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VISION FOR THE WIGOS SPACE-BASED COMPONENT IN 2040

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WMO regularly reviews its Vision of future global observing systems to support weather, climate and related environmental applications. The 2040 Vision of the WIGOS space-based component systems is intended to provide a shared, high-level goal to guide the efforts of WMO Member states and satellite operators in the evolution of satellite-based observing systems. It is based on an attempted anticipation of user requirements in the WMO application areas, and technological capabilities, in 2040. The Vision, to be developed and finalized by 2018 under CBS auspices, will be based on a broad consultation of user communities, WMO Technical Commissions, and space agencies.

This document provides draft v0.2 of the Vision, using an initial draft developed by the CBS Expert Team on Satellite Systems (ET-SAT), input from a workshop held at WMO Secretariat on 18-20 November 2015, and taking into consideration comments provided at WMO meetings held in the January – April 2016 timeframe.

CGMS operators are invited to provide comments on the draft, by 8 July 2016. This will allow for sufficient time to consider the comments in a new draft of the Vision to be endorsed by CBS-16 in November 2016.

Action/Recommendation proposed: CGMS operators to provide comments on draft v0.2 of the Vision for the WIGOS space-based components in 2040, by 8 July 2016.

Appendix A. Draft version 0.2 of the “Vision for the WIGOS space-based component in 2040”

Appendix B. Review schedule for further development of, consultation on and approval of the “Vision for the WIGOS space-based component in 2040”

VISION FOR THE WIGOS SPACE-BASED COMPONENT IN 2040

1. The 2040 Vision of the WIGOS space-based component systems is intended to provide a shared, high-level goal to guide the efforts of WMO Member states and satellite operators in the evolution of satellite-based observing systems. It is based on an attempted anticipation of user requirements in the WMO application areas, and technological capabilities, in 2040. The "Vision 2040", to be developed and finalized by 2018 under CBS auspices, will be based on a broad consultation of user communities, WMO Technical Commissions, and space agencies.

2. The draft of the 2040 Vision is developed through an incremental approach with reference to the current baseline (and Vision for 20252. Developing the initial draft of the "Vision 2040" was through an incremental approach with reference to the existing "Vision for the Global Observing System (GOS) in 2025" (hereafter called "Vision 2025")), in investigating what should be added, reinforced or improved, and what could be performed differently in the future in order to best respond to user needs. The "Vision 2025" was approved at the 14th Session of the Commission for Basic Systems (CBS-XIV, Dubrovnik, 2009) and is available in English, French, Spanish, Russian, Chinese, and Arabic at http://www.wmo.int/pages/prog/www/OSY/gos-vision.html.

3. The Vision 2025 was developed in order to guide the evolution of global observing systems in the coming decades, and the goals within it are intended to be challenging but achievable. It covers both surface-based and space-based observing systems and is intended to address the requirements for observations of all WMO programmes and WMO co-sponsored programmes. It was written to take account of requirements for observations, as documented by the WMO Rolling Review of Requirements (RRR) for observations in the database of user requirements (now called "OSCAR/Requirements"), and of the perceived key gaps between requirements and capabilities as documented in the Statements of Guidance for those Application Areas covered by the RRR process. It also took account of expected advances in observing technology as perceived at the time of writing.

4. The Vision 2025 has played a useful role. The current version of the Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP) is primarily a response to the Vision 2025. The Vision 2025 has been used widely within the WMO community and in discussions with partners, to provide a concise and easily intelligible statement of the types of developments in observing systems that would best serve the needs of WMO Members.

5. The Vision 2025 has been used by the WMO Space Programme in its interactions, on behalf of WMO Members, with space agencies through CGMS and other forums. Although this has been very valuable, the role of the Vision 2025 for this specific purpose has now become more limited, because of the long lead times for developing satellite programmes. In this regard, 2025 is almost "tomorrow", and space agencies are looking for a longer term vision to motivate their future programmes and to guide their collective response to WMO needs.

6. Following discussion at IPET-OSDE-1 and ICT-IOS-8 in April 2014, it was agreed that a "Vision for the space-based component of WIGOS in 2040" (henceforth: "2040 Vision") should be developed.

7. An initial draft of the 2040 Vision was prepared by the CBS Expert Team on Satellite Systems (ET-SAT), in consultation with CGMS, building on the outcome of a "WIGOS Space

2040" workshop (Geneva, 18-20 November 2015) and additional input from the Inter-Programme Coordination Team on Space Weather (ICTSW) .

