

The Addis Ababa INTERMAGNET magnetic observatory

Arnaud Chulliat¹, Laike Mariam Asfaw², Atalay Ayele², Abebe Albie²,
Asnakech Estifanos², Xavier Lalanne¹, Jean Savary¹, François Truong¹

¹*Institut de Physique du Globe de Paris, 4 place Jussieu, 75005 Paris, France*

²*Geophysical Observatory, Addis Ababa University, Faculty of Science, P.O. Box 1176, Addis Ababa, Ethiopia*

Abstract

The Addis Ababa magnetic observatory (IAGA code AAE) is one in only two magnetic observatories located within less than one degree of the magnetic dip equator, and the only one in Africa. It started its operations in 1958 and joined INTERMAGNET (the worldwide network of magnetic observatories) in 1997, following the installation of new digital instruments by GOAAU and Institut de Physique du Globe de Paris. Since September 2008, the observatory produces one-second data and distributes them in quasi-real time using an upgraded fluxgate magnetometer and a new data acquisition system developed by IPGP. Since the beginning of 2009, baseline-corrected, quasi-definitive data are produced and distributed on a monthly basis using a new, dedicated data processing software. Both developments satisfy the most recent INTERMAGNET recommendations. Main uses of the Addis Ababa magnetic data include main field modelling, detection of geomagnetic jerks and equatorial electrojet studies, in combination with other ground data and data from low-Earth orbiting satellites such as Ørsted, CHAMP and the upcoming ESA Swarm mission. One-second data should enlarge the community of users to the space physicists studying geomagnetic pulsations.

1. Introduction

Geomagnetic recordings at the Geophysical Observatory, Addis Ababa University (GOAAU), started in January 1958, shortly after the establishment of the Observatory under the International Geophysical Year program. The IAGA code AAE was attributed to the observatory. In 1997, GOAAU and Institut de Physique du Globe de Paris (IPGP) installed new magnetometers, after which the observatory gained official INTERMAGNET magnetic observatory (IMO) status. INTERMAGNET is a global network of cooperating digital magnetic observatories, adopting modern standard specifications for measuring and recording equipment and transmitting data in quasi-real time via Geomagnetic Information Nodes to the scientific community (see www.intermagnet.org and St Louis, 2008). Since its foundation in 1987, INTERMAGNET has greatly expanded and now comprises more than hundred magnetic observatories distributed on all continents. In September 2008, the vector magnetometer and data acquisition system installed in Addis Ababa were upgraded in order to being able to record filtered one-second data, in agreement with the latest INTERMAGNET recommendations.

This paper presents the layout and instrumentation of the Addis Ababa magnetic observatory (section 2), as well as the method used to process its data (section 3). Then it reviews the main uses of the Addis Ababa geomagnetic data, focusing on the main field and

secular variation (section 4), and the equatorial electrojet (section 5). Finally, future prospects for the observatory are discussed (section 5)

2. Layout and instrumentation

The Addis Ababa magnetic observatory is located on the premises of the Addis Ababa University (GOAAU campus), in downtown Addis Ababa. It is made of two side by side pavilions, one used as the variation room and the other as the absolute house (Figure 1). Both pavilions are isolated from other buildings, in order to reduce magnetic disturbances caused by human activities. Due to the very sensitive instruments used in a magnetic observatory, a safety distance of about 70 m is required between the magnetic pavilions and the nearest occupied building, road, etc. Although the observatory is located in the very center of the city of Addis Ababa, this requirement has been fulfilled over the last fifty years.

Magnetic field variations are recorded using an IGP VM391 vector magnetometer (Figure 2). This instrument is a ring-core, 3-axis fluxgate magnetometer. It has been developed at IGP since the mid-1990s and is installed in all ten magnetic observatories of the IGP network (Courtillot and Chulliat, 2009). It is homocentric, i.e., it measures the three components of the field at the same point. This property is particularly useful in Addis Ababa where the magnetic field gradient is very large due to underlying basaltic rocks.

