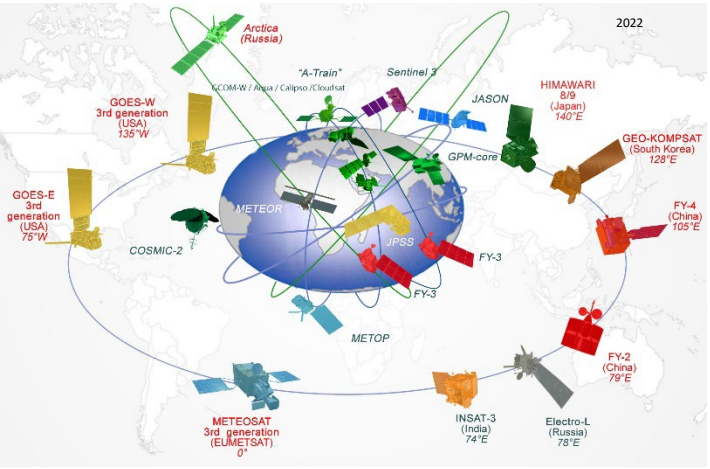

Combined Report from the CGMS WGI Task Groups on Direct Broadcast Systems and LEO Coordination of Orbits

Presented to CGMS-51 WG-I, Agenda Item 5.1
Monday 24 April 2023

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Coordination Group for Meteorological Satellites

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Agenda

1. "SWOT Analysis on Global Low Latency Data Access from LEO Meteorological Satellites"
   - Action WGI/A50.09 Context
   - SWOT case study 1: GEO relay
   - SWOT case study 2: LEO/MEO relay
   - SWOT case study 3: global network of ground stations
   - SWOT conclusion

2. Actions Proposal to WGI for CGMS-52
   - Creation of Low Latency Data Access TG
   - Document Memo on Satellite Platform as a Service (SPaaS)

3. Terms of References
   - ToR Proposal for a Low Latency Data Access task group, merging the Direct Broadcast and LEO Orbit Coordination TGs into one.

CGMS-51 Action #1 Context:

- Action #1: combined action for “Coordination of LEO Orbits” & “Direct Broadcast Systems” Task Groups

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.

For further background on this action, please refer to:

- SWOT analysis on Low Latency Data Access from LEO meteorological satellites CGMS-50-CGMS-WP-08 (link here: *CGMS-50-CGMS-WP-08)*
- Andrew Monham CGMS-50 presentation slides 5,6 (link here: *PPT)*

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Context:

- CMA, EUMETSAT and NOAA roadmap plan on the usage of direct broadcast (local missions) will carry on until the 2030s, at least.
- The historical distinction between global and local missions could be merged beyond this point in the next generation of LEO meteorological satellites.

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 EPS - Arctic Weather Constellation	2025 - 2037 2024 - 2029	~2042 ~2042

