Bureau Central de Magnétisme Terrestre

Director: M. Chaussidon

Strategic Plan 2024-2028

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Foreword

This document is the fourth five-year strategic plan for the BCMT after those released in September 2010, January 2014 and December 2018. 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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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). It is also the "Service National d'Observation" (SNO) in Magnetism of the CNRS-INSU. The primary mission of the BCMT is to provide ground geomagnetic observations of the highest quality to the scientific community, to industry and to citizens, in France and abroad. Two French institutions are currently involved in BCMT operation, IPGP and Ecole et Observatoire des Sciences de la Terre (EOST) in Strasbourg. Several others, including the "Institut Polaire Français" (IPEV) or the CNES, provide financial and/or staff 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, France) and observatories in areas such as western Africa where observations are sparse. Currently, five of the BCMT observatories are part of INTERMAGNET, the global network of magnetic observatories. The BCMT also operates variometer and repeat station networks in metropolitan France. It 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 type of data are freely distributed by the BCMT: preliminary one-second or one-minute observatory data in real time (less than 5 min, from 10 observatories) or near real time (less than 24 h, all observatories); quasi-definitive data with a one- to three-month delay; definitive data with a minimum of one-year delay; variation and repeat station data; declination map; geomagnetic indices. BCMT data are made available through its data repository website https://www.bcmt.fr, and redistributed towards international community via repositories of World Data Centers for Geomagnetism (e.g. WDC Edinburgh, UK, on https://www.wdc.bgs.ac.uk) or INTERMAGNET network on https://intermagnet.github.io.

The aims of the BCMT for the upcoming five-year period (2024-2028) are to maintain the observation networks, 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 are:

- improving the observational infrastructure over France with the extension of the variometer station network
- integrating new observatories in INTERMAGNET
- improving the trustworthiness of BCMT data repository
- digitising some of available historical magnetograms
- producing fluxgate magnetometers, starting the production of Helium optically-pumped magnetometers and the development of a highly-stable, self-calibrating, instrument
- increase the frequency range of observations, up to e.g. $\sim$1 kHz, to provide complementary information in view of ionospheric and space-weather research.

To realise these objectives, the workforce needs to be increased in EOST with the recruitment of, preferably, two engineers, and in IPGP by having a new scientist for deeper investigation of the mass of high quality data collected.

Contents

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. Later, the "Institut National des Sciences de l'Univers" (INSU, one of the institutes of the Centre National de la Recherche Scientifique, CNRS) set the BCMT as a Service National d'Observation (SNO) in geomagnetism.

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 communities as, for instance, they are the only direct source of information on the dynamics of the Earth's liquid outer core. The latter control the past and future evolution of the geomagnetic field that greatly influences the environment of our planet. Ground-based geomagnetic observations provide in addition key information on the magnetic fields generated in the ionosphere/magnetosphere. These data are also necessary to build reference magnetic field models that are in turn used by the industry and citizens for orientation and navigation purpose. Few examples are: directional drilling activities, attitude control of satellites, bearing of devices like smartphones, orientation of maps, backup navigation systems on aircrafts or vessels and landing strip numbering. Finally, ground-based geomagnetic observations are used to mitigate the risk associated with space-weather because fast geomagnetic field variations can damage human industrial infrastructure on ground (e.g. power lines, HF communication capabilities) and at satellite altitudes.

To carry out this mission the BCMT is currently collecting, processing and distributing magnetic data from 17 observatories worldwide distributed. Some of these observatories are located on remote places, and several are operated in foreign countries in collaboration with local institutions. The rapid population and economic growth, particularly in Africa and Asia, are associated with an increase of anthropogenic noise that affects magnetic data quality and has to be handled. Similarly in Antarctica and the sub-Antarctic (in TAAF), even though the observatories are situated in areas covered by the Antarctic Treaty and have a nature reserve status, maintaining a low level of anthropogenic noise in the data remains a challenge. All these factors add up to a significant workload for maintaining the observatories and processing the data. The growing importance of space-weather activities and the need of ground-based data for the success of satellite survey missions 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 (when possible) in case of observatory failure, but also by developing robust measurement platforms, including sensors, efficient data transmission protocols and processing software. The distributed data are minted with Digital Object Identifiers (DOI) and are given a licence so that French-domestic or international customers can use and 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 (IPEV) and the Centre National d'Etudes Spatiales (CNES). IPGP and EOST also support the service.

This document is the fourth five-year strategic plan for the BCMT and it follows the "Strategic Plan 2019-2023" (see Reference documents). 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 the 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 a reference document for the upcoming funding and staffing requests,
- to be a reference document for 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 this document, after a short section recalling the mission and vision of the BCMT, the role of the BCMT inside the national and international communities 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), the required activities and developments for the BCMT to reach these objectives are described. In the final section, a provisional timeline is presented.

2 Missions and vision

The following statement on the BCMT mission has been modified for the "Strategic Plan 2019-2023" (see Reference documents) to point out the responsibilities of the service in term of data management and distribution. It is still valid today.

> *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 communities, and those of the French administrations, businesses and citizens.*

In this statement, ground-based geomagnetic observations include different types of data from magnetic observatories, variometer and repeat station networks. The data are collected through very accurate measurements of the Earth's magnetic field, typically having a noise level smaller than 2-3 nT. Magnetic observatories differ from simple variometer stations in that they provide consistent data 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 manual absolute measurements, used to calibrate the data and correct them for their drifts (e.g. Rasson 2017, Lesur et al. 2017). Various data products are derived from magnetic observatories, including geomagnetic indices that are measures of magnetic activity due to Sun-Earth interactions (e.g. Mayaud 1980, Chambodut et al. 2013). Magnetic repeat stations are points at the Earth's surface where absolute measurements are made on a 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 stated in 2010 has been modified to highlight the complementary role of observatory and satellite data sets in the geomagnetic observation system :

> *The vision of the* BCMT *is to be one of the key components of the global geomagnetic observation system, comprising both ground-based and satellite-based infrastructures. This requires combining a high level of consistency and robustness in its long-term operations, a capacity to observe the geomagnetic field variations in a large range of frequencies, 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, St-Louis et al. 2020). 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 communities

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 time series of ground magnetic observations (Figure 1). It follows that the BCMT is officially in charge of operational 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 the metropolitan magnetic variation and repeat station networks. It takes care of the whole life-cycle of the produced datasets, from acquisition up to quality assessment and long-term preservation. These data are managed by the BCMT data repository and distributed through its official Web portal [1].

