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Efforts to Improve Global Operational Space Weather Service Effectiveness by the Coordinated Group of Meteorological Satellite Operators

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Abstract

CGMS - the Coordination Group for Meteorological Satellites - is the group for global coordination of meteorological satellite systems, consisting of 16 governmental organisations from around the globe. The scope of activities was expanded in 2018 with the formation of the Space Weather Coordination Group. The coordination is pursued from an end-to-end perspective, between operators of space weather sensors on satellites, through space weather service providers and onto end-user communities, including the satellite operations community.

With a particular focus on the application to the spacecraft operations community, this Paper explains the value coming from the space weather coordination between the CGMS Members in the following areas:

- The coordination of existing and planned sensing of solar and near-Earth environment necessary for operational space weather services, such that gaps in global space-borne instrument capability may be identified and mitigated within the international space-faring community;
- The quality and reliability of the end-to-end space weather data provision and whether it is really fulfilling the needs and expectations of the user community;
- Collection of spacecraft operator anomaly reports, potentially related to the space environment, to contribute to a database of space weather effects for usage by satellite designers, operators and service providers in increasing the robustness of satellites and their missions against space environmental effects, and mitigating risks of routine spacecraft operation.
- Identifying opportunities for inter-calibration of space weather sensors between operators to improve consistency of global data sets

The interactions in this respect with the spacecraft operations community are elaborated further, in particular:

- The results of surveys conducted with satellite operator end-users, which together with similar surveys of data providers and service providers help to identify the priorities for improvements in the end-to-end data provision;
- The role of the spacecraft operations community in supplying satellite anomaly reporting data in order that an effective database can be established with which to analyse these inputs, taking into account constraints on data confidentiality and resources.
- The compilation of user needs and existing / planned assets in the WMO (World Meteorological Organisation) OSCAR Database.

Finally, the Paper indicates how these CGMS activities fit into the jigsaw of the various, international operational space weather actors and the contribution spacecraft operators can make to promoting the focus on truly operational space weather service provision in the associated international space weather workshops conducted in the US, Europe and Asia.

Keywords: (Space Weather, Anomalies, CGMS, OSCAR)

Acronyms/Abbreviations

CGMS - Coordination Group for Meteorological Satellites
COSMIC-2 - Constellation Observing System for Meteorology, Ionosphere, and Climate-2
GEO – Geostationary Orbit
GRAS – GPS Receiver for Atmospheric Sounding
ICAO – International Civil Aviation Organization
ISES – International Space Environment Service

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LEO – Low Earth Orbit
NGDC – National Geophysical Data Center (NOAA)
NCEI - National Centers for Environmental Information (NOAA)
OSCAR – Observing Systems Capability Analysis and Review Tool
SWCG - Space Weather Coordination Group
WMO - World Meteorological Organisation

1. Introduction

CGMS - the Coordination Group for Meteorological Satellites - is the group for global coordination of meteorological satellite systems, consisting of 16 governmental organisations from around the globe (Fig.1.)

Fig.1. CGMS Members

The main goals of the Coordination Group for Meteorological Satellites are to support operational weather monitoring and forecasting as well as climate monitoring, in response to requirements formulated by WMO (World Meteorological Organisation), its programmes and other programmes jointly supported by WMO and other international agencies.

It is the policy of CGMS to coordinate satellite systems of its members with an end-to-end perspective, including protection of in-orbit assets and support to users (including the satellite operations community), as required to facilitate and develop shared access to and use of satellite data and products in various applications.

The objectives of CGMS are formalised within its Charter:

- CGMS provides a forum for the exchange of technical information on geostationary and polar-orbiting meteorological satellite systems and research & development missions, such as reporting on current meteorological satellite status and future plans, telecommunications matters, operations, inter-calibration of sensors, processing algorithms, products and their validation, data transmission formats and future data transmission standards.
- CGMS harmonises meteorological satellite mission parameters (such as orbits, sensors, data formats and downlink frequencies) to the greatest extent possible.
- CGMS encourages complementarity, compatibility and possible mutual back-up in the event of system failure through cooperative mission planning, compatible meteorological data products and services and the coordination of space and data-related activities, thus complementing the work of other international satellite coordinating mechanisms.