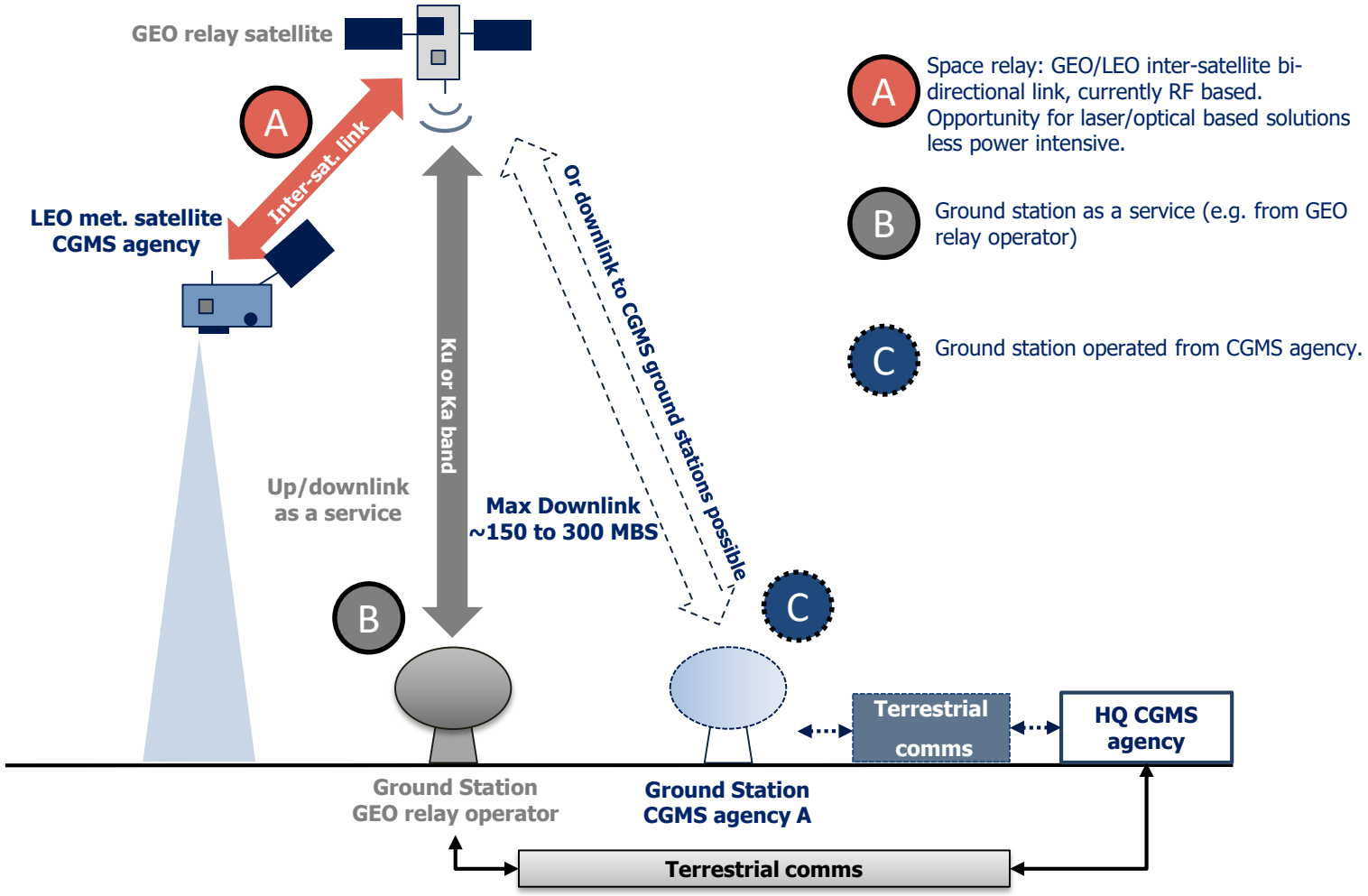
Confirmed Direct Broadcast Agenda for CGMS agencies

High level requirements to for the **"Strength, Weakness, Opportunity and Threat (SWOT) analysis of emerging solution(s) providing global low latency data from a LEO meteorological satellite"**:

- Constant data access to LEO weather satellite ("internet in space")
- Low latency downlink (in ms) with data rate > 100 Mbps
- Uplink possibility
- Timeline for new solution: beyond 2030
- No particular restrictions for downlink

SWOT case study 1: GEO Relay

Global low latency data repatriation via GEO relay constellation



A — Space relay: GEO/LEO inter-satellite bi-directional link, currently RF based. Opportunity for laser/optical based solutions less power intensive.

B — Ground station as a service (e.g. from GEO relay operator)

C — Ground station operated from CGMS agency.

