COUNTRY HYDROMET DIAGNOSTICS

Informing policy and investment decisions for high-quality weather forecasts, early warning systems, and climate information in developing countries.

July 2024

Democratic Republic of Congo
Peer Review Report

Reviewing Agency:
Federal Office of Meteorology and Climatology - MeteoSwiss

Authors:
Frédéric P.A. Vogt, Alexander Haefele, Fabio Fontana, Moritz Flubacher, Sanne Schnyder

WORLD METEOROLOGICAL ORGANIZATION

SOFF Weather and climate data for resilience
Systematic Observations Financing Facility

Alliance for Hydromet Development

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

MeteoSwiss

METTELSAT

Banque Africaine de Développement
African Development Bank

African Development Fund
Fonds Africain de Développement

Zürich-Airport
27.9.24

Prof. Christof Appenzeller, Permanent Representative (PR) of Switzerland with the World Meteorological Organization (WMO), MeteoSwiss, Operation Center 1, CH-8058 Zurich-Airport, Switzerland: international@meteoswiss.ch

and to:

Kinshasa
27.09.2024

Prof. Joseph Itela Y'Ilondo, Permanent Representative (PR) of the Democratic Republic of Congo with the World Meteorological Organization (WMO), METTELSAT, Chaussée Mzée L.D. Kabila, Binza Météo, Kinshasa, Democratic Republic of Congo: meteordcongo@gmail.com

Authorisation for release of this report has been received from the Peer Reviewing Agency and the Country NMHS as of 15.09.2024.

Impressum

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss
Operation Center 1 | P.O. Box | CH-8058 Zurich-Airport
international@meteoswiss.ch

Disclaimer

This report has been prepared by MeteoSwiss in close collaboration with METTELSAT and other relevant stakeholders between January and July 2024. While reasonable care and skill have been taken in preparing this report, no representation or warranty, expressed or implied, is made as to the accuracy, completeness, or suitability of the information and assumptions relied upon, and we do not accept any liability whatsoever for any direct or consequential loss arising from any use of this report or its contents.

Acknowledgements

We thank the METTELSAT personnel at the sites of Kinshasa-Binza, Mbandaka, Kananga and Gemena for their warm welcome, their availability, and the many in-depth discussions and presentations that took place during the on-site visits made in support of the assembly of this report. Our gratitude also goes to the METTELSAT members of the "Cellule d'Execution du Projet" SOFF, whose support was critical to the success of these on-site visits.

The visits of the METTELSAT stations located in Mbandaka, Kananga and Gemena were made possible thanks to the existence of UN Humanitarian Air Service (UNHAS[1]) flights between Kinshasa and these three locations. We are extremely grateful for the adjustments made by UNHAS to their regular route schedule in support of these site visits, which proved crucial to this work.

We also extend our most sincere thanks to the Embassy of Switzerland in Kinshasa, and in particular to the ambassador Chasper Sarott and the deputy head of mission Samira Cizero, for the extensive support provided to MeteoSwiss in the realization of its mission in the DRC.

[1] https://www.wfp.org/unhas

Table of Contents

List of abbreviations

CHD	Country Hydromet Diagnostics
CREWS	Climate Risk and Early Warning Systems
DRC	Democratic Republic of Congo
GBON	Global Basic Observing Network
GISC	Global Information Service Center
ICT	Information and Communications Technology
METTELSAT	"Agence Nationale de Météorologie et Télédétection par Satellite" (DRC's NMHS)
NMHS	National Meteorological and Hydrological Services
SOFF	Systematic Observations Financing Facility
SOP	Standard Operating Procedure
UN	United Nations
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organization

Résumé Exécutif en français

Dans les années 1960, peu après l'indépendance de la République Démocratique du Congo (RDC), environ 128 stations météorologiques de surface et 7 stations de radiosondage (pas toutes utilisées régulièrement) existaient dans le pays, avec un centre d'étalonnage régional à Kinshasa. En juillet 2024, moins de 25% de ces sites sont encore en activité, avec uniquement des mesures de surface. De plus, le centre d'étalonnage de Kinshasa n'est plus opérationnel. Cette situation, qui se reflète dans les diagnostics hydromet de la RDC résumés dans la Fig. 1, est le résultat, en grande partie, d'une longue série d'investissements insuffisants dans les infrastructures et les ressources humaines.

Le soutien financier du gouvernement faisant toujours défaut, une amélioration durable des Services Météorologiques et Hydrologiques Nationaux (SMHN) de la RDC doit encore se matérialiser. Il convient notamment de mentionner ici le Programme d'Action National d'Adaptation au Changement Climatique de la RDC (Ministère de l'Environnement, 2006). Dans ce plan élaboré il y a près de 20 ans, le « renforcement des capacités des services météorologiques nationaux » était classé 8ème des 10 mesures d'atténuation/adaptation au changement climatique. Ainsi, les SMHN de la RDC n'ont pas reçu de soutien financier de la part du gouvernement de la RDC dans le cadre de ce programme. La perte d'infrastructures et de capacités des SMHN de la RDC qui en résulte aujourd’hui implique que leur capacité à surveiller et à quantifier l'ampleur du changement climatique dans l'ensemble du pays est de plus en plus compromise. Ceci, à son tour, affecte directement la capacité de la RDC à anticiper et donc à faire face aux impacts du changement climatique, tels qu'une fréquence plus élevée de conditions météorologiques extrêmes.

Les récents projets de développement des capacités des SMHN de la RDC par la Banque Mondiale, l'Organisation Météorologique Mondiale (WMO) et d'autres partenaires internationaux n'ont pas eu l'impact espéré. Les rapports d'achèvement de ces différents projets énumèrent les nombreux défis qui ont affecté leurs résultats (WMO, 2023, 2023b ; World Bank, 2023, 2024). L'état actuel des infrastructures et des capacités opérationnelles des SMHN de la RDC a également entraîné un important déficit d'image auprès de leurs partenaires, y compris les partenaires gouvernementaux. S'ils peuvent explicitement démontrer leur capacité à exploiter et maintenir un réseau de stations météorologiques automatisées dans toute la RDC (un exploit que plusieurs entités nationales ont tenté de réaliser), les SMHN de la RDC pourraient améliorer de manière significative leur image vis-à-vis de leurs partenaires. D'autres mesures essentielles pour rétablir la confiance dans les SMHN de la RDC sont énumérées à l'annexe 2. Elles comprennent, entre autres, la nécessité de disposer des moyens financiers nécessaires à l'accomplissement des tâches qui leur sont confiées; l'élaboration et la mise en œuvre d'une stratégie formelle sur 5 ou 10 ans; le déploiement de processus financiers sains pour garantir la meilleure utilisation possible des investissements en vue de la réalisation des objectifs de projets; la prévention de toute nouvelle perte de biens immobiliers.

L'exploitation d'un réseau de stations météorologiques/hydrologiques automatisées en RDC, sans parler de leur utilisation à des fins de prévision, de surveillance du climat et d'émission d’alertes précoces, n'est pas une mince affaire. L'étendue du pays et son indice de développement humain, associés à l'état actuel des infrastructures de transport et de communication, ainsi qu'à l'instabilité dans les régions orientales, compliquent la tâche. Pour y parvenir, les SMHN de la RDC ont besoin d'un soutien financier, technique et humain à long terme pour que leurs infrastructures d'observation soient rétablies et stabilisées, et que leur personnel soit formé au fonctionnement et à l'exploitation d'un réseau d'observation météorologique et hydrologique moderne. À cet égard, il est primordial que tout effort déployé pour soutenir les SMHN de la RDC prenne en compte, planifie et garantisse que les SMHN de la RDC puissent effectivement supporter, de manière durable, tous les coûts opérationnels associés à un investissement donné tout au long de son cycle de vie. Dans le cas contraire, les avantages des futurs investissements potentiels pourraient ne pas se matérialiser et les SMHN de la RDC seraient continuellement et de plus en plus mis au défi d'améliorer la perception externe de leurs partenaires. Cette situation doit être évitée à tout prix - les SMHN ne peuvent réussir dans leur mission que s'ils sont considérés comme un partenaire de confiance.

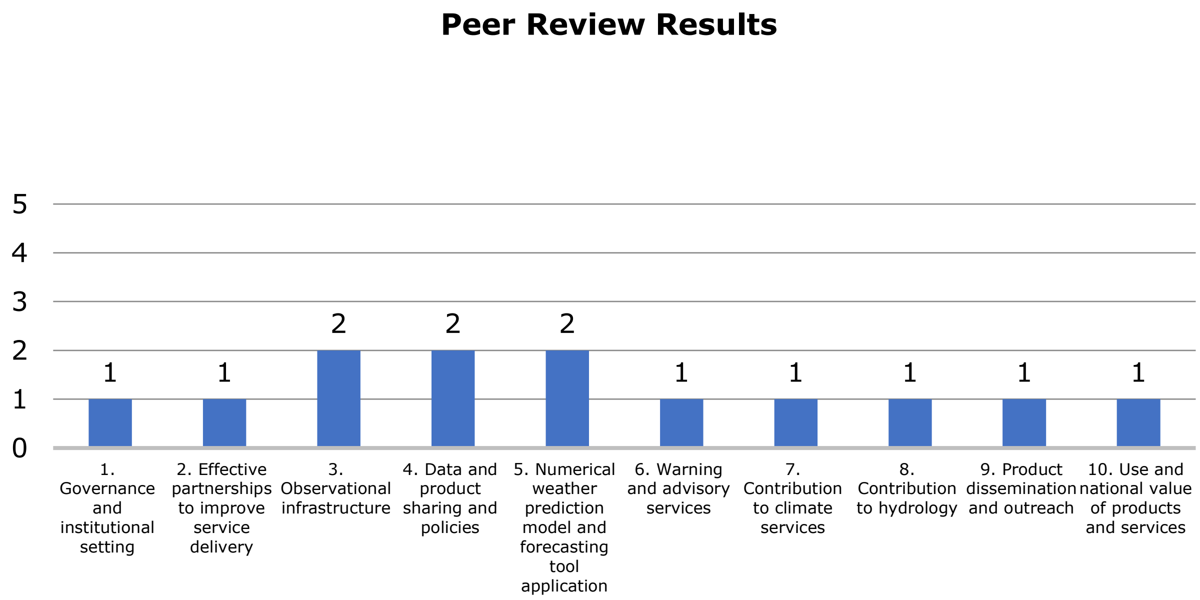
Executive Summary

In the 1960's, shortly after the Democratic Republic of Congo (DRC) achieved independence, some 128 surface and 7 upper-air meteorological stations (not all of which were in regular use) existed country-wide, together with a regional calibration center in Kinshasa. As of July 2024, less than 25% of the original sites are still in activity, with (partial) surface measurements only. The calibration facility in Kinshasa is also no longer operational. This situation, which is reflected in the DRC's Hydromet Diagnostics summarized in Fig. 1, is the result, in large, of a long-standing stream of insufficient investments in infrastructures and human resources.

With financial support from the government still lacking, a lasting improvement in the state of the DRC's National Meteorological and Hydrological Services (NMHS) is yet to be realized. From that perspective, it is worth mentioning here the DRC's Climate Change Adaptation National Action Plan (Ministère de l'Environnement, 2006). In this plan assembled nearly 20 years ago, the "strengthening of the national meteorological services" was ranked 8 out of 10 climate change mitigation/adaptation measures. Consequently, the DRC's NMHS did not receive specific financial support from the DRC government within the scope of that program. The resulting loss of infrastructures and capabilities of the DRC's NMHS implies that their ability to monitor and quantify the extent of climate change throughout the country is becoming increasingly compromised. This, in turn, is also directly affecting the ability of the DRC to anticipate and thus cope with the impacts of climate change, such as a higher frequency of extreme weather.

Recent capacity development programs by the World Bank, WMO and other international partners did not have the anticipated impact in terms of the strengthening of DRC's NMHS. The completion reports from these various projects list the several challenges that affected their outcomes (WMO, 2023, 2023b; World bank, 2023, 2024). The current state of DRC's NMHS infrastructures and operational capabilities has also resulted in an important image deficit amongst their stakeholders, including governmental partners. If they can explicitly demonstrate their ability to operate and maintain a network of automated weather stations throughout the DRC (a feat that several national entities have attempted to achieve), DRC's NMHS would potentially significantly improve their standing vis-à-vis their stakeholders. Other key elements to re-establish trust in DRC's NMHS are listed in Annex 2. These include, among others, the need to be given the financial means to perform their assigned tasks; the assembly and implementation of a formal 5/10-year strategy; the deployment of sound financial processes to ensure the best possible use of financial investments towards project goals; the prevention of any further losses of real estate.

Operating a network of automated weather/hydrological stations in the DRC, let alone exploiting them for forecasting, climate monitoring and early warning purposes, is no small feat. The large size of the country and its Human Development Index, coupled to the current state of the transport and communication infrastructures, as well as instability in the eastern regions, all make this a complicated task. To achieve it, DRC's NMHS require dedicated long-term financial, technical and human support to see its observational infrastructure re-established and stabilized, and its staff trained to operate and exploit a modern meteorological and hydrological observation network. In that respect, it is paramount that any effort deployed in support of DRC's NMHS considers, plans, and ensures that DRC's NMHS can in fact bear, in a sustainable manner, all the operational costs associated to any given investment throughout its life cycle. Otherwise, the benefits of potential future investments may not materialize, and the DRC's NMHS would be continuously and increasingly challenged to improve the external perception by their stakeholders. This should be prevented at all costs – NMHS can only be successful if they are seen as a trusted partner.