8. The 2040 Vision is formulated based on two main elements: expected evolution of space-based observing technology, and an anticipation of user needs for satellite-based observations in the 14 application areas that are recognized and documented by WMO, by 2040.

9. It should be recalled that the current space-based observing system as described in the Manual on WIGOS includes a constellation of advanced geostationary satellites, a three-orbit constellation of polar-orbiting satellites supporting atmospheric sounding and other missions, other operational missions on various orbits suited e.g. for altimetry or radio-occultation, with a general principle of operational continuity and near real-time data availability. Although there remain gaps and scope for improvement, this system is a solid foundation underpinning the successful operation of the World Weather Watch and other major WMO programmes.

10. The 2040 Vision addresses specifically the space-based components of WIGOS, mainly because of the long lead times in space programme development cycles. It is clear however that the space segment will be supplemented by the surface-based components of WIGOS, for example to provide surface-based reference measurements, in the many applications where both satellite and surface-based data are required, or for measurements that cannot be achieved from space.

11. In addition, the 2040 Vision recognizes that satellite ground segments are critical such that users can effectively exploit satellite missions, i.e., sufficient investments in application development and user training; maintenance of efficient data dissemination systems meeting user needs for timeliness and completeness; new approaches for data processing, storage, and access (including big data analytics), given the increase in data volumes; effective user-provider feedback mechanisms; and NRT access to operational and R&D mission data when relevant.

12. There is now a complete draft of the "Vision for the space-based component of WIGOS in 2040" (version 0.2) – see Appendix A. For this draft, comments received at the following WMO meetings were taken into account: the Presidents of Technical Commissions meeting on 19-20 January 2016, the 13th session of the Consultative Meeting on High-Level Policy on Satellite Matters (CM-13, 28-29 January 2016), the CBS Inter-Programme Expert Team on Satellite Utilization and Products (IPET-SUP-2, 23-26 February 2016), and the CBS Inter-Programme Expert Team on Observing System Design and Evolution (IPET-OSDE-2, 11-14 April 2016). Appendix B contains a tentative schedule for the further development of this Vision, for its review by various stakeholders and for its eventual approval.

APPENDIX A

VISION FOR THE WIGOS SPACE-BASED COMPONENT IN 2040
DRAFT V0.2

Document Change Record

Date	Status
12 Nov 2015	ET-SAT-10 Working Paper 3.1
21 Dec 2015	Modifications based on input from ET-SAT-10 (17 Nov 2015), WIGOS Space 2040 Workshop (18-20 Nov 2015, Geneva) and ICTSW (18 Dec 2015)
11 Jan 2016	Revision based on comments by Chair IPET-OSDE and WMO Secretariat (OBS/SAT)
13 Jan 2016	Corrections to mission tables for Tier 1 and 2
19 Jan 2016	Additional comments by Chair IPET-OSDE
4 May 2016	Revisions by Chair ET-SAT and WMO Secretariat

1. Introduction

This document describes a new vision of the space-based observing components contributing to the WMO Integrated Global Observing System (WIGOS) in 2040. This new vision (henceforth referred to as the "WIGOS Space Vision 2040" or simply "Vision") is formulated based on two main elements: expected evolution of space-based observing technology, and an anticipation of user needs for satellite-based observations in the 14 application areas that are recognized and documented by WMO[1], by 2040.

The initial draft of the Vision was provided by the WMO/CBS Expert Team on Satellite Systems (ET-SAT) composed of representatives of space agencies, in consultation with the Coordination Group for Meteorological Satellites (CGMS), building on the outcome of the WIGOS Space 2040 workshop[2], Geneva, 18-20 November 2015) and additional input from the Inter-Programme Coordination Team on Space Weather (ICTSW) . A revision was prepared based on feedback received from three sets of consultations – the WMO Presidents of Technical Commissions meeting (19-20 January 2016), the Consultative Meeting on High Level Policy on Satellite Matters (CM-13, 28-29 January 2016), and the WMO CBS Inter-Programme Expert Team on Satellite Utilization and Products (IPET-SUP-2, 23-26 February 2016). Additional iterations are expected as additional groups (representing a variety of viewpoints, including the research community) are consulted, with an aim of providing a draft version for formal consideration by the WMO Commission on Basic Systems, and eventually endorsement by WMO Congress.

[1] http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html
[2] http://www.wmo.int/pages/prog/sat/meetings/WIGOSSpace2040.php (Presentations); http://www.wmo.int/pages/prog/sat/meetings/documents/ListofParticipants.pdf (List of participants)

It should be first recalled that the current space-based observing system as described in the Manual on WIGOS includes a constellation of advanced geostationary satellites, a three-orbit constellation of polar-orbiting satellites supporting atmospheric sounding and other missions, other operational missions on various orbits suited e.g. for altimetry or radio-occultation, with a general principle of operational continuity and near real-time data availability. Although there remain gaps and scope for improvement, this system is a solid foundation underpinning the successful operation of the World Weather Watch and other major WMO programmes.