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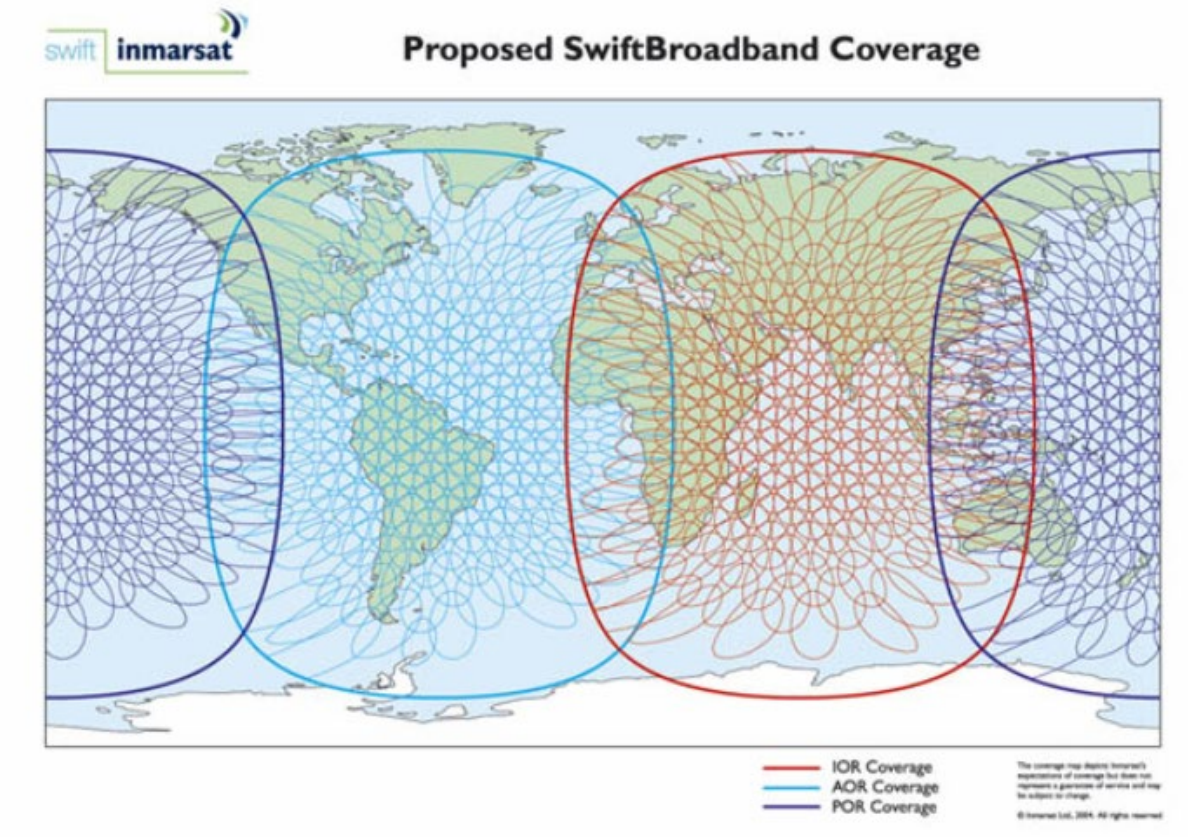
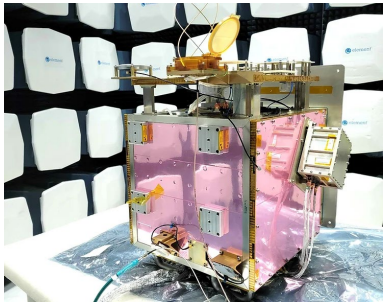


Inmarsat global beams footprints (image credit: Inmarsat)



- Commercial offers of satellite platform as a service with 200kbps internet connection within Inmarsat footprints (loftorbital).
- Quarterly launch.
- Downlink receivers points located on top of Microsoft Azure cloud.

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 kE/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 **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:** • 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?)

