CGMS-51-WGI-WP-06
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Prepared by WGI
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Combined Report from the CGMS WGI Task Groups on Direct Broadcast Systems and LEO Coordination of Orbits

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1 WGI COMBINED REPORT: DIRECT BROADCAST SYSTEMS AND LEO COORDINATION OF ORBITS TASK GROUPS

1.1 About CGMS

The Coordination Group for Meteorological Satellites (CGMS) is the group that globally coordinates meteorological satellite systems. This includes protection of orbit assets, contingency planning, improvement of quality of data, support to users, facilitation of shared data access and development of the use of satellite products in key application areas.

The coordination is pursued from an end-to-end perspective, through development of multi-lateral coordination and cooperation across all meteorological satellite operators in close coordination with the user community such as WMO, IOC-UNESCO, and other user entities.

EUMETSAT is the permanent secretariat of the CGMS and responsible for securing the annual plenary session, following up of plenary actions, guiding CGMS during the inter-sessional periods between plenary sessions, guiding the CGMS working groups, and general management and administration.
There are five CGMS Working Groups: WG I on satellite systems and operations; WG II on satellite data and products; WG III on operational continuity and contingency planning; WG IV on support for end users; and SWCG on space weather coordination.

The Direct Broadcast Task Group and the LEO Coordination of Orbits Task Group belong to the WG-I, more information can be found on the CGMS website.

1.2 Document Structure

- **Section 1** (present section): Provides a review of the CGMS actions assigned jointly to the Direct Broadcast and LEO Coordination of Orbits task group for CGMS-51:
  - Action WGI/A50.09
  - Action WGI/A50.10
- **Section 2:** Contains response to Action WGI/A50.09 with the study Paper “Strengths, Weaknesses, Opportunities, And Threats (Swot) Analysis Of Global Low Latency Data Access From Leo Meteorological Satellites”.
- **Section 3:** Contains proposed actions for next CGMS-52.
- **Appendix A:** Contains a proposal for Terms of References (ToR) of a merged Direct Broadcast and LEO Coordination of Orbits task groups into a single “Low Latency Data Access Task Group

1.3 Action WGI/A50.09

Following a previous SWOT study [CGMS-50-CGMS-WP-08] presented in CGMS-50, the study scope was extended from a local to global low latency data access perspective from LEO meteorological satellites.

In Section 2 of this document, a paper has been written in response to the CGMS action WGI/A50.09, detailed on Table 1 below:

Action #	Description	Deadline
WGI/A50.09	Build on the SWOT analysis on Low Latency Data Access from LEO meteorological satellites (CGMS-50-CGMS-WP-08) work and broaden its scope to include the following, thereby removing historical requirement and architectural boundaries between global data access and direct broadcast systems: Global data coverage and access; Temporal coverage over a given geographic area; Low latency data delivery; Perform further study on the possible usage of emerging technologies identified by the SWOT analysis. The two Task Groups should hold meetings and agree on a proposed way forward for a consolidated SWOT analysis, and present to CGMS-51 for consideration. All CGMS agencies are encouraged to nominate participants to contribute to this activity.	CGMS-51

Table 1: CGMS-51 action WGI/A50.09

1.4 Action WGI/A50.10

Action #	Description	Deadline
WGI/A50.10	Task Group on the Coordination of LEO Orbits and Task Group on Direct Broadcast Systems to review the overlap between the proposed (BP) for the Coordination of Data Acquisition for Low Earth Orbit (LEO) Satellite Systems and the already published Best practices in support to local and regional processing of LEO direct broadcast data (CGMS/DOC/18/1008274), and propose a way forward for both best practices. The updated best practices drafts should be sent for review before CGMS-51 and presented to CGMS-51.	

Response to this action is covered in CGMS-51-CGMS-WP-02.

2 STRENGTHS, WEAKNESSES, OPPORTUNITIES, AND THREATS (SWOT) ANALYSIS OF GLOBAL LOW LATENCY DATA ACCESS FROM LEO METEOROLOGICAL SATELLITES

Working Paper summary:

The core meteorological satellite systems in LEO orbits, and other operational satellite systems where applicable, should ensure low latency data access of imagery, sounding, and other real-time data of interest to users. Application areas where low latency and availability is suitable include Severe Weather Monitoring, Nowcasting and Short- and Medium-Range Numerical Weather Prediction. Other application areas could also benefit from very low latency products, e.g. ionospheric monitoring.

Today, LEO meteorological satellites have two distinct services for providing low latency data to users:

- Global service: where the full orbit data is stored on-board and served at the pole(s)
- Regional or local service: real time dissemination of instruments data to a network of direct broadcasts stations.

The historical distinction between global and regional missions could disappear in the next generation of LEO meteorological satellites, with constant data access to the satellites (internet in space concept).

The goal of this CGMS paper is to identify low latency data access solutions that could be part of the next generation of LEO meteorological satellites and assess them through a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. This SWOT analysis paper is extending the scope of the previous CGMS paper [CGMS-50-CGMS-WP-08] which focused on for regional low latency data access. Three global low latency data access solutions are studied in this paper:

1. GEO Data Relay Service (GEO DRS)
2. MEO/LEO Data Relay Service (LEO DRS)
3. Global Network of Ground Stations Service (GNGS)

Section 2.5 compares the pros and cons of each solutions and section 2.6 summarises the findings.

2.1 Context and scope

Today, the LEO meteorological satellites families of CGMS agencies have two distinct services for providing data to users:

- Global service: where the full or half LEO orbit data is stored on-board and served at the pole(s). This mission provides global coverage at high latency (> 1 hour)
- Regional or local service: real time direct broadcast dissemination of data to a network of direct broadcasts stations. This mission provides regional coverage at low latency.

The global and regional data services serve different communities, which have different requirements, needs, knowledge and post-processing capabilities. In particular, the regional users only receive direct broadcast local data which is available with almost no delay for processing.

Direct Broadcast systems will be part of the next generation of the CMA, EUMETSAT and NOAA satellites as shown on Table 2.

CGMS agency	Satellite Series with Direct Broadcast System	Launch window	End of Operations
CMA	FY-3F, G, H	2022 - 2031	~2036
NOAA	JPSS2, 3 and 4	2022 – 2038	~2043
EUMETSAT	EPS-SG	2025 – 2037	~2042
	EPS-Sterna	2024 – 2029	~2042

Table 2: Confirmed Direct Broadcast Agenda for CGMS agencies

The historical distinction between global and regional missions could disappear in the next generation of LEO meteorological satellites, with constant data access to the satellites. This paper aims at studying solutions that reduce the time between data acquisition and on-ground availability globally.

Three low latency data access solutions have been identified in this paper, studied in three separate SWOT analyses:

- Section 2.1: SWOT analysis for GEO Data Relay Service
- Section 2.3: SWOT analysis for LEO/MEO Data Relay Service
- Section 2.4: SWOT analysis for Global Network of Ground Stations

These way regional and global users access the data would be impacted:

- Option 1: Global and regional services will be both replaced by a new architecture (likely option, considered in this paper).

- Option 2: Beside the new architecture, both the global and the regional services will remain as a back-up on the LEO meteorological satellite. This will require to have several data transmission systems which require real estate, mass, power introducing additional complexity to the satellite (unlikely option, not considered in this paper).

