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The Magnetic Observatory on Tatuoca, Belém, Brazil: History and Recent Developments

Morschhauser Achim[1], Brando Soares Gabriel[2], Haseloff Jürgen[1], Bronkalla Oliver[1], Protásio José[2], Pinheiro Katia[2], and Matzka Jürgen[1]

[1]GFZ German Research Centre for Geosciences
[2]Observatorio Nacional

Correspondence to: Achim Morschhauser (mors/at/gfz-potsdam.de)

Abstract.

The Tatuoca magnetic observatory (IAGA code: TTB) is located on a small island in the Amazonian delta in the state Pará of Brazil. Its location close to the geomagnetic equator and within the South Atlantic Magnetic Anomaly offers a high scientific return of the observatory's data. A joint effort by Observatorio Nacional, Brazil (ON) and the GFZ German Research Centre for Geosciences (GFZ) was undertaken starting from 2015 in order to modernize the observatory with the goal to join the INTERMAGNET network and to provide real-time data access. In this paper, we will describe the history of the observatory, recent improvements, and plans for the near future. In addition, we will give some comments on absolute observations of the geomagnetic field near the geomagnetic equator.

1 Introduction

The Tatuoca magnetic observatory (TTB) has a long history, and its roots go back to as early as 1933 when a temporal magnetic observatory was set up on the island of Tatuoca (Gama, 1955). Already at that time, the site of the observatory was chosen to fall within low magnetic latitudes (Gama, 1955), and an inclination of 18.18° was measured when a permanent magnetic observatory was opened on Tatuoca Island in 1954 (195, 1955). Eventually, the northward moving equator passed the observatory in March 2013 (Fig. 1). The closest neighbouring observatory of Tatuoca is located in Kourou (KOU, French Guyana) at a distance of about 700 km north and 400 km west of Tatuoca (Fig. 1), and was installed in 1996 by the Institut de Physique du Globe de Paris (IPGP). While TTB is currently under the full influence of the equatorial electrojet (EEJ), KOU is far enough from the magnetic equator to record this signal. Thus, subtracting the magnetic data recorded at KOU from those recorded at TTB will isolate the magnetic signal of the EEJ from the signal of the solar quiet and ring currrent magnetic fields (c.f. Manoj et al., 2006). Moreover, the Tatuoca observatory is located within the South Atlantic Magnetic Anomaly (SAMA) (Hulot et al., 2015), and shows a strong secular variation of almost 200 nT/yr in the radial component as predicted by, e.g., IGRF-12 (Thébault et al., 2015).

The Observatorio Nacional (ON) and the German Research Centre for Geosciences (GFZ) are currently preparing the Tatuoca observatory to join the INTERMAGNET network. This will add a third observatory to the INTERMAGNET equatorial

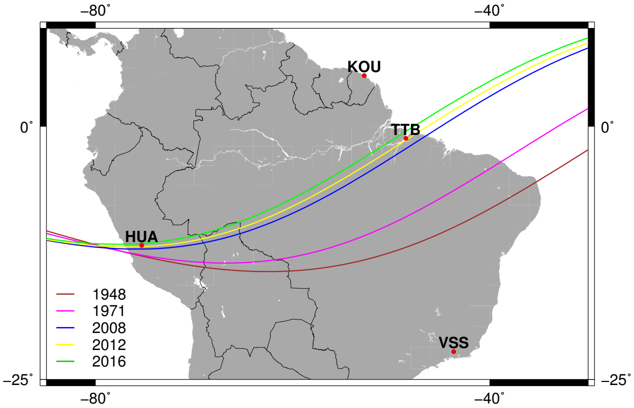

Figure 1. The location of the Tatuoca (TTB) observatory is shown along with INTERMAGNET observatories in the region (Kourou (KOU), Huancayo (HUA), and Vassouras (VSS)). In addition, the location of the geomagnetic equator according to IGRF is shown for different years between 1948 and 2016, as indicated by the colors.

observatories, besides Huancayo and Addis Ababa. In 2015 and 2016, two trips were organized to Tatuoca in order to equip the observatory with modern instrumentation, to train the local observers doing a different type of absolute measurements, and to update data processing routines. Also, real-time data become more important with respect to applications for Space Weather monitoring and directional drilling (Buchanan et al., 2013), and a long-term goal of this project is to provide real-time data of TTB.

In this paper, we will first give an overview of the observatory location and its infrastructure. Then, we will summarize the history of the observatory, with a focus on the technical and operational state before the initiation of this project. This summary is followed by a description of the recent improvements and the current state of the observatory before we shortly comment on data and its availability. The paper concludes with a summary and outlook.

