# Enabling climate services through mobile network operator data

## Opportunities for CML rainfall data to strengthen rural climate resilience

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# Contents

## Acronyms and abbreviations

| | |
|---|---|
| **AI** | Artificial intelligence |
| **API** | Application programming interface |
| **AWS** | Automated weather station |
| **CML** | Commercial microwave link |
| **CSP** | Climate service provider |
| **CSR** | Corporate social responsibility |
| **DDAS** | Data-driven agricultural advisory service |
| **ESA** | European Space Agency |
| **EUMETSAT** | European Organisation for the Exploitation of Meteorological Satellites |
| **GPM** | Global precipitation measurement |
| **GWE** | Global weather enterprise |
| **IoT** | Internet of things |
| **IVR** | Interactive voice response |
| **IWMI** | International Water Management Institute |
| **JAXA** | Japan Aeronautical Exploration Agency |
| **KNMI** | Royal Netherlands Meteorological Institute |
| **LMIC** | Low- and middle-income country |
| **MNO** | Mobile network operator |
| **NASA** | National Aeronautics and Space Administration |
| **NMHS** | National meteorological and hydrological service |
| **NWC SAF** | Nowcasting Satellite Application Facility |
| **SDGs** | Sustainable Development Goals |
| **sFTP** | Secure file transfer protocol |
| **SLMET** | Sri Lankan Department of Meteorology |
| **SMS** | Short message service |
| **SNMP** | Simple network management protocol |
| **TU Delft** | Delft University of Technology |
| **UAV** | Unmanned aerial vehicle |
| **USSD** | Unstructured supplementary service data |
| **VAS** | Value-added services |
| **WMO** | World Meteorological Institute |
| **WUR** | Wageningen University and Research |

# Executive summary

**Climate change has made weather patterns harder to predict, and extreme events like droughts and floods more frequent and severe.**

In this changing climate, accurate and localised weather forecasts are vital decision-making tools and crucial to build the resilience of local communities.

While reliable and localised weather information is urgently needed, weather observation data in low- and middle-income countries (LMICs) is scarce and of poor quality, limiting the value of existing weather services. In Africa, for example, weather station density is eight times lower than the World Meteorological Institute's (WMO) minimum recommended level.

Worldwide, a growing number of mobile network operators (MNOs) have been working with third parties (e.g. academic institutions and weather and technology companies) to provide high-resolution rainfall observations using commercial microwave link (CML) data from their mobile backhaul network. As one of the organisations active in this space, the GSMA AgriTech programme has been building evidence that CML data is an accurate and reliable source of rainfall observation, and exploring use cases and business models that support the development of sustainable CML rainfall data services.

This report captures what we have learned from our work with MNOs, researchers and climate service providers (CSPs), and synthesises content from previous GSMA publications to outline the technical, operational and commercial opportunity to use CML rainfall data to develop innovative weather and climate services.

# Key messages and recommendations

Realising the opportunity of CML data to drive innovation in vital climate services depends on the collaboration of key stakeholders, including MNOs, climate service providers, and donors. The key messages and recommendations in this report address each of these stakeholder groups.

## MNOs

Wireless backhaul, specifically CMLs, is an untapped opportunity for rainfall observation.

Rainfall data can be provided from wireless backhaul using open-source software for data access and rainfall retrieval.

MNOs can benefit from CML rainfall services by monetising the data, entering new sectors and improving corporate social responsibility.

Flood early warnings are considered the most viable entry point for CML rainfall data services due to the added value of CML data and high ROI.

## Climate service providers

CML rainfall data provides a unique source of quantitative precipitation estimates with an extensive coverage area, high spatiotemporal resolution and real-time availability.

Accessibility is the main barrier to using CML rainfall observations and can be improved through the development and/or vetting of software to access CML data.

A strong business case for MNOs to provide CML rainfall observations is crucial for long-term collaborations.

## Donors

Future funding is urged to focus on the operationalisation and commercialisation of CML rainfall data sources, namely:

Optimising rainfall retrieval algorithms to provide consistent results across CML networks and climatological zones.

Researching the integration of rainfall data from CMLs and geostationary satellites to provide a hybrid data source.

Supporting the identification and development of software to facilitate real-time access to CML data.

Supporting projects that use CML rainfall data to develop services with maximum potential for impact, such as rainfall nowcasting and flood early warnings.

Supporting initiatives to explore how public, private and academic organisations can collaborate to develop and provide commercially sustainable CML services.

# 1 Introduction

**The impacts of climate change are increasingly being felt, and disproportionately so in low- and middle-income countries (LMICs). Across Africa, for example, the climate has warmed more than the global average since pre-industrial times.**

This has contributed to an increased incidence of heat waves, extensive floods, tropical cyclones and prolonged droughts. In addition to causing considerable economic damage, the continent is also coping with the effects on food security.

An extended drought is affecting the lives of 58 million people in East Africa and internally displaced around 14 million people in Sub-Saharan Africa in 2021.[1] Asia is experiencing a similar increase in the intensity and frequency of extreme weather events, and the devastating floods in Pakistan[2] in 2022 are just one example.

In a changing climate, accurate and localised weather forecasts are a vital decision-making tool. Smallholder farmers who have access to timely rainfall forecasts for their area can make more informed production decisions throughout the growing season. Seasonal forecasts can help farmers make better choices about crop types and varieties and how to time land preparation and planting. Early warnings allow farmers to quickly adjust their agricultural activities and protect their crops, while predictions of local climate and agroecological changes can enable rural communities to identify future sources of livelihood. However, climate change has made weather patterns harder to predict, and extreme events like droughts and floods have become more frequent and severe. It is estimated that temperature rise has contributed to a 34% reduction in agricultural productivity in Africa since 1961.[3]

While reliable and localised weather information is urgently needed, weather observation data in LMICs is scarce and of poor quality, limiting the value of existing weather services. While national meteorological and hydrological agencies (NMHS) routinely produce weather and seasonal forecasts, these are sometimes hindered by poor infrastructure and lack of adequate weather station coverage. In Africa, for example, weather station density is eight times lower than the World Meteorological Institute's (WMO) minimum recommended level.[4] This lack of on-site measurement makes precipitation particularly difficult to project.

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[1] WMO. (2022). State of the Climate in Africa 2021.

[2] WMO. (16 September 2022). "Climate change likely increased intense rainfall in Pakistan: study".

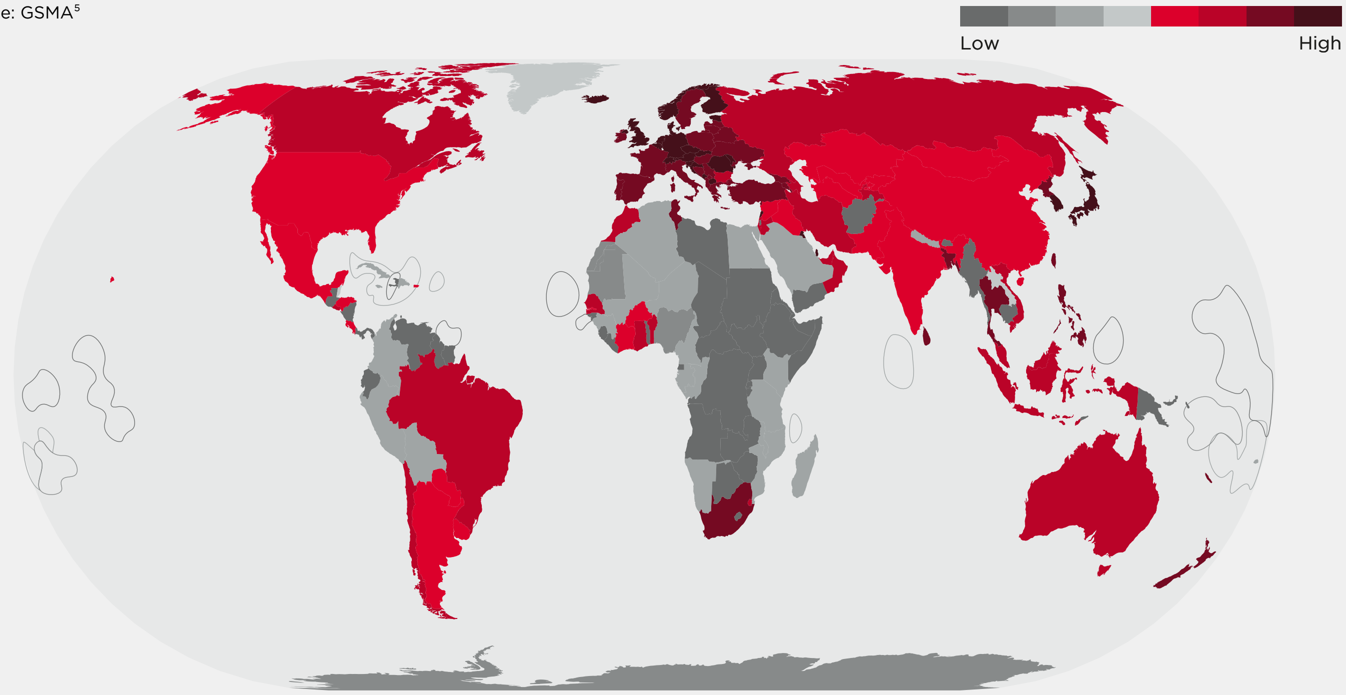
[3] WMO. (2022). State of the Climate in Africa 2021.

[4] World Bank. (2015). Creating an Atmosphere of Cooperation in Sub-Saharan Africa by Strengthening Weather, Climate and Hydrological Services.

**Figure 1**

## Density of surface weather observations

Source: GSMA[5]



Worldwide, a growing number of mobile network operators (MNOs) have been working with third parties (e.g. academic institutions and weather and technology companies) to provide rainfall observation data using data from their mobile networks. Mobile base stations are connected by backhaul networks that distribute data throughout the mobile network. This network is comprised of fibre optic cables or wireless connections using microwave radio frequencies. During rainfall events, these wireless commercial microwave links (CMLs) are disrupted, weakening signal strength at the receiving device. These reductions in signal strength can be used to calculate rainfall intensity, and data from CMLs can be used to create accurate rainfall maps, providing much needed ground-based weather measurements in places where dedicated weather observations are lacking.

Together with academic partners the Royal Netherlands Meteorological Institute (KNMI), Wageningen University and Research (WUR) and Delft University of Technology (TU Delft), and mobile industry partners MTN Nigeria, Dialog Axiata Sri Lanka[6] and Digicel Papua New Guinea,[7] the GSMA AgriTech programme has been building evidence that CML data is an accurate and reliable source of rainfall observation, and exploring use cases and business models that would support the development of sustainable CML rainfall data services.

This work has involved testing the technical feasibility of CML data for rainfall observation in tropical countries, validating the use of CML data for rainfall estimation in tropical countries by comparing it with ground-level data sources and partnering with agricultural and weather service providers to explore the added value of CML rainfall observations. These activities are part of the mission of the GSMA AgriTech programme to play a catalytic role in promoting the use of mobile Internet of Things (IoT) and big data, including CML, to strengthen the climate resilience of smallholder farmers.

This report captures what we have learned from our work with MNOs and weather and climate service providers (CSPs). It synthesises content from previous GSMA publications on this topic and outlines our current understanding of the opportunity to use CML rainfall estimation to develop climate services. This opportunity cuts across three areas:

- Technical – the contribution of CML data to the weather observation landscape
- Operational – the resources required to develop CML rainfall data services and
- Commercial – the added value of CML rainfall data for climate services

This research will inform MNOs, the primary audience of this report, of the opportunity to engage with CML rainfall data. The report will also help CSPs understand the opportunity to work with CML data and make recommendations to donors on which CML-related activities would have the greatest impact.

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[5] Adapted from: Systematic Observations Financing Facility. (2020). The gaps in the Global Basic Observations Network (GBON).

[6] GSMA. (2019). Rainfall monitoring through mobile technology in Sri Lanka.

[7] GSMA. (2022). Exploring opportunities for climate services in Papua New Guinea with Digicel.

# 1.1
# Methodology

The findings of this report are based on a combination of primary and secondary research. Semi-structured interviews were conducted with several stakeholder groups, including MNOs, mobile network hardware vendors, academic and research institutes, agritech companies and weather and climate service providers. Primary research was triangulated and corroborated with internal and external secondary sources, both qualitative and quantitative. Internal sources include an extensive library of GSMA reports, toolkits and market assessments. External sources include industry-recognised publications, such as by the World Bank, the WMO and academic literature on the use of CML data for rainfall observation.

Chapter 2 provides a brief overview of rainfall data sources in LMICs before discussing the principles and effectiveness of approaches using CML data for rainfall observation. It draws on published academic studies, as well as unpublished research outputs from the GSMA's CML engagements.

Chapter 3 approaches CML rainfall observation from a more practical perspective, outlining the conditions that make a mobile network conducive to CML rainfall observation, before outlining the practical steps involved in developing CML rainfall data services.

Chapter 4 discusses the services that CML rainfall observations are most likely to support, including service creation steps, the added value of CML rainfall data and the business models typically used to provide these services.

Finally, Chapter 5 provides key messages and recommendations for MNOs, CSPs and donors on the potential of CML rainfall estimation and next steps in the sustainable provision of this valuable but untapped source of data.

**BOX 1**

## GSMA engagements on CML rainfall observation

This report also draws on the research and experience of GSMA-led projects with MNOs and technical partners to implement and validate the principles of rainfall observation from CML data. This work took place in Nigeria, Sri Lanka and Papua New Guinea. Partners across the three workstreams were WUR, KNMI and TU Delft. This consortium provided the intellectual resources to convert CML data into rainfall estimates and use ground-level data sources to assess the accuracy of the CML data.

The work in Nigeria and Sri Lanka, which started in 2019 and will run until 2023, was funded by the UK Foreign, Commonwealth & Development Office (FCDO). MNO partners were MTN Nigeria and Dialog Axiata Sri Lanka. In Sri Lanka, Spanish company Hyds worked to develop an online service providing CML rainfall data in near-real time.

The work in Papua New Guinea was funded by the Australia Department of Foreign Affairs and Trade (DFAT) and ran from 2020 to 2022. The MNO partner in Papua New Guinea was Digicel.

# 2 Technical: Using CML data for rainfall observation

**Existing mobile infrastructure presents a unique opportunity for real-time rainfall observation. Data generated from mobile backhaul – the connection between base stations and the mobile core – can be used opportunistically to observe rainfall. This chapter introduces the technical principles behind CML rainfall observation and reviews available evidence on the coverage, resolution and accuracy of CML rainfall observations. It then compares CML rainfall data with other rainfall data sources and explores how they can complement one another.**

To determine the potential for CML rainfall observation to fill gaps in weather observations and add value to weather and climate services, this section reviews the latest research and draws on experiences from GSMA AgriTech projects. Together, these outline the level of geographic coverage that CML rainfall observations can provide, and demonstrate the accuracy of CML rainfall observation using current approaches and the known limitations of these methods.

# 2.1

# CML rainfall data in the weather observation landscape

The landscape of weather observation in LMICs is typically characterised by sparse networks of ground-level weather stations, both automated and manual, and data from meteorological satellite missions. Functional weather radar is only found in a few countries and is hindered by the cost of purchase and maintenance. Table 1 provides an initial comparison of rainfall data sources commonly available in LMICs, which the following sections will cover in more detail.

**Table 1**

## Comparison of rainfall data sources

Source: GSMA

⬜ Very low 🟪 Low 🟥 Medium 🟫 High ⬛ Very high

| | Geostationary weather satellites | Global precipitation measurement (GPM) mission | Automated weather stations (AWS) | Commercial microwave links (CMLs) |
|---|---|---|---|---|
| **Coverage** | ⬛ Global | ⬛ Global | ⬜ Local/point source | 🟫 Regional |
| **Resolution** | 🟫 ≥3×3 km, 15 min | 🟪 10×10 km, 30 min | ⬜ Point measurement, 60 min | ⬛ ~2×2 km, ≤15 min |
| **Availability** | 🟫 Real time | 🟪 360 min delay | 🟫 Real time | 🟫 Real time |
| **Accuracy** | Low | Medium | Very high | High |
| **Accessibility** | 🟫 Free | 🟫 Free | 🟪 Accessible through NMHS | 🟪 Accessible through MNO |
| **Limitations** | Rainfall is measured very indirectly[8] | Low resolution and high latency; rainfall is measured relatively indirectly[9] | Provide only local observations, low density across LMICs | Limited coverage (correlated to population density), only accessible through MNOs |

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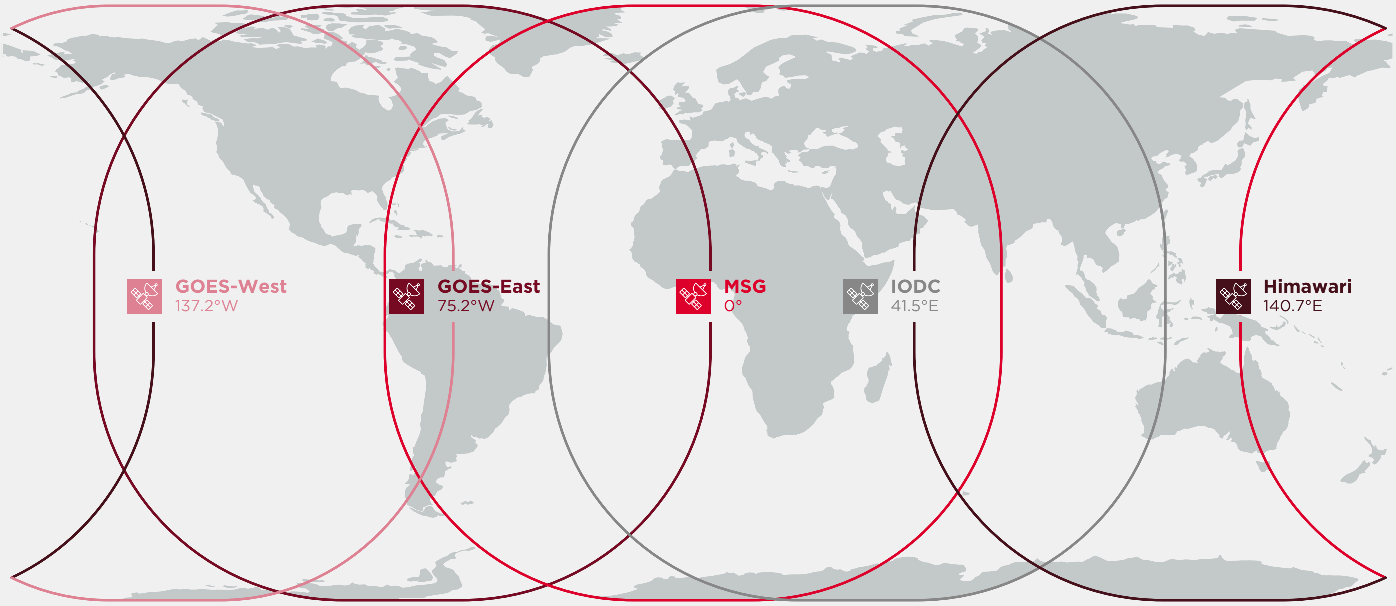
[8] Geostationary satellites infer rainfall from observed cloud top temperatures.

