

DEVELOPMENT OF A VISION OF WIGOS SPACE-BASED COMPONENT IN 2040

HLPP reference: 1.1 Coordination of observing systems

The WMO Space Programme – through the Commission for Basic Systems (CBS) Expert Team on Satellite Systems (ET-SAT) - has initiated the development of a “Vision for the Space Based Component of WIGOS in 2040” in response to the request from CBS in September 2014 (See Appendix 1).

The development of a Vision was approached by three different angles:

- First of all, the new vision should aim to respond to the anticipated societal needs of 2040, in the context of WIGOS and of the Global Framework for Climate Services (GFCS). A starting point is to address the unfulfilled requirements expressed in the Statements of Guidance of WMO application areas in the Rolling Review of Requirements. Looking ahead, the vision should consider the increasing maturity of some space applications and the emerging requirements of new application areas which are not fully addressed by current plans.
- The vision should consider the opportunities opened or anticipated from advances in satellite and instrument technology, including the lessons learnt from demonstration missions that, by 2040, will be mature for transition from R&D or demonstration stage to operational stage (e.g. GPM, Doppler lidar), and possible new concepts. Rapid progress in technological capabilities will allow improved performances in terms of spectral and temporal resolution, which also bears on the amount of data to be exchanged.
- Finally, attention should be paid to emerging changes in the provider community considering the increased number of space-faring nations, the range of possible approaches between large and very small satellite programmes, and the balance to be found between an increasing capability of the private sector to contribute to the system and the specific responsibilities of governmental entities.

Opportunities and risks should be carefully analysed considering the possible technological evolution, as well as the key strategies for optimal integration of space-based and surface-based observation capabilities.

A WIGOS Space 2040 Workshop is tentatively planned on 18-20 November in Geneva to support dialogue between space agencies and major user communities (Appendix 2).

Action/Recommendation proposed:

- CGMS members to consider the preliminary considerations on the Vision of WIGOS space-based components in 2040 and provide feedback to WMO through their representative in ET-SAT (or directly to jlafeuille@wmo.int if they are not represented in ET-SAT).
- CGMS Members to note the planned WIGOS Space W2040 workshop tentatively planned on 18-20 November 2015 in Geneva.

Appendix 1:

**ET-SAT input to the Vision of WIGOS Space-Based
Components in 2040 (Draft 3, 14/04/2015)**

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1. INTRODUCTION

In September 2014, the Extraordinary Session of the Commission for Basic Systems (CBS-Ext(2014)) encouraged the initiative to develop a new Vision of the WMO Integrated Global Observing Systems (WIGOS) component observing systems in 2040, which would ultimately replace the current “Vision of the Global Observing System in 2025” (hereafter named “Vision-2025”) adopted in 2009 by the Executive Council. The new vision should take into account the advances in remote-sensing and satellite technology, the increasing maturity of space applications (e.g. to air quality, hydrology, and cryosphere monitoring), the diversity of orbits and mission concepts required for a balanced and robust space-based observing system.

The new horizon of the vision was set to 2040 in order to be ahead of currently firm satellite plans, since a vision document should serve as guidance in the early planning stage rather than just reflect existing plans. The Vision shall be ambitious but achievable. A key input from ET-SAT is thus to inform WMO on the range of capabilities expected to be technically achievable by 2040.

The present statement focuses on the changes proposed to the space-based part of the Vision-2025 in order to evolve into a “Vision of WIGOS Space-based components in 2040”.

Three main drivers were identified for these changes:

- Observation requirements remaining unfulfilled in the Vision-2025
The Statements of Guidance¹ of several WMO application areas indicate that improvements in resolution or accuracy are required for many of the variables that are addressed in the Vision-2025. A few other of the required variables are not addressed at all in the Vision-2025, either because their measurement was not considered feasible in the 2025 timeframe or because these requirements have emerged after the Vision was developed.

In particular, since the scope of WIGOS now encompasses the Global Atmospheric Watch (GAW), the WMO Hydrological Observing System (WHOS), the Global Cryosphere Watch (GCW) in addition to the World Weather Watch Global Observing System (GOS), and may include a “Space Weather Watch” in the future. The observation needs of atmospheric composition, hydrology, cryosphere, and space weather must thus be addressed in a more comprehensive way than in the Vision-2025. Particular attention must be paid to climate monitoring needs, a strategic priority, which is addressed below through consideration of the Architecture for Climate Monitoring from Space.

