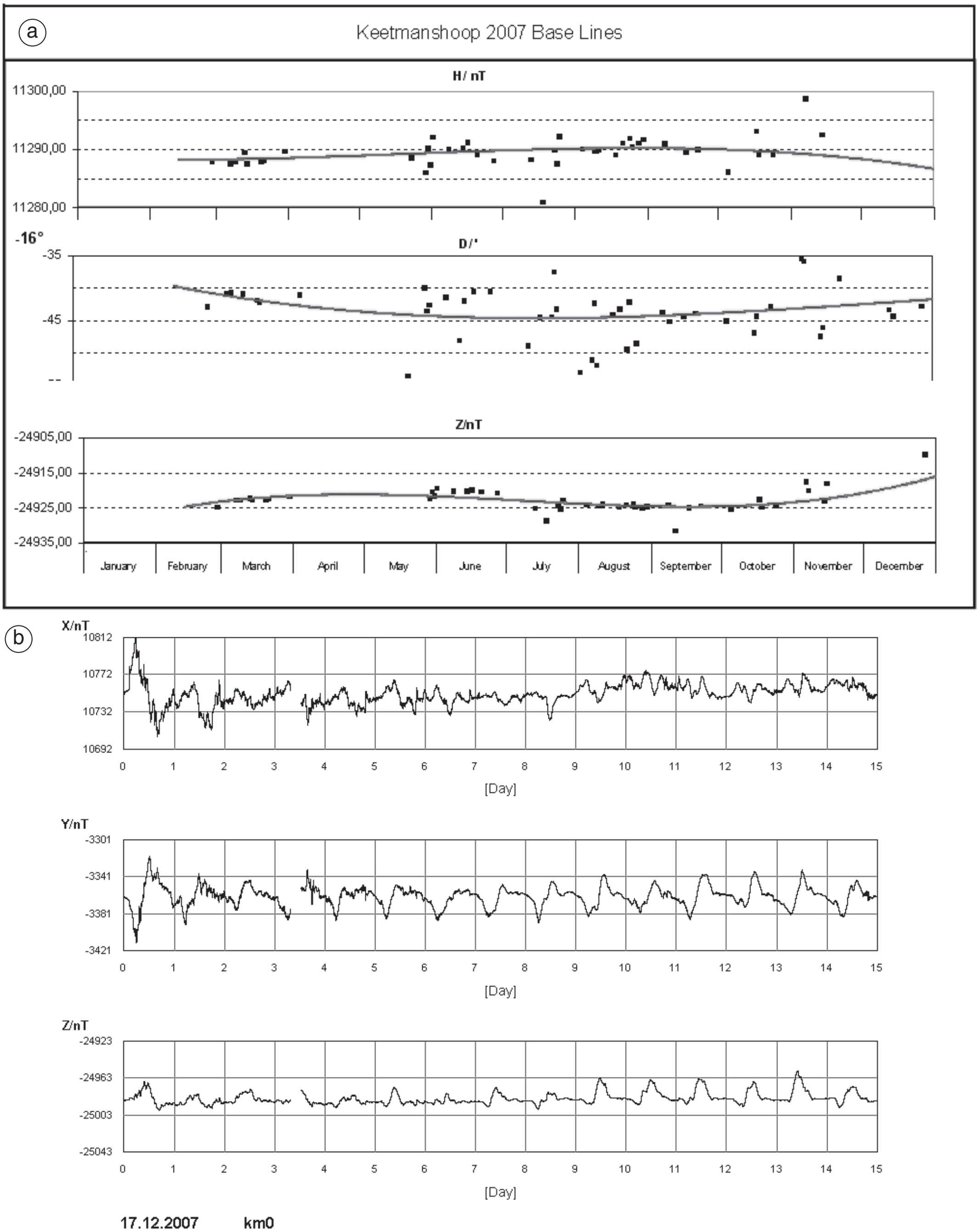

Fig. 7a,b. Expamples for data from KMH observatory. a) Measured (black dots) and adopted (grey line) base lines for 2007. b) One minute values of the north (X), east (Y) and vertical (Z) component for the time interval December 17 to 31, 2007.

imuth angles to two trigonometric beacons in the distance and a newly painted mark on the airport building wall some 340 m away were determined by land surveyors from Namibia.

