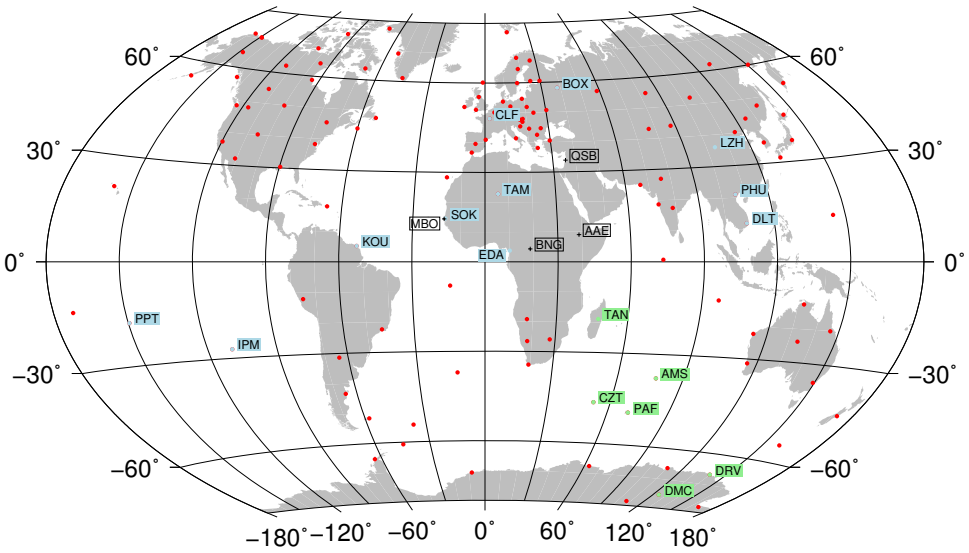
Bureau Central de Magnétisme Terrestre

Activity Report 2019-2021

31st May 2021



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Foreword

This document describes the activities undertaken by the French national service of magnetic observatories to maintain its network of stations around the world. It has been prepared in view of the BCMT Scientific Council meeting that will be held on June 2021, the 10^{th}.

Reference documents

Lesur, V., and Chambodut, A. (2018), Strategic Plan 2019-2023, Bureau Central de Magnétisme Terrestre, (http://www.BCMT.fr/pdf/StrategicPlan.pdf).

Love J. et al. (2018), Report of the Scientific Council of the Bureau Central de Magnétisme Terrestre, Bureau Central de Magnétisme Terrestre, (http://www.BCMT.fr/pdf/BCMT SC Report 2018.pdf)

List of Acronyms

BCMT: *Bureau Central de Magnétisme Terrestre*

CNES: *Centre National des Etudes Spatiales*, French space agency

CNRS: *Centre National de la Recherche Scientifique*

EOST: *Ecole et Observatoire des Sciences de la Terre*

FTE: Full Time Equivalent

INSU: *Institut National des Sciences de l'Univers*

IPEV: *Institut Polaire Français*- Paul Emile Victor, French Polar Institute

IPGP: *Institut de Physique du Globe de Paris*

ISGI: International Service of Geomagnetic Indices

SANSA: *South African National Space Agency*

SHOM: *Service Hydrographique et Océanographique de la Marine*, French Naval Hydrographic and Oceanic Service

SNO: *Service National d'Observation*, National Service of Observation

TAAF: *Terres Australes et Antarctiques Françaises*, French Austral Territories

Contents

1 Introduction

The "Bureau Central de Magnétisme Terrestre" (BCMT) is a French national service of observation for geomagnetism of the CNRS-INSU, and its role is to record and distribute ground geomagnetic observations. Created in 1921, and attached to IPGP, the activities of the BCMT are described in a five-year strategic plan [Lesur & Chambodut , 2018] and follow the advises and recommendations of a scientific council [Love et al., 2018]. This council meets regularly, and the present report has been established for the mid-term review of BCMT activities for the period 2019-2023.

Maintaining an observation service as the BCMT requires significant resources, and these are justified by the importance of the scientific objectives for which magnetic data are needed. We start therefore this report by recalling these scientific objectives. Next is given a short description on the status of each of the actions recommended by the scientific council in its last report. The report then describes, in a synthetic form, the current resources of the BCMT, the organization of the IPGP and EOST observation services, the status of the BCMT network of magnetic observatories and the status of the projects undertaken in the framework of the strategic plan 2019-2023 [Lesur & Chambodut , 2018]. Next are presented the planned activities for the two coming years. We conclude in section (9).

2 Scientific objectives

Magnetic data are used for core dynamic, mantle conductivity, and tectonic studies, all linked to the past history of our planet. They are also used to understand the current dynamic of the ionosphere and magnetosphere. Furthermore, magnetic indices are derived from the data and these are used in space-weather applications, or to study the long-term evolution of our environment. Traditionally magnetic data are used for mineral and oil exploration and for orientation purpose through reference model of the main field. Possibly the latter is the best example of how useful are magnetic data: main field models are used for the orientation of numerous devices ranging from smart-phones, vessels, planes and satellites to boreholes. As an observation service the BCMT aims at providing data for most of these applications.