¹ See : <http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html#SOG>

- Advances in technology
Recent or anticipated advances in technology are opening new opportunities for instruments, orbital concepts, data management, telecommunications, and satellite systems in general. New technology may provide efficient alternatives to existing observation techniques and strategies, or a valuable supplement to them. It is a progressive process: as their technology readiness levels are going up, some observation techniques which were recommended for 2025 as pathfinders can be operational by 2040, while the latest emerging technologies which are being demonstrated may be recommended as operational pathfinders for the 2025-2040 time frame.
- Changes in the providers' community
The space-based component of the WMO GOS has been relying for decades on a small number of agencies from a small number of WMO Members (or consortia of Members). Multiple changes are occurring: on one hand, these historical contributors have a much stronger technical capability to support the observing system; on the other hand, as space activities have matured from the early demonstration to an operational stage, these agencies are bound to justify their investments by solid cost-benefit considerations.

In the same time, there is a large growth potential with the emergence of additional space-faring nations, willing to enter the space business as part of an overall technology development strategy.

Finally, the growth of commercial space applications induces opens the possibility of different business models of public and private agents.

All these factors, coupled with the technological advances in satellite systems, may provide opportunities of new satellite programme concepts but also raise new issues, given their implications on the international coordination mechanisms.

These aspects are reviewed below. Recommendations are expressed for a way forward.

2. OBSERVATION NEEDS

2.1. Unfulfilled requirements, gaps or weaknesses noted in the Statements of Guidance

The Statements of Guidance available from the WMO various application areas have identified limitations on a number of measurements. Most of these needs have been addressed

in the Vision-2025. However, as of 2015, the capabilities required for 2025 have not yet been all implemented, or haven't yet achieved the foreseen coverage, space/time resolution or performance. Such gaps are legitimate since we are not yet in 2025, and mainly confirm the relevance of the Vision-2025.

In some other cases, the Statements of Guidance were updated after the Vision-2025 was finalized, and the needed capabilities may not be captured in the Vision-2025, or the target specified in the Vision-2025 is not sufficient to meet the requirements, thus requiring an update of the Vision-2025.

The limitations which can be referred to the elements of the Vision-2025 are summarized below:

- Geostationary constellation
 - The quality of Atmospheric Motion Winds (AMV) should improve,
 - Hyperspectral IR sounding is not yet implemented
- Core meteorological sun-synchronous orbit (SSO) constellation
 - There are concerns for the continuity, because of the vulnerability to early failure and lack of a well-defined contingency plan (unlike for the geostationary constellation),
 - The radiometric resolution (NE Δ T) of microwave (MW) sounders is still marginal.
- Other sustained missions
 - The spatial resolution of MW imagery is a limiting factor of soil moisture and snow water equivalent MW products for agriculture and hydrology,
 - the Global Navigation Satellite Systems (GNSS) radio-occultation (RO) coverage should be increased to ensure a higher number of occultations per day, and their regular distribution around the globe through different orbit inclinations (The “number of receivers” mentioned in the Vision-2025 is not a representative indicator)
 - More scatterometers and altimeters are needed to achieve adequate sampling for oceanic applications (for currents, waves, coastal area monitoring)
 - A space-borne precipitation radar is available experimentally but such radars should become operational (with near real-time availability and mission continuity)
 - The number of particle detectors is not sufficient for a representative sampling of particle flows in the near Earth space environment
- Operational pathfinders to become operational
 - A Doppler lidar (for 3D wind, aerosol) is not yet available at a demonstration stage but the operational need for such a capability is reiterated, especially for deriving 3D winds.
 - Imagery missions on High-Eccentricity Orbits (HEO) are planned but not yet implemented; as there is increased interest for permanent monitoring of polar (especially arctic) areas in the context of the GCW, and for polar winds and volcanic eruption monitoring, such missions should be considered for operational status,

- Low frequency MW observation of salinity and soil moisture was successfully demonstrated with SMOS, now continuing with SMAP and should be brought to «operational» status in the near future.
- Other operational pathfinders
 - A Cloud radar and a Cloud lidar mission have been successfully demonstrated with CALIPSO and CLOUDSAT for 9 years, and the case for an operational follow-on should be further investigated
 - The request to demonstrate a Geostationary MW imaging/sounding is confirmed
 - The potential of gravity field measurements, such as performed by R&D missions (GRACE, GRACE-FO, GOCE, SWARM) should be further demonstrated for ground water.