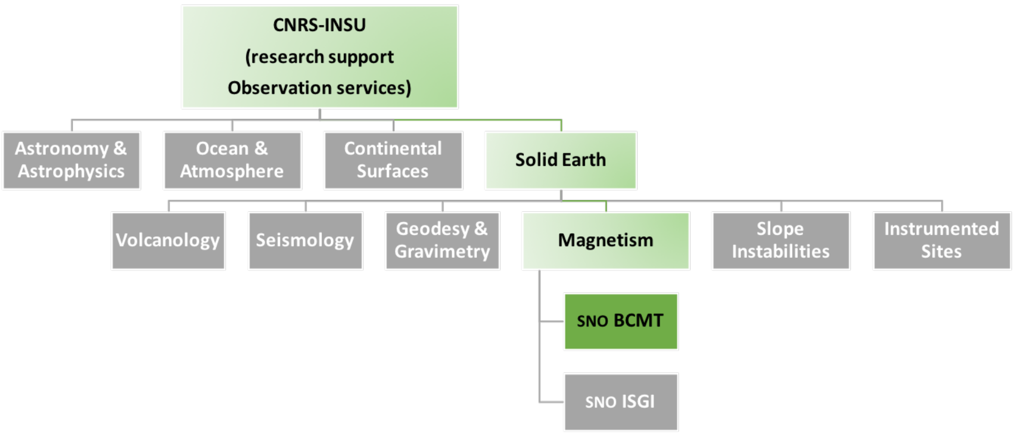

Figure 1: Position of BCMT inside CNRS-INSU as a research support observation service.

The BCMT is, or will soon become, part of two French research infrastructures:

- the new research infrastructure EPOS-FRANCE [2] that aims at rationalising all French solid earth observation resources and facilities, in particular the instrumental and acquisition chains, from the management of instrumented sites to the management of data in thematic data repositories. (EPOS-FRANCE will be formally set-up in October 2023 but discussions and actions are taken since early 2022.)
- The research infrastructure DATA TERRA [3] is a e-infrastructure that encompasses a collection of data hubs dedicated to Earth system and environment data and services. It aims at developing a structure for accessing and processing data, products and services geared towards

[1] http://www.bcmt.fr
[2] https://www.epos-france.fr/
[3] https://www.data-terra.org/en/

observing, understanding and predicting in an integrated manner the history, mechanisms and evolution of the Earth system in response to global changes.

The BCMT is a stakeholder in these two infrastructures. Through EPOS-FRANCE, BCMT will be able to exchange information with all the other French operators of in-situ observations. Through DATA TERRA and its data hub in Solid Earth Sciences FORM@TER [4], BCMT can expose its data and develop new services encouraging inter- and trans-disciplinary research.
This structuring is important. It is steered by the French authorities (the Ministry for Higher Education and Research and the CNRS). Although the internal operation and management of the BCMT should not be affected, future financial or personnel application processes may undergo significant changes.

The BCMT is the national reference, and expert for all questions regarding ground magnetic measurements and their use. The user communities, both academic and industrial, find in the BCMT a privileged contact for all questions relating to the geomagnetic field, but also regarding measurement methods of its strength and direction. Furthermore, the national observatory provides an infrastructure to test and calibrate magnetometers for marine, land, airborne and satellite survey missions.

Finally, at French level, the BCMT scientists are taking part in various inter-agency working groups such as "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 operators that may be impacted by major geomagnetic events (ground electricity providers, space 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 three ways to INTERMAGNET:

- through its network of observatories. The BCMT maintains 17 observatories, and some of these are 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. It endeavours to run these observatories following the quality standards set by INTERMAGNET. Currently, five of the BCMT observatories are part of INTERMAGNET.

- 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.

- The IPGP maintains in Paris a "GIN" that facilitate the flux of data from foreign institutions towards the main INTERMAGNET data repository. It maintains also the main INTERMAGNET repository for validation of definitive data.

Outside distributing data to networks and data repositories, the BCMT scientists are involved in other European and international organisations such as IAGA working groups, CoreTrustSeal Board and assembly of reviewers, and EPOS ERIC [5] thematic core service on geomagnetic observations.

[4] https://www.poleterresolide.fr/
[5] https://www.epos-eu.org/

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.

4.1.1 Staff

In IPGP, there are two scientists, three engineers, two technicians looking after the observatories. V. Lesur has been in charge of the IPGP magnetic observatory service and BCMT since September 2015. A. Telali, formerly IPGP technician, has been promoted CNRS engineer in 2018. J.P. Rivierre, started working as technician at the national observatory the same year. T. Luc, electronics engineer, left the observation service in January 2022. One further engineer is currently present in the service: F. Tournier, IT engineer on fixed term contract supported by the CNES for three years. He started his position on July 2022. A further engineer position is open for a short term contract supported by IPGP, as a replacement of T. Luc. We aim at being able to turn this position into a permanent position after few years. Overall the available work force in IPGP magnetic observation service remained constant over the last five years.

In EOST, there are currently two scientists, one engineer and contributions from EOST technical team that gathers engineers and technicians of multiple skills and expertises. On the observatory sites, observers are civil volunteers, trained each year by EOST but employed by IPEV. They spend around 25% of their work-time onto magnetic observatory duties. In addition, due to changes in the types of contracts and of their profiles, yearly-trained observers are no longer involved in the post-winterer processing of magnetic measurements. In June 2023, M. Fotze, electronics engineer, left EOST. A forthcoming engineer position is envisioned and ranked as an EOST priority. This position will be shared equally on EOST sub-antarctic and antarctic (TAAF) magnetic and seismological observatory services. Overall the available work force in EOST magnetic observation service has been halved over the last five years.

4.1.2 Funding

The funding of the BCMT is roughly balanced between CNRS-INSU, IPGP, EOST and IPEV. The CNRS-INSU has maintained its funding around 106 $k€$ over the last years, shared between IPGP and EOST observation services according to the annual project planning. The contributions from institutions and other agencies are listed below :

CNES	KOU observatory operation	27 $k€$ in 2023
IPGP	CLF observatory operation	85 $k€$ in 2023
EOST	Welschbruch geophysical station operation	20 $k€$ in 2023
UNISTRA	Welschbruch magnetic hut (planned)	85 $k€$ in 2023
IPEV	AMS, CZT, DMC, DRV & PAF observatories operations	92 $k€$ in 2022

The above numbers do not include indirect costs nor, for example, salaries of permanent staff. With the increase of energy costs and general inflation, the running costs for the site of CLF observatory (e.g. electricity, fuel, cleaning) mobilise a significant part of the dedicated budget. The remaining part can be used for scientific activities. However, IPGP has also been providing independent funding for the renovation of Chambon-la-Forêt observatory infrastructure and buildings (76.5 $k€$ over 2020-2022). Significant renovation costs are planned for 2023.
The direct and indirect costs covered by IPEV for running costs, maintenance and support of EOST

observatories sum up above 700 $k€$ per year (717 $k€$ in 2021, 902 $k€$ in 2020), mainly because of the observatories remoteness and the obvious associated costs in all budget headings.