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 heavily used for building magnetic field models, including the 13^{th} version of the International Geomagnetic Reference Field (IGRF) that has been released in early 2020.

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, we try to 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), starting with locations where universities or organisations are particularly interested in these data and are ready to help us setting up the stations.

3 Action review

In the report from the last scientific council five actions were recommended as a response of identified challenges. The full text of this report is available on the BCMT web site [Love et al., 2018]. Unfortunately we have not been able to finalize all these actions. We give below a short review of their current status:

+ **Action 1:** *New staff at* EOST
  A scientist, Ingo Wardinski, has been hired by the INSU and assigned as a "*Physicien-Adjoint*" to the magnetic observation service of EOST. A new engineer is also likely to be assigned to this service by 2022 for 25% FTE.

+ **Action 2:** *Standardization*
  Due to the pandemic, the expected regular meetings of the BCMT had to be postponed. We hope to be able to resume these meetings in the second half of 2021 and start the standardization process. The two first objectives are to use the same baseline estimation process, and to test the new IPGP magnetometers (see **Action 3**) in EOST.

+ **Action 3:** *New magnetometer*
  The electronic part of the new magnetometer has been finalized and fully tested. Delays have been generated in this project due to the difficulties in producing new sensors. We nonetheless hope to have two completed magnetometers after the summer 2021. Performances of these magnetometers will be described at the next IAGA workshop (the last meeting has been cancelled), and a submission to an EGU free access journal is planned.

+ **Action 4:** *M'bour and Papeete Observatories*
  The M'bour observatory (MBO) is now closed and the Sop-NiaKhar (SOK) observation site has been open in replacement.
  The relocation of the Pamatai (PPT) observatory has been postponed, due to difficulties in traveling during the pandemic. However, since September 2020, regular and high quality absolute measurements are made. Therefore, following the demand of local observers, a refurbishment of the observation huts has been organized.

+ **Action 5:** *Addis Ababa Observatory*
  The last contact in 2019 with Addis Ababa (AAE) observatory did not resolve the current situation (our instruments have not been sent back, and there is no progress regarding finding a new observation site). We have been informed that GFZ started a project for a new observatory there, with no output yet. SANSA seems to have also a plan to open an observation site to the north of Addis Ababa. We do not try further to resume observations in Ethiopia.

4 Ressources

Two institutions participate to the activities of the BCMT : IPGP and EOST. The list of staff associated to their magnetic observation services is given in table (1). There are notable changes since 2018:

- For IPGP, after the retirement of the senior engineer X. Lalanne, A. Telali, previously IPGP technician, became a CNRS engineer. The very large range of responsibilities of X. Lalanne in the observation service has been spread across the other personnel of the service. J.P. Rivierre, senior technician has been hired. His activities mainly focus on magnetic observatory data processing, although he also participates to the observatory maintenance.

- For EOST, a new scientist, I. Wardinski (IW), has been hired as an Associate Physicist in September 2019. Due to the pandemic, telecommuting and postponing of missions have been chosen in 2020. A first "handover" mission for the three Austral observatories was carried out, between A.Chambodut (AC) and IW, in spring 2021. AC is working closely with IW for a progressive transfer of management, starting now for the four Southern Territories and Madagascar observatories, and later for the two Antarctic observatories. This transfer will be completed at the end of the current four-year IPEV project, in August 2023.
  A need for a new multi-task engineer working only at 25%FTE for BCMT, was ranked as a priority 2 at EOST in September 2020 (the 40%FTE need expressed in 2019 has not been validated by CNRS-INSU). We hope the position to be opened and filled in 2022, but EOST cannot take any commitment on the opening of this position for 2022 as this is a CNRS-INSU decision.

There is no major evolution regarding the budget. The main funding agency for the BCMT is the CNRS-INSU that has maintained its funding around 110k€ 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 2020.
IPGP	Funding CLF observatory operation	85 k€ in 2020.
EOST	Funding geophysical station basic support & equipment	15 k€ in 2020.
IPEV	Funding AMS, CZT, DMC, DRV & PAF observatories operations	111 k€ in 2020.

The above numbers do not include indirect costs, nor salaries of permanent staff. As an example, the direct and indirect costs covered by IPEV for logistical support, missions and manpower of EOST observatories sum up to about 500 k€ per year (510 k€ over Jul.2019-Aug.2020).

Table 1: List of personnel involved in BCMT activities

Name	**Grade & Activity**	FTE
Lesur V.	Physicist (IPGP). Head of IPGP magnetic observatories. Management of the IPGP observatory service and, in particular, responsible of the data quality.	30%
Wardinski I.	Associate Physicist (EOST). Head of EOST magnetic observatories. Magnetic observatory management, data processing and quality control.	30%
Chambodut A.	Physicist (EOST). Operation management of the observatories in Antarctica, links with SNO International Service of Geomagnetic Indices.	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). 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.	Engineer, CNRS (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%
Rivierre J.P.	Technician (IPGP). Data processing.	100%

5 Organization of IPGP and EOST observation services

In this section, we would like to rapidly describe the work organization inside the observation services with an emphasis on three aspects: maintenance of observatories, observers/staff training and routine data management.