2 History of the observatory

The story of the Tatuoca magnetic observatory started in 1925 when the National Observatory of Brazil (ON) considered to install a permanent station within the equatorial region. This goal was reinforced by a recommendation of the International Union of Geodesy and Geophysics (IUGG) in 1933, after an Assembly in Lisboa. At this date, two “La Cour” type magnetographs were provided by the International Polar Year Commission to the National Observatory of Brazil. Subsequently, Sr. Marquez (ON) was in charge to find a location free from artificial magnetic disturbances, and he chose a small island owned by the Brazilian Government and close to the city of Belém. The magnetic station at Tatuoca Island operated only from September 1933 until January 1934 due to lack of funding. Important results of these recordings were published in 1951 by the Temporary Commission on the Liquidation of the Polar Year 1933-34. In the subsequent years, the Tatuoca Project had been halted due to budget limitations, especially due to World War II.

In 1951, UNESCO offered a Ruska Field Theodolite Magnetometer Inductor for absolute measurements to the National Observatory of Brazil (ON), with the condition that the Brazilian Government will finance the necessary buildings. The construction of the variometer and absolute houses on Tatuoca Island was completed in 1953, and the office and other buildings were ready in 1954. In this year, a magnetograph was supplied by the Inter American Geodetic Survey which was installed by Mr. W. Parkinson and by the director of ON. Many tests on the absolute and variometer measurements were performed to check the feasibility of a magnetic observatory on Tatuoca Island. However, due to logistic problems, this was achieved only in 1957 when Mr. J. Kozlosky (Inter American Geodetic Survey) visited the island for a few days. On 19^{th} August 1957, Tatuoca magnetic observatory started its operation by measuring continuously the geomagnetic field, except for many data gaps between 1979 and 1980 due to technical problems and renovation at TTB (Ferreira, 1990). Hourly mean data from Tatuoca were published each year in internal reports of ON. In addition, most hourly mean values from 1957 to 1959, 1964 to 1965, and from 1990 to 1999 are published at the World Data Centre Edinburg (WDC).

In May 1996, a digital automatic station was installed in Tatuoca and the classical variometers were disabled. However, the digital station presented problems in February 1997 and the classical variometers were reactivated (Ferreira, 1998). Finally, the last magnetogram from the classical variometers on Tatuoca were obtained on May 13^{th}, 2007. The classical variometers stopped working due to the lack of photograph paper, which was out of production. As a substitute, a LEMI 417 variometer was installed for continuous vector measurements. Also, a POS-1 scalar magnetometer was installed in 2007, which stopped working in 2013 due to unsufficient power supply.

3 Observatory location and setup

The Tatuoca magnetic observatory is located at 1.205°S and 311.487°E (geodetic coordinates) on a small island within the Amazon Delta in the state of Pará in Brazil, and the island is located a one-hour boat trip away from the port of Icoaraci close to the city of Belém (Figs. 1 and 2). Further, the island of Tatuoca has an approximate size of 460 m by 300 m, and is largely covered by dense vegetation (Fig. 3). As a big advantage, the island is exclusively used by the observatory and owned by the Brazilian government. Therefore, it is well protected from any artificial disturbances, and had never been relocated during its 65 years of history.

On the island of Tatuoca, several buildings are located which are related to the observatory (Fig. 3). From south to north, there exist a living house for the observatory staff, an electronics house with the batteries and solar regulators as well as a small office, and a storage house with diesel generators. In the northeast corner of the island, the absolute and variometer houses are located (Fig. 4).

A schematic drawing of the variometer house is shown in Fig. 5. The variometer house consists of an outer corridor (light gray) and an inner isolated room (dark gray). The inner room is equipped with two solid and large pillars, and one smaller pillar in the southeastern corner (all shown in black). In addition, two wooden shelves are located in the southern part of the inner room (black-gray checkerboarded). On the eastermost of the solid pillars, a LEMI-417 vector fluxgate magnetometer is located (yellow circle), and the electronics of this instrument is located near the entrance of the variometer house (yellow rectangle).