Element	Maturity level score
1. Governance and institutional setting	1
2. Effective partnerships to improve service delivery	1
3. Observational infrastructure	2
4. Data and product sharing and policies	2
5. Numerical weather prediction model and forecasting tool application	2
6. Warning and advisory services	1
7. Contribution to climate services	1
8. Contribution to hydrology	1
9. Product dissemination and outreach	1
10. Use and national value of products and services	1

Fig. 1: Review results based on the 10 elements of CHD

Chapter 1: General information

Introduction

The Democratic Republic of Congo (DRC) is located in Central Africa where it straddles the Equator Line. It is the second largest country (with an area of 2'345'409 km^2) of the continent, and the fourth most populated (with over 102 million inhabitants). It ranks 180 out of 193 countries in terms of its Human Development Index (UNDP, 2024).

Most of the country is part of the Congo Basin. The central low-lying zone experiences tropical conditions. Savannas and grasslands are located further away from the Equator Line, to the South and North respectively. The East of the country hosts a mountainous region that belongs to the Western portion of the African Rift, with the highest peak of the Rwenzori range reaching up to 5'109 m amsl.

The DRC gained its independence in 1960. At the time, its meteorological network was comprised of some 128 surface and 7 upper-air stations (then state-of-the-art; METTELSAT, 2024b). Kinshasa was also home of a regional meteorological calibration centre. Since then, however, the meteorological observation network of the DRC has seen almost no investments by the successive governments. As a result, the observation network, which is managed by METTELSAT, is subject to an ongoing decline.

Between 2016 and 2023, METTELSAT benefitted from two large capacity development projects that supplemented one another: the World Bank's "Strengthening Hydro-Meteorological and Climate Services Project" (P159217; USD 8.03 million), and the CREWS "DR Congo - Strengthening Hydro-Meteorological and Early Warning Services" project (CProj/01/DRC; USD 3.09 million). Several official documents from these two projects, which we shall jointly refer to as the "Hydromet project" for simplicity, were used in the assembly of this report.

CHD methodology

The Federal Office of Meteorology and Climatology – MeteoSwiss carried out this Country Hydromet Diagnostic as part of the Systematic Observations Financing Facility (SOFF) Readiness Phase in the DRC, a project for which it acts as SOFF peer advisor.

The information used to assemble this CHD was gathered by MeteoSwiss between January and July 2024. Documents from the Hydromet project represent an important source of information regarding the current state of METTELSAT. The data derived from these project documents were verified and complemented by a series of bilateral discussions between representatives of MeteoSwiss and METTELSAT and some of its stakeholders, both remotely and during an on-site visit to the DRC from 27.05.2024 to 14.06.2024.

Chapter 2: Country Hydromet Diagnostics

Element 1: Governance and institutional setting

1.1 Existence of Act or Policy describing the NMHS legal mandate and its scope.

The current legal status of METTELSAT, initially founded in 1991, is specified in a dedicated decree (no. 22/40) from 12.10.2012. On 13.05.2019, a decree (no. 22/019) established a national framework[2] to aid in the decision-making process for questions related to meteorological and climatological issues in the DRC. However, this framework is not yet operational, and its relevant committees remain to be assembled. A law regulating and clarifying the functional assignments of institutions in the hydrological and meteorological sector in the DRC was drafted as part of the Hydromet project in 2022-2023 and subsequently submitted to the responsible ministry. As of July 2024, this law has not been formally discussed by the government: its current status is unknown.

1.2 Existence of Strategic, Operational and Risk Management plans and their reporting as part of oversight and management.

METTELSAT does not have any current Strategic, Operational and/or Risk Management plan. A draft strategic plan was assembled (METTELSAT, 2021) as part of the Hydromet project, but was never implemented in practice, and has not been kept updated. There is a draft operational plan for the observation network (METTELSAT, 2024b).

1.3 Government budget allocation consistently covers the needs of the NMHS in terms of its national, regional, and global responsibilities and based, among others, on cost-benefit analysis of the service. Evidence of sufficient staffing to cover core functions.

METTELSAT faces a long-standing stream of insufficient budget allocations from the government, coupled with an inexistent revenue generation from aeronautical services (WMO, 2023) because of a "*long-standing dispute with the Airways Agency*[3]" (World Bank, 2023). With the government not meeting pension obligations, a significant number of METTELSAT employees are today above retirement age. The reported annual budget of METTELSAT for 2024 is of USD 275'000.-, with 82% going towards staff costs, and 18% to operational costs.

1.4 Proportion of staff (availability of in-house, seconded, contracted-out) with adequate training in relevant disciplines, including scientific, technical, and information and communication technologies (ICT). Institutional and policy arrangements in-country to support training needs of NMHS.

The majority of METTELSAT staff have received appropriate training in their discipline, but only few have received recent training on modern scientific, technical and ICT technologies. A majority of METTELSAT personnel is yet to be trained for the operation and exploitation of modern meteorological infrastructures and tools (WMO, 2023). As of July 2024, METTELSAT reports 623 staff members nation-wide with a male/female ratio of 87%/13%, of which 42% are unpaid.

[2] In french, "Cadre National des Services Météorologiques"
[3] In french, "Régie des Voies Aériennes" (RVA)

1.5 Experience and track record in implementing internationally funded hydromet projects as well as research and development projects in general.

The Hydromet project is the most recent significant internationally funded project for METTELSAT. Its outcome was deemed "Moderately Unsatisfactory" (World Bank, 2023).

Summary score and recommendations for Element 1:
1 - METTELSAT has a clearly defined but weakly implemented mandate. Recent attempts at improving this state of affair have not yielded results. METTELSAT also faces significant funding issues and needs to develop a coherent/comprehensive strategic vision for its future. Most of its staff still need to receive training to exploit modern meteorological infrastructures.

Element 2: Effective partnerships to improve service delivery

2.1. Effective partnerships for service delivery in place with other government institutions.

At least 10 partnership agreements have been signed between METTELSAT and key stakeholders, as part of the Hydromet project (WMO, 2023b). As of July 2024 however, interactions, discussions, coordination and data exchange occurring as a result of these partnership agreements remain to be setup.

2.2. Effective partnerships in place at the national and international level with the private sector, research centres and academia, including joint research and innovation projects.

At least 2 partnership agreements signed as part of the Hydromet project involve educational and/or research-generating partners in the DRC (i.e. ISTA - "Institut Supérieur des Techniques Appliquées" and INERA - "Institut National pour l'Etude et la Recherche Agronomiques"). Despite these agreements, effective partnerships remain to be established with the private sector or academia. Coordination between meteorological and climatological stakeholders in the DRC occurring as a result of the decree 22/019 from 13.05.2019 also remains to be setup.

2.3. Effective partnerships in place with international climate and development finance partners.

METTELSAT maintains relatively close ties with the African Development Bank (AfDB), which are likely to be strengthened further through SOFF (with AfDB being the implementing entity in the DRC). Interactions with the World Bank have ended for the Hydromet project, but METTELSAT remains involved (marginally) in the World Bank project P169021 ("National Agriculture Development Program"). CREWS might remain active in the DRC in the future, at a level and through specific endeavours that remain to be formalized as of July 2024 (i.e., CREWS-ASW, CREWS-Central Africa, …).

2.4. New or enhanced products, services or dissemination techniques or new uses or applications of existing products and services that culminated from these relationships.

In February 2022, METTELSAT resumed issuing meteorological forecasts (after a 12-year hiatus) as a result of the Hydromet project (Kalubi, 2022; Ngiambukulu, 2022). These forecasts take the form of a single prediction for the following day, for 28 cities in the DRC (METTELSAT, 2024). Their dissemination and impact amongst stakeholders and the population remain however marginal: with the METTELSAT website no longer operational, the forecasts are only circulated via a single email mailing list, and sent to a limited number of newspapers in the Kinshasa area. As of July 2024, no data from the automated weather stations deployed as part of the Hydromet project are being shared internationally on the GTS/WIS.

Summary score, recommendations, and comments for Element 2:

1 – Although METTELSAT is largely aware of the interests and needs of key governmental and international stakeholders in its products and services, effective and lasting partnerships are yet to be established. This is driven, in large, by METTELSAT being challenged to deliver products and/or services with the quality, frequency and/or reliability requested by its stakeholders. Considerable efforts must be made to improve the resulting image and trust deficit of METTELSAT vis-à-vis its stakeholders.

Element 3: Observational infrastructure

3.1. Average horizontal resolution in km of both synoptic surface and upper-air observations, including compliance with the Global Basic Observing Network (GBON) regulations.

As of July 2024, the DRC is not GBON compliant, be it at a national or individual site level for any of its stations. We refer the interested reader to the GBON National Gap Analysis performed as part of the SOFF Readiness Phase (WMO, 2024; see also Annex 5). There are no operational radiosounding systems in the DRC, except for one system (unused due to lack of resources) deployed on the site of Binza in Kinshasa via the "China Aid" project. As of July 2024, none of the data acquired by the 12 automated weather stations deployed as part of the Hydromet project are available internationally.

3.2. Additional observations used for nowcasting and specialized purposes.

METTELSAT does record soil temperatures at different depths (manually, via mercury thermometers) at several of its sites, for agrometeorological purposes. Data exploitation remains however very limited, as most measurements remain to be digitized.

3.3. Standard Operating Practices in place for the deployment, maintenance, calibrations and quality assurance of the observational network.

There are no formal SOPs in place at METTELSAT for the deployment, maintenance, calibrations and/or quality assurance of the observational network. Current practices derive from (then state-of-the-art) procedures in place in the 1960's. There is no coordination between the different METTELSAT sites, that all operate in isolation.

3.4 Implementation of sustainable newer approaches to observations.

A national WIGOS Implementation Plan is in the process of being drafted at the level of METTELSAT (METTELSAT, 2024b), but the timeline for its implementation at the National level is uncertain. As part of the SOFF project, a National Contribution Plan (to see the DRC become GBON compliant) is also in the process of being drafted.

3.5. Percentage of the surface observations that depend on automatic techniques.

0%, as METTELSAT relies on manual observations for its operations. In 2023, 12 automated weather stations have been deployed as part of the Hydromet project, but their data are essentially not used operationally by METTELSAT. The regular & long-term maintenance of these stations is neither setup nor secured. Several have already experienced partial/total system failures or were vandalized. Without a rapid investment to repair/secure/maintain these stations, their decline is bound to become irreversible, in a manner similar to the CIMEL stations deployed in 2008-2009 as part of the "Emergency Multisector Rehabilitation and Reconstruction Project" from the World Bank.

Summary score, recommendations, and comments for Element 3

2 – The observational network of METTELSAT is comprised of 33 active sites as of July 2024, none of which are GBON compliant. METTELSAT relies primarily on manual measurements for its operations. All the sites are facing a rapid decline, be it in terms of quantity/quality of equipment, real estate (see e.g. the 2004-2014-2023 sequence of satellite images of the METTELSAT headquarters), or staff availability. The deployment of automated weather stations on several sites (in at least 3 distinct projects) did not stop this decline. The data from automatic weather stations systems have also not yet been integrated in the METTELSAT operational chain.

Element 4: Data and product sharing and policies

4.1. Percentage of GBON compliance – for how many prescribed surface and upper-air stations are observations exchanged internationally. Usage of regional WIGOS centres.

0%. None of the METTELSAT stations are GBON compliant as of July 2024. None of the automatic stations see their data accessible internationally, including the 12 stations recently installed as part of the Hydromet project. The limited data shared internationally by METTELSAT is acquired and transferred manually to GISC Casablanca.

4.2. A formal policy and practice for the free and open sharing of observational data.

METTELSAT does not have a formal policy regarding the free and open sharing of observational data.

4.3. Main data and products received from external sources in a national, regional and global context, such as model and satellite data.

METTELSAT is equipped with a functional PUMA (Project for Preparing the Use of Meteosat second generation Africa) satellite reception system (at its headquarters) that provides them access to EUMETCast. As part of the Hydromet project, they have also gained access to the MESSIR-NEO software (deployed on a physical server at the METTELSAT headquarters), that provides them with access to global numerical models, SADIS, and data from the GTS/WIS.

Summary score, recommendations, and comments for Element 4

2 – A very limited amount of (manual) data from METTELSAT stations are being shared internationally as of June 2024. Although several of the automatic weather stations installed as part of the Hydromet project in 2023 are already partly/fully defective, most remain able to transmit their data to EUMETSAT in Darmstadt (Germany) via Meteosat 11 and dedicated communication channels allocated to METTELSAT. The transmitted data is in a clear, readable (CSV) format, that is however incompatible with direct ingestion by the GTS. It was intended to have this data transferred back to METTELSAT for ingestion in MESSIR-NEO, conversion to SYNOP, and upload to the GTS via the Regional Telecommunication Hub of Brazzaville. So far however, data formatting and connectivity issues (between Darmstadt and Kinshasa, as well as between Kinshasa and Brazzaville) have prevented this plan to be realized. From that perspective, the advent of WIS and WIS 2.0 Boxes offers an enticing perspective: that of deploying a cloud-based WIS 2.0 Box able to receive data from METTELSAT automatic weather stations directly from EUMETSAT in Germany. Doing so would significantly simplify the data flow to WIS: data flow which would in turn also become significantly more robust.

Element 5: Numerical model and forecasting tool application

5.1. Model and remote sensed products form the primary source for products across the different forecasting timescales.

METTELSAT forecasters issue once per day a single forecast for the major cities in the DRC, valid for the following day (METTELSAT, 2024). These forecasts are assembled manually, primarily via an assessment of material from the ARPEGE and GFS numerical models, and from METEOSAT images. ECMWF material is in principle available but is currently not being exploited due to the lack of appropriate training.

5.2. a) Models run internally (and sustainably), b) Data assimilation and verification performed, c) appropriateness of horizontal and vertical resolution.

METTELSAT does not run any numerical model internally.

5.3. Probabilistic forecasts produced and, if so, based on ensemble predictions.

METTELSAT does not generate probabilistic forecasts.