Maintenance of observatories

IPGP observation service is organizing (administration, logistic and finance) 2 to 3 missions per year towards African and equatorial observatories over Spring (March to June) or in early Autumn (September to October). These periods are not only chosen to avoid peaks in temperature or rainy seasons, but they are also dictated by administrative constraints: funding missions from November to March is difficult because all budgets must be closed by the end of the year and funds are often available again only mid-/end-February.

EOST observation service is organizing 2 to 3 missions per year. The service has to comply with constraints dictated by the remoteness of observatories (logistical constraints, summer in the Southern hemisphere, vessel rotations) and the organization of the missions by the IPEV.

Observers/staff training

For most observatories, IPGP observation service trains local staff of partner institutions for magnetic calibration measurements and light observatory maintenance. The quantity and quality of absolute observations depends therefore heavily on the local staff motivation, on which IPGP observation service has little influence.

EOST observation service trains annually, over more than 2 months, in France, ten new civil service volunteers on magnetic absolute observation and light observatory maintenance. The trainees are not necessarily having prior knowledge of observation or even physics. They remain with a limited FTE devoted to magnetic observatory and do not always have a strong motivation for magnetic observations.

Data management

Both IPGP and EOST observation services experience an increase in anthropogenic disturbances in magnetic data, even for the most remote observatories. Data processing workload has therefore considerably increased over the years. Efforts required to obtain high quality data are often underestimated and are not fully appreciated outside the observer community.

Outside the observation service management that, with the processing and data management, requires a continuous work along the year, the IPGP observation service organizes its work as a response to failing instrumentation or acquisition systems in observatories. Two or three observatories consume, year after years, most of the service resources. Planning the activity for the coming years is therefore particularly difficult. This is in contrast with the EOST observation service which calendar year has a regular and perpetual course with a planning over, at least, the two forthcoming years. Fixing failure in instrumentation or acquisition chains have to be achieved only at the time of a planned mission. This EOST recurrent activity is summarised in synthetic diagram shown in Figure (1).

6 Network status

In this section we present the current status of the BCMT observatory and repeat station network. We also describe the status of variometer station project in metropolitan France. The full list of observatories is provided in table (2). Some of these observatories are closed, but the data are still available from our database. These closed observatories will not be described further in this paragraph. Important changes in the BCMT network have occurred in the last years: Edéa (EDA) observatory has been opened in Cameroon in 2018, Lanzhou (LZH) observatory in China and M'Bour (MBO) observatory in Senegal, were closed in 2019, and finally Sop (SOK) observatory has been opened in Senegal in 2020.

[1] The IAGA code will need to be confirmed.

[2] The observatory is partially operating – e.g. missing absolute measurements

[3] A new observatory should open in 2021 or 2022 ∼100km away from previous LZH observatory site

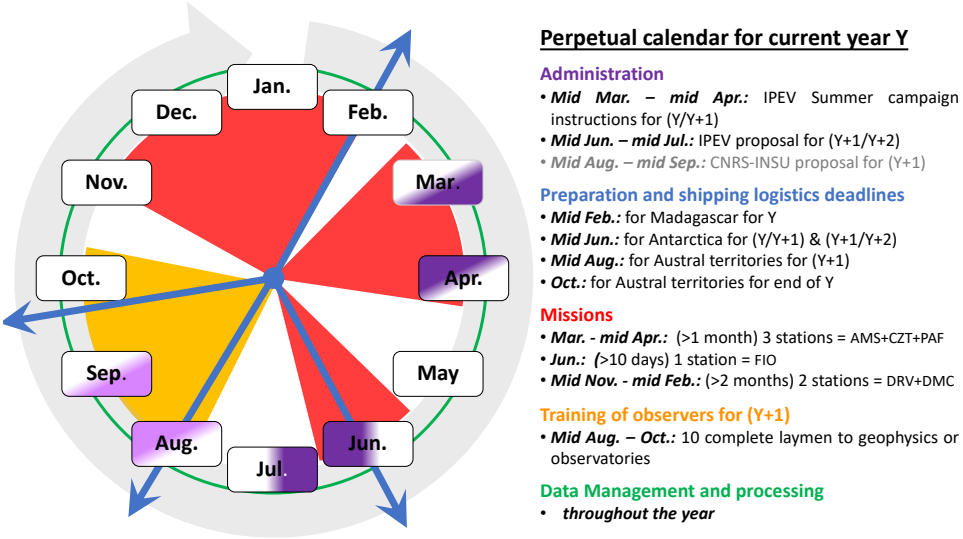

Figure 1: Synthetic diagram of EOST recurrent activities.

AAE: The Addis Ababa, was running from 1958 to 2015. The observatory had to be shut down when a new electric urban train service started in Addis Ababa creating a large amount of noise. Data transfer to INTERMAGNET and BCMT has been stopped in November 2015. Re-opening of this observatory is unlikely, as local collaborators do not show the intention to help for its relocation.