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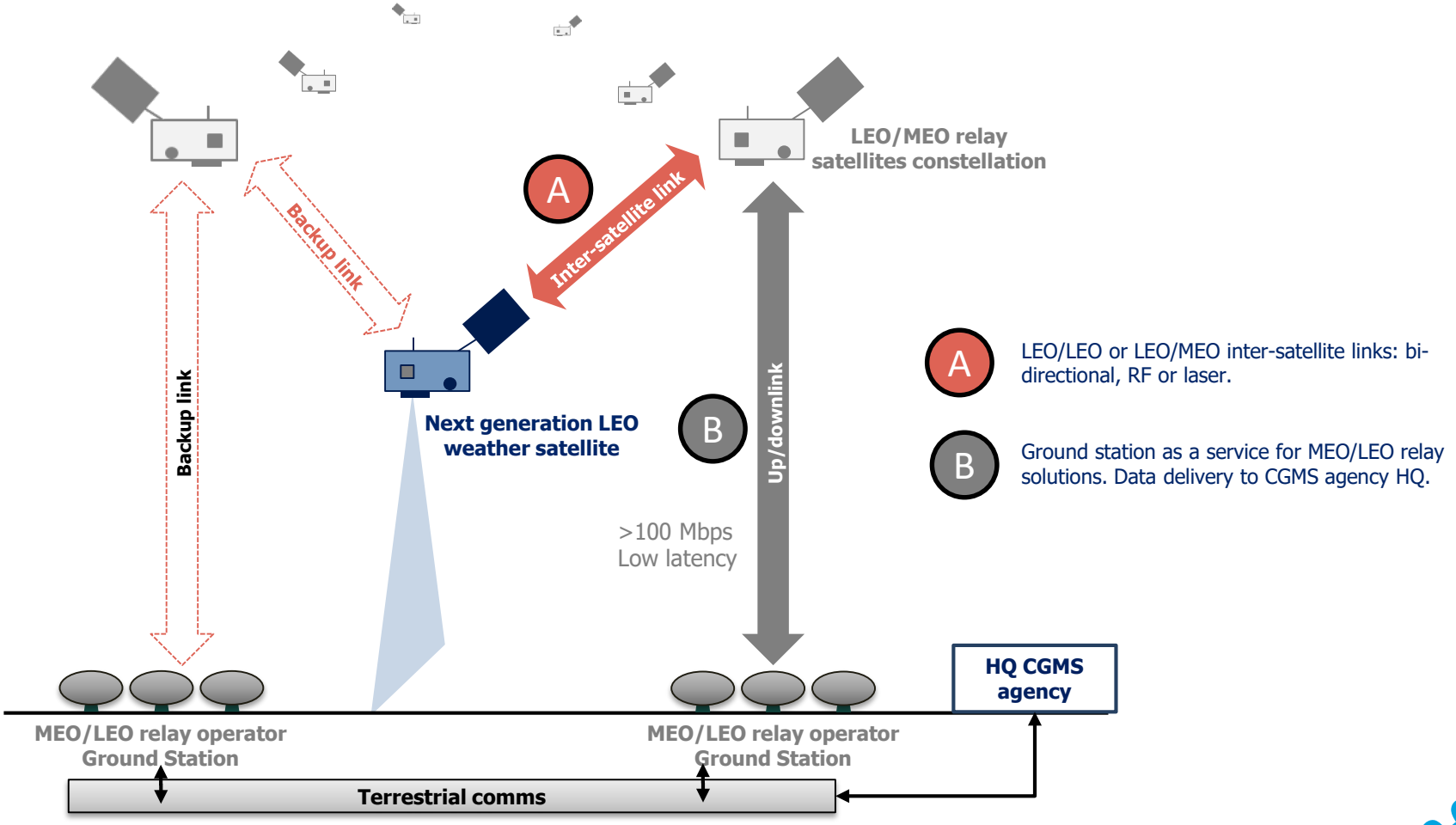
SWOT case study 2: LEO/MEO Relay

Global low latency data repatriation via LEO/MEO relay constellation



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(a) (b)