2.2 SWOT analysis for GEO Data Relay Service

The SWOT analysis performed in this section considers the use of a GEO data relay service to provide global low latency data access from a LEO meteorological satellite. The Figure 1 below shows an overview of the GEO data relay service system which consists of:

(A) GEO Relay Space segment;
(B) Ground station as a service from GEO relay operator;
or
(C) Ground station operated by CGMS agency;

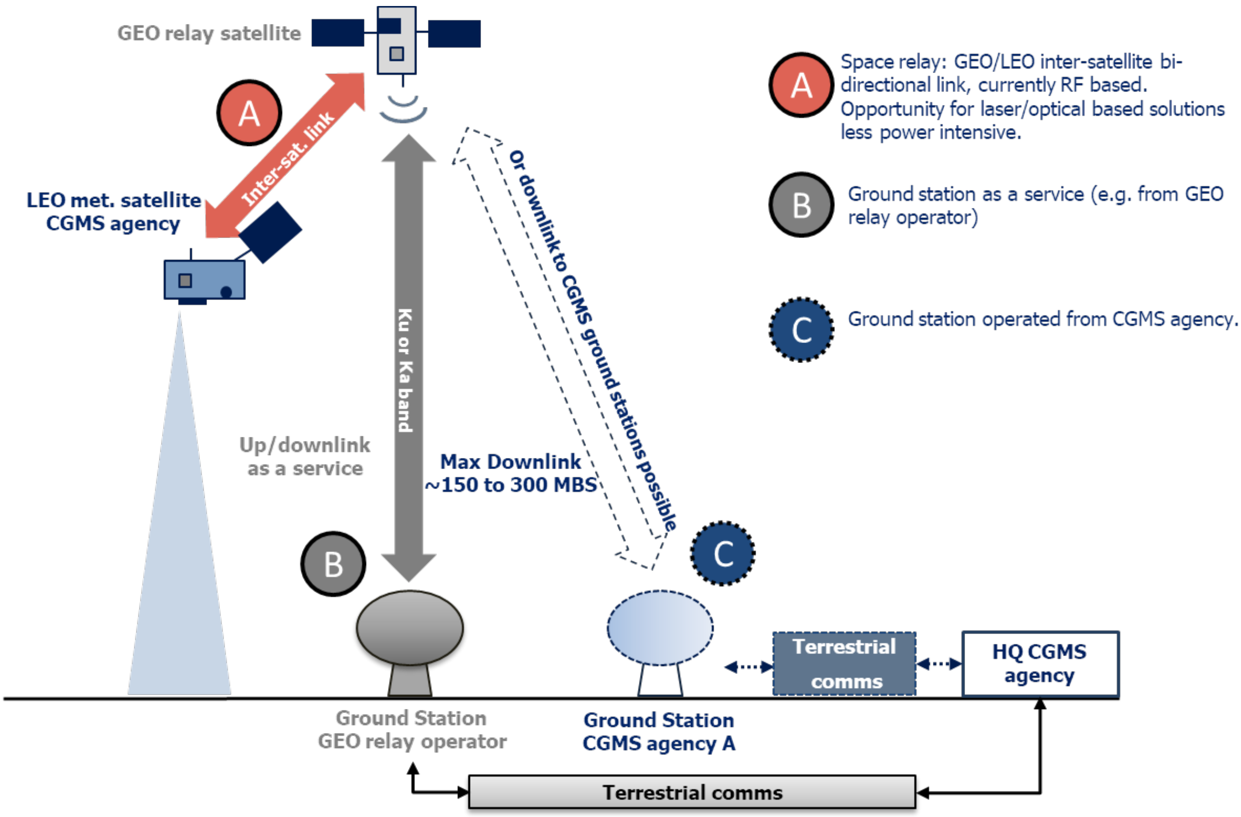

Figure 1: GEO Data Relay Service

2.2.1 GEO Relay Space Segment

The space segment is composed of one or several LEO meteorological satellites and a minimum of 3 GEO relay satellites needed to provide worldwide coverage (see Figure 2). Global coverage would most likely be offered from a set of GEO relay operators depending on the globe location. However some operators already offer a full global coverage service (e.g. Inmarsat Global Xpress).

A series of 3 to 4 GEO relay satellite receives data from the LEO meteorological satellite via an inter-satellite link and repatriates it to a ground station. They are two possible LEO to GEO solutions for this:

i. The GEO global beam satellites (presented below)
ii. GEO equipped with steerable antenna (e.g. as done for NOAA TDRS and EDRS). These need to be scheduled by the transmitting satellites are not designed to take multiple, parallel transmissions. This solution would be

expensive, as only a few satellites could be supported if a RT link is required (rather than transmission of recorded data) when in visibility. Advantage of this solution is support for polar measurements and relatively straightforward to schedule transmissions (equivalent to transmission to a ground station).

Currently, the inter-satellite links between a LEO and GEO using beams are RF based signal. For example, a digital beam formed via a phased array antenna on a LEO satellite would be suitable, although bringing the signal from the LEO meteorological orbit (800 km) to a GEO orbit (36 000 km) would consumes a large amount of on-board power. If inter-satellite links evolve to an optical (laser) base solution, this could help reducing power consumption required for transmitting signal. A bi-directional link offers the possibility of sending data in low latency to the LEO satellite, however this also brings security risk regarding satellite commanding operations.

Each GEO satellite has multiple beams covering specific sections of the terrestrial globe (see Figure 2). At the nadir of the GEO satellite, a LEO satellite would be changing GEO beams in short amount of time (~seconds) which would require a precise on-board LEO software to manage connections changes between beams. In case of loss of a prime GEO relay satellite, redundancy will have to be managed on a beam-by-beam footprint cases.
Upcoming opportunities with GEO relay hosting a large aperture antenna providing a wide beam which would allow to maintain a LEO / GEO connectivity over a longer period of time (LEO satellite would likely remain within the same beam when visible from the GEO satellite).

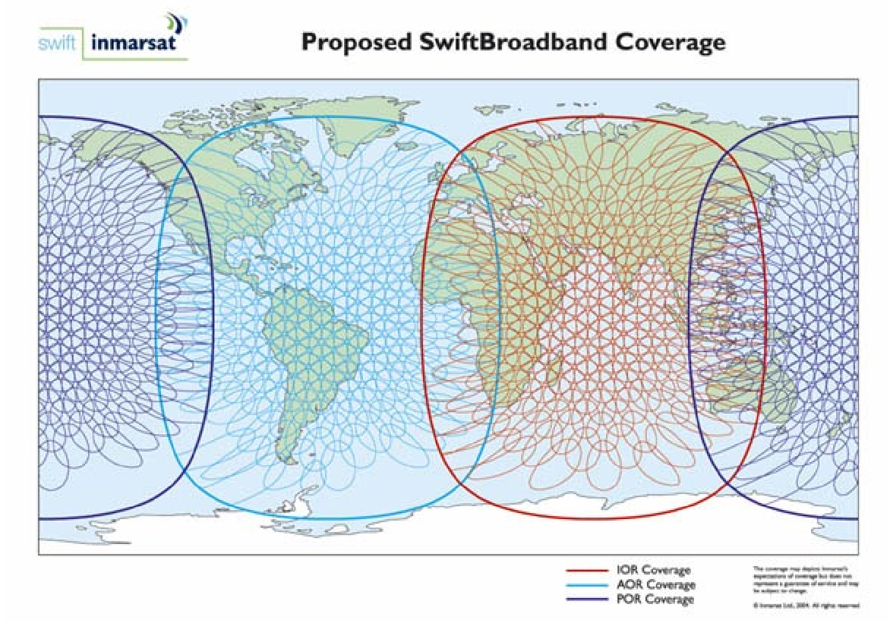

Figure 2: Inmarsat global beams footprints (image credit: Inmarsat)

Some GEO relay satellites also cover the poles if the LEO orbit >500km (e.g. Inmarsat 3 satellites). This would not be the case for all GEO relay satellites which would then mean a potential loss of connection to the LEO satellites at the poles.