Three persons from the airport staff were originally trained during the installation of the observatory to carry out the absolute measurements. However, over the course of time it has turned out that people better motivated to do the measurements with the required accuracy could be found by paying some nearby residents to take care of this task a few hours per week. The people were trained during a visit to KMH by HMO personnel and will also be invited to HMO for further training.

More details about KHM observatory are given by Linthe *et al.* (2007). The construction work carried out by contractors was supervised and the instruments were installed during visits of GFZ and HMO personnel to the site. This observatory was completed and running by May 2006. Examples of data for the same time intervals as for VRE in fig. 4 are given in fig. 7. The baseline is again a third degree polynomial over 14 months. The recordings are transmitted daily via a cell phone modem connection and

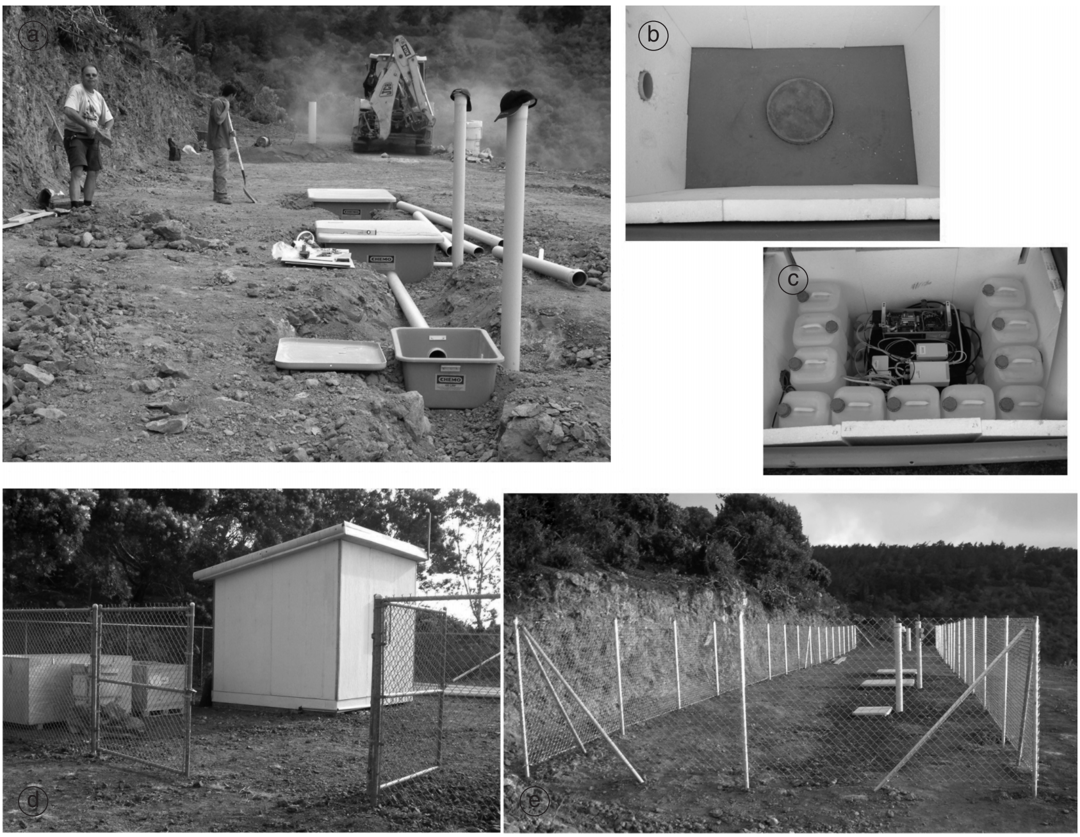

Fig. 8a-e. The new STH observatory. a) Installation of the plastic containers for recording equipment with cable trenches. b) FGE magnetometer sensor pillar in one of the containers, lined with styrofoam for thermal insulation. c) FGE electronics unit in another container, already partly surrounded by water cans for further thermal insulation. d) Computer building of the IDA seismological station, which now also houses the geomagnetic observatory computers. e) Overview over the observatory premises just after installation had been finished.

