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CGMS consolidated position on the update of the WIGOS Vision 2040

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INTRODUCTION

The WIGOS Vision 2040 is an essential reference point for CGMS efforts to develop the space-based observing system. CGMS remains committed to review the CGMS baseline with respect to the WIGOS Vision and identify options for expanding the response to the Vision.

The WIGOS Vision 2050 should support CGMS members by:

- Defining a common set of high-priority, core observations, aligned to global product needs.
- Facilitating global coordination and optimising resources across public and commercial capabilities.
- Emphasising the need for fit-for-purpose data delivery, ensuring the observing system is tightly linked to downstream product requirements.

The current WIGOS Vision supports CGMS members in their efforts to fund long-term programmes for space-based observations that encompass all upstream, midstream, and downstream activities necessary for critical observations. The Vision also provides an incentive for development of further space-based observational capabilities, complementary to already existing and planned satellite systems. Clear articulation of global user needs and alignment with operational services (e.g., weather services) will help drive strategic investment.

The key elements of the satellite architecture described in the WIGOS Vision 2050 should be:

- Long-term committed reference operational missions reliably providing fit-for-purpose observations of critical parameters required by major global applications and deployed upon agreed reference orbits; and
- Additional capabilities with sufficient reliability and continuity, in supplemental orbits, providing complementary temporal and spatial sampling and potential continuity and/or new capabilities.

The value of satellite observations for monitoring the weather, the climate, and the Earth system in general, and the impact on societies and economies have never been so high. Adapting and optimising global observation architectures in view of responding to operational requirements and dealing with evolving environment is therefore a must for space agencies. Key examples are atmospheric parameters such as temperature, moisture, wind, greenhouse gases, aerosols, etc., observed by a combination of radio-occultation, microwave, infrared and lidar technology.

In the rapidly changing environment, there is a need to find the right balance between the different components of an overall satellite observing architecture, which should continue to deliver cost-effective and fit-for-purpose data to operational meteorological users and respond to their evolving operational and possible demand for more innovative observations. The cooperation between satellite operators gathered within the framework of CGMS will be essential to achieve this.

CGMS will strive to ensure that the contributions of its members in response to the WIGOS Vision 2050 are coordinated to form a coherent and complementary System of Systems, that will serve the needs of the operational weather and climate community, as well as many users and applications as possible.

Pathfinder constellations relying on "NewSpace" approaches, with quality data and a related level of reliability to demonstrate emerging capabilities and/or can provide more cost-effective ways to provide critical data record continuity.

CGMS members will work with all relevant public and private partners to ensure technical and scientific coordination of the overall System of Systems, such as coordination of orbits, downlinks, data access, product algorithms and formats. CGMS will leverage coordination with other initiatives such as the CEOS Virtual Constellations, with the goal of optimising the value of the overall architecture and minimising gaps.

In accordance with the policy principles of the WMO Unified Data Policy Resolution (Res. 1), CGMS members will continue to encourage sharing the observational data openly and freely, for the benefit of all and to maximise the value of Earth observations to societies.

It must be emphasised that WMO should strengthen its efforts to explain both the benefits for the global meteorological community and the wider socio-economic benefits, to help CGMS members to secure the necessary funding from politicians and governments. (The EUMETSAT socio-economic benefits study for EPS-Aeolus and EPS-Sterna provides an example).

Coverage of User Requirements for Earth System Monitoring

Numerical Weather Prediction (NWP), conventional or AI-based, remains the anchor application area for satellite observations. The NWP impact of satellite observations is extensively proven and the potential for improvements remains very high, in particular from additional µwave, radio-occultation and scatterometer technology, expanded exploitation of hyperspectral IR observations and new observations like wind LIDAR with strong proven impact on NWP.

Nowcasting and early warnings will remain a critical application area in particular for geostationary imaging and sounding data. Short-term forecasting of rapidly evolving localised severe weather events requires high spatiotemporal resolution monitoring. For developing countries and regions lacking mature radar networks, satellite-based nowcasting systems are essential. Beyond standard NWP parameters (e.g., clouds/precipitation, 3D wind/thermal/moisture fields, etc.), these systems need additional critical parameters, including atmospheric parameters (Typhoon/convective system structures and environmental fields) and boundary layer and surface parameters (pressure, winds, visibility, air pollution, shortwave radiation, lightning, dust storms, and volcanic activity). Satellite-based monitoring systems must achieve minute-level temporal resolution and 10- to 100-meter spatial resolution to support early warning systems for secondary disasters including flash floods, landslides, storm surges, and wildfires. This enhanced capability will better support developing economies and disaster response.