4.2 Infrastructure

The French infrastructure in place for the observation of the geomagnetic field has significantly evolved since the last strategic plan (see Reference documents). We present below successively

Name	**Grade & Activity**	FTE
Lesur V.	Physicist (IPGP). Head of IPGP magnetic observatories. Observatory service and BCMT management. Data processing and quality control.	30%
Chambodut A.	Physicist (EOST). Head of EOST magnetic observatories. Management & maintenance of the observatories. Data processing and quality control. Responsible of relationships with IPEV.	30%
Coïsson P.	Associate Physicist (IPGP), Ionospheric and Space weather applications. Data processing and quality control	30%
Wardinski I.	Associate Physicist (EOST). Training of observers. Observatory maintenance. Data processing.	30%
Bernard A.	Senior engineer, CNRS (EOST). System administrator. Computing infrastructure. Data management and quality control. Observatory Maintenance. Responsible of annual training of observers.	40%
Maury V.	Senior engineer, CNRS (IPGP). System administrator. Computing infrastructure & Data management	100%
Heumez B.	Engineer, CNRS (IPGP). Geomagnetic network management. Data processing and observatory maintenance.	100%
Telali A.	Engineer, CNRS (IPGP). Scientific instrumentation R&D (data acquisition systems software, signal processing and calibrations). Instrumentation and observatory maintenance.	100%
Rivierre J.P.	Senior technician (IPGP). Data processing and observatory maintenance.	100%
Parmentier E.	Technician CNRS (IPGP). Maintenance of the national observatory infrastructure.	100%
Tournier, F.	Engineer CNRS/CNES, (IPGP). Software development. Space-weather applications	100%
TBD	Engineer, (IPGP). Scientific instrumentation R&D. Instrumentation and observatory maintenance.	100%

Table 1: List of personnel involved in BCMT activities in second half of 2023 (top: permanent, bottom: short-term contract).

information on the observatories, the network of variometer and repeat stations, the instruments and 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.

- 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 and constrained for French Austral and Antarctic territories (TAAF). Missions and equipment shipments must be planned more than one year in advance. Daily calibration measurements are performed by IPEV civil volunteers trained each year by EOST. Maintenance of the systems is only possible during few days each year, for each of the southern land stations. EOST provides the instrumentation, maintain the acquisition chains and process the data. An exception is the Malagasy observatory FIH that is run in the same way as IPGP's observatories.

The full list of the 17 BCMT operational 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.

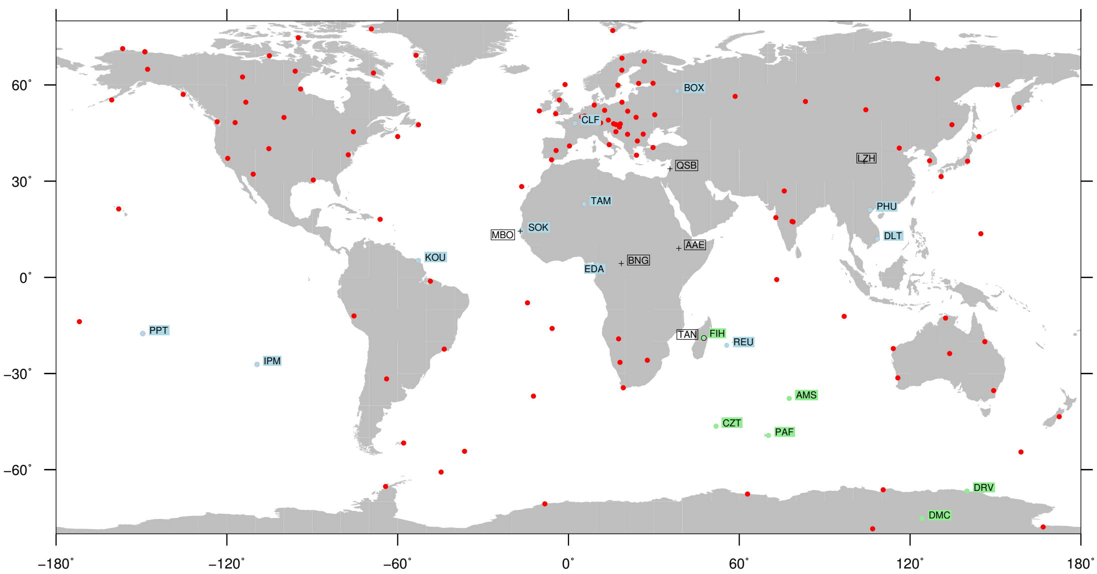

Figure 2: Location of observatories. In red: INTERMAGNET observatories. In blue: BCMT observatories maintained by IPGP. In green: BCMT observatories maintained by EOST. In black: BCMT former observatories.

Some magnetic observatories of the network have lost their affiliation to INTERMAGNET either because of difficulties or delays in producing definitive data or because data are too noisy (e.g.

code	name	location	status	institutions
AAE	Addis Ababa	Ethiopia	closed 2015	IPGP/ A.A. UNIV.
AMS	Martin de Viviès	France (Amsterdam Island)	operating	EOST
BNG	Bangui	Central African Republic	closed 2011	IRD/IPGP
BOX	Borok	Russia	unclear	BGO TPE RAS/IPGP
CLF	Chambon-la-Forêt	France (Loiret)	INTERMAGNET	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	Cameroon	operating	IRGM/IPGP
FIH	Fihaonana	Madagascar	unclear	IOGA/EOST
IPM	Easter Island	Chile	operating	DMC/IPGP
KOU	Kourou	France (Guyana)	INTERMAGNET	IPGP
LZH	Lanzhou	China	closed 2019	LIS CEA/IPGP
MBO	Mbour	Senegal	closed 2020	IPGP/IRD
PAF	Port-aux-Français	France (Kerguelen Island)	operating	EOST
PHU	Phu Thuy	Vietnam	INTERMAGNET	IG VAST/IPGP
PSM	Parc Saint-Maur	France	closed 1900	IPGP
PPT	Pamatai	France (Tahiti)	INTERMAGNET	CEA/IPGP
QSB	Qsaybeh	Lebanon	closed 2007	Leb. CNRS/IPGP
REU	Le Tampon	France (La Réunion)	operating	IPGP
SOK	Sop Niakhar	Senegal	operating	IPGP/IRD
TAM	Tamanrasset	Algeria	INTERMAGNET	CRAAG/IPGP
TAN	Antananarivo	Madagascar	closed 2009	IOGA/EOST
VLJ	Val-Joyeux	France	closed 1936	IPGP

Table 2: List of observatories that are, or have been, operated by BCMT. "INTERMAGNET" observatoires are of course "operating" observatories. The status of Borok (BOX) and Fihaonana (FIH) observatories are unclear as data are produced but not transmitted.