AMS: Amsterdam Island observatory is operating in routine mode. There have been no major problems. Absolute magnetic measurements are performed regularly. However, a large amount of unprocessed data has been accumulated at EOST due to staff shortages, as routine operational work has been prioritised over final data processing until early 2020. Before end of summer 2021, the final data (up to December 2020 included) will be transmitted to the BCMT database.
Recently, in March 2021, we learned that the TAAF plans to install a solar farm near the observatory shelters, at a distance of less than 150 metres. However, the dimensions of the farm and its impact on magnetic measurements are still unknown. The EOST team is currently exchanging information with the TAAF on a daily basis, in order to remind the TAAF of the technical and scientific constraints of the magnetic observatory and, to direct the project towards minimising the impacts (anthropogenic magnetic disturbance). Moving the observatory is not envisaged at this stage.

BOX: The Borok observatory has been running without major difficulties over the last years. The building infrastructure has been renovated in 2013. The data acquisition system has been upgraded in 2016. Since then, BOX delivers 1-sec data. In agreement with RAS this observatory has been added to the database under BCMT DOI associated with definitive and variation data. Similarly RAS minted a DOI for the BOX data files in their database. We have no way to check or impose the consistency between the BCMT and RAS files. By restriction of the Russian authorities, data are only delivered after 24 hours delay.
Environmental constraints are significant, with seasonal low temperatures. Every year, few fast changes of temperature in the sensor room are observed before and after winter, generally 5° to 15° Celsius over few days. These temperature changes are too fast to be efficiently corrected by the frequent and good absolute measures. They are however noticeable on the baseline fast drifts

Table 2: List of observatories maintained by BCMT:

Code	Country	Institutions	Name	Status	Remark
AAE	Ethiopia	GO AAU & IPGP	Addis Ababa	closed	
AMS	France (TAAF)	EOST & IPEV	Amsterdam Island	operating	
BNG	Rep. Centre Afr.	IPGP	Bangui	closed	
BOX	Russia	BGO IPE RAS & IPGP	Borok	operating	INTERMAGNET
CLF	France	IPGP	Chambon-la-Forêt	operating	INTERMAGNET
CZT	France (TAAF)	EOST & IPEV	Crozet Archipelago	operating	
DLT	Vietnam	IG VAST & IPGP	Da Lat	operating	INTERMAGNET
DMC	Antarctica	EOST & IPEV	Dôme C-Concordia	operating	
DRV	Antarctica (TAAF)	EOST & IPEV	Dumont d'Urville	operating	
EDA	Cameroun	IRGM & IPGP	Edéa	operating	
FIO[1]	Madagascar	IOGA & EOST	Fihaonana	partial [2]	
IPM	Chili	DMC & IPGP	Ile de Pâques	partial[2]	
KOU	France	IPGP	Kourou	operating	INTERMAGNET
LZH	China	LIS CEA & IPGP	Lanzhou	suspended[3]	
MBO	Senegal	IRD & IPGP	M'Bour	closed	
PAF	France (TAAF)	EOST & IPEV	Kerguelen islands	operating	
PHU	Vietnam	IG VAST & IPGP	Phu Thuy	partial[2]	INTERMAGNET
PPT	France	IPGP	Pamatai	operating	INTERMAGNET
QSB	Lebanon	CNRS (Lebanon) & IPGP	Qsaybeh	closed	
SOK	Senegal	IPGP	Sop-Niakhar	operating	
TAM	Algeria	CRAAG & IPGP	Tamanrasset	operating	INTERMAGNET
TAN	Madagascar	IOGA & EOST	Antananarivo	closed	

and they have an incidence on the δF stability during those periods of time. In winter 2020, a malfunction and very low temperature (-30° Celsius) froze the water heating system, a punctual electric heater has been installed causing disturbances and steps in the data for few weeks.

CLF: The historical sensor vault of the observatory, where one of the backup acquisition system is installed, is still often flooded. The three shelters built in 2016 to house the instruments are used as main, backup and tests facilities respectively. The calibration baseline shows a lesser stability for the shelter data than for those of the historical vault probably due to the slow settlement and seasonal change of temperature of the pillars.
Absolute measurements are made three times per week by 3 different observers to help maintaining CLF data to the highest achievable accuracy. Nonetheless a signal of industrial origin contaminates the data at periods between 3 and 10 minutes. A series of punctual measurements have been made few kilometers away from CLF site, indicating that the signal is not produced locally, but is due to a very remote source.
In 2018, an archeomagnetic laboratory has been installed on the observatory site in a under-used building far away from the observation shelters. Similarly, the construction of a building for archiving marine drilled cores has been realized in 2019. Although it is not directly related to the BCMT activities, these developments have added a positive human activity on the isolated site

and have no impact on the magnetic cleanness of the observatory data. The BCMT archives dating from 1883 to present have been removed from the basement of the main building, classified by date, and stored in a dry room next to the archeomagnetic laboratory.

CZT: Crozet archipelago observatory is operating in routine mode. There have been no major problems. Absolute magnetic measurements are performed regularly. However, as for Amsterdam observatory, unprocessed data has been accumulated up to early 2020. Before the end of summer 2021, the final data (up to December 2020 included) will be transmitted to the BCMT database.