Summary score, recommendations, and comments for Element 5

2 – The forecasting capabilities of METTELSAT are very limited: they rely on the manual analysis of global numerical models and satellite imagery, with a single 24-hr lead time, with forecasts distributed by emails 81%[4] of the days. The observations from METTELSAT's own network are not used for forecasting and used only very occasionally for forecast validation purposes, because of their poor degree of availability (1/3hr, for only a handful of sites) and lack of accessibility to the forecasters. The lack of training and dedicated tools strongly limits the ability of METTELSAT to exploit global models to their full potential, for example to generate longer-term forecasts.

[4] Forecast availability statistics based on the months of June and July 2024.

Element 6: Warning and advisory services

6.1. Warning and alert service cover 24/7.

METTELSAT does not currently have a warning and alert service. Their 24-hr forecasts include some limited impact-based assessments for precipitation (METTELSAT, 2024). But as of July 2024, METTELSAT does neither have the technical capacity nor the means to generate and disseminate warnings and alerts. METTELSAT also does not operate 24/7.

6.2. Hydrometeorological hazards for which forecasting and warning capacity is available and whether feedback and lessons learned are included to improve warnings.

METTELSAT does not currently have a mechanism to process feedback, perform formal assessments or implement lessons-learned regarding the warnings included in their 24-hr forecasts.

6.3. Common alerting procedures in place based on impact-based services and scenarios taking hazard, exposure and vulnerability information into account and with registered alerting authorities.

No alerting procedures are established.

Summary score, recommendations, and comments for Element 6

1 – METTELSAT currently produces some (very limited) impact-based forecasts, with impacts related solely to precipitation. There are no alerting procedures in place, and no established, operational collaborations with relevant governmental and/or regional stakeholders. In-situ (manual) observations are also not available to the forecasters in real-time. Although it is currently not used for that purpose, the access of METTELSAT to the MESSIR-NEO software at its headquarters could possibly allow to improve this situation, while also facilitating the processing of complex datasets and enabling the generation of a wider range of natural hazard alerts.

Element 7: Contribution to Climate Services

7.1. Where relevant, contribution to climate services according to the established capacity for the provision of climate services.

The climatology division of METTELSAT constructs (on a monthly basis) 3-month seasonal forecasts by means of the Climate Predictability Tool (CPT; https://iri.columbia.edu/our-expertise/climate/tools/cpt/). The quality of these seasonal forecasts is likely to be affected by the scarcity of observational data in the DRC, at a level that however remains to be clarified.

The use of the METTELSAT seasonal forecasts by stakeholders remains very limited. As mentioned under Point 1.1, the national framework to aid in the decision-making process for questions related to meteorological and climatological issues in the DRC (created in 2019) has yet to become operational. Furthermore, an operational interface with the Ministry for the Environment (that is responsible for handling all matters related to the mitigation of the impacts of climate-change) still needs to be established.

Summary score, recommendations, and comments for Element 7

1 – METTELSAT has a limited capacity to provide climate services to its stakeholders. It produces 3-month seasonal forecasts, but the model output statistics (MOS) are not being assessed. The extent to which the ingestion of observational data could help improve/refine these forecasts is therefore unknown at this time. A mechanism, tool or system that allows climate services users to interact with METTELSAT, for example to ensure co-production and tailoring of services for decision support and feedback, remains to be established.

Element 8: Contribution to hydrology

8.1. Where relevant, standard products such as quantitative precipitation estimation and forecasts are produced on a routine basis according to the requirements of the hydrological community.

METTELSAT incorporates the National Hydrological Service of the DRC. However, it does not currently provide the hydrological community of the DRC with dedicated precipitation estimations and forecasts. As part of the Hydromet project, a series of hydrological stations and pluviometers were deployed throughout two specific river basins (N'Djili river in Kinshasa, and Kalamu river in Boma – Kongo Central), with the intention for METTELSAT to be able to generate riverine flood alerts. This objective has not yet been achieved. As of July 2024, the dedicated & detailed hydrological models for these two river basins have not yet been set up, data transfer between the stations and the METTELSAT headquarters has not been established, and the network has not been calibrated. Since their installation, several stations have also been vandalized or experienced technical failures.

8.2. SOPs in place to formalize the relation between Met Service and Hydrology Agency, showing evidence that the whole value chain is addressed.

N/A

8.3. Data sharing agreements (between local and national agencies, and across international borders as required) on hydrological data in place or under development.

METTELSAT has signed a series of partnership agreements with key hydrological stakeholders, but these have never been implemented in practice. Agreements dedicated to the matter of data sharing also remain to be established.

8.4 Joint projects/initiatives with hydrological community designed to build hydrometeorological cooperation.

In addition to the Hydromet project, METTELSAT is also involved in at least 3 other hydrological development projects that are in the planning phase (National Agricultural Development Program, Oubangui watershed management, CREWS Central Africa) with distinct financing partners (World Bank, African Development Bank, CREWS). METTELSAT does not have any joint project/initiatives solely with national partners. In fact, the lack of financial/technical means that has prevented METTELSAT from deploying/maintaining a hydrological network throughout the country has led other governmental agencies to deploy their own networks (e.g., for maritime and fluvial navigation, or agricultural purposes).

Summary score, recommendations, and comments for Element 8

1 – METTELSAT is the National Hydrological Service of the DRC. However, in the absence of a suitable nation-wide hydrological network, some of the METTELSAT stakeholders have been deploying their own observing network (e.g., the Fluvial Navigation Agency). METTELSAT currently lacks the means to assemble national hydrological forecasts and predictions, let alone regional ones. The Hydromet project aimed at deploying observing stations and dedicated hydrological models for two river basins in the vicinity of Kinshasa. As of July 2024, however, the relevant models are not operational, and several observing stations are no longer operational, with most unable to transfer their data to the METTELSAT headquarters.

Element 9: Product dissemination and outreach

9.1. Channels used for user-centred communication and ability to support those channels (for example, does the NMHS operate its own television, video or audio production facilities? Does it effectively use cutting-edge techniques?).

METTELSAT forecasts are distributed via WhatsApp and an email mailing list. The METTELSAT website set up as part of the Hydromet project is no longer operational as of July 2024 due to a lack of funds to cover the hosting costs, following the end of the project. The METTELSAT communication department can interact with newspapers, for example to share specific project news. These interactions, however, are centred around Kinshasa, and the reach of METTELSAT to media in the provinces remains essentially inexistant.

9.2. Education and awareness initiatives in place.

No initiatives in the areas of education and awareness were identified as of July 2024.

9.3. Special measures in place to reach marginalized communities and indigenous people.

No special measures to reach marginalized communities and indigenous people were identified as of July 2024.

Summary score, recommendations, and comments for Element 9

1 – Although it does have a communication department, the ability of METTELSAT to communicate with the general population remains very limited, in particular to disseminate its products (i.e. forecasts and warnings). The geographical characteristics of the DRC evidently render this task particularly challenging, with numerous isolated communities, several distinct languages, and generally inadequate communication infrastructures in the provinces.

Element 10: Use and national value of products and services

10.1. Formalized platform to engage with users in order to co-design improved services.

No formalized platform to engage with users was identified as of July 2024.

10.2. Independent user satisfaction surveys are conducted, and the results used to inform service improvement.

No user satisfaction surveys are being conducted by METTELSAT as of July 2024.

10.3. Quality management processes that satisfy key user needs and support continuous improvement.

No established quality management processes were identified as of July 2024. A quality management process for aeronautical services was intended to be set up as part of the Hydromet project, but it yet remains to be formally implemented.

Summary score, recommendations, and comments for Element 10

1 – METTELSAT currently does not engage with its users and stakeholders. This is in large driven by the general lack of services provided to its stakeholders in the first place. The World Bank conducted a detailed evaluation of the social and economic benefits associated to a strengthening of METTELSAT, as part of the Hydromet project (World Bank, 2023 & 2024). This evaluation underscores the crucial importance for METTELSAT to secure a suitable operational budget, if the expected social and economic benefits are to be realized.

Annex 1 Consultations (including experts and stakeholder consultations)

2024-01-12: Exchange with Jean-Baptiste Migraine, WMO, with regards to the CREWS project in the DRC.

2024-05-27 to 2024-06-14: Visit of F.P.A. Vogt (MeteoSwiss) to the DRC:
- 2024-05-29: Visit of the METTELSAT "Binza" station.
- 2024-05-30: Visits of the METTELSAT "N'Djili" and "N'Dolo" stations.
- 2024-05-31: Visit of the METTELSAT forecast room in Kinshasa.
- 2024-06-03: Visit of the METTELSAT "Mbandaka" station, incl. the regional headquarters.
- 2024-06-04: Visit of the METTELSAT "Kananga" station.
- 2024-06-05: Q&A session on this CHD document with METTELSAT division heads.
- 2024-06-06: Visit of the METTELSAT "Gemena" station.
- 2024-06-10: Discussion with the INERA – Institut National d'Etude et Recherche Agronomiques.
- 2024-06-11: Discussion with Kylie Tendon, Médecins Sans Frontières.

Annex 2 Urgent needs reported

The METTELSAT most urgent needs can be summarized as follows:

- Budget: METTELSAT needs to be given the financial means to perform its assigned tasks (operational costs incl. communication, human resources incl. formation, pensions); the professional relationship between METTELSAT and the Airways Authority (RVA) needs to be normalized; the question of the redistribution of aeronautical taxes in the DRC needs to be resolved.

- Human resources: a careful assessment of the staffing situation at the different METTELSAT sites is urgently needed (incl. the identification of paid & unpaid staff, the individual presence rate, the effective roles & responsibilities, retirements); all the active personnel need to be provided with adequate training to operate/exploit a modern meteorological network; METTELSAT needs to become an employer that attracts and retains highly-qualified staff.

- Management: a 5/10-year strategy for METTELSAT needs to be assembled, implemented, and assessed at regular intervals, ideally together with international partners; METTELSAT needs to deploy sound processes to ensure the best possible use of financial investments towards project goals; the METTELSAT Board of Directors needs to meet at regular interval.

- Observational infrastructure: a stepwise plan needs to be drawn to meet GBON requirements: first for existing stations, before planning a network extension to meet surface and upper-air GBON requirements at the national level; existing/future automated systems need to be integrated in the operational chain of METTELSAT (incl. maintenance, exploitation, data collection, data storage).

- Real estate: further losses need to be prevented; existing structures need maintenance and refurbishment; reliable and efficient communication channels need to be established between stations and the METTELSAT headquarters in Kinshasa.

Annex 3 Information supplied through WMO

N/A

Annex 4 List of materials used

Cabinet du Président de la République, *Décret no 12/040 portant statuts d'un établissement public dénommé « Agence Nationale de Météorologie et de Télédétection par Satellite », en sigle Mettelsat*, Journal Officiel de la République Démocratique du Congo, 2012.

Cabinet du Président de la République, *Décret no 22/19 du 13 mai 2022 portant création, organisation et fonctionnement du cadre national des services climatologiques en République Démocratique du Congo*, Journal Officiel de la République Démocratique du Congo, 2022.

Google Earth Pro, *Satellite images over Binza-Kinshasa, evolution between 2004 and 2024 illustrating the (ongoing) loss of real estate suffered by METTELSAT*.

Kalubi T. D., *RDC: le bulletin météo de la Mettelsat reprend 12 ans après*, Ouragan, 2022.

METTELSAT, *La stratégie de la METTELSAT*, 2021.

METTELSAT, *Bulletin météorologique quotidien no091 élaboré le jeudi 27/06/2024*, 2024.

METTELSAT, *Plan directeur de réseau d'observation météorologique synoptique de surface de la METTELSAT*, 2024b.

Ministère de l'environnement, *Programme d'Action National d'Adaptation au Changement Climatique de la République Démocratique du Congo*, 2006.

Ngiambukulu O.-D., *Enfin, la Mettelsat publie son premier bulletin météorologique*, Forum des As, 2022.

UNDP, *Human Development Report 2023/2024*, United Nations Development Programme, New York, 2024.

World Bank*, Implementation completion and results report on the grants in the amount of US$5,329,452 from the Global Environment Facility's Least Developed Countries Fund (TFA4390) and in the amount of US$2,700,000 from the Global Facility For Disaster Reduction and Recovery (TFA4389) to the Democratic Republic of Congo for a Strengthening Hydro-Meteorological and Climate Services Project (P159217)*, Report No. ICR00006208, 2023.

World Bank, *Strengthening hydrometeorological and climatological services (P159217) -- Economic Analysis + List of project Deliverables*, 2024.

WMO, *DR Congo project Progress Monitoring*, Mission Report, 2023.

WMO, *Project completion mission – Strengthen Meteorological, Hydrological and Climate Services (Hydromet P159217)*, Mission Report, 2023b.

WMO, *GBON National Gap Analysis – Democratic Republic of Congo*, 2024 (included as Annex 5).

June 21, 2024

Systematic Observations Financing Facility

GBON National Gap Analysis

Democratic Republic of Congo

Systematic Observations
Financing Facility

Weather and climate data for resilience

Screening of the National Gap Analysis (NGA)
of the Democratic Republic of Congo

WMO Technical Authority screens the GBON National Gap Analysis to ensure consistency with the GBON regulations and provides feedback for revisions as needed. *The screening of the NGA is conducted according to the SOFF Operational Guidance Handbook, version: 04.07.2023 and the provisions in Decision 5.7 of the SOFF Steering Committee.*

Following iterations with peer advisor and beneficiary country, WMO Technical Authority confirms that the National Gap Analysis is consistent with GBON regulations. While the WMO GBON Global Gap Analysis identified the need for 59 surface stations and 10 upper air station over land to meet the GBON horizontal requirement, the **WMO Technical Authority confirms the NGA results which indicate the need for 68 surface land stations and 12 upper station based on specific national circumstances.**

Date: 18 November 2024

Signature:

Albert Fischer

Director, WIGOS Branch, Infrastructure Department, WMO

GBON National Gap Analysis
Democratic Republic of Congo

ISO 3166-1 Alpha-3: COD

Beneficiary Country Focal Point and Institution	Joseph Itela Y'llondo - *meteordcongo@gmail.com* Agence Nationale de Météorologie et de Télédétection par Satellite **METTELSAT**
Peer Advisor Focal Point and Institution	Frédéric P.A. Vogt - *frederic.vogt@meteoswiss.ch* Alexander Haefele - *alexander.haefele@meteoswiss.ch* Fabio Fontana - *fabio.fontana@meteoswiss.ch* Federal Office of Meteorology and Climatology **MeteoSwiss**

Table of contents

Disclaimer

All information in this document is valid as of June 21, 2024, unless otherwise specified. In particular, statements related to the information content of OSCAR/Surface are prone to become obsolete as updates/corrections are implemented.