DLT observatory). Others do not have this affiliation because they have been installed only recently (e.g. SOK and REU observatories). However BCMT is aiming at having all observatories run under the same high quality standards of operations. Two sets of instruments are deployed:

- a tri-axis fluxgate magnetometer and a scalar magnetometer located in a thermally insulated or temperature controlled vault, pavilion or box. They record the geomagnetic field variations on a continuous basis leading to the so called variation data;

- a "DI-flux" (i.e. a non-magnetic theodolite with a mono-axis fluxgate magnetometer mounted on top of its occular), 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 repetitive 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 (noticeable over only a few weeks). Recently, some technological systems have become available to replace the need of frequent human measurements. They remain very expensive ($\simeq$80 k€) and have not shown yet stable performances in challenging operational settings, therefore manual absolute measurements are still needed. 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 variation and calibration data 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.

Several points are worth mentioning regarding the status of the BCMT network:

-AMS Amsterdam Island observatory is operating in routine mode. Late 2021, the French Austral and Antarctic Territories (TAAF) installed a solar farm near the observatory shelters, at a distance of less than 150 metres. The dimensions of the farm and its impact on magnetic measurements remain low (<1 nT) however noticeable in second data. The EOST team is exchanging with TAAF logistics througth IPEV to maintain the low impact of the anthropogenic magnetic disturbance. Moving the observatory is not possible as the entire island is a nature reserve where no new building or environmental change are permitted, no matter how small.

-BOX The flux of data from Borok observatory (BOX) has been stopped by Russian authorities in April 2022. We have little hope for the flux of data to resume soon. We know nonetheless that the observatory is still functional and that data are collected and stored.

-CZT Crozet archipelago observatory is operating in routine mode. From December 2022 up to March 2023, an amateur radio mission took place on the station at less than 300m from the magnetic observatory shelters. This leisure activity was supervised by the TAAF prefecture following discussions with the French Polar Institute and EOST. The emission frequencies remained outside the 1-14 MHz range, which had already caused considerable disruptions to observatory data in Amsterdam during a similar mission in 2014.

-DLT Records of the Dal Lat observatory (DLT) (Vietnam) have shown frequent large jumps over the last years due to heavy construction works in the plots of land close to the observatory. We cannot guarantee the continuity and quality of the data for this observatory and therefore the BCMT do not provide these data to INTERMAGNET although, when possible, quasi-definitive and definitive data are produced and distributed on the BCMT portal.

-EDA Edéa observatory (Cameroon) is one of the newest of BCMT. Calibration measurements are rare and their quality is limited. It is not possible to estimate accurate definitive data. We are in contact with the IRGM to try to find a solution to this problem. A mission is planned in summer 2023 to upgrade the data acquisition chain and the power management infrastructure.

-IPM The estimation of definitive data for the observatory on Easter Island (IPM) has been impossible over recent years due to the lack of handmade calibration measurements. This is due to the lack of training of local staff, combined with difficulties linked to local administrative constraints for accessing the absolute pillar, installed on the airport premises. The plan to upgrade the observatory and built a main pillar closer to the airport building has been postponed for several years due to COVID pandemic and associated travel restrictions. We investigate the possibility to install semi-automatic absolute observation systems. We aim at upgrading the observatory setting in autumn 2023. This upgrade would facilitate more regular and higher quality absolute measurements in the coming years.

-LZH The level of noise in Lanzhou observatory reached too high values in 2018 to maintain the observatory that has therefore been closed. We are still in contact with the local university. They are planning to re-open an observatory nearly 100 km to the north.

-MBO & SOK The M'bour (MBO) observatory (Senegal) had to be closed because the "Institut pour la recherche et le développement" (IRD) sold the land where the observatory was set. The observatory has been closed on the 10/03/2020 and the Sop/Niakhar observatory (SOK) opened just after, 60km to the East of M'Bour. Unfortunately this was just at the beginning of the COVID pandemic and absolute measurement could only start a year later. The vector instrument failed in the summer 2022 because of the concurrent actions of rodents and heavy rain. Measurements were restarted in October 2022. The observatory is running smoothly since. We aim at being able to apply for INTERMAGNET status in 2024.

-PHU The Phu Thui observatory (Vietnam) failed in 2019, and a mission was planned for 2020 to restart the observatory. Unfortunately, due to the COVID pandemic, this mission had to be cancelled. Following the end of the travel restrictions, the observatory was re-installed in December 2022. It is now powered by solar panels. The observations have re-started normally, but we observed a slightly higher level of noise due to the increase traffic in the area.

-REU The observatory in La Réunion (REU) was opened in November 2022. The observatory is located not too far from the IPGP Volcanological Observatory, and a staff member, Frédéric Pesquiera, is in charge of calibration measurements and light maintenance of the observatory. Magnetic gradients are very strong on this volcanic Island, but the monitoring of the magnetic field on the island is important both for scientific studies on the volcano, and because of the expected large growth of the geomagnetic field intensity in this area. Few adjustments of the observatory setting will be probably needed, and a year of calibrated data accumulated are required before applying to INTERMAGNET.

-TAN & FIH The Tananarive observatory has been closed in 2009 and activities moved in June 2017 on a new site FIH at about 60 km from the historical one. A field mission took place in June 2022: to fix problems occurred onto the data transmission due to the local telecommunication operator, and, to collect the few manual absolute measurements that the trained observer managed to achieve during the COVID pandemic.

4.2.2 Repeat station network

The 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. For this network 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 has been surveyed six times over the last ten years and the data are shared with the international community through the MAGNETE program [6]. We observed over these last 10 years a degradation of the data quality, not because of the measurement technique, but because airport runways are made of slightly magnetised material that generate jumps and discontinuities when maintenance work are made. The data, as they have been collected over the last decade do not contribute to a better description of the magnetic field variations over the French territory.
We see two ways forward: either completely redesign the repeat station network, with the expectation that the data that will be collected on the new network contribute significantly to the magnetic field description, or, abandon the repeat station measurements. Given the cost and energy necessary to maintain a repeat station network, we would like to stop the current measurement campaigns and replace the repeat station network by a variometer network. This point is described in more details in the next sections 5 and 6.