[9] The GPM mission measures rainfall using microwave emissions and/or radar backscatter.

**Figure 2**

Global coverage of geostationary satellites

Source: GSMA[10]



## Geostationary weather satellites

Geostationary satellites spin at the same rate as the earth, providing frequent imagery of the same area to help detect and forecast rapidly developing extreme weather.[11] Geostationary satellites are operated by numerous national space agencies to achieve global coverage[12] and data is made publicly available online. The frequency and resolution of data depends on the instruments used. Imagery from the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), for example, is refreshed every 15 minutes and captured at a 3 km resolution.[13]

Rainfall monitoring can be conducted using statistical techniques based on cloud-top temperatures[14] and benefits from calibration-to-surface observations. Several agencies operate geostationary satellites (see Figure 2) and the instruments they use are constantly being upgraded. For example, the launch of the European Space Agency's (ESA) Meteosat Third Generation satellites in late 2022 has introduced a host of improvements, including an upgrade in spatial resolution to 1×1 km.[15]

## Global Precipitation Measurement (GPM) mission

The Global Precipitation Measurement (GPM) mission is an international collaboration co-led by the National Aeronautics and Space Administration (NASA) and the Japan Aeronautical Exploration Agency (JAXA) to advance precipitation estimation from space for research and practical applications.[16] Satellites provided by a consortium of international partners contribute measurements from a variety of sensors (notably microwave radiometers and cloud / precipitation radars) to generate and disseminate global precipitation products. Data is made publicly available online. Precipitation data with global coverage is available every 30 minutes at about a 10 km resolution. Data from real-time products is available approximately six hours after observation.

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[10] Ceamanos, C. et al. (2021). Quasi-global Maps of Daily Aerosol Optical Depth from a Ring of Five Geostationary Meteorological Satellites using AERUS-GEO.

[11] EUMETSAT Meteosat Series.

[12] Including NOAA (Americas), EUMETSAT (Europe, Africa), ISRO (South Asia) and JMA (Southeast Asia).

[13] EUMETSAT Meteosat Series.

[14] EARS Earth Environment Monitoring – Delft. (2014). FESA Micro-Insurance: Crop Insurance Reaching Every Farmer in Africa.

[15] Meteostat Third Generation.

[16] NASA's Global Precipitation Measurement Mission (GPM): https://gpm.nasa.gov/

## Automated weather stations (AWS)

Networks of ground-based weather stations make a variety of surface observations, including temperature, rainfall and wind. They are typically operated by NMHS and, in some cases, by private companies and civil society organisations (CSOs).[17] Weather station coverage in LMICs is low. Sub-Saharan Africa has one weather station per 26,000 km² – eight times lower than the WMO's minimum recommended level.[18] In India, the density is approximately one per 16,000 km².[19] Under ideal circumstances, precipitation data from AWS is available in near-real time, typically at one-hour intervals. Manual weather stations provide readings every three hours or less.

## Commercial microwave links (CMLs)

CMLs present an opportunity to measure ground-level rainfall by measuring signal reduction in the microwave links that connect mobile backhaul networks. Mobile network coverage has expanded rapidly in recent decades, and today more than 90% of the population of most countries are covered by a mobile signal.[20] Mobile network coverage is closely related to population density, so there are fewer links in rural areas and more in urban areas. CML data can be used to create rainfall maps at a grid resolution of 4 km or less.[21] The sampling frequency of CML data depends on the extraction method, but is typically 15 minutes and can be as little as one second.[22]

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[17] Trans-African Hydro-Meteorological Observatory (TAHMO).

[18] World Bank. (2015). Creating an Atmosphere of Cooperation in Sub-Saharan Africa by Strengthening Weather, Climate and Hydrological Services.

[19] Pai, D.S. et al. (2014). Development of a new high spatial resolution (0.25° × 0.25°) long period (1901–2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region.

[20] ITU. (2021). Measuring Digital Development Facts and Figures 2021.

[21] Overeem, A. et al. (2016). Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network.

[22] Chwala, C. et al. (2016). Real-time data acquisition of commercial microwave link networks for hydrometeorological applications.

# 2.2

# CML rainfall observation: How it works

Mobile backhaul networks are responsible for distributing data through a mobile network by connecting mobile base stations to one another. While fibre optic cables provide the most data capacity, wireless backhaul plays a vital role at sites where fibre is not accessible or affordable. Wireless backhaul is currently the most common backhaul method worldwide and this is expected to continue for the foreseeable future.[23] Wireless backhaul networks traditionally use radio waves at the lower end of microwave frequencies (6–42 GHz) to transmit data, linking one tower to another.[24] The frequency of CMLs determines their properties, with lower frequencies travelling longer distances before suffering attenuation and higher frequencies supporting higher volumes of data.

When rain falls in the path of a CML, water absorbs and scatters the microwave signals, reducing the signal strength at the receiving tower. By comparing the signal levels during rainfall to representative levels during dry weather, the CML data can be converted into accurate rainfall measurements. Using these basic principles, each link in a wireless backhaul network can function as a rain gauge, providing an observation of rainfall intensity over the link path.

Algorithms to retrieve rainfall data from CMLs have been developed by numerous academic (e.g. RAINLINK,[25] pycomlink[26]) and commercial groups (e.g. Tomorrow.io,[27] Atmoscell,[28] Ericsson[29]). While approaches can vary, they follow the same five basic processing steps outlined in Figure 3. After (1) acquiring CML data on received signal levels, it is (2) analysed to distinguish rainfall events from any noise, and (3) the signal level during dry periods is used as the baseline to calculate the level of attenuation during rainfall events. These attenuation levels (4) are used to calculate rainfall intensity, after which (5) the rainfall intensities from all CMLs are interpolated onto a spatial grid that provides the rainfall fields.

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[23] GSMA. (2021). Wireless Backhaul Evolution.

[24] GSMA. (2021). Spectrum for Wireless Backhaul.

[25] Overeem et al. (n.d.). RAINLINK: Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network.

[26] pycomlink: https://github.com/pycomlink/pycomlink#readme

[27] www.tomorrow.io

[28] www.atmoscell.com

[29] www.ericsson.com/en

Figure 3

## Using mobile networks for rainfall estimation

Source: GSMA

**>94%**

Mobile networks cover >94% of populations in LMICs.[30]

Backhaul networks connect mobile base stations in a mobile network.

**>60%**

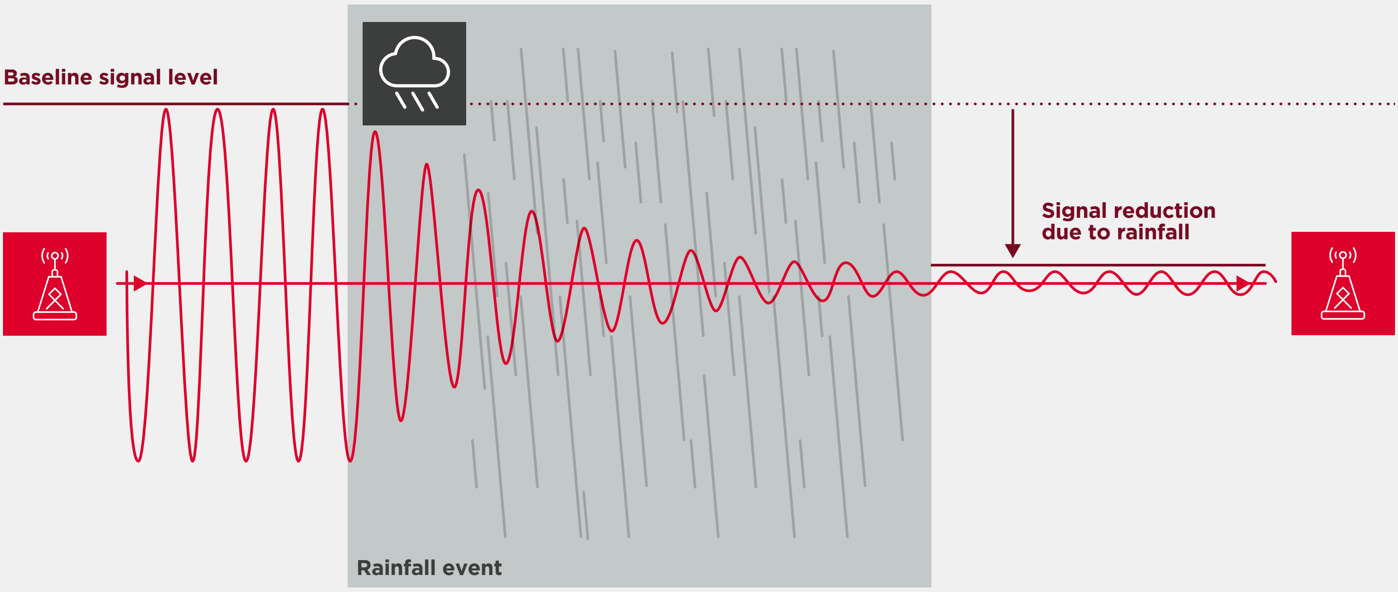
>60% of backhaul connections are wireless and use CMLs (more in rural settings).[31]

CMLs use radio frequencies to transmit data from one base station to another.

Each CML in a wireless backhaul network can be used for rainfall observation.

▼ When rain falls in the path of a CML, water absorbs and scatters the signal, reducing its strength at the receiving tower.

These reductions in signal strength can be converted into rainfall intensities.



▼ Five steps used by algorithms to process CML data for rainfall[32]

1. Acquire CML data
2. Identify rainfall events
3. Determine baseline signal level
4. Extract rainfall rates from reductions in signal strength
5. Generate rainfall maps

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30 ITU. (2021). Measuring Digital Development Facts and Figures 2021.

31 GSMA. (2021). Wireless Backhaul Evolution.

32 Chwala, C. and Kunstmann, H. (2019). Commercial microwave link networks for rainfall observation: Assessment of the current status and future challenges.

# 2.3

# How much data is available? Coverage and resolution

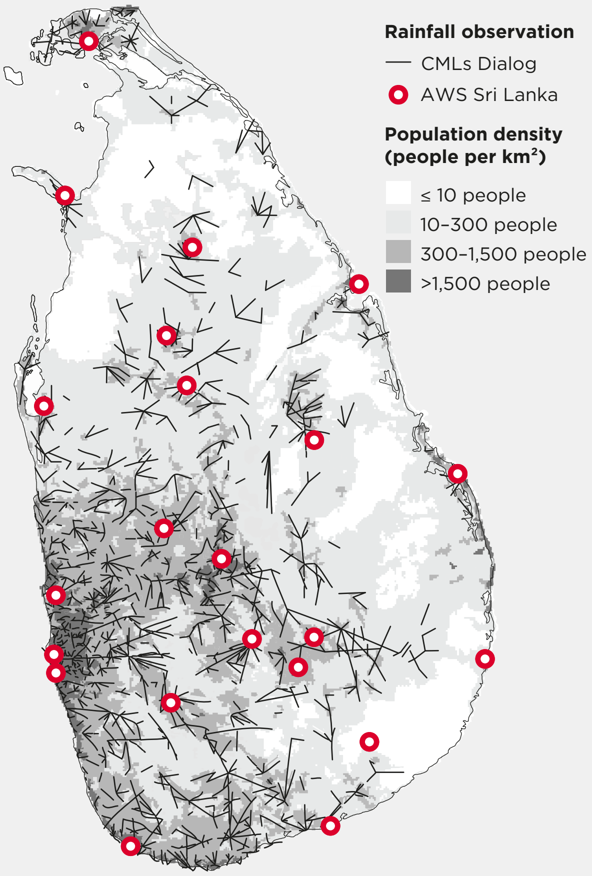
Wireless backhaul networks are closely correlated with mobile network coverage. At least 60% of links are connected through CMLs on average, and this number is expanding rapidly in rural areas. Since there is no public data on mobile backhaul networks, mobile network coverage serves as a useful proxy for CML coverage. Mobile networks have expanded rapidly to cover 94% of the general population and 88% of the rural population of LMICs.[33] The boundaries of CML coverage are drawn by national borders, beyond which backhaul networks are beyond the remit of nationally operating MNOs. Coverage is also restricted by bodies of water, which create reflections of transmitted signals that render the resulting data unusable for rainfall estimation.

Within countries, coverage is limited to populated areas. Figure 4 illustrates the case of Sri Lanka, where population density and CML networks are closely correlated. Although networks are sparser in rural areas, links are present and offer significantly better coverage than AWS networks. Where several MNOs operate in the same market (a common scenario), each will have a slightly different network footprint, with some networks providing better coverage of certain areas and the most extensive coverage provided when data from all networks is combined. Typically, the density of mobile networks mirrors population density, with more and shorter links in urban areas and fewer and longer links in rural areas. Where networks become too sparse or links too long, rainfall estimation is no longer possible (see Figure 5). However, even where only minimum conditions are met, rainfall data can still be provided with a high degree of accuracy and resolution.[34]

**Figure 4**

Population density and CML networks in Sri Lanka

Source: GSMA



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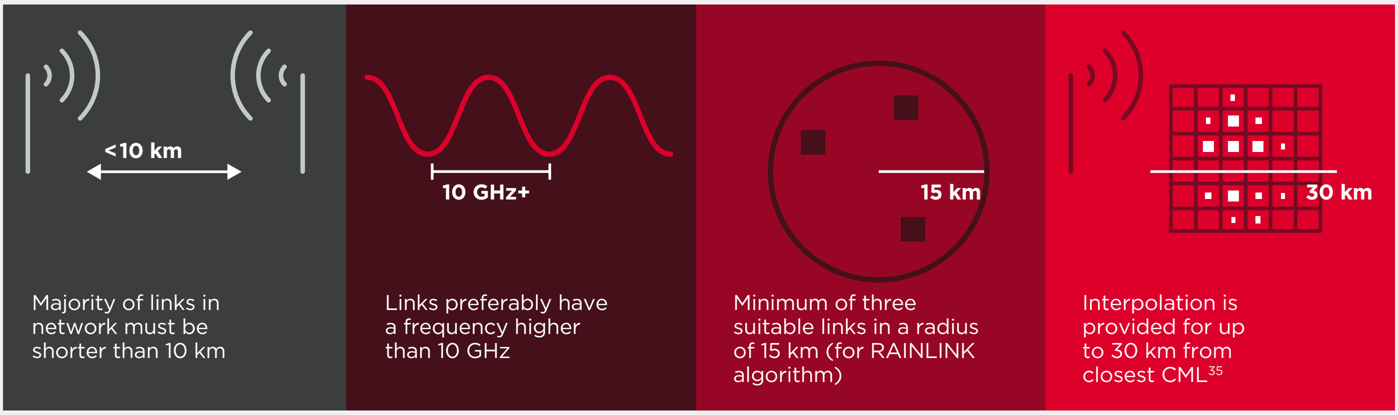
[33] ITU. (2021). Measuring Digital Development Facts and Figures 2021.

[34] Rios Gaona, M.F. et al. (2017). Evaluation of Rainfall Products Derived From Satellites and Microwave Links for The Netherlands.

Figure 5

## Minimum requirements of CML networks for rainfall observation

Source: GSMA



Majority of links in network must be shorter than 10 km

Links preferably have a frequency higher than 10 GHz

Minimum of three suitable links in a radius of 15 km (for RAINLINK algorithm)

Interpolation is provided for up to 30 km from closest CML[35]

In CML networks, each link provides a measurement of rainfall over the link path, often treated as a point measurement. Due to the density of observations a CML network typically provides, these point estimates can be interpolated onto a continuous grid of rainfall estimates (with a cell size of 1–4 km²) that extends up to 30 km from the closest CML. The distance to which rainfall is interpolated from a CML depends on the spatial correlation of rainfall in an area and the temporal resolution used, as weather events in tropical climates are more localised and longer events are likely to have higher correlation over larger distances. Figure 6 provides an indication of the increase in rainfall data points that CML rainfall observation can provide. In addition to providing significantly more locations from which to take measurements, CML rainfall observation also allows measurements to be taken more frequently. Depending on the approach used to extract the CML data, observations are made every 15 minutes or even more frequently, up to every second.