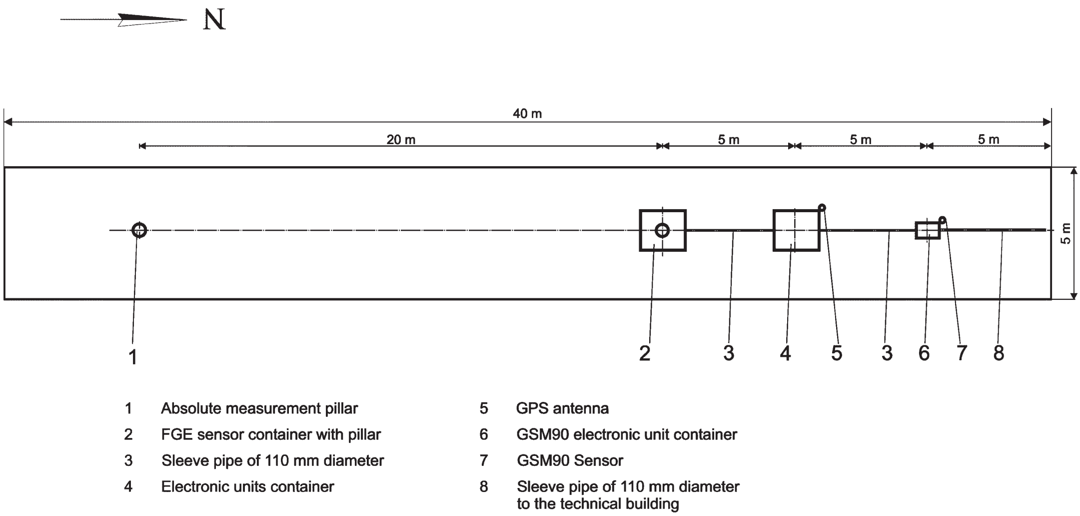

Fig. 9. Outline of the observatory installations.

the absolute measurement values are sent via a web form to HMO, where data processing and distribution are carried out.

2.3. *St. Helena*

Establishing a remote observatory on the island of St. Helena was a particular challenge. Access to the island is only possible by a ship connecting Ascension island, St. Helena, Cape Town and Walvis Bay on a fixed but somewhat irregular schedule. Also, such an installation is costly both in time and money. The complete observatory installation by GFZ staff therefore had to be done during one 16-day visit, requiring careful planning to achieve a long enough but not extensive stay on the island.

To install this observatory logistical support was obtained from the IDA seismological network of the University of California at San Diego (UCSD), which has one of its stations on St. Helena. For the geomagnetic observatory a piece of government land, next to the IDA station, has been leased free of charge. The station is located at the end of a cul-de-sac and has electricity and telephone connection, yet is far away from human and technical disturbances. This observatory land of 40 by 5 m lies on a slope of the mountainous island, some 25 km away from the capital, Jamestown. Due to the difficulty to visit the island it was not possible to do a survey for magnetic homogeneity of the planned observatory area beforehand. The strongly magnetic volcanic rocks of the island cause very steep gradients of the order of 5 nT/m within the observatory premises, and a difference of 250 nT between absolute and variation pillar, which could not be avoided. The area was fenced with a nonmagnetic aluminum fence for security. The exact coordinates of this new observatory will be determined in the near future by land surveyors.