Several regions of the Democratic Republic of Congo, namely the ones in the East (North-Kivu and Ituri), are subject to severe security threats and active, long-lasting armed conflicts. The GBON target and associated station list discussed in this report should therefore be considered a long-term goal. The deployment/exploitation of any given GBON station is subject to METTELSAT and its personnel gaining stable, safe, long-term access to the station site.

This file was compiled using the 2024/10/22 - v1.0 soffreport LaTeX class.

1 Country information from the baseline GBON Global Gap Analysis

The country-specific results of the WMO baseline global GBON gap analysis for the Democratic Republic of Congo, assembled in June 2023 as part of the SOFF "first batch" evaluations and communicated to MeteoSwiss by the SOFF Secretariat on January 4, 2024, is presented in Table 1.

Table 1: GBON Global Gap Analysis for the Democratic Republic of Congo.

GBON Requirements	Target	Reporting to req.	Gap to improve	Gap new	Gap total
Surface land stations Horizontal res.: 200 km	59	0	35	24	59
Upper-air stations on land Horizontal res.: 500 km	10	0	0	10	10

2 Analysis of existing GBON stations and their status against GBON requirements

As of January 2024, 59 COD stations were formally assigned to GBON in OSCAR/Surface. The information associated to these entries should however be treated with caution, as a non-negligible part of it is outdated and/or erroneous. Two types of problems affect the reliability of the data. On the one hand, several sets of coordinates have a wrong latitude sign. This also seems to have caused one station (KASONGO) to be registered twice, with two homonymous sites located symmetrically above and below the equator (WIGOS-IDs 0-180-0-64264 vs 0-20000-64264). Station coordinates in general are specified with an accuracy of $\sim$10 km on OSCAR/Surface, which hinders the ability to understand the immediate surrounding of stations from satellite images. On the other hand, and perhaps more importantly, 27 of these stations are formally no longer in activity[1] according to the following definition:

Definition 1. A station is deemed to be **in activity** if it is visited on a very regular basis by METTELSAT personnel as part of their operational duties.

For these 27 stations, the status of the equipment on the ground, the continued meteorological suitability of the station site, and limitations in terms of physical access are all uncertain (METTELSAT, 2023).

As of March 2024, METTELSAT reported that 33 COD stations were in activity throughout the country (see Fig. 1 and Tables 2 & 3). Among these, 32 are assigned to GBON on OSCAR/Surface[2]. The 33 stations in activity all host manual systems that are used for assembling synoptic reports. Automatic weather stations from (at least) two different manufacturers have been deployed on (at least) 20 of these stations in recent years, as part of several development programs and collaborations (including CREWS). Out of these 20 automatic weather stations, at least 6 are no longer operational as of November 7, 2024.

The only COD GBON data to reach the GTS and contribute to the station statistics reported on WDQMS are acquired using the manual systems. Over the month of December 2023, the WDQMS indicates partial data availability of less than 30% for 15 stations[3] (see Table 3). No data was received from any other GBON station over that month, which is representative of the state of the network in 2023 as a whole.

Several organisations have deployed parallel networks of meteorological stations in the Democratic Republic of Congo over the years. These organizations include, for example, the National Agronomical Research Institute (INERA - *Institut*

[1] COD stations that are assigned to GBON on OSCAR/Surface but no longer in activity as of November 7, 2024 are: BAFWASENDE 0-20000-0-64056, BASANKUSU 0-20000-0-64008, BASOKO 0-20000-0-64018, BONDO 0-20000-0-64021, BUMBA 0-20000-0-64016, DILOLO 0-20000-0-64301, KABINDA 0-180-0-64005, KAHEMBA 0-180-0-64223, KALIMA 0-20000-0-64156, KAMINABASE 0-20000-0-64315, KASONGO 0-20000-0-64264, KASONGO 0-180-0-64264, KENGE 0-20000-0-64217, KITONA 0-20000-0-64203, LIBENGE 0-20000-0-64015, LUOZI 0-20000-0-64209, LUPUTA 0-20000-0-64248, LUSAMBO 0-20000-0-64246, MAMBASA 0-20000-0-64071, MITWABA 0-20000-0-64348, RUTSHURU 0-20000-0-64157, SANDOA 0-20000-0-64303, SHABUNDA 0-180-0-64165, UBUNDU 0-20000-0-64159, WALIKALE 0-20000-0-64170, WAMBA 0-180-0-64068, and WATSA 0-20000-0-64074

[2] The station of Beni in Nord-Kivu is the only METTELSAT operational station that had not yet been associated to GBON in OSCAR/Surface as of November 7, 2024. This station was set up as part of the so-called "Hydromet" project (World Bank, 2023).

[3] 13 stations transmit pressure measurements; 14 stations transmit temperature and relative humidity measurements; 15 stations transmit wind measurements

National pour l'Étude et la Recherche Agronomiques), and the MONUSCO[4]. None of these networks are sharing data internationally, and in fact never were intended to do so. They serve very specific purposes for the organizations that set them up, that are under no obligation to abide by GBON regulations (be it in terms of data quality or availability). These organizations will all strongly benefit from the outcome of SOFF investments in improving the METTELSAT network of meteorological stations. However, these alternate networks (whose current states are very comparable to the METTELSAT network, if not worse) cannot be taken into consideration when assessing the GBON compliance of the Democratic Republic of Congo at a national level.

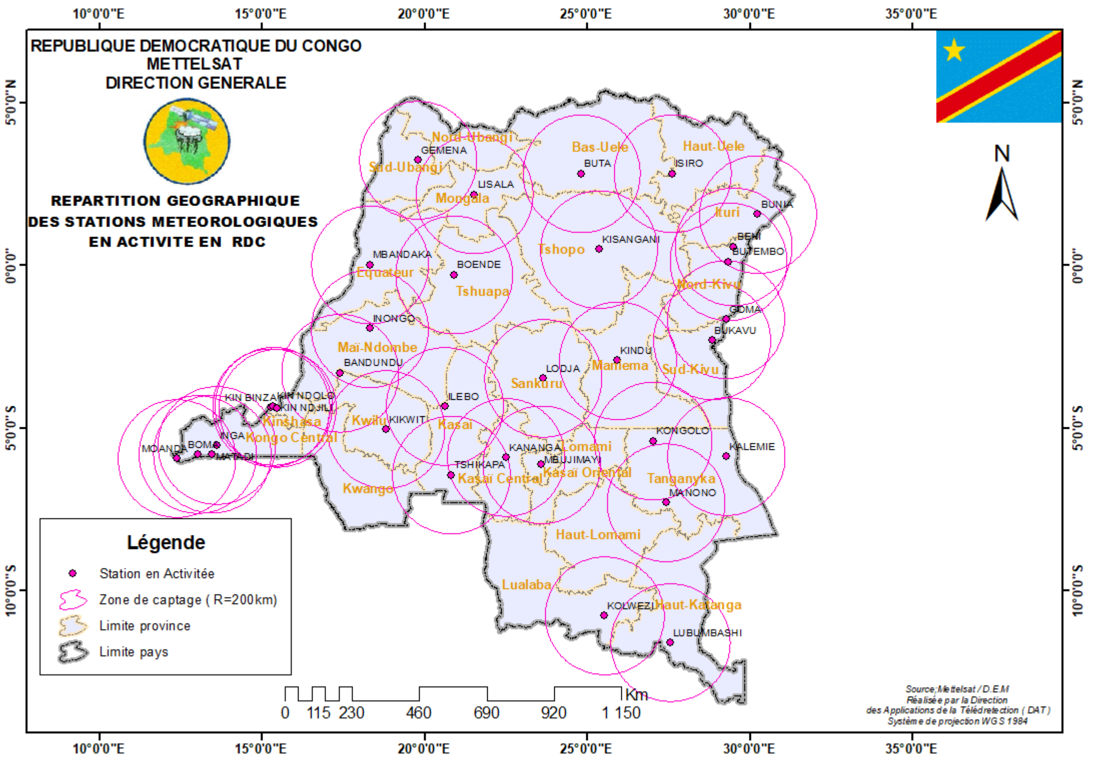


Figure 1: Map of the 33 METTELSAT surface (land) stations in activity (according to Definition 1) as of March 2024. Source: METTELSAT

[4]United Nations Organization Stabilization Mission in the Democratic Republic of the Congo
→ `https://peacekeeping.un.org/en/mission/monusco`

Table 2: Assessment of COD stations in activity per their operational status and network ownership. This list includes all the stations reported to be in activity (according to Definition 1) by METTELSAT as of November 7, 2024. It is not to be confused with the list of stations assigned to GBON on OSCAR/Surface.

GBON Requirements	Observation stations in activity (# of stations)			
	NMHS network		Third party network	
	Reporting to req.	To improve	Reporting to req.	To improve
Surface land stations Horizontal res.: 200 km Variables: SLP, T, H, W, P, SD	0	33	0	0
Upper-air stations on land Horizontal res.: 500 km Vertical res.: 100 m, $\geq$30 hPa Variables: T, H, W	0	0	0	0
Surface marine stations in EEZs Horizontal res.: 500 km Variables: SLP, SST	0	0	0	0
Upper-air stations in EEZs Horizontal res.: 1000 km Variables: T, H, W	0	0	0	0

Table 3: Assessment of characteristics for stations currently in activity. The reporting cycle is measured using WDQMS for the wind variables, and accounts for data transmission issues towards the GTS. These values are taken for weekdays, as the amount of observations drops on weekends. Various technical issues prevent COD automated weather stations from contributing data to the GTS.

Station name	Type	Owner	Funding source	GBON variable measured							Reporting cycle [obs/day]	GBON compliant ?
				SLP	T	H	W	P	SD	SST		
BANDUNDU	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
BENI	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
BOENDE	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼4	No
BOMA	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼2	No
BUKAVU	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
BUNIA	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
BUTA	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼2	No
BUTEMBO	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
GEMENA	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼1	No
GOMA	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼2	No
ILEBO	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼2	No
INGA	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
INONGO	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
ISIRO	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
KALEMIE	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼2	No
KANANGA	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼1	No
KIKWIT	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼2	No
KINDU	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
KINSHASA/BINZA	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼3	No
KINSHASA/N'DJILI	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼5	No
KINSHASA/N'DOLO	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼1	No
KISANGANI	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼2	No
KOLWEZI	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
KONGOLO	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
LISALA	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
LODJA	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
LUBUMBASHI	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼1	No
MANONO	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
MATADI	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
MBANDAKA	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
MBUJI-MAYI	surface	METTELSAT	METTELSAT	×	×	×	×	×			∼3	No
MOANDA	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No
TSHIKAPA	surface	METTELSAT	METTELSAT	×	×	×	×	×			0	No

3 Results of the GBON National Gap Analysis

We summarize in Table 4 the outcome of the GBON National Gap Analysis for the Democratic Republic of Congo. Each category will be discussed separately in Secs. 3.1 to 3.4. Given their geographical distribution, 5 (out of 33) stations that are in activity today are not recommended to be considered for GBON.

Table 4: Results of the GBON National Gap Analysis

GBON Requirements	Global GBON target	Approved national target	Reporting	Gap	
				To improve	New
Surface land stations Horizontal res.: 200 km Variables: SLP, T, H, W, P, SD Observing cycle: 1/1 h	59	68	0	28	40
Upper-air stations on land Horizontal res.: 500 km Vertical res.: 100 m, ≥30 hPa Variables: T, H, W Observing cycle: 2/24 h	10	12	0	0	12
Surface marine stations in EEZs Horizontal res.: 500 km Variables: SLP, SST Observing cycle: 1/1 h	1	1	0	0	1
Upper-air stations in EEZs Horizontal res.: 1000 km Variables: T, H, W Observing cycle: 2/24 h	0	0	0	0	0

3.1 Surface stations (land)

We present in Fig. 2 a network map of 68 COD surface (land) station sites that we find are sufficient to achieve GBON compliance at the country level (see Table 6 for details). Station sites are primarily selected from a list of 128 historical sites for meteorological observations in the Democratic Republic of Congo (see Appendix B for details), with the following exception:

- Yangambi, the inclusion of which is warranted on the basis of the strong synergy potential with the research activities of the National Agronomical Research Institute (INERA - *Institut National pour l'Étude et la Recherche Agronomique*) at that location (see e.g. Sibret et al., 2022; Kasongo Yakusu et al., 2023).

When selecting sites, preference is given to locations that are either in activity today, or are considered by METTELSAT to be best suited for rehabilitation (as of November 2023, based on site access, security and long-term viability; METTELSAT, 2023), with one exception:

- Monkoto, a very remote site where the headquarters of the Salonga National Park are located. Salonga National Park is a UNESCO World Heritage site, and the largest tropical rainforest reserve in Africa: a status which would very much warrant the inclusion of this area within the GBON network, given its importance for climate on a global scale.

The 20 sites hosting automated weather stations installed recently (be they still operational or not) are selected in priority. Additional sites are chosen to 1) decrease the network horizontal resolution ρ below the GBON threshold of 200 km (see Appendix A.2), and 2) maximize the network baseline influence area $A^*_{\rm inf}$ (see Definition 3 in Appendix A.1). The local population density, topography, and lightning frequency are also used to guide the selection of sites of interest for the GBON network (see Appendix C for the corresponding maps).