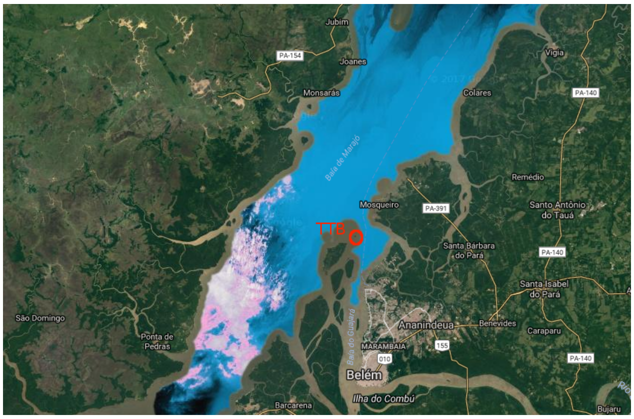

Figure 2. Satellite image of the Tatuoca island and its surroundings (©TerraMetrics, Kartendateen 2017 / Google 2017). The city of Belém is located to the south of Tatuoca island and the observatory.

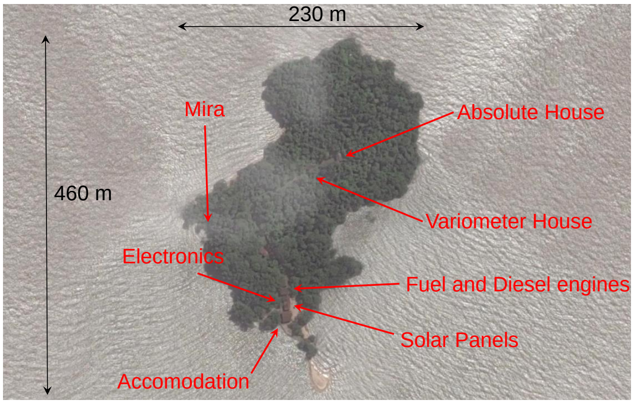

Figure 3. Satellite image of the Tatuoca island (©Google 2016). The main buildings and infrastructure of the observatory are marked and annotated.

The LEMI system is powered by a 45 Ah lead-acid battery which is charged by a dedicated 30 W solar panel on the roof of the variometer house. Further, a POS-2 proton gradiometer is located in the southeastern corner of the variometer house (white circle). This instrument was never in operation and has been removed in October 2016 (see below).

The absolute house has an approximate size of 4.8 by 8.0 m, and is roughly oriented in N-S direction. It houses ten pillars, four of which are located at the northern end, including the main pillar, and six of which are located at the southern end. The latter pillars carry several historic instruments, including the Ruska theodolite donated by UNESCO. The main pillar is equipped with a ZEISS 020B theodolite in degree-scale to which a Canadian EDA fluxgate magnetometer has been attached. The EDA fluxgate has an analogue current reading, and therefore the absolute measurements had to be performed with the zero residual method (Newitt et al., 1996, p. 43ff). As described in Sec. 4, the fluxgate has been replaced with a digital instrument during our first trip in November 2015. For absolute measurements, an azimuth mark is located at a distance of 150 m to the

Figure 4. The variometer and absolute houses of Tatuoca observatory are shown. These are located at the northeast corner of the island (Fig. 3).

southwest. Further, a GEM System GSM-19 proton overhauser magnetometer is available for measuring the magnetic field intensity. Until recently, the time of the absolute measurements was taken from an analogue wall clock which is regularly set according to the GPS time of the LEMI electronics in the variometer house.

In total, there are three observers and one cook who swap shifts in teams of two each week. Therefore, the observatory is usually occupied by two persons who do two consecutive absolute measurements on three days each week. In addition, the head of the observatory and one technician and are both located in Belém, and frequently visit the island. For this purpose, and for transporting goods and fuel to the island, the observatory owns a small motorboat.

Concerning power supply, the observatory is equipped with recently upgraded solar panels of nominal 324 W total, charging eight 165 Ah lead-acid batteries, i.e. 1320 Ah. In addition, there exist two diesel generators of 5 and 6 kW at 120 V which also can be used to charge the batteries. The diesel generator directly powers the lights in the variometer and absolute houses via a dedicated electric cable system. The batteries provide energy mainly for the accomodation building via a 127 V inverter. In parallel, the batteries power the recently installed equipment (Sec. 4).

4 Recent improvements

With the intention to prepare the Tatuoca Observatory to join the INTERMAGNET network, a team of ON and GFZ visited the observatory for two weeks from November 17th, 2015 to November 27th, 2015. During this time, new instruments were installed and new methods for absolute measurements were introduced. During a follow-up visit from October 24th, 2016 to October 28th, some further improvements to the instrumentation and absolute measurements were made, as described below.