By 2050, the operational meteorological applications will have evolved to require an appropriate representation of the Earth system as a whole. Therefore, it is critical that those observational needs are reflected in the WIGOS 2050 Vision. In addition to the observations of the thermodynamical state and the geo-chemical atmospheric composition of the atmosphere, the Vision should represent all components of the hydrosphere including clouds, precipitation, ocean and land water bodies, as well as cryosphere and biosphere. When considering the increased importance of the interconnectedness of the different components of the Earth system, it is likely that observations of the human-related aspect of the Earth system should also be accounted for. It is recommended to account for the growing list of Essential climate variables (ECVs), but also for the Essential Agriculture variables (EGVs) and the Essential Biodiversity Variables (EBVs) in addition to other variables.

Atmospheric chemistry/air quality/aerosol applications should also be a priority area for satellite applications. This should encompass meteorological parameters (temperature, pressure, clouds, water vapour, winds, humidity) as well as air quality gases (SO2, NO2, CO, NOx, O3, PM2.5, aerosols, chemical composition of aerosols) and greenhouse gases (CO2, CH4, N2O, O3, CFCs, HFCs), with particular emphasis over the Northern Hemisphere. Fire radiative power and parameters required for UV Index and Air Quality Health Index, as well as hydrology observations.

The WIGOS Vision should seek to address data gaps in the polar and high mountain regions recognising environmental change in these regions can have wide reaching impacts well outside the Arctic, Antarctic and high mountain regions.

A robust space weather monitoring network should be described with solar instrumentation deployed at Lagrange Points L1 and L5 combined with near-Earth detectors, enabling real-time tracking of solar wind, energetic particles, and geomagnetic disturbances. Building on the successful contributions of CGMS members, such as NOAA's DSCOVR mission, the ISRO Aditya-L1 mission and contributions from CMA, the next critical phase involves establishing a coordinated global early warning network to facilitate timely data sharing between space agencies and improve predictive models for solar storm impacts. This integrated system will significantly enhance our ability to forecast and mitigate disruptive space weather events affecting critical Earth infrastructure.

Core Constellation

The role of the Tier 1 backbone of geostationary and polar-orbiting satellites should be strengthened as providing the core fit-for-purpose observations of critical parameters required by major global applications and deployed upon agreed reference orbits.

The WIGOS Vision 2050 should prioritise observation areas where continuity, accuracy, and timeliness of observations which underpin weather forecasting and have high socio-economic value including:

- IR/VIS/µwave sounding from geostationary and Sun-synchronous orbits;
- Atmospheric profiling and wind retrievals;
- Radio Occultation;
- Sensors for flood prediction and extreme precipitation, where enhanced resolution and coverage are key;
- Ocean surface winds and sea state monitoring; and
- Core Space Weather observations.

The core constellation must support integrated observing systems that enable end-to-end data use for Earth system prediction, particularly tailored to national and regional decision-making.

The WIGOS vision must recognise the criticality of sustainable use of space, including space debris mitigation, sustainable use of orbits and the need for sustainable design of satellite missions according to internationally agreed standards.

MULTI-TIER CONCEPT

As we look toward the WIGOS Vision for 2050, we find it appropriate to retain the multi-tier approach from the 2040 Vision, and in particular the definition of subcomponents 1 and 2 as:

<u>Subcomponent 1:</u> Specified Backbone system with specified configuration and measurement approaches

<u>Subcomponent 2:</u> Flexible Backbone System with open orbit configuration and flexibility to optimise implementation

It is expected that subcomponent 1 to a significant extent reflects the long-term planning of CGMS members for operational continuity, whereas Subcomponent 2 includes observations that are of high priority to WMO and are under consideration by CGMS members.

Regarding the lower-tier subcomponents 3 and 4, encompassing operational pathfinders, technology and science demonstrators, and additional capabilities, we would recommend a reorganisation and the utilisation of an approach that allows the development of solutions that focus on innovative pathways driven by clear goals for operational satellite needs and priorities explicitly stated by WMO. These clear goals, in turn, would be established as part of a review and recommended path established within the WMO requirements process. This modification would allow creative but aligned development.

Defining the tier structure more flexibility will allow this desired goal to be achieved. It is not obvious for example that the Vision needs to specify the number of orbits for the LEO satellites, given that the expectation is that we will have many smallsats in the future covering LEO. Perhaps focus could be given on ensuring global coverage at a certain temporal refresh rate. The tiered approach should also serve to gracefully converge the various types of satellites: operational, research and commercial ones.

EMERGING CAPABILITIES

Several important new measurement capabilities could become operationally mature in the next 2 decades, in particular the following should be addressed in the WIGOS Vision 2050:

- Spaceborne LiDAR: enabling high-precision wind, cloud, and aerosol profiling;
- Hyperspectral microwave and full-spectrum infrared sounding: offering finer vertical resolution and improved atmospheric profiling;
- Passive microwave from GEO;
- Passive/active microwave from smallsats or constellations: improving revisit times and regional coverage for precipitation and surface parameters;

- Spaceborne precipitation and cloud radars, which are already part of the backbone system, are evolving to incorporate capabilities such as Doppler measurement; and
- Quantum sensing might provide future capabilities in next two decades.