With a mean distance between (neighboring) stations $\rho = 213.1$ km (see Appendix A.2 for details), a 59-sites network (which corresponds to the baseline GBON target estimate, see Sec. 1) does not meet the GBON low-density horizontal resolution requirement of 200 km. One should note that this measurement does account for existing and proposed GBON sites in neighboring countries, including South Sudan, Uganda, Rwanda, Tanzania, and Zambia which are all SOFF beneficiary countries, as well as Angola, the Republic of Congo, and the Central African Republic. The addition of 9 stations (for a total of 68 surface stations) is sufficient to bring the network horizontal resolution down to $\rho = 199.2$ km.

We list in Table 5 these additional stations in the order they are added to the network, alongside the scientific motivation for their inclusion.

Table 5: List of 9 surface (land) stations required for COD to meet the low-density GBON requirements, in addition to the baseline set of 59 stations chosen to maximize the network baseline area of influence. Stations were chosen and added sequentially until the network horizontal resolution ρ decreased below 200 km.

Station name	Justification
LUPUTA	high population density
OPIENGE	complex topography, baseline area of influence
LUBAO	baseline area of influence
PANGA	baseline area of influence
FESHI	baseline area of influence
MONKOTO	baseline area of influence
KWAMOUTH	baseline area of influence, fluvial navigation
LUKOLEA	baseline area of influence, fluvial navigation
MUTSHATSHA	baseline area of influence

3.2 Upper-air stations (land)

A total of 7 sites used to host upper-air (land) stations (see Table 7 in Appendix B for details), but none remain in activity today. We present in Fig. 3 a network map of 12 upper-air (land) stations sufficient to meet the GBON horizontal resolution of $\rho_{\mathrm{GBON}} = 500$ km. Specifically, given the disposition of the country and the existing/planned GBON upper-air (land) stations in its immediate vicinity, we find that an additional 2 stations in addition to the baseline estimate (for a total of 12 stations) are sufficient to meet the low-density GBON requirements.

3.3 Surface stations (marine)

The size of the COD Exclusive Economic Zone (EEZ) in the South Atlantic Ocean could eventually warrant the installation of 1 GBON surface (marine) station for compliance purposes. There is, however, a strong potential for international synergies given the thickness of the EEZ (∼35 km). GBON compliance over the COD EEZ area could certainly be achieved by means of surface (marine) stations located in neighboring EEZs.

3.4 Upper-air stations (marine)

The size of the COD EEZ does not warrant the existence of an upper-air marine station for GBON compliance purposes.

3.5 Recommended surface, upper-air and marine stations to be designated to GBON

We present in Table 6 the list of stations recommended to become operational before being designated to GBON, in order for the Democratic Republic of Congo to meet the low-density GBON requirements. **We note that several of these stations are located in regions subject to severe security threats and active armed conflicts. This list should therefore be considered a long-term goal, with the actual deployment of a given station requiring that METTELSAT and its personnel gain stable, safe, long-term access to the station site.** This list is assembled based on the data available at the time of writing. The need to alter the suggestion of a specific site (in favor of a neighboring one) may arise over time, as the local geo-political, security, economical, and connectivity situation evolves.

Table 6: Recommended surface, upper-air and marine stations to become operational before being designated to GBON, in order for the Democratic Republic of Congo to meet the low-density GBON requirements. Station coordinates are approximate, with an accuracy of ∼10 km for the sites that are no longer in activity today.

	Province	Station name	Type	Latitude	Longitude	In activity ?
1	KINSHASA	KINSHASA/N'DJILI	Surface/Upper-air	-4.3868	+15.4482	yes
2	KONGO CENTRAL	MATADI	Surface	-5.7945	+13.4403	yes
3	KWILU	BANDUNDU	Surface	-3.3089	+17.3752	yes

Table 6: continued.

	Province	Station name	Type	Latitude	Longitude	In activity ?
4	KWILU	KIKWIT	Surface/Upper-air	-5.0394	+18.7840	yes
5	KWANGO	KENGE	Surface	-4.8376	+17.0294	no
6	KWANGO	FESHI	Surface	-6.1170	+18.1330	no
7	KWANGO	KASONGOLUNDA	Surface	-6.4830	+16.8170	no
8	KWANGO	KAHEMBA	Surface	-7.3330	+19.0000	no
9	MAINDOMBE	INONGO	Surface	-1.9456	+18.2856	yes
10	MAINDOMBE	OSHWE	Surface	-3.4170	+19.7500	no
11	MAINDOMBE	KWAMOUTH	Surface	-3.1830	+16.2330	no
12	EQUATEUR	MBANDAKA	Surface/Upper-air	+0.0214	+18.2911	yes
13	EQUATEUR	BASANKUSU	Surface	+1.2247	+19.7907	no
14	EQUATEUR	LUKOLELA	Surface	-1.0500	+17.2000	no
15	MONGALA	LISALA	Surface/Upper-air	+2.1761	+21.5037	yes
16	MONGALA	BUMBA	Surface	+2.1830	+22.5500	no
17	TSHUAPA	MONKOTO	Surface	-1.7437	+20.6848	no
18	TSHUAPA	DJOLU	Surface	+0.5500	+22.4500	no
19	TSHUAPA	BOENDE	Surface	-0.2865	+20.8796	yes
20	TSHUAPA	BOKUNGU	Surface	-0.6000	+22.3330	no
21	NORD UBANGI	GBADOLITE	Surface	+4.3000	+21.2000	no
22	SUD UBANGI	GEMENA	Surface	+3.2373	+19.7697	yes
23	BAS-UELE	BONDO	Surface	+3.8000	+23.0820	no
24	BAS-UELE	ANGO	Surface	+4.0170	+25.8670	no
25	BAS-UELE	BUTA	Surface/Upper-air	+2.8217	+24.7965	yes
26	HAUT-UELE	ISIRO	Surface	+2.8226	+27.5982	yes
27	HAUT-UELE	WATSA	Surface	+3.0670	+29.5000	no
28	TSHOPO	KISANGANI	Surface/Upper-air	+0.4904	+25.3327	yes
29	TSHOPO	YANGAMBI	Surface	+0.8198	+24.4562	no
30	TSHOPO	BAFWASENDE	Surface	+1.0830	+27.0130	no
31	TSHOPO	OPALA	Surface	-0.5830	+24.3500	no
32	TSHOPO	OPIENGE	Surface	+0.1670	+27.5000	no
33	TSHOPO	PANGA	Surface	+1.8330	+26.4170	no
34	ITURI	BUNIA	Surface/Upper-air	+1.5686	+30.2210	yes
35	NORD-KIVU	GOMA	Surface	-1.6604	+29.2395	yes
36	NORD-KIVU	BUTEMBO	Surface	+0.1157	+29.3135	yes
37	NORD-KIVU	BENI	Surface	+0.5758	+29.4713	yes
38	NORD-KIVU	WALIKALE	Surface	-1.4170	+28.0330	no
39	SUD-KIVU	BUKAVU	Surface/Upper-air	-2.3119	+28.8089	yes
40	SUD-KIVU	SHABUNDA	Surface	-2.6830	+27.3800	no
41	SUD-KIVU	FIZI	Surface	-4.3000	+28.9500	no
42	MANIEMA	KINDU	Surface	-2.9271	+25.9140	yes
43	MANIEMA	LUBUTU	Surface	-0.7500	+26.5670	no
44	MANIEMA	KIBOMBO	Surface	-3.9170	+25.9330	no
45	MANIEMA	LUBAO	Surface	-5.3000	+25.7500	no
46	SANKURU	LODJA	Surface	-3.4660	+23.6180	yes
47	SANKURU	LOMELA	Surface	-2.3000	+23.2830	no
48	SANKURU	LUSAMBO	Surface	-4.9649	+23.3825	no

Table 6: continued.

	Province	Station name	Type	Latitude	Longitude	In activity ?
49	KASAI CENTRAL	KANANGA	Surface/Upper-air	-5.8990	+22.4778	yes
50	KASAI	TSHIKAPA	Surface	-6.4394	+20.7930	yes
51	KASAI	DEKESE	Surface	-3.4670	+21.4170	no
52	KASAI	ILEBO	Surface	-4.3287	+20.5919	yes
53	KASAI ORIENTAL	MBUJI-MAYI	Surface	-6.1245	+23.5711	yes
54	LOMAMI	LUPUTA	Surface	-7.1330	+23.7330	no
55	HAUT LOMAMI	KABONGO	Surface	-7.3330	+25.5830	no
56	HAUT LOMAMI	KAMINAVILLE	Surface	-8.7330	+25.0000	no
57	TANGANIKA	KALEMIE	Surface	-5.8721	+29.2481	yes
58	TANGANIKA	KONGOLO	Surface	-5.3948	+26.9978	yes
59	TANGANIKA	MANONO	Surface/Upper-air	-7.2901	+27.3951	yes
60	TANGANIKA	MOBA	Surface	-7.0500	+29.7120	no
61	LUALABA	KOLWEZI	Surface	-10.7653	+25.5092	yes
62	LUALABA	KAPANGA	Surface/Upper-air	-8.3500	+22.6500	no
63	LUALABA	MUTSHATSHA	Surface	-10.8170	+24.4640	no
64	LUALABA	SANDOA	Surface	-9.6330	+22.8500	no
65	LUALABA	DILOLO	Surface	-10.6830	+22.3330	no
66	HAUT KATANGA	LUBUMBASHI	Surface/Upper-air	-11.5894	+27.5298	yes
67	HAUT KATANGA	KASENGA	Surface	-10.3830	+28.6170	no
68	HAUT KATANGA	MITWABA	Surface	-8.6000	+27.3330	no

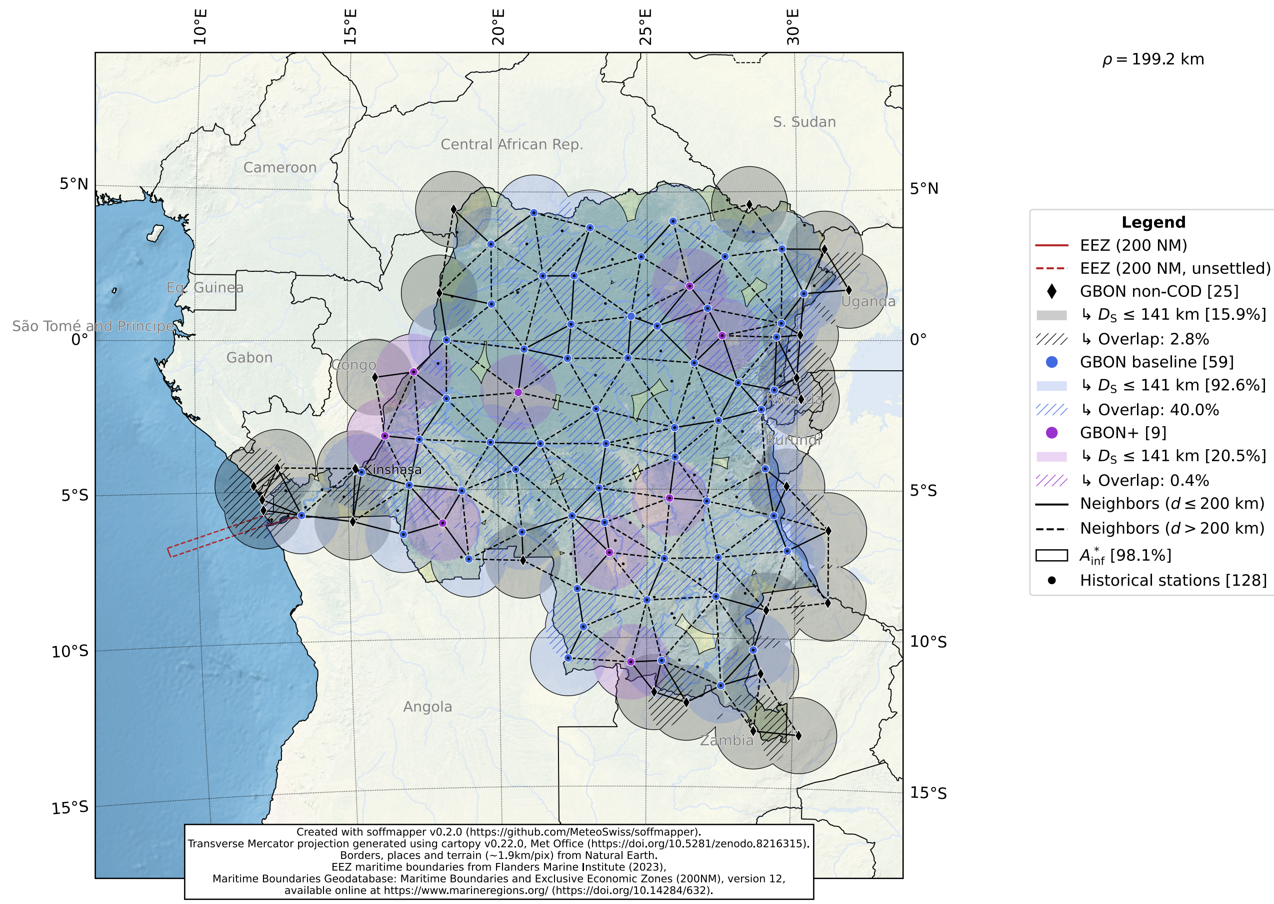


Figure 2: Network of 68 surface (land) stations (blue and purple discs) sufficient for the Democratic Republic of Congo to meet the low-density GBON horizontal resolution requirement. The corresponding network horizontal resolution is $\rho = 199.2$ km. This measurement accounts for existing/proposed GBON stations in neighboring countries (black diamonds). Purple discs mark the 9 stations added on top of the baseline 59 sites (blue discs) to have $\rho < \rho_{\text{GBON}} = 200$ km. Neighboring stations (as defined in Appendix A.2) are connected by straight black lines (continuous, if the stations are closer than 200 km from one another, dashed otherwise). A disk with a radius $R^*_{\text{inf}} = 141$ km (see Appendix A.1) is drawn around each station. The resulting network baseline area of influence is $A^*_{\text{inf}} = 98.1\%$ of the country area.