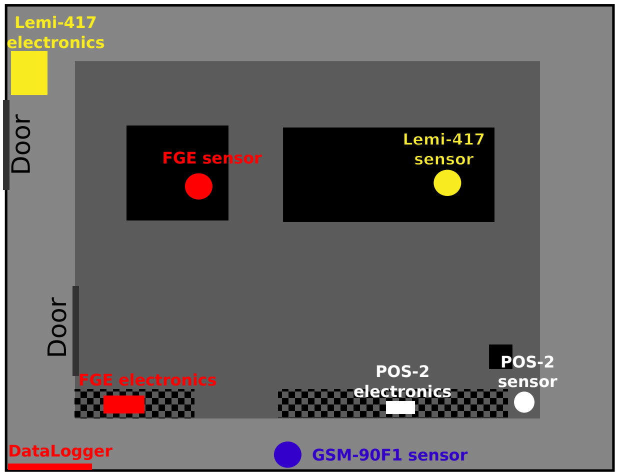

Figure 5. Schematics of the variometer house. The insulated inner room is shown in dark grey. Further, the equipment that has been installed prior to 2015 is shown in white (removed 2015) and yellow (in operation after 2015), the equipment installed in 2015 is shown in red, and the equipment installed in 2016 is shown in blue. Black areas refer to solid stone pillars in the variometer house, black checkerboarded areas refer to shelves, and doors are shown in black as well.

Figure 6. The thermally insulated inner room of the variometer house: The new FGE sensor is placed on the pillar in the front (left), and the LEMI 417 sensor is placed on the pillar in the back. To the right, a part of the shelf with the FGE electronics is visible.

4.1 Variometer House

A Technical University of Denmark (DTU) FGE fluxgate variometer was installed in the variometer house on November, 21th, 2015 (Pedersen and Merenyi, 2016; Rasmussen and Lauridsen, 1990), and baselines are available for this variometer since November 22, 2015. As shown in Fig. 5 and 6, the FGE was installed on the existing western socket, at a distance of about 2.2 m from the LEMI-417 sensor. For testing purposes and as a backup system, the LEMI was kept in operation. The FGE was oriented to magnetic north (HDZ) by minimizing the output of its unbiased Y-sensor while an appropriate bias field was chosen for the X (horizontal north) and Z (vertical down) channels in order to extend the dynamic range of the readings to

Figure 7. The plastic tube is shown that is used to protect the power supply and fibre optics cable running from the electronics house (visible at the far end in the image) to the variometer house (not visible).

the available range of ±10 μT. The FGE electronics was first placed on the southeastern shelf and moved to the southwestern shelf in October 2016, at a distance of 2.4 m from the FGE sensor (Fig. 5). At the time of installation, the FGE electronics box was also modified to house a MinGEO ObsDAQ 24-bit analog to digital converter. Any additional electronic equipment was placed in the southwestern corner of the outer corridor (Fig. 5). This equipment consists of a RaspberryPi datalogger system and transformers for powering the FGE and the datalogger. The RaspberryPi has the advantage of low power consumption and easy availability. For more details on the datalogger system, please refer to Morschhauser et al. (2017), this issue.

Absolute scalar measurements in the variometer house are useful to check the calibration and resolution of the variometer data. In Tatuoca, a POS-1 and POS-2 with sensors were previously installed. However, no consistent readings could be obtained when testing these instruments. Therefore, we have removed the non-operational POS-1 and POS-2 electronics and sensors in November 2015. As a replacement, a GEMSystem GSM-90F1 overhauser magnetometer was installed in October 2016 (blue symbols in Fig. 5).

4.2 Power Supply

The newly installed electronics in the variometer house (the FGE fluxgate magnetometer, the GSM-90F1 overhauser magnetometer, and the datalogging system) are powered by the existing solar cells and batteries which are located in the southern part of the island (Fig. 3). In order to transmit power over a distance of 150 m, the 12 V direct current (DC) of the lead-acid batteries is converted to 220 V alternate current (AC) using a commercial 300 W inverter. The power supply line consists of a 3-wire 1.5 mm^2 power cable (H05RN-F 3X1.5) which was installed in a protective plastic tube (Fig. 7). This plastic tube was shallowly burried and can later be used as a ductwork for future installations. As lightnings occur frequently near the equator, currents may be induced in the power line by nearby lightning strikes. The currents may easily destroy the sensitive electronics in the variometer house. Therefore, the installation was protected by FURSE (ESP240-16A/BX) overcurrent protectors at each end of the powerline. The grounding of these protectors was improved in October 2016 by installing three 2 - 2.5 m long copper rods with a diameter of 12 mm which were connected to the FURSE via 16 mm^2 copper cables.