The work of the CGMS is structured through a number of Work Groups that report to an annual Plenary Meeting attended by the senior management of the CGMS Member Organisations:

- Working Group I: Satellite systems and operations
- Working Group II: Satellite data and products
- Working Group III: Operational continuity and contingency planning
- Working Group IV: Data access and end user support
- SWCG: Space weather coordination group (added in 2018).

The SWCG supports the continuity and integration of space-based observing capabilities for operational space weather products and services throughout CGMS and the user community and the CGMS satellite operators with regard to space weather phenomena.

The SWCG works closely with the other working groups, to ensure the expertise in those various fields integrate space weather operational systems within the scope of their activities. In particular, the SWCG pursues coordination from an end-to-end perspective, between operators of space weather sensors on satellites, through space weather service providers and onto end-user communities, including the satellite operations community.

With a particular focus on the application to the spacecraft operations community, this Paper explains the value coming from the space weather coordination between the CGMS Members.

2. Overview of CGMS Space Weather Activities

Fig.2. CGMS Space Weather Activities

Activities involving the CGMS Space Weather Working Group are depicted in Fig.2. Working together with the other CGMS Working Groups, the CGMS is engaged in:

- The coordination between the member agencies of existing and planned in-orbit sensing of the solar and near-Earth environment to meet the needs of operational space weather services, such that gaps in and risks to the continuity of the global space-borne instrument capability may be identified and mitigated in a timely manner within the international space-faring community;
- Assessing the quality and reliability of the end-to-end space weather data provision through surveys and other interactions with user organisations to see whether it is really fulfilling the needs and expectations of the user community and where improvements may be required;
- Collection of spacecraft operator anomaly reports, potentially related to the space environment, to contribute to a database of space weather effects for usage by satellite designers, operators and service providers in increasing the robustness of satellites and their missions against space environmental effects and mitigating associated risks in routine spacecraft operation;
- Identifying opportunities for inter-calibration of space weather sensors between operators to improve consistency of global data sets;
- Devising improvements to existing mission systems to increase data availability and reduce latency and considering advanced concepts, leveraging modern technologies, to offer users potential step change improvements in data delivery from space systems.

The interactions in this respect with the spacecraft operations community are elaborated further below.

3. Survey of Space Weather Data Usage by Spacecraft Operators

CGMS has conducted surveys with satellite operator end-users, which together with similar surveys of data providers and service providers are helping to identify the priorities for improvements in the end-to-end data provision from sensors on CGMS Member Agency spacecraft.

In 2017, a survey of CGMS Members was performed concerning the usage of their spacecraft operators of Space Weather Data. The results of the survey (responses were from NOAA, NASA, JMA and EUMETSAT) illustrated that Space Weather data is regularly consulted when assessing the potential root cause of a satellite anomaly.

Furthermore, the operators use forecast data in order to assess the expected drag environment in LEO, as input to orbit predictions.

However, amongst CGMS members responding to the survey, there was little evidence of usage of space weather forecast information by satellite operators to mitigate satellite system operational risks. Nevertheless, some commercial operators have reported their active usage of space weather service data, in particular SES of Luxembourg (GEO Communication Satellite Services) and Airbus-DS (UK) who operate satellite systems on behalf of the UK Ministry of Defence.

It is important to understand why satellite operators have, in general, not been actively using space weather service inputs and what needs to be done in order to ensure a value-added service can be offered and recognised as such by the satellite operator user community. The most significant reason is that operators believe their satellites to be sufficiently protected by design (radiation hardening), backed up by an absence of critical anomalies suffered during the past two decades of operations. Consequently, there has generally been insufficient motivation to look more deeply into the issue.