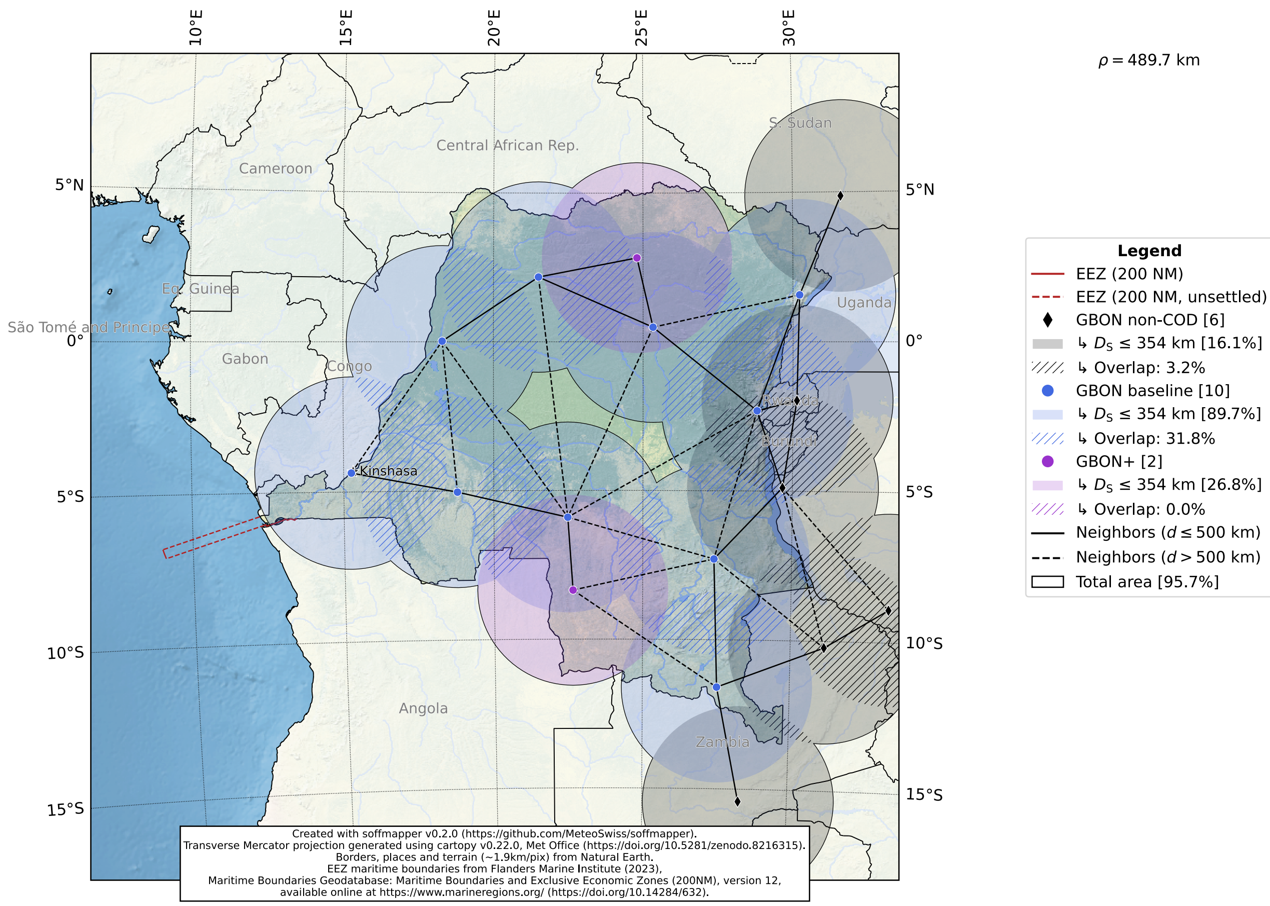


Figure 3: Same as Fig. 2, but for the 12 upper-air (land) stations (blue and purple discs) sufficient for the Democratic Republic of Congo to meet the low-density GBON horizontal resolution requirement. The corresponding network horizontal resolution is $\rho = 489.7$ km, with a baseline area of influence of $A^*_{\mathrm{inf}} = 95.7\%$ derived using a station radius of influence of $R^*_{\mathrm{inf}} = 354$ km (see Appendix A.1).

4 Report completion signatures

Peer Advisor signature
Beneficiary Country signature
WMO Technical Authority screening signature

References

Gallier, J. (2011). Dirichlet–Voronoi Diagrams and Delaunay Triangulations. In Gallier, J., editor, *Geometric Methods and Applications: For Computer Science and Engineering*, Texts in Applied Mathematics, pages 301–319. Springer, New York, NY.

Kasongo Yakusu, E., Van Acker, J., Van de Vyver, H., Bourland, N., Mbifo Ndiapo, J., Besango Likwela, T., Lokonda Wa Kipifo, M., Mbuya Kankolongo, A., Van den Bulcke, J., Beeckman, H., Bauters, M., Boeckx, P., Verbeeck, H., Jacobsen, K., Demarée, G., Gellens-Meulenberghs, F., and Hubau, W. (2023). Ground-based climate data show evidence of warming and intensification of the seasonal rainfall cycle during the 1960–2020 period in Yangambi, central Congo Basin. *Climatic Change*, 176(10):142.

METTELSAT (2023). Plan directeur de réseau d'observation météorologique synoptique de surface de la METTELSAT. Technical report, Agence Nationale de Météorlogie et de télédétection par satellite "METTELSAT", Ministère des transports, voies des communications et désenclavement, République Démocratique du Congo.

Saalfeld, A. (1999). Delaunay Triangulations and Stereographic Projections. *Cartography and Geographic Information Science*, 26(4):289–296.

Sibret, T., Bauters, M., Bulonza, E., Lefevre, L., Cerutti, P. O., Lokonda, M., Mbifo, J., Michel, B., Verbeeck, H., and Boeckx, P. (2022). CongoFlux – The First Eddy Covariance Flux Tower in the Congo Basin. *Frontiers in Soil Science*, 2.

WMO (2021). Manual on the WMO Integrated Global Observing System - Annex VIII to the WMO Technical Regulations. Technical Report WMO-No. 1160, World Meteorological Organization, Geneva.

WMO (2023). Guide to the Global Basic Observing Network. Technical Report EC-76/Doc. 3.2(3), Annex, World Meteorological Organization, Geneva.

World Bank (2023). Democratic Republic of Congo - Strengthening Hydro-Meteorological and Climate Services Project. Implementation Completion and Results Report ICR6208, World Bank.

4 Report completion signatures

Peer Advisor signature

Payerne, Switzerland, 24 June 2024

Beneficiary Country signature

Prs/RDC Directeur Général de METTELSAT.
24 Juin 2024.

WMO Technical Authority screening signature

References

Gallier, J. (2011). Dirichlet–Voronoi Diagrams and Delaunay Triangulations. In Gallier, J., editor, *Geometric Methods and Applications: For Computer Science and Engineering*, Texts in Applied Mathematics, pages 301–319. Springer, New York, NY.

Kasongo Yakusu, E., Van Acker, J., Van de Vyver, H., Bourland, N., Mbifo Ndiapo, J., Besango Likwela, T., Lokonda Wa Kipifo, M., Mbuya Kankolongo, A., Van den Bulcke, J., Beeckman, H., Bauters, M., Boeckx, P., Verbeeck, H., Jacobsen, K., Demarée, G., Gellens-Meulenberghs, F., and Hubau, W. (2023). Ground-based climate data show evidence of warming and intensification of the seasonal rainfall cycle during the 1960–2020 period in Yangambi, central Congo Basin. *Climatic Change*, 176(10):142.

METTELSAT (2023). Plan directeur de réseau d'observation météorologique synoptique de surface de la METTELSAT. Technical report, Agence Nationale de Météorlogie et de télédétection par satellite "METTELSAT", Ministère des transports, voies des communications et désenclavement, République Démocratique du Congo.

Saalfeld, A. (1999). Delaunay Triangulations and Stereographic Projections. *Cartography and Geographic Information Science*, 26(4):289–296.

Sibret, T., Bauters, M., Bulonza, E., Lefevre, L., Cerutti, P. O., Lokonda, M., Mbifo, J., Michel, B., Verbeeck, H., and Boeckx, P. (2022). CongoFlux – The First Eddy Covariance Flux Tower in the Congo Basin. *Frontiers in Soil Science*, 2.

WMO (2021). Manual on the WMO Integrated Global Observing System - Annex VIII to the WMO Technical Regulations. Technical Report WMO-No. 1160, World Meteorological Organization, Geneva.

WMO (2023). Guide to the Global Basic Observing Network. Technical Report EC-76/Doc. 3.2(3), Annex, World Meteorological Organization, Geneva.

World Bank (2023). Democratic Republic of Congo - Strengthening Hydro-Meteorological and Climate Services Project. Implementation Completion and Results Report ICR6208, World Bank.

Appendix A Assessment metrics for national networks of GBON stations

A.1 Network baseline area of influence A^*_{inf}

Let us begin by introducing the concept of a radius of influence for GBON stations:

Definition 2. The **radius of influence** R_{inf} of a given GBON station corresponds to the maximum horizontal distance between the station and any geographical location situated closer to this station than any other GBON station.

As per this definition, the radius of influence of a given GBON station is solely determined by the spatial distribution of the network stations. It evidently does not mean that the measurements of a given GBON station will be *representative* of all the locations situated up to the radius of influence. The representativity of specific measurements is dependant on the geophysical variable under consideration, and can be heavily influenced by numerous variables: for example, by the local terrain composition and topography.

We shall refer to ρ_{GBON} as the *GBON horizontal resolution*, as defined in WMO (2021) (article 3.2.2.7, note 4, p.52; see also WMO, 2023). As per these regulations, GBON-designated stations should not be located more than ρ_{GBON} apart, on average.

A so-called *baseline* GBON gap analysis has been performed by the WMO for all SOFF beneficiary countries (see Sec. 1). This analysis relies on the assumption that GBON stations are being distributed on a regular, orthogonal, two-dimensional grid[5] (see Fig. 4). Under this specific premise, all stations have the same **baseline radius of influence** of:

$$R^*_{\text{inf}} = \frac{\sqrt{2}}{2}\rho_{\text{GBON}} \tag{1}$$

The standard GBON horizontal resolutions of 200 km and 500 km (for surface and upper-air stations on land, respectively) translate into baseline radii of influence of $R^*_{\text{inf},200} \approx 141$ km and $R^*_{\text{inf},500} \approx 354$ km.

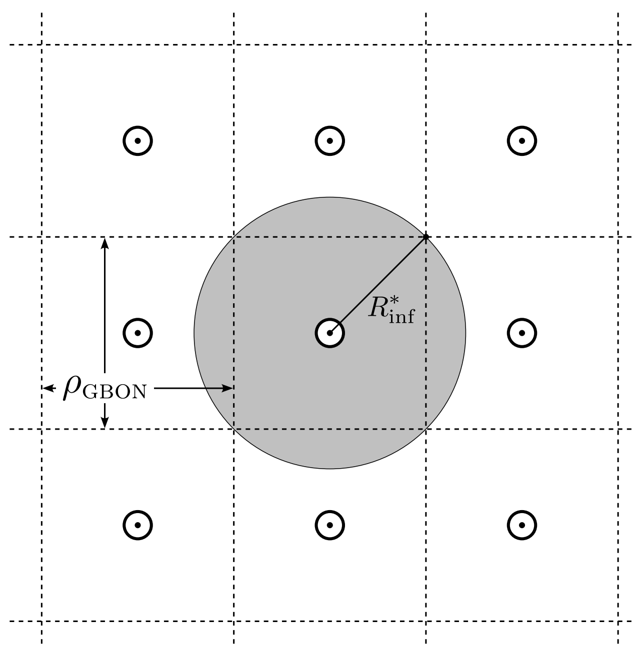


Figure 4: Schematic network of GBON stations (dot-circled symbols) distributed on a regular, orthogonal, two-dimensional grid. This theoretical setup is used to derive baseline GBON gaps by the WMO. Each grid cell has a size of $\rho_{\text{GBON}} \times \rho_{\text{GBON}}$. With this distribution of stations, any point in the plane is located at most R^*_{inf} away from any GBON station.

[5] The WMO Technical Authority confirmed, on 2024-01-08, that the baseline GBON gap is obtained by dividing the surface area of a given country by $(\rho_{\text{GBON}} \times \rho_{\text{GBON}})$.

In our analysis, we rely on this concept of baseline radius of influence R^*_{inf} to derive the network baseline area of influence:

Definition 3. The **baseline area of influence** A^*_{inf} of a network of GBON stations corresponds to all the zones situated within a distance of at most R^*_{inf} from any GBON station in the network.

We express A^*_{inf} as a percentage of the country surface area when considering national networks. Given Eq. 1, one can see that the WMO (indirectly) requires a value of $A^*_{\text{inf}} = 100\,\%$ when performing a baseline GBON gap analysis.

This metric provides a useful indication of what surface area *might* be located too far from any GBON station in a given network. It must be stressed, however, that achieving $A^*_{\text{inf}} = 100\,\%$ is not a formal GBON requirement per se. The meteorological importance of spatial gaps in the baseline surface coverage of a given GBON network must be evaluated against the actual measurement representativity of the nearest GBON stations (given the local population density, terrain topgraphy, regional climatology, etc ...).