Figure 6

## CML networks greatly multiply ground-level rainfall observations

Source: GSMA

**Nigeria**

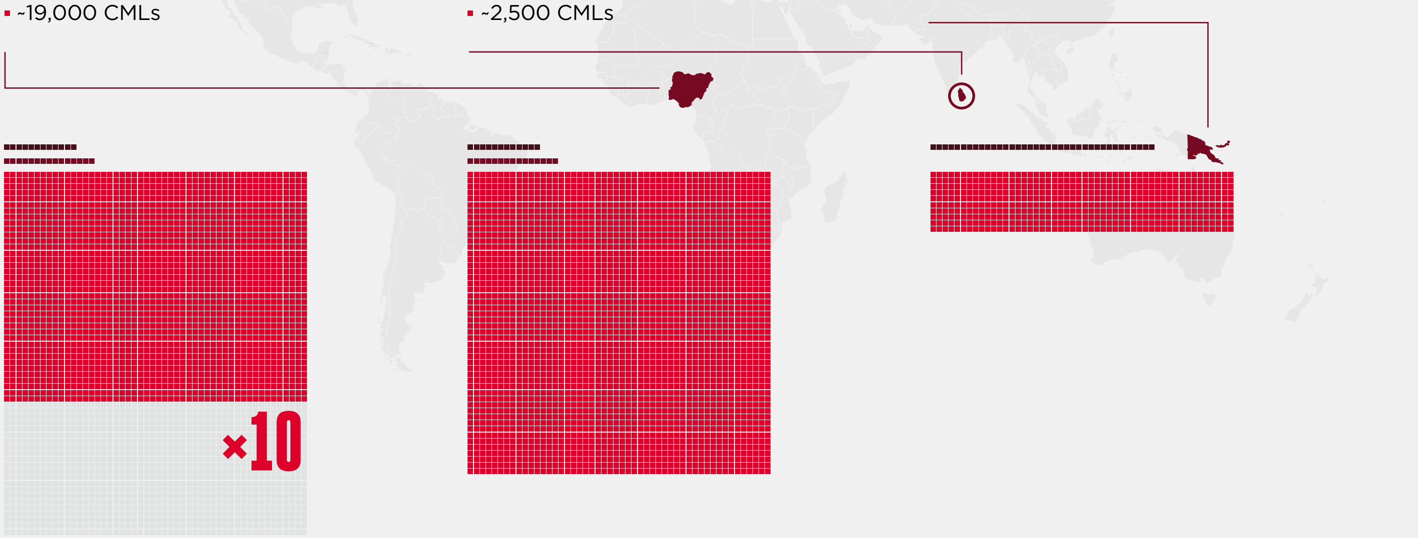
- 12 NIMET hourly stations,[36]
- ~30 TAHMO stations,[37]
- ~19,000 CMLs

**Sri Lanka**

- 22 SLMET hourly stations,[38]
- 10 Dialog hourly stations,
- ~2,500 CMLs

**Papua New Guinea**

- 37 PNG Climate hourly stations,[39]
- ~500 CMLs



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[35] Graf, M. et al. (2019). Rainfall estimation from a German-wide commercial microwave link network: optimized processing and validation for one year of data.

[36] Nigerian Meteorological Agency (NIMET).

[37] Trans-African Hydro-Meteorological Observatory (TAHMO).

[38] Department of Meteorology Sri Lanka.

[39] The Climate Monitoring Network of Papua New Guinea.

## CASE STUDY 1

# CML network characteristics and rainfall observation

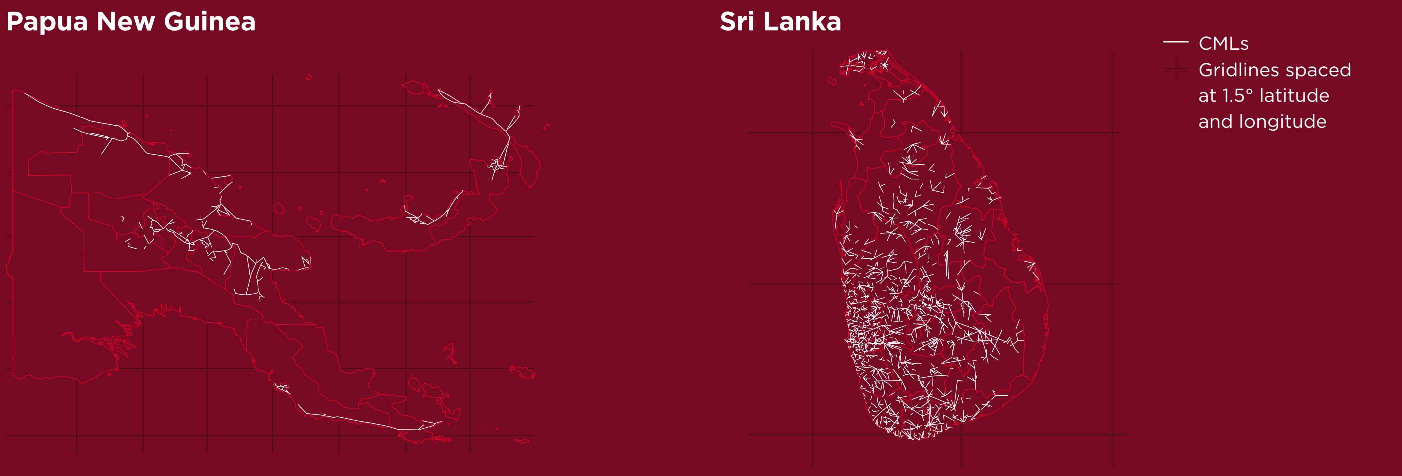
The influence of network characteristics on the ability to provide CML rainfall observations can be illustrated by the contrasting contexts of Papua New Guinea and Sri Lanka (see Figure 7). Papua New Guinea is characterised by a mountainous landscape, a population concentrated in several urban centres and large, sparsely populated areas. The mobile backhaul network of Digicel reflects this distribution with clusters of short CMLs in urban areas connected with few, relatively long CMLs in rural areas. In contrast, Sri Lanka has a more uniform population density, with Dialog Axiata's CML network providing extensive coverage of the country (see Figure 4).

In terms of link length and frequency, the network in Papua New Guinea has a relatively high number of long (>15 km) low frequency (<8 GHz) links. In Sri Lanka's network, all links have a frequency higher than 10 GHz and only a few are longer than 15 km. As a result, accurate CML rainfall observation in Papua New Guinea is only possible in urban areas while rural areas remain largely uncovered. In Sri Lanka, CML rainfall observations can be provided for most of the country's surface area.

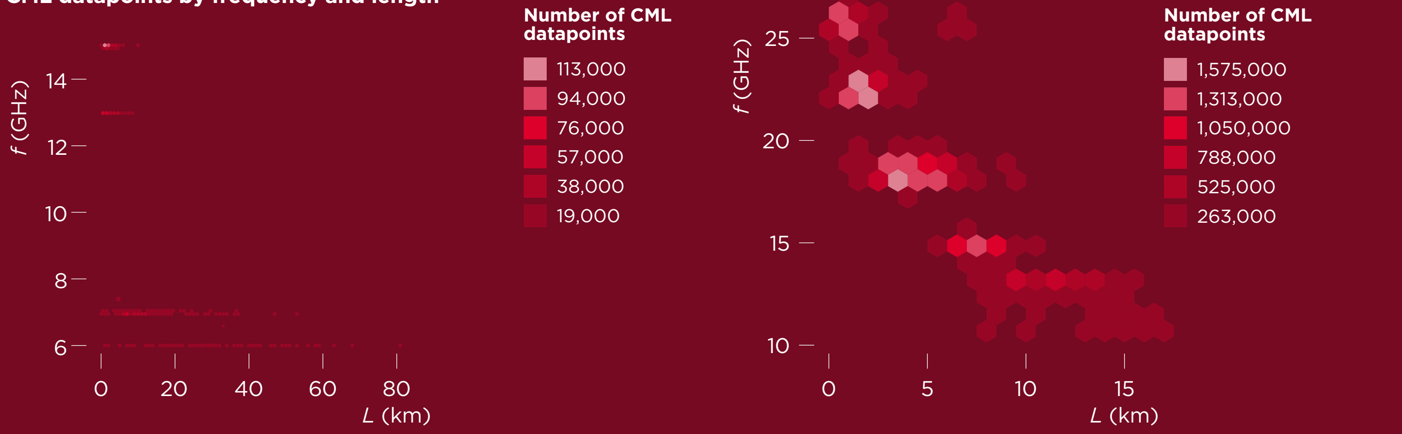
**Figure 7**

Comparison of CML networks in Papua New Guinea and Sri Lanka

Source: GSMA



**CML datapoints by frequency and length**



# 2.4

# How reliable is CML rainfall data? Accuracy and limitations

To assess the accuracy of CML rainfall observations, they can be compared to other available rainfall data sources. In high-income countries (HICs), weather radar data adjusted by ground-level measurements from rain gauges[40] is the typical benchmark. In LMICs, the lack of reliable ground-level weather observations makes them difficult to validate and optimise. In most cases, data from a limited number of weather stations is available from the NMHS and potentially from private companies and CSOs. While satellite rainfall data is available for these markets, it is generally not regarded as a valid benchmark due to the indirect nature of satellite rainfall measurement.

The inherent limitations of using CML data for rainfall observation are outlined in section 2.4.1. Sections 2.4.2 and 2.4.3 review the results of large-scale studies that used data from more than 1,000 links collected over six months or more and compared them to available reference data. Studies from HICs (section 2.4.2) have been briefly reviewed to compare how CMLs, rain gauges and satellite data perform against the gold standard for precipitation measurement: gauge-adjusted radar. The next section (2.4.3) presents results from GSMA AgriTech engagements with MNOs, which have been the most extensive studies conducted in tropical markets.

## 2.4.1 Inherent limitations of CML rainfall observation

Once the contextual requirements for CML rainfall observation are met (see section 2.3), several other challenges inherent to CML rainfall observation need to be addressed. First, since rainfall is essentially "noise" in the CML signal data, a key challenge is distinguishing it from other sources of noise in the signal. For instance, these can be caused by reflection of the beam, dew formation on the antennas, and dust.[41] Due to the significant signal reductions caused by intense rainfall events, these are relatively easy to identify. However, low-intensity rainfall events can be masked by, or have a similar profile as, other sources of noise.

Another inherent limitation is the range of rainfall intensity that a CML signal can identify. When rainfall reaches an intensity that causes the CML signal to fail completely, any further increase in intensity is lost. However, mobile network engineers typically plan new CML paths (length and frequency) that take local rainfall patterns into account and ensure they are available 99.999% of the time.[42] This also ensures that rainfall attenuation can be measured.

Finally, the principles of CML rainfall observation have so far only been applied to liquid forms of precipitation. Non-liquid forms, such as hail, sleet and snow, have fundamentally different physical characteristics to liquid rainfall and do not provide similarly uniform signal attenuation patterns.

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[40] Rain gauges are instruments, often one component of a weather station, that measure rainfall quantities.

[41] Overeem, A. et al. (2021). Tropical rainfall monitoring with commercial microwave links in Sri Lanka.

[42] Chwala, C. and Kunstmann, H. (2019). Commercial microwave link networks for rainfall observation: Assessment of the current status and future challenges.

## 2.4.2 Results from temperate high-income countries

Studies conducted in HICs, specifically the Netherlands and Germany, provide the most extensive datasets for the evaluation of CML rainfall observations to date. In these studies, CML rainfall data from thousands of links collected over six months or more is compared to gauge-adjusted radar rainfall data. Some studies also include rain gauge data and rainfall data from various satellite sources, providing a valuable benchmarking exercise for CML rainfall observation data. Given the extensive datasets used, these studies provide the clearest indication of the accuracy and limitations of CML rainfall observations, albeit for temperate climates. Figure 8 illustrates the metric used to compare measurements and some of the complications associated with interpreting results.

The results of several studies conducted in markets with extensive rainfall data from rain gauge-adjusted radar[43] show the potential of CML rainfall observation as an additional source of quantitative precipitation. A study by Overeem et al. compares both CML and rain gauge data from the Netherlands to radar data. This analysis shows that CML rainfall maps have the same level of accuracy as hourly rain gauge rainfall maps during summer months.[44] A study by Rios Gaona et al. makes a similar comparison, but with various sources of satellite data. Given the higher data resolution in this study (30 minutes instead of hourly), the overall correlation results are lower. However, CML data is clearly more accurate than data from both geostationary satellites (MSG CPP and MSG NIPE) and IMERG sources. Finally, an extensive study conducted by Graf et al. in Germany confirms a strong correlation between CML and radar precipitation data.

**Figure 8**

### Comparing rainfall data sources

Source: GSMA

**Many metrics are available to assess the quality of rainfall estimates.**

Here, the key metric used is the coefficient of determination ($r^2$), which shows the strength of a linear model by explaining how much of the variation of one variable can be explained by the other. It can be a figure between 0 and 1, with $r^2=1$ showing perfect correlation.

**Imperfections in the measurements of both sources make it more complicated to interpret where the error was caused.**

If the $r^2$ value is low, assuming there is no additional information, it is difficult to attribute the error to either data source.

**Differences in temporal and/or spatial resolution will influence results.**

Lower resolution data typically achieve higher correlation as errors average out when aggregating over longer temporal and spatial scales.

**Figure 9**

### Key findings from HICs

Source: GSMA

**CML rainfall maps outperform rainfall maps based on rain gauges during periods without frozen precipitation.[45]**

**CML rainfall observations significantly outperform satellite data from both Meteosat and GPM IMERG.[46]**

**Higher CML network densities are more likely, but not necessary, to provide more accurate observations.[47,48]**

**CML rainfall observations tend to overestimate rainfall intensity compared to radar.[49]**

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[43] Rain gauge-adjusted radar data combines data from rain gauges and rainfall radar. This is considered the gold standard for rainfall measurement and is used as a benchmark for other data sources.

[44] CML rainfall observation only works for liquid forms of precipitation. In winter months, when frozen precipitation such as snow, sleet and hail also fall, this approach yields less reliable results.

[45] Overeem, A. et al. (2016). Two and a half years of radio link rainfall maps.

[46] Rios Gaona, M.F. et al. (2017). Evaluation of Rainfall Products Derived From Satellites and Microwave Links for The Netherlands.

[47] Rios Gaona, M.F. et al. (2015). Measurement and interpolation uncertainties in rainfall maps from cellular communication networks.

[48] Overeem, A. et al. (2016). Two and a half years of radio link rainfall maps.

[49] Ibid.

# Results

Table 2

## Results of comparisons of CML-, rain gauge- and satellite-data to radar rainfall maps

Source: GSMA

⬜ Very weak 🟪 Weak 🟥 Medium 🟫 Moderately strong ⬛ Strong

| | Data source | Correlation to radar | Study |
|---|---|---|---|
| **CML** | RAINLINK, hourly, summer | ⬛ $r^2=0.70$ | Overeem et al., 2016, Netherlands[50] |
| **Rain gauges** | Hourly, summer | ⬛ $r^2=0.67$ | |
| **CML** | RAINLINK, 30 min, summer | 🟪 $r^2=0.37$ | Rios Gaona et al., 2017, Netherlands[51] |
| **Satellite** | IMERG,[52] 30 min, summer | ⬜ $r^2=0.10$ | |
| **Satellite** | MSG CPP,[53] 30 min, summer | ⬜ $r^2=0.09$ | |
| **Satellite** | MSG NIPE,[54] 30 min, summer | ⬜ $r^2=0.01$ | |
| **CML** | pycomlink, hourly, summer | 🟫 $r^2=0.55$ | Graf et al., 2019, Germany[55] |

Table 3

## Study details: comparisons of CML, rain gauges and satellite to radar

Source: GSMA

| | | |
|---|---|---|
| **Overeem et al.,** Netherlands, 2016 | Study duration and coverage | Data was collected over 2.5 years covering the Netherlands |
| | CML data | 2,044 link paths from the T-Mobile network; spatial resolution of 0.92 km$^2$ at 15-minute intervals, processed using RAINLINK |
| | Rain gauge data | 32 automatic rain gauges for hourly data, 325 manual rain gauges for daily data |
| | Radar data | Gauge-adjusted radar rainfall data was used with a resolution of 0.9 km$^2$ and 5-minute intervals |
| **Rios Gaona et al.,** Netherlands, 2017 | Study duration and coverage | Data was collected over a 6-month period covering the Netherlands |
| | CML data | 2,044 link paths from the T-Mobile network; spatial resolution of 0.9 km$^2$ at 15-minute intervals, processed using RAINLINK |
| | Radar data | Gauge-adjusted radar rainfall data was used with a resolution of 0.9 km$^2$ and 5-minute intervals |
| | Satellite IMERG | Integrated Multisatellite Retrievals for Global Precipitation Measurement (IMERG) final run; spatial resolution of 77 km$^2$ and 30 minutes |
| | Satellite MSG CPP | Meteosat Second Generation (MSG) Cloud Physical Properties (CPP); resolution of 28 km$^2$ and 15 minutes (daytime only) |
| | Satellite MSG NIPE | Meteosat Second Generation (MSG) Nighttime Infrared Precipitation Estimation (NIPE); resolution of 28 km$^2$ and 15 minutes |
| **Graf et al.,** Germany, 2019 | Study duration and coverage | Data was collected over 1 year with partial coverage of Germany |
| | CML data | 1,952 link paths operated by Ericsson in Germany; resolution of 1 km$^2$ and 1 minute, processed using pycomlink |
| | Radar data | Radar-Online-Anreichung data set (RADOLAN-RW) of the German Weather Service (DWD); resolution of 1 km$^2$ and 1 hour |

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[50] Overeem, A. et al. (2016). Two and a half years of radio link rainfall maps.

[51] Rios Gaona, M.F. et al. (2017). Evaluation of Rainfall Products Derived From Satellites and Microwave Links for The Netherlands.

[52] IMERG: Integrated Multisatellite Retrievals for Global Precipitation Measurement.

[53] Meteosat Second Generation Cloud Physical Properties.

[54] Meteosat Second Generation Nighttime Infrared Precipitation Estimation.

[55] Graf, M. et al. (2019). Rainfall estimation from a German-wide commercial microwave link network: optimized processing and validation for one year of data.