Similarly to KMH, functional constructions are used. The permanent recording equipment consists again of a suspended FGE variometer, a GSM90, a GPS receiver and a MAGDALOG datalogger developed at Niemegk observatory. Three smaller containers were used instead of one big unit, the advantage being that commercially available containers could be used and shipped more easily than one large construction. Moreover, it is easier to position the instruments far enough apart to avoid electrical interferences. The containers with ground dimensions of 1.2 by 1.6 m and a height of 1 m

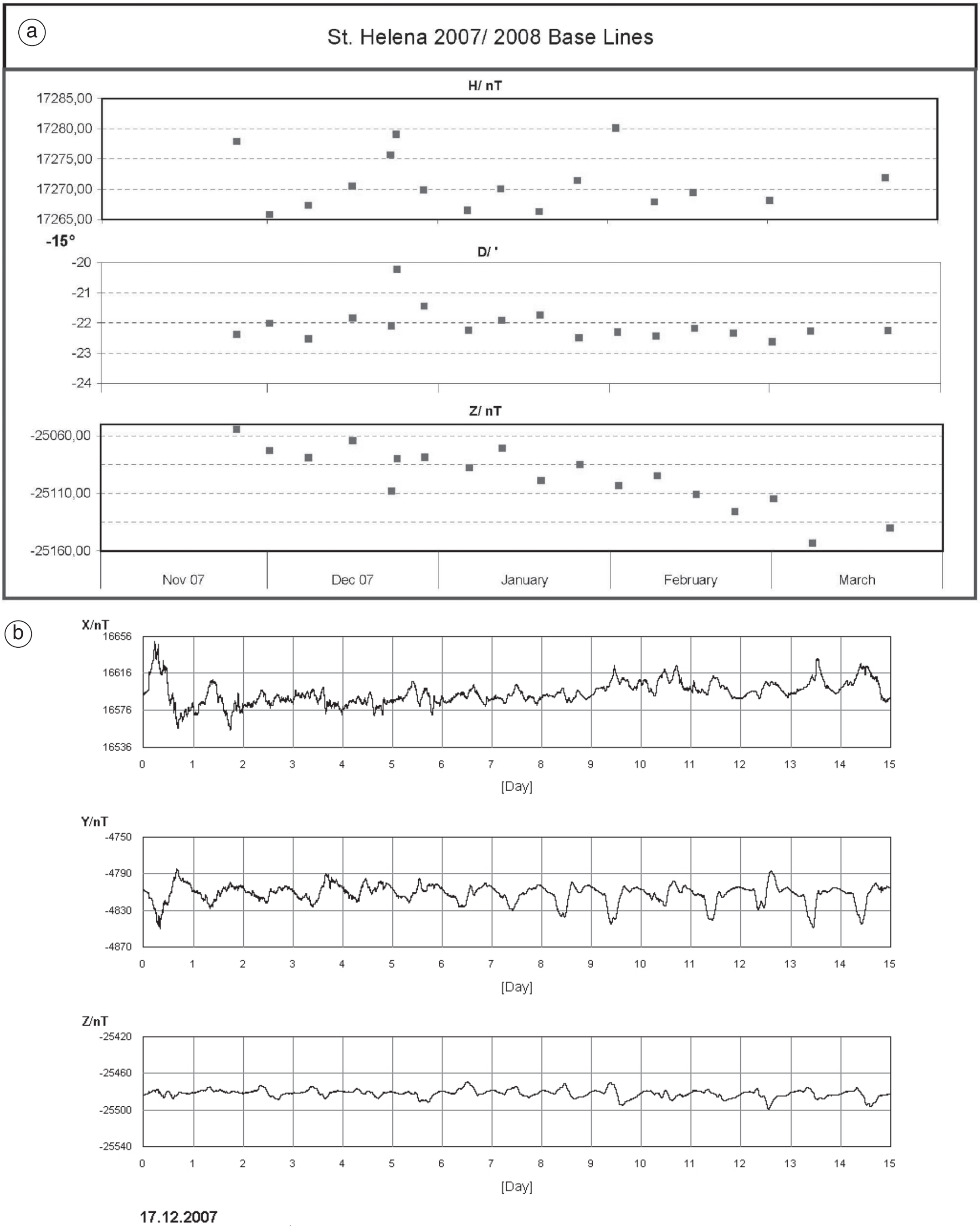

Fig. 10a,b. Expamples for data from STH observatory. a) Measured (black dots) baselines for November 2007 to January 2008. The scatter of the first measurements will be reduced as the observer gains experience. b) One minute values of the north (X), east (Y) and vertical (Z) component for the time interval December 17 to 31, 2007.