4.2.3 Variometer network

For few years, the IPGP has been deploying variometer stations in France. This follows the request from institutions and scientists to have magnetic base stations, running continuously, over area where magnetic surveys are planned. It is also in line with our objective to have an observation infrastructure better adapted to ionospheric studies.

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

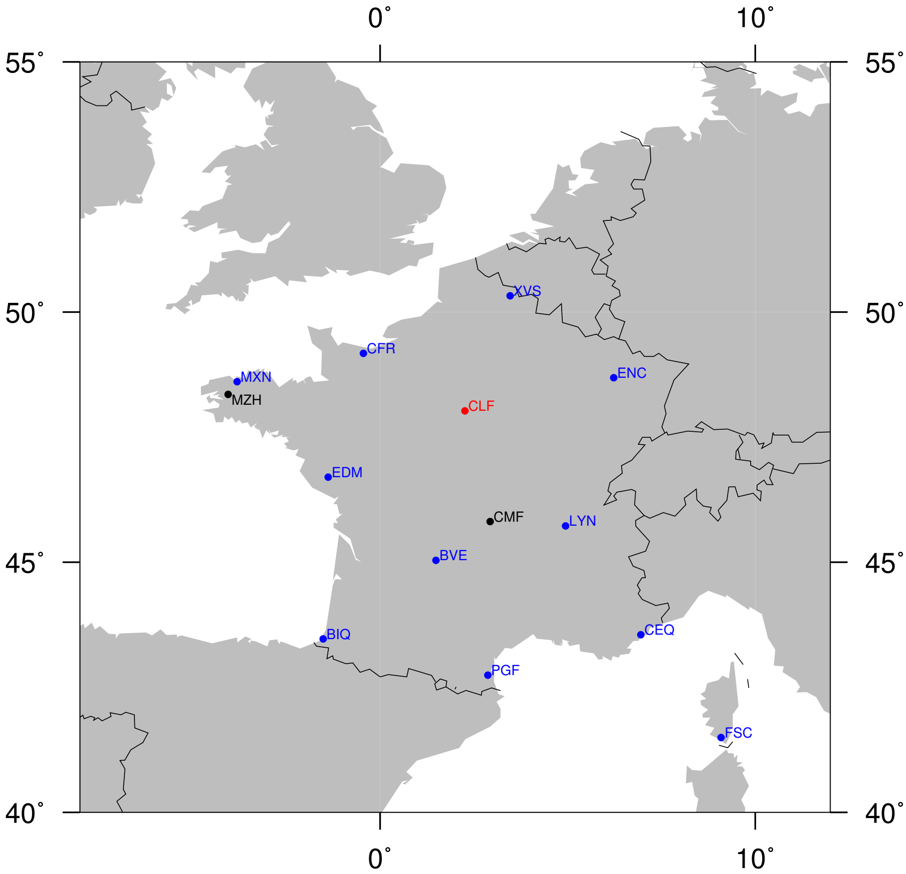

Figure 3: In blue, location of the BCMT repeat station network. The position of the national magnetic observatory (CLF) is given in red and the variometer stations positions are shown in black.

Currently only two variometer stations are in place. The vector and scalar magnetic field components are measured with a three axial fluxgate and a scalar magnetometers. Observatory quality instruments are used. 1 second vector data and 0.2 Hz scalar data are recorded continuously and sent every five minutes to the main IPGP server. Real time data acquisition is possible. The list of currently-deployed variometer stations is given in table 3, they are also represented on the map of figurre 3.

code	location	site	start date	status	Institutions
CMF	Clermont Ferrand	Vulcania	11/2021	in operation	IPGP/UCFA
MZH	Hanvec	Menez-Meur	05/2023	in operation	IPGP/SHOM

Table 3: List of variometer stations operated by BCMT

4.2.4 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 expertise to develop vector and scalar absolute instruments.

Scalar magnetometers
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 not all technical equipment and expertise were available at the observatory. This was particularly limiting for the production of helium cells. Very recently, these requirement have become available within IPGP and "Université Paris Cité".

However all IPGP observatories are still equipped with proton magnetometers. These are mainly SM90 magnetometers – a modified versions of the GemSystems GSM-90 magnetometers that is sampling the field at 0.2 Hz. One observatory (PPT) is still using an SM100 derived from the CEA-LETI instrument used onboard CHAMP and OERSTED satellites. This instrument is sampling the field at 1 Hz, but it cannot be properly maintained on long term.

All EOST observatories are equipped with proton precession magnetometers of the GemSystems GSM-90 magnetometers that are sampling the field at 0.1 Hz or 1 Hz.

Vector magnetometers
Up to recently, only fluxgate vector magnetometers VM391 were used in IPGP's observatories. These instruments are ageing and new Digital Vector Magnetometers (DVM18 and DVM19) have been developed, tested, and installed in some observatories. These new magnetometers are full range and are therefore much easier to calibrate than the previous magnetometer versions. The REU and PHU observatories are now equipped with DVM18 instruments. A DVM19 was given to EOST for testing and evaluation purpose. All variometer stations are equipped with DVM19 magnetometer. The production of these new magnetometers is being slowed down by the current worldwide shortage of electronic components.

The vector magnetometers used in EOST magnetic observatories are DMI FGE, except for AMS & DRV where the primary instrument remains Thomson fluxgate VFO.

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

Other equipment
On the site of Chambon-la-forêt observatory, electric measurements were made from 2012 to 2021, when the recording equipment was taken back by its owner. In the same observatory, testing and calibrating facilities are available, including a shielded room where the ambient magnetic field does not exceed 100 nT and a set of Helmholtz coils. A non-magnetic thermal chamber allows magnetometers to be tested at all temperatures from -5°C to 45°C and their temperature coefficients to be precisely determined. The calibration facilities are often made available to users not related to the BCMT. In 2022, they were used to test the magnetic shielding of a seismometer prepared by IPGP for the Farside Seismic Suite (FSS) mission to the Moon.

4.2.5 Data acquisition and processing systems

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

The current versions of the data acquisition system in IPGP observatories are the so called ENO3 and ENO4 versions. The ENO3 delivers hourly files of one-second data through a consolidated `http` protocol. Quasi-real time data are sent through an *Earthworm* protocol, but this data flow is not fully stable. The ENO4 version sends one-second data 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 over the ENO3 version 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. The ENO4 also handles leap seconds.

