A NEW MEASUREMENT METHOD FOR MAGNETIC REPEAT STATIONS

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SUMMARY

The relevance of traditional magnetic repeat station networks to geomagnetic modeling has been increasingly challenged during the last decade, as the Ørsted and CHAMP satellites provided data of unprecedented precision and spatial resolution. Yet magnetic repeat networks organized on a national or regional basis can still be viewed as relatively inexpensive safety nets in case satellite data are not available. Here we present a new method for magnetic repeat measurements, where repeat stations are located on airports, azimuth sightings are determined using GNSS geodetic receivers and magnetic measurements are performed at night (around 0200 local time). This method aims at improving the measurement precision while keeping the cost low, by facilitating the measurement execution. It was first implemented in metropolitan France during the summer 2012. Its full evaluation will be made in 2013, after a first reoccupation of the new French repeat network.

1. INTRODUCTION

Magnetic repeat stations are precisely located points at the Earth's surface, where the three components of the geomagnetic field are regularly measured to the highest possible accuracy, in order to determine the geomagnetic secular variation (Newitt et al., 1996). The role of magnetic repeat stations is to complement magnetic observatories, by providing data in areas where the installation of a full observatory would be too costly and/or impossible due to the lack of infrastructure and local manpower. For this reason, many countries have set up magnetic repeat station networks in order to regularly update geomagnetic charts on their territory. In France, a national repeat station network was set up in 1947, expanded and upgraded in 1965 and reoccupied every five years until 2007 (Chulliat, 2012).

The advent of magnetic satellites such as Ørsted and CHAMP has challenged this traditional approach. High-precision, vector satellite data make it possible to calculate geomagnetic secular variation models of unprecedented spatial resolution without using repeat station measurements. For example, the latest International Geomagnetic Reference Field model (Finlay et al., 2010) provides the average secular variation between 2005 and 2010 up to spherical harmonic degree 13. Some research models actually provide the time-varying secular variation up to degree 13 over the entire decade (e.g., Lesur et al., 2010). Within the *Bureau Central de Magnétisme Terrestre*, the French organization in charge of ground magnetic measurements, a decision was made to continue repeat station measurements as a "safety net" in case no high-precision satellite data are available for an extended period of time in the future, but using a smaller network and an improved measurement method in order to reduce the overall cost of each measurement campaign. The key ideas of the new method are to implement stations on airports, use the Global Navigation Satellite System (GNSS) for precise azimuth measurements and perform magnetic measurements at night, when ionospheric disturbances are minimal.

Here we present the new method and how it was implemented in metropolitan France over the summer 2012. A full evaluation of the method will be made in 2013, after a second measurement campaign, by comparing the obtained secular variation with the secular variation provided by the IGRF model and, if available, the first models derived from the upcoming ESA Swarm satellite mission (Friis-Christensen et al., 2006).

2. NEW METHOD: KEY IDEAS

Implementing stations on airports

French magnetic repeat stations setup between 1947 and 1965 were materialized by a survey marker buried or semi-buried in the soil, sometimes along roads in colocation with stations of the French Reference Leveling Network, and more often in fields under an agreement with local owners (often farmers). Fifty years later, the leveling network is no more maintained as it was largely replaced by a GNSS network, some roads have been enlarged and some private properties have changed owner. As a result, keeping survey markers intact from one survey to the next becomes more difficult. In addition, some prominent features used as azimuth marks (e.g., church steeples, lighthouses, telecommunication antennas, etc.) have been modified during building maintenance operations or have become invisible due to vegetation growth. For all these reasons, it was decided to start a new network from scratch and two objectives were assigned to the stations of the new network: the sustainability of the site (public premise versus private property) and its magnetic cleanliness along an extended period of time.