were buried in the ground some 5 m apart. One contains the vector magnetometer sensor on a concrete pillar, one the Overhauser magnetometer electronics unit and the third one the vector magnetometer electronics including the data logger. The GSM90 sensor is mounted on a plastic pipe about 1.5 m above the ground. Cable trenches with pipe casing connect the instruments in the containers to a computer in the seismological station building 70 m away. Figure 8 shows the setup with some details and fig. 9 gives a sketch of the observatory premises.

The absolute instruments consist of a Zeiss 010B theodolite with a Bartington sensor and a GSM19 to monitor the significant pillar difference on a regular basis. A stable absolute pillar was constructed with a roof and some canvas weather protection in one corner of the observatory premises. An azimuth mark made of concrete with a painted aluminum tip on top was installed on the hillside across a valley, about 470 m away.

The necessary absolute observations are carried out on a contract basis by a person living near-by, who is also contracted by UCSD to take care of the seismological station. He has been trained during the installation visit of the GFZ staff and will visit Niemegk observatory for further training soon. The recordings are transmitted regularly via internet and the absolute measurement protocols are sent by e-mail to Niemegk observatory, where data processing and distribution are carried out. The observatory is fully operational since November 2007 and some of the first data are shown in fig. 10. An adopted baseline is not shown, because the time span is rather short and the measurements look quite scattered. We are optimistic that the scatter will be reduced as the observer gains experience. He will be invited to Niemegk observatory for further training in 2008.

3. Repeat station surveys

The aim of geomagnetic repeat station surveys is to obtain additional data concerning the internal magnetic field particularly in areas with sparse observatory coverage. A network of up to 75 repeat stations has been established by HMO in South Africa, Namibia, Botswana and Zimbabwe since 1939. A network of this size, however, cannot easily be surveyed each year and from 2000 to 2004 only 8 selected stations were surveyed annually (Kotzé *et al.*, 2007). Since 2005 we managed to survey a set of 40 well-distributed stations in South Africa, Namiba and Botswana annually (fig. 11) by collaborative efforts between HMO and GFZ. Limited time and personnel resources and distances between the stations in the order of 200 to 400 km still made it a challenging task, given the fact that either a large number of observations or variometer recordings at each station are necessary in order to eliminate external field variations in the best possible way in order to obtain representative internal field values (see Newitt *et al.* (1996) for details).

3.1. *Survey practice*

We opted for the compromise of setting up a three-component variometer at each station for a minimum of 15 hours including the night. The justification for this choice is described by Korte *et al.* (2007) and summarized in Section 3.2. With an average station distance of about 300 km, the following tight schedule allowed us to generally measure one station per day and to visit all stations within three months using one two-person team per month:

- drive to a station, arriving in the (early) afternoon
- set up the variometer
- wait 2 to 3 hours for the variometer to stabilize
- take 4 sets of absolute measurements in the evening
- take 4 sets of absolute measurements the next morning
- pack together and drive to the next station, again arriving in the (early) afternoon.

This scheme proved very efficient and extra days were necessary only when the driving distance was too large or heavy rain prevented measurements. A very helpful precondition is that all stations consist of sturdy pillars with clear center marks, many of them suitable for direct mounting of the theodolite without a tri-