A.2 Network horizontal resolution ρ

The GBON compliance criteria are not defined in terms of the network baseline area of influence A^*_{inf}, but rather in terms of its horizontal resolution ρ:

Definition 4. The **horizontal resolution** ρ of a network of meteorological stations, in the GBON sense, is equal to the average separation between (neighbor) stations (WMO, 2021, 2023).

The main difficulty in measuring ρ for a real network of irregularly-distributed stations lies in the identification of *neighbors*. Fortunately, the Voronoï tessellation technique provides us with a natural, logical, and straightforward means to do so.

Performing a Voronoï tessellation of stations consists is subdividing the surface of the Earth into a series of cells. Each cell, one per station, contains all the locations situated closest to a given station than any other. We present in Fig. 5 an illustration of this method on the plane, but the same concept can be applied on the Earth geoid. The cell boundaries are comprised of sites located at the same distance from two near-by stations. Voronoï cells thus provide for a natural definition of stations in geometric proximity from one another:

Definition 5. Two meteorological stations within a given network are deemed to be **in geometric proximity** from one another if their respective Voronoï cells share a common vertex.

Pairs of stations in geometric proximity can be identified directly by means of a Delaunay triangulation, which corresponds to the dual graph of the Voronoï tessellation (see Fig. 5). Doing so directly on the Earth geoid is feasible, but one can also exploit the characteristics of Stereographic projections to transpose the problem in two-dimensions (see e.g. Saalfeld, 1999; Gallier, 2011), which is easier to handle from a computational perspective. The use of a Stereographic projection (to convert stations longitudes and latitudes) is paramount to ensure that the list of station pairs found to be in geometric proximity in the (projected) plane is exactly applicable to the Earth geoid.

The use of Delaunay triangulation in a geographically-limited area of the Earth (e.g. for a network of GBON stations at a national level) implies the assembly of a convex hull. Some stations might then be deemed to be in geometric proximity from one another (despite being located several hundreds of kilometers apart) on the basis that their Voronoï cells are in contact (sometimes literally) on the other side of the Earth. In practice, one would hardly consider such stations to be *neighbors*, which we define as follows instead:

Definition 6. Two meteorological stations are **neighbors** from one another if they are in geometric proximity from one another according to Definition 5 and:

1. no other station in the network is located closer than them to the mid-point location of the Great Circle arc connecting them, or
2. they are located within a polygon formed entirely by network stations that are neighbors from one another.

Thinking in terms of Voronoï tessellation, the first sub-clause implies that the Great Circle arc connecting two neighbor stations must only cross their own two Voronoï cells, and none other. The second sub-clause ensures that this selection criteria is only used to cull Delaunay vertices in the outer regions of the network (see Fig. 5).

Having identified pairs of neighbor stations throughout a given network, it is then straightforward to compile the list of associated horizontal separations (measured along Great Circles on the Earth), and compute the network horizontal resolution ρ as their average. A network of GBON stations would then be formally compliant with the GBON regulations if $\rho \leq \rho_{\text{GBON}}$.

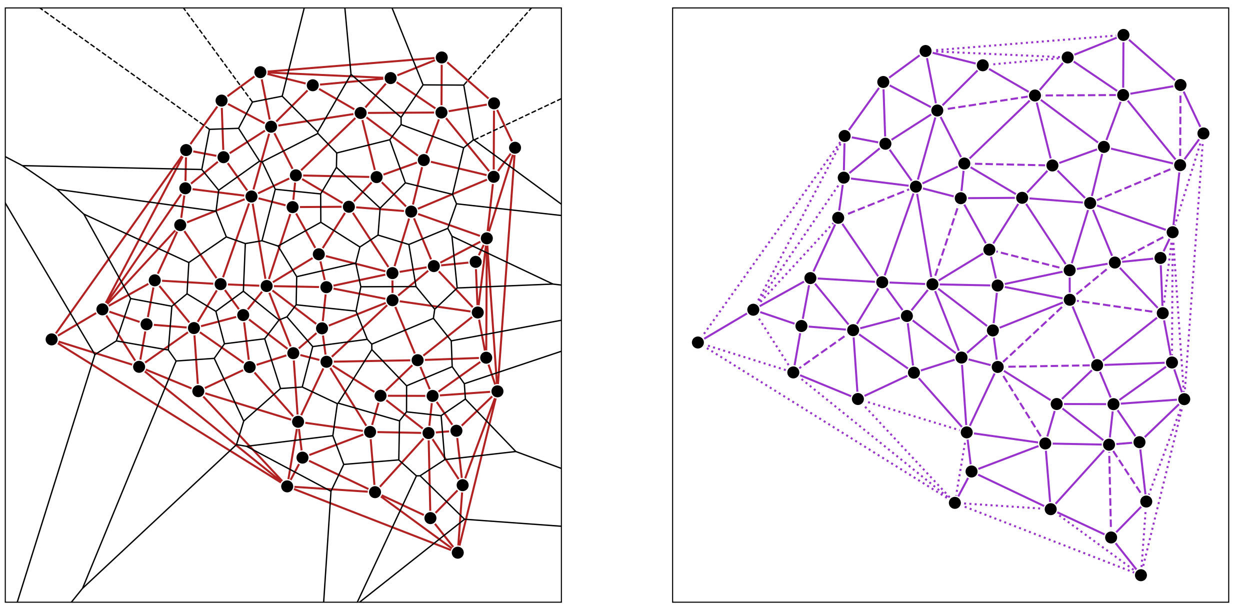


Figure 5: Left: illustration of the Voronoï tessellation (black lines) in the two-dimensional plane, for a network of 59 stations (black points). Voronoï cells provide for a natural means to identify sites in geometric proximity. All sites in geometric proximity from one another are connected by red lines, which are identified by means of Delaunay triangulation. Right: sites in geometric proximity but that are not *neighbors* according to Definition 6 are connected by dotted lines. All other connections indicate neighbor sites. Dashed connections indicate cases for which both sub-clauses 1 and 2 of Definition 6 are true.

Appendix B List of historical COD meteorological measurement sites

We present in Table 7 the list of historical meteorological measurement sites in the Democratic Republic of Congo, according to METTELSAT (2023).

Table 7: Historical COD meteorological stations and their status as of November 7, 2024. Station coordinates approximate, with an accuracy of ∼10 km for the sites that are not in activity.

	Province	Station name	Type (historical)	Latitude	Longitude	In activity ?
1	KINSHASA	KINSHASA/N'DJILI	Surface	-4.3868	+15.4482	yes
2	KINSHASA	KINSHASA/N'DOLO	Surface	-4.3255	+15.3262	yes
3	KINSHASA	KINSHASA/BINZA	Surface/Upper-air	-4.3700	+15.2555	yes
4	KONGO CENTRAL	MATADI	Surface	-5.7945	+13.4403	yes
5	KONGO CENTRAL	MBANZANGUNGU	Surface	-5.2000	+14.8500	no
6	KONGO CENTRAL	INGA	Surface	-5.5285	+13.5770	yes
7	KONGO CENTRAL	KITONA	Surface	-5.9170	+12.4500	no
8	KONGO CENTRAL	BOMA	Surface	-5.8064	+12.9970	yes
9	KONGO CENTRAL	MOANDA	Surface	-5.9315	+12.3529	yes
10	KONGO CENTRAL	TSHELA	Surface	-4.9670	+12.9330	no
11	KONGO CENTRAL	LUOZI	Surface	-4.9500	+14.1330	no
12	KWILU	BANDUNDU	Surface	-3.3089	+17.3752	yes
13	KWILU	KIKWIT	Surface	-5.0394	+18.7840	yes
14	KWILU	GUNGU	Surface	-5.7500	+19.4830	no
15	KWANGO	KENGE	Surface	-4.8376	+17.0294	no
16	KWANGO	FESHI	Surface	-6.1170	+18.1330	no
17	KWANGO	KASONGOLUNDA	Surface	-6.4830	+16.8170	no
18	KWANGO	KAHEMBA	Surface	-7.3330	+19.0000	no
19	KWANGO	PANZI	Surface	-7.2670	+18.7500	no
20	KWANGO	POPOKABAKA	Surface	-5.6830	+16.6330	no
21	MAINDOMBE	INONGO	Surface	-1.9456	+18.2856	yes
22	MAINDOMBE	OSHWE	Surface	-3.4170	+19.7500	no
23	MAINDOMBE	KWAMOUTH	Surface	-3.1830	+16.2330	no
24	EQUATEUR	MBANDAKA	Surface/Upper-air	+0.0214	+18.2911	yes
25	EQUATEUR	BASANKUSU	Surface	+1.2247	+19.7907	no
26	EQUATEUR	BIKORO	Surface	-0.7670	+18.0120	no
27	EQUATEUR	LUKOLELA	Surface	-1.0500	+17.2000	no
28	EQUATEUR	BOMONGO	Surface	+1.4830	+18.4830	no
29	MONGALA	LISALA	Surface	+2.1761	+21.5037	yes
30	MONGALA	BUMBA	Surface	+2.1830	+22.5500	no
31	MONGALA	MONKOTO	Surface	+1.6170	+20.6670	no
32	TSHUAPA	DJOLU	Surface	+0.5500	+22.4500	no
33	TSHUAPA	BOENDE	Surface	-0.2865	+20.8796	yes
34	TSHUAPA	BOKUNGU	Surface	-0.6000	+22.3330	no
35	NORD UBANGI	GBADOLITE	Surface	+4.3000	+21.2000	no
36	NORD UBANGI	ABOUMOMBAZI	Surface	+3.6950	+22.1500	no
37	NORD UBANGI	BUSINGA	Surface	+3.2500	+20.9670	no
38	SUD UBANGI	LIBENGE	Surface	+3.6330	+18.6330	no
39	SUD UBANGI	GEMENA	Surface	+3.2373	+19.7697	yes
40	BAS-UELE	BONDO	Surface	+3.8000	+23.0820	no

Table 7: continued.

	Province	Station name	Type (historical)	Latitude	Longitude	In activity ?
41	BAS-UELE	AKETI	Surface	+2.7330	+23.8330	no
42	BAS-UELE	ANGO	Surface	+4.0170	+25.8670	no
43	BAS-UELE	TITULE	Surface	+3.2500	+25.5300	no
44	BAS-UELE	BUTA	Surface	+2.8217	+24.7965	yes
45	BAS-UELE	POKO	Surface	+3.1500	+26.8330	no
46	HAUT-UELE	NIANGARA	Surface	+3.7000	+27.9000	no
47	HAUT-UELE	DORUMA	Surface	+4.7170	+27.6910	no
48	HAUT-UELE	DUNGU	Surface	+3.6500	+28.5500	no
49	HAUT-UELE	ABA	Surface	+3.8600	+30.2550	no
50	HAUT-UELE	ISIRO	Surface	+2.8226	+27.5982	yes
51	HAUT-UELE	WAMBA	Surface	+2.1500	+28.0000	no
52	HAUT-UELE	WATSA	Surface	+3.0670	+29.5000	no
53	TSHOPO	KISANGANI	Surface/Upper-air	+0.4904	+25.3327	yes
54	TSHOPO	IKELA	Surface	-1.1670	+23.2670	no
55	TSHOPO	BASOKO	Surface	+1.2500	+23.6000	no
56	TSHOPO	BANALIA	Surface	+1.5330	+25.0330	no
57	TSHOPO	ISANGI	Surface	+0.7500	+24.7500	no
58	TSHOPO	BAFWASENDE	Surface	+1.0830	+27.0130	no
59	TSHOPO	LOWA	Surface	-1.3670	+25.8170	no
60	TSHOPO	OPALA	Surface	-0.5830	+24.3500	no
61	TSHOPO	UBUNDU	Surface	-0.3500	+25.4500	no
62	TSHOPO	OPIENGE	Surface	+0.1670	+27.5000	no
63	TSHOPO	PANGA	Surface	+1.8330	+26.4170	no
64	ITURI	BUNIA	Surface/Upper-air	+1.5686	+30.2210	yes
65	ITURI	MAMBASA	Surface	+1.3670	+29.0670	no
66	ITURI	DJUGU	Surface	+1.8330	+30.5670	no
67	ITURI	MAHAGI	Surface	+2.3000	+30.9830	no
68	ITURI	ARU	Surface	+2.8670	+30.8330	no
69	ITURI	ALAMBI	Surface	+2.8670	+30.8330	no
70	NORD-KIVU	GOMA	Surface	-1.6604	+29.2395	yes
71	NORD-KIVU	RUTSHURU	Surface	-1.1830	+29.4500	no
72	NORD-KIVU	BUTEMBO	Surface	+0.1157	+29.3135	yes
73	NORD-KIVU	MUTWANGA	Surface	-0.3330	+29.7330	no
74	NORD-KIVU	BENI	Surface	+0.5758	+29.4713	yes
75	NORD-KIVU	WALIKALE	Surface	-1.4170	+28.0330	no
76	SUD-KIVU	BUKAVU	Surface/Upper-air	-2.3119	+28.8089	yes
77	SUD-KIVU	SHABUNDA	Surface	-2.6830	+27.3800	no
78	SUD-KIVU	KAMITUGA	Surface	-3.0500	+28.1830	no
79	SUD-KIVU	KALOLE	Surface	-3.6330	+27.3330	no
80	SUD-KIVU	FIZI	Surface	-4.3000	+28.9500	no
81	MANIEMA	KINDU	Surface	-2.9271	+25.9140	yes
82	MANIEMA	LUBUTU	Surface	-0.7500	+26.5670	no
83	MANIEMA	PUNIA	Surface	-1.4500	+26.4000	no
84	MANIEMA	KALIMA	Surface	-2.6000	+26.5500	no
85	MANIEMA	KIBOMBO	Surface	-3.9170	+25.9330	no

Table 7: continued.