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 needs to be modernised in particular to handle data provided through the ENO4 acquisition system. The interface has been built to ingest these data that are now made available to users in IAGA2002 daily file format that are updated, in principle, every 5 minutes. New FORTRAN codes have been developed to handle the baseline estimation, the treatment of absolute calibration measurements and the estimation of definitive data. These codes include new features such as estimating error statistics of observatory definitive data. Work is in progress to include these FORTRAN codes in a new software, with an efficient interface, that also handle the flow of data inside the database to ease and secure the data management and distribution.

The data acquisition system in EOST observatories is the so called M.A.R.Cell - Magnetic Acquisition and Recording Cell. It delivers at 12 h U.T. files of second data through emails with secured local copies, both on the embedded system and on-site processing PC.

In EOST, data processing software is made of a series of independent codes which were developed to be used for all stations by trained but non-specialist observers. However, with the current working force in EOST, the definitive data processing cannot be done in due time for all observatories. In an attempt to fasten the data processing, and possibly to reduce the workload, softwares are currently being optimised in python language (use of MagPy library).

4.3 Observatory data

4.3.1 Data types

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

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

These data are accessible through the BCMT portal (www.bcmt.fr), through the INTERMAGNET portal[7] for the observatories recognised by this organisation, and by other distribution platforms – e.g. WDC.

One-minute-mean and hourly-mean data are derived from the raw one-second data, using filters defined by INTERMAGNET, and are released as soon as available. IPGP observatory real time data are distributed on request as one-minute-means. One-second data could also be distributed, but they have never been requested. Currently only NOAA requests these one-minute-mean data. This real time service is in place only for observatories with the old ENO3 acquisition system and with this equipment consolidated daily one-second-data files are provided each hour as concatenated files that, at the end of a day, contain 86400 data values. The observatories equipped with the new ENO4 system provide consolidated daily one-second or one-minutes-data files every 5 minutes. They are immediately made available on the BCMT database and then transmitted to INTERMAGNET. If required these data can also be made available in real-time. The EOST observatories are not currently providing quasi-real time raw second data despite a planning to do so in the previous BCMT strategic plan. A VPN server, similar to the one used by the seismologists for tsunamis alerts, is installed at EOST. Work is still in progress between TAAF, IPEV and EOST. It has been

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

postponed in 2020 due to COVID pandemic, then protocols had been slightly changed and still demand operationnal tests. 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 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 institutes that provide one-second quasi-definitive data, which is a significant effort because of the amount of data to be processed. 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, definitive data up to year 2022 have been produced for observatories providing data with the exception of IPM and EDA where operators are not currently making absolute measurements. In EOST the situation is very 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 most observatories as soon as the data are available. It is then compiled in monthly files, but these are not currently distributed in a convenient format. They are distributed to a list of interested institutions and users, through monthly emails. A format similar to the IAGA2002 format, as the one used by ISGI, would be more appropriate.
- The SC and SSC alerts. They are based on a provisional algorithm that search for simultaneous strong gradients in all available real-time data 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. We are currently re-building this software, to have more consolidated results and to be able to publish them on the BCMT website.
- The declination map over the metropolitan French territories that is produced after each repeat station survey, and distributed through the BCMT website.

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, documents from BCMT 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 governance; this list is not exhaustive. The statistics of magnetic observatory data file downloads from the BCMT website from 2017 to 2022 are available in Figure 4.

In contrast, the INTERMAGNET website distributes exclusively magnetic data. Despite that, this organisation is an important mean to provide the recorded data to the broad scientific community.

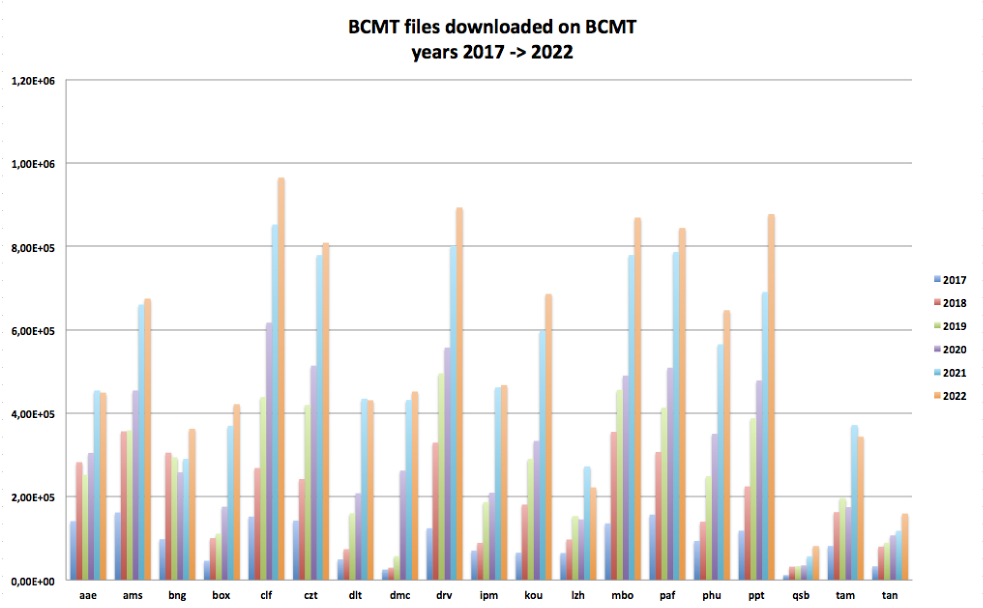

Figure 4: Number of data file downloads from the BCMT website and DOI link, per observatory. Each file provides a day of vector and scalar data with their metadata. Statistics are not available for recent observatories: EDA, SOK, REU.

Also, several other services generate data-products from data dowloaded from INTERMAGNET. This is for example the case of the SUPERMAG[8] 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.

As already stated in Section 3, e-infrastructures are developed at national and European levels :

- DATA TERRA deploys a comprehensive platform for accessing and processing FAIR data, products and services with a view to implement inter-disciplinary approaches on the whole Earth system and environment. BCMT data repository is directly feeding, and connected, to the data hub devoted to solid Earth, FORM@TER.

- EPOS European Research Infrastructure offers a multi-disciplinary open data portal for integrated access to Solid Earth science datasets. BCMT data repository is indirectly connected to the portal through INTERMAGNET which acts as an unified access point for all magnetic observatory data.

5 Objectives

In this section are described the objectives of the BCMT for the 2024 to 2028 period. They are separated in term of administrative, scientific and data distribution objectives.