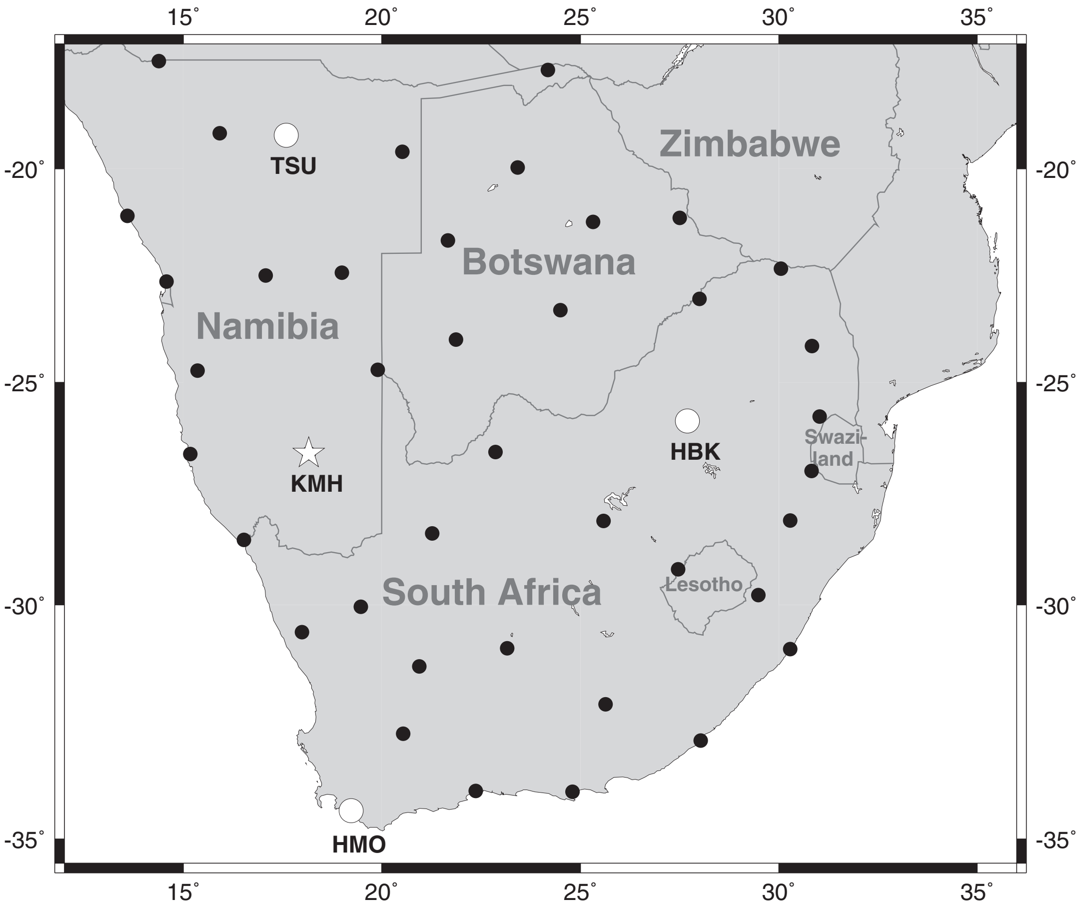

Fig. 11. Repeat station network.

pod. However, temperature conditions have to be favorable in order to quickly achieve temperature stability for the variometer when it is buried in the ground for thermal insulation. In the warm climate of the southern African countries this usually was the case after only 1 to 2 hours, while *e.g.* in Germany our experience is that this can sometimes require up to 6 hours.

3.2. *Data processing*

Repeat station data processing aims at eliminating all external and induced field influences from the measurement and give a representative main field value. This is achieved by using the variation recordings of a variometer or the nearest observatory to reduce the measured values to *e.g.* a quiet night time or, for easier comparability, an annual mean (see Newitt *et al.* (1996). We used on-site variometers because the nearest observatory for most of the stations is in excess of 400 km away so that differences in field variations between the two locations may cause significant errors. However, with less than a full day of variometer recordings we do not necessarily cover truly quiet nighttimes. Preparatory studies suggested that an average over a full night is a good compromise in moderately disturbed conditions at mid latitudes (Korte *et al*., 2007).

Our data are reduced to quiet night times using the local variometer recordings, and from there to annual means by means of the nearest observatory recordings. Estimates of secular variation have to be taken into account in this step due to the strong secular variation gradients in this area (see Korte *et al.* (2007) for details).