Indeed, reported anomaly statistics do show that solar activity has not caused significant issues on the CGMS member satellites to date. A look at solar activity since the dawn of the space age indicates that we have been fortunate to operate in a relatively benign environment, with the most significant event being the Halloween storms of October-November 2003, which caused several satellite anomalies [1]. In the past, solar events of far higher magnitude have occurred, the most famous being the Carrington Event of 1859. There is a significant probability of a reoccurrence of a solar storm of similar magnitude which would severely challenge the design resilience of all space and ground assets [2,3,4]. This issue and what can be done to improve overall resilience against super-storms which reach Earth in the order of once a century is discussed in detail in [5].

4. Space Weather Spacecraft Anomaly Database

The relationship between the different actors in ensuring and improving operational safety from an unpredictable space weather environment can be depicted as a feedback triangle as illustrated in Fig. 3. In order to improve on the quality of the interactions between these actors for the purpose of improving spacecraft resilience against the space weather environment, a process is established at CGMS level to collect spacecraft anomaly data from its members. The CGMS is aiming to develop processing algorithms for statistical analysis as a means to improve satellite design standards, defining the space environment alert thresholds and the overall understanding of spacecraft operators needs by Service Providers.

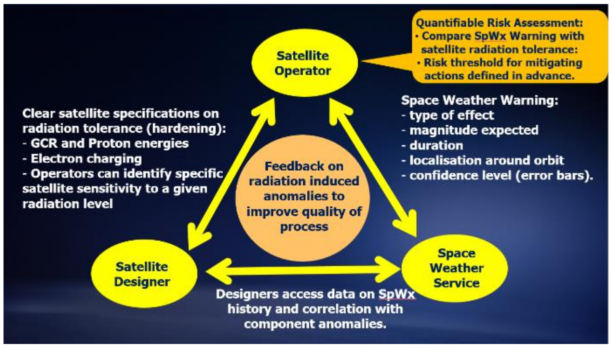

Fig.3. Space weather resilience improvement triangle

The CGMS has requested those members responsible for their own spacecraft operations to report on spacecraft anomalies for which a link to the space weather environment is suspected, or cannot be ruled out. If in doubt, the spacecraft operator is encouraged to supply all anomaly information.

The anomaly reports themselves are requested using the form reproduced in Fig 4. with an example entry taken from a typical CGMS member LEO satellite.

CGMS-49 XXX-WP-XX
V1, DATE

3 IMPACT ON <NAME OF SATELLITE SERIES A> SATELLITES DUE TO SPACE WEATHER *(LEO EXAMPLE ENTRY PROVIDED)*

Source: Recommendations for Contents of Anomaly Database for Correlation with Space Weather Phenomena, P. O'Brien, J.E. Mazur, T. Guild, November 2011, AEROSPACE Report No.TOR-2011(3903)-5.

1. Date and Universal Time of the anomaly	**2. Fully specified location of the anomaly** (spacecraft location)	**3. Velocity or orbital elements at time of the anomaly**	4. Eclipse state of the vehicle (full, penumbra, partial, none)	5. Vector to Sun in spacecraft coordinates	6. Velocity vector of spacecraft in spacecraft coordinates	7. Initial guess at type of anomaly (See taxonomy below)	8. Estimated confidence of that guess	9. Anomaly category (e.g., affected system or kind of disruption)	10. Vehicle identity	11. Notes (e.g. unusual operational states or recent changes to operations (recent commands, attitude scheme, etc.)
2018-12-19 13:18:50	*LON[deg] = 57.511W LAT[deg] = 1.056S (SAA)*	*a[km] = 7204.569 e[-] = 0.00143 i[deg] = 98.808 RAAN[deg] = 50.199 PSO[deg] = 180.996 PSO[rad] = 3.15897*	*none*		*VY [km/s] = -7.425 VZ [km/s] = 0.197*	*Geomagnetically trapped protons/ electrons*	*high*	*Payload software processor*	*Agency LEO satellite*	*Power cycle restored functionality*

Taxonomy of Satellite Anomalies Caused by In Situ Charged Particle Environment (to be used for column 7):