## 2.4.3 Results from tropical low- and middle-income countries

Until recently, only a few studies applied the principles of CML rainfall observation to tropical LMICs. A study in Burkina Faso studied the performance of one CML over the 2012 monsoon season,[56] while in Pakistan a study analysed data from 35 CMLs captured over 60 days.[57] While these studies provided valuable initial proof of concept, recent projects led by GSMA AgriTech in Sri Lanka, Nigeria and Papua New Guinea enabled access to, and evaluation of, country-wide CML datasets in LMICs spanning six months or more. Although rain gauge data was sourced in these countries as a reference, availability was limited. Still, these studies provide insight into the potential value and challenges of CML rainfall data services in LMICs. The key findings and results of these projects are provided in Figure 10.

Studies from LMICs show a wide range of results, from strong to very weak correlations, depending on the market, climate type and network characteristics. Understanding which factors produce better results is hampered by a lack of reliable rain gauge data. Not enough data is available to make detailed comparisons of, for example, urban and rural areas or dry and wet areas within a country. It also means that when there is a low correlation between CML and rain gauge data, it is almost impossible to determine which data source is responsible for the error.

**Figure 10**

Key findings from tropical LMICs

Source: GSMA

**CML data showed a mix of strong to very weak correlation with rain gauge data**

- Sri Lanka showed strong correlation across the country.
- In Nigeria, results varied between moderately strong and very weak correlation, depending on climate type.
- Papua New Guinea showed weak to very weak correlation across the country.

**The different climate types across Nigeria affected results significantly.**

- The tropical climate zones in the central and southern areas performed better than the arid northern areas, indicating the suitability of the RAINLINK algorithm for relatively wet areas.

**Network topology affected results in Papua New Guinea, with rural areas performing the worst.**

- The wireless backhaul network in Papua New Guinea is characterised by clusters of short links in urban areas and sparse, long, low-frequency links in rural areas that are not conducive to CML rainfall observation (see section 2.3).

**From the studies, it is not possible to identify which proportion of errors lies with the CML rainfall data versus the rain gauge data.**

- In all studies, errors and inconsistencies were found in the rain gauge data, complicating the interpretation of results.

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[56] Doumounia, A. et al. (2014). Rainfall monitoring based on microwave links from cellular telecommunication networks: First results from a West African test bed.

[57] Afzal, M.S. et al. (2018). Real time rainfall estimation using microwave signals of cellular communication networks: a case study of Faisalabad, Pakistan.

Despite these challenges, several general lessons can be drawn from the research. The study in Sri Lanka showed strong correlations to rain gauges, indicating strong performance of the approach. In Nigeria, contrasting results were found between the northern (dry) and the central and southern (wet) areas, indicating that the rainfall retrieval algorithm used (RAINLINK) is less suited to quantifying the type of precipitation found in the north of the country. To improve these results, the algorithm, which was developed for the temperate climate of the Netherlands, must be optimised to the semi-arid climate of northern Nigeria (see section 3.3.2). In Papua New Guinea, the results were overall weaker than in Nigeria or Sri Lanka. This could be attributed to the network in Papua New Guinea using longer links at lower frequencies, but it could also be related to the extreme precipitation amounts experienced in the country, which is ranked third wettest in the world.[58] The effects of network structure are clearly seen when moving from urban to rural areas where the predominance of very long, low-frequency links leads to very weak performance (see Case study 1).

Table 4

## Results of comparisons of CML to rain gauges in tropical LMICs

Source: GSMA

⬜ Very weak 🟪 Weak 🟥 Medium 🟫 Moderately strong ⬛ Strong

| **CML data source** | | **Correlation to rain gauges** | **Study** |
|---|---|---|---|
| **Sri Lanka** | RAINLINK, hourly | 🟫 $r^2$=0.57 | Overeem, A. et al., 2021, Sri Lanka[59] |
| **Sri Lanka** | RAINLINK, daily | ⬛ $r^2$= 0.79 | |
| **Ibadan (Mid)** | RAINLINK, daily | 🟫 $r^2$=0.48 | Droste, A. et al., 2022, Nigeria[60] |
| **Port Harcourt (South)** | RAINLINK, daily | 🟫 $r^2$=0.41 | |
| **Kaduna (North)** | RAINLINK, daily | ⬜ $r^2$=0.18 | |
| **Lae City (Urban)** | RAINLINK, daily | 🟪 $r^2$=0.28 | Droste, A. et al., 2022, Papua New Guinea[61] |
| **Port Moresby (Urban)** | RAINLINK, daily | 🟪 $r^2$=0.26 | |
| **Yangoru (Rural)** | RAINLINK, daily | ⬜ $r^2$=0.01 | |

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[58] World Bank Data. (n.d.). Average precipitation in depth (mm per year).

[59] Overeem, A. et al. (2021). Tropical rainfall monitoring with commercial microwave links in Sri Lanka.

[60] Droste, A. et al. (2022). Estimating rainfall using a dense Commercial Microwave Link (CML) network in Nigeria. Unpublished.

[61] Droste, A. et al. (2022). Commercial Microwave Link data exploration in Papua New Guinea. Unpublished.

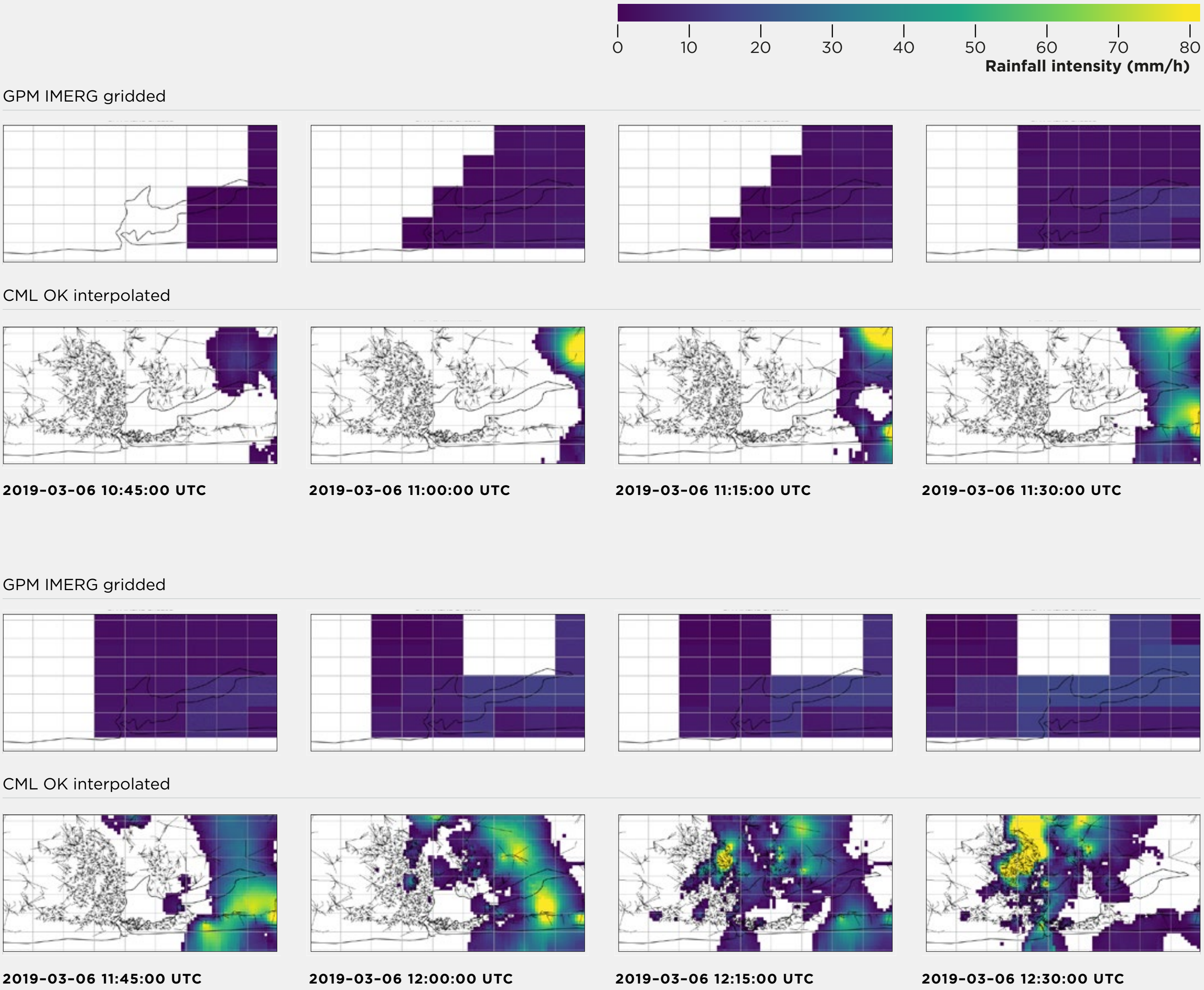
## Results: comparison to satellite data

Qualitative comparisons to satellite data were made to show that CML data can provide better rainfall observations than satellite rainfall data. An example is given in Figure 11, which provides a series of images from a rainfall event passing over Lagos on 6 March 2019. For each point in time, a visualisation is provided of rainfall intensities from satellite data[62] (top) and CML data (bottom). CML data improves resolution from 100km² to 1 km² and from 30 minutes to 15 minutes. It is also available in real time while GPM IMERG data is available six hours after the event. CML data also shows a greater range of rainfall intensity, indicated by the yellow areas of high intensity.

**Figure 11**

### Comparison of CML and satellite rainfall data: passing showers, Lagos, 6 March 2019

Source: GSMA



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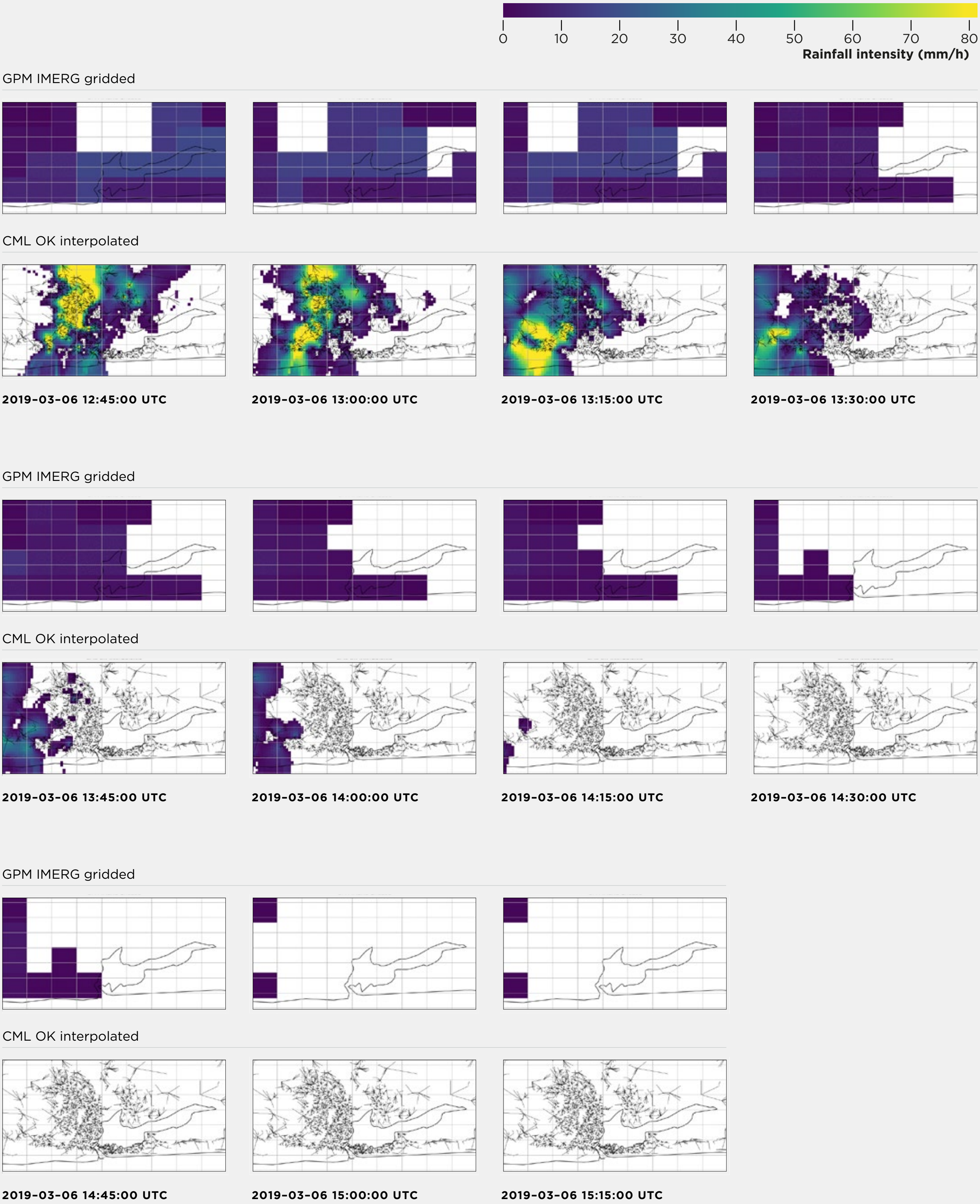
[62] IMERG GPM: https://gpm.nasa.gov/data/imerg.

**Figure 11 continued**

# Comparison of CML and satellite rainfall data: passing showers, Lagos, 6 March 2019

Source: GSMA



GPM IMERG gridded

CML OK interpolated

**2019-03-06 12:45:00 UTC** **2019-03-06 13:00:00 UTC** **2019-03-06 13:15:00 UTC** **2019-03-06 13:30:00 UTC**

GPM IMERG gridded

CML OK interpolated

**2019-03-06 13:45:00 UTC** **2019-03-06 14:00:00 UTC** **2019-03-06 14:15:00 UTC** **2019-03-06 14:30:00 UTC**

GPM IMERG gridded

CML OK interpolated

**2019-03-06 14:45:00 UTC** **2019-03-06 15:00:00 UTC** **2019-03-06 15:15:00 UTC**

Figure 12

## Study details: GSMA engagements on CML in tropical LMICs

Source: GSMA

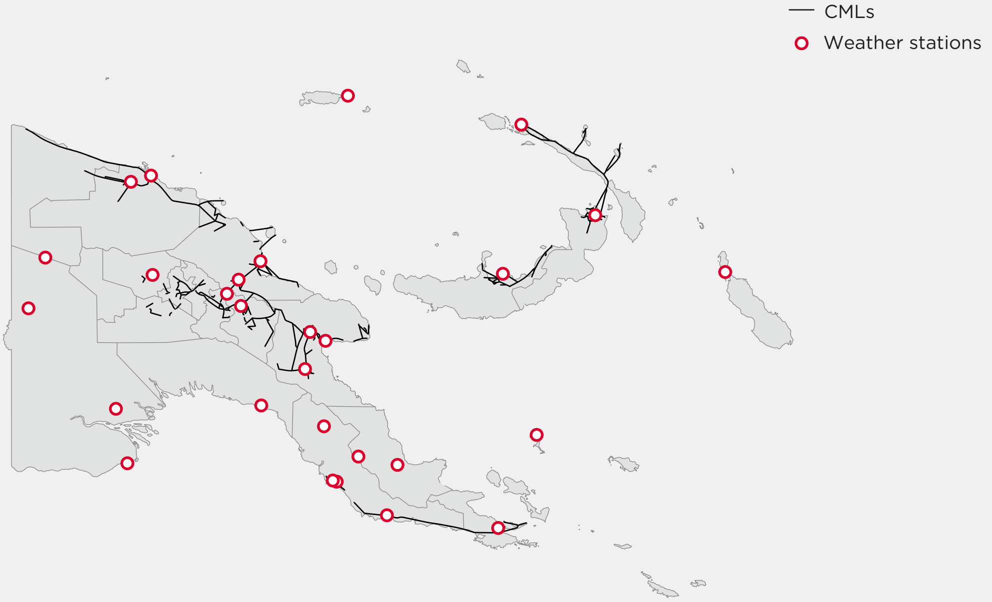
### Papua New Guinea

**Data collection period**
December 2020–August 2021

**Links accessed**
500, Digicel

**Resolution**
2×2 km, 15 minutes

**Reference data**
Obtained from PNGclimate.net for 12 weather stations



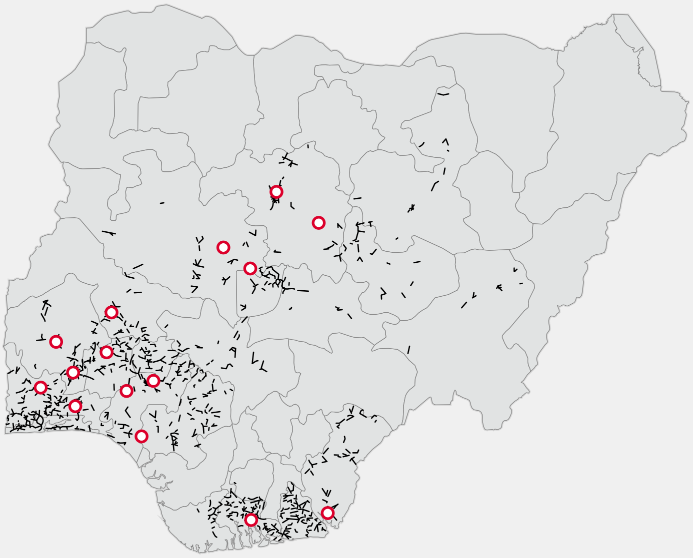
### Nigeria

**Data collection period**
April–October 2020

**Links accessed**
12,000, MTN

**Resolution**
1×1 km, 15 minutes

**Reference data**
Obtained from Nigerian Meteorological Agency (NIMET) for 12 weather stations



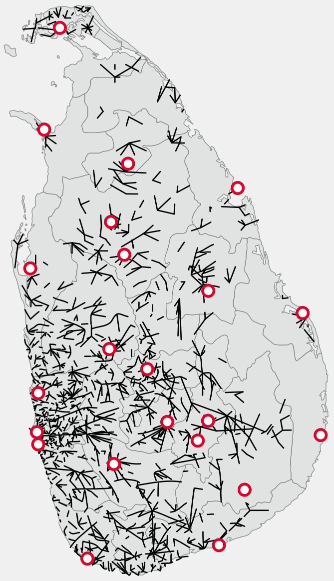
### Sri Lanka

**Data collection period**
September–December 2019

**Links accessed**
1,326, Dialog Axiata

**Resolution**
2×2 km, 15 minutes

**Reference data**
Obtained from Sri Lanka Department of Meteorology for 12 hourly and 23 daily weather stations



# 3

# Operational: Developing CML rainfall data services

**This chapter outlines the resources and process required for MNOs to develop CML rainfall observation services. This process closely mirrors the steps taken by the GSMA-led CML initiatives described in the methodology.**

The key enablers of, and barriers to, the creation of data services are highlighted, including the network structure, software and potential regulatory considerations required for rainfall estimation. The role of mobile ecosystem players in enabling CML rainfall services is then explored, specifically mobile network hardware and software vendors, as well as ownership models of CML rainfall data service platforms.