The IGP VM391 has recently been upgraded in order to produce filtered one-second data instead of filtered one-minute data. One-second data are obtained by sampling the field at 5 Hz and applying a 15-points Gaussian filter with a cut-off frequency at 0.3 Hz. Above this frequency, the magnetometer intrinsic noise becomes larger than geomagnetic variations and low-noise instruments such as search coils have to be used. A new data acquisition system named “ENO3” has been developed in order to provide GPS time synchronization and accurate time lag correction. The ENO3 includes additional functionalities such as configuration through a web interface, data transmission through the Internet and local or Web control display. The complete one-second system fulfills INTERMAGNET requirements for one-second data, including the 10 pT resolution and the 10 ms timing accuracy requirements. More details can be found in Chulliat et al. (2009). This system was installed in Addis Ababa in September 2008.

The variation room also contains an Overhauser-type scalar magnetometer Geomag SM90R, which provides measurements of the scalar field every 5 s. By taking the difference between the field modulus computed from the vector components and that directly measured by the scalar magnetometer it is possible to detect anomalies such as spikes, jumps or drifts of non-natural origin in the measured vector field. For example, if a ferrous object is moved in the vicinity of the magnetometer pavilion, the associated magnetic perturbation will be slightly different at the location of the vector magnetometer and at the location of the scalar magnetometer, resulting in a detectable drift in the scalar residual.

Special attention has been paid to temperature control in the variation room, as fluxgate magnetometers are very sensitive to temperature variations (the typical temperature coefficient of the VM391 is 0.3 nT/°). A double roof made of straw was built in 2006. In addition, a large number of plastic bottles filled with water were placed around the sensor and magnetometer electronics to increase the thermal inertia of the system. These simple, low tech methods acting as a low pass filter helped reducing the diurnal temperature variation at the sensor and at the electronic part to less than 1° (and the weekly variation to less than a few degrees), thus ensuring a temperature perturbation of less than 1 nT in one day. This can be checked from the continuous temperature recordings (near the sensor and near the electronic

part of the magnetometer) and by looking at the scalar residual as the scalar magnetometer, which is not sensitive to temperature variations.

Following INTERMAGNET recommendations, absolute measurements are performed at least once a week (and usually twice a week) at Addis Ababa magnetic observatory (Figure 3). Such measurements are needed to periodically recalibrate the fluxgate magnetometer (which otherwise would drift due to seasonal temperature variations, aging of electronic components, mechanical effects, etc.) and compensate slow movements of the pillar on which the magnetometer is installed. Absolute measurements of the declination and inclination are performed using a “DI-flux” constituted of a single-axis fluxgate magnetometer mounted on an amagnetic theodolite (see, e.g., Jankowski and Sucksdorf, 1996). The magnetic field intensity is provided by the scalar magnetometer. Pillar differences are regularly measured using an additional scalar magnetometer mainly to characterize magnetic thermal effect induced by the basaltic soil.

3. Data processing

Raw one-second data are transmitted in quasi-real time (less than 1 hr) through the Internet to the Paris Geomagnetic Information Node, where they are made available to users on the IGP website (www.bcmf.fr). Raw one-minute data are calculated using a Gaussian digital filter from one-second data and are made available on the same website and on the central INTERMAGNET website (www.intermagnet.org). INTERMAGNET is currently developing the capability to distribute one-second data on its website.

Within one month, the following data processing is made: (a) despiking and removal of disturbances of artificial origin, (b) correction of the data using a temporary baseline calculated from the latest absolute measurements since the beginning of the current civil year. Step (a) is performed using semi-automatic tools and involves interactions between the local GOAAU team and the IGP team based in Chambon la Forêt (France). Step (b) is performed using MAGIS (acronym for “Magnetic Information System”), a dedicated software recently developed by Truong et al. (2009) at IGP. Once validated, the resulting baseline-corrected, clean data are considered as very close to definitive data (within less than a few nT) and hence referred to as “quasi-definitive”. These data are distributed on the IGP webpage (www.bcmf.fr). This procedure is new and was introduced following the need expressed by the main field modeling community to have baseline-corrected data available after a shorter time span than the traditional one year delay (see INTERMAGNET’s 2008 report to IMOs).

After the end of the civil year, definitive data are produced by calculating the full annual baselines for each component (Figure 4) and completing the data cleaning. These data are distributed by INTERMAGNET on its central website (www.intermagnet.org) and on an annual DVD containing the definitive data from the entire network.