DLT: Open in 1978, Da Lat observatory joined the BCMT and digital instruments were installed in 2010. The amount of missing data due to storm activities and consequent damages, has been decreased following an upgrade of earthing of the equipment in 2018.
There is, over the years, a drastic increase of noise level in the data. It has been previously observed during summer periods, due to greenhouses activities nearby. The problem has worsened in the last 3 years with the constructions of hotels and guesthouses, each time closer to the observatory shelters, as the area became a holiday destination. Local collaborators have no power over the sale of surrounding lands and regrettably cannot obtain a site to move away from these booming developments. DLT data are therefore scattered with data gaps and jumps. The amount of post treatment is heavy. The resulting definitive data, in terms of quantity and quality, is uncertain and raise the question of the relevance of a magnetic observatory in this site. Absolute measurements are made twice a week by a well-trained, competent observer.

DMC: Dôme C observatory is operating in routine mode. There have been no major problems. Absolute magnetic measurements are performed regularly. However, a certain amount of unprocessed data has been accumulated at EOST due to staff shortages, as routine operational work has been prioritised over final data processing until 2019. Before the end of summer 2021, the final data (up to December 2020 included) will be transmitted to the BCMT database.

DRV: Dumont d'Urville observatory is operating in routine mode. There have been no major problems. Absolute magnetic measurements are performed regularly. However, a large amount of unprocessed data has been accumulated at EOST due to staff shortages, as routine operational work has been prioritised over final data processing until 2019. Before the end of summer 2021, the final data (up to December 2020 included) will be transmitted to the BCMT database.
Recently, in March 2021, we learned that the TAAF plans to install a Galileo station near the observatory shelters, at a distance of less than 150 metres. This includes a building of over 100 square metres, associated cable trays, antennas and active transmission in a bandwidth that is not supposed to impact magnetic observatory instruments. The EOST team is currently exchanging information with IPEV and TAAF, in order to remind the TAAF of the technical and scientific constraints of the magnetic observatory and, to direct the project towards minimising the impacts (anthropogenic magnetic disturbance). Moving the observatory is not envisaged at this stage.

EDA: This observatory opened early 2018. It has since suffered from minor failures due to regular power failures and subsequent data gaps. The data quality has improved following the replacement of the vector magnetometer (from LEMI 035 to VM391) in May 2019. Unfortunately, despite the training of local staff, calibration measurements are not yet in the quality and quantity standard as defined by INTERMAGNET.

FIO: Fihaonana observatory opened in late 2017 to replace the Antananarivo (TAN) observatory. The distance between the two sites is about 60 km and the long time between the two installation (> 9

years) do not allow a satisfactory linkage of the individual time series.
It has since then suffered from minor failures due to regular power outages and subsequent data gaps. Unfortunately, despite the training of local staff, regular calibration measurements are complicated to be organized and achieved. Indeed, the host institution in Madagascar experiences substantial changes in the staff of the geomagnetism scientific team. Calibration measurements only began in 2019 on an irregular basis and stopped since the beginning of the Covid pandemic, as it was impossible for the staff to reach the observatory.

IPM: The acquisition has been working relatively well since the opening of IPM in 2009. The proximity of the observatory with the airport and a nearby quarry is source of disturbances. Therefore a rigorous and time-consuming data processing by IPGP on 1-sec data is required and explains the percentage of missing minutes values.
Good and frequent absolute measurements have always been difficult to obtain. The regular change of local staff on the Island since 2018 has made it difficult to maintain trained observers. Our attempts to have a permanent referent observer on the Island is, so far, unsuccessful. The recent travel regulations have postponed our program of training onsite and maintenance of the observatory. The replacement of malfunctioning scalar magnetometer is underway remotely, but very difficult. The observatory will lose its INTERMAGNET status at the end of this year.

KOU: Over the last years, the 1-second data set is nearly complete. Technical problems are solved quickly by observers. Absolute measurements are made once a week, by contract with a local company. The costs for this service are covered by CNES. Environmental constraints are significant, with high hydrometry and high temperatures. The absolute measurement shelter has been rebuilt in 2020. Over the last years, 2 projects of developments in the vicinity of the observatory have been avoided: the construction of a missile launcher tower and a meteorological radar. This shows that a close contact with local institutions and observers is the key for maintaining a clean magnetic observatory environment even for a remote site as Kourou.

LZH: After years of decreasing data quality due to urban activity growth, the observatory ceased recording in April 2019 following the opening of a new light-train line in Lanzhou. Our equipment (except theodolite) has been shipped back shortly after. Decision has been made to resume our collaboration with the Chinese institute despite the conviction that they have all the required expertise and technology to run an observatory at INTERMAGNET level by themselves. A new facility has been built 150km away from LZH. The shelter to house BCMT equipment is nearly completed. New equipment will be installed and a new observatory named after signature of a joint convention.

PAF: Port-Aux-Français observatory is operating in routine mode. There have been no major problems. Absolute magnetic measurements are performed regularly. However, a large amount of unprocessed data has been accumulated at EOST due to staff shortages, as routine operational work has been prioritised over final data processing until 2019. Before the end of summer 2021, the final data (up to December 2020 included) will be transmitted to the BCMT database.