# 3.1

# CML rainfall service development milestones

To develop rainfall services from CML data, several steps need to be taken to access the data, process and validate the data and outputs and, finally, provide access to third parties. Each of these steps requires different types and amounts of resources.

Figure 13 outlines key milestones in the development of CML rainfall services and the key resource requirements for each one. Each activity is discussed in more detail in the following sections.

**Figure 13**

CML service development milestones

Source: GSMA

| **Milestone** | **Activity** | **Key resource requirements** |
|---|---|---|
| Identity validation data sources<br>**See 3.2.2** | Investigate availability of rainfall data for validation.<br>— Ideally from ground-level sources such as weather stations or radar<br>— Satellite data from geostationary satellies may also be used | Intellectual |
| Check regulatory requirements<br>**See 3.2.3, 3.2.4** | Confirm sharing of site locations and transmission frequency with regulatory team.<br>Investigate national meteorological regulatiosn regarding sharing and monetisation of rainfall observation data and derivative services. | Regulatory |
| Confirm viability of CML data<br>**See 3.3.1** | Extract sample data from network management system:<br>— Metadata containing site locations and transmission frequencies<br>— Transmission data including transmitted and received signal levels | Technical<br>Intellectual |
| Check network structure<br>**See 3.2.1** | Analyse metadata to confirm CML network structure and coverage are conducive to rainfall observation.<br>— Remove links that are too long (≥10 km) or too low frequency (<10 GHz) | Intellectual |
| Store CML data for validation<br>**See 3.3.1** | Initiate periodic extraction and storage of CML transmission data to collect at least one year of CML data for the network.<br>Obtain validation rainfall data covering the same period, geography and temporal resolution. | Technical |
| Validate rainfall algorithm<br>**See 3.3.2** | Convert CML transmission data into rainfall maps.<br>Assess accuracy of CML rainfall observations through comparison with validation data.<br>Optimise rainfall calculation algorithm to local conditions. | Intellectual<br>Human |
| Automate CML data processing<br>**See 3.3.3** | Automate extraction, storage and sharing of CML data.<br>Automate processing of CML data to rainfall observations. | Technical |
| Enable CML data accessibility<br>**See 3.3.3** | Develop appropriate front-end applications to enable access to rainfall data<br>— APIs<br>— Map visualisations | Technical |

■ Confirm prerequisites for CML service creation ■ Access and store CML data ■ Validate and optimise rainfall algorithm ■ Develop real-time data service

# 3.2
# Prerequisites for CML service creation

To utilise CMLs from wireless backhaul networks successfully, several conditions must be met, from the physical structure of the mobile network to the availability of ground-level rainfall reference data and conducive regulations or policies to sharing CML data and providing weather services. These conditions are discussed in more detail in the following sections.

## 3.2.1 Mobile network structure

As discussed in section 2.3, a mobile wireless backhaul network must meet several conditions to enable rainfall observation. First, individual CMLs must be no longer than 10 km to provide a valid point estimate for the centre of the link. Second, the frequency should preferably be higher than 10 GHz to be sufficiently sensitive to capture rain events. Finally, some algorithms, such as RAINLINK, triangulate data from links in close proximity to distinguish rainfall from noise. In these cases, there needs to be a minimum of three links within a radius of 15 km to run the algorithm.

## 3.2.2 Availability of reference data

Reference data refers to rainfall data from an independent source that is used to compare and calibrate the algorithms used for rainfall retrieval. As the accuracy of CML rainfall observations can be influenced by factors such as climate type and network structure (see section 2.4), validating CML rainfall data against a trusted, independent data set is important, and can also help to calibrate the rainfall retrieval algorithm. Surface-based weather stations will provide the most reliable data, but such networks are often scarce in LMICs. Furthermore, NMHS may be reluctant to share data widely, particularly with the private sector out of concern that private companies would compete with them on service provision.[63]

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[63] World Bank. (2021). Public and Private Engagement in Hydromet Services: From Rivalry to Coproduction in Meteorological and Hydrological Service Delivery.

## 3.2.3 Sensitivity of sharing CML frequency and locations

The data required to provide CML rainfall observations contains several potentially sensitive fields for MNOs and their partners, which could prevent this data from being used.

The **frequencies (GHz) CMLs use to transmit signals** in a link directly influence their sensitivity to rainfall and are crucial inputs for rainfall retrieval algorithms. To operate their networks, MNOs must obtain the rights to use specific frequency bands for their services, typically through auctions run by national regulatory bodies. The frequencies at which mobile base stations operate within a network are therefore strategically significant for MNOs, perhaps making them reluctant to share this information with third parties.

The **locations of mobile base stations** are vital to rainfall retrieval algorithms as they enable rainfall amounts to be added to a map and then interpolated. Given the importance of communications networks in modern economies, they may be considered strategic infrastructure to be shielded from hostile parties. This is particularly the case when base station infrastructure (secure sites, masts and power supplies) is provided by a third party to multiple MNOs. In these cases, disclosing this information to third parties may be prohibited.

## 3.2.4 Sensitivity of providing weather data and services

Typically, weather services are provided by NMHSs. These services are responsible for collecting weather observation data and providing (public) weather services. Ideally, weather observation data would be provided openly as a public good. However, in LMICs where services may be underfunded, or NMHSs are set up as self-sustaining agencies, the sale of this data can be a necessary income stream for the NMHS to recover the cost of data collection and fund other activities.[64] As a result, weather data from a private source like CML rainfall observation may not be welcomed. For example, in Indonesia, the publication of data from non-NMHS observation stations is prohibited, squashing private services.[65]

It is common for meteorological laws to reinforce public sector monopolies over the development and sale of observational data and forecasting services.[66] This is not always the case, however, and organisations such as Earth Networks[67] have demonstrated it is possible to collaborate with NMHS in the development of observational weather data infrastructure and services.

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[64] World Bank. (2021). Public and Private Engagement in Hydromet Services: From Rivalry to Coproduction in Meteorological and Hydrological Service Delivery.

[65] World Bank. (2019). The Power of Partnership: Public and Private Engagement in Hydromet Services.

[66] World Bank. (2021). Public and Private Engagement in Hydromet Services: From Rivalry to Coproduction in Meteorological and Hydrological Service Delivery.

[67] Earth Networks. (25 March 2019). "Earth Networks Announces Completion of Severe Weather Early Warning System for PAGASA".

# 3.3
# Service creation elements

This chapter outlines the activities and resources required to develop CML rainfall data services. This includes the technical work involved in accessing and storing CML data, including a specification of which data is required. It also discusses the processing of CML data, validating the resulting rainfall data and steps that can be taken to improve the performance of CML rainfall retrieval algorithms. Finally, additional steps to enable real-time availability of CML data are discussed. Where relevant, examples are given from GSMA engagements.

## 3.3.1 Accessing and storing CML data

The first step in the development of CML rainfall data services is to access and extract the required data from the network. This data typically consists of two elements: metadata, which includes information about the CMLs from which the signal levels are being collected; and performance data, which provides the signal level data used to identify fluctuations and derive rainfall rates. The metadata includes location and link frequency, which enables the CML to be located and its length to be determined, while transmission frequency is used by the rainfall retrieval algorithm to convert signal reduction to rainfall intensity. The performance data includes, at minimum, a date and time stamp, the link identifier and the level of signal reduction. While metadata does not change frequently, and can therefore be updated periodically, performance data must be sampled at the desired temporal resolution, typically every 15 minutes or less. See Table 5 for data specifications.

During the development process, varying amounts of CML data are required. To confirm the viability of CML data, the metadata and one week of performance data for the entire network need to be extracted. This will enable simple tests to ensure that the metadata and performance data can be linked using the link identifiers, and that it is in a format that can be processed using rain retrieval algorithms. Once the viability of the CML data has been confirmed, data must then be collected, stored and used to validate the accuracy of the retrieved rainfall data and to calibrate the retrieval algorithm, where possible. For validation studies, a reference rainfall dataset from ground-level stations must also be sourced. To provide rainfall data services, CML data must be accessed and processed continuously, ideally in real time.

Table 5

## CML data required for rainfall observation

Source: GSMA

| **Metadata** | **Performance data** | **Additional information (not required)** |
|---|---|---|
| — Identifier of microwave link<br>— Latitude and longitude of start and end of CML (e.g. in WGS84 degrees)<br>— Frequency of the transmitted radiation (GHz) | — Identifier of microwave link<br>— Date and time of measurement with time zone (e.g. UTC)<br>— Received signal level (dBm), either:<br>• Minimum and maximum received signal power over 15-minute intervals<br>• Instantaneous value every second, minute or 15 minutes<br>• Average value over 15 minutes<br>— Transmitted power levels (where links use varying transmitted power levels)<br>• In this case, only instantaneous values can be used for received signal level | — Polarisation of the transmitted signals (horizontal or vertical) can improve accuracy<br>— Transmitted power levels as an additional reference<br>— Height of the antennae above ground level and above sea level to facilitate comparisons with other sources |

## CASE STUDY 2

# Ericsson Advanced Microwave Insights[68]

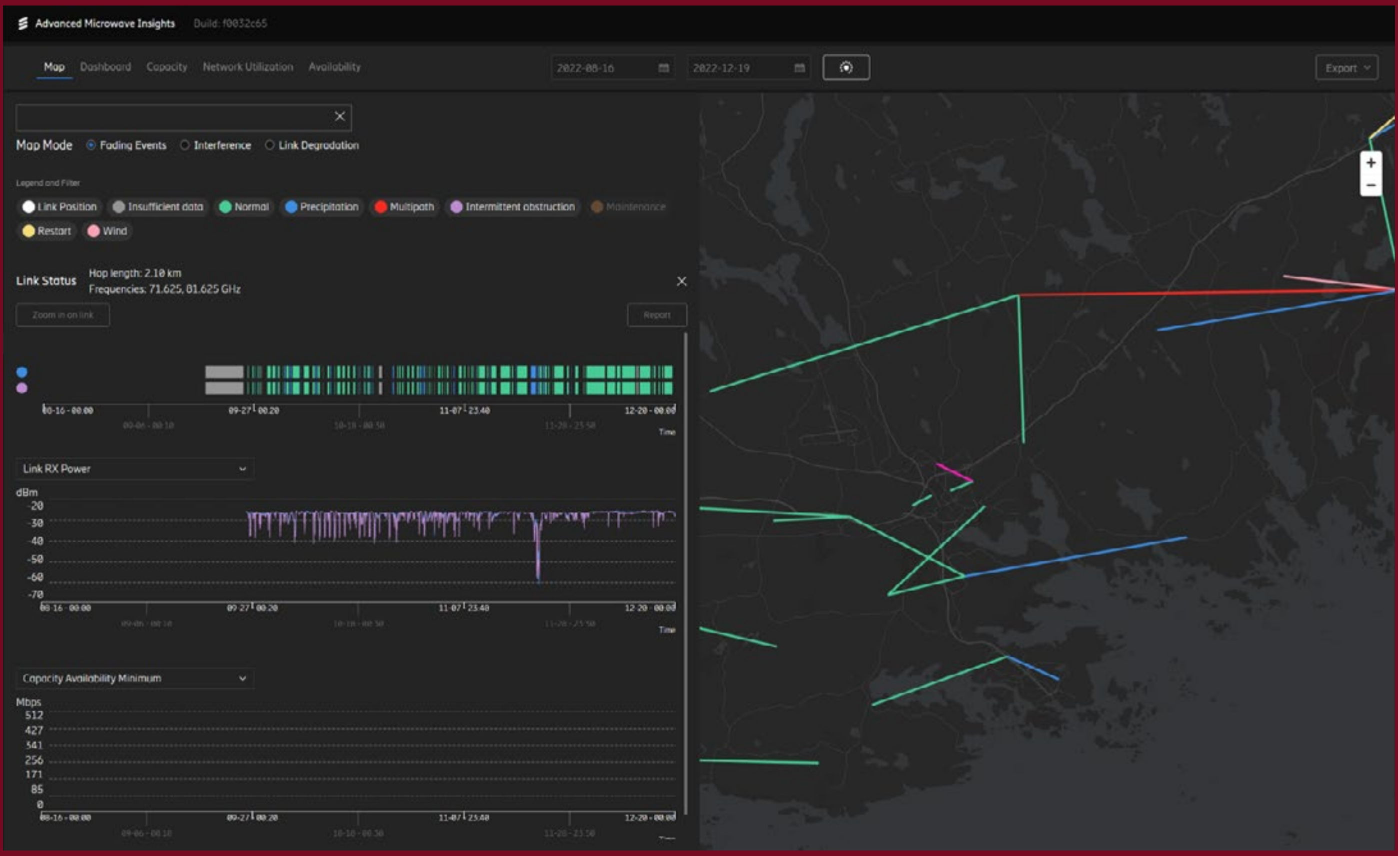
CML data provides crucial information about the integrity of a mobile wireless backhaul network and is typically monitored on an ad hoc basis to identify existing issues. Ericsson uses a combination of real-time CML data sampling at 10 seconds sampling rate and artificial intelligence (AI) analysis to identify a range of issues, including rainfall, signal interference, mast sway, blocked line of sight, and multipath propagation. These network issues are displayed on a web map interface (see Figure 14) to enable them to be managed proactively. This can significantly reduce network maintenance costs as network issues can be avoided and resources deployed proactively.

To enable high-speed, real-time CML data sampling, Ericsson developed a data collector that makes CML data available to the analytics software. Implementation of this and similar systems makes CML data readily available for rainfall observation, and provides an initial filtering of rainfall events, significantly reducing the cost of data access.

**Figure 14**

Example of impact from precipitation on a 2.1 km long E-band link during fall 2022

Source: Ericsson



Map Mode ◉ Fading Events ○ Interference ○ Link Degradation

Link Status Hop length: 2.10 km
Frequencies: 71.625, 81.625 GHz

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[68] www.ericsson.com/en/portfolio/networks/ericsson-radio-system/mobile-transport/microwave/microwave-analytics-/advanced-microwave-insights

### Technical resources

To monitor the stability of their networks, MNOs access CML data on an ad hoc basis through network management software. However, the software and hardware they use are not always conducive to the continuous extraction of CML data for rainfall monitoring. Data extraction may require manual steps from network engineers. The data may also not meet the requirements for rainfall observation and the servers may not be set up to store and share this data. To compound these challenges, MNOs often use different hardware vendors in their networks, with each vendor requiring a different network management system to access data from CMLs.

While some software from hardware vendors is conducive to CML data extraction, such as Huawei's Network Cloud Engine (NCE), third-party software can enable CML data to be sourced from multiple hardware vendors (e.g. Infosim StableNet) and provide additional functionality for configuring data collection (e.g. pySNMPdaq). Hardware vendors are recognising the opportunity to use CML data to improve network performance monitoring, such as Ericsson's software development described in Case study 2.

The installation of an additional server that resides outside the mobile network enables CML data to be stored and shared with third parties without compromising the security of the mobile network. Figure 15 outlines the data extraction process.

### Intellectual resources

Additional intellectual resources may be required, including third-party software for data acquisition such as pySNMPdaq and Infosim StableNet. These software packages communicate directly with CML hardware devices and can extract performance data.

### Human resources

To set up and run the systems required for data extraction, the network management team will need to configure the network management system. Depending on the functionality of the acquisition software, they may be able to set up a script that extracts the data automatically. If not, they will need to extract it manually. IT engineers may be required to configure the jump server, storage space and scripts to transfer the data from the mobile network environment to the jump server storage. External consultants may need to be engaged when third-party data acquisition software is installed.

**Figure 15**

## CML data extraction process for third-party processing

Source: GSMA

## CASE STUDY 3

# Data extraction

The data extraction process will differ depending on the hardware and software used, as well as internal processes and structures. The following are two examples of steps taken by MNOs to automate the extraction of CML data from their mobile network.

### MTN Nigeria: installation of Stablenet

In the MTN network, hardware from Ericsson and Huawei constitutes the majority of CMLs. Initially, data from Huawei links was only available for manual extraction through their NCE software. Ericsson data was not available at all due to limited server capacity (not all links in the network could be handled), resulting in inconsistent data.

To overcome these limitations and build a single access point for all CML data, MTN invested in the Stablenet network management system. This system enables network hardware to be integrated across multiple vendors by polling network devices directly through the simple network management protocol (SNMP) used universally by network devices. Automation of data extraction is simplified as Stablenet enables reports to be created that specify the data to be collected. These reports can be programmed to run at set intervals, making data continuously available. The data is backed up to an internal server that sits outside the mobile network to provide secure access to third parties. Setting up the internal server and enabling data flows required the involvement of the Information Systems team and consent from the Risk and Compliance Division.