4. Main uses of the data: main field and secular variation

A very important use of the geomagnetic data provided by the Addis Ababa magnetic observatory is the calculation of global models of the main geomagnetic field and its secular variation, such as the International Geomagnetic Reference Field (e.g., Maus et al., 2005), the CM4 comprehensive model (Sabaka et al., 2004) and the *gufm* historical field model (Jackson et al., 2000). Due to its geographical isolation with respect to other IMOs, the Addis Ababa observatory provides the only secular variation data at the Earth surface in a circle of about 2300 km radius (the nearest IMO is the Bangui observatory, located 2291 km in the West

direction). Even at times when magnetic satellites such as Ørsted and CHAMP provide high-precision magnetic field measurements at a much higher spatial resolution than the INTERMAGNET network, magnetic observatory data are used for validating satellite data and for complementing them, especially in global secular variation models. At times when no satellite data are available, for example after 2010 and before the launch of the upcoming Swarm mission (planned in mid-2011), observatory data are the only data available for main field modelling.

Another use related to the geomagnetic secular variation (and thus requiring precise and frequent absolute measurements) is the investigation of geomagnetic jerks, defined as discontinuities in the second order time derivative of the secular variation (Courillot et al., 1978) and recently detected in satellite data (Olsen and Manda, 2007). Despite numerous phenomenological and theoretical studies, the origin of geomagnetic jerks remains unclear. As can be seen on [Figure 5](#), the secular variation recorded in Addis Ababa since 1958 contains several known geomagnetic jerks: around 1980, 1990, 2003 and 2005. Note that the signal to noise ratio becomes larger after 1997, due to the improvement of the observatory equipments.

5. Main uses of the data: equatorial electrojet

The Addis Ababa magnetic observatory is located very near the magnetic dip equator, where the Earth's main magnetic field is exactly horizontal. Its dip latitude in 2006 was 0.72°N , making it the second closest INTERMAGNET observatory to the dip equator after Huancayo (Peru). This location is ideal for observing the magnetic signature of the equatorial electrojet (EEJ), an eastward electrical current flowing along the magnetic dip equator in the dayside E region of the ionosphere, at around 110 km altitude (e.g., Heelis, 2004). The EEJ is caused by a local enhancement of the E region electrical conductivity in the region where the main magnetic field is roughly horizontal (an effect theoretically discovered by Cowling, 1933). This is why the diurnal variation generated by the EEJ at the ground is larger than the one generated by the Sq current system at higher latitudes. In Addis Ababa, the average amplitude of the diurnal variation of the horizontal component is about 70 nT on geomagnetically quiet days ([Figure 6](#)), to be compared with 30 nT for the Sq variation at a mid-latitude observatory such as Chambon la Forêt (France).

Since its discovery at Huancayo in the 1940s (Bartels and Johnston, 1940; Egedal, 1947), a large number of theoretical and observational studies have been devoted to the EEJ. Several recent observational studies were aimed at characterizing the spatio-temporal variations of the mean EEJ, either from ground data (e.g., Doumouya et al., 2003) or magnetic satellite data (e.g., Lühr et al., 2006; Le Mouél et al., 2006; Alken and Maus, 2007). Like for the main magnetic field, satellite data are very useful in providing descriptions of the spatial variability of the EEJ with a much higher resolution than ground data. However, ground data remain essential for understanding the time variability of the EEJ and its spatial correlation lengths, as was recently shown by Manoj et al. (2006) using data from Addis Ababa (among data from other observatories and satellites).

The “counter-electrojet” (CEJ), discovered by Gouin and Mayaud (1967), is a temporary inversion of the EEJ direction occurring in the morning or evening. As can be seen on [Figure 6](#), the signature of a morning CEJ is present in the average diurnal variation at Addis Ababa. This is in good agreement with Le Mouél et al. (2006), who found that a morning CEJ is present in the average EEJ signal over the entire African sector, based on CHAMP satellite data.