1. Electrostatic discharge (charging)
    1.1 Surface charging
        1.1.1 Plasma sheet (subauroral)
        1.1.2 Auroral
    1.2 Internal charging
        1.2.1 Subsurface charging (e.g., beneath blanket)
        1.2.2 Deep charging (e.g., inside a box)
2. Single-Event Effects
    2.1 Protons
        2.1.1 Solar proton event
        2.1.2 Geomagnetically trapped protons
    2.2 Heavy ions
        2.2.1 Galactic Cosmic Rays
        2.2.2 Solar energetic particles
        2.2.3 Geomagnetically trapped heavy ions
3. Total Dose
    3.1 Long-term dose accumulation (multiple causes combined)
    3.2 Short-term (days or less) dose accumulation
        3.2.1 Solar protons
        3.2.2 Geomagnetically trapped protons

3.1.3 Geomagnetically trapped electrons

Fig.4. Space weather spacecraft anomaly report template

As stated on the form itself, the form was devised from [6]. The template document available on the CGMS website explains the meaning of each required field.

The role of the Anomaly Form envisaged by the above reference is to populate a database of space weather related anomalies. In 2011, this was maintained by NOAA's National Geophysical Data Center (NGDC), in partnership with the Space Weather Prediction Center (SWPC). However, this database is no longer active. The referenced paper describes a statistical model (for GEO satellites only) based on the anomaly data, relating observable (and forecastable) environmental parameters to an anomaly probability, a so-called "Hazard Quotient", that satellite operators can take into account in their operational planning. However, the model relies on a significant input of Space Weather related anomaly data from a variety of spacecraft and such a large input of data was not achieved.

Therefore currently, there is no systematic processing of the forms on-going. However, a commitment by satellite operators to provide regular inputs would help ensure resources can be found to process and utilise the data for the benefit of CGMS Members and the wider space community. Indeed, in response to discussion held in the European Space Weather Week in 2017, NOAA NCEI stressed the importance of CGMS Members contributions in a dedicated Working Paper to CGMS-46 [7]. Furthermore, the 2018 NCEI report stresses the requests made in the original 2011 Aerospace report, that reoccurrences of anomalies should continue to be reported, even if the cause has been understood and mitigating operational actions put in place, otherwise the information to Space Weather experts is being artificially shortened and less useful.

To progress, the CGMS SWCG has established a dedicated Task Group for a Space Weather Spacecraft Anomaly Database, consisting of CGMS Member Agency nominated participants from the relevant Working Groups, as well as experts representing the other potential database users:

- spacecraft operations experts
- spacecraft design experts in space weather resilience / standards committees
- space weather service providers

The main issues to be addressed by the Task Group are to ensure that there are:

- recognised recipients of the anomaly forms
- use cases to validate that the anomaly information in the forms is fit for purpose
- sufficient guidelines to the spacecraft operators on data collection which can be incorporated into the regular reporting mechanisms
- resources assigned to build and maintain a database of anomalies
- defined processes in place to make use of the collected data
- clear objectives supporting user groups, whether they be space weather researchers, spacecraft design engineering authorities and standardisation bodies, space weather service providers or spacecraft owner/operators.
- mechanisms in place to overcome confidentiality and security concerns.

It is worth dwelling on this last point, as experience has shown that even within CGMS itself, many satellite operators are not able to provide satellite anomaly information due to security and confidentiality issues surrounding their satellite missions.

One approach is to allow reports without identifying the specific spacecraft, but providing all other data. Although the location information in the reports would allow the identification of the specific vehicle, this approach is nevertheless sufficient for some operators. Of course, without the location, the analysis against space environment hazards is nearly impossible.

Alternatively, non-disclosure agreements could allow the database itself to contain the full identities of the spacecraft, but bind the recipients not to divulge the details – only the statistical results could be shared, and even then, only with the space vehicles' identities anonymised. While this provides the best case for the database analysts, enforcement and therefore acceptability may be problematic.