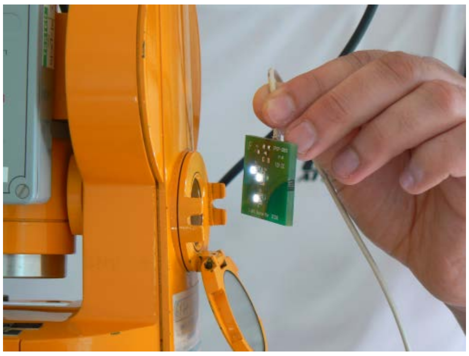
Airports satisfy very well these two requirements, provided some precautions are taken. For the first requirement, it is necessary to select airports belonging to a public authority and having no risk of being closed in a foreseeable future. This is the case for all airports that were selected for the new repeat station network. Regarding the second requirement, the positioning of the measurement mark on the airstrip axis offers a good guarantee of stability of the magnetic environment. In France the runway is generally made of several layers of compacted limestone gravel and a final layer of bituminous concrete which are largely nonmagnetic. Secondly, the runway is about 45 m wide and, as no obstacle over an angle of 5° is allowed from the edge of the airstrip, there is very low risk that a significant building is erected at a distance less than 100 meters from the magnetic station. In addition to their favorable magnetic properties, airports offer a perfect line of sight along the runway to install the azimuth target.

Finally, it is worth noting that, as aeronautical charts are referenced to the magnetic North, airport authorities are interested in accurate magnetic declination measurement on their premises.

Performing night-time measurements

Our experience on airborne or marine surveys shown that precise removal of the diurnal variation can't be achieved when the distance to the reference station is greater than 200 km. Some groups install a 3-axis variometer in the vicinity of the magnetic repeat station, but the installation of such an equipment is not easy and relatively time consuming, as it is needed to ensure a good enough mechanical and thermal stability. For these reasons, we decided to operate at times when the diurnal variation is minimum, between 2 and 4 LT (i.e., between 4 and 6 a.m. in French summer time). This time slot also has the advantage of minimizing the interferences with airport operations.

Operating by night in a steel-free environment is not easy and some devices have to be built for this purpose. The most important is the theodolite lighting device. We developed a dedicated system for the Zeiss 010 theodolite (Figure 1a), as light paths are specific for each type of theodolite. It consists of a small PC board of FR4 equipped with 3 white LED and feed in D.C through a nonmagnetic coaxial cable. The second lighting device is the azimuth target. We made a 20 cm square surface with black and white sectors backlighted by white LEDs (Figure 1b). Schematics and pictures for both systems are available on demand.



1a :The lighting device for Zeiss 010

1b : The illuminated azimuth marker

Using GNSS

Operating at night means that the use of prominent features as azimuth marks is no more possible, since these features cannot be easily illuminated. Star sighting requires considerable training to be performed to the required level of accuracy, and is weather dependent. By contrast, determining the azimuth using GNSS is easier and this is the method we chose.

The GNSS method consists in setting up GNSS geodetic receivers (Trimble NetR9 in our experiment) at the two ends of a 420 m baseline defined by the theodolite and the target, and recording the GNSS signal phase observables at 1Hz frequency. The acquisition lasts about 5 hours. We used the Ashtech Solution software for the data post processing that determines the precise positions of the two receivers, from which we calculated the azimuth of the baseline defined by the two receivers. Figure 2 shows the azimuth calculated at each epoch of the acquisition (example of Lyon airport). The determination of geodetic azimuth by GNSS reaches an accuracy range of 1- 5 arc-second, well below the requested accuracy of 20 arc-second obtained by Sun or star sighting. As was observed in the Cannes airport, where the measurement session had to be interrupted due to an emergency sanitary flight, the requested accuracy is even reached for short acquisition duration (3 hours).

Thanks to the short length of the baseline and the field environment, the accuracy of the GNSS measurements is quite good. On the airport runways, there is no more interfering obstructions (as buildings, trees…), which leads to an increased number of satellites seen by the receiver, an increased strength of satellite geometry, fewer satellite signal multi-paths and less corruption of GNSS measurements.