	Province	Station name	Type (historical)	Latitude	Longitude	In activity ?
86	MANIEMA	KABAMBARE	Surface	-4.6830	+27.6500	no
87	MANIEMA	KASONGO	Surface	-4.5170	+26.5830	no
88	MANIEMA	LUBAO	Surface	-5.3000	+25.7500	no
89	SANKURU	LODJA	Surface	-3.4660	+23.6180	yes
90	SANKURU	LOMELA	Surface	-2.3000	+23.2830	no
91	SANKURU	LUSAMBO	Surface	-4.9649	+23.3825	no
92	SANKURU	KATAKOKOMBE	Surface	-3.4500	+24.3500	no
93	SANKURU	LUBEFU	Surface	-4.7170	+24.4330	no
94	KASAI CENTRAL	KANANGA	Surface/Upper-air	-5.8990	+22.4778	yes
95	KASAI CENTRAL	LUIZA	Surface	-7.1830	+22.4330	no
96	KASAI	TSHIKAPA	Surface	-6.4394	+20.7930	yes
97	KASAI	LWEBO	Surface	-5.3670	+21.3670	no
98	KASAI	DEKESE	Surface	-3.4670	+21.4170	no
99	KASAI	ILEBO	Surface	-4.3287	+20.5919	yes
100	KASAI ORIENTAL	MBUJI-MAYI	Surface	-6.1245	+23.5711	yes
101	LOMAMI	KABINDA	Surface	-6.1330	+24.4330	no
102	LOMAMI	NGANDAJIKA	Surface	-6.7330	+23.9330	no
103	LOMAMI	LUPUTA	Surface	-7.1330	+23.7330	no
104	HAUT LOMAMI	BUKAMA	Surface	-9.1830	+25.8500	no
105	HAUT LOMAMI	KANIAMA	Surface	-7.5170	+24.2000	no
106	HAUT LOMAMI	KABONGO	Surface	-7.3330	+25.5830	no
107	HAUT LOMAMI	KAMINAVILLE	Surface	-8.7330	+25.0000	no
108	HAUT LOMAMI	KAMINABASE	Surface	-8.6330	+25.2500	no
109	HAUT LOMAMI	MALEMBANKULU	Surface	-8.0170	+26.7830	no
110	TANGANIKA	KALEMIE	Surface	-5.8721	+29.2481	yes
111	TANGANIKA	KONGOLO	Surface	-5.3948	+26.9978	yes
112	TANGANIKA	NYUNZU	Surface	-5.2500	+28.0000	no
113	TANGANIKA	MANONO	Surface	-7.2901	+27.3951	yes
114	TANGANIKA	MOBA	Surface	-7.0500	+29.7120	no
115	TANGANIKA	KABALO	Surface	-6.0330	+26.8670	no
116	LUALABA	KOLWEZI	Surface	-10.7653	+25.5092	yes
117	LUALABA	KAPANGA	Surface	-8.3500	+22.6500	no
118	LUALABA	LUBUDI	Surface	-9.3330	+25.9330	no
119	LUALABA	MUTSHATSHA	Surface	-10.8170	+24.4640	no
120	LUALABA	SANDOA	Surface	-9.6330	+22.8500	no
121	LUALABA	TENKE	Surface	-10.7500	+26.1170	no
122	LUALABA	DILOLO	Surface	-10.6830	+22.3330	no
123	HAUT KATANGA	LUBUMBASHI	Surface/Upper-air	-11.5894	+27.5298	yes
124	HAUT KATANGA	PWETO	Surface	-8.4830	+28.3170	no
125	HAUT KATANGA	PANDA	Surface	-10.9670	+26.7330	no
126	HAUT KATANGA	KASENGA	Surface	-10.3830	+28.6170	no
127	HAUT KATANGA	SAKANIA	Surface	-12.7500	+28.5670	no
128	HAUT KATANGA	MITWABA	Surface	-8.6000	+27.3330	no

Appendix C Supplementary network maps

This Appendix contains a series of additional maps used to support the derivation of the GBON target for the Democratic Republic of Congo. These are comprised of the proposed surface (land) stations (sufficient to meet GBON compliance at a national level) overlaid on maps of:

- Fig. 6: the population density,
- Fig. 7: the terrain elevation, and
- Fig. 8: the lightning frequency.

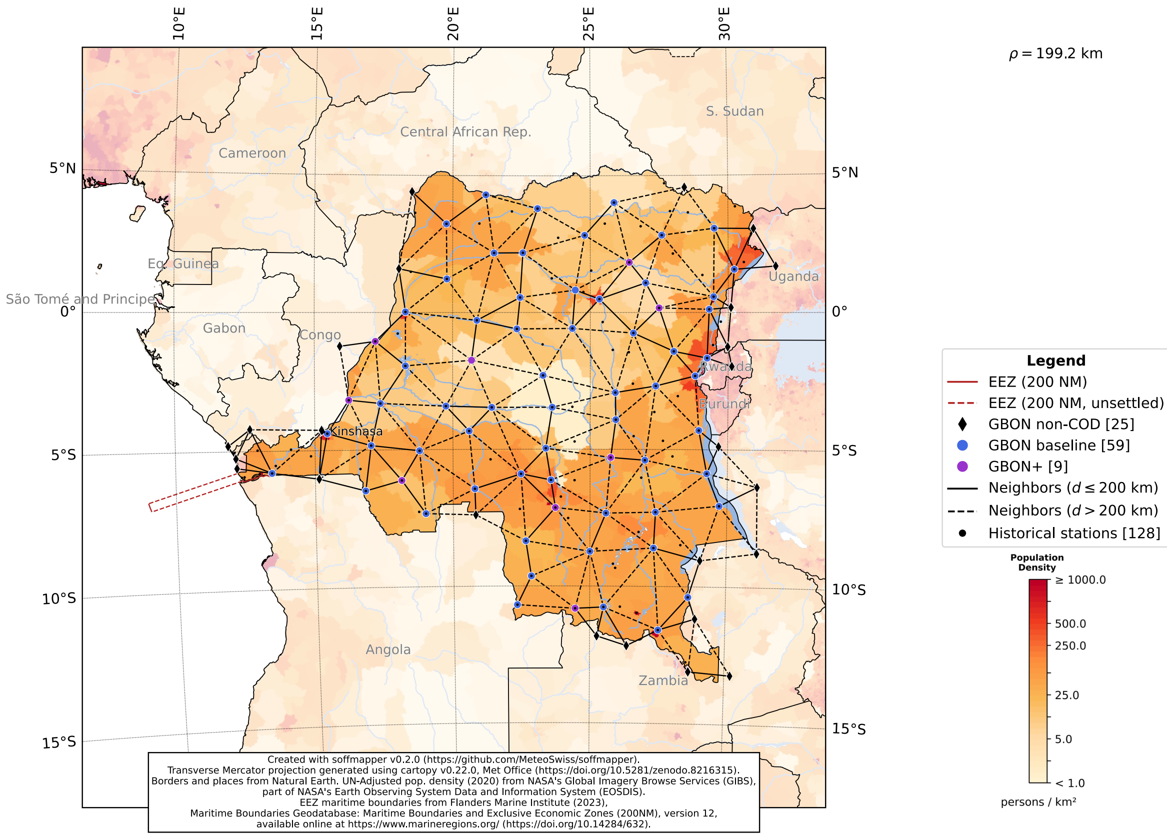


Figure 6: Same as Fig. 2, but with the proposed network overlaid over the COD population density.

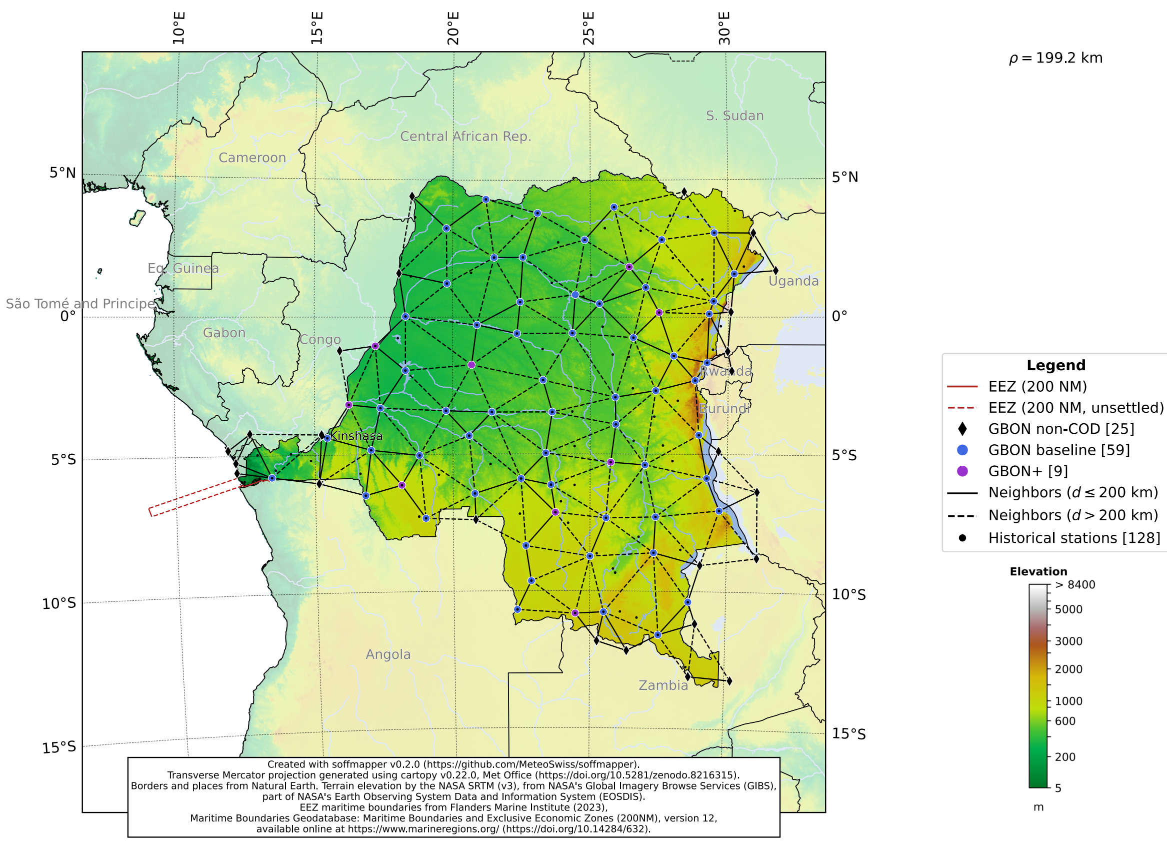


Figure 7: Same as Fig. 2, but with the proposed network overlaid over the COD elevation map.

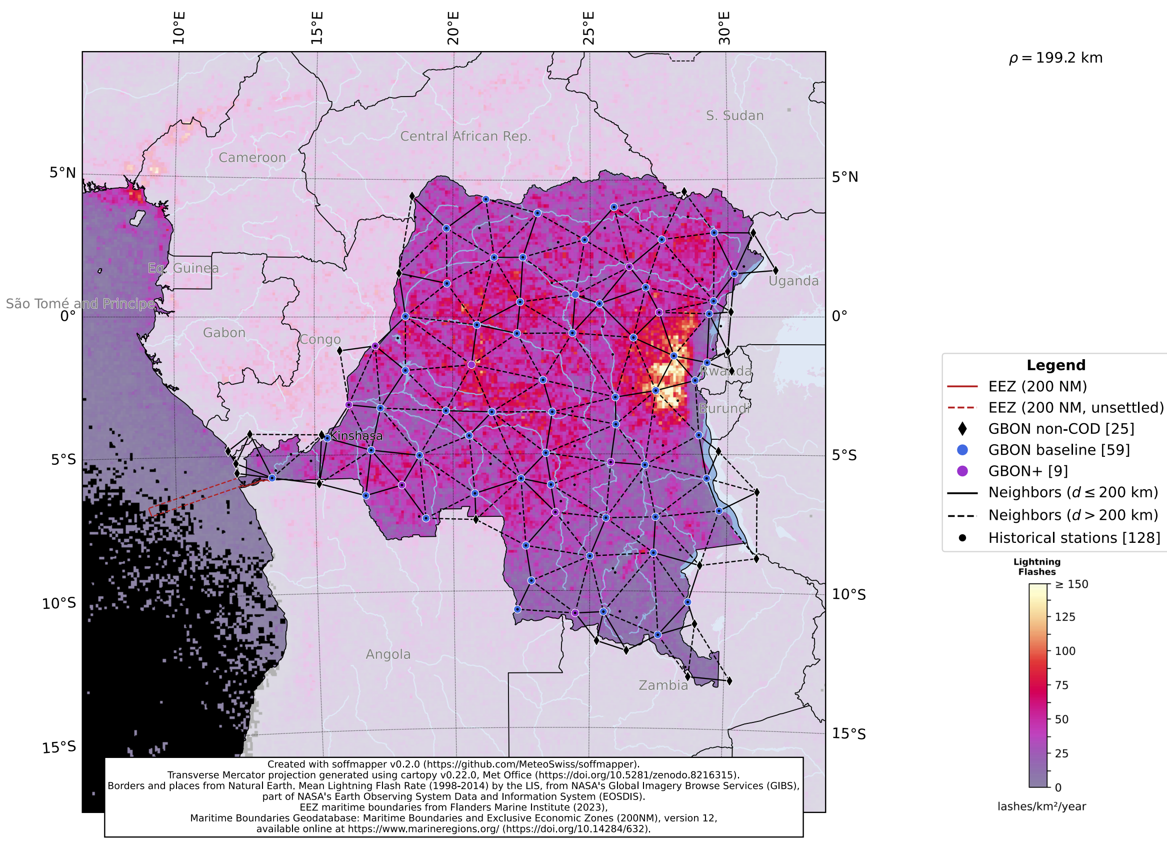


Figure 8: Same as Fig. 2, but with the proposed network overlaid over the COD lightning frequency map. The hotspot to the East of the country has the highest-recorded lightning frequency on Earth.