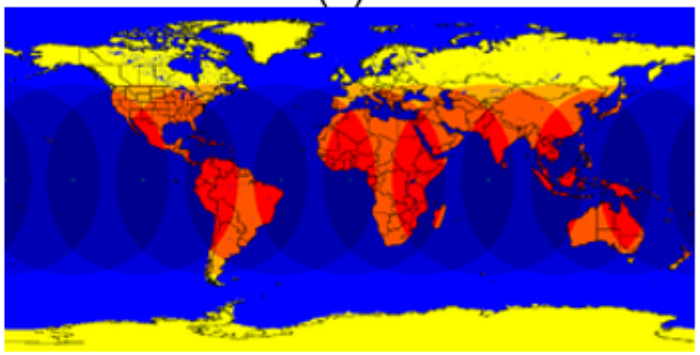
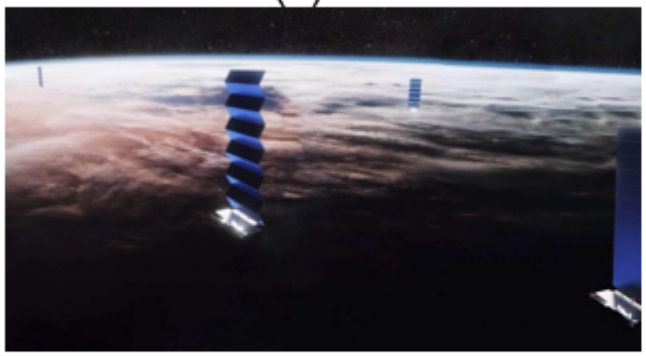
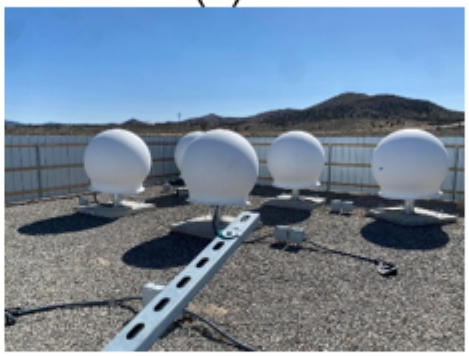


Figure 4: Boeing O3b mPOWER constellation of 11 MEO satellites with (a) artist view of constellation (image credit SES) (b) constellation ground footprint (image credit SES)

(a) (b) (c)





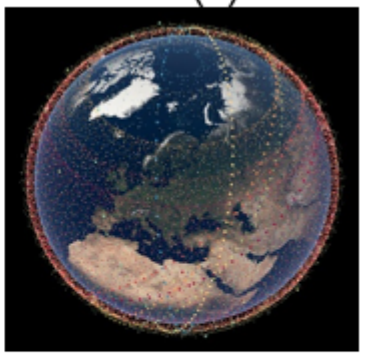


Figure 5: SpaceX Starlink constellation with (a) artist view of constellation (image credit SpaceX) (b) typical Starlink ground station gateway (image credit Reditt) (c) Visualisation of the 30 000 planned satellites from the Starlink Generation 2 constellation as of 2022. Different sub-constellations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

S Strengths	W Weaknesses	O Opportunities	T Threats
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?)