4.3 Data transmission

In the same building as the batteries are located (labelled “electronics” in Fig. 3), a netbook and a 3G router were installed. The netbook can connect to remote servers using a reverse SSH tunnel via the 3G network. Indeed, increasing coverage by mobile telecommunication network makes data transmission easy and cheap even in more remote places where expensive solutions (satellites, direct link, dedicated landlines) would have been the only alternative before. However, the SIM card that was used to transfer the variometer data stopped working from February, 4th to July 20th, 2016. Since then, data transfer has been reliable thanks to a new SIM card. The laptop is also used as a backup for the variometer data and displays a daily magnetogram for the local staff to check the correct operation of the system. Since October 2016, the absolute measurements are also manually stored in the netbook and transmitted to a remote server. In this way, quasi-definitive data can be produced with reduced latency. Due to initial problems with a fibre-optical link between the variometer house and the electronics house, the data are manually downloaded from the RaspberryPi datalogger in the variometer house on a daily basis via an ethernet link. Since February 2017, the fibre optics link is fully operational and data is continuously transmitted to a remote server.

4.4 Absolute Measurements

In the absolute house, changes were kept at a minimum level while making some significant improvements: First, the EDA fluxgate (E.D.A. electronics Ltd., Ottawa, CA) was replaced by a DTU model G fluxgate and electronics (serial number 0151, sensor PIL 7451) on November, 24th, 2015 after eighteen absolute measurements to determine baselines for the FGE variometer were made. Second, the absolute house was cleared from a number of magnetic and nonmagnetic objects on November, 26th, 2015. As a result, potential future movement of magnetic objects and associated changes in the level of the observatory (showing up as apparent changes in the baselines) can be avoided. Also, a clean absolute house makes it easier to identify new and potentially magnetic objects that have accidentally been forgotten. Before and after removing these objects, five absolute measurements were done, respectively. These ten absolute measurements revealed a difference in the absolute level of the observatory of +1.5 nT in the horizontal component (H) and +0.4’ (≈3 nT) in declination (D) after the removal of these objects while no difference was found for the vertical component. We note that any change in the absolute level should not exceed one nT in order to preserve the accuracy of the secular variation data from TTB (Matzka et al., 2010). This could have been achieved by correcting all future or past data with an appropriate constant offset. However, there are strong indications that the absolute level of the observatory was not stable to better than 3 nT in the previous periods, and therefore the previous data have not been corrected for this relatively low change in the observatory’s absolute level. Instead, the baseline was adopted by introducing a baseline jump corresponding to the jump in the measured absolute values.

In consequence of installing the model G fluxgate, the residual method of absolute measurements was introduced (Jankowsky and Sucksdorff, 1996, p. 89; Worthington and Matzka, 2017, this issue). In this way, the accuracy of the available ZEISS theodolite 020B can be fully used by exactly positioning the horizontal (vertical) circle to full arcmin’s during the declination (inclination) measurement. Otherwise, the resolution of the angular readings would have to be estimated to 0.1 arcminutes for the 020B theodolite. In particular, three pairs of absolute measurements are done per week, and the time is taken from a

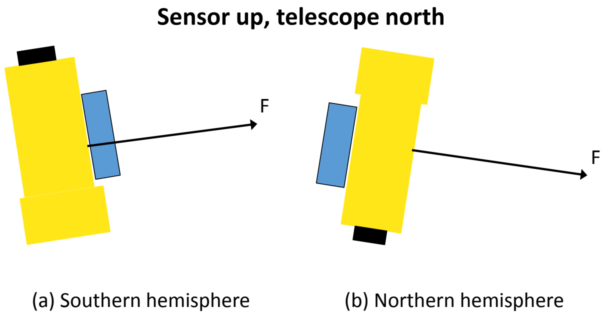

Figure 8. The position "sensor up, telescope north" is shown for a theodolite near the magnetic equator on the southern hemisphere (a) and the northern hemisphere (b). Depending on the magnetic hemisphere, these positions differ by 180°.

wall clock set according to the LEMI GPS in the variometer house. However, this clock is magnetic and had to be located far enough from the observer, making it hard to read. Therefore, it was replaced by an almost nonmagnetic stopwatch in October 2016. This stopwatch allows to easily read the time with one second accuracy and is set according to the system time of the netbook in the electronics house. In turn, the netbook's system time is synchronized via NTP with its GPS and several remote NTP servers.