The current price of the GEO relay service is approximately 2k/euros/month per Mbps (costing provided by ESTEC). The evolution of the GEO relay service cost is expected to decrease as a result of increased competition on the on GEO relay market as well in the MEO / LEO relay market.

2.2.2 GEO Relay Ground Station

Two options exist for the GEO relay ground segment which are (B) Ground Station as a service, likely from the GEO relay provider or (C) Ground Station operated from the CGMS agency. The purchase of a GEO relay as an end 2 end service, meaning that the GEO operator delivers data as a service, is relatively new on the market but will likely become a common option in the future.

Independently from the choice of operation between (B) and (C), a GEO relay ground segment will be composed of a ground station and a terrestrial communications link with the CGMS agency headquarter.

The downlink from the GEO relay satellite is bi-directional and typically done via RF signal in Ku or Ka band with a data rate per GEO beams of 150 Mbps to 300 Mbps.

The GEO Relay Service SWOT analysis is summarised in the Table 3 below.

2.2.3 SWOT Table for GEO Relay

S Strengths	W Weaknesses	O Opportunities	T Threats
Ground stations and coverage: • Global real time coverage, <1s latency in data processors • Simple design: ground stations typically operated by relay satellite service provider • Option to keep downlink to own ground station(s) **Data downlink:** • Bi-directional low latency • Adaptable to variable payload data generation rate, like day/night variation **Satellite:** • Adequate for supporting small satellites and larger constellations • No data buffering required on LEO weather satellite as global relay coverage provided **Maturity:** • GEO market already mature to provide relay service	**Cost:** • Bandwidth cost of ~1 Mbps for 2 k$/month **Downlink:** • No certitude to be able to secure downlink bandwidth (relay service shared with other customers) • No independent processing of local raw data. **Satellite:** • RF inter-satellite link from LEO to GEO power intensive • Fast change between GEO beams requiring precise on-board software to manage connection to GEO relay • No poles coverage (depending on GEO providers)	**Downlink:** • Standardised laser/optical inter-satellite links would reduce satellite on-board power usage. • Wide aperture beam (single LEO/GEO connection rather than multiple beams connections) • Possibility of the CGMS satellite sharing the same GEO relay resource • Direct availability of data worldwide through cloud or other dissemination mechanisms. **New GEO relay market providers:** • Inmarsat, SES Astra and many others • CGMS GEO satellites could be equipped with a transponder that could relay data received from LEO satellites **Cost:** • Increased market competition expected to decrease cost	**Coverage:** • Complexity if multiple providers for worldwide service • Lack of standardised inter-satellite communication = risk of lock with a single provider **Risks:** • Reliance / dependence on a commercial service for the downlink **Security:** • Security risk via uplink commands to CGMS satellite (maintain TTC as independent capability?) **Coordination:** • Role of CGMS inter agency coordination unclear for data exchange mechanism (e.g. via cloud?)

Table 3: SWOT Analysis for GEO Data Relay Service

2.3 SWOT analysis for LEO/MEO Data Relay Service

The SWOT analysis performed in this section considers the use of a LEO or MEO data relay constellation to provide global low latency data access from a LEO meteorological satellite.

The Figure 3 below shows an overview of either a LEO or MEO data relay service system which consists of:

(A) LEO/MEO Relay Space Segment;
(B) Ground Station as a service from LEO/MEO relay operator;

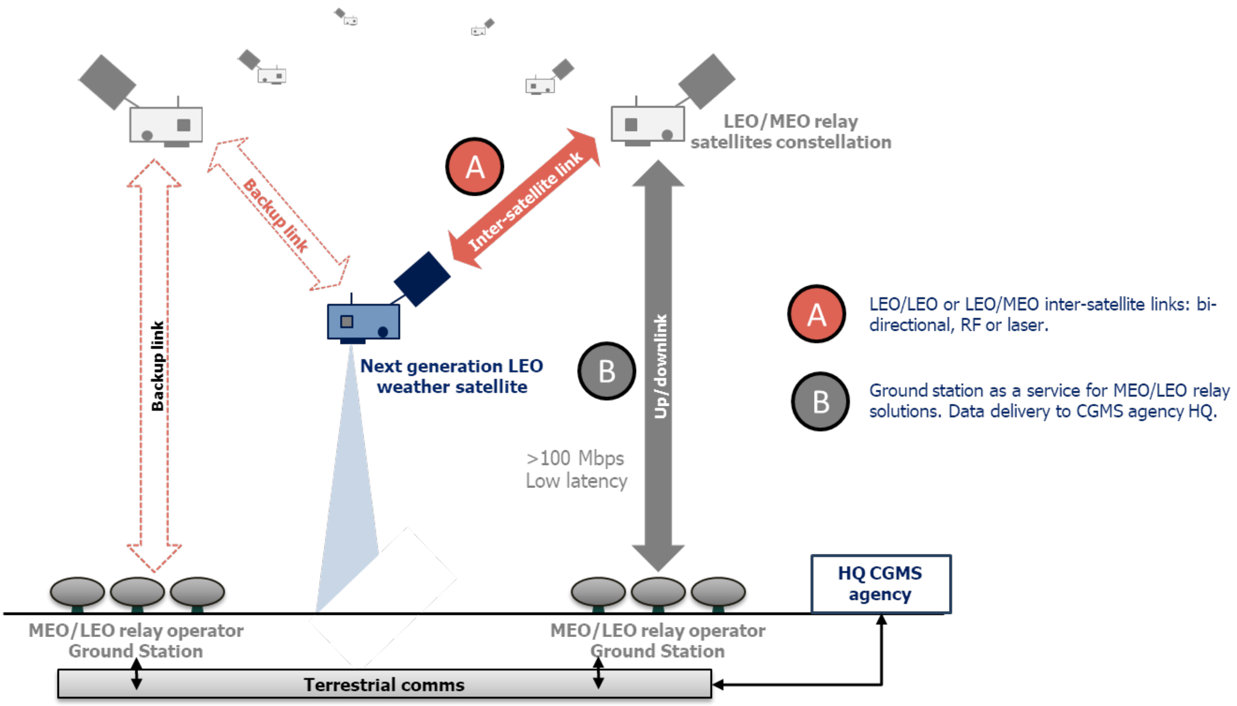

Figure 3: LEO/MEO Data Relay Service

2.3.1 LEO/MEO Relay Space Segment

The space segment is composed of at least one LEO meteorological satellite and a LEO/MEO relay constellation. The number of relay satellites could range from a dozen for a MEO constellation (e.g. 11 satellites for O3b SES, see Figure 4) to several thousand for a LEO constellation (12000 satellites for SpaceX Starlink V1 system with option to extend to 42000 for Starlink V2 system).