Of particular interest for space weather applications is the concept of observatory pairs, one below the EEJ and the other one just outside its region of influence on the same

meridian, which was recently put forward by Anderson et al. (2002). These authors showed that calculating the difference between the horizontal component and its night reference value at both observatories and taking the difference enables to separate the EEJ effect from the Sq effect and recover the vertical plasma drift velocity in the ionospheric *F* region (Anderson et al., 2002). Unfortunately there is no other IMO around $\pm 5^\circ$ dip latitude on the same meridian as Addis Ababa; the closest one is the Qsaybeh observatory in Lebanon.

6. Future prospects

The production of quasi-definitive data on a monthly basis addresses the need expressed by several main field modelers to include observatory data into their models without having to wait for the definitive data (published one year later). It is still in prototype mode but should be fully operational before the launch of the ESA Swarm mission, planned in 2011. It is therefore anticipated that Addis Ababa magnetic data will be used to calculate and/or validate global main field and secular variation models during the Swarm mission, including level 2 data products of the mission itself. Other uses for Addis Ababa quasi-definitive data during the Swarm mission include global modeling of the ionospheric field (including the EEJ) and the magnetospheric field.

The second recent improvement made to the Addis Ababa magnetic observatory is the capability to produce and distribute one-second data. These data are mostly used by space physicists studying rapid variations of the external magnetic field, such as ULF waves and sudden impulses. An exciting new topic is the use Pi2 pulsations to time and locate the onset of substorms (Chi et al., 2009). It is therefore expected that the community of users of Addis Ababa magnetic data will get larger in the coming years.

Acknowledgements

The Addis Ababa magnetic observatory is operated within the framework of a cooperative agreement between GOAAU and IPGP. On the French side, funding for the equipments is provided by CNRS-INSU; funding for the operations is provided by the French Ministry of Research. This is IPGP contribution number 2598.

References

- Alken, P. and S. Maus (2007), Spatio-temporal characterization of the equatorial electrojet from CHAMP, Ørsted and SAC-C satellite magnetic measurements, *J. Geophys. Res.*, 112, A09305, doi:10.1029/2007JA012524.
- Anderson, D., A. Anghel, K. Yumoto, M. Ishitsuka and E. Kudeki (2002), Estimating daytime vertical ExB drift velocities in the equatorial F-region using ground-based magnetometer observations, *Geophys. Res. Lett.*, 29, 1596, doi:10.1029/2001GL014562.
- Bartels, J. and H. F. Johnston (1940), Geomagnetic tides in horizontal intensity at Huancayo, p. I, *J. Geophys. Res.*, 45, 269-308.
- Chi, P. J., C. T. Russell and S. Ohtani (2009), Substorm onset timing via traveltime magnetoseismology, *Geophys. Res. Lett.*, 36, L08107, doi:10.1029/2008GL036574.
- Chulliat, A., J. Savary, K. Telali and X. Lalanne (2009), Acquisition of 1-second data in IPGP magnetic observatories, *Proceedings of the XIIIth IAGA Workshop on Geomagnetic*