The identification of a "Trusted Agent" has therefore been widely discussed in Space Weather fora. The Trusted Agent would be able to hold all this proprietary and sensitive data, and establish a legal framework for sharing it with a strong non-disclosure agreement. While this may work in a controlled, national context, achieving a similar setup with a centralised database to work in an international context can be foreseen to be problematic.

In the international context, it is proposed to consider targeting a dispersed anomaly database with trusted agents specific to a group of regional operators. As long as procedures and processing methods are coordinated internationally and considered reliable, anonymised results from each regional database could be shared and integrated. Support of regional government agencies in helping to facilitate the communication between owner/operators with the respective space weather experts managing their part of the database would be beneficial. It is therefore proposed to validate this concept in close liaison with global CGMS member agencies with a report due to CGMS-50 in spring 2022.

Additionally, access to a more statistically significant set of data is required to extract maximum value to all actors involved. It is therefore proposed to poll commercial operators as to their willingness and ability to share such anomaly data, such that the knowledge base can leverage the experience of large fleet operations in various orbital domains. In this respect, engaging with the commercial operators to jointly find solutions for overcoming barriers to providing perceived commercially sensitive data is to be attempted, in line with the Trusted Agent model mentioned above.

With the potential benefit of feedback from space weather experts being made available in return for the effort put into providing the data, it can be expected that a virtuous cycle of improvements in mitigating environmental risk and increasing our understanding of the environment itself can result.

Spacecraft operators already able to volunteer participation in such a scheme should contact the authors.

5. What is the Gap based on Current Space Weather Observation Capabilities?

The measurement of the phenomena most critical for assessment of risks to spacecraft operators requires primarily in-orbit instrumentation, resulting in a much lower level of measurement capability than could have been expected from deployment of lower cost and more reliable and flexible ground-based systems. This will impact the accuracy of the forecasts and the confidence in that data from the end-user perspective. A look to the World Meteorological Organisation's (WMO) OSCAR Database is informative of the in-orbit space weather capabilities in existence today, or planned in the near future, such as the Solar Activity Monitoring example provided in Fig.5.

CGMS works closely with the WMO in assessing the ability of the CGMS Member Agencies to provide space weather sensors to meet the WMO requirements. The WMO OSCAR Database contains a compilation of user needs and existing / planned assets and CGMS derive their members planning for new missions to ensure continuity of operational data provision, as well as to formulating their baseline for current commitments. Furthermore, an assessment is performed on an annual basis to identify any risk that these commitments will not be met, e.g., due to spacecraft failure or postponed launches of replacement missions. This process is the same for meteorological data and space weather data.

Of relevance to spacecraft operators is the importance of mission lifetime extensions to provide robustness in the operational continuity of societally important data flows. In the era of space debris mitigation requirements, such extensions are no longer as straight forward to implement as in the past, where satellites were generally operated until they failed in-orbit. A discussion of the specific issues associated to this can be found in [8].