The scatter of the eight individual measurements at each station provides a good estimate of uncertainties due to measurement and instrument errors as well as due to imperfect elimination of short-term field variations. A check for systematic differences between evening and morning measurements moreover confirms the baseline stability of the variometer as a necessary precondition for high quality results. We obtained very good results for most of the stations with a maximum deviation from the average of the eight results not exceeding 1.5 nT in general. The final data uncertainties are estimated as ±3 nT in each component, taking into account considerations about the accuracy of reduction to undisturbed internal field (Korte *et al.*, 2007). First regional models of secular variation in southern Africa based on these new measurements can be found in Kotzé *et al.* (2007).

4. Conclusions and outlook

GFZ currently operates three remote geomagnetic observatories in the SAA area, each with different challenges in terms of infrastructure and absolute measurement staff. Plastic containers buried in the ground with insulation by styrofoam and simple water bottles and a shading roof proved to be an excellent, low-cost solution for housing the variation recording equipment in regions without severe frost. Three small containers for vector variometer, Overhauser magnetometer and associated electronics units, respectively, are preferable to one large container to facilitate sufficient separation between different electronic components, thereby eliminating unwanted disturbances between the instruments.

Some fencing for security is necessary in most locations. Placing the observatory inside the perimeters of an airport can be an economical solution, provided the airport premises are large enough to ensure long-term magnetic cleanliness. Consultation with the airport management is therefore crucial. Moreover, the airport might also provide necessary infrastructure like a room for the data logging computer, and access to electricity and telecommunication facilities at reasonable cost. Alternatively, collaborations with other institutions sharing the infrastructure of existing seismological, gravimetric or meteorology station networks help to reduce the costs of remote geomagnetic observatories.

An important factor determining the quality of a remote geomagnetic observatory is the availability of competent and reliable persons to perform the weekly absolute measurements. Nearby residents can potentially be trained to do this task, but if there is no one with a scientific or technical background to appreciate the importance of the measurements it can be extremely difficult to obtain high quality results over a long time. According to our experience it is useful to invite the observers for occasional training visits to one of our traditional, permanently staffed observatories to ensure constant motivation.

None of the three observatories has INTERMAGNET status yet, VRE because of the missing real-time data availability, and KMH and STH because the required one year of high-quality data had not yet been reached before the last application deadline. Our aim is to achieve INTERMAGNET membership for all the observatories with data availability via the INTERMAGNET website (www.intermagnet.org). Currently the data from VRE and KMH are being prepared for the applications for an IAGA code as a first step, and they will be delivered to the World Data Centers in Boulder and Edinburgh as soon as the codes are obtained. Until that time data are available upon request from GFZ, Niemegk observatory (VRE, STH) and HMO (KMH).

To increase the magnetic data distribution around the SAA, HMO and GFZ are continuing to carry out annual repeat station measurements at 40 stations throughout South Africa, Namibia and Botswana. An efficient scheme to manage observations at such a spacious network of remote stations with limited resources has been described here.

The repeat station data are available from the WDCs Edinburgh (http://www.wdc.bgs.ac.uk) and Boulder (http://www.ngdc.noaa.gov). We plan to continue these annual surveys during the next years as a low-cost complement to continuously recording observatories.

However, only continuous recordings can reveal full details regarding temporal field change and the different magnetic field contributions. The Danish Meteorological Institute (DMI) and Danish National Space Centre (DNSC) plan to install a new observatory on the island of Tristan da Cunha in 2008 or 2009 (Matzka *et al.*, 2009, this issue). GFZ is also planning to install further remote observatories in the near future. The most advanced plans are for an observatory on the Azores in cooperation with the University of the Azores, and one in Botswana in cooperation with the Department of Geological Survey, Botswana. A good network of geomagnetic observatories, not only in the crucial southern African and Atlantic area, will be an important complement to the upcoming ESA Swarm magnetic satellite constellation mission, scheduled for launch in 2010.

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