The new Vision will thus be considered through an incremental approach with reference to the current baseline, in investigating what should be added, reinforced or improved, and what could be performed differently in the future in order to best respond to the needs.

The following main drivers of change are identified:

- Emerging user requirements from new applications that are not, or only partly captured in the current Vision for 2025. Today, these are mainly related to atmospheric composition, cryosphere, hydrology and space weather.
- An increased need fora resilient observing system, with more applications and services routinely utilizing satellite data; this applies not only to weather but also for example to climate applications where the impact of potential gaps in the observing system on the continuity of climate time series is particularly severe;
- Recent or anticipated advances in remote sensing technology, satellite system design and satellite programme management, which will enable to meet currently unfulfilled performance requirements, implementation of currently experimental or newly demonstrated techniques, and possibly alternative, more cost-effective approaches;
- Changes in the satellite providers' community that will involve more space-faring nations, increased maturity of satellite industry, and increasing pressure to demonstrate benefit to cost of public satellite investment, and to face commercial satellite initiatives.

This Vision addresses specifically the space-based components of WIGOS, mainly because of the long lead times in space programme development cycles. As noted above, it attempts to address the evolving interests of WMO Members by moving beyond the traditional WMO focus on observations for weather applications by taking on more of an Earth system viewpoint.

It is clear however that the space segment must be complemented by the surface-based components of WIGOS, for example to provide surface-based reference measurements using a multi-tiered approach (i.e., a smaller number of high quality ground sites that are part of a much larger network of stations that provide significant geographical coverage), in the many applications where both satellite and surface-based data are required, and for measurements that cannot be achieved from space. Just as this document considers both the increased need and capability for space-based observations in the 2040 timeframe, similar increases must be considered for the surface-based components of WIGOS, which could potentially have some significant differences in 2040 from the current capability.

In addition, satellite ground segments are critical such that users can effectively exploit satellite missions, i.e., sufficient investments in application development and user training; maintenance of efficient data dissemination systems meeting user needs for timeliness and completeness; new approaches for data processing, storage, and access (including big data analytics), given increasing data volumes; effective user-provider feedback mechanisms; and NRT access to operational and R&D mission data when relevant.

Since data management is an area under rapid technological development, the paradigm of satellite ground segment design will evolve over time. Consideration will also need to be given to the availability of the radio frequency spectrum for satellite data downlink given the increasing pressures associated with advances in telecommunications.

The Vision recognizes the need for flexibility that can support unanticipated areas of research and application, in particular those cases where community members identify and demonstrate that observations thought to be useful for one purpose (or set of environmental parameters) can be applied, either individually or as a group, to a very different area of application.

This Vision does not provide guidance regarding data policy.

2. General trends in user requirements

It is difficult to predict the requirements for satellite data in support of weather, water, climate and related environmental applications in 2040. Nevertheless, for the purpose of developing the Vision, an attempt has been made to anticipate the evolution of user needs, based on broad consultation with users and general expected trends in the use of satellite data; compared to the present, it is expected that users will require in 2040:

- higher resolution observations, better temporal and spatial sampling/coverage,
- improved data quality and consistent uncertainty characterization ,
- novel data types, allowing insight into Earth system processes hitherto poorly understood,
- efficient and interoperable data representation, given the exponential growth of data volumes.

These trends are reinforced by the growing role of integrated numerical Earth system modeling that will serve many applications and cover a seamless range of forecast ranges. More data streams are expected to be assimilated in numerical modeling frameworks, and this more effectively due to improvements in Earth system process understanding, refined assimilation methods, and better handling of observation uncertainty. Simultaneous observations of several variables/phenomena, as well as multiple observations of the same phenomenon will be beneficial to numerical weather prediction, to atmosphere, ocean, land and coupled reanalyses, and to many other applications. Sustained observations of the ECVs will provide the baseline for global climate monitoring and related climate applications.