PHU: Thunderstorms have always been a major problem in Phu Thuy. As every year, the observatory was severely damaged by thunder strike in 2019, and 55% of the data were lost that year. The vector magnetometer is not functioning at the moment. A difficult remote maintenance is underway (change of equipment). The mission planned in May 2020 to convert PHU to 100% solar powered had to be cancelled due to travel restrictions. We managed to contract a local company to

pre-install the solar panels. It is hoped the new installation will avoid thunder strike damages. The only observer lives at a walking distance from the observatory. Recent work on the nearby road increased subsequently the traffic, generating further work regarding the data cleaning process made in IPGP.

PPT: The PPT observatory, unique in the southern part of the Pacific Ocean, suffers from a high level of anthropogenic noise due to housing estate developments in the surrounding area. It is our opinion that in few years the observatory data quality will drop below the acceptable level for scientific use of the data. We do plan to relocate the observatory on the island, but this is a difficult work that will take several years. We have not found, so far, an organization or university that is ready to support us.
Absolute data measurements have been particularly sparse in PPT, well below the INTERMAGNET standards (typically once par month) in recent years. However since September 2019 the team of observers has made good weekly absolute measures. Following this improvement, we have agreed to refurbish in the year the ageing observatory shelters.

SOK: The M'Bour observatory provided high quality data with nearly daily absolute measurements for years. Unfortunately IRD (Institut de Recherche pour le Développement) had to sale the land where the M'Bour observatory was situated. The observatory had to be closed, and that came with the loss of very competent and pro-active observers.
Despite a very tight schedule we have been able to open, with significant help from IRD, a new observation site 60km away from MBO, near the tiny village of Sop. Recording started in a week after shutting down MBO, and training of a contracted observer is underway.
The magnetometers have been installed underground to minimize temperature changes in this harsh environment with high temperatures amplitudes and diurnal variation reaching 25°. The observatory has then been running without major difficulties since March 2020 : less than 2% of the data have been lost in the year due to either rare interruptions of the acquisition system associated with electric power shortage, or failure of the data transmission system.

TAM: No visit to Tamanrasset observatory has been possible in recent years due to access restriction imposed by French and Algerian authorities. The last visit to the observatory was in 2005. However, the observatory is well maintained, in working order, and if necessary, upgraded by competent and pro-active local staff.
Typically, three absolute measurements are made per week in this observatory. 1-Hz data have been available since 2010, and near real time data distribution has been in place since March 2011. There is practically no loss of data.

The French 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. The measurement method relies on GPS measurements for azimuths determination and night-time magnetic vector measurements in order to minimise external field contributions. This network was surveyed in 2012, 2013, 2015, 2017 and last year, in 2020, despite difficult conditions due to the covid pandemic. Surveying the repeat station network takes roughly a month and a half, for two operators working jointly. During the 2020 survey the Biarritz station had to be dropped due to a major change in the magnetic environment of the station, however, a station from the Spanish network is situated less than 30km away. A new site will be set before the next survey, such as to optimise the Franco-Spanish combined network. 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. Data are shared with the

international community through the magnetE program and new collaboration with neighbor countries are made to ease and unify our networks (Spain and Belgium).

Beside the observatory and repeat station network, we have started a program to set variometer stations. Our first project of variometer station started in 2020 with the SHOM ("*Service Hydrographique et Océanographique de la Marine*"). The SHOM needs to have access to stable and continuous magnetic data recorded in the vicinity of Brest. Technical specifications for acquiring such data have been provided to the SHOM in order to find an installation site. They suggested to use a military site near Hanvec (29460, Finistère). In June 2020, a ground survey has been made to verify the site local magnetic gradients. It appeared that the site is appropriate for setting a station but, despite the support of the local military authorities, our application was rejected in October 2020 at higher hierarchical level. A new site has been found relatively close to the military site in the "Domaine de Menez-Meur", part of the "Geopark Armorique". Our request for installing a magnetic station has been received very favorably by the park director as well as by the local administrative instance of the villages where the park is situated. A survey has been conducted in February 2021. We are now waiting to be authorized to start the building work. This process takes few months as the site is in principle protected. We expect to start the building work at the end of the summer 2021, to have a station providing data by the end of the year.

7 Projects progress

Outside the activities linked to observatory maintenance and data processing, a series of projects were defined in the Strategic Plan [Lesur & Chambodut , 2018]. These were defined along three axis: Observations (O), Data Management (M), and Instruments (I). In figure 2 are shown the planned, actual, and newly defined activities, along with their time-lines.

Regarding observations, two new observatories were to be installed: in Edéa (Cameroon) and Sop near Niahkar (Senegal) – activities O1 EDA and O1 MBO. These two new observatories are now operational. Displacement of PPT observatory – activity O1 PPT, has been postponed as we currently receive continuously good quality absolute measurements. In 2020, planned activities around FIO observatory – activity O1 TAN/FIO, had to be postponed due to travel limitations associated with the covid 19 pandemic. Although originally not planned we have started preparing the installation of a new observatory in La Réunion, in collaboration with the local IPGP volcanic observatory – activity O1 REU.