Additional needs which were not captured in the Vision-2025 have emerged from the atmospheric chemistry, cryosphere, and space weather communities, and atmospheric physics. They include:

- Limb sounders, which are essential to ensure continuous observation of stratospheric ozone and trace gases. (The Vision-2025 calls for “Atmospheric composition instruments” including UV sounders in GEO and LEO, but does not address the needs of atmospheric composition observation in a comprehensive manner)
- Lidar altimeters, to measure ice sheets, sea ice, and lake level for climate monitoring, oceanic and hydrology applications
- Sub-mm imagery, for cloud phase determination and better understanding and monitoring of precipitation
- NIR spectrometer, as a demonstration mission to derive surface pressure
- Continuity of solar/interplanetary observation at Lagrangian points (L1, L4/L5) to monitor solar eruptive events and forecast their impact on Earth.
- Multi-angle, multi-polarization observations should be considered instead of simply dual-angle view radiometry to inform on aerosols and atmospheric radiation budget.

As a minimum, the needs above should be addressed in the Vision-2040.

2.2. Consequences of observation-model linkage

There has been tremendous progress in modeling, which results in improved performances to provide accurate forecasts and coupling of multiple subsystems of the Earth’s environment. This progress goes along with an increased ability to assimilate a variety of satellite data. Assimilation has therefore become a massive “client” of satellite data, as confirmed for instance at the NWP impact workshops. The assimilation function serves primarily the NWP and climate forecast models and other coupled models (ocean-atmosphere coupled model, or whole atmosphere models including the thermosphere, or coupled ionospheric models). The assimilation also plays a role of data integrator which supports potentially a wide range of other applications beyond weather and climate forecasting.

The range of variables to be incorporated in the assimilation process will expand as we move towards a comprehensive integrated system. By 2040 it is anticipated that global modeling

will be available with 5 km x 1h resolution, and user needs in most application areas could then be met by this “blended system”. The new vision of space-based observation must analyse how this major trend affects the priorities for designing the observing system.

The following can be highlighted:

- The requirements for surface pressure and 3D wind are reinforced and supported by OSSEs;
- Time/space resolution should be further improved;
- Timeliness and regular space and time sampling should be ensured;
- Importance of error characterization, as the analysis is almost not sensitive to individual errors of each instrument which are corrected when the error distribution is known and stable;
- A few high-quality (low-error) anchor measurements are useful to control the model bias;
- Trade-off may be considered between space and time resolution versus radiometric resolution.
- For reanalysis purposes, it is of utmost importance to maintain continuity of data records (and quick retrieval of missing data in case of communication outage).

2.3. Architecture for Climate Monitoring from Space

- Towards a virtual climate constellation

Monitoring climate variability and climate change is a foundation for the Global Framework for Climate Services (GFCS). WMO Resolution 19 (Cg.16) calls for an Architecture for Climate Monitoring from Space². This architecture should be reflected by specific provisions in WMO Regulatory Material (e.g. the Manual on WIGOS) defining voluntary commitments of WMO Members to implement capabilities through their space agencies and related institutions. The architecture is an end-to-end system encompassing four pillars: (i) Earth’s environment sensing; (ii) climate record creation and preservation; (iii) climate applications; (iv) decision making. The creation of climate records, their applications and subsequent decisions are beyond the scope of WIGOS, but the first pillar (sensing) is a component of WIGOS, and one of the drivers of the present Vision.

Many of the variables required for climate monitoring are also required for other applications (weather, hydrology, air quality, ocean applications, land use, etc.). The climate observation capabilities should thus be integrated with the observing capabilities of these other applications as far as technically relevant, while recognizing that different requirements can apply: for instance, decadal stability is important for climate, while round-the-clock continuity and timeliness is more important for nowcasting. The “sensing” pillar of the climate monitoring architecture thus should not be a physically separated «climate monitoring constellation» but a “virtual climate constellation”. It should be a “climate view” of the integrated observing system, giving confidence that climate requirements can be met by this system.

The joint CEOS-CGMS Working Group on Climate has undertaken a comprehensive inventory of Essential Climate Variables (ECV) Climate Data Records (CDR) in order to identify gaps with respect to ECV needs. This exercise will ensure that datasets from current

² Res.19 (Cg-16) - [Architecture for Climate Monitoring from Space](#)

and past missions are effectively exploited. It is however less efficient to provide guidance on future missions, which is the scope of the present Vision. Indeed, looking forward to 2040, the first challenge is to ensure that the long-term plans of the satellite provider community will include provisions for sensors offering adequate performance, coverage, and resolution to meet climate needs. This depends on engineering options which are defined many years ahead of the definition of climate data sets processing chains.