5 Special considerations for absolute measurements near the magnetic equator

The standard concepts and observation routines of absolute measurements are challenged at the equator for a number of reasons. Mainly, these challenges result from the trivial fact that inclination is close to zero near the magnetic equator.

A first problem arises as the telescope is nearly vertical during inclination measurements and a zenith ocular is needed to read the vertical circle for positions where the telescope points upwards (for an alternative method, see Brunke and Matzka (2017)). This situation is even complicated by the fact that the widely used Zeiss Theo 020B has no degree numbers on the vertical circle from 162° to 179° and from 181° to 198°. Thus, only the minute marks can be read from the vertical circle if the telescope is pointing down. A slow and cumbersome remedy is to count the number of degree-marks between the closest numbered mark and the desired telescope postion. Another method is to assume a feasible degree number (e.g. the same one as with the last absolute measurement) and to compare the results of the absolute measurement (baselines, sensor offset, collimation angles) with the previous absolute measurements. In this way, a wrong reading will lead to non-consistent absolute measurements and can easily be identified. Then, the corresponding erroneous reading of the vertical circle must be corrected by a full degree or even multiples of it, and the correct absolute value can be calculated.

Another problem near the magnetic equator arises as formulas to calculate inclination from DI-flux measurements differ in sign for the northern and southern hemisphere (note that Eq. 5.4 of Jankowsky and Sucksdorff (1996, p. 95) has the wrong sign for the southern hemisphere as well as other sign errors (Matzka and Hansen, 2007)). When the geomagnetic equator is passing the observatory location due to secular variation, it may even happen that an observatory changes its magnetic hemisphere during a single absolute measurement due to the additional daily variation.

Further, telescope positions during inclination measurements are typically denoted ’Sensor up, telescope North’ and so on. If the inclination is very shallow, however, it is not easy to identify if the telescope actually points south or north, and if the sensor is positioned up or down relative to the telescope. Here, a simple rule can help to find the correct position: on the northern hemisphere, the north-pointing telescope will always point upwards, and on the southern hemisphere, the north-pointing telescope will always point downwards (Fig. 8). This still may lead to some confusion if an observatory is changing magnetic hemispheres due to the movement of the magnetic equator. Then, certain positions, e.g. ’Sensor up, telescope North’ will instantaneously be rotated by 180 degrees (see Fig. 8. However, observers might not realize this situation immediately due to the slow change in inclination and they might report readings in mixed up positions.

Moreover, sun observations are potentially necessary to determine geographic north. In this case, the standard methods that involve the leading and trailing limb of the sun are not practicable as the sun is moving nearly vertically. Special considerations on sun observations are detailed in Wienert (1970, p. 136).

Still, absolute observations near the magnetic equator do not only make the measurement process more complicated. Since the vertical component is close to zero, the leveling of the telescope is not very critical for declination measurements at the magnetic equator. On the other hand, leveling errors can cause significant problems for observatories at mid- to high-latitudes, and usually happen due to inexperienced or careless observers.

6 Data

All available digital variometer data of Tatuoca have been processed along with the available absolute measurements. These data include the recordings of the LEMI variometer from June 2008 to December 2016 and the recordings of the FGE variometer from November 2015 to January 2016. These data will soon be made available at the German Research Centre for Gesciences (GFZ) and the World Data Centre (WDC). Here, we will give a short example of the observed daily variations and present the preliminary base values of the observatory.

On November 21$^{\mathrm{st}}$, 2015, the first full day of data was recorded by the DTU FGE variometer. The recorded variations of the X (roughly geomagnetic north), Y (roughly geomagnetic east), and Z (vertical down) components are shown in Fig. 9. On this single day, the signal of the equatorial electrojet (EEJ) is visible as an increase in the X-sensor readings during daytime (time in UTC), underlining the importance of the observatory to study the EEJ.

The preliminary base values of the observatory are shown in Fig. 10 for the horizontal (H_0) field, the declination (D_0), and the vertical field (Z_0). The base values presented here have not been ckecked for outliers caused by transposed digits or other mistakes in the absolute measurements after January, 2016. On the left (Fig. 10a), the base values for the LEMI-417 are shown. Two abrupt changes in the base values (especially D_0) can most likely be attributed to a realignment of the LEMI sensor to geomagnetic North. Further, the base values of the FGE sensor are shown in Fig. 10b, but with a significantly different scaling