Seasonal-to-decadal predictions will, among others, require higher-resolution ocean surface and sub-surface observations, such as of salinity, SST and sea ice, as well as information on the stratospheric state, solar spectral irradiance, and soil moisture. Ocean applications will, inter alia, require operational satellite-based observations of essential ocean variables that can be measured from satellites, including ocean surface topography, SST, ocean colour, sea ice, winds and sea state. Nowcasting, severe weather forecasting, disaster risk reduction and climate adaptation will particularly require impact-related data, such as on precipitation, temperature, sea level rise, ice formation and distribution, and winds. Managing and monitoring climate change mitigation as follow-up to the 2015 Paris Agreement will need greenhouse gas and other carbon budget-related observations, as well as information related to renewable energy generation such as on winds and solar irradiance. Applications related to health and the environment will require all observations needed for a “chemical weather forecast”, with variables characterizing atmospheric composition at the forefront, such as ozone, aerosols, trace gases, and atmospheric pollutants. Satellites will play a particularly important role in supporting applications in the data-sparse Polar Regions and provide insight into changes in ice sheets, sea ice, and glaciers.

The need to maintain continuous data records for real time and for reanalysis purposes calls for robustness of the whole data chain: contingency plans need to ensure continuity and regularly assess and thus minimize the risk of sensor gaps; the integrity of the radio frequency spectrum that is critical for space-based sensing needs to be preserved; data processing infrastructures require protection against damage or intrusion through appropriate IT security measures.

Rigorous error characterization, through intercalibration with reference standards (on-ground, in-orbit, and in space), will leverage the quality of the whole system. Measurement traceability will also be a key for the use of future space-based observations for climate monitoring and modeling, which also puts particular priority on ensuring long-term performance stability, comparability of new sensors with heritage datasets, long-term continuity of Essential Climate Variables, and generation and long-term preservation of Fundamental Climate Data Records. Accuracy requirements for reference standards should consider the full range of research and applications for space based Earth Observations, although decadal climate change observations are likely to dominate the need for high accuracy.

Specific observations are required, already in the near term, in several specific application areas:

- limb sounding for atmospheric composition in the stratosphere and mesosphere, for climate modelling;
- lidar altimetry in support of cryosphere monitoring, needed to support the new emphasis of Arctic activities in particular;

- hydrology, with the increasing importance of water resource management and flood prevention, should benefit of lidar altimetry but should progressively exploit gravity field measurements for operational monitoring of groundwater;
- SAR imagery and high-resolution optical imagery should be more systematically exploited for applications in the cryosphere, for example for ice sheet and glacier monitoring, deriving refined sea ice parameters, snow properties and permafrost changes;
- water cycle modeling will benefit of sub-mm imagery for cloud phase detection;
- atmospheric radiation budget modeling will be improved through systematic assimilation of multi-angle, multi-polarization radiances allowing a better specification of aerosols and clouds;
- the accuracy of surface pressure derived from NIR spectrometry and 3D fields of horizontal winds from Doppler lidar should be assessed, with a view to improve the atmospheric dynamics in NWP models;
- finally, solar observations on and off the Earth-Sun line (e.g. at L1, and L5), in situ solar wind at Lagrange point L1, and possibly beyond, magnetic field measurements at L1 and GEO, measurement of energetic particles at GEO, LEO and across the magnetosphere, will be needed on a fully operational basis to support the warning of major space weather events.

It will be beneficial to invest in further development of forward operators (for model-based simulation of observations) and, related to this, improved radiative transfer models and spectroscopic databases that are needed to enhance the utility of observations in numerical model frameworks.

The following sections describe trends in satellite systems and programmes. These, together with anticipated user needs outlined above, have led to the formulation of the WIGOS Space Vision 2040 that represents an ambitious, but at the same time realistic and cost-effective target (section 5).

3. Trends in system capabilities

It is anticipated that rapid progress on remote sensing technology will lead to higher signal sensitivity of sensors, which translates into higher spatial, temporal, spectral and/or radiometric resolution. However, progress will not only result of doing the same measurements with better performance, but also from a better use of the electromagnetic signal by different ways:

- the remote sensing frequency spectrum used for optical measurements will expand in both directions, towards UV and far IR, and wider use will also be made of the MW spectrum, subject to adequate frequency protection;

- hyperspectral sensors will be used not only in IR but also in the UV, VIS, NIR and MW ranges, providing a wealth of information, opening new fields for research and generating a dramatic increase in data volumes and processing demand;
- polarization of radiation can be further exploited, for example in Synthetic Aperture Radar imagery;
- combinations of active and passive measurements including bi-static measurements by formation-flying spacecraft can be exploited;
- radar scatterometry can be supplemented by GNSS-based reflectometry;
- the radio-occultation technique can also be generalized, in using additional frequencies (beyond the current L1, L2 and L5 GPS frequencies) to maximize the sensitivity to atmospheric variables, and monitoring more systematically the ionosphere including ionospheric scintillation.