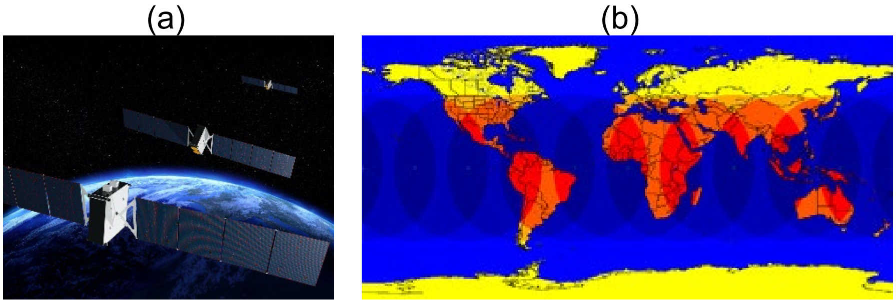

Figure 4: Boeing O3b mPOWER constellation of 11 MEO satellites with (a) artist view of constellation (image credit SES) (b) constellation ground footprint (image credit SES)

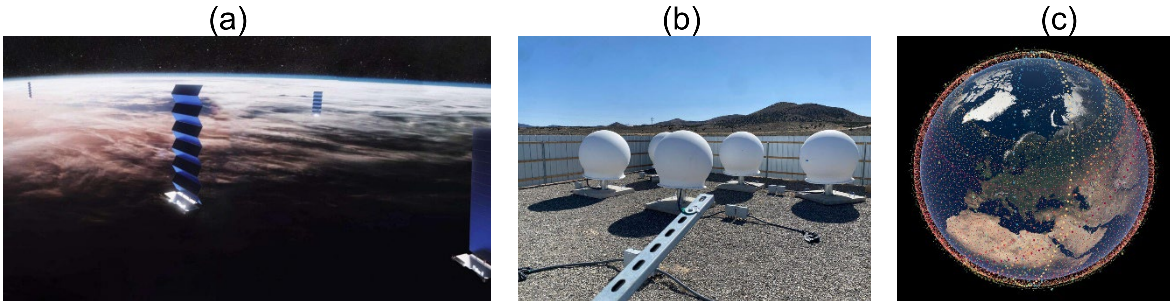

Figure 5: SpaceX Starlink constellation with (a) artist view of constellation (image credit SpaceX) (b) typical Starlink ground station gateway (image credit Reditt) (c) Visualisation of the 30 000 planned satellites from the Starlink Generation 2 constellation as of 2022. Different sub-constellations are illustrated with a different colour (image credit ESO).

Inter-satellite link between LEO/MEO are currently RF based, which is the case for the O3b MEO constellation and Starlink V1.0. However, next generation of Starlink V1.5 and V2.0 satellites will uses laser inter-satellites communication. Laser based communications have the advantages of light weight and lower on-board power consumption but brings a threat of compatibility as they are currently no standards.

Although the cost of a MEO relay constellation is similar to GEO relay, the cost of LEO relay is much lower of about 110 dollar for 50 Mbps per month for a personal Starlink user and 5000 dollar per month for a marine corporate user with higher bandwidth of up to 350 Mbps (https://www.starlink.com/maritime). Therefore, accounting for the price of a corporate Starlink user, brings an indicative price of 15 dollar per Mbps for a LEO relay constellation.

Currently, some LEO constellation, such as Starlink, do not accept space communications from external satellites (e.g. from non-Starlink satellites). It could be that future Starlink satellites will provide an entry connection point for external satellites, although it is not confirmed at this point in time. Another possibility could be achieved via third party relay-2-relay satellites offer a connection bridge between a LEO weather satellite and a Starlink type constellation, see Figure 6.

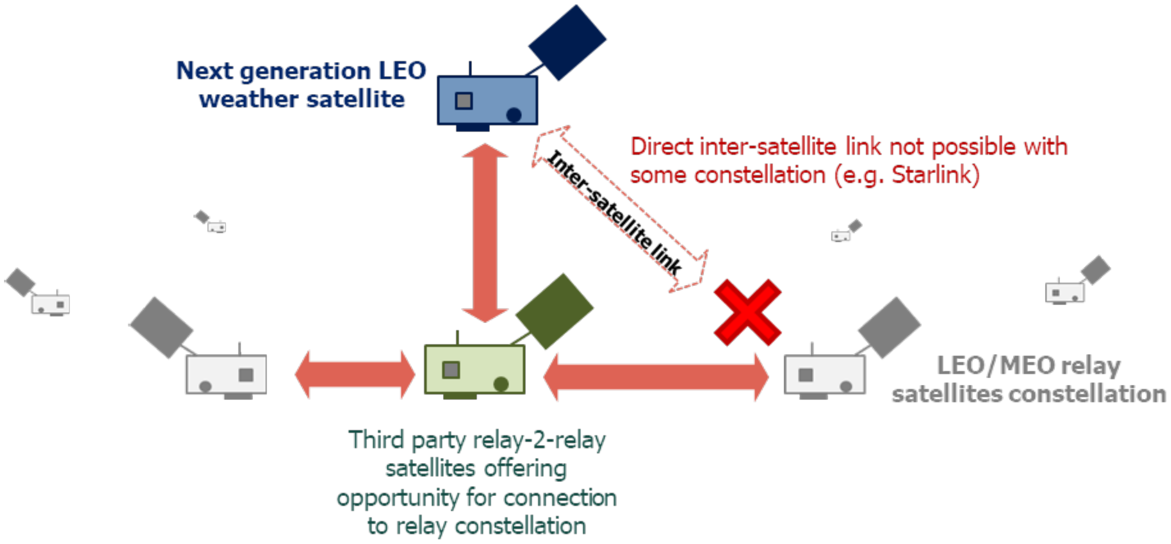

Figure 6: Third Party relay-2-relay offering entry connection point to a Starlink type constellation.

2.3.2 LEO/MEO Relay Ground Station

For downlink, the Ku and Ka bands are the current standard, which for example used for the MEO and Starlink V1 satellites. However, the V2.0 Starlink satellites will fly in a lower ~350 km orbit and operate in V band.

For MEO and LEO constellations, the ground stations are operated by the relay satellites operator meaning that the data access to/from the LEO meteorological satellite is providing as a service.