- Observatory Instruments, Data Acquisition and Processing, June 9-18 2008, Golden, USA*, in press.
- Courtillot, V., J. Ducruix and J.-L. Le Mouél (1978), Sur une acceleration récente de la variation séculaire du champ magnétique terrestre, *C. R. Acad. Sci. Paris, D* 287, 1095-1098.
- Courtillot, V. and A. Chulliat, Eds. (2009), *Magnetic results 2006*, 264 pp., Bureau Central de Magnétisme Terrestre, Paris.
- Cowling, T. G. (1933), The electrical conductivity of an ionized gas in the presence of a magnetic field, *Mon. Not. R. Astron. Soc.*, 93, 90-98.
- Doumouya, V., Y. Cohen, B. R. Arora and K. Yumuto (2003), Local time and longitude dependence of the equatorial electrojet magnetic effects, *J. Atmos. Sol. Terr. Phys.*, 65, 1265-1282.
- Egedal, J. (1947), The magnetic diurnal variation of the horizontal force near the magnetic equator, *Terr. Magn. Atmos. Electr.*, 52, 449-451.
- Heelis, R. A. (2004), Electrodynamics in the low and middle latitude ionosphere: A tutorial, *J. Atmos. Sol. Terr. Phys.*, 66, 825-838.
- Jackson, A., A. R. T. Jonkers and M. R. Walker (2000), Four centuries of geomagnetic secular variation from historical records, *Phil. Trans. R. Soc. Lond. A*, 358, 957-990.
- Jankowski, J. and C. Sucksdorff (1996), *Guide for Magnetic Measurements and Observatory Practice*, 232 pp., IAGA, Warsaw.
- Le Mouél, J.-L., P. Shebalin and A. Chulliat (2006), The field of the equatorial electrojet from CHAMP data, *Ann. Geophys.*, 24, 515-527.
- Lühr, H., S. Maus, and M. Rother (2004), Noon-time equatorial electrojet: Its spatial features as determined by the CHAMP satellite, *J. Geophys. Res.*, 109, A01306, doi:10.1029/2002JA009656.
- Manoj, C., H. Lühr, S. Maus and N. Nagarajan (2006), Evidence for short spatial correlation lengths of the noontime equatorial electrojet inferred from the comparison of satellite and ground magnetic data, *J. Geophys. Res.*, 111, A11312, doi:10.1029/2006JA011855.
- Maus, S., S. McLean, D. Dater, H. Lühr, M. Rother, W. Mai and S. Choi (2005), NGDC/GFZ candidate models for the 10th generation International Geomagnetic Reference Model, *Earth Planets Space*, 57, 1151-1156.
- Olsen, N. and M. Manda (2007), Investigation of a secular variation impulse using satellite data: The 2003 geomagnetic jerk, *Earth Planet. Sci. Lett.*, 255, 94-105.
- Sabaka, T. J., N. Olsen and M. Purucker (2004), Extending comprehensive models of the Earth's magnetic field with Ørsted and CHAMP data, *Geophys. J. Int.*, 159, 521-547.
- St-Louis, B., Ed. (2008), *INTERMAGNET Technical Reference Manual, Version 4.4*, 94 pp., INTERMAGNET, Edinburgh.
- Truong, F., X. Lalanne and A. Chulliat (2009), MAGIS: The information system of IGP magnetic observatories, *Proceedings of the XIIIth IAGA Workshop on Geomagnetic Observatory Instruments, Data Acquisition and Processing, June 9-18 2008, Golden, USA*, in press.



Figure 1: The two pavilions on the AAU campus used as the variation room (right) and the absolute house (left).

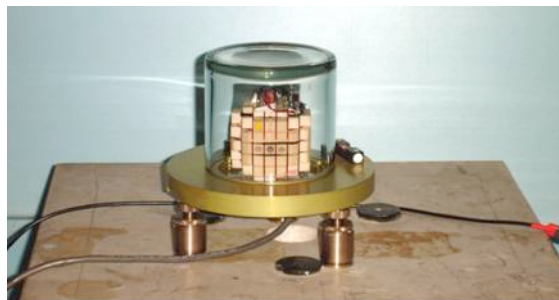


Figure 2: The IPGP VM391 fluxgate magnetometer.



Figure 3: Absolute measurement using a “DI-flux” and a scalar magnetometer at Addis Ababa magnetic observatory. (The photographed observer is Abebe Albie Toro.)