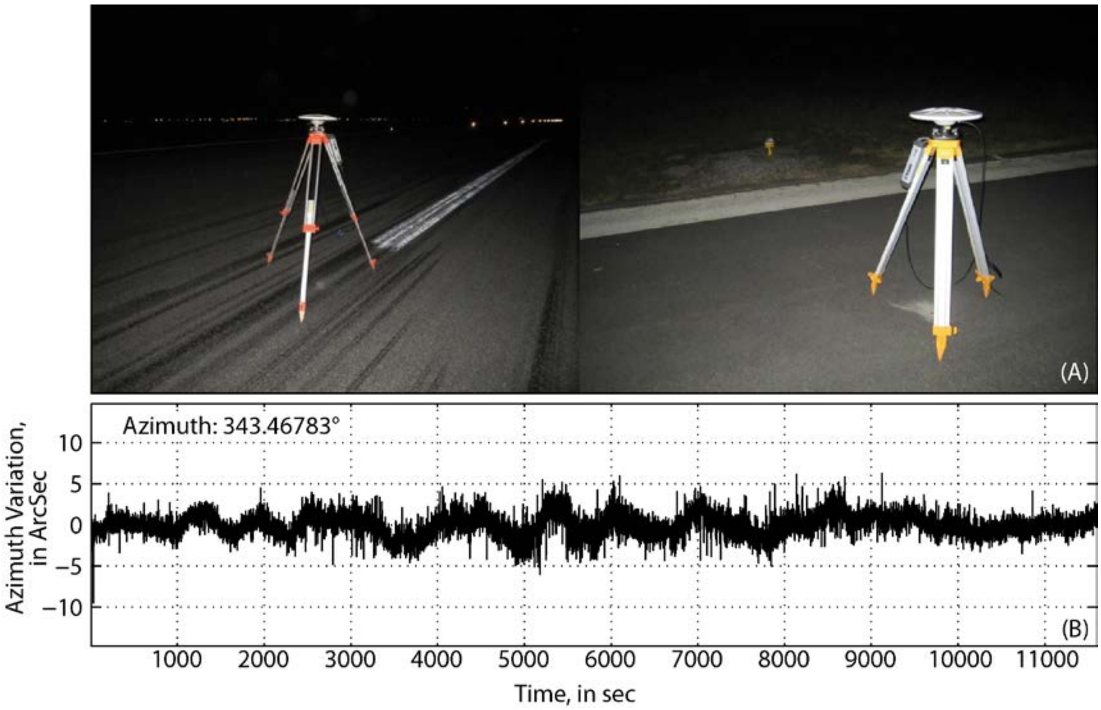


Figure 2: (A) GNSS receivers set up on the runway of the Lyon-Bron airport. (B) Azimuth variation recorded in the same airport.

3. NEW METHOD: OPERATION WORKFLOW DURING THE 2012 SURVEY

The new French repeat stations network is made of eleven stations covering the territory of metropolitan France (Figure 3). This distribution of stations is thought to be sufficient to guarantee a precision of the secular variation over France similar to that obtained from satellite measurements. This will be checked after the 2013 measurement campaign.

Operations on airports require several months of preparation and cannot be improvised or easily re-scheduled. Even if the airports we selected are closed at night, they can be used for landing by an aircraft in distress or for a sanitary flight. In the first case, the airport authorities have to issue a NOTAM to inform all flight that such runway will be unusable in any case during this specific night. In the second case, a 1-hour pre-alert is common and sufficient to remove all equipment's from the runway. Of course safety and security regulations bust me strictly observed. Operators must wear fluorescent yellow safety vest to enhance their visibility when working on airport grounds, the car must be equipped with an orange flashing light and the operators must dispose a VHF radio or cell phones. Operator's IDs and car documents must be provided to airport authorities several days in advance.

The installation and first occupation of the new repeat station network was organized in three 5-day sessions mobilizing 2 operators each. One airport was occupied every night and a distance between 450 and 600 km was travelled by car every day.

A typical installation and measurement session happens as follows. The 2-person team arrives on the airport at 5 p.m. (French summer time), so that a daylight visual reconnaissance of the runway is possible, in order to locate a flat section of 420 m - the distance between 7 runway lighting markers - for the azimuth sighting. Only a few minutes are available, inserted between the aeronautical operations. The team comes back at the airport closing time in order to deploy the GNSS geodetic equipment. On the runway central axis, at the place identified during the afternoon reconnaissance, a quick magnetic check is done with a scalar magnetometer. Then a 10 mm hole is drilled and a steel free marker is placed (see below). A steel-free tripod is installed vertically and a geodetic GNSS antenna is precisely centered with respect to the ground marker. The same operation is done at a distance of 420 m for the azimuth mark, but generally not on the runway central axis – as the magnetic environment is not sensitive – but on the runway at 1 m distance from a lighting aid for easy recovering in the future. Both receivers are switched on for a 1-Hz sampling rate recording, until the beginning of the magnetic measurements.

A few hours later, after taking some rest at a nearby hotel, the team comes back to the airport at 3:30 a.m. for the magnetic measurement. The antenna of the GNSS receiver on the runway axis tripod is replaced by the DI-Flux theodolite precisely centered on the ground marker and the second antenna is replaced by the azimuth backlighted target.

A scalar magnetometer is set up for continuous recording a few meters away from the theodolite. A seat and a table are placed for the operator who notes the observations on a logbook. Great care is taken for keeping magnetic and lighting devices at a safe distance from the theodolite.

Generally a set of 8 complete observations can be performed before 6 a.m. Then, 15 minutes are sufficient to remove all the equipments before the runway is inspected and the air operations restart (around 6 a.m.)

No onsite data check is performed, because the team has to take some rest before travelling to the next station, and also because operations on an airport must be scheduled several days in advance and therefore no additional measurement and/or change in the experimental setup could be made on the same day anyway. In case of instrument malfunction or measurement errors at a given site, a new campaign for this site has to be organized later. However, the measurements made each day are sent by email to a second team in the IPGP offices, in order to detect a possible malfunction of the DI-flux or the scalar magnetometer.

Subsequent reoccupations of the new repeat station network will be easier. Before reoccupying each station, we will ask to the airport authorities to check for the presence of the ground marker. If the ground marker is still there, no new GNSS geodetic measurement will be necessary.

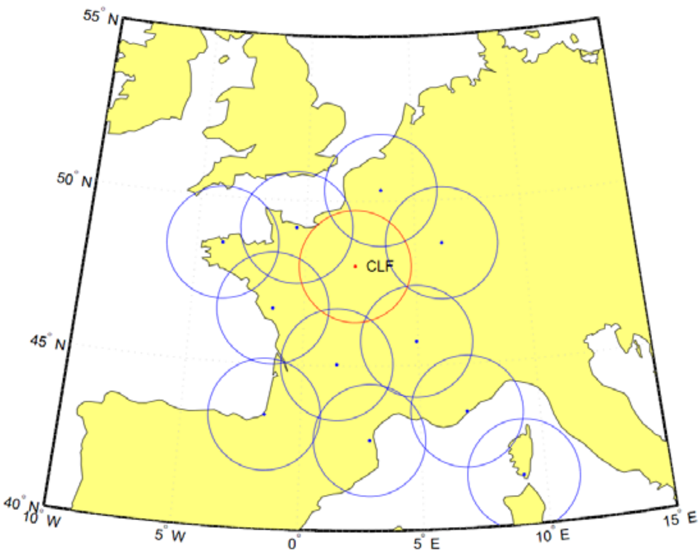


Figure 3 – Map of the new repeat station network for metropolitan France. Circles centered on each station and of radius 1.7° are shown.

4. REFERENCES

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