Satellite observations are also determined by the choice of orbit; more diversity will be possible in this respect, too, thanks to a wider community of space faring nations, provided that the overall planning can be optimized under the auspices of WMO, with the aim to make the various satellite programmes complementary and interoperable (rather than overlapping and duplicating each other). The future space-based observing system should rely on the historical geostationary and low-Earth orbit sun-synchronous constellations, but also include high eccentricity orbits that would permanently cover the Polar regions, low-Earth orbit satellites with low or high inclination for a comprehensive sampling of the global atmosphere, and lower-flying platforms, for example with short-life nanosatellites serving as gap fillers. A space station could be used for demonstration of new sensors, and, in the overlap region of space-based and surface-based observing systems, sub-orbital flights of balloons or unmanned aerial vehicles will also contribute. Calibration references should be an integral part of the system, including Earth surface targets, in-orbit reference standards, and lunar observatories to use the Moon as a transfer standard.

Using a diversity of orbits will improve sampling the Earth's environment and remove sampling biases that a single source of measurement can introduce. They will facilitate simultaneous observations of several variables/phenomena, as well as multiple observations of the same phenomenon, both with benefits to applications. Multiple orbits will also increase the overall robustness of the system, but require a special effort on interoperability (on the provider side) and agility (on the user side). The diversity of mission concepts goes along with a diversity in programmatic approaches: the overall system should be composed of, on the one hand, the classical series of recurrent large satellite programmes which provide a solid and stable foundation with a visibility over two decades, and on the other hand, smaller satellite programmes with shorter life cycles, more limited scope, more experimental payloads, and with faster, more flexible decision processes.

Data management and data access will remain a challenge over the coming decades, as progress in information technology is constantly challenged by the growth of data volumes and the requirements for increasing timeliness of data delivery by many users. At the same time, for building the historical record, long-term data preservation of these data must be managed. Higher connectivity and more providers of satellite data raise the question of interoperability and IT security that must be addressed with very high attention. Handling the growth of data volumes requires an expansion of telecommunications capacity, through identified networks, cloud concepts or collaborative systems. For example, DBNet (formerly named RARS) is a collaborative, default-tolerant network using the Direct Broadcast service available for many satellite systems. DBNet is a cost-effective complement or alternative to more expensive ground station networks. A trade-off needs to be found between exchanging data and exchanging products derived from the data, which raises the question of where the processing is performed, and how it is controlled. The prospect of distributed processing using multiple data sources is critically dependent on consistent data representation, detailed quality information, and comprehensive, standardized metadata. WMO provides a framework in the area of data management, for developing best practices and fostering cooperation with the goal to achieve maximum overall efficiency and quality.

4. Evolving paradigm of satellite programmes

The space-based observing system will continue to rely on both operational and R&D missions, which are pursuing different objectives and are optimized along different priorities. This is in no way an impediment: operational users are encouraged to make use of R&D mission data, and R&D missions may benefit of flight opportunities on operational programmes. Moreover, the transition process from mature research programmes to operational missions should be systematically supported and controlled in considering the technological maturity (robustness, availability, affordability), the operational maturity (possible long-term and real-time service continuity), the user maturity (evidence of a user community and applications with demonstrated benefit), and organizational maturity (established structures and mechanisms for user-provider interaction on requirements, system specifications, feedback, assessment of benefits, and funding schemes).

As the number of space-faring nations increases, it will be justified to aim at a wider distribution of the space-based observation effort among WMO Members. This is an opportunity, but with associated challenges: the need for an increasingly strong international cooperation to avoid duplication of efforts and to ensure the interoperability of all components. While the WMO Space Programme is an overall framework for global coordination, different models will be followed to implement truly international satellite programmes: bilateral cooperation between agencies, inter-governmental regional organizations such as EUMETSAT and ESA, more flexible regional programmes (e.g. a potential future African Space Programme) or consortia under private law with governmental stakeholders (like e.g. the current DMC constellation or CLS-Argos).