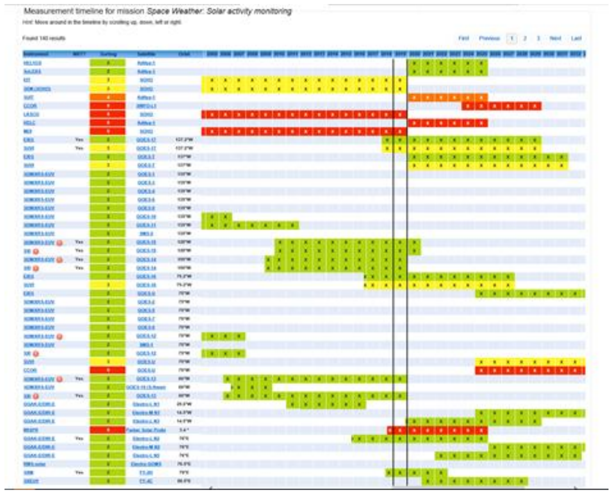

Fig.5. WMO OSCAR gap analysis example

6. Improving Data Access from Operational Satellite Systems

Space Weather in-orbit sensing capabilities and provision of associated operational services to end-users is certainly not as mature as the corresponding meteorological mission services enabled by CGMS member satellites. Some of the supporting infrastructure was originally designed to meet research goals, such that achieving the availabilities and low data latencies required by operational users is not straightforward. Increasingly operational missions, through design, are being prepared to meet the user needs. The user community is also maturing in their operational requirements for space weather service, one of the most notable examples being the International Civil Aviation Organization (ICAO) Space Weather Network [9]. This is a 24/7 service to provide real-time and worldwide space weather updates for commercial and general aviation. The new service will generate and share space weather advisories using the existing aeronautical fixed network for international aviation using data collected from dedicated space weather centres in the following consortia:

- the ACFJ consortium of Australia, Canada, France and Japan,
- the PECASUS consortium comprising Austria, Belgium, Cyprus, Finland, Germany, Italy, Netherlands, Poland and the United Kingdom;
- a third centre operated by the United States.
- Russian and Chinese regional centres are also expected to move to global service provision.
- South Africa also supports the regional services.

All of the global and regional centres will be focusing on solar events which can potentially impact air transport-related High Frequency communications, GNSS-based navigation and surveillance, and radiation levels on board civilian aircraft.

CGMS is therefore actively interacting through surveys and other users such as ICAO and the ISES (International Space Environment Services) [10], many of whose members are active in the ICAO Space Weather network.

Issues concerning data availability, latency, formats and metadata, inter-calibration needs between sensors are being identified and specific pilot projects formulated to ensure the maximum value can be extracted from the existing resources in orbit. This same feedback is also used to develop concepts for new missions. Given the efforts made by spacecraft operators to maximise the availability of the spacecraft instruments under their responsibility, it is essential that these CGMS efforts ensure that true user value is derived from them and expanded as far as possible to the global user community.

Some examples are considered below:

a) As part of the technology testing performed on the EUMETSAT Metop-A satellite as a precursor to it's de-orbiting [11], it has been ascertained that the GRAS (GPS Receiver for Atmospheric Sounding) instrument, designed to perform neutral atmosphere radio occultations can be patched to produce ionospheric occultations up to 300km altitude without significant degradation to the core meteorological mission. Performing this patch on the still-operational Metop-B and Metop-C satellite will enable useful scintillation and Total Electron Density measurements to be performed from 2021, prior to the arrival of the Metop-SG RO instrument operational service, foreseen around 2024 (see Fig. 6.)

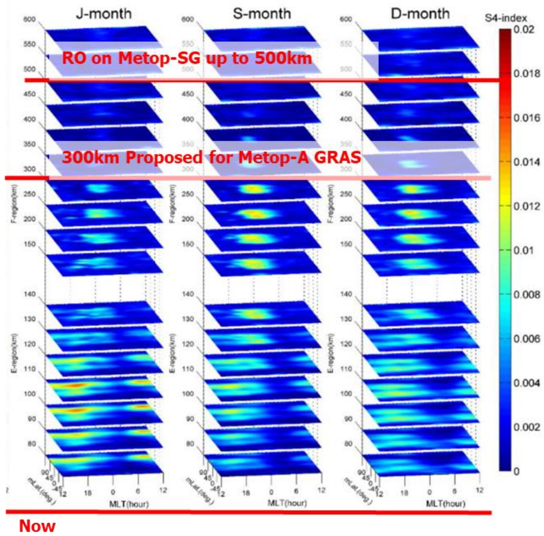

Fig.6. Metop Ionospheric Radio Occultation

b) Another improvement related to ionspheric radio occultation is the work ongoing to reduce the latency of data provision, as requirements are more stringent than those for neutral atmosphere measurement. Improvements are being made both in new mission design, such as the COSMIC-2 (Constellation Observing System for Meteorology, Ionosphere, and Climate-2) mission (NOAA, USAF, NSPO, UCAR partnership) as well as addressing issues with existing or already designed mission systems which, while meeting the needs of the meteorological community, did not so far address more stringent space weather service needs.
Regarding new missions, the COSMIC-2 mission uses a network of ground stations in its low inclination "tropical" orbit to reduce data latency to a target 30 minutes median (Fig. 7.)