### Digicel Papua New Guinea: CML data extraction from Huawei NCE

During the study period, Digicel's network used CML device hardware from three manufacturers. CML data was not available from two of these manufacturers as links were either being phased out or were too long for rainfall estimation. Data from Huawei links, the remaining manufacturer, were accessed through Huawei's NCE software. Extraction from this software to an internal server was automated using NCE to provide rolling storage of seven days of CML data. The resulting datasets were transferred to the server of KNMI once a week. Setting up NCE to extract the data took the network team about one day, and monitoring and uploading data to the KNMI server took approximately 30 minutes per week.

## 3.3.2 Validating and optimising CML rainfall observation

Once CML data has been accessed, it needs to be analysed to confirm whether it is valid for rainfall observation.

First, a small sample of data, typically the metadata and one week of performance data (ideally covering a rainfall event in the coverage area), is used to sense-check the suitability of the data. This involves ensuring that the metadata and performance data can be linked successfully, and then processing the resulting dataset with a rainfall retrieval algorithm. The outputs of the algorithm will be a map of suitable CMLs for rainfall retrieval and a map of rainfall intensities for any rainfall events in the study period. These can be sanity-checked to ensure that the network provides adequate coverage and that rainfall retrieval is successful.

Validation of CML rainfall observation requires a dataset that covers a minimum of one year or at least one wet season in countries with distinct dry/wet seasons. This data is compared to a reference dataset from ground-level data sources to assess the accuracy of the CML rainfall observations (see section 2.4). Depending on the extent of the reference data, the accuracy of the algorithm can be assessed in various contexts, such as urban and rural, and for different climate types within the coverage area. Section 2.4.3 provides the results of validation studies for GSMA engagements.

The rainfall retrieval algorithm can be optimised to local conditions depending on the results of the validation exercise. Optimisations can focus on adjusting the parameters used to convert signal strength reductions to rainfall intensity to better reflect the local climate. To achieve this, data on drop size distribution (DSD), or the physical characteristics of rainfall, is required to determine the correct parameters. A more incremental improvement would be using the reference dataset to fine-tune the algorithm, essentially retrofitting parameters in the algorithm to better match the reference data.

#### Technical resources

Since third-party experts typically process CML data into rainfall observations, no additional technical resources are required by the MNO. The experts processing the data will need computing equipment that can process these large datasets.

#### Intellectual resources

Various types of data are required during this step:

- CML data that covers at minimum one rainy season, but ideally one year or more of data for the entire network
- Reference rainfall data from ground-level sources (e.g. rain gauges) that covers the same period and area as the CML data
- To optimise algorithms, DSD data from different climate zones in the country covering at least one rainy season (which does not have to overlap with the study period)

An algorithm is required to process the CML data into rainfall observations and interpolate them onto a spatial grid, as outlined in section 2.2. RAINLINK and pycomlink are two open-source packages that can perform this processing.

#### Human resources

Technical experts will need time to aggregate and pre-process the various data sources, process the CML data using the rainfall retrieval algorithm, run the comparison of CML rainfall data to the reference data set, analyse the results and perform any necessary algorithm optimisations. The time required for each of these steps may vary significantly depending on the state of the data and the outcomes of the analyses. The time ranges provided in Table 6 are estimates based on GSMA projects. These estimates assume that the MNO is active and involved in providing and interpreting the metadata and performance data, the process for coupling metadata and performance data is clear, the person performing the work has a working knowledge of the relevant coding language (i.e. R or Python) and reference data is available in digital format.

Table 6

### Estimated time required for CML data processing and optimisation

Source: GSMA

| Activity | Estimated time required |
|---|---|
| Aggregate and pre-process data | 1–4 weeks |
| Configure and run rainfall retrieval | 1 week |
| Compare CML data to reference rainfall data | 2–4 weeks |
| Optimise algorithms | 1–2 weeks |

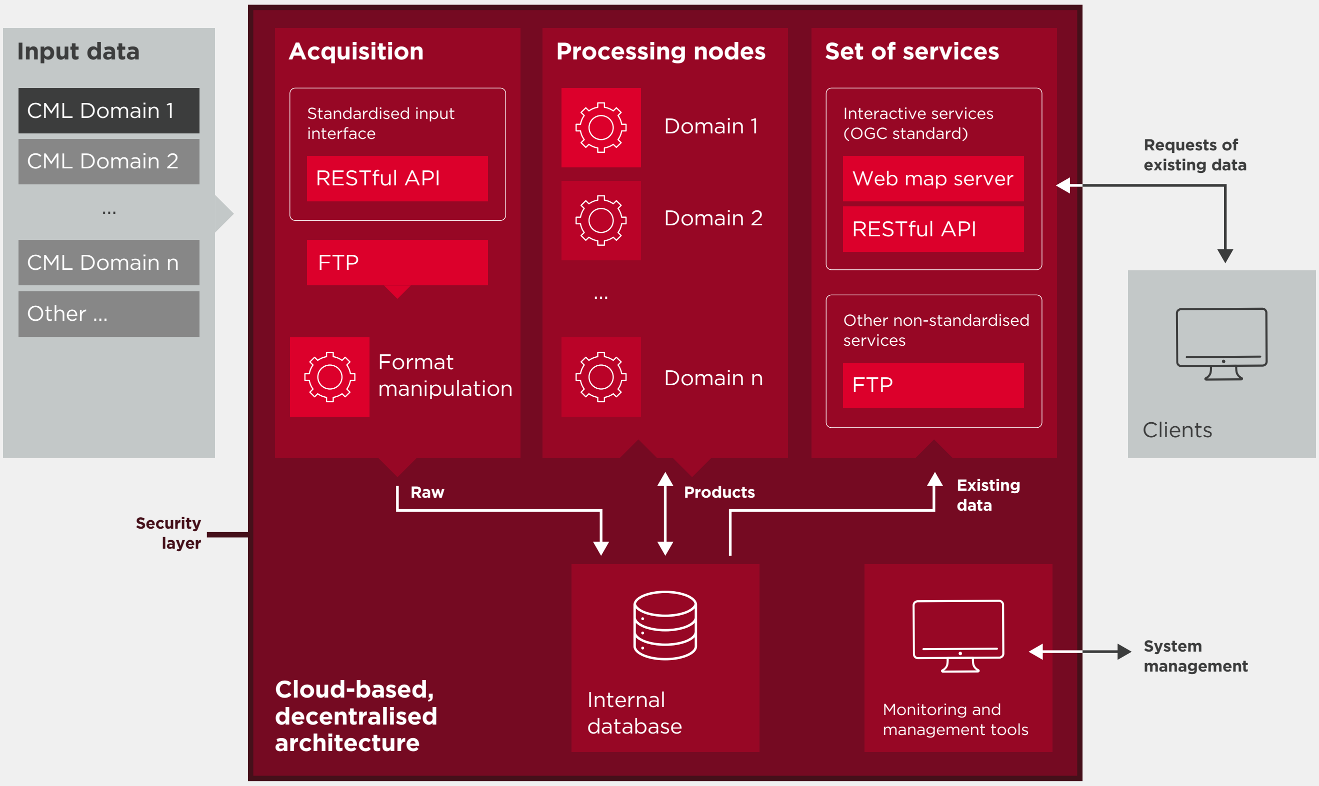
## 3.3.3 Enabling real-time CML rainfall data

To develop data services that can be used to create weather and climate services requires automating the data acquisition and processing chain and providing front-end services, such as APIs and interactive rainfall maps. Numerous approaches can be taken. This section highlights the approach taken by GSMA technical partner Hyds for Dialog Sri Lanka (described in more detail in Case study 4).[69] Figure 16 shows the structure of the CML rainfall service they developed.

**Figure 16**

Structure of CML rainfall service

Source: GSMA



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[69] www.hyds.es

**Technical requirements**

To enable rainfall data services, CML data must be extracted and made available periodically by the MNO (see section 3.3.1). The system acquires this periodic CML data using the interface provided (API, secure file transfer protocol (sFTP)). This data is then pre-processed for use in the RAINLINK algorithm and stored. The processing node runs RAINLINK every time new input data is sourced and stores the output data in the internal database. A set of services provides access to the rainfall data. These include a REST-API to interact with the system and acquire the desired products while allowing the administrator to control access to the products. A web map server generates layers of the rainfall data that can be readily incorporated into map viewers. Figure 17 shows the technical requirements for implementing the system on Amazon Web Services, based on CML data from Dialog's CML network.

While this approach enabled research and pilot testing of the use of near-real time rainfall data in climate services, commercial applications with many users and stringent requirements will require a more integrated system that streamlines the data-processing steps and moves to a faster and more robust code base.

**Intellectual resources**

Provision of real-time rainfall data from CMLs requires a near-real time source of CML data (as specified in section 3.3.1) and an optimised rainfall retrieval algorithm (as specified in section 3.3.2).

Figure 17

## Illustrative system requirements for a CML rainfall data service

Source: GSMA

| Item description | Requirement |
|---|---|
| **CPU and RAM** | **t3.2 xlarge 8vCPU 32 GB RAM** |
| **Storage** | |
| CML data from ~2,500 link paths @ 15-minute intervals | 24 GB per year |
| Gridded rainfall data for 32,000 km$^2$ @ 15-minute intervals, 2 km grid | 2.4 GB per year |
| **Total storage** | **26.4 GB per year** |

## CASE STUDY 4

# Dialog’s real-time CML data service, developed by Hyds

As part of the CML engagement with Dialog Axiata Sri Lanka, the GSMA commissioned hydrometeorological innovative solutions provider Hyds[70] to develop a real-time CML rainfall data service based on the algorithms developed and optimised by technical partners WUR, KNMI and TU Delft (see section 1.1 for more information on this engagement).

The structure of the system is outlined in Figure 16. Data is transferred from Dialog’s jump server every 15 minutes using sFTP, then formats are standardised before it is stored in the internal database. Once the data is available in the database, it is processed using RAINLINK to generate rainfall observations. This data is stored in the internal database and can be accessed through a web map server (see Figure 18), RESTful API or through sFTP transfer. A user management system is included to provide secure access to output services.

The system was developed on Hyds’ internal servers before being transferred to an Amazon Web Services server. After delivering the service, Hyds provided proactive maintenance that included monitoring and troubleshooting the functioning of the service, configuring APIs as required and updating the service to accommodate changes to the Dialog CML network and updates to the RAINLINK algorithm.

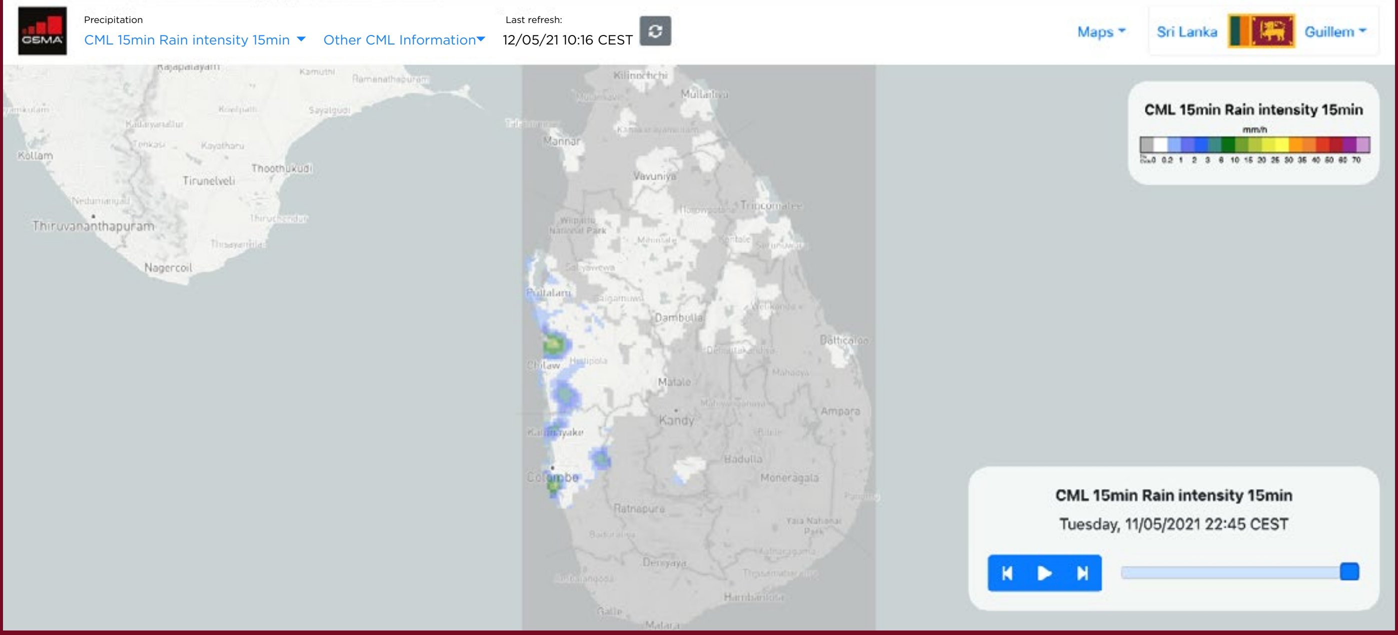
The entire process, from CML data acquisition to providing rainfall data, takes approximately 75 minutes (about 60 minutes to acquire CML data from Huawei NCE and about 10 minutes to process it with RAINLINK). Development work to shift data acquisition from Huawei’s NCE to dedicated pySNMPdaq software will drastically reduce the time it takes to acquire CML data, from approximately 60 minutes to five minutes.

To enable services levels required by commercial applications, the RAINLINK algorithm would need to be optimized for a real time use. Different optimizations could be implemented, such as a smarter processing logic to remove redundant calculations, using parallel computing and creating multiple CML area divisions to significantly speed up the algorithm. Additionally, the system will need to be scaled according to the number of active users in the system.

**Figure 18**

CML real-time system web map viewer

Source: GSMA



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[70] www.hyds.es

# 4

# Commercial: Enabling innovation in climate services with CML rainfall data

**This chapter presents the most relevant use cases for CML rainfall data, providing a brief overview of key actors, service creation activities, business models and return on investment (ROI). It also highlights the added value of CML rainfall observations.**

Given the nascent stage of CML rainfall observation and the need for continued investment to develop CML data services, it is crucial to identify services that could benefit from CML rainfall observations and garner the support to fuel this development.

Services for the agricultural sector would likely have a high socio-economic impact, but general weather services are a likelier entry point as they can serve several, and potentially more lucrative, sectors, as well as provide an important public service.

Section 4.1 identifies the weather services to which CML rainfall observations would add the most value while section 4.2 looks at agriculture-specific services. Section 4.3 discusses the business opportunities and approaches MNOs can pursue in the provision of CML rainfall services.

# 4.1

# Potential use cases: Weather services

The main purpose of hydrometeorological services is to support public and private sector decision-making in the face of weather, climate and hydrological hazards.[71] While weather services have historically been firmly within the remit of public NMHS, there is growing recognition of the potential value of private sector contributions. The Global Weather Enterprise (GWE) fosters global engagement between public, private and academic sectors that share a common goal of providing accurate and reliable weather information and services that save lives, protect infrastructure and enhance economic outcomes.[72] Achieving the Sustainable Development Goals (SDGs), especially in the context of climate change, requires all members of the GWE to maximise synergies to improve weather and climate services.[73]

The provision of rainfall observation data from wireless mobile backhaul networks is one way the private sector could contribute to the GWE. The high-resolution, quantitative precipitation estimates that CML data can provide are relevant to many hydrometeorological services, including rainstorm monitoring, flash flood forecasting and 24- to 48-hour weather forecasts.[74] They also enable verification and fine-tuning of forecasting models through model calibration, post-processing and downscaling.[75]

However, public-private collaboration in weather services can be contentious in many countries due to national regulations and institutional structures.[76] For example, the NMHS in many LMICs and some HICs rely on the sale of meteorological data and provision of industry-specific services[77] as a revenue source. In other contexts, where public institutions are prohibited from commercial activities, they may limit access to their data, legislate against the private sector providing services and cross-subsidise the provision of industry-specific services.[78]

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[71] World Bank. (2019). Weathering the change: how to improve hydromet services in developing countries?

[72] Ibid.

[73] Thorpe, A. and Rogers, D. (2018). The future of the global weather enterprise.

[74] World Bank. (2019). Weathering the change: how to improve hydromet services in developing countries?

[75] Ibid.

[76] World Bank. (2021). Public and private engagement in hydromet services: from rivalry to co-production.

[77] Ibid.

[78] World Bank. (2019). The power of partnership: public and private engagement in hydromet services.

Despite such challenges, collaborations between MNOs and public NMHS are underway. For example, to provide infrastructure to aggregate rainfall observation data,[79] to provide official severe weather early warnings,[80] to co-locate AWS with mobile base stations[81] and to use weather forecast data to provide agricultural value-added services (VAS), such as Myanmar's Site Pyo.[82] It can also be argued that collaborations with NMHSs are necessary in the provision of services demanding immediate action, such as early warnings, as otherwise there is the potential for confusion and a lack of consistency which would undermine actions taken on the basis of the warnings.

Collaborations with public NMHS to provide weather services using CML rainfall observations fall under two basic frameworks: CML rainfall data-as-a-service and co-production of weather services.[83]

With **CML rainfall data-as-a-service**, the sourcing of rainfall observations for public weather services is outsourced by the NMHS to an MNO. To further monetise the data, the agreement restricts the use of rainfall data for private commercial services. This framework requires the NMHS to have the means to pay for the rainfall data.

Under the **co-production** framework, both organisations collaborate to improve the production and/or delivery of weather services. This can involve exchanging resources and services in kind or revenue sharing from the services they develop. For example, the NMHS provides weather forecast data (improved with CML rainfall observations) that the MNO delivers through their VAS offering.

The following two sections focus on the development and provision of two weather services: rainfall nowcasting and flood early warnings. These services benefit most from CML rainfall observations and can be provided with relatively little additional data.

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[79] World Bank. (2019). The power of partnership: public and private engagement in hydromet services.

[80] Ibid.

[81] Ibid.

[82] GSMA. (2017). Ooredoo Myanmar Site Pyo.