- Gap analysis and long-term planning

The Vision should determine the sensing capabilities (sensor characteristics and orbital configurations) envisioned to respond to the needs of climate and climate processes monitoring. A comprehensive review of space-based sensing needs is contained in the “Satellite Supplement”³ to the updated GCOS Implementation Plan.

With reference to the Rolling Review of Requirements, four steps can be considered: Climate observation requirements; Assessment of the planned sensing capability; Gap analysis; Recommended/requested enhancements to fill the gaps. A critical issue is to characterize the long-term plans and monitor them with a sufficient granularity to inform on the potential of a mission to support Essential Climate Variables (ECV). The CGMS Baseline is an attempt to record the long-term commitments of CGMS Members, but it is not detailed enough to characterize the suitability of a planned mission to meet climate needs. A more detailed inventory is thus needed, recording the technical features driving the sensor performances. The inventory should also take into account the various degrees of confirmation of the plans depending on the time scale, from “considered” to “firmly planned”, in order to make a risk analysis. This risk analysis should also take into account the uniqueness of certain missions (e.g. one Total Solar Irradiance sensor) or the possible redundancy or availability of alternative concepts.

In addition, the architecture should define key processes ensuring the sustainability and suitability of these capabilities: stability, continuity, and traceability of observations. This is further discussed below.

- Stability

The comparability of sensors of consecutive generations should be ensured through the systematic assessment, in the design phase, of how the new measurements can be compared with heritage datasets for the ECVs that are expected to be supported.

- Continuity

The baseline plans should include some redundancy to minimize the risk of gaps due to programme delays or technical failure, as well as contingency planning to be activated when a risk of gap reaches a critical level. The range of actions that can be considered in this respect include for instance: relocating and activating a spare satellite (in the case of GEO), advancing the launch of a replacement, implementing a quick gap-filler mission. The latter option is facilitated with very small satellites which may not have a long lifetime or comprehensive payload but may provide useful capability when needed.

- Calibration and traceability

Accurate and consistent calibration is essential for the detection of climate trends. Precise pre-launch calibration and characterization is necessary but not sufficient. Sensor inter-calibration improves the consistency of contemporaneous sensors but the need for consistency between consecutive missions over decades remains a challenge. GCOS monitoring principles call for systematic overlap between consecutive missions, which is helpful but not always possible; moreover, it only minimizes the bias between consecutive missions. Therefore the full benefit

³ Systematic observation requirements for satellite-based data products for climate, 2011 update (GCOS-154)

of climate observation would only be taken if measurements were traceable to absolute standards.

3. TECHNOLOGY OPPORTUNITIES

Are there major advances in remote-sensing and satellite technology opening new perspectives for space-based observation for WMO Programmes ? The following sections are discussing the opportunities of technology advances in terms of sensors, satellite systems and data management respectively, as well as related emerging issues.

3.1. Satellite systems

A diversity of orbits can be used beyond the traditional GEO and Sun-synchronous to achieve a better coverage/time sampling of the environment in a cost-efficient and flexible way, including HEO / GEO / MEO / LEO Sun-synchronous / LEO inclined / near-space platforms.

The core GEO and 3 sun-synchronous orbital plans are the foundation of the current space-based observing system and should remain as a backbone. NWP impact studies however show the importance of a homogeneous sampling, and reveal that a diversity of observing approaches is an element of robustness, since the reduction of one element is partly offset by a greater weight given to other elements in the assimilation process. The planned contributions of new space-faring nations gives an opportunity of augmenting the backbone system with e.g. sun-synchronous satellites with a diversity of ECT to optimize the temporal sampling, as well as inclined orbits to resolve the diurnal cycle. The natural drifting of orbital plans can be used to optimize the distribution and usefulness of secondary LEO/SSO satellites.

The traditional observing system can also be enhanced in the future by an array of near-space platforms, e.g. balloons or solar-powered Unmanned Aerial Vehicles (UAV) on top of atmosphere (e.g. 100 km) enabling both in-situ and remote-sensing measurements.