These technologies will require system-wide coordination to ensure their outputs are timely, calibrated, and integrated into operational workflows.

Signal of Opportunity (SoOp), the re-utilization of existing satellite transmissions within bands allocated for communications or navigation, has emerged in recent years as an alternative microwave remote sensing technique with great promise for making measurements in previously inaccessible frequencies. A well-known case is GNSS reflectometry, but other opportunities could be considered in the Vision for WIGOS.

COMMERCIAL CAPABILITIES

The WIGOS Vision 2050 should:

- Recognise the growing role of commercial providers and enable their integration and interoperability through open, unified standards, procurement pathways, and assurance of data quality and latency.

- Enable, where appropriate, hybrid models of public-private partnerships, which support continuity of observations (e.g., atmospheric sounding or precipitation monitoring) while leveraging the agility of commercial innovation and providing value-for-money.

- Explore partnerships with commercial entities and citizen science platforms for bottom-up, crowdsourced data calibration and validation.

- Acknowledge additional operational concepts and science analysis to work with more complex inputs to operational satellite products for weather. CGMS members expect the future will include many more and slightly different instruments coming in through multiple data pathways that may have differing processing and latency.

The contributions of commercial providers might become an important component of the future System of Systems to ensuring wider availability for high-impact observations of demonstrated quality, where these contributions also meet targets for affordability and value-for-money. Coordination between CGMS members will be important to increase the collective value of the hybrid architecture outcome. As part of this coordination, CGMS members will aim at continuing enhancing the coordination of the data procurement mechanisms needed to acquire satellite data from the commercial sector, consistent with the CGMS Best Practices for commercial data buys. This includes the provision of non-redundant data, interoperable data sharing, harmonisation of data processing and quality control, improved change management, and cross-calibration with reference missions. Further, CGMS members will be encouraged to continue to share best practices for end user license agreements and commercial procurements aimed at balancing the needs of this coordination while complying with national regulations and policies.

IMPACT OF ARTIFICIAL INTELLIGENCE

It is the view of CGMS that AI may:

- Enable more adaptive and intelligent requirements setting, particularly in complex, evolving use environments.
- Improve observing system simulation and optimisation, helping to identify observational trade-offs and prioritise system design.
- Allow for real-time data compression, patching, triage and quality control to reduce storage and bandwidth demands, thereby supporting more efficient networks, particularly important as data volumes and technological interconnectedness continue to increase.
- Provide a mechanism to amplify the capabilities of existing satellite systems to create synthetic sensors and boost performance.
- Serve to generate a pathway where satellite-based information becomes more easily used by numerical weather prediction and benefits from feedback from numerical weather prediction that inform the evolution of global constellations.
- Enable further use of onboard decision-making, dynamic tasking and adaptive manoeuvring, facilitating stable and autonomous constellation operation with reduced dependence on continuous ground control.

The Vision should reflect AI as a tool not only for data use but also for system planning and product development and instrument enhancement.

AI weather models also require observations to forecast the future weather, so the need for observations is not in doubt. However, AI weather models may require different observations than traditional NWP models - though it is very early to state exactly in which way this may evolve.

AI and AI weather models may be useful in defining future observation requirements, focusing on the most important aspects for weather prediction and nowcasting accuracy. This could lead to requirements for more data covering the full electromagnetic spectrum from ultra-violet to terra-hertz radio frequencies, or it could lead to focusing on ""information content"" and reducing the number of observations to minimise ""information duplication or overlap"".

GROUND SEGMENT ASPECTS

The Vision must emphasise data timeliness and accessibility as key system performance metrics, specifically:

- Latency requirements should be product-driven, tied to operational use cases where the sensor to user timeline is considered.
- Investment in ground segment and data transport infrastructure and any innovative solutions therein should be considered as critical as space segment enhancements.

The Digital Twin, Internet of Things and smart sensor concepts can be a major driver for the evolution of data access. Massive data pools combined with processing capabilities on cloud platforms will promote open data and enable unified access.

To the greatest extent possible, CGMS members will strive to openly share tools, codes, and algorithms as well as harmonise ground processing systems to make the data as consistent as possible, which in turn is expected to reduce costs and barriers to interoperability.

CGMS members will aim at coordinating planning, designing, and procuring the individual components of the overall ground architecture as much as feasible, to achieve synergistic capabilities, save costs, and for the goal of optimising the value of the observations to a maximum number of users, applications and models.