5.1 Organisation and administration

The situation regarding manpower is critical for the EOST observation service whereas it remains stable at IPGP service.

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

At national level, the renewal rate for CNRS engineer position is 3 departures for 1 replacement. EOST, as a research structure with dual supervision from the CNRS and the University of Strasbourg, has made it a high priority to create an electronics engineer position shared between the two services (magnetism and seismology) operating observatories in TAAF. The information has been passed on to the supervision authorities and we are confident that a position will be created/opened. EOST magnetic observatory service has a support from EOST through contributions from its technical team.

IPGP observation service has maintained so far its number of engineers and technicians. However E. Parmentier, technician in charge of the maintenance of Chambon-la-forêt observatory, is likely to retire in the coming five years. His replacement is absolutely necessary as it is not possible to have a safe working and living environment without an agent to maintain the site. The IPGP observatory service would benefit from a new scientist (Phys. Adj.). The area of research should preferably be oriented towards internal geomagnetism which remain the main objective of ground observatory observations. However, the goal is to increase the scientific workforce for analysing the raw observatory and variation station second data that carry an abundance of information on our environment. Given the amount of data collected through the new variometer network, the service lack scientific workforce to investigate new observables such as tidal, volcanic eruption or tsunami signals or induced and ionospheric currents signals.

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 homogeneous 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 objective 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. These fields are 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 1 Hz data, and the distance between recording stations exceed several hundred of kilometres. An evolution of the observation infrastructure is therefore needed. It is described in the next sections.

5.3 Data dissemination objectives

E-infrastructures are evolving rapidly at national, European and international levels (see Section 3). Against this backdrop, the magnetic data usage is rapidly changing, with users coming from very diverse communities and having new expectations for added values products and tools. Whereas traditionally data were directly distributed through INTERMAGNET, WDC and BCMT portals, data products and services relying on these same data are nowadays developed (e.g. SUPERMAG).

Our objective, aligned with the requirements of authorities and funders but also with the needs of user communities, are thus that all of our data and data products (including historical ones, electric measurements, variometer data, ...) are made available to the largest possible community through the BCMT portal towards global e-infrastructures. This appears to be particularly important for several BCMT observatories that are not part of INTERMAGNET and for the distribution of variometer station data. It follows that the BCMT data repository has to improve its practices and internal processes.

6 Required activities to reach the objectives

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 Maintenance of the networks

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 external field modelling and space weather applications (scientific objective SO2) would benefit from such a network. The BCMT contributes significantly to this through its 17 observatories, located at remote places in the world and a network of repeat and variometer stations. It is therefore our prime objective to maintain the observatory network and integrate all observatories in INTERMAGNET. This objective requires also the evolution of our repeat and variometer station network.

6.1.1 Observational infrastructure over mainland France (O1)

The magnetic observation infrastructure over mainland France has to be revised. The current infrastructure includes the national observatory, two variometer stations and a repeat station network. The latter, as pointed out before, is too noisy and acquired data are not used for science objectives. The national magnetic observatory data are noisy, due to the electric railway between Orléans and Paris, situated 27 km away from the observatory. The variometer stations we developed appear to be robust, with little temperature dependence, and provide good quality data. We will therefore aim at:

O1.1 reducing the level of noise in the national observatory data, by installing a variometer station to the west of the train line and combining data from the variometer station and the national observatory. This plan requires finding a suitable place for a variometer station that can be used for long term observation. We expect that only data with periods shorter than 1 h will be affected.

O1.2 setting a variometer station in a remote place such that high-quality measurements of the natural signal in the period range from 1 s to 1 h are available over France. This range could be extended to higher frequencies when the required instruments are available.

O1.3 replacing the repeat station network with a variometer station network such that data can be used for ionospheric modelling and space-weather science objectives. Such a variometer network will however require annual maintenance visits and associated calibration measurements.

These developments will run over the five coming years as the team is not able to build and install more than one variometer station a year. One of the most difficult point in these developments is to find secured environments to run variometer stations over long time periods.

6.1.2 Integration of observatories to INTERMAGNET (O2)

O2.1 The EDA observatory has been opened in early 2018, and is providing variation data but no absolute measurement. There is a maintenance work necessary to upgrade the data acquisition chain from ENO3 to ENO4 and repair part of the system that has been damaged by lightning. This maintenance work is planed for 2023. Over the coming year we will aim at re-organising the work with the local collaborating institution (the IRGM) such that absolute measurements are made, possibly by involving local scientists – e.g. through PhD student co-supervision. Alternatively we may try to install an instrument that makes the measurements, but these are expensive and the observation environment challenging (temperature can exceed 50° Celsius). We would like to have this observatory integrated to the INTERMAGNET network by 2027.

O2.2 The situation is similar in IPM observatory. A mission is planned for end 2023 to re-build an absolute pillar closer to the premises of the local collaborating institution (Dirección Meteorológica de Chile) in order to facilitate the realisation of absolute measurements. In case absolute measurements are still not carried out, we will have to install and automatic instrument. We hope to be able to maintain the observatory inside INTERMAGNET, or else we would aim at re-integrating INTERMAGNET by 2026.

O2.3 The new REU observatory will require adjustment of its settings to reduce δF variations. We expect this to take place end of 2023, or beginning of 2024. After a year, the observatory should be able to be part of INTERMAGNET.

Other observatories from IPGP observatory service will also require maintenance for, in particular, an upgrade of their acquisition chains from ENO3 to ENO4. All observatories are likely to be upgraded by 2029.

O2.4 In whole TAAF territories, logistical teams are doing their utmost to comply with the requests and injunctions of the prefecture, the regulatory and verification bodies for international nature reserves, and the auditors of the Antarctic Treaty, on the implementation of sustainable development solutions and green energy sources. While logistical teams are well aware of the possible disturbances and impacts on flora and fauna, in-situ observation systems for physical environmental parameters are sometimes overlooked. Magnetic observatories are one such system, especially as the anthropogenic electromagnetic disturbances at each of the scientific bases, are neither felt nor visible other than through the BCMT's instrumental measurements. From 2023 onward, our action in synergy with IPEV will be to remind, through consolidated documentation, the successive generations of District managers (on-site representatives of the Prefect's authority and French sovereignty during a winter-over) at each of the 4 TAAF stations of (i) the importance of magnetically quiet zones around the shelters and (ii) the need to avoid introducing electromagnetic disturbances (carrier currents, radio transmissions, DC/AC transformers, etc).