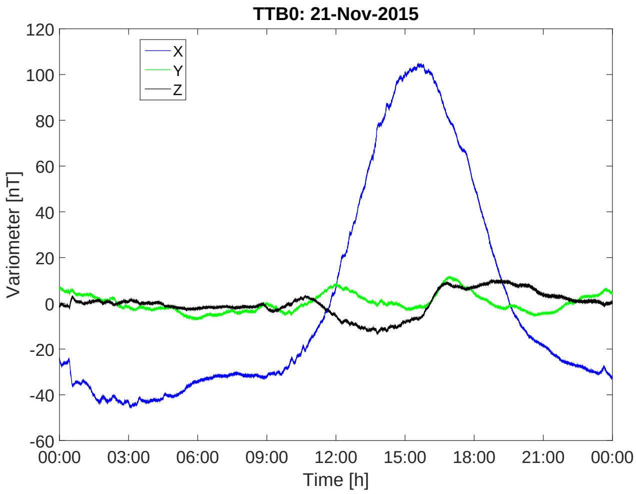

Figure 9. First full day of variometer data of the DTU FGE variometer raw data with 1 Hz resolution. Time is in UTC. The X-sensor is roughly oriented to magnetic north, and the increased amplitude during daytime due to the equatorial electrojet is visible.

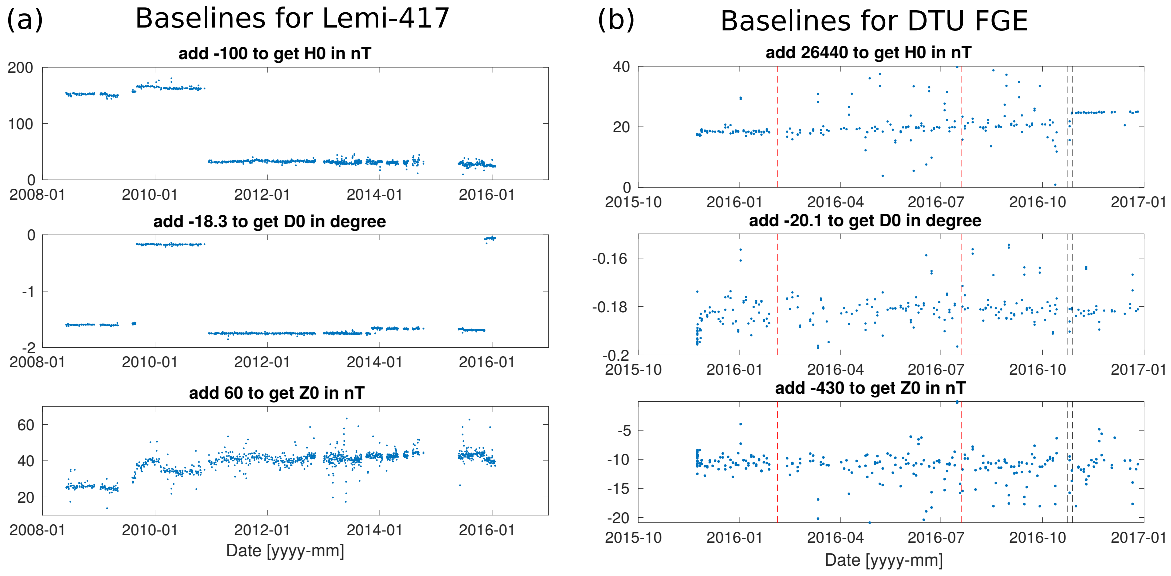

Figure 10. Base values for the Tatuoca observatory are shown for (a) the LEMI-417 variometer, and (b) the DTU FGE variometer. For the period between the vertical red lines, regular data download was not available. Further, vertical black lines indicate the visit to Tatuoca in October 2016.

than for the LEMI sensor. Here, the vertical red lines indicate the period for which direct data transmission from Tatuoca was not possible, and the vertical black lines indicate the beginning and end of the visits to Tatuoca.

Table 1. Variances of the base values for the LEMI sensor and the FGE sensor. The variances have been calculated for the horizontal field component (H), declination (D), and the vertical field component (Z) for four different periods.

Instrument:	LEMI		FGE		
Period:	I	II	II	III	IV
H_0 [nT]	2.74	2.40	2.29	9.44	0.76
D_0 [arcsec]	36.60	28.36	27.55	48.62	43.43
Z_0 [nT]	3.32	3.22	1.40	3.06	2.78

Period I the time until the first visit (2008-06-02 to 2015-11-17). Period II is the time from after the first visit until the internet connection was lost (2015-11-28 to 2016-02-03.
Period III is the time when internet connection was lost to before the second visit (2016-02-05 to 2016-10-23).
Period IV is the time after the second visit until a lightning strike occurred (2016-10-29 to 2016-12-30).