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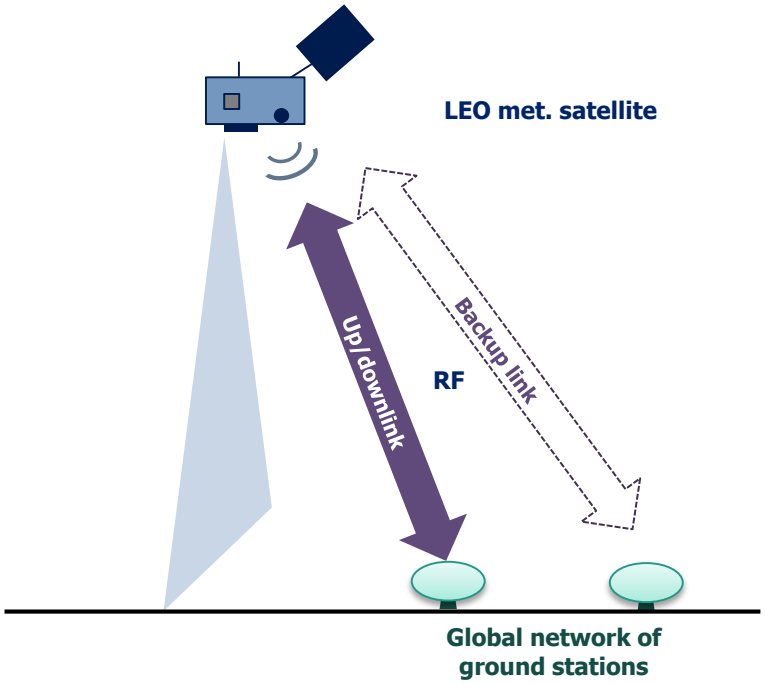
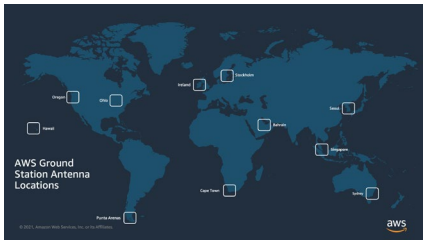
SWOT case study 3: global network of ground stations

Global low latency data repatriation via a global network of ground stations



RBC signals map of ground stations



AWS map of ground stations

KSAT map of ground stations

Starlink map of ground stations (US only)

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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)	**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

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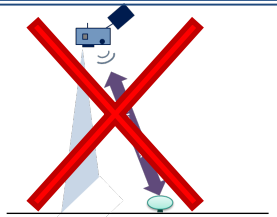
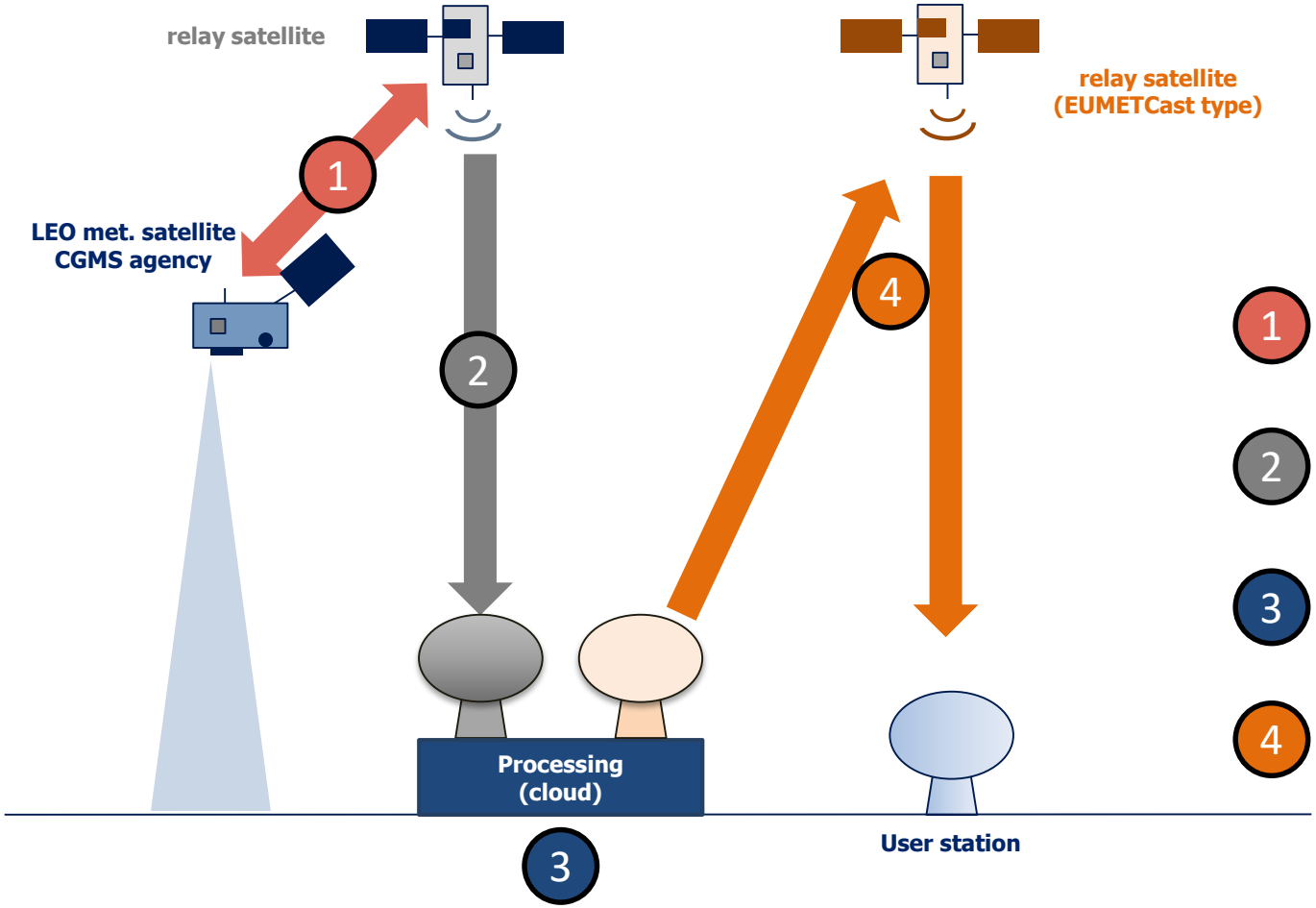
SWOT Conclusion 1: user access to data impacted