[83] World Bank. (2021). Public and private engagement in hydromet services: from rivalry to co-production.

## 4.1.1 Rainfall nowcasting

Rainfall nowcasting provides high-resolution rainfall forecasts up to six hours in advance. They are based on high-resolution rainfall observations (typically radar) that are spatially extrapolated into the future.[84] Interest in nowcasting for Africa[85] has been sparked by the availability of satellite nowcasting models provided by the Nowcasting Satellite Application Facility[86] (NWC SAF), which draws on second-generation data from EUMETSAT. In agriculture, nowcasts can alert value chain actors to impending storms and heavy rainfall, allowing them to act more quickly to mitigate losses.

### Service creation

CML rainfall observations are typically the only high-resolution rainfall data source available in LMICs with similar properties to radar data. Open-source nowcasting models can be used to generate nowcasts[87] and have proven effective at generating nowcasts using only CML data.[88] However, given the limited geographical coverage of CML rainfall data (as described in section 2.2), supplementing it with precipitation data from geostationary satellites[89,90] is desirable and, in some cases, may be necessary to provide viable nowcasting services. However, obtaining a homogeneous dataset from two separate sources is a challenge and requires further investigation.

Nowcast data can be used to design a variety of services, including data services, nowcast maps and heavy rainfall early warnings, depending on the target user group. MNOs are well placed to support the delivery of nowcast services as they can provide the data infrastructure to develop APIs and can use their mobile channels to deliver rainfall early warnings.

### Relevance

Nowcast data can be used to generate a variety of public and private services for specific industries:[91]

- Transport: visibility and detection of thunderstorms, evaluation of road safety
- Energy: hydroelectric power generation
- Emergency services/disaster response: flash flood and landslide early warnings (see below)
- Agriculture: heavy rainfall warnings
- Construction: heavy rainfall warnings
- Sports and leisure: (heavy) rainfall warnings
- Aviation: visibility and detection of thunderstorms

### Key actors

Two groups of stakeholders are involved in the creation of CML-enabled rainfall nowcasting services: MNOs that provide the CML data and the hydrometeorological service providers (including public, private and academic organisations) that process the CML data into rainfall observations and generate nowcasts from the CML rainfall data.

### Revenue models

Revenue can be generated from rainfall nowcasts by providing early warnings or nowcast data services to weather-sensitive industries on a subscription basis. Consumer services can also generate advertising revenue from nowcasting maps. MNOs may also derive positive benefits from the provision of nowcasts as VAS, including market share and customer retention.

**Figure 19**

Rainfall nowcasting: service creation steps

Source: GSMA

| Data collection | Analysis | Service design | Service delivery |
|---|---|---|---|
| **High-resolution rainfall observations**<br>- CML<br>- Geostationary satellite | **Probabilistic nowcasting of rainfall fields**<br>- Statistical e.g. pySTEPS<br>- Machine learning | **Rainfall nowcast data**<br>**Rainfall nowcast maps**<br>**Rainfall early warnings** | **Application programming interface (API)**<br>**Online services**<br>**Mobile channels (SMS, USSD, IVR)** |

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[84] World Meteorological Organisation. (2017). Guidelines for Nowcasting Techniques.

[85] SWIFT. (2021). The future of African nowcasting.

[86] www.nwcsaf.org

[87] https://pysteps.github.io/

[88] Imhoff, R.O. et al. (2020). Rainfall nowcasting using commercial microwave links.

[89] https://africanswift.org/about/

[90] Hill, P.G. et al. (2020). How skilful are Nowcasting Satellite Applications Facility products for tropical Africa?

[91] SWIFT. (2021). The future of African nowcasting.

## 4.1.2 Flood early warning systems

One of the impacts of climate change is the increased intensity and frequency of extreme weather events. Floods are the most frequent natural disaster and affect the largest number of people globally.[92] Early warning systems (EWS) are a key tool to prevent extreme weather events from turning into climate disasters. Recognising the importance of multi-hazard early warnings and building on the Sendai Framework for Disaster Risk Reduction,[93] the United Nations announced in 2022 a new plan to ensure that every person on Earth is protected by an EWS within five years.[94]

Flood EWS that use CML rainfall observations can provide advance warning of floods caused by intense rainfall over a relatively small area (flash floods) or intense rainfall causing bodies of water to rise and overflow onto neighbouring lands (river floods). The short timespan between a rainfall event and a flash flood makes this type of event very difficult to forecast. Flash flood EWS can be very effective at preventing fatalities due to the efficiency of such systems and the relatively low cost of evacuating for a flash flood.[95]

### Service creation

Precipitation data is one of the key data inputs for flood early warnings. CML rainfall observations can provide high-resolution rainfall data with a high degree of accuracy, especially in urban areas where the human impact of flash floods is greatest. CML rainfall data can be combined with geostationary satellite rainfall data and available ground-level sources to improve coverage and accuracy.[96] For riverine flood early warnings, data on water levels is an additional data input that can significantly improve accuracy. Innovations in river flow observations include the use of low-cost cameras to capture images of river flow that are analysed using computer vision approaches.[97]

Input data is modelled using hydrological analysis that determines the rainfall thresholds at which surface runoff occurs and the routes that the runoff will take. This is crucial to determining where to issue early warnings.[98] Data outputs can be used to develop data services for integration in third-party models, to deliver (flash) flood early warnings directly to at-risk populations and to create risk maps that provide an overview of at-risk areas. MNOs have a key role to play in delivering (flash) flood early warnings as they can use cell broadcast technology to send warning short message services (SMS) to users in specific areas.

**Figure 20**

### Flood early warning: service creation steps

Source: GSMA

| Data collection | Analysis | Service design | Service delivery |
|---|---|---|---|
| **High-resolution rainfall observations**<br>– CML<br>– Geostationary satellite<br>– Ground-level data (rainfall, water levels) | **Hydrological analysis**<br>– Determine rainfall thresholds<br>– Determine runoff routes | **Flood risk data** | **Application programming interface (API)** |
| | | **Flood risk maps** | **Online services** |
| | | **Flood early warnings** | **Mobile channels (Cell broadcast, SMS, USSD, IVR)** |

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[92] Center for Research on the Epidemiology of Disasters. (2018). Economic Losses, Poverty & Disasters 1998–2017.

[93] UNDRR. (n.d.). Sendai Framework for Disaster Risk Reduction 2015–2030.

[94] United Nations. (23 March 2022). "UN weather agency to spearhead 5 year early warning plan, boosting climate action". *UN News*.

[95] Hoedjes, J.C.B. et al. (2014). A Conceptual Flash Flood Early Warning System for Africa, Based on Terrestrial Microwave Links and Flash Flood Guidance.

[96] Ibid.

[97] Winsemius, H. et al. (2021). OpenRiverCam, open-source operational discharge monitoring with low-cost cameras.

[98] Hoedjes, J.C.B. et al. (2014). A Conceptual Flash Flood Early Warning System for Africa, Based on Terrestrial Microwave Links and Flash Flood Guidance.

### Relevance

Early warnings enable people to act quickly to prevent the loss of assets and lives in anticipation of a flood event. They have been extremely cost-effective, with estimates showing that spending $800 million on EWS in LMICs would avoid $3 billion to $16 billion per year in losses.[99] To maximise their impact, flood early warnings should be provided as a public service to the general population and as tailored services for weather-sensitive industries.

### Key actors

MNOs can play a multi-faceted role in the creation and delivery of flood early warnings. In addition to providing the CML (rainfall) data, they can also provide the data connectivity to collect data from ground-level gauges and IoT sensors, and the dissemination channel for early warnings through the use of cell broadcast technology. Hydrometeorological service providers, meanwhile, source supplementary data where needed, integrate the data inputs and run the hydrological models to determine whether and where to issue warnings.

### Revenue models

Early warnings are typically provided as a public service and require public or donor funding to operate. Commercial services can be provided to the public or weather-sensitive industries on a subscription basis or as a mobile VAS, which may increase market share and customer retention.

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[99] Global Commission for Adaptation. (2019). Adapt now: A global call for leadership on climate resilience.

# 4.2

# Potential use cases: Agriculture

A range of digital services can mitigate the challenges smallholder farmers face and improve the functioning of agricultural value chains, particularly in the last mile.[100] Figure 21 outlines how digital agriculture sub-use cases can address challenges posed by climate change in the long- and short-term and highlights digital agricultural services that derive significant added value from CML rainfall observations. The following sections focus on data-driven agricultural advisory services (DDAS) and agricultural insurance. Early warnings for the agriculture sector were covered in section 4.1.2.

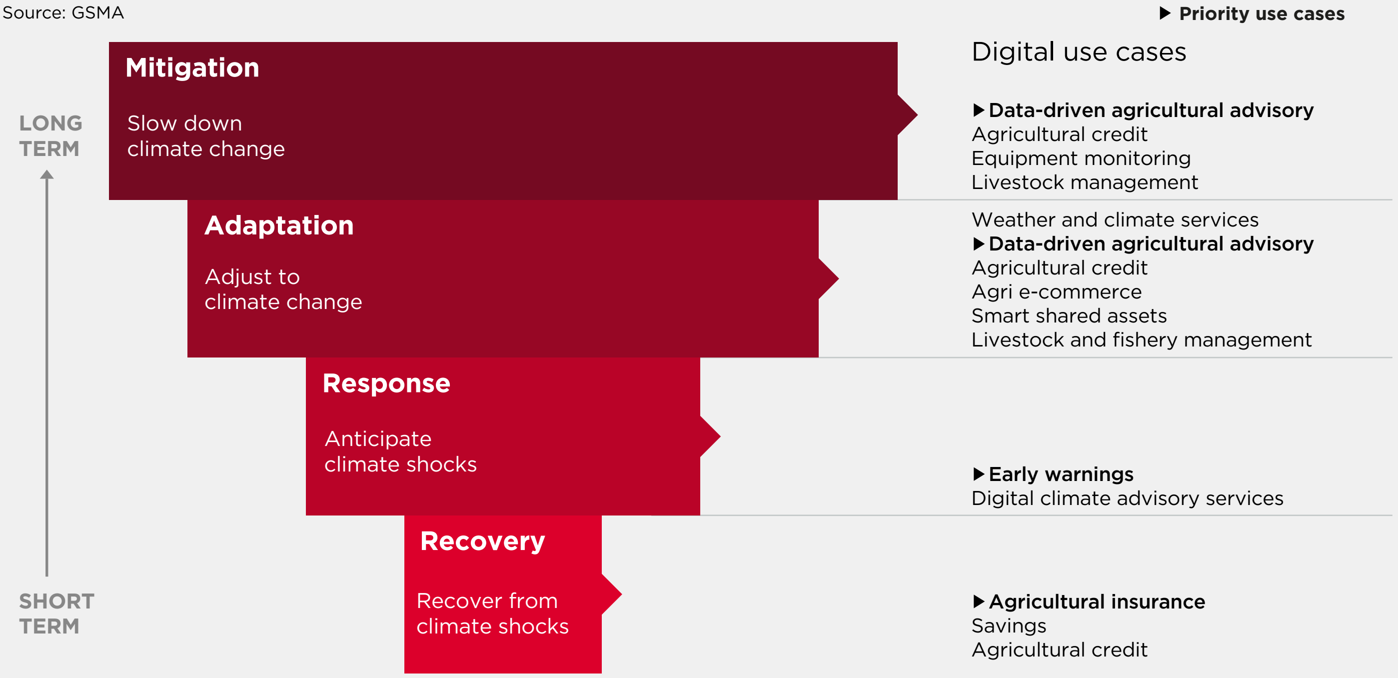

Figure 21

Digital agriculture and climate resilience

Source: GSMA

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[100] The "last mile" refers to the web of relationships and transactions between farmers, crop buyers and input suppliers. GSMA. (2020). Digital Agricultural Maps.

## 4.2.1 Rainfall index insurance

Digital agricultural insurance services, such as index or parametric insurance, rely on secondary data sources such as weather and crop observations for actuarial modelling. This greatly reduces the cost of assessing claims compared to traditional indemnity-based insurance services.[101] Leading service providers, such as Acre Africa, Pula Advisors and OKO, typically use data from satellite observations and/or crop-cutting experiments to infer the adverse impacts of weather conditions on farmers and determine damages and pay-outs. CML rainfall observations have the potential to be an additional data source for rainfall-specific insurance.

### Service creation

The creation of index insurance services requires extensive historical data on variables of interest, which is then used to develop actuarial models to assess risk. For example, satellite data can be used to monitor water availability to plants and identify areas of drought. To distinguish drought from normal or exceptionally wet years, historical data is used to analyse trends and create a risk model. This process is called actuarial modelling. Once the model has been established, (near)-real time observations from the same data source are used to determine whether specific thresholds have been met to trigger pay-outs. Basic farmer registration data, including location, is required to determine and activate pay-outs.

Designing index insurance services for smallholder farmers often involves bundling insurance with complementary services, such as loans or inputs, to maximise value and enable viable revenue models. For example, bundling weather index insurance and loan products can reduce the risk of providing loans to smallholder farmers. Weather risks are covered and the loans that farmers receive pay for the insurance product. Integrating digital technologies, such as mobile money for pay-outs and mobile channels for product registration, can also reduce the cost of delivering insurance services and help them to scale.

### Relevance

Economic losses from weather and climate events increased seven-fold between 1970 and 2010, and will continue to rise as the impacts of climate change become more intense and widespread.[102] However, insurance coverage of smallholder farmers is still extremely limited. An estimated 20% of smallholders in LMICs are covered and just 3% in Sub-Saharan Africa.[103] A recent analysis has indicated that an increase in insurance penetration of just 1% could reduce economic losses in LMICs by 22%.[104]

Figure 22

Rainfall index insurance: service creation steps

Source: GSMA

| Data collection | Analysis | Service design | Service delivery |
|---|---|---|---|
| **High-resolution rainfall observations**<br>- AWS<br>- CML<br>- Geostationary satellite | **Actuarial modelling to develop a risk model that determins the threshold for payouts.** | **Bundling**<br>- Input<br>- Credit<br>- Other insurance services | **Smartphone apps** |
| **Historical rainfall data (>10 years)**<br>- From same sources as rainfall observations | | **Mobile money integration**<br>- Reduce costs to collect fees and make pay-outs | **Mobile channels (SMS, USSD, IVR)** |
| **Basic farm data**<br>- Farm location<br>- Crops cultivated<br>- Mobile number | | | **Face-to-face** |

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[101] GSMA. (2020). Agricultural insurance for smallholder farmers: Digital innovations for scale.

[102] ISF Advisors. (2022). State of the sector: agri-insurance for smallholder farmers.

[103] ISF Advisors. (2018). Protecting growing prosperity: agricultural insurance in the developing world.

[104] Lloyds. (2018). A world at risk: closing the insurance gap.

**Key actors**

Insurtechs, such as Pula, OKO, and eLeaf, have been driving forces in index insurance innovation. They typically cover key service creation steps, including data collection and modelling, as well as service delivery. These organisations either provide the services independently or partner with existing (re-) insurers. Other collaborators include organisations that offer services or products that can be bundled with insurance, such as loan and input providers, government agencies interested in subsidising or providing insurance and development agencies, agribusinesses and service platforms (including those provided by MNOs) that can aggregate demand for insurance services among smallholder farmers.

**Revenue models**

Several approaches are being used to generate revenue from insurance services. Government-subsidised agricultural insurance services are among the most scaled-up insurance programmes in operation. Subscription-based services are provided by OKO, for example, but require substantial marketing and user education to be successful. Bundled services are the most common and enable cost- and revenue-sharing with services such as loans and products such as inputs.

## CASE STUDY 5

# Sanasa and Dialog

Sanasa General Insurance Company (SGIC) was established in 2003 as a micro insurance provider with the main focus of serving rural masses using the network of Sanasa Thrift & Credit Societies, the largest network of savings and credit cooperatives in Sri Lanka, consisting of over 8,000 cooperatives and over 3.7 million members. These cooperatives represent a large part of Sanasa's customers. For the agricultural sector, Sanasa general insurance provides over 53 indemnity-based insurance products and rainfall index insurance for rice (paddy), tea, papaya and banana.

Sanasa has a partnership with MNO Dialog Axiata to provide rainfall index insurance for tea, with Sanasa providing the insurance product and Dialog educating and subsidising customers. In tea cultivation, there is a strong relationship between rainfall and yield, which allows the service to use rainfall as a proxy for yield loss. The insurance covers excess and deficit rainfall monitored over monthly time periods, with pay-outs made once a trigger (predetermined rainfall amount) is reached. The pay-out is a set minimum value plus an additional percentage depending on the degree to which actual rainfall differs from the "normal" volume.

To develop the risk model, Sanasa used more than 30 years of historical rainfall data from the Sri Lankan Department of Meteorology (SLMET) rain gauges. This ensured that the baseline and trigger rainfall amounts accurately reflected the climatic variations and allowed pricing to be set for the service. However, the coverage of SLMET weather stations is limited and reliability issues were encountered with manual gauges. Efforts to install weather stations in rural communities encountered maintenance difficulties that resulted in unreliable readings. In 2019, a partnership with the International Water Management Institute[105] (IWMI) facilitated access to satellite data that was used in areas not covered by rain gauges.

Sanasa and Dialog are exploring the use of CML data as an additional source for monitoring rainfall thresholds and determining insurance pay-outs. Since there is not sufficient historical data to develop risk models based on this source alone, pilot studies will need to be carried out over several years to confirm the suitability of using CML data. These studies will look at the reliability of CML rainfall data compared to weather stations and make qualitative comparisons to human observations. Including CML data as a higher resolution data source is attractive as it has the potential to reduce basis risk. However, sufficient historical data (at least 20–30 years) is required to develop the risk model at this higher resolution.