O2.5 The FIH observatory is providing variational data but very few absolute measurements. A mission in June 2022 allowed to ensure the maintenance of the acquisition and instrumental chains. In 2024, we aim at strengthening the absolute measurement achievement by finding an agreement with observers of the host organisation. Until absolute measurements become more regular, we can't foreseen when the observatory may become part of INTERMAGNET.

EOST's observatories are considerably behind in providing definitive data. As the urgent need for an electronics engineer has already been highlighted and prioritised by EOST, the 2024 request would be for another technical staff member to process the observatory magnetic data. In the short term, the team should be relying on short contracts to lighten the workload on the most basic processing and checks.

6.2 Magnetic data management

6.2.1 BCMT data repository improvements (D0)

BCMT data repository and distribution chains include : (i) the MAGIS software (IPGP data processing & managing software) that allows ingestion of data, and (ii) the BCMT web portal that enable data exposition to the public. The definition of trustworthy data repositories has evolved since the last couple of years. Self-assessment and commitment to engage the drafting of a data repository certification file is an efficient process to promote good data management practices in a sustainable way as part of a FAIR approach. BCMT will be able to identify its weak points and the required upgrade to implement, such as to formalise required documents (e.g.: a formal preservation plan), to enhance metadata sharing discovery, to plan development of Application Programming Interfaces, ... This action will require involvement of all stakeholders inside BCMT and is closely related to required activity D1. Although essential, this activity cannot be prioritised over operational tasks.

6.2.2 IPGP data processing & managing software (D1)

The data processing software MAGIS has been in used for more than a decade in IPGP. In this software the data integration, treatment and distribution were mixed and were not organised as independent tasks. Therefore, the software has been particularly difficult to upgrade and control. Over the last two years we deployed the ENO4 data acquisition device. This implied that we had to develop a new data integration software. We still need to:

D1.1 Finalise the separation between processing and distribution software, such that the distribution is made exclusively from the BCMT database. The distribution will still have to be adapted to requirements from different distribution platforms.

D1.2 Extract the efficient interface for de-spiking the data from MAGIS, to make it an independent software module, and integrate the FORTRAN codes previously developed for baseline estimation and definitive data estimation.

This will lead to a new modular data processing software suite that will ultimately replace MAGIS. This work will require several years of developments as we do not have the human resources to rewrite rapidly the full software.

6.2.3 Digitise old magnetic records (D2)

There are large sets of magnetic archives, both in IPGP and EOST, that remain only partially accessible for science studies. We have developed a software to digitise magnetic time series, extracted from paper magnetograms of BCMT archives, to produce data sets at $\sim$1-minute resolution, or better if meaningful, depending on the magnetometer setup. Some of these magnetograms have been formerly digitised as hourly spot-values. The aim of this software is to be able to analyse specific events, such are large magnetic storms, like those of solar cycles 18 and 19. During the coming years, this activity will continue in four steps:

D2.1 Use the currently available software to digitise magnetograms associated with interesting events in view of scientific studies.

D2.2 Upgrade the current software to include more sophisticated image processing techniques. These could be applied to efficiently remove the horizontal axis from the magnetic time series or to improve the time reconstruction. Other adaptations might be needed to successfully use the software on other magnetograms than those acquired in IPGP.

D2.3 Find or develop an efficient digitisation system, based on glass-plate scanners or camera scanner, in order to be able also to digitise magnetograms on rolls of paper.

D2.4 Make these records available through the BCMT web-interface. An adaptation of this interface to web-services and API dedicated to these types of data will be necessary.

6.2.4 Distribution of indices and other data products (D3)

D3.1 Indices, in particular the K index, are not routinely calculated for all observatories. This process has to be implemented for the new observatories such as EDA, SOK and REU. Furthermore, the current software output the K index is a format that is not easy to handle. We plan to revise that following the advises and decisions made in ISGI.

D3.2 The geometry of IPGP network that covers a large range of longitudes allows to identify sudden commencements. We have tested so far several new approaches and algorithms. This work should be finished by end of 2023, but several adjustment to the distribution approach and web interface will probably be necessary in 2024. This work is supported by CNES.

6.3 Instruments

6.3.1 Build, test and put in production new digital vector instruments (I1)

I1.1 The new digital vector magnetometer has been fully tested and set in production in its two versions DVM18 and DVM19. The former version is recycling old VM91 sensors, while the latter uses a newly developed, simpler and less expensive, sensor. We plan to build one or two new instruments per year, the bottleneck for higher production rate is the difficulty in acquiring the needed electronic parts, and of course the man power requirements associated with the production of an instrument. These new instruments will first be used to replace failing vector instruments in observatories, and second for the network of variometer stations that we will set in France.

6.3.2 Develop a new scalar absolute instrument (I2)

I2.1 All BCMT observatories are currently equipped with proton scalar magnetometers. Older version were able to sample the field at 1 Hz, but for the most recent versions only a 0.5 Hz sampling rate is possible. Furthermore the newest instruments present a too high failing rate, with also significant difficulties regarding the connections to the digitisers. We have therefore restarted the production of absolute scalar Helium pumped magnetometers. We found a solution inside IPGP for the production of Helium cells. Again, we will have difficulties in finding the required electronic parts and we don't think we will be able to produce more than one or two instruments a year. However, these instruments will allow to sample the magnetic field strength at a high sampling rate and to withstand larger gradients that classic proton magnetometers.

I2.2 Because of the very large difference in frequency operating range, there is a possibility that scalar Helium pumped magnetometers can be run in close proximity to fluxgate magnetometers. This has to be tested and, if the tests are successful, may lead to the development of self-calibrating magnetometers. This was a project of the previous strategic plan that we did not find time to tackle. We aim at starting it during the coming five years.

6.3.3 Develop an instrumentation to acquire data at 1 kHz sampling rate (I3)

I3.1 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 acquisition campaigns of the Swarm ESA mission, and (2 kHz) acquisition is planned for the future NanoMagSat mission. Ground data covering the same range of frequencies would help their interpretation. Search coils systems have been tested in CLF, end of 2018. We expect to record Schumann resonances, pulsations and also sferics.

7 Time line

In Figure (7) is defined a provisional time line for the different activities described in the previous sections. These come of course on the top of the usual work required for the observatory and station maintenance, and the work required to process and distribute acquired data. A meeting of the BCMT scientific council is planned in 2026, as a mid-term review of the planned activities, and in 2028. Only yearly working meetings inside the BCMT are planned, as by experience we know that a higher frequency is not sustainable.

Figure 5: Time-lines of the planned activities. Dark blue activities are those that will be given the highest priority. Lightest blue activities have low priority either because they come later in the time-line, or the availability of human resources to tackle the task are still uncertain.

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