- Users no longer access LEO satellite raw data.
- Users to access processed products instead.





1. LEO meteorological raw data sent to relay satellite.
2. Relay satellite repatriates raw data to the ground (e.g. directly to cloud infrastructures)
3. Processing of raw data to L1/L2 products (likely in cloud)
4. Products sent to users via relay satellite(s) (e.g. EUMETCast type system)

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SWOT Conclusion: ownership of access to data

Ownership of the end-to-end transmission chain

- Historical lessons to limit dependence on third parties to secure a timely and systematically access to data.
- 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.

➔ Keeping ownership of the access to LEO meteorological is key, having full control on the end-to-end data dissemination chain.

➔ New market opportunities are offering innovative way of low latency data access from LEO meteorological data.

➔ A possible outcome from this SWOT study could be that future LEO weather satellites systems have a backbone LEO weather satellites with full ownership of the data chain, completed by potentially lower cost LEO satellites using innovative low latency data access mechanisms.

Actions Proposal to WGI for CGMS-52

1. Proposal for a merged Low Latency Data Access from LEO Satellites Task Group

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.
- Provide merged Terms of Reference for this joint group. Preliminary ToR draft are provided in slides 17-19, which will be iterated with WGI at Kick-Off of the proposed Task Group.

Actions Proposal to WGI for CGMS-52

2. Satellite Platform as a Service

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.

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.

Terms of References (draft) – Low Latency Data Access Task Group from LEO satellites

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;

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Terms of References (draft) – Low Latency Data Access Task Group from LEO satellites

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;
Specific studies may be actioned by WGI to the LLDA TG to assess impact of new technologies on enabling innovative solutions to achieve low latency data access from LEO weather satellites.

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. Specific mailing list for the new TG: L-WGI_LLDA@LISTSERV.EUMETSAT.INT.

Terms of References (draft) – Low Latency Data Access Task Group from LEO satellites

7. The LLDA yearly documents deliverables consist of:

- Item 1: Report from the CGMS WGI Task Group on Low Latency Data Access from 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 from LEO Satellites - latest version and new proposals (EUMETSAT)

End

Thank you for your attention

Special thank you for in kind time contribution from Frank Zeppenfeldt (ESA/ESTEC) and Maurizio Betto (EUMETSAT/ESTEC) on the SWOT analysis.

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