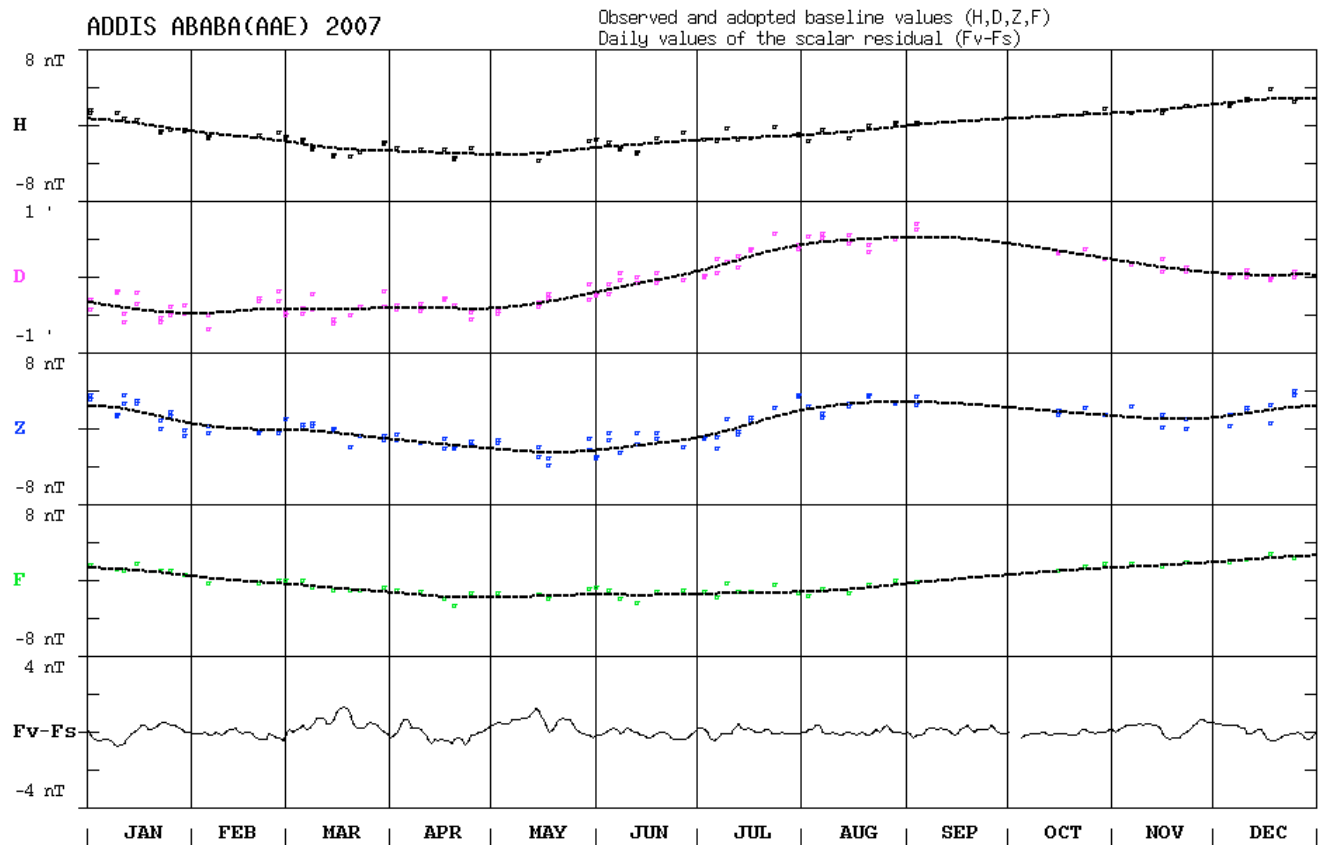


Figure 4: Observed (dots) and adopted (lines) baseline values in 2007; daily values of the scalar residuals. Baseline values for the total field (F) are obtained from measurements of the difference field between the absolute pillar (in the absolute house) and the scalar magnetometer pillar (in the variation room).