The possibility of acquiring high frequency magnetic data in CLF – activity O2 HF, has been tested but the installation of the instrumentation had to be postponed because finding a new observation site would be preferable. The network of the repeat stations has been surveyed over the summer 2020 – activity O3 REPT. ST., the next survey is planned for spring 2022. The status of the project for the installation of variometer stations – activity O3 VAR. ST., is described in section (6). Finally, we maintain the observation of Electric data in CLF – activity O4 MT, as it is done at little cost and it can ultimately give us information on the structure and origin of noise in CLF magnetic data.

Regarding the data management, DOI have been minted to the BCMT definitive and variational data base. A licence has been set for all these data – activities M1 DOI, LICENCE.

A new operational software has been set for absolute data ingestion, baseline estimation and definitive data production. It provides error estimates for the definitive data. However, the user interface for data

visualisation, de-noising and distribution still needs to be finalised – activity M2 PROC. SOFT. The software (under MATLAB) for the exploitation of "La Cour" digital archives is working efficiently for magnetically quiet days. Developments are still required to work with perturbed days – activity M3 DIG. ARCH.. The planned work on magnetic indices – activity M4, included the upgrade of the Sudden Commencements (SCs) and magnetic events detection software. This activity is postponed to a later date as the work on the processing software (activity M2) has first to be finalized.

Finally, the digital part of the new magnetometer has been partially redesigned, fully tested and shows very good performances – activity I1. The setting of a new, more robust, less expensive, sensor is nearly finished. Prototypes in glass-polyamide and PEEK have been tested but their dependencies on temperature are too high for observatory instruments. Ceramic versions have been ordered – activity I2. The design of the variometer station is well advanced and will rely on the newly develop observatory vector magnetometer, combined with a scalar proton magnetometer. Powered through solar-panels, the stations will be based on a setting similar to the SOK observatory. Further details on the design will be possible when the first station will be installed – activity I3. The development of a self calibrating vector instrument – activity I4, is postponed to a later date as to avoid a too large workload for the team.

8 Planned activities

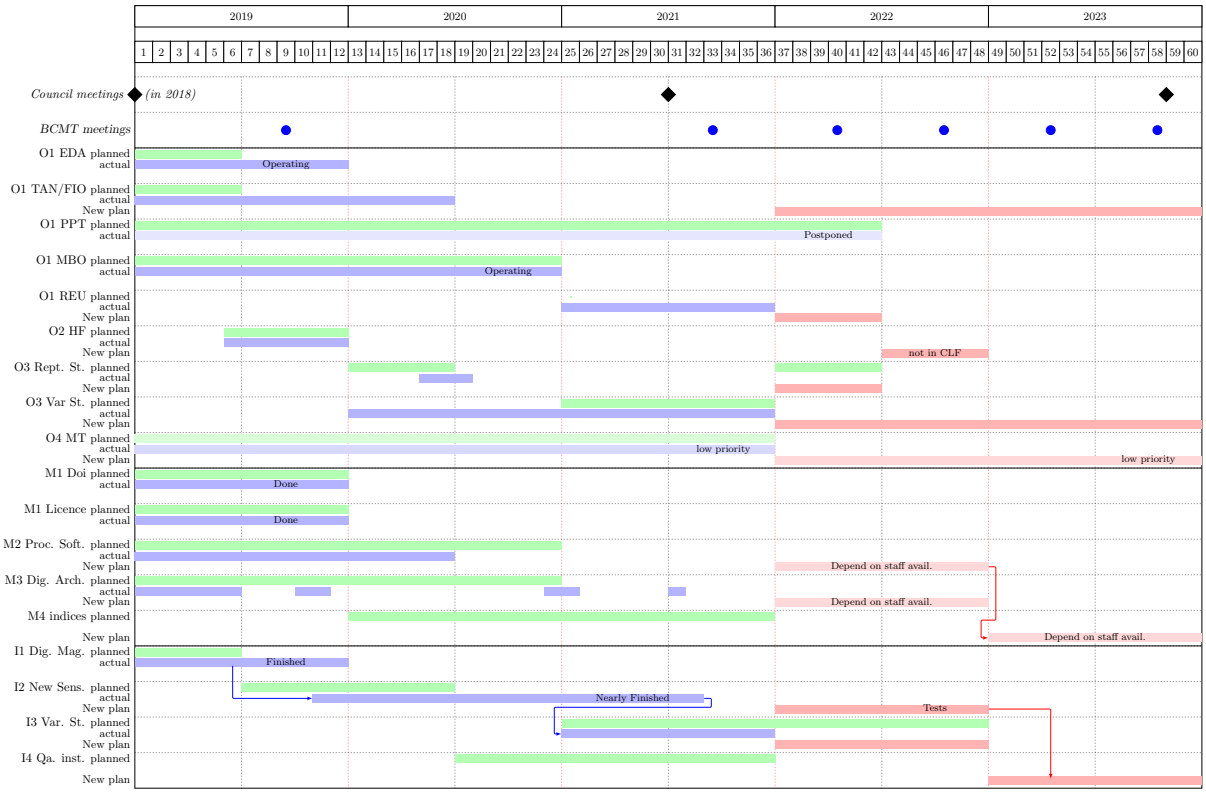

Figure 2: Time-lines of the projects: activities as defined in the strategic plan are shown in green, activities over 2019-2021 are shown in blue, newly planned activities over 2022-2023 are shown in red

8.1 Observation

O1 FIO Two missions to Madagascar planned in 2020 and 2021 were cancelled because of the pandemic. A mission is scheduled for June 2022 to maintain the whole instrumental chain and to find a way to physically enable (travel) and to incentivise absolute measurements.