Another evolution to be considered with attention is the evolving role of the commercial sector. While satellite industry has historically assumed a role of contractor delivering a system to the governmental customer, industry might act in different ways in the future: as the implementing agent of the government to deliver data rather than systems; by sharing the financial and technical risk in a public/private partnership; by implementing satellite missions on a purely commercial basis, either by adding a mission as a payload hosted on a commercial telecommunication platform, or by designing an environmental satellite programme on its own. These possible paradigm shifts could open opportunities to enhance the observing system, thanks to the potentially high reactivity of some private companies. There are also major risks associated with a changing role of industry which should be anticipated, and addressed with caution, in the following areas:

- Limitations to exchange of data due to its commercialization, resulting in overall less availability of data;
- Lack of publicly-available information on the detailed technical specifications of the system, resulting in loss of traceability and reliability;
- Inability to participate in global coordination under the auspices of WMO, since a private company has its own market objectives and cannot be bound by the same international commitments as a governmental agency;
- Risk that the political attractiveness and potential benefits of commercial initiatives in the short term undermine the decision processes and funding mechanisms of long-term national or regional programmes which are essential to meet national, regional or global requirements.

Given these opportunities and threats, it is important to identify the conditions under which commercial initiatives addressing space-based observing systems could make a successful contribution to society.

There is a continuing need for governmental commitments by WMO Members, implemented by governmental agencies or any other government-designated agent, to preserve the possibility of coordinated, global optimization of the system, including gap assessments and contingency planning, international data exchange and interoperability under WMO auspices. WMO Resolution 40 (Cg-XII)[3] provides a conceptual framework to define how public and private data provision can complement each other: in order to ensure the provision of “essential data” freely, Members must have governmental control on a WMO-coordinated backbone observing system, while commercial operators could enhance the system in providing “additional data”. Public/private partnerships may combine these two aspects, for instance, with a programme delivering a freely accessible “essential” service responding to the specifications defined by the governmental authority, and an “additional” service marketed by the commercial operator towards specific customers. Without pretending any coordination of commercial initiatives, the WMO Vision can have a beneficial influence on the provision of observations by commercial operators through setting overall system aims and priorities and highlighting the importance of data quality and interoperability standards.

[3] https://www.wmo.int/pages/about/Resolution40_en.html

5. The Vision

Trying to outline the architecture of the space-based observing system envisioned for 2040, the first difficulty for space agencies is to anticipate and understand the user needs 25 years ahead, and for users to anticipate the potential future capabilities. The needed dialogue was the motivation for the WMO WIGOS Space 2040 workshop held in November 2015. Below, an outline is given of the possible configuration of the Vision. Rather than prescribing every component, a balance has been struck between being specific enough to provide clear guidance on how to achieve a robust and reliable system, and being open to opportunities and initiatives that can currently not be anticipated. The proposed Vision consists of 4 components:

1. A detailed specified backbone system, the basis for Members' commitments, addressing the vital needs for data critical to satellite applications with pre-determined orbital configuration and measurement approach. This specified backbone should as a minimum include all the elements of the 2025 Vision and current CGMS baseline with a few necessary additions and improvements; it would ensure the long-term stability of the system;
2. An equally important component to provide other critical data is defined in a more open way, without predetermining the final orbital configuration or measurement approach, in order to preserve the flexibility necessary to optimize the system based on latest demonstrated technologies and impact studies;
3. Operational pathfinders, and technology or science demonstrators should be planned, to pave the way for future evolution of the system beyond 2040 and also to inform user requirements beyond those that are currently recognized but which may be identified by research and/or operational communities in the future;
4. The observing system should also take advantage of other contributions of WMO Members and third parties including governmental, academic or commercial initiatives, which could augment the backbone elements to provide more "essential" or "additional" data.

It is worth noting that the grouping of observations into four components is not done to represent sequential priorities (e.g., all component one observations should be done before any component two observations should be done). Indeed, the expectation is that the observations listed under all components are important, and the major difference separating them at this point is the sense of the strength of the consensus about the optimal measurement approach and the maturity of that approach (higher for component one than for component two). It is possible that over the intervening years between now and 2040, some observations currently identified as being in component two could "graduate" to component one. Since the expectation is that this Vision will be revisited well before 2040, there should be ample opportunities to reassess the assignment of observations to the individual components well before 2040.

Component 1: Backbone system with specified orbital configuration and measurement approaches

The backbone system, building on/enhancing current vision of the observing system should include:

Instruments:	**Geophysical variables and phenomena:**
Geostationary ring	
Frequent multi-spectral VIS/IR imagery	Cloud amount, type, top height/temperature; wind (through tracking cloud and water vapour features); sea/land surface temperature; precipitation; aerosols; snow cover; vegetation cover; albedo; atmospheric stability; fires; volcanic ash
IR hyperspectral sounders	Atmospheric temperature, humidity; wind (through tracking cloud and water vapour features); rapidly evolving mesoscale features; sea/land surface temperature; cloud amount and top height/temperature; atmospheric composition (aerosols, ozone, greenhouse gases, trace gases)
Lightning mapper	Lightning (in particular cloud to cloud), location of intense convection.
UV/VIS/NIR sounder	Ozone , trace gases, aerosol, humidity, cloud top height
Low-Earth orbiting sun-synchronous core constellation in 3 orbital planes (morning, afternoon, early morning)	
IR hyperspectral sounders MW sounders	Atmospheric temperature and humidity; sea/land surface temperature; cloud amount, water content and top height/temperature; precipitation; atmospheric composition (aerosols, ozone, greenhouse gases, trace gases)
VIS/IR imager including Day/Night band	Cloud amount, type, top height/temperature; wind (high latitudes, through tracking cloud and water vapour features); sea/land surface temperature; precipitation; aerosols; snow and ice cover; vegetation cover; albedo; atmospheric stability
MW imagers	Sea ice; total column water vapour; precipitation; sea surface wind speed [and direction]; cloud liquid water; sea/land surface temperature; soil moisture
Scatterometers	Sea surface wind speed and direction; sea ice; soil moisture
Low-Earth orbit sun-synchronous satellites at 3 additional Equatorial Crossing Times, *for improved robustness and improved time sampling particularly for monitoring precipitation*	
Other Low-Earth orbit satellites	
Wide-swath radar altimeters, and high-altitude, inclined, high-precision orbit altimeters	Ocean surface topography; sea level; ocean wave height; lake levels; sea and land ice topography
IR dual-angle view imager	Sea surface temperature (of climate monitoring quality); aerosols; cloud properties
MW imagery at 6.7 GHz	Sea surface temperature (all-weather)
Low-frequency MW imagery	Soil moisture, ocean salinity, sea surface wind, sea-ice thickness
MW cross-track upper stratospheric and mesospheric sounder	Atmospheric temperature profiles in stratosphere and mesosphere
UV/VIS/NIR sounder, nadir and limb	Atmospheric composition including H_2O
Precipitation and cloud radars, in inclined orbits	Precipitation (liquid and solid), cloud phase/ top height/ particle distribution/ amount, aerosol, dust, volcanic ash
MW sounder and imager in inclined orbits	Total column water vapour; precipitation; sea surface wind speed [and direction]; cloud liquid water; sea/land surface temperature; soil moisture
Absolutely calibrated broadband radiometer, and TSI and SSI radiometer	Broadband radiative flux; Earth radiation budget; total solar irradiance; spectral solar irradiance
GNSS radio occultation (basic constellation)	Atmospheric temperature and humidity; ionospheric electron density
Narrow-band or hyperspectral imagery	Ocean colour; vegetation (including burnt areas); aerosols; cloud properties; albedo
High-resolution multi-spectral VIS/IR imagers	Land use, vegetation; flood, landslide monitoring
SAR imagery and altimetry	Sea state, sea ice, ice sheets, soil moisture, floods
Gravimetry mission	Ground water, oceanography
Other missions	
Solar wind in situ plasma and energetic particles, magnetic field, at L1	Energetic particle flux and energy spectrum (Radiation storms, geomagnetic storms)
Solar coronagraph and radio-spectrograph, at L1	Solar imagery (Detection of Coronal Mass Ejections and solar activity monitoring)
In-situ plasma probes and energetic particle spectrometers at GEO and LEO, and magnetic field at GEO	Energetic particle flux and energy spectrum (Radiation storms, geomagnetic storms)
Magnetometers on GEO orbit	Geomagnetic field at GEO altitude (geomagnetic storms)
On-orbit measurement reference standards for VIS/NIR, IR, MW absolute calibration	

Component 2. Backbone system – Open measurement approaches (flexibility to optimize the implementation)