The use of manned space platforms should be discussed. The International Space Station (ISS) had its operational life extended and should remain available for at least part of the period until 2040. It offers an attractive flight opportunity for several EO payloads (RapidScat and CATS at present, and SAGE-III, LIS and possibly others in the near future), and was considered by some other candidate missions (e.g. CLARREO). The ISS offers the advantage of considerable on-board resources (energy, computing power and data rate). Lessons learnt show however important constraints linked to the mission selection process, the contaminated environment (vibration, radiation), the specific orbit (400 km, 51° inclination, regular altitude manoeuvres), which are not compatible with every mission. Financially, if an ISS flight opportunity was available at no or marginal cost, then it could be an efficient tool for instrument technology demonstration.

Missions should not only be considered individually but also in terms of constellations. Actual constellations are satellites operated in a coordinated manner to provide altogether a certain coverage. The term “virtual constellations” was introduced by CEOS to designate a looser coordination of missions contributing to common objectives, with coordinated efforts

for the generation of products. A particular type of constellation is achieved by formation flying, where satellites are maintained at stable – and small- distance in order to have quasi identical fields of view and use their sensors synergistically. The concept of synthetic large scale aperture achieved with formation flying satellites should be explored.

The concept of large multi-mission platforms is questioned by the emergence of dedicated, possibly short-life, micro- and nano-platforms. This is not only a technical performance issue but also a programmatic issue having regard to the decision process, the funding scheme and the need for long-term operational perspective on one hand, and on the other hand for instance the advantage of rapid gap fillers. In this respect, the two approaches are complementing each other.

Challenges need to be addressed if we move towards a more diverse and distributed capability:

- importance of interoperability, through the definition and implementation of adequate standards.
- agility and resilience may be required from the users in order to achieve operational reliability.

These elements need to be taken into account in a contingency plan, considering the need for in orbit hot back-up, the possibility of gap filler missions and re-launch policy.

3.2. Remote-sensing: emerging instrument technology

We should consider the lessons learnt from recently launched or completed R&D and demonstration missions. It is expected that by 2040, space-based Doppler lidar will not only be demonstrated but have reached a technology readiness level ensuring operational reliability which should enable operational 3D wind and aerosol observation

Advantage can be taken of a wide range of measurement concepts, without restricting our view to the most classical irradiance measurements. Beyond the traditional multispectral and hyperspectral passive radiometry, we should bear in mind:

- Multi-angle, polarimetric measurements
- Active measurements by radars, including SAR imagers, altimeters and scatterometers,
- Active measurements by lidars, including Doppler and DIAL
- Use of GNSS radio-occultation, including phase shift measurements, or ocean reflection
- Limb measurements by occultation of Sun, moon or stars
- Particle detection (for space environment monitoring) at various energy levels,
- Accelerometry, ranging (*for gravity field, satellite drag, thermosphere density*)
- Zeeman effect (*solar magnetic field*)
- ...

High sensitivity sensors allow fine spectral resolution, smaller pixel size, rapid integration time, which translates into improved horizontal, vertical, and temporal resolution consistent with evolving resolution of the models. New parts of the spectrum can be exploited: far IR (for ...), UV (for oceans), sub-millimeter channels (cloud phase). The use of microwave

measurements should considerably extend, including high temporal resolution MW imagery/sounding. In this respect, we should investigate the respective advantages of Geostationary MW or of a constellation of small LEO satellites in inclined orbit. An emerging application is also the use of NIR spectrometer to derive surface pressure, a parameter requested by generations of meteorologists.

Hyperspectral measurements are affordable in VIS, NIR, thermal IR (for biosphere, land surface), in UV, VIS and IR for tracking particular species in atmospheric composition either in nadir or limb viewing for stratospheric monitoring. Hyperspectral MW observation should be available and will provide increased vertical resolution observation in all-weather conditions, extending the capability to observe the vertical profile of hydrometeors.

Better use can be made of active and colocated active/passive sensors, as is already currently done with radar altimeters coupled with a microwave imager to get the atmospheric correction. An efficient combination of active and passive measurements can be also the use of a bistatic configuration augmenting an active sensor. The use of Synthetic Aperture Radar imagers should continue to expand, and include polarimetric measurements.

While GNSS radio-occultation (RO) has become a widely used information source for NWP, climate monitoring and ionosphere monitoring, it is anticipated that a much better coverage will be provided by fleets of RO receivers accommodated on small satellites. The benefit of RO could further expand through the use of additional frequencies; recommendations in this respect should be made to GNSS system operators. The sensors should be optimized in order to support lower troposphere (temp, humidity, clouds) and ionosphere (TEC, scintillation) monitoring. The use of GNSS signals reflected at the surface of the ocean can inform on wind speed, wave height, and sea level.

3.3. