BUREAU CENTRAL DE MAGNÉTISME TERRESTRE
France

Bureau Central de Magnétisme Terrestre
Director: M. Chaussidon

# Strategic Plan 2019-2023

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## Foreword

This document is the third quadrennial strategic plan for the BCMT after the "Strategic Plan 2010-2012" and the "Strategic Plan 2014-2018" released respectively in September 2010 and January 2014. It defines the main projects and activities of the BCMT for the forthcoming years such that it fulfils its missions and responds to the evolution of the scientific and societal needs.

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# Contents

# Executive Summary

The Bureau Central de Magnétisme Terrestre (BCMT) is a French organisation founded in 1921 and attached to the Institut de Physique du Globe de Paris (Paris IPGP). The primary mission of the BCMT is to provide ground geomagnetic observations of the highest quality to the scientific community, to industrial and to citizens, in France and abroad. Since 2008, the BCMT has been recognised as the Service National d'Observation (SNO) in Magnetism by the Centre National de la Recherche Scientifique (CNRS). Two French institutions are involved in BCMT operations, IPGP and Ecole et Observatoire des Sciences de la Terre (EOST) in Strasbourg. Several others, including CNRS-INSU and the Institut Polaire Français (IPEV), provide financial and/or human support. An international Scientific Council, set up in 2009, meets every two or three years to review BCMT activities and to provide advices and recommendations to the BCMT.

To achieve its mission, the BCMT operates a network of 17 magnetic observatories distributed on 6 continents, including the National Magnetic Observatory located in Chambon la Forêt, Loiret, and a repeat station network in metropolitan France. The BCMT observatory network represents about 15% of INTERMAGNET, the global network of magnetic observatories, and contributes to filling geographical gaps in scientifically interesting locations. The BCMT develops its own line of dedicated instruments, taking advantage of the Chambon la Forêt site where unique testing and calibration facilities are available. In-house instrument development provides significant flexibility and reliability to BCMT operations. Several data products are distributed by the BCMT: preliminary one-second or one-minute data in real time (less than 5 min, 9 observatories) or near real time (less than 24 h, all observatories); quasi-definitive data with a one-month delay and definitive data with a one-year delay; repeat station data products such as a declination map; geomagnetic indices. BCMT data are available on its webpage (www.bcmt.fr), on INTERMAGNET'/s webpage (www.intermagnet.org) and on several other data infrastructures such as SUPERMAG website (http://supermag.jhuapl.edu/).

The aims of the BCMT for the upcoming five-year period (2019-2023) are to maintain, if possible develop, the observation network, to manage the produced data, and to upgrade the current systems of observation (sensors and acquisition chains) in place in the observatories. These are associated with scientific objectives: long term evolution of the geomagnetic field and support to satellite survey missions (e.g ESA's Swarm mission); space weather and space climate; observatory techniques and instruments. Noteworthy projects include: finalising the setting of Edéa (Cameroon) and Antananarivo (Madagascar) observatories, relocation of M'bour (Sénégal) and Pamatai (Tahiti) observatories, development of a network of variometer stations over France, minting of digital object identifiers and setting licences for all data, cataloguing all available historical data and digitise some of them, finalising the new low-noise digital vector magnetometer, and start the development of a highly-stable, self-calibrating, instrument.

# 1 Introduction

The "Bureau Central de Magnétisme Terrestre" (hereinafter BCMT) has been established by decree in 1921 and attached to the "Institut de Physique du Globe de Paris" (IPGP) that has been founded around the same epoch. In 2008, the "Institut National des Sciences de l'Univers" (INSU, one of the institutes of the Centre National de la Recherche Scientifique, CNRS) set up a Service National d'Observation (SNO) in Magnetism, which was delegated to the BCMT. Together with another SNO, the "International Service of Geomagnetic Indices" (ISGI), they form one of the so-called "Actions Nationales d'Observation" (ANO) of the INSU solid Earth department.

The mission of the BCMT is to provide ground-based geomagnetic observations and data products of the highest quality, addressing the needs of the French and international geosciences research community, and those of the French administrations, businesses and citizens. Such data are of prime importance for the scientific community as they are the only direct source of information on the dynamics of the Earth's liquid outer core. The latters control the past and future evolution of the geomagnetic field that greatly influences the environment of our planet. In a similar way, ground-based geomagnetic observations provide information on the flow of plasma in the upper layers of the atmosphere. These data are also necessary to build reference magnetic field models that are in turn used by the industry and citizens for orientation purpose. Few examples are: directional drilling activities, the orientation of satellites and mobile phones, the orientation of maps, backup navigation systems on aircrafts and vessels. Finally, in recent years, ground-based geomagnetic observations have also been used to mitigate the risk associated with space-weather because fast geomagnetic field variations can damage industrial ground infrastructures such as power-lines, and limit HF communication capabilities for our national ground, marine and air forces.

To carry out this mission the BCMT is currently collecting, processing and distributing magnetic data from 17 observatories in the world. This represents a challenge given the workforce available because some of these observatories are located on remote island, or places, and several are operated in foreign countries, in collaboration with local institutions. Furthermore the rapid population and economic growth in Africa, and Asia, is associated with a significant increase of anthropogenic noise that has to be handle. The growing importance of space-weather activities and the need of ground-based data for the success of satellite survey mission, impose to maintain the network of observatories currently in place, and possibly to increase the density of measurement stations over French territories. They also impose to minimise downtime for observatories and to process efficiently and rapidly the collected data that ultimately have to be distributed through national and international data repository or data distribution infrastructures. These tasks are tackled by fast intervention in case of observatory failure, but also by developing efficient data transmission protocols, processing software and robust measurement platforms, including sensors. Finally distributed data must be minted with Digital Object Identifiers (DOI) and a licence set so that French-domestic or international customers can collect them, use them and, if necessary, properly reference them.

Two French institutions are operating these magnetic observatories: the IPGP and the "Ecole et Observatoire des Sciences de la Terre" (EOST), located in Strasbourg. The observation service is mainly funded by the CNRS-INSU, with strong support from the Institut polaire français Paul-Emile Victor (IPEV) and the Centre National d'Etudes Spatiales (CNES). IPGP and EOST also support the service.

This document is the third quadrennial strategic plan for the BCMT after the "Strategic Plan 2010-2012", hereafter referred to as (Chulliat & Chambodut 2010) and the "Strategic Plan 2014-2018", hereafter referred to as (Chulliat & Chambodut 2014). It defines the main projects and activities of the BCMT for the forthcoming years such that the BCMT fulfils its missions, follows the current state of art in data management and responds to the evolution of the scientific and societal needs.

The purpose of this plan is:

- to give a snapshot of the current BCMT state regarding finance, equipment and workforce,
- to be used as a reference document for the upcoming funding and staffing requests,
- to be used as a reference document by the BCMT Scientific Council in its future reviews of the BCMT operations,
- to provide a framework for the BCMT management team in order to prioritise among the various projects and activities.

In the rest of this document, after a short section recalling the mission and vision of the BCMT, the role of the BCMT inside the national and international community and the current status of the infrastructures and services, are successively described. In particular, we give an overview of the current BCMT situation in term of staffing and funding, observational infrastructure, and data or data products distribution. We turn next to the organisational, scientific and data dissemination objectives. In section (6), are described the required activities and developments for the BCMT to reach these objectives. In the final section, a provisional timeline is presented.

# 2 Missions and vision

The following statement on the BCMT mission was modified for this version of the strategic plan to point out the responsibilities of the service in term of data management and distribution. It provides a more accurate description of what is expected from the BCMT.

> *The mission of the* BCMT *is to make ground-based geomagnetic observations, manage and distribute acquired data, associated metadata and products, addressing the needs of the French and international geosciences research community, and those of the French administrations, businesses and citizens.*

In this statement, ground-based geomagnetic observations include different types of data from magnetic observatories, magnetometer networks and repeat stations. Magnetic observatories differ from simple magnetometers in that they provide very accurate measurements of the Earth's magnetic field, typically within less than 2-3 nT, over long time intervals, typically decades. This is achieved by using multiple instruments (generally one scalar magnetometer and one vector magnetometer) and the frequent reiteration of so-called absolute measurements, used to calibrate the data and correct them for their drifts (e.g. Rasson 2017, Lesur et al. 2017). Other types of data are also acquired and distributed by observatories, like quasi real-time raw magnetic data, or measurements of ground electrical potentials. Various data products are derived from magnetic observatories, including geomagnetic indices that are measures of geomagnetic disturbances (e.g. Mayaud 1980, Chambodut et al. 2013). Magnetic repeat stations are points at the Earth's surface where absolute measurements are made on regular basis, typically every one to five years, in order to improve the spatial resolution of geomagnetic secular variation models (Newitt et al. 1996).

The vision adopted in 2010 is and will remain unchanged for the upcoming five years:

> *The vision of the* BCMT *is to be one of the key components of the global geomagnetic observation system, combining a high level of consistency and robustness in its long-term operations and an ability to quickly innovate as a response to new scientific and societal needs.*

This statement stresses two important points. First, geomagnetism is a science that relies on global observations and therefore, to be relevant, the BCMT should be actively participating in initiatives and organisations aiming at improving the global geomagnetic observation system. These include the International Association of Geomagnetism and Aeronomy (IAGA) that coordinates geomagnetic observations, models and indices worldwide, and INTERMAGNET, the global network of digital magnetic observatories (INTERMAGNET 1991). Second, innovation should be at the core of BCMT activities because geomagnetism, as a science, is progressing fast and the primary mission of the BCMT is to address scientific needs.

# 3 Role of the BCMT inside the national and international community

## 3.1 National Level

The BCMT is a Service National d'Observation (SNO) in Magnetism. It constitutes the only French structure, endorsed by the CNRS-INSU, for recording, managing and distributing ground long-standing magnetic observations (Figure 1). It follows that the BCMT is officially in charge of op-

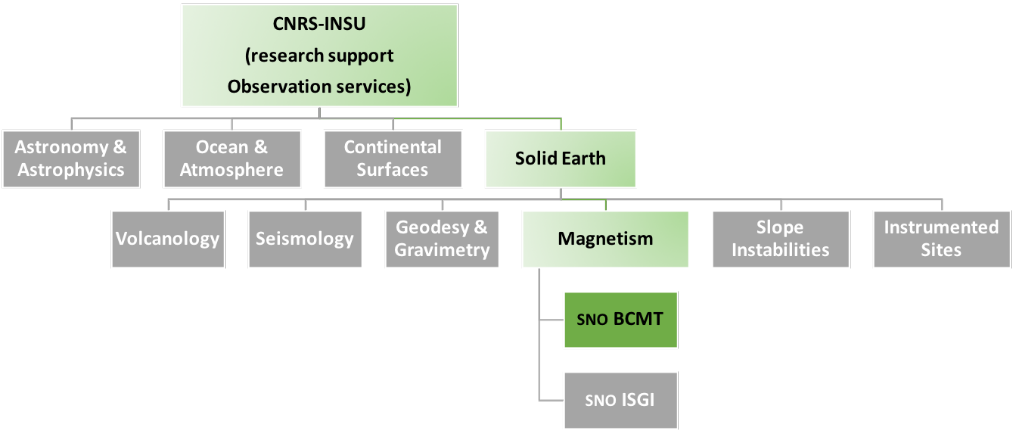


Figure 1: Position of BCMT inside CNRS-INSU as a research support observation service.

erational management of the French national magnetic observatory of Chambon-la-Forêt (Loiret, France), a network of more than sixteen observatories throughout the world, and of a metropolitan magnetic repeat station network. It takes care of the whole life-cycle of the produced datasets, from acquisition up to quality assessment and longstanding repository. These data are distributed through the BCMT official Web portal [1].

The BCMT is also part of the French Data Pole in Solid Earth Sciences (Pole de données FORM@TER [2]). FORM@TER is a French research infrastructure which aims at federating existing data centres of the Solid Earth community:

- to facilitate articulation with European and international systems – e.g. EPOS,
- to allow wider access to data,
- to contribute to the creation of new products and services by adding value to the available data.

Because of its responsibility regarding the national observatory, the BCMT is a contact point for questions made by structures, organisations or laboratories, regarding not only the geomagnetic field, but also regarding measurement methods of its strength and direction. Furthermore, the

[1] http://www.bcmt.fr
[2] https://www.poleterresolide.fr/

national observatory infrastructure is used to test and calibrate magnetometers for marine, land, airborne and satellite survey missions.

Finally, at French level, the BCMT is taking part in the various actions that need an input and expertise on ground magnetic measurements. In particular, the BCMT scientists are members of the "Organisation Française de Recherche et Application en Météorologie de l'Espace" (OFRAME) and the "Groupe de Coordination en Météorologie de l'Espace" (GCME) that gathers in France several ministries, industries and the operators that may be impacted by major geomagnetic events (ground electricity providers, spatial operators...).

## 3.2 International Level

The BCMT is the main contact point for the international community on all aspects regarding magnetic observatories management in France.

The main international infrastructure that distribute magnetic data and provide recommendations on magnetic observatory operations is INTERMAGNET. The BCMT contributes in two ways to INTERMAGNET:

- through its network of observatories. The French contribution represents roughly 15% of the international network of observatories. The observatories are run following the quality standards set by INTERMAGNET. The BCMT maintains observatories in particularly remote and difficult areas where no other institutions have set observatories such as North- and Equatorial-Africa, South-East Pacific Ocean, Southern part of the Indian Ocean.
- by participating to the operations committee. Two members of the BCMT (two engineers) are part of three of the INTERMAGNET operations committee working groups: DEFINITIVE DATA, IMO APPLICATIONS, WWW/GINS AND DATA FORMATS, but none are participating to the INTERMAGNET executive committee since 2014.

Outside distributing data to networks and data repositories, the BCMT scientists are involved in other international tasks, inside IAGA, or for the organisation and distribution of data inside European infrastructure as EPOS [3].

[3] http://ec.europa.eu/research/infrastructures/pdf/ri_landscape_2017.pdf

# 4 Current Status

This section briefly presents the current status of the BCMT in term of staff & funding, observational infrastructure and data products.

## 4.1 Staff & Funding

The full list of scientists, engineers and technicians working in the IPGP and EOST services linked to the BCMT, is given in Table 1.

In IPGP, there are two scientists, three engineers, two technicians and one part-time administrator looking after the observatories. Arnaud Chulliat was head of the IPGP magnetic observatory service until January 2014, and has been replaced by Vincent Lesur, in September 2015. In between, Xavier Lalanne, now retired, overtook the responsibility of the service. Pierdavide Coïsson, has been appointed as a "Physicien Adjoint" in February 2014 and affected to the national observatory in Chambon-la-Forêt. He is in charge of developing inside the observatory, ionospheric physics and space weather applications.

In EOST, there is currently one scientist, and also 1.30 Full Time Equivalent (FTE) engineers looking after the observatories. The EOST service knows a constant decrease of the allocated FTE since 2010. In January 2010, Jean-Jacques Schott (scientist, former head of the service) retired and Jacques Durand (Senior engineer) left. They were never replaced. From 2012 to 2015, Sylvain Morvana was working part-time (0.5 FTE) as engineer in the service, and Jihane Sayadi (0.25 FTE) overtook part of his tasks from October 2015. She left the service in 2017. On the observatory sites, the magnetic calibration measurements are made daily by observers, that are appointed only for a year, and spend only a small part of their working time on this task.

The main funding agency for the BCMT is the CNRS-INSU that has maintained its funding around 106 *k*€ over the last years, shared between IPGP and EOST according to the annual project planning. Other agencies are contributing to the observatory network operations:

| | | |
|---|---|---|
| CNES | Funding KOU observatory operation | 26 *k*€ in 2018. |
| IPGP | Funding CLF observatory operation | 85 *k*€ in 2018. |
| EOST | Funding Welschbruch geophysical station & equipment | 15 *k*€ in 2018. |
| IPEV | Funding running costs for AMS, CZT, DMC, DRV & PAF observatories | 67 *k*€ in 2018. |

IPGP has also been providing independent funding for the renovation of Chambon-la-Forêt observatory infrastructure and buildings (180 *k*€ over 2014-2016). The above numbers do not include indirect costs nor, for example, salaries of permanent staff. As an example, the direct and indirect costs covered by IPEV for logistical support and manpower of EOST observatories sum up to around 500 *k*€ per year (483 *k*€ in 2017).

## 4.2 Infrastructure

The French infrastructures in place for the observation of the geomagnetic field have only marginally evolved since the last strategic plan (Chulliat & Chambodut 2014) in 2014. We present below successively information on the observatories, the network of repeat stations, the instruments and the calibration facilities, and finally the data acquisition, processing and distribution systems.

### 4.2.1 Observatories

IPGP and EOST have been for some years the only two institutions in France in charge of maintaining observatories, as well as processing, calibrating and distributing the acquired data and associated metadata. The organisation of these two institutions is radically different mainly due to the constraints generated by the observatory location and accessibility.

| Name | Grade & Activity | FTE |
|---|---|---|
| Lesur V. | Physicist (IPGP). Director of IPGP magnetic observatories. Operation management of the observatories and, in particular, responsible of the data quality. | 30% |
| Chambodut A. | Physicist (EOST). Director of EOST magnetic observatories. Operation management of the observatories and, in particular, responsible of the data quality. | 30% |
| Coïsson P. | Associate Physicist (IPGP), Ionospheric and Space weather applications. | 30% |
| Bernard A. | Senior engineer, CNRS (EOST). System administrator Computing infrastructure & Data management Training of Observers. | 30% |
| Maury V. | Senior engineer, CNRS (IPGP). System administrator, Computing infrastructure & Data management | 100% |
| Fotze M. | Engineer, CNRS (EOST). Technical Director of the EOST Observatories. Acquisition R&D. | 100% |
| Heumez B. | Engineer, CNRS (IPGP). Geomagnetic network management. Data processing. | 100% |
| Luc T. | Engineer, CNRS (IPGP). Scientific instrumentation R&D and maintenance (electronics design and development). | 100% |
| Telali A. | Technician, (IPGP). Scientific instrumentation R&D and maintenance (data acquisition systems software, signal processing and calibrations). | 100% |
| Parmentier E. | Technician CNRS (IPGP). Maintenance of the national observatory infrastructure. | 100% |
| Kouadio A. | Office assistant, (IPGP). Administration. | 40% |

Table 1: List of personnels involved in BCMT activities

- IPGP runs most of its observatories in close cooperation with other national or foreign institutions, that are in charge of the weekly calibration measurements and, depending of their capabilities, small maintenance work on the acquisition systems. IPGP provides the instrumentation, maintain the acquisition chains and process the data.

- EOST is running its observatories in close logistical cooperation with the French polar institute (IPEV). Logistics and planning remain extremely heavy for French Austral and Antarctic territories. Missions and equipment shipments must be planned more than one year in advance. Maintenance of the systems is only possible during few days each year, for each of the southern land stations. An exception is the Antananarivo observatory that is run in the same way as IPGP's observatory.

The full list of the 17 BCMT observatories is given in the table 2 and a map of the network is shown in Figure 2. These list and figure include observatories that have been closed either because they became noisy, or because they became unmanageable, usually for safety reasons.

| code | name | location | status | institutions |
|---|---|---|---|---|
| AAE | Addis Ababa | Etiopia | not operating | IPGP/ GO A.A. UNIV. |
| AMS | Martin de Viviès | France (Amsterdam Island) | operating | EOST |
| BNG | Bangui | Central African Republic | closed | IRD/IPGP |
| BOX | Borok | Russia | operating | BGO TPE RAS/IPGP |
| CLF | Chambon-la-Forêt | France (Loiret) | operating | IPGP |
| CZT | Port Alfred | France (Crozet Island) | operating | EOST |
| DLT | DaLat | Vietnam | operating | IG VAST/IPGP |
| DMC | Dome C | Antarctica | operating | EOST |
| DRV | Dumont d'Urville | Antarctica | operating | EOST |
| EDA | Edéa | Cameroun | operating | IRGM/IPGP |
| IPM | Easter Island | Chile | operating | DMC/IPGP |
| KOU | Kourou | France (Guyana) | operating | IPGP |
| LZH | Lanzhou | China | operating | LIS CEA/IPGP |
| MBO | Mbour | Senegal | operating | IPGP/IRD |
| PAF | Port-aux-Français | France (Kerguelen Island) | operating | EOST |
| PHU | Phu Thuy | Vietnam | operating | IG VAST/IPGP |
| PSM | Parc Saint-Maur | France | closed | IPGP |
| PPT | Pamatai | France (Tahiti) | operating | CEA/IPGP |
| QSB | Qsaybeh | Lebanon | not operating | Lebanese CNRS/IPGP |
| TAM | Tamanrasset | Algeria | operating | CRAAG/IPGP |
| TAN | Antananarivo | Madagascar | operating | IOGA/EOST |
| VLJ | Val-Joyeux | France | closed | IPGP |

Table 2: List of observatories that are, or have been, operated by BCMT

Although some magnetic observatories of the network have lost their affiliation to INTERMAGNET because of difficulties in producing in time definitive data, all observatories are still run under the same high quality standards, with two sets of instruments:

- a tri-axis fluxgate magnetometer and a scalar magnetometer located in a thermally insulated or temperature controlled vault, pavilion or box, and recording the geomagnetic field variations on a continuous basis;

- a "DI-flux" (i.e. a non-magnetic theodolite with a mono-axis fluxgate magnetometer mounted on top of it) and, often, a second scalar magnetometer located in a pavilion or hut where weekly, up to daily, calibration measurements (so called "absolute measurements") are performed.

These absolute measurements are performed by a trained operator in order to calibrate the vector magnetometer. It is a time consuming and tiresome activity that is nonetheless a critical point of the observatory operations leading to high quality data. These measurements are necessary as all existing vector magnetometers unavoidably drift in time (over only a few weeks) and the currently existing systems to replace human operators remain extremely expensive ($\simeq$80 $k$€ ) and require significant maintenance work. In order to meet the high quality standards set by INTERMAGNET, BCMT observers are trained on a regular basis, either on-site for remote observatories, at the Chambon-la-Forêt observatory (IPGP) or at the Welschbruch geophysical station (EOST), near Strasbourg. The data either collected continuously or by an operator, are all sent to the processing centres in IPGP and EOST, where they are treated before being forwarded to the BCMT data centre, to INTERMAGNET via Paris Geomagnetic International Node (GIN), or to other organisations or infrastructures.

Three important changes in the BCMT network have occurred in the last years:

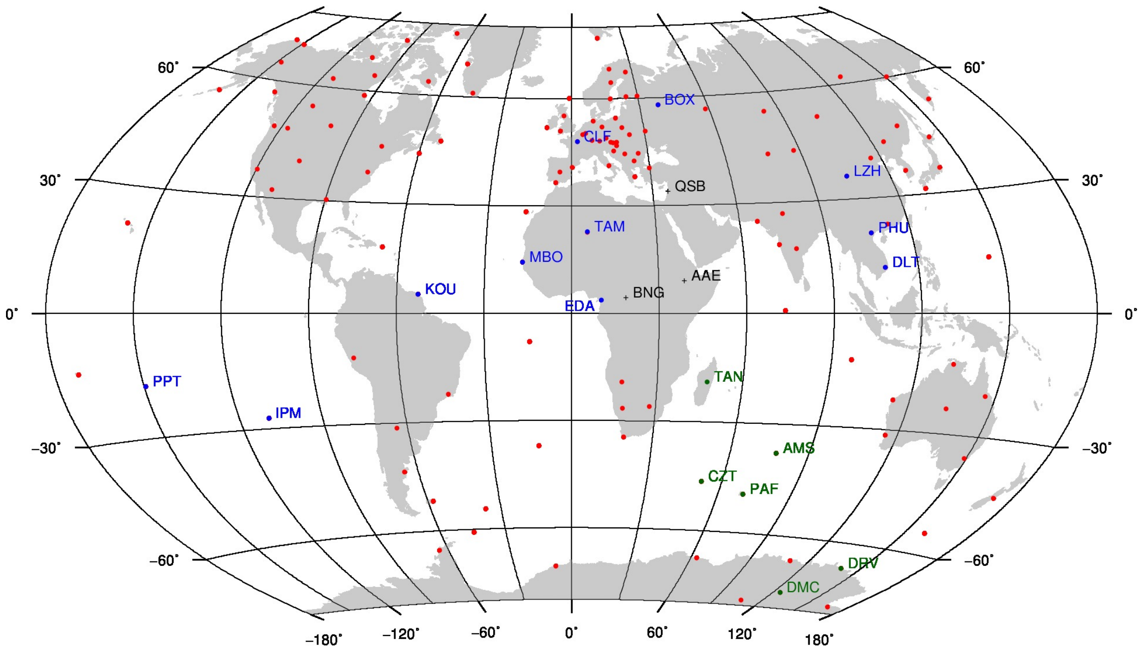


Figure 2: Location of observatories. In red: INTERMAGNET observatories. In blue: BCMT observatories maintained by IPGP. In green: BCMT observatories maintained by EOST. In black: BCMT observatories that are no-longer delivering data.

- First, the Edéa (EDA) observatory has been opened in Cameroon and is already producing data. The setting of this observatory was planned in 2012 in replacement of the Bangui (BNG) observatory that has been closed in July 2011. The EDA opening has been delayed for several years mainly due to changes of personnel inside the IPGP observatory service. The project was restarted in 2016, the infrastructure building started in November 2017 and finished in 2018. First data are now available but remain noisy. Adjustment of the setting is planned for end 2018 or beginning 2019. We expect having high quality data available in the first months of 2019.

- Second the AAE observatory became noisy following the start of an electric train service in Addis Ababa in August 2015. Further, important construction work took place on the observatory site in 2016-2017. There is no hope re-opening the observatory, and local collaborators show no intent on helping relocating the observatory. We will not be able to open an observatory in Ethiopia in the forthcoming few years.

- Finally the Tananarive observatory has been fully reopened in June 2017 on a new site at about 60 km from the historical one. The theodolite was already conveyed on site in June 2016. First absolute measurements were performed during 2017 after training a new dedicated observer in Strasbourg. In October 2018, a scientist that will be in charge of the data processing will come in Strasbourg to be trained.

#### 4.2.2 Repeat station network

A new network of 11 repeat stations located on airport runways has been established in 2012. The geographical distribution of the stations was set to cover homogeneously the metropolitan France (Figure 3). It does not include oversea territories or departments. Furthermore, a new measurement method was developed, relying on GPS measurements for azimuths determination and night-time magnetic measurements in order to minimise external field contributions (Lalanne et al. 2013). This network was surveyed in 2012 and 2013, and on a biennial basis since. We plan to continue surveying this network during the Swarm mission in order to evaluate by comparison with satellite based models if such measurements are necessary, or if the European network of observatory is dense enough to fully describe the evolution of the main field. Surveying the repeat station network takes roughly a month for two operators working jointly. Data are shared with the international community through the MAGNETE program [4].

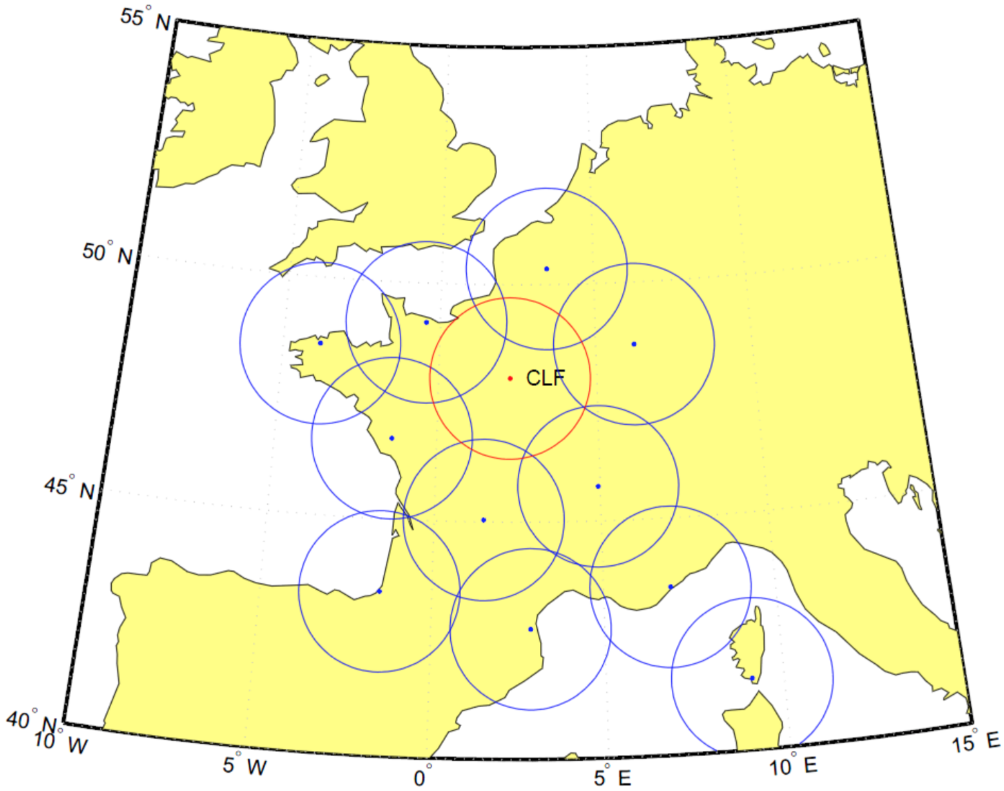


Figure 3: Location of the BCMT repeat station network, including the national magnetic observatory in CLF. Circles have a 1.7° radius.

### 4.2.3 Instruments and calibration facilities

The BCMT is one of the rare institutions in the world building instruments for the long-term record of the geomagnetic field in observatories. The technical team in IPGP has the technology to develop vector and scalar absolute instruments.

A prototype of an optically pumped helium magnetometer providing scalar absolute measurements of the geomagnetic field has been developed and tested in 2012-2013. It has shown very good performances but producing helium cells remains a difficult, time-consuming task. Therefore all IPGP observatories are still equipped with proton magnetometers. These are the SM90 – a modified versions of the GemSystems GSM-90 magnetometers that is sampling the field at 0.2Hz, and the SM100 derived from the CEA-LETI instrument used onboard CHAMP and OERSTED satellites. The

[4] http://magnete-group.org/

latter is sampling the field at 1Hz. For the vector instruments the version of the fluxgate vector magnetometer in place in IPGP's observatories is the VM391 (see Figure 4), excepted in Edéa where a LEMI35 is temporarily in place. These VM391 instruments are ageing and a new version is planned to be released by the end of 2018, for which the analogue part has been reduced to a minimum. The new instrument, the DVM18 (for Digital Vector Magnetometer), is expected to be full range and to have a weaker dependency on temperature variations. As soon as the new instrument is successfully tested in CLF, it will be set in IPGP observatories. The renewal of the vector instruments will take several years.

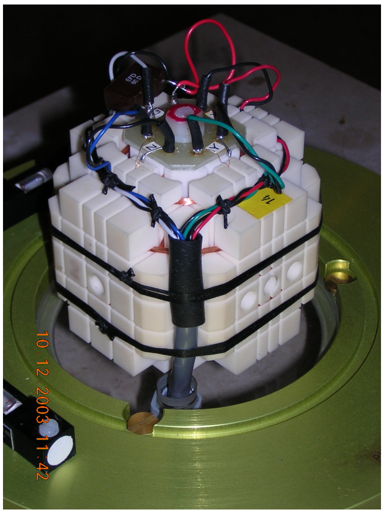


Figure 4: Homocentric vector magnetometer VM391 used in IPGP magnetic observatories

The instruments used in EOST observatories remain still heterogeneous in kind. In 2011, a long-term replacement plan for the complete rejuvenation of observatory instruments was initiated. The scalar magnetometers are now replaced at 60% by GemSystems GSM-90F1 instruments. The variometers are still old Thomson VFO installed in late 70's in half of 6 magnetic stations. They may be replaced by DVM18 instruments if they perform as expected in these difficult environmental conditions.

In all EOST and IPGP observatories, theodolites are equipped with Bartington probe MAG01H.

On the national observatory site in Chambon-la-Forêt (CLF) only, two sets of three electric dipoles were installed in 2012 to measure the spontaneous electrical potential along different directions. Each set of three dipoles form a large triangle with nearly 100m basis length. There were placed at two different depths for testing purpose. Electric potential values have been measured since and are made available on the BCMT website.

Testing and calibrating facilities are available on the same site, including a shielded room where the ambient magnetic field does not exceed 100 nT and a set of Helmholtz coils. A new non-magnetic thermal chamber was built in 2011-2012, allowing magnetometers to be tested at all temperatures from -5°C to 45°C and their temperature coefficients to be precisely determined. The Chambon-la-Forêt site and calibration facilities are often made available to users not related to the BCMT. For example, the "Laboratoire de Physique des Plasmas" (LPP, Ecole Polytechnique) together with an international team has tested the search coils, fluxgate and scalar magnetometers of the upcoming JUICE mission to Jupiter Icy Moons.

Finally, although it is not directly related to the BCMT activities, an archeomagnetic laboratory has been installed on the site of the national observatory in rooms far off the observation shelters. Similarly, the construction of a building for archiving marine drilled cores will be soon under construction. These developments are made taking care not to compromise the magnetic cleanness of the observatory.

#### 4.2.4 Data acquisition and processing systems

Magnetic data acquisition and processing systems have, up to now, been developed nearly independently in IPGP and EOST.

The current version of the data acquisition system in IPGP observatories is the so called ENO3 version. It delivers hourly files of second data through a consolidated `http` protocol. Quasi-real time data are sent through an *Earthworm* protocol. The latter is commercialised by ISTI (Instrumental Software Technologies, Inc.). Due to infrastructure constraints, the flux of data delivered by *Earthworm* in our setting is not fully stable. A new version of the acquisition system (the ENO4 version) has been therefore developed and is under test. In this new version, second data are sent every 5 minutes through a robust secured `http` protocol. It includes the possibility of using a secured `mqtt` (message queuing telemetry transport), that is a real time protocol to transfer data. The main improvement for this new ENO is the operating system that is now a system with true real time capabilities: `QNX`, whereas in the version 3 the ENO operating system was simply Windows.

In IPGP, the processing software MAGIS to remove spikes, estimate baseline values and compute definitive data, includes an efficient graphic interface that allows to process rapidly observatory data. However, this software is composed of intricate parts of codes, each using different coding languages and techniques. It follows that the software is difficult to maintain and cannot be easily updated. A new suite of FORTRAN codes has therefore been developed, that includes new features such as estimating error statistics of observatory definitive data. The latest baselines of some of the BCMT observatories have been computed with these new techniques. It is planned to embed these FORTRAN codes in a new software, with an efficient interface, that will also handle the flow of data inside the database to ease and secure the data handling and distribution.

The current version of the data acquisition system (in place since 2009) in EOST observatories is the so called M.A.R.Cell 1.0 version (for *Magnetic Acquisition and Recording Cell 1.0*). It delivers at 12hU.T. files of second data through emails with secured local copies, both on the embedded system and on-site processing PC. Up to late 2017, it appeared impossible to get real-time Internet connection in all remote magnetic observatories. A new version of the acquisition system (the M.A.R.Cell 2.0) was nonetheless developed to allow the forthcoming use of direct VPN connection towards the stations. The new version is already in place at TAN and DRV magnetic observatories.

In EOST the data processing software is made of a series of independent MATLAB codes. These codes are working very well and were developed to be used for all stations by trained but non-specialists observers. However, with the current working force in EOST, this data processing cannot be done in due time for all observatories. In an attempt to homogenise the data processing approach inside the BCMT, and possibly to reduce the workload, it is planned to use the processing software under development at IPGP as soon as an efficient graphic interface is in place.

## 4.3 Observatory data

### 4.3.1 Data types

BCMT is providing four types of magnetic data to the user community:

- Quasi-real time raw minute-mean data.
- Non-calibrated second and minute-mean data.
- Quasi-definitive data.
- Definitive data.

These data are accessible either through the BCMT portal (www.bcmt.fr) or the INTERMAGNET portal [5].

IPGP quasi-real time data are distributed as minute-means, although second data are available but have never been required. They are made available on BCMT and INTERMAGNET data bases, and

[5] http://www.intermagnet.org

are also directly distributed to organisations that require them (e.g. French Airforce, NOAA). Only two IPGP observatories are not distributing data in quasi-real time because of national regulations. These are Borok (BOX) and Lanzhou (LZH). The EOST observatories are not currently providing quasi-real time raw second data, but will soon be all set to do so. A VPN server, similar to the one used by the seismologists for tsunamis alerts, has been installed at EOST. Work is in progress at IPEV, the collaborating institution, to give the necessary bandwidth to transfer back to EOST the data. The first observatory delivering such data should be DRV as it is already equipped with real-time protocol and acquisition.

Non-calibrated second and minute-mean data are distributed by all BCMT observatories. Second data from IPGP observatories are released each hour, as concatenated files that, at the end of a day, contain 86400 data values. Again Borok (BOX) and Lanzhou (LZH) observatories are exceptions: data are released after 12 hours. Minute-mean and hourly-mean data are derived from these second data, using filters defined by INTERMAGNET (2012), and are released as soon as available. Second and minute-mean data from EOST observatories are released each day at 12h U.T, and are distributed within few hours on BCMT website.

Quasi-definitive data have been developed in recent years to speed-up delivery of calibrated observatory data in view of using them together with satellite data. They are typically delivered within three months after acquisition. They consist on data that have been corrected for spikes and discontinuities, and that have also been partially calibrated from a limited set of absolute data measurements. IPGP is one of the rare institute that provide second quasi-definitive data, which is a significant effort because of the amount of data to be processed. Here again the Lanzhou (LZH) observatory is an exception because the level of noise precludes the production of second definitive data in limited time. The lack of manpower in EOST magnetic observation service precludes the production of quasi-definitive data.

Definitive data are the final products of magnetic observatories. INTERMAGNET expects to have the definitive data processed and delivered six months after the last data collected in the year. Unfortunately, despite the efforts made, this is rarely the case because of the workload associated with the production of second quasi-definitive data and the handling of noise or discontinuities for some of the remote observatories. In IPGP observation service, delays have been slowly increasing up to two years, but they have been partially cleared by the introduction of new baseline calculation software. Definitive data up to year 2016 have been produced. Year 2017 should be handled before the end of the year 2018. In EOST the situation is even more difficult due to the lack of manpower. All the information is however carefully kept such that if they are not produced immediately, definitive data can be derived at a later date.

#### 4.3.2 Data products

Data resulting from the observation of the geomagnetic field are distributed to users, but they are also processed to generate higher level products. These include:

- The K index that is produced for each observatory as soon as the data are available. It is then compiled in monthly files, but these are not distributed in a convenient format. They are distributed to a list of interested institutions and users, by emails, each month. A format similar to the IAGA2002 format, as the one used by ISGI, would be more appropriate.

- The SC alert. It is based on a provisional algorithm that search for simultaneous strong gradients in all available time series of BCMT observatories. It is produced in real time and delivered by emails to specific users – e.g. French Airforce, NOAA. There is a demand for this type of information also by other French space-weather services. The algorithm needs to be finalised and published.

- The declination map over the metropolitan French territories that is produced after each repeat station survey, and distributed through the BCMT web site. The data are also sent to the MAGNETE program to be incorporated in the European map of declination. A new version should be produced soon, to which BCMT scientists will contribute.

### 4.3.3 Data distribution

All data recorded in BCMT observatories are distributed first through the BCMT website. Interested users or institutions can freely download data either from a web interface, or through an FTP protocol. On the same website can be found magnetic data, electric data, archives, links to other related websites, information on the data and observatories (metadata), products, publications from the observatory and information on the BCMT missions and gouvernance; this list is not exhaustive.

In contrast, the INTERMAGNET website distribute exclusively magnetic data. Despite that, this organisation is our main gate to provide the recorded data to the scientific community. Also, several databases are generated from data dowloaded from INTERMAGNET. This is for example the case of the SUPERMAG, a database largely used by the scientific community working on the magnetic field generated in the upper layers of the atmosphere, and also by the space-weather community.

Databases are also developed at European and National level, EPOS and FORM@TER respectively, to distribute together several types of data. These databases are, for magnetic data, fed from INTERMAGNET and BCMT databases.

Finally, some institutions directly contacted us to receive magnetic data, or derived products, in quasi real-time. This is the case of the French Air-force, or NOAA.

# 5 Objectives

## 5.1 Organisation and administration

As described previously, the BCMT is one of the national service of observations (SNO) of the CNRS-INSU. In this administration it is register inside the ST-ANO-04 – i.e. associated with Solid Earth studies and geomagnetism. This fits well with the traditional objective of magnetic observatories that were set to study the evolution of the core field. However, this original objective has evolved in recent years to enclose space-weather and space-climate studies. The AA-ANO-06 is dedicated to Astronomy and Astrophysics, for the monitoring of the Sun and the immediate spatial environment of the Earth. It is therefore associated with space-weather and space-climate. Our objective is to obtain the double affiliation ST-ANO-04 & AA-ANO-06 so that our observations activities are recognised, and our data used, in both fields of research.

The situation regarding manpower is difficult in general for the BCMT, but is critical for the EOST observation service. We tackle this problem by firstly aiming at increasing collaboration inside the BCMT such as to have compatible data acquisition systems, and similar data processing and storage structures, secondly, by developing efficient and modern processing tools, and finally, by having a common and balanced strategy for increasing the workforce inside the BCMT. Our objective for this latter point is to have a new scientist attached to the EOST observation service next year, and to increase the workforce by having a new technician or engineer associated with this service in the coming 4 years.

## 5.2 Scientific objectives

Magnetic observatories have been traditionally set-up to follow, and ultimately understand, the slow evolution of the main field. This remains our main objective. It imposes on us to maintain a long-term coherence in the data, and to contribute as much as possible to a homogenous and global coverage of the Earth. This is achieved by maintaining in working order remote and isolated observatories. Calibrated data have to be distributed in due time as they are essential for an optimal interpretation of data collected by satellite mission as the European Space Agency (ESA) Swarm multi-satellite mission. In particular observatory data are crucial elements for building magnetic field models, including the forthcoming version of the International Geomagnetic Reference Field (IGRF).

A second objectif with a growing importance for our society is to provide the necessary data to describe and understand the fast variations of the fields of external origins: the ionospheric and magnetospheric fields. They are particularly difficult to separate from fields generated inside the Earth and are therefore the main limitations to describe accurately the core field. These fields are also strongly affected by perturbations in the ionosphere and magnetosphere, that impact our technologies, our positioning and communication systems and, at high latitudes, the industrial infrastructures – e.g. power lines. Although a global coverage is important to describe the large scale magnetospheric field, ionospheric disruptions remain at relatively short spatial scales with sometimes very short temporal scales. The infrastructure currently in place for the observation of the geomagnetic field is not well suited for ionospheric studies: recording systems are set to provide only 1Hz data, and the distance between recording stations exceed several hundred of kilometres. An evolution of the observation infrastructure is therefore needed and, as described in the next sections, should focus on increasing the data sampling rate at the national observatory, and put in place a denser network of variometer stations – i.e. stations where the variations of the field is recorded, but where data are not calibrated.

## 5.3 Data dissemination objectives

Data dissemination infrastructures are evolving rapidly both at national, European and larger international level. Whereas traditionally data were distributed through INTERMAGNET and BCMT portals, alternative distribution centres, associated with the growing interest in ionospheric and magnetospheric physics, are now used by a significant part of the scientific community – e.g. SUPERMAG [6]. A new European infrastructure, EPOS, is currently under development and will distribute magnetic data to an even larger community. Similarly a French infrastructure, FORM@TER, is already providing data from the BCMT aiming at the same goals than EPOS.

Our objectives is that all our data, including electric measurements, variometer near real-time data, old data, meta-data, and products derived from these data are delivered to the largest possible science community through both the BCMT portal and these new infrastructures. This implies introducing licences and Digital Object Identifiers (DOI) for each of different types of data. The work has already been done for the BCMT definitive data set that has a DOI (DOI:10.18715/BCMT.MAG.DEF). Regarding the licence, we set a CC:BY:NC licence (Creative Commons Attribution-NonCommercial 4.0 International License) for all magnetic data, although that may change in the future if proper instructions are provided by the CNRS-INSU on this issue.

We note that part of the data are not yet in a format that can be distributed through web-interface, and that for some others, as the $K$ indices, there is no plan to distribute them through international infrastructures. Very large sets of magnetic records are on photographic papers or on simple paper rolls. These records carry much more information than the digital hourly spot values that are currently available in the databases. Valuable archives are also made of research notes and booklets of surveys made by successive researchers and observers of French institutions. Cataloguing this mass of records is currently on going and should be continued over the coming years. We are also studying the best way to digitise specific events, such are large magnetic storms, that occurred in the second part of the 20$^{\text{th}}$ century. Once the protocol for digitising the photographic papers has been defined, we plan to organise a systematic work to cover records from the 19$^{\text{th}}$, and possibly 18$^{\text{th}}$, solar cycles. Our objective is to make these records available through the BCMT web-interface that will need to be refurbished to get rid of the old FTP servers, and replace them with proper web-services and Application Programming Interfaces (API).

[6] http://supermag.jhuapl.edu

# 6 Required activities and developments

As described above the BCMT scientific objectives are gathered along two main themes:

- Core field and secular variation (SO1)
- External field and space weather (SO2).

These scientific objectives are completed with data management objectives (DO1). All these require a series of activities and developments that we have organised under three headings corresponding to types of activities. The last subsection set the timeline and defines the priority order for these activities.

## 6.1 Observatories

### 6.1.1 Maintenance of the network (O1)

Accurate models of the core field (scientific objective SO1) can be derived only if a worldwide uniform distribution of magnetic observatories, all providing high quality data, is in place. Similarly space weather predictions (scientific objective SO2) benefit from this "ideal" network. The BCMT contributes significantly to this organisation through its 17 observatories, located at remote places in the world. It is therefore our prime objective to maintain, and if possible extend this network. Unfortunately, given the workforce available, it is already a challenge handling these observatories, and an extension of the network cannot be planned.

As pointed above the EDA observatory has been open early 2018, and is already providing data, although these data are not yet of the expected quality. We aim at submitting this observatory for an affiliation to INTERMAGNET at the end of 2019. For this we need to adjust the setting in order to reduce the noise level, and train the local staff so that accurate calibration measurements are made on a regular basis on the observatory site. These activities are planned for 2019. They may be extended over 2020 if this is required to achieve the quality expected by INTERMAGNET.

The new TAN observatory has been set in a remote place at more than 4 hours from the observatory historical location. It is set on the ground of a seismological station from the CTBTO to benefit from the same security services. The magnetic observatory is already providing data, towards "Institut et Observatoire Géophysique d' Antananarivo" (IOGA) and EOST. These data will be processed at the end of 2018 in view of an application to INTERMAGNET at the end of 2019. The current main limitation is the organisation of regular absolute measurements. They are currently done only when the seismological station is visited. A reliable, permanent, means of transport for the magnetic observer has to be put in place.

The PTT observatory requires particular attention. The level of anthropogenic noise keeps on increasing and it has been found that a housing estate is under development nearby the observatory. It is our opinion that in few years the observatory data quality will drop below a level acceptable for scientific use of the data. Because of the importance of this isolated observatory in southern part of the Pacific Ocean, we plan to relocate it. This is a difficult work that will take several years. We will try to find before the end of 2019 an organisation or university that is ready to support us in this project. The choice of the observatory location will be particularly important if we want to have an observatory running with minimum perturbations for decades. Construction work will probably not take place before end of 2020, to have an observatory in working order in 2021 or 2022.

Finally, we have been informed on the 4th of September that IRD (Institut de Recherche pour le Développement) will have to sell the ground where the M'Bour observatory (MBO) is situated. The schedule is extremely tight and give us less than a year to relocate the observatory. Even with a strong support from IRD, it is unrealistic to hope having a new running observatory in such a short time. We will aim at reducing the interruption of the observations in Senegal to less than a year and to have the first data released in 2020.

### 6.1.2 Increase magnetic data acquisition frequency in CLF (O2)

Magnetic signals at frequencies above 1 Hz are worth recording in magnetic observatories as they provide useful information about the state of the ionosphere. These kind of data are therefore needed to study ionospheric physics and for space weather applications (scientific objective SO2). Data recorded at relatively high frequencies (250 Hz) are also available through the Swarm ESA mission, and ground data covering the same range of frequencies would help their interpretation. The "Laboratoire de Physique des Plasma" (LPP) is a French laboratory, part of the "Ecole Polytecnique" in Saclay, that develops instruments for satellite missions. It has offered to lend us instruments together with a system of acquisition to record high frequency magnetic data. This test system will be installed in CLF end of 2018. Our goal is to test if CLF site is well suited to record magnetic data in the range of 1 Hz to 1 kHz. We expect to record properly Schuman resonances, pulsations and also low frequency whistlers that have been observed in Swarm scalar data. This system will also allow to cooperate more actively with the magnetotelluric community by providing data that may be used as remote station for determination of conductivity profils.

On the technical side, we need to define how the data have to be stored and what are the required IT resources to store these data. This effort will be done in close collaboration with the geomagnetic working group in IPGP that is processing the scalar data collected at 250 Hz. The workload for the observatory team should in principle remain small as there is no need to systematically clean or calibrate these data.

The experiment will run at least for a year and a critical assessment of the benefits will be made to decide if it is worth installing such a recording system in CLF over the Swarm mission duration, or for longer periods. The equipment can be bought at reasonable prices, and if successful, the experiment can be extended in other observatories of the network, such as in Kourou or in the Southern Hemisphere.

### 6.1.3 Network of repeat and variometer stations (O3)

IPGP is maintaining a network of repeat stations that is surveyed every two or three years. This network has been reduced to only 12 stations in 2012 such as to have a proper coverage of the metropolitan French territories while reducing to a minimum the workload of the observation team. The collected data are shared with other European data sets, in the "MAGNETE" program, to map detailed variations of the geomagnetic field components over Europe (scientific objective SO1). It is not clear yet if collecting these data is beneficial for science, but this point will be assessed at the end of the Swarm mission. Meanwhile, it is planned to keep on collecting these data on a regular basis.

The network of national observatories over Europe may be good enough to follow the core field variations, but it is clearly not adapted to track perturbations of the ionospheric magnetic field (scientific objective SO2). This could be achieved over French territories by setting a network of variometer stations. We have received recently demands from the French marine and air forces to develop such variometer stations. These kinds of data would be also beneficial for space weather applications. Once the repeat station is set, the workload for the observatory team remain relatively low since again there is no need to process or calibrate the data.

Our objective is therefore in 2019 to develop a robust variometer station and to set this station in one of the airports of the repeat station network. This will allow on one hand to maintain the variometer station while surveying the repeat station network, and on the other hand, to limit the workload associated with the repeat station survey by using the variometer station to reduce the collected data. We plan to record 1 Hz data for a year and then assess the quality and usefulness of the data. If successful, further variometer stations will be set in other airports of the repeat station network or in Africa, with the support of the French Airforce. We do not expect being able to set more than one variometer station per year. Our objective is to have four variometer stations set before 2024.

#### 6.1.4 Record electric potential data at observatory sites (O4)

Since 2012 electric potential data are recorded in CFL between three sets of electrodes more than 100 m apart. These data are available online through the BCMT portal but, to our knowledge, have never been used for scientific investigations. We have been solicited by Alexey Kuvshinov to set similar electrical data acquisition systems on other observatory sites with the objective of having a better image of the upper mantle conductivity. Such an objective is closely linked to the SO1 science objective as the conductivity of the upper mantle generates induced fields that are particularly difficult to separate from other internal sources such as the core field. The first targeted observatories would be Easter Island observatory (IPM) and Kourou observatory (KOU).

We note that a similar system has been set earlier in French Austral territories, but it has been dismantled in early 2000's due to difficulties in transferring data; This sorts of issues can be now more easily resolved.

### 6.2 Magnetic data

#### 6.2.1 Digital Object Identifiers (DOIs) and licences (M1)

As described in the data dissemination objectives (DO1), we need to set DOIs to all our different data records. This has been done for a subset of our definitive observatory data – i.e. all currently running observatories with the exception of Tamanrasset (TAM ), Lanzhou (LZH) and Borok (BOX). For the two first we did not receive an agreement from the institutions, for the latter, we must discuss with the Russian Academy of Sciences that wants to set DOIs for all Russian magnetic observatories. We have to set soon a DOI for the BCMT variometer data – i.e. non-calibrated data, and for the electric data. Any new type of data that, in the future, may be distributed through the BCMT portal will have a DOI.

The licence type that has been attributed to all data is the "creative commons" licence CC:BY:NC that allows to use freely the data outside commercial activities for which agreement of the owner is required. We point out that no requirement has been set yet, by the minister or parent bodies as the CNRS, regarding the type of licences that should be associated to the data, but that may change is the coming years.

#### 6.2.2 Development of a new observatory processing software (M2)

The BCMT runs 17 observatories generating data that need to be processed. There is only a limited workforce for this task in IPGP, even less in EOST. Delays have been accumulated over the last years, leading to a late delivery of definitive data to INTERMAGNET. The situation is so difficult in EOST that definitive data could not be delivered in time, and some observatories have lost their INTERMAGNET affiliations. A successful approach in IPGP has been to build a suite of software that helps, and speed up the processing of observatory data. Unfortunately, these tools are not well adapted to EOST specific needs. Furthermore the software, in its current form, cannot be easily modified to include modern, more efficient ways of processing data. We therefore need to rebuild a data processing software.

The path we follow is to build FORTRAN computation modules with well defined input variables, that are called from a user friendly interface with strong graphical support. A key point is the database infrastructure and the way synchronisation is achieved between different copies of the database, particularly when there is a limited access to Internet. Some of the computation modules already exist: handling of calibration data, calculation of baselines with error-bars, calculation of definitive data and their statistics. Some remain to develop – e.g. Wavelet filters to identify noisy records.

### 6.2.3 Catalogue and digitise old magnetic records (M3)

As indicated before, there are large sets of magnetic archives, both in IPGP and EOST that remain little exploited for science studies. A first step is to build an organised catalogue of the archives, and then to put it online such that scientists interested in these data can ask for a copy. However, listing available data is often not enough; examples have to be provided such that the value of these archives becomes more obvious. To this end, we have started scanning old photographic magnetic records corresponding to magnetic storm times and show that during these storms the digital hourly value database already available gives an oversimplified view of the magnetic field activity. So scanned magnetic photographic records may provide valuable data for studying historical geomagnetic storms and the long-term evolution of geomagnetic activity (scientific objective SO2). Ultimately, these scans will have to be made available online together with the catalogue.

### 6.2.4 Finalise SC detection, indices, and distribution software (M4)

The detection of sudden commencement (sudden impulse or sudden storm commencement) is a vivid topic in both Space Weather community and for protection of industrial infrastructures. Ebro Observatory (Spain) is officially in charge of the definition of the international definitive list of SC. However, several institutes, including BCMT, make available automatic detection and alert of SC. The aim is here to contribute to the official list by providing our Spanish colleagues regular automatic report for all detected SC in BCMT data. Other institutions (e.g. French AirForce, OFRAME "Organisation Française de Recherche et Application en Météorologie de l'Espace") have shown an interest in such near real-time information. The provision of the SC information does not require a large amount of manpower, but nonetheless the current algorithm for detection needs to be consolidated. Also, the format of the information provided and the way it is forwarded to interested institutions needs to be better defined and implemented in our distribution software.

In a similar way the indices derived from BCMT observatory data, such as the K indices, are provided in an old format, difficult to use and distribute. Here again, we have to think on a way to distribute efficiently these data such that they can be used by the space-weather scientific community and other interested institutions. The same problem has to be addressed for indices derived from new kind of collected data such as the CLF high frequency data, or the variometer data.

## 6.3 Instruments

Because of the lack of manpower, the activities of the IPGP observatory service regarding the development of observatory equipment have been reduced to a minimum introducing massive delays in the planned activities. Four axes of developments are described below. IPGP and EOST plan to work in close cooperation for these activities because the instruments in place for both institutions are ageing.

### 6.3.1 Finalise and test new digital vector instrument (I1)

The development of a new digital vector variometer instrument started in 2013. The idea is to reduce to a minimum the analogue part of the acquisition electronics and allow this way to build a full range instrument. The major advantage of this approach is that the instruments can be accurately calibrated with a good control on their temperature dependence.

The electronics of this new instrument have been developed and evaluated. Results show remarkable performances. The remaining steps include reducing the size of electronic cards, finalising minor points, and testing in real conditions the instrument. For this, it is planned to use the sensors of the VM391 – i.e. the instruments currently used in IPGP observatories. No major difficulties are expected and this work should not extend more than few months in 2019. The instrument should be also tested independently by EOST.

#### 6.3.2 Develop a new sensor unit for vector instrument (I2)

The sensors of the VM391 are homocentric ( – i.e. they measure the magnetic field vector at a single point in space) but are expensive to build, and lack of resolution. This comes from the size of the coils measuring the field. A new generation of sensors will therefore be designed with higher resolution. A simpler approach will be used, focusing on the cost and simplicity of the sensor. The material and preliminary designed steps have been made. We expect to have these new sensors in test after 18 months, roughly at the beginning of 2020.

#### 6.3.3 Adapt and produce variometer stations (I3)

To progress regarding our science objective SO2, it is important to set over French metropolitan territories variometer stations. A model of variometer station, with a simple and robust design, has therefore to be set. The idea is to have a design simple enough such that it can be installed by technicians with little or no knowledge in observatory operations.

A station was build, but never installed, to measure magnetic variation close to the magnetic equator in Djibouti. The design of this station has to be adapted to our specific needs in French airports, keeping in minds that stations may later be installed in more challenging environments – e.g. in Africa. We hope to have a station ready under test in 2020, to start installation in airports in 2021.

#### 6.3.4 Design and prepare a prototype of a quasi-absolute instrument (I4)

Keeping observers of remote observatories motivated when their main tasks are often little or not related to geomagnetism is a major challenge. It would be a massive step forward to have automatic instruments, so that calibration measurements are required only once a month or less. Currently, the poor quality and the low occurrence rate of the hand made absolute measurements in some observatories, is the main source of difficulty and work overload for the scientists and engineers in charge of processing the data. Automatic instruments exist, but they remain excessively expensive and still require yearly complete maintenance that precludes their installation in remote places.
We want to study this problem and will try do design an instrument free of mechanical moving pieces, and associated piezoelectric motors.

# 7 Time line

A provisional time line is defined in Figure (5) for the coming five years, with a priority order ranging from high in dark green, to low in dark red, with two intermediate states in light colours. It is clear that on top of the tasks defined, the usual daily maintenance and data processing work has to be done.

Our priority is to finalise TAN and EDA observatories, but that should not take more than few months. Then our first task is to relocate MBO and PPT observatories. By experience we know that rebuilding an observatory in a foreign country takes up to three years. This includes finding a collaborative institute, writing convention, preparing the required equipment, shipping the equipment, building the observatory, training staff and, of course, solving unforeseen difficulties that are always appearing along the way. We hope to be able to reduce this time span to two years for MBO because of the strong support from IRD. We need also urgently to renew our processing software. We want also to finalise, as soon as possible, new vector magnetometers. All other tasks are postponed to 2021 or after.

Although there are at the moment only few tasks with high priorities in 2022 and 2023, we have no doubt that this situation will evolve in the next two years and this working plan will need to be revised for its mid-term review in 2021.

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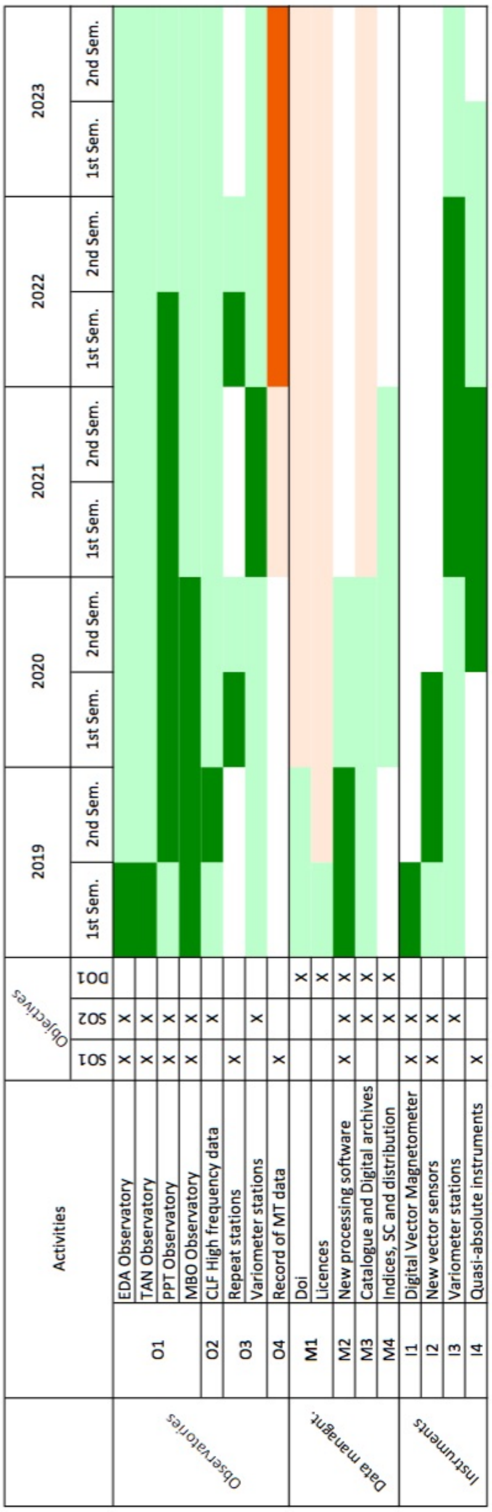


Figure 5: Provisional time line for the BCMT activities for the 2019-2023 period.