Instruments:	Geophysical variables and phenomena:
GNSS reflectrometry missions, passive MW, SAR	Surface wind and sea state
Lidar (Doppler and dual/triple-frequency backscatter)	Wind and aerosol profiling
Lidar (single wavelength) (in addition to radar missions mentioned in Tier 1)	Sea ice thickness
Lidar (DIAL)	Atmospheric moisture profiling
Sub-mm imagery	Cloud phase detection
NIR imagery	CO2, CH4
Multi-angle, multi-polarization radiometers	Aerosols, radiation budget
Multi-polarization SAR, hyperspectral VIS	High-resolution land and ocean observation
GEO or LEO constellation of high-temporal frequency MW sounding	Atmospheric temperature, humidity and wind; sea/land surface temperature; cloud amount, water content and top height/temperature; atmospheric composition (aerosols, ozone, greenhouse gases, trace gases)
NIR spectrometry	Surface pressure
UV/VIS/NIR/IR/MW limb sounder	Ozone , trace gases, aerosol, humidity, cloud top height
HEO VIS/IR mission for continuous polar coverage (Arctic and Antarctica)	Sea ice; cloud amount, type, top height/temperature; wind (through tracking cloud and water vapour features); sea/land surface temperature; precipitation; aerosols; snow cover; vegetation cover; albedo; atmospheric stability; fires; volcanic ash
Solar magnetograph , solar EUV/X-ray imager and EUV/X-ray irradiance, both on the Earth-Sun line (e.g. L1, GEO) and off the Earth-Sun line (e.g. L5, L4)	Solar activity (Detection of solar flares, Coronal Mass Ejections and precursor events)
Solar wind in situ plasma and energetic particles and magnetic field off the Earth-Sun line (e.g. L5)	Solar wind; energetic particles; interplanetary magnetic field
Solar coronagraph and heliospheric imager off the Earth-Sun line (e.g. L4, L5)	Solar heliospheric imagery (Detection and monitoring of Coronal Mass Ejections travelling to the Earth)
Magnetospheric energetic particles	Energetic particle flux and energy spectrum (geomagnetic storms)

Component 3. Operational pathfinders and technology and science demonstrators

Instruments:	Geophysical variables and phenomena:
GNSS RO additional constellation for enhanced atmospheric/ionospheric soundings, including additional frequencies optimized for atmospheric sounding	Atmospheric temperature and humidity; ionospheric electron density
Radar and lidar for vegetation mapping	Vegetation parameters, Above-ground biomass
Hyperspectral MW sensors	Atmospheric temperature, humidity and wind; sea/land surface temperature; cloud amount, water content and top height/temperature; atmospheric composition (aerosols, ozone, greenhouse gases, trace gases)
Solar coronal magnetic field imager, solar wind beyond L1	Solar wind, geomagnetic activity
Ionosphere/ thermosphere spectral imager (e.g. GEO, HEO, MEO, LEO)	
Ionospheric electron and major ion density	
Thermospheric neutral density and constituents	

This category of missions should include process study missions, for which the content and duration would have to be determined on a case by case basis, depending on process cycles considered. Such missions could rely on a diverse range of platforms. For instance, nanosatellites may be used for demonstration or science missions, and for contingency planning as gap fillers, without excluding the use of nanosatellites also in Tier 2 missions. At the other end of the platform size spectrum, the use of orbiting platforms (comparable to the International Space Station) can also be an option for demonstration or science missions.

Component 4. Other contributions from WMO members and third parties

The observing system should also take advantage of other capabilities implemented by WMO Members and third parties, which could be governmental, e.g., academic projects, or commercial initiatives, willing to exploit particular technical or market opportunities. Such capabilities could augment the backbone elements in providing more “essential” or “additional” data.

WMO would not pretend to coordinate these contributions, but could recommend standards and best practices that the operators may consider to comply with in order to facilitate the user uptake of such capabilities and maximize the chance that the data provided are interoperable with the backbone system and provide a useful contribution to the community.

APPENDIX B

DRAFT REVIEW SCHEDULE

Vision for the WIGOS Space-based Components in 2040

Version used	Review body	Comment Period	Remarks
V.20160119	PTC-2016	19-20 Jan 2016	Comments received
	CM-13	21-29 Jan 2016	Comments received
	EUMETSAT	29 Jan- 5 Feb 2016	No response
V.20160119	IPET-SUP-2	23-27 Feb 2016	Comments received
V.20160119	Space weather task team of CGMS	12 Feb – 15 May 2016	Email by Secretariat on 12 Feb 2016
V.20160119	WMO CBS IPET-OSDE-2	11-14 Apr 2016	
	WMO CBS ICT-IOS-9	18-21 Apr 2016	Secretariat to subsequently generate V0.2 , using all comments received thus far
V0.2	CGMS -44	20 May – 8 Jul 2016	Open for comments by CGMS before and after CGMS-44; Secretariat to subsequently generate V1.0
V1.0	CBS-16 (23-29 Nov 2016)	1 Sep – 1 Dec 2016	Secretariat to subsequently generate V1.1
V1.1	WMO Members, Technical Commissions, Other user communities, ICTSW, CEOS and CGMS Agencies	Q1-Q2/2017	Letter by WMO Secretary-General in Q1 2017
	Joint ET-SAT-11 / IPET-SUP-3 Meeting	3-7 Apr 2017	To discuss status of Vision
	70th WMO Executive Council	May/June 2018	To endorse final draft, for submission to Cg-18
	18th World Meteorological Congress	May/June 2019	To endorse Vision