O1 REU La Réunion Island is situated close to the maximum of magnetic field total intensity variation in the southern hemisphere over the coming 5 years, as forecast by the IGRF-13. On this Island IPGP runs a volcanic observatory. Setting and running a magnetic observatory there seems therefore a sensible choice. An IPGP technician has been already trained for absolute measurement and observatory maintenance. He will take his position at La Réunion volcanic observatory over the summer 2021 and there will help setting and then running the observatory.

O1 HF Record of high frequency data has been postponed to the second half of 2022. We hope to be able to set up an efficient recording system by end of 2022.

O3 REP ST The next survey of the French repeat station network is planned in Spring/Summer 2022. A new station has to be set in replacement of Biarritz station.

O3 VAR ST Given the limitation linked to the pandemic and the administrative constraints, it is likely that the setting of the variometer station in Hanvec will continue over 2022. There is also a demand from University of Clermont-Ferrand to set a variometer station in the Observatoire-du-Puy, or in a location not too far from Clermont-Ferrand. This will probably require to work on this project also in 2023.

O4 MT Electric measurements will be continued in CLF over the coming two years.

8.2 Data Management

M2 PROC. SOFT. The processing software is not finalised due to a lack of manpower (IT engineer) in the observation service. Continuation of these developments may be possible if a project proposal that includes hiring an IT engineer, is funded. In case it is not, an alternative way of doing the work will have to be found.

M3 DIG. ARCH. This project aims at building a MatLab software to digitize La Cour photographic magnetograms. This software is developed slowly (two months per year) by Dr. A. Garcia, funded on IPGP magnetic observatory service resources. As long as Dr. A. Garcia accepts to do this work, these developments will continue. Several months of work are still necessary to finalise the software for magnetically active periods.

M4 INDICES We would like to consolidate our algorithm for automatic detection of SCs (Sudden commencements) in quasi-real time and set an effective way of distributing the information. This requires first that our processing software is running. This activity is therefore planned for 2023 and will be possible only if we have the required manpower. As for the M2 PROC. SOFT. activity, this is the subject of a project proposal that we hope will be funded by CNES.

8.3 Instrumentation

I2 NEW SENS. The new sensor will be finalized soon and as, ultimately, all our observatories will be upgraded with this instrument, it has to be tested over a year in European observatory conditions. This will be done in both IPGP and EOST during 2022.

I3 VAR. ST. As described before, two new variometer stations are planned and it is likely that they will not both been installed before end of 2022. Adjustments of the station infrastructures and recording systems will be very likely necessary.

I4 QA. INST. We will come back on working on quasi-absolute (self calibrating) instruments only in 2023.

9 Conclusion

Looking back on the activities over the last two and a half years, a very significant amount of work has been achieved. The pandemic and administrative difficulties slowed down progresses, but their impacts have not been the same on all tasks and actions. The main difficulties were associated with the postponed maintenance of some observatories, such as Phu Thuy (PHU) and Easter Island (IPM). In some cases, the pandemic also prevented the organization of calibration measurements as in EDA, SOK and FIO. Other projects have also been delayed, with less obvious effects, as the instrument developments and collaboration between IPGP and EOST observation services.

For the coming two years, we are concerned with the continuation of observations in DLT, AMS and DRV. For these observatories, difficulties are linked to a growing anthropogenic noise and there is very little we can do about it. We may be forced to move our instrumentation from DLT to one of the two other Vietnamese observatories that have not been yet upgraded to INTERMAGNET standards. However, we will not set this as one of our priority, unless the scientific committee think otherwise. For the AMS & DRV observatories, the only course of action is to discuss with IPEV and TAAF in order to preserve acceptable observation conditions. We may have to turn to the international community and to ask for support letters showing the importance of maintaining continuous observations in these remote areas.

Another source of concern is our ability to distribute our data sets and associated metadata in an efficient way. There are two aspects to this issue. First the international community is not well organized to distribute non-INTERMAGNET observatory and variometer station data particularly in (quasi-)real time. We observe that we have more and more data falling in this category. Second, we struggle to find the resources (mainly manpower) to maintain our IT infrastructure and processing software at the level requested by the new standards of data curation and FAIR principles.

Our approach to tackle this latter issue is to finance manpower through different scientific projects. Moreover, we aim at having a support from IPGP data center, and collaborate with the French data infrastructure for Solid Earth - ForM@Ter. We may also take advantage of possible developments within national projects (such as in the national GaiaData project).

Finally, we would like to thanks the different agencies that support our activities, and the scientific council that helps us in organizing our work and objectives along the years.