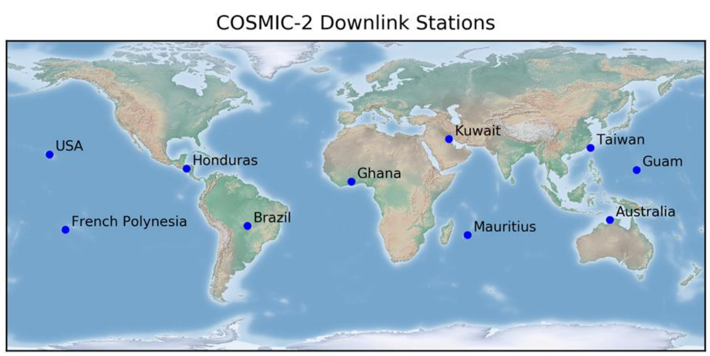

Fig.7. COSMIC-2 Downlink Stations for Low Latency

c) In terms of improving existing and planned systems, one potential candidate is EUMETSAT's Metop polar systems, both first and second generation, which could potentially leverage existing regional ground station networks to provide specific low latency capability for radio occultation as well as charged particle monitoring data (Fig 8.)

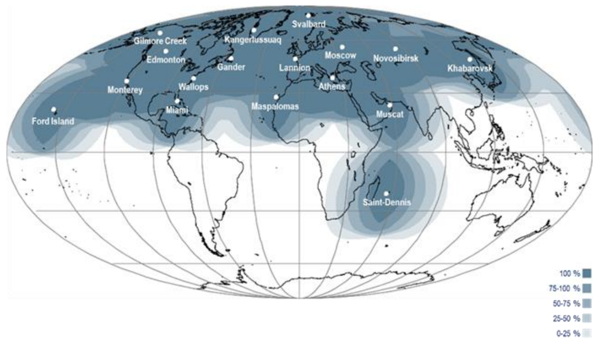

Fig.8. Direct broadcast network supporting Metop

CGMS is furthermore embarking on a new initiative as to how to leverage inter-agency cooperation to take advantage of changing mission concepts and technologies, such as satellite data relay, Digital Beam-Forming Network antennas, cloud data access etc. within the new era of smaller satellite constellations along with the existing and planned larger reference missions. The objective is to maximise the return and minimise the cost for all meteorological and space weather data provision. Note that this may well include taking benefit from the increasing global commercial capabilities in this respect.

7. Opportunities for Spacecraft Operators to get their requirements heard

The various activities described in this paper will impact the mission concepts and spacecraft operations requirements over the coming decades. Both as a user of space weather services to ensure the resilience of in-orbit assets and as an operator of space missions sensing the space weather environment, spacecraft operators have a pivotal role to play in the effective maturation of these operational services.

To this end, spacecraft operators, from government and commercial organisations are encouraged to state their interest in participating in the various activity areas outlined above.

Furthermore, spacecraft operators can provide feedback to the space weather community who are engaged in developing truly operational space weather service provision in the associated international space weather workshops conducted in the US, Europe and Asia [12,13,14].

8. Conclusions

With the combined resources of 16 leading global space and meteorological satellite agencies, CGMS is striving to improve the quality and impact of operational space weather services derived from satellite data. Several activity areas have been highlighted in this paper, where the spacecraft operations community can play a role in definition of requirements, as well as being well placed to directly benefit from those same activities.

As these activities progress, CGMS shall engage with the spacecraft operations community, reporting progress and inviting interactive participation through surveys and other outreach efforts.

With the increasing role of commercial satellite operations, opportunities exist to leverage the scale of those operations in coordination with these CGMS activities and operators representing both government and commercial entities are encouraged to participate.

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