2.3.3 SWOT Table for LEO/MEO Relay

S Strengths	W Weaknesses	O Opportunities	T Threats
Cost: • Starting price of 5$ per Mbps **Ground stations and coverage:** • For LEO relay constellation: global low latency coverage • Data as a service: potential cost reduction as ground stations operated by relay satellite service provider • Simple unique contractual interface for ground stations **Data downlink:** • Adaptable to variable payload data generation rate, like day/night variation **Satellite:** • Adequate for supporting small satellites and satellite constellations • Save weight and power consumption on LEO satellite (especially with laser based solutions) • No data buffering required on LEO weather satellite as global relay coverage provided	**Compatibility:** • Space relay not possible with some current constellation (e.g. Starlink) • No standards on laser inter-satellite links **Coverage:** • For current MEO relay satellites: no poles coverage **Data:** • Bandwidth shared with other users • No independent processing of local raw data. **Maturity:** • Some LEO constellations do not provide relay for space relay (need of a third party connecting satellite)	**Downlink:** • Improved standardisation of inter satellite communication, especially optical/laser solutions. • Direct availability of data worldwide through cloud or other dissemination mechanisms. **Compatibility:** • Possibility of third party industries launching relay-2-relay satellites, offering entry connection point to relay constellation **Market:** • LEO relay service expected to mature across the next decade • Increasing number of market providers offering possibility of redundancy at constellation level	**Coverage:** • Lack of standardised inter-satellite communication = risk of lock with a single provider **Risks:** • Dependence on a commercial service for the downlink • LEO relay constellation still a volatile market with possibility of providers financial bankruptcy **Security:** • Security risk via uplink commands to CGMS satellite (maintain TTC as independent capability?) **Coordination:** • Role of CGMS inter agency coordination unclear for data exchange mechanism (e.g. via cloud?)

Table 4: SWOT Analysis for LEO/MEO Data Relay Service

2.4 SWOT analysis for Global Network of Ground Stations

2.4.1 <u>Global Network of Ground Stations</u>

The SWOT analysis performed in this section considers the use of a global network of ground stations as a service to provide global low latency data access from a LEO meteorological satellite.

The Figure 7a below shows an overview of a global ground segment service which consists of:

(A) Space Segment;
(B) Ground station as a service from one or several operators;

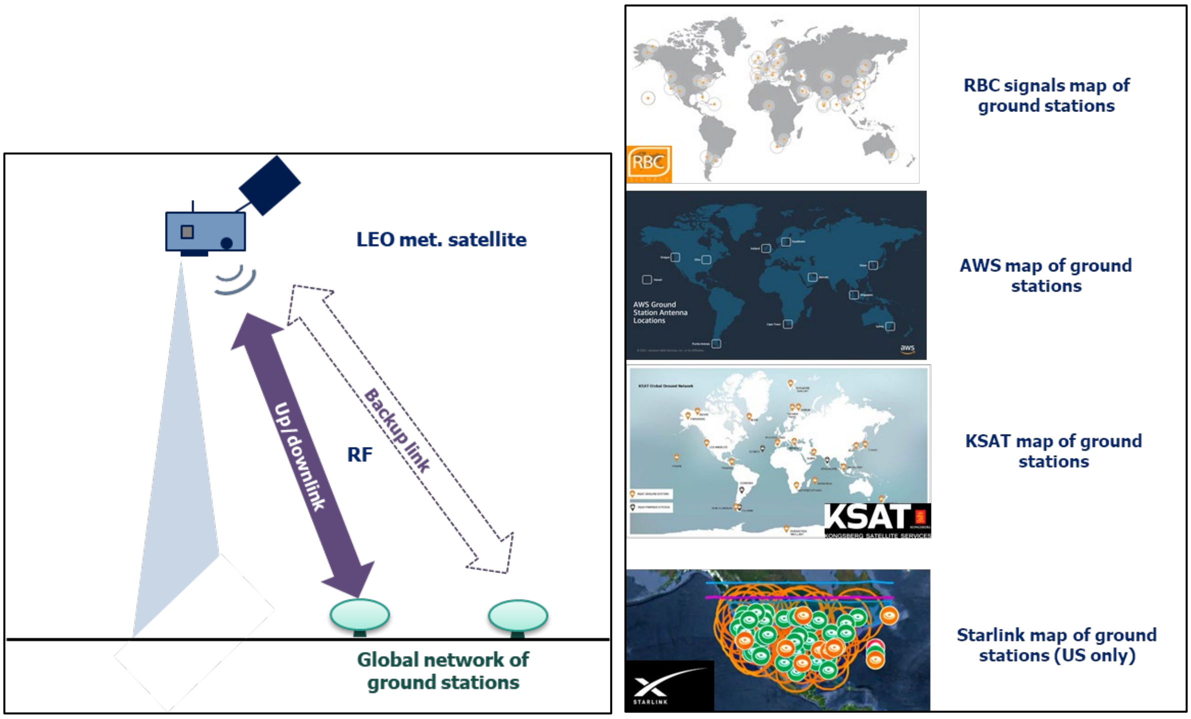

Figure 7: (a) Global Network of Ground Stations (b) Non-exhaustive list of current global network ground stations

The Figure 7b shows a current list of a global network of ground stations providers. Network of traditional tracking antennas are found to be more expensive and sparse than phased array (example of Starlink stations map in the US).

It is expected that the development of global network of phased array stations will grow over the next years as they present advantages to traditional antennas for LEO satellites (G. He, 2021).

The SWOT analysis presented in the Table 5 below is performed assuming a global network of phased array ground stations to repatriate data from LEO meteorological satellites.

The cost assumption will vary depending on the number of passes acquisition over an orbit. Assumption is made that the acquisition cost of a 15 minutes LEO pass is around 100$.

Doing a simple assumption that a LEO satellite constantly in visibility of a station, over a 30 days period (43200 minutes) with a data rate of 100 Mbps gives a cost of ~3k$ per Mbps per month (2880$ rounded up).

2.4.2 Case Study: Ground Stations as a Service

NOAA recently opted for the option of Ground System as a Service to decrease global latency for LEO satellites.

NOAA contracted Kongsberg (KSATLite) to provide ground services for the JPSS (SNPP, NOAA-20, NOAA-21) program. Svalbard (SVL) is uniquely located to track 14 Leo passes per day. This removes the need of a second ground station in an attempt cover “blind” contacts and improves the orbit coverage to 100%.
Prior to the use of (SVL) there where non-visible contacts daily (NOAA-18, NOAA-19) resulting in at least a 101 minute delay on payload data. This removal of this delay now allows NOAA to provide all data to partners and users within the data latency requirements.

2.4.3 SWOT Table for Global Network of Ground Stations

S Strengths	W Weaknesses	O Opportunities	T Threats
Data downlink: • Low latency access to regional data (as for DB) • Possible data downlink to other CGMS agencies • Less sensitive to signal attenuation by weather conditions through multiple possible links to ground (and adaptable data signal strength) **Ground stations:** • Support uplink communications from the ground **Satellites:** • Adequate for supporting small satellites and constellations • Adaptable to variable payload data generation rate, like day/night variation • Digital beamforming (multiple simultaneous beams serving multiple ground stations)	**Coverage:** • Uncovered oceanic geographical areas = loss of signal (need of inter-satellite links) • Elevation mask of 5° or more for phased array, requiring larger number of ground stations **Ground stations:** • Potential sophisticated design needed to react in case of ground station dropdown. • High number of stations required **Maturity:** • Lack of standardised protocols • Currently no commercial offer yet on a global network of phased array stations (low maturity) **Cost:** • 3k$ per Mbps per month (assuming constant visibility from a station)	**Data downlink:** • On-board data storage while flying over uncovered areas (data buffering) **Satellite:** • Could be combined with other data relay satellites via satellite-to-satellite communication **Ground stations:** • Usage of cloud and private ground stations network to process and repatriate data • Private sector currently building numerous ground stations • Well suited for decentralised cloud processing **Maturity:** • Standardisation of phased array protocols so one terminal could receive other small satellite data	**Satellite:** • Potential in-orbit RF interference with other phased array satellites **Ground stations and coverage:** • Stations could be located in geopolitically unstable regions to provide coverage

Table 5: SWOT Analysis for Global Network of Ground Stations

2.5 Comparison of global low latency data access solutions

This section compares the pros and cons of each solutions through a list of criteria identified in the SWOT analyses, being (i) downlink rate (ii) global latency (iii) coverage (iv) cost (v) maturity (vi) spacecraft design (vii) inter-compatibility.