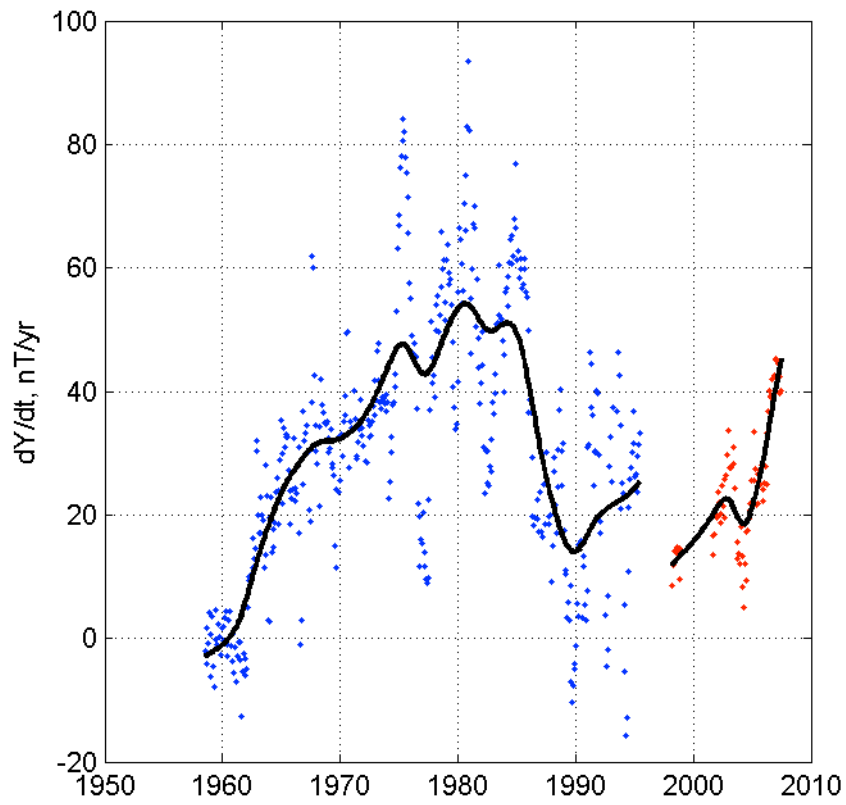


Figure 5: Secular variation of the East component (dY/dt) from 1958 to 1995 (blue dots) and from 1997 to 2007 (red dots), fitted by smoothed cubic splines (thick black lines).

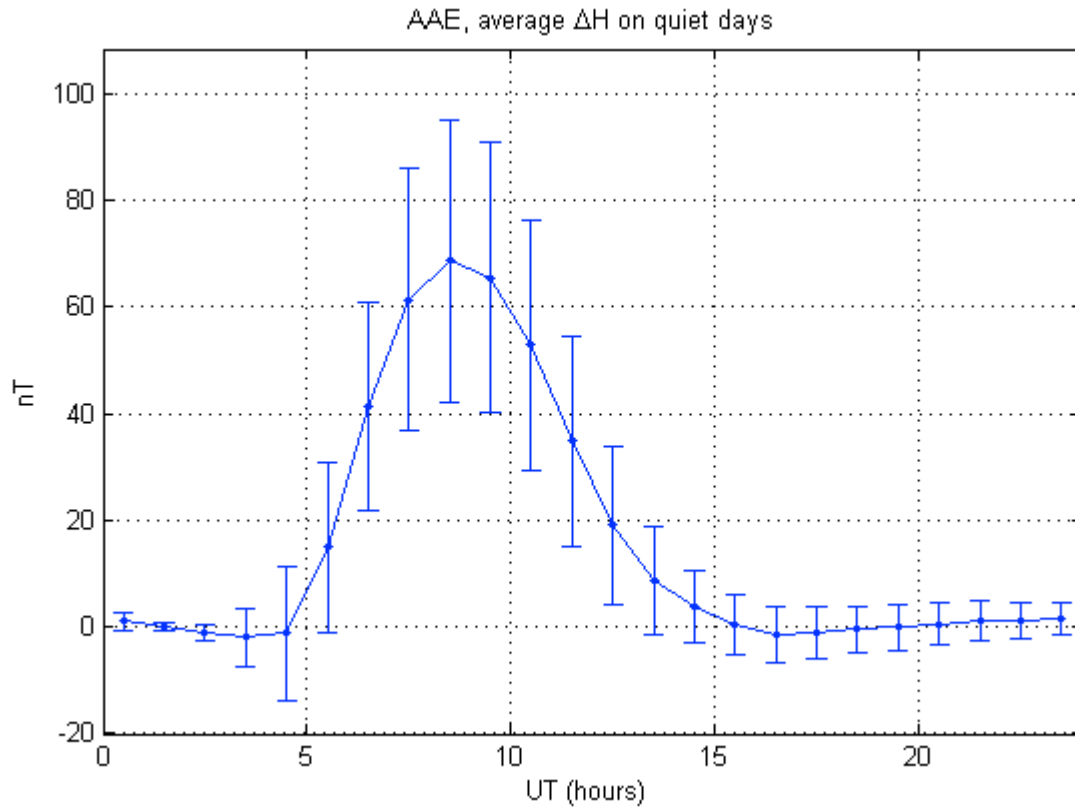


Figure 6: Average difference for each UT hour between the H component and its night reference level, from March 26 to September 30, 2006 (quiet days only). Error bars correspond to standard deviations of the differences.