The variances of the preliminary base values were estimated by first linearly detrending the data. This detrending was done separately for periods when the base values changed abruptly. Then, the standard deviation was calculed for different periods and for the horizontal field, the declination, and the vertical field. In Tab. 1, the resulting standard deviations are summarized. Overall, the base values are stable to within 3 nT, but very large outliers occur frequently. For the period before our first visit (period I: 2008-06-02 - 2015-11-17), only LEMI data are available, and standard deviations are a bit higher as compared to period II, which spans the time from after the first visit to before the internet connection was lost (2015-11-28 to 2016-02-03). Also, the variances of the base values as derived from the FGE sensor are slightly smaller than those of the LEMI sensor, confirming the quality of the FGE instrument. When Internet connection was lost until the second visit (period III: 2015-02-05 to 2016-10-23), the variances of the base values significantly increased in all three components to a level that would be problematic for an Intermagnet observatory. Mainly, the reason is that no immediate feedback could be given to the observatory staff doing the absolute measurements, underlining the importance of regular data transmission for ensuring data quality. After our most recent visit in October 2016 (period IV: 2016-10-29 to 2016-12-30), the quality of absolute measurements has improved, although significant scatter still occurs in D_0 and Z_0. However, it is expected that a more detailed investigation and correction or removal of misreadings in the absolute measurements in the course of preparing the definitve data 2016 will lead to a significantly better standard deviation.

7 Summary and Outlook

Since 2015, the Observatorio Nacional (ON) of Brazil and the German Research Centre for Geosciences (GFZ) have collaborated in preparing the Tatuoca magnetic observatory to become a member of the Intermagnet network of magnetic observatories. Intermagnet has defined criteria for quality control and data checking, and provides centralized infrastructure for data

Figure 11. The power cable between the variometer house and the electronics house was damaged a few meters from the variometer house due to currents induced by a lightning strike close to Tatuoca observatory on December 31st, 2016.

distribution (Love and Chulliat, 2013). Thus, our efforts will add an observatory adhering to high data quality standards at an insteresting location within the magnetic equator and the south atlantic magnetic anomaly.

As of the end of 2016, a new DTU suspended variometer is installed on Tatuoca along with a modern datalogging system and a GemSystems GSM-90F1 scalar magnetometer. Further, a 3G modem is used to transmit the data to central servers on a daily basis. As well, the EDA fluxgate magnetometer on the ZEISS 020B theodolite in the absolute house was replaced with a DTU fluxgate model G. This latter change allowed to introduce the residual method of absolute measurements, increasing the accuracy of absolute measurements. Definitive base values have been calculated for the period from 2008 to 2015, and preliminary baselines are available for 2016. Most of the time, the base values are stable to within 3 nT, but very large outliers exist. Also, we experienced that it is important to provide immediate feedback to the observatory staff in order to assure high quality absolute measurements. This is particularly important, as a variety of peculiarities complicate absolute measurements near the equator. For example, missing degree marks at some vertical telescope positions make the readings prone to errors.

On the 31st of December 2016, a lightning strike hit the island of Tatuoca. In consequence, severe currents were induced in the power cable between the variometer house and the electronics house (Fig. 11). Apparently, the lightning protection in the variometer house was protecting the sensitive GSM and FGE electronics, but further testing is required. However, the 10 m ethernet cable attached to the datalogging system was unprotected, and induced currents destroyed the RaspberryPi. Also, the inverter, the netbook, and solar charge controllers were destroyed, probably due to induced currents in the cables leading to the batteries and solar panels. This event underlines the importance of lightning protection at magnetic observatories. We intend to fully repair the damage in February and March 2017.

Although the observatory is in a promising state, further improvements are needed to become a reliable member of the Intermagnet network. First, the stability of the baseline still can be improved. Second, the power supply chain for data recording should become independent of the power supply chain that is available for living and housing of the observatory staff.

In addition to these major tasks, there exists various smaller improvements that we may consider in the future. For example, the temperature of the FGE sensors electronics is changing by approximately four degrees per day. Such a temperature change may change the calibration constants of the variometer. Therefore, we may install an electrical heating and additional isolation to stabilize the temperature of the sensor and electronics. Other examples for future improvements include a direct illumination of the theodolite for better readability by using LEDs, and attaching the LEMI variometer to the variometer power supply. The latter will eliminate any potential signal of the DC current that powers the LEMI via solar cells.

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