2.5.1 Downlink Rate

Very low (<1 Mbps) − −	Low (≥50 Mbps) −	Sufficient (≥100 Mbps) − / +	High (150 to 300 Mbps) +	Very High (>300 Mbps) + +
			GEO DRS GNGS	LEO DRS

Table 6: Comparison of downlink rate

Data rates identified in the SWOT analyses in Section 2 were:

- GEO DRS: data rate per GEO beams between 150 Mbps to 300 Mbps
- LEO DRS: up to 350 Mbps for Starlink Maritime
- GNGS: typical Ka bands data rate around 300 Mbps

The data rates of the technological solutions studied in this paper would therefore be sufficient to cover a current LEO weather satellite need of around 100 Mbps.

2.5.2 Global Latency

Very poor (>100 min) − −	Poor (>50 min) −	Neutral (<30 min) − / +	Good (<1 min) +	Very good (<1 s) + +
		GNGS	GEO DRS	LEO DRS

Table 7: Comparison of latency

Today, global products from LEO weather satellites are typically received at the poles. With a LEO weather satellite half orbit time of around 50 minutes, there is significant latency from the start of the half orbit acquisition to reception of data.

- Latency for GEO DRS would be in ms, although some GEO satellites do not provide visibility at the poles. Latency would then be degraded for a couple of minutes while the LEO satellite is out of visibility from the GEO satellites (see Figure 2). Therefore GEO DRS score is in between Very good (<1s) and Neutral (<10 min).
- LEO DRS has the ability to offer constant low latency data access (ms) across a whole orbit, a LEO DRS constellation providing constant access.
- With GNGS, data would be received several time across an orbit which is similar to today's local DBNET service. This solution as limitation over ocean areas which can be left uncovered by ground stations. Therefore GNGS score is neutral, close to today's solution of global and local services.

2.5.3 Coverage

Very poor (ocean and large land gaps) – –	Poor (ocean and small land gaps) –	Neutral (ocean gaps) – / +	Good (small gaps, e.g. poles) +	Very good (Global) + +
		GNGS	GEO DRS	LEO DRS

Table 8: Comparison of coverage

Currently, local coverage is achieved through a network of direct broadcast ground stations. Coverage by the direct broadcast stations is different depending on the instruments, see DBNET page on WMO website: https://community.wmo.int/activity-areas/wmo-space-programme-wsp/dbnet

- GEO DRS have coverage limitation at the poles (depending on the GEO satellites)
- LEO DRS offer global coverage
- GNGS main limitation is over ocean region, which can be left uncovered by ground stations

2.5.4 Cost

Very important (6k$/Mbps/m) – –	Important (3k$/Mbps/m) –	Intermediate (1k$/Mbps/m) – / +	Low (300$/Mbps/m) +	Very low (30$/Mbps/m) + +
	GEO DRS GNGS			LEO DRS

Table 9: Comparison of cost

In Section 2, following costs were estimated and are summarised on Figure 8:

- GEO DRS: 2000 $/Mbps/month
- LEO DRS: 15 $/Mbps/month
- GNGS: 3000 $/Mbps/month

The monthly cost for GEO DRS and GNGS are found to be two order of magnitude greater than a LEO DRS rate – although in this case the Starlink cost used as a LEO DRS example has a limited SLA. Still, the cost of a LEO DRS per Mbps per month is found to be very cost effective when compared to a GEO DRS or GNGS.

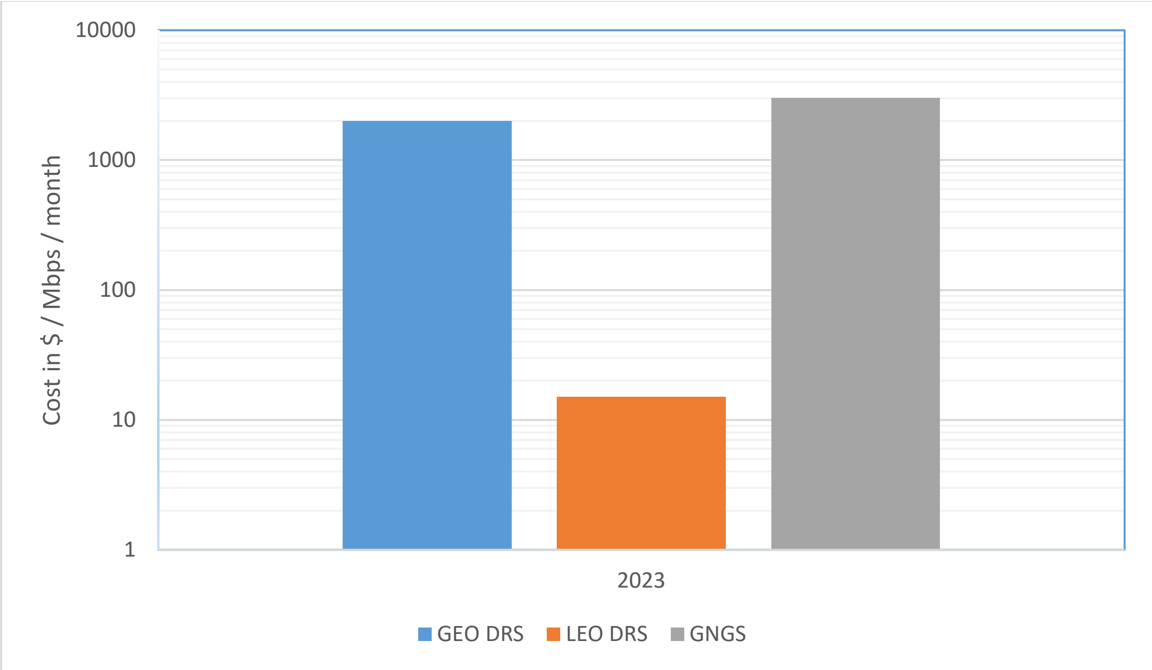

Figure 8: Comparison of cost between GEO DRS, LEO DRS and GNGS

2.5.5 Availability

Very poor – –	Poor –	Neutral –/+	Good +	Very good + +
	GEO DRS LEO DRS GNGS			

Table 10: Comparison of cost

Although relay satellites and network of ground stations are known to be reliable, these systems resources are shared with other users. The control of the dissemination chains belongs to an industrial third party, which could potentially negatively impact reliability. The availability of such systems would be lower than the current CGMS LEO meteorological satellites, hence the category poor was chosen.