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[105] www.iwmi.cgiar.org

## 4.2.2 Data-driven agriculture

Data-driven agricultural advisory services enable evidence-based decision-making by integrating a variety of data sources.[106] DDAS build on conventional advisory services by considering a user's location and current local agrometeorological conditions to tailor advice. While water availability to plants and areas of drought can be reliably measured using satellite data on evapotranspiration,[107] rainfall observations can inform specific agricultural practices, such as land preparation, fertiliser application and irrigation.[108] At a more macro level, business-to-business (B2B) and business-to-government (B2G) DDAS can inform strategic decisions, including where to invest, and more operational decisions, such as optimising crop-sourcing activities.

### Service creation

DDAS draw on several data sources, including primary data from remote-sensing sources such as satellites and unmanned aerial vehicles (UAVs); in situ sensors such as soil sensors and weather stations; survey data and service-generated data; as well as secondary data sources, such as agronomic research data, weather and climate forecasts and socio-economic data. These sources may be analysed through several approaches, including machine learning, modelling and expert assessments to generate location and time-specific insights. These insights can be developed into agricultural advisory content, applying user-centred design to ensure advice is relevant to the end user in both content and format, and appropriate for the intended delivery channel. Services are delivered through a range of digital and digitally enabled face-to-face channels, including extension visits, call centres, mobile apps and chatbots.

### Relevance

Digital advisory services are a cost-effective way to improve yields and influence the adoption of beneficial agricultural practices.[109] They have also been shown to improve farmers' ability to plan their production and deal with weather-related risks.[110] Although few rigorous studies have been conducted on the impact of DDAS, agritech companies such as CropIn and DeHaat Agrevolution in India see DDAS as central to their operations. They use it in their service platforms to guide input decisions and in the application of good agricultural practices to improve the quality and quantity of crops produced by smallholder farmers.[111] The success of this approach and the rapid scaling up of implementing organisations indicate that DDAS is effective at achieving these goals.

Figure 23

## Data-driven agriculture: service creation steps

Source: GSMA

**Data collection**

**Primary data**
- Remote sensing
- Sensors
- Survey
- Service-generated

**Secondary data**
- Agrononic research data
- Advisory content
- Weather and climate data
- Socio-economic data

**Analysis**

**Machine learning / AI**

**Modelling**
- Crop
- Pest and disease
- Emissions
- Logistics

**Software and cloud services**
- Cloud computing
- Analysis software

**Service design**

**User-centred design**

**Content localisation**

**Expert assessment**

**Content formatting**

**Quality assurance**

**Service delivery**

**Face-to-face**

**Basic phones**
- Call centres
- IVR
- SMS
- USSD

**Web-enabled**
- Smartphone apps
- Dashboards
- Audio-visual content
- Messaging / social media

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[106] GSMA. (2022). Data-driven advisory services for climate-smart smallholder agriculture.

[107] Evapotranspiration measures the movement of water from the land surface into the atmosphere. One major constituent of this is transpiration, the movement of water from the soil to the atmosphere via plants.

[108] GSMA. (2022). Data-driven advisory services for climate-smart smallholder agriculture.

[109] Fabregas, R. (2019). Realizing the potential of digital development: The case of agricultural advice.

[110] Baumüller, H. (2017). The Little We Know: An Exploratory Literature Review on the Utility of Mobile Phone-Enabled Services for Smallholder Farmers.

[111] GSMA. (2022). Data-driven advisory services for climate-smart smallholder agriculture.

### Key actors

The variety of data sources, analytical approaches, service design and delivery approaches used to create DDAS is a reflection of the diverse actors involved. Typically, DDAS are created by an agritech company that is the service owner. Their core activities are applying user-centred approaches to service development and delivering advice through innovative and inclusive channels. Where companies provide a bundle of agricultural services, they focus on the development of the digital services platform and onboarding of partners that provide bundled services. In this case, they also maintain a network of field agents that register new users and deliver services.

Agricultural research institutes are key partners of service owners as they provide data and content on good agricultural practices and play a role in the expert assessment of data to provide advice and/or quality assurance of advisory content. Additional partners include weather services and precision agriculture providers that provide access to additional data sources, and extension services that enable user registration and face-to-face content delivery. MNOs can play a role in providing digital channels for service delivery, such as SMS, interactive voice response (IVR) or VAS platforms.

### Revenue models

Several revenue models are being used in the provision of DDAS. Advisory services are commonly provided as a stand-alone service to farmers or organisations on a subscription basis. Due to the difficulty of generating sales to smallholder farmers, these are often subsidised through public or donor funding. User registration data and data on farmer activities, where available, enable targeted advertising by input providers and other rural service providers, enabling an additional data stream. In bundled DDAS provision, advisory services are often provided for free. The cost of service delivery is shared across the portfolio of bundled services, and revenues from bundled services such as the sale of inputs or mobile services are used to cross-subsidise the creation of DDAS.

## CASE STUDY 6

# Hello Tractor and MTN Nigeria

Hello Tractor,[112] founded in 2014, is an agritech company providing smallholder farmers access to shared tractor services. Hello Tractor enables farm equipment sharing by offering a low-cost, IoT-enabled monitoring device that can be installed on any tractor, and a digital booking system that enables farmers to access tractors in their area. Hello Tractor makes mechanisation accessible to smallholder farmers while expanding the area that tractor owners can service. They use a network of digitally enabled rural booking agents to aggregate demand and place orders, providing additional rural employment opportunities.

The Tractor Owner app provides tools to help a tractor owner build their business and optimise their operations. To do this, it draws on several data sources including monitoring data from the tractor, demand from the booking app and weather observations and forecasts. This data is combined to improve planning of planting time, optimise tractor service delivery routes and mitigate weather-related service delays. In Nigeria, Hello Tractor identified a gap in the weather observations they are currently using, which, given the highly localised and volatile weather events occurring in their areas of operation, makes it challenging to optimise logistics.

Hello Tractor recognises the opportunity of high-resolution CML rainfall data to fill this data gap and improve their tractor utilisation. They have worked with the GSMA and MTN Nigeria to conduct an initial feasibility study to validate the correlation between CML rainfall observations and historical tractor activity and how this contributes to forecasting of demand for tractor services. Beyond using data from MTN Nigeria to improve logistics and demand modelling, Hello Tractor sees an opportunity to work with MTN to target the marketing of their services based on socio-demographic data that MTN holds on their customers.

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[112] https://hellotractor.com

# 4.3
# MNO involvement in CML rainfall data services

Using CML data for rainfall observation presents a unique opportunity to close some of the weather data gaps in LMICs. However, the provision of rainfall data sits outside the core business of the MNOs that own the data. Many active in this field have cited this as one of the main barriers to collaborating with MNOs to access CML data. Compared to the provision of mobile connectivity, CML data has limited commercial potential. However, there are several opportunities that may provide MNOs with sufficient incentive, especially given the limited resources needed to enable access to CML data.

Once the decision has been made to provide CML rainfall services, there are several ownership options depending on the level of data processing the MNO takes on. This chapter will explore potential business opportunities for MNOs to provide CML data and potential ownership models they can use to provide services.

## 4.3.1 Business opportunities of CML rainfall services for MNOs

CML rainfall services present opportunities for MNOs to monetise data generated by their existing mobile network infrastructure, to have a positive socio-economic impact and to enable the development or improvement of VAS. It is hoped that these opportunities, balanced against the modest investments required to make CML data available for rainfall estimation, are enough to entice more MNOs to provide such services.

### Data monetisation

CML data is a valuable and unique source of weather data that can provide an additional revenue stream through the sale of the data. Once a suitable platform for accessing and sharing the data is established, it can be sold to interested parties such as NMHS and private weather companies for further monetisation (given there is a favourable regulatory environment, see section 4.1). The value of this data depends on several factors that vary by market, including the availability of alternative sources and the maturity of climate services and their users (weather-sensitive sectors). During early stages, climate services are more likely to use freely available data sources to develop services, such as satellite data, and may not be able to generate value from the additional resolution and precision offered by CML data. The likely entry point for data monetisation services would be well-established industries such as utilities (hydropower) or aviation, where improved climate information has an immediate impact on returns.

**Service creation**

An alternative approach, which could be better suited to a less mature climate services sector and user base, is to forge partnerships with organisations to create services that use CML rainfall data and other MNO assets, such as service delivery channels. This approach is more likely to uncover use cases and markets where CML data could add the most value. These partnerships reduce the risk of collaboration for CSPs by reducing the upfront costs and sharing the risks and rewards of service creation through revenue-sharing models. For MNOs not yet providing relevant services, this can be a way to enter strategic partnerships with organisations that could open access to new markets.

**Corporate social responsibility**

Practicing corporate social responsibility (CSR) enables companies to be aware of, and enhance, the impact they have on all aspects of society, including economic, social and environmental. The mobile industry has been at the forefront of CSR. In 2016, it became the first industry to commit to accelerating the achievement of the SDGs and has made steady progress ever since.[113] More recently, the mobile industry committed to becoming net zero by 2050, with more than 50 MNOs representing 63% of the industry by revenue committing to rapidly cut their emissions over the next decade.[114] The significant value that CML rainfall data can add to weather and climate services in LMICs, especially flood early warnings, presents a significant opportunity for MNOs to impact SDG 13: Climate Action. It also provides an opportunity to build relationships and foster goodwill with government agencies, such as NMHS and disaster management centres. Given the increased interest of the global donor community in public services like early warnings, pursuing services with high socio-economic impact (e.g. early warnings for urban flooding) are likely to attract funding that would cover service development costs.

## 4.3.2 MNO ownership models for CML rainfall data services

The provision of CML data services by MNOs follows two main approaches: outsourcing data processing and commercialisation to third parties, or conducting these activities in-house. In both cases, the MNO must provide access to the CML data source. The choice of approach will depend largely on the business opportunities pursued. Owning the data service is most likely attractive to MNOs that use the CML data to improve or create services provided in-house. MNOs that are solely interested in monetising the data are likely to sell unprocessed CML data.

MNO-owned services conduct most activities in the processing chain of CML rainfall data, including storage, processing and sharing (where relevant). Given the niche intellectual resources required for these steps, this is typically done with the support of specialised technical service providers (see Case study 4 on Dialog Axiata Sri Lanka's real-time CML data service). Owning CML rainfall data services would allow MNOs to integrate them with existing services and to maintain control over data sharing and further commercialisation.

Third party-owned services are those that process raw CML data and integrate it in existing services or license it for further commercialisation. These require agreements with MNOs to acquire CML data on a subscription or revenue-sharing basis. While relatively few resources are needed to put agreements in place, negotiating them is complicated by the unclear value of CML data and derivative services. Third parties must be in a position to generate sufficient revenues to justify paying for this data, which may be challenging in countries where weather services and weather-sensitive industries are not sufficiently mature.

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[113] GSMA. (2022). 2022 Mobile Industry Impact Report.

[114] GSMA. (2022). Mobile Net Zero: State of the Industry on Climate Action 2022.

## 5

# Key messages and recommendations

**This report presents the opportunity for CML data to provide valuable weather data and enable rural climate resilience. Realising this opportunity depends on the collaboration of key stakeholders.**

The MNOs that own the mobile network devices that generate this data must be incentivised and enabled to provide it. Hydrometeorological service providers are domain experts that can process and quality-assure the data and use it to develop services. Donors can provide the funding needed to move past the research and development (R&D) stage and conduct pilots of live services that demonstrate the value of CML rainfall data. The recommendations in this report are tailored to each of these stakeholder groups.

# 5.1
# MNOs

**Wireless backhaul, specifically CMLs, is an untapped opportunity for rainfall observation.**

Mobile networks present a unique opportunity to provide high-resolution weather data from existing infrastructure. A growing body of research in both HICs and LMICs shows that CMLs can provide rainfall data with much higher accuracy and resolution than satellite data, providing radar-like data in countries without radar. This data has the potential to significantly improve weather and climate services in LMICs that typically have limited observation infrastructure.

**Rainfall data can be provided from wireless backhaul using open-source software for data access and rainfall retrieval.**

CML data for rainfall observation can be accessed using existing network management software or dedicated (open source) software. The resource requirements for implementing these systems are relatively low, especially for the implementation of R&D or pilot projects. Processing and validation of CML rainfall data can be done in-house in collaboration with technical specialists or outsourced. The automation of data extraction and processing enables the provision of real-time rainfall data services.

**MNOs can benefit from CML rainfall services by monetising the data, entering new sectors and improving corporate social responsibility.**

To maximise societal impact and revenue, CML rainfall data can be provided to third parties under data licensing agreements that limit its use by public and private sector actors. Collaborations with public and private weather service providers to develop new services can open access to new sectors and can be enriched with complementary MNO assets, including their IoT network, data management and information delivery services. The provision of CML rainfall data can enable weather services that have a significant positive socio-economic impact and can foster goodwill from government and the public alike.

**Flood early warnings are considered the most viable entry point for CML rainfall data services due to the added value of CML data and high ROI.**

Floods are the most frequent natural disaster and affect the largest number of people globally. Early warnings enable people to act quickly to prevent the loss of assets and lives, with estimates showing that $1 spent on early warning can avoid up to $20 worth of losses. CML rainfall observations can provide the high-resolution, real-time data necessary for flood early warning systems, especially in urban areas where the human and economic impacts of floods are greatest. Early warnings are attracting interest from the global development community, with the United Nations announcing in 2022 a new plan to ensure everyone in the world is covered by an EWS by 2027. This interest presents an opportunity for MNOs to collaborate with technical experts to develop their CML capabilities and play a role in providing early warnings to the public and private sectors.

# 5.2
# Climate service providers

**CML rainfall data provides a unique source of quantitative precipitation estimates with an extensive coverage area, high spatiotemporal resolution and real-time availability.**

With mobile networks covering more than 90% of the population of LMICs, CML data is an unprecedented resource for rainfall observation. Research in HICs has shown that CML rainfall observations provide similar accuracy as rain gauges and significantly outperform satellite data sources. Results from tropical markets reinforce these results, although a lack of ground-truth data impedes validation studies. Accuracy may be affected by network structure, and gains can be made by localising rainfall retrieval algorithms. CML rainfall observations are a strong complement to rainfall data from geostationary satellites, as they provide high levels of accuracy and resolution while satellite data fills coverage gaps.

**Accessibility is the main barrier to using CML rainfall observations and can be improved through the development and/or vetting of software to access CML data.**

Reducing the cost of accessing CML data will reduce the barriers for MNOs to collaborate on the provision of CML rainfall services. In addition to providing the intellectual resources to process and validate CML data, CSPs can support the installation or upgrading of software to access CML data in the form needed for rainfall observation. Much research has focussed on the conversion and optimisation of CML data to rainfall observations. However, the development of software to access CML data across hardware vendors, together with research that demonstrates the minimal load the data places on the network, are likely to address the practical concerns of MNOs.

**A strong business case for MNOs to provide CML rainfall observations is crucial for long-term collaborations.**

It is important to understand the motivations of MNOs to engage in CML work and to propose collaborations that address them. MNOs are typically motivated by data monetisation, the development of new services or CSR. Collaborations in which an MNO's contribution goes beyond CML data to service delivery, for example, would add more value and likely be more desirable to MNOs. CSPs are naturally placed to identify opportunities for climate services creation and attract funding to support them. Funding for technical development combined with a clear long-term business opportunity would create even more incentives for MNOs to participate.

# 5.3
# Donors

Donors have a crucial role in de-risking R&D for CML rainfall data services. While improvements can be made in retrieving rainfall observations from CML data, particularly consistency across contexts, there is sufficient evidence to demonstrate the value of this approach. Efforts must therefore be made to operationalise and commercialise CML rainfall data services, which would likely create an incentive for MNOs – the owners of this data – to collaborate.

## Suggested activities to support:

**Research and development**

*Optimising rainfall retrieval algorithms to provide consistent results across CML networks and climatological zones.*

Further studies are needed to refine existing algorithms by understanding the impacts of specific network characteristics (especially link length and frequency) and climate types. Such studies should use data from at least several hundreds of CMLs for more than six months to generate sufficient data points. Due to the difficulty of sourcing ground-level sources for data verification, such projects would benefit from funding to national or private weather providers to expand and run weather observations during the study period.

*Researching the integration of rainfall data from CMLs and geostationary satellites to provide a hybrid data source.*

Rainfall data from CMLs and geostationary satellites have strong complementarities. CMLs provide accurate high-resolution data but with coverage bound by population and national borders, while satellite data provides almost unlimited coverage but with less accuracy and lower resolution. Combining these data sources would fill the coverage gaps of CML data and may improve the accuracy of satellite models through real-time calibration with CML rainfall data.

**Operationalisation**

*Supporting the identification and development of software to facilitate real-time access to CML data.*

Conventional network management systems are typically not ideal sources of CML data for rainfall observation, as they are not intended to run at the resolution or duration required and are often hardware specific. This is an issue in backhaul networks, which often use devices from multiple hardware vendors. Developing dedicated “‘plug-and-play” tools that address these limitations and are cost-effective to install, and collecting evidence of their low impact on MNO networks, are likely to significantly lower barriers for MNOS to provide CML data for rainfall observation.

**Commercialisation**

*Supporting projects that use CML rainfall data to develop services with maximum potential for impact, such as rainfall nowcasting and flood early warnings.*

Donor-funded projects on CML rainfall data have so far focussed on R&D for rainfall retrieval from CMLs. To move toward the practical application of this technology, projects are needed that demonstrate the added value of CML data in high-impact use cases, such as rainfall nowcasting and flood early warnings. Lessons from these projects will provide further insight into operationalisation while also providing data to calculate ROI, which may help to mobilise additional support for CML projects.

*Supporting initiatives to explore how public, private and academic organisations can collaborate to develop and provide commercially sustainable CML services.*

CML rainfall data services are dependent on contributions from several organisations. At minimum, the MNOs providing the data and research and the hydrometeorological organisations producing the rainfall data and derivative services. Given that weather services are typically provided by the private sector, collaborations with NMHS are likely to maximise the impact of CML rainfall data and may even be a prerequisite for service creation. Understanding how the needs of these various sectors can be met sustainably is key to unlocking the value of CML rainfall data.

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