2.5.6 Maturity

Very poor – –	Poor –	Neutral –/+	Good +	Very good + +
LEO DRS			GEO DRS GNGS	

Table 11: Comparison of maturity

- GEO DRS is a mature sector, with several commercial actors already providing a global data relay service (see section 2.2.1).

- The LEO DRS is an upcoming market. Issues found for LEO data relay constellation flying at lower orbits than weather satellites is that LEO relay satellite constellations are currently not equipped with space directed antenna (antenna only directed towards earth). SLA of LEO DRS is also low with potential outages.
- GNGS is a mature market for RF communications with traditional steerable antennas. The phased array ground stations is developing although without global providers yet available.

2.5.7 Spacecraft Design

Very poor − −	Poor −	Neutral −/+	Good +	Very good + +
		GNGS	GEO DRS LEO DRS	

Table 12: Comparison of spacecraft

This section compares the added advantage or disadvantages of the low latency data access solutions on the LEO weather satellite design.

- GEO DRS: savings in weight and power consumption assuming low power optical inter-satellite link. Signal would still need to be transmitted over a long distance from a LEO to GEO orbit (energy consumption would be quite important for RF based signal).
- LEO DRS: savings in weight (no antenna) and power consumption assuming low power optical inter-satellite link. Low inter-satellite distance required between two LEO orbits.
- GNGS: no specific changes in spacecraft compared to current LEO weather satellites.

2.5.8 Inter-Compatibility (standards)

Very poor − −	Poor −	Neutral −/+	Good +	Very good + +
LEO DRS	GEO DRS			GNGS

Table 13: Comparison of compatibility

This section compares the inter-compatibility between constellation or operators for each solutions (e.g. compatibility possibility between two different GEO DRS constellation).

- GEO DRS and LEO DRS: with currently no standards on inter-satellite communications, high likelihood that a dedicated inter-satellite communication modem will be required to connect to a specific constellation. Creation of inter-satellite standards communications (particularly optical) would be beneficial as the same modem could be used to connect to multiple constellations.
- LEO DRS: communications are not possible with relay satellites flying beneath LEO weather satellites (relay antenna currently only facing at nadir towards earth). Laser inter-satellite communications are also specific to LEO DRS provider.

- GNGS: ground stations can be adapted according to spacecraft space to ground interface control specifications leading to very good compatibility to ground stations operators.

2.5.9 Comparison summary

The score of the low latency data access solutions are summarised in Table 14 with a score of 3 for GEO DRS, 5 for LEO DRS and 3 for GNGS.
LEO DRS has the greatest score, however the current maturity of the LEO DRS in 2023 is low and would not meet CGMS agency's needs. Starlink was used as a case study, at the present moment this constellation doesn't provide connection to external satellites (connection only possible from ground users). The LEO DRS market is expected to mature across the next years and is appearing to be a promising solution for the next generation of LEO satellites in the late 2030's to the 2040's period.

	GEO DRS	**LEO DRS**	**GNGS**
Downlink Rate	+	++	+
Global Latency	+	++	+/-
Coverage	+	++	+/-
Cost	-	++	-
Availability	-	-	-
Maturity	+	--	+
Spacecraft	+	+	+/-
Compatibility	-	--	++
TOTAL	**3**	**5**	**3**

Table 14: Summary of GEO DRS, LEO DRS and GNGS Comparison

2.6 SWOT Analysis Conclusion

2.6.1 Market conditions

The three different technical solutions identified in this paper that have the potential to offer global low latency data access are (i) GEO DRS – detailed in section 2.2 (ii) LEO/MEO DRS – detailed in section 2.3 and (iii) GNGS – detailed in section 2.4.

Market solutions for global low latency data access already exist today, with available offers from GEO DRS and GNGS. In the future, maturity of LEO DRS is expected to improve offering sufficient data rate and bandwidth at a competitive cost. The cost of GEO DRS and GNGS was found two order of magnitude greater than a LEO DRS (taking Starlink as a case study), which could make LEO DRS an attractive solution despite a lower SLA (see section 2.5.4).

2.6.2 Data supply to users

The way users access LEO meteorological data will be impacted by the solutions studied in this paper. Instead of having direct access to the satellite raw data as today, regional users will instead access processed products from a geostationary satellite (EUMETCast type).

Figure 9 provides an overview of access to regional data. The LEO meteorological satellite sends raw data to a relay satellite, that transfers the raw data to a processing centre on the ground, where data is processed to L1/L2 products. This processing centre could be a cloud decentralised platform. The products are then sent to users via a EUMETCast type solution, using a relay satellite as dissemination.

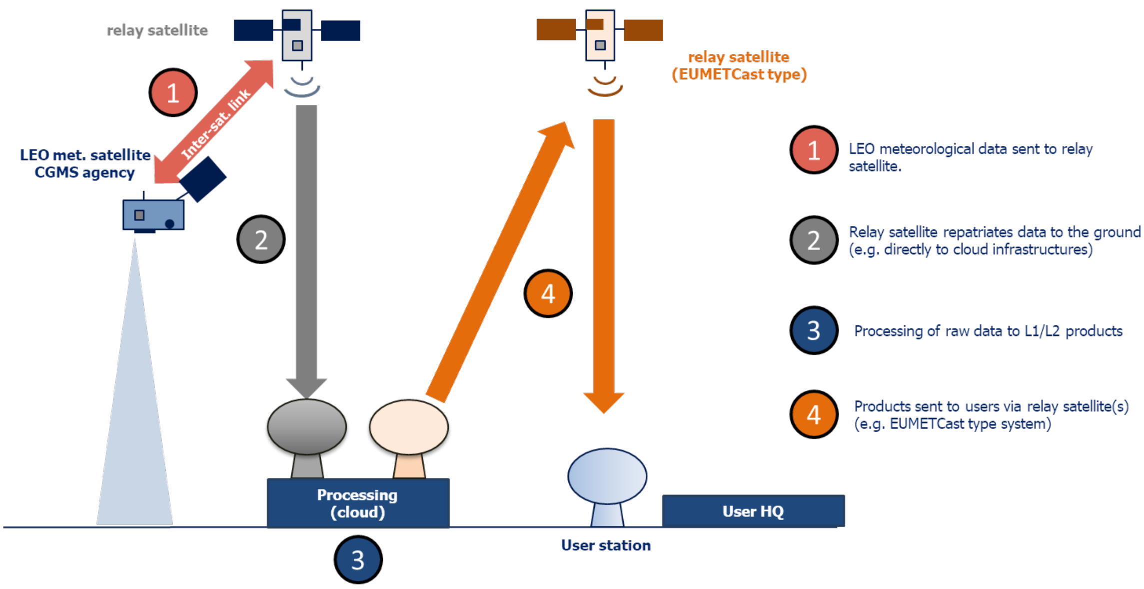

Figure 9: User access to regional data impact

2.6.3 Ownership of the end-to-end transmission chain

Currently, CGMS agencies retain full ownership of the data transmission chain. There are historical lessons to limit dependence on third parties to secure a timely and systematically access to data. For example, the reception points at the poles to the operating centres of the CMGS agencies have a dedicated terrestrial link to keep ownership of the transmission chain.
Commercial services have risks, enterprises subject to change (new shareholder, change of group, bankruptcy, etc). Political scenario may also change and impose bans and restrictions on commercial services.

2.6.4 Summary

Keeping ownership of the access to LEO meteorological is key, keeping full control on the end-to-end data dissemination chain. However, new market opportunities are offering innovative way of low latency data access from LEO meteorological data. A possible outcome from this study could be that future LEO weather satellites systems have a backbone LEO meteorological satellites where the ownership of the data chain is conserved (as for the FY3/JPSS/METOP satellites of today), completed by lower cost LEO satellites constellation using innovative low latency data access mechanisms as detailed in this paper.

Timeliness being one critical aspect of a LEO weather satellite for now-casting and numerical weather applications, innovative and cost effective solutions offering global low latency data access mechanisms could be part of future LEO weather satellites programmes. The implications of this transition could result into global services (orbit data reception at the poles) and local services (direct broadcast) to be merged into a single global low latency data service. Requirements for these new types of LEO meteorological satellites would need to be assessed, for example in terms of the space segment architecture, orbit types, orbit coordination, etc.

3 ACTIONS AND/OR RECOMMENDATIONS FOR CONSIDERATION BY CGMS WG-I

3.1 Proposed Actions for Consideration by CGMS WG-I

3.1.1 <u>Proposal for a merged Low Latency Data Access from LEO Satellites Task Group</u>

The joint Direct Broadcast Systems and LEO Coordination tasks groups SWOT analyses, performed in response to Action WGI/A50.09, has explored the emerging technologies which can be expected to remove the historical architectural boundaries between global data access and direct broadcast systems, providing low latency data delivery for both global and local applications.

It is proposed to close Action WGI/A50.09 and propose a new action to continue the effort:

- Merge the two tasks groups into a single “Low latency Data Access from LEO Satellites” task group, with Andrew Monham and Antoine Jeanjean as co-chairs. A preliminary draft of the merged Terms of Reference for this joint group is provided in Annex and will be at the Kick-Off of the proposed Task Group for iteration with WGI and taking into account the specific goals from the CGMS Position Papers, in particular the “Future Information Technologies” and “Future Observing (Hybrid) Space Infrastructures”.

As part of this action, it is proposed to :

- Merge the LEO (Global) and DB (regional) best practices into a single “Low Latency Best Practices” document proposed to be structured as follow:
    - Common BPs for both regional and global missions
    - BPs specific for DB
    - BPs specific for global mission

3.1.2 <u>Satellite Platform as a Service</u>

During the ESA IoT for Earth Observation workshop, presentations were given on innovative concept of satellite platform as a service (SPaaS). The commercial concept is to provide a full integrated service on a satellite platform providing power, commanding, internet downlink, launch service, etc. The customer furnished item is an instrument payload.

Some SPaaS providers offers a downlink internet connection via GEO relay solutions. The ground reception points are located on directly on the rooftop of cloud providers, offering low timeliness before processing.

SPaaS are highly relevant to the topic of low latency data from LEO satellites, therefore it would be beneficial to further analyse SPaaS in a CGMS document memo in terms of internet connection speed, hosted instruments specifications (size/weight/power), orbit type, satellite lifetime and cost breakdown.

Proposed action:

- Analyse potential role of SPaaS, considering current and expected providers, internet connection speed, hosted instruments specifications (size/weight/power), orbit type, satellite lifetime and cost breakdown. Report to CGMS-52.

3.2 Recommendations for CGMS WG-I

WGI is invited to:

- take note on the SWOT analysis presented in Section 2;
- consider the proposed actions for CGMS-52 summarised below:
  1. To merge the DB and LEO tasks groups into a “Low Latency Data Access from LEO Satellites” TG with new ToR and combined best practices document.
  2. Analyse potential role of SPaaS, considering current and expected providers, internet connection speed, hosted instruments specifications (size/weight/power), orbit type, satellite lifetime and cost breakdown. Report to CGMS-52.

APPENDIX A TERMS OF REFERENCE (TOR)

The current ToR for the LEO Coordination task group are defined in the following document CGMS-49-EUMETSAT-WP-05.

The Direct Broadcast task group does not have endorsed ToR, however higher level WGI objectives 4 and 5 related to direct broadcast are (see https://cgms-info.org/about-cgms/working-group-i/):

4) To address technical and operational aspects of direct broadcast services (present and future) of mutual or global interest for the CGMS agencies;

5) To promote standards and interoperability and operational procedures to the CGMS agencies for the benefit of the user community of their direct broadcast services and the associated regional retransmission services;

The LEO ToR and Direct Broadcast WGI objectives are used as inputs for the draft Latency Data Access Task Group ToR proposed below in Appendix A.1 below.

A.1 Proposed Low Latency Data Access (LLDA) ToR

1. To provide a forum for CGMS agencies to address improving LEO satellite systems low latency data access from both a global and regional perspective, harnessing common emerging technologies and taking account of the evolution of the commercial and agency space systems. It is foreseen that historical boundaries between global and regional mission requirements and architectures may be substantially eliminated. This shall include analysis of:
    a. Novel methods to achieve global data coverage and access;
    b. Temporal coverage over a given geographic area;
    c. Low latency data delivery
    d. Reducing pass scheduling conflicts
    e. Maximising the amount of instrument observation collected
    f. Reducing risk of radio frequency interference
    g. Fixed temporal separation between instrument observation
    h. Reduced risk of satellite proximity

2. To address technical and operational aspects of direct broadcast services (present and future) of mutual or global interest for the CGMS agencies;

3. To promote standards and interoperability and operational procedures to the CGMS agencies for the benefit of the user community of their direct broadcast services and the associated regional retransmission services;

4. To explore impact of space-based data relay systems;

5. The LLDA task group report to CGMS WGI;

6. The LLDA task group will nominate a chair. It will meet at least once a year, and more if necessary, and will pursue its work by correspondence between its meetings.

The proposal to CGMS WGI is to nominate Andrew Monham and Antoine Jeanjean as co-chairs of the LLDA task group. The TG will meet at least 3 times per year. It is proposed to use a specific mailing list for the new TG: L-WGI_LLDA@LISTSERV.EUMETSAT.INT.

7. The LLDA yearly documents deliverables consist of:
   - Item 1: Report from the CGMS WGI Task Group on Low Latency Data Access of LEO satellites (EUMETSAT)
   - Item 2: Operational systems status report of LEO satellites + status of implementation of best practices (CMA)
   - Item 3: Operational systems status report of LEO satellites + status of implementation of best practices (EUMETSAT)
   - Item 4: Operational systems status report of LEO satellites + status of implementation of best practices (NOAA)
   - Item 5: Best Practices for Low Latency Data Access of LEO Satellites - latest version and new proposals (EUMETSAT)

APPENDIX B ACRONYMS

Acronym	Definition
CGMS	The Coordination Group for Meteorological Satellites
GEO DRS	Geostationary Earth Orbit Data Relay Service
GNGS	Global Network of Ground Stations
LEO DRS	Low Earth Orbit Data Relay Service
NWP	Numerical Weather Predictions
RF	Radio Frequency
WG	Working Group

Table 15: Acronyms Definition

APPENDIX C BIBLIOGRAPHY

G. He, X. G. (2021). A Review of Multibeam Phased Array Antennas as LEO Satellite Constellation Ground Station. *IEEE* , vol. 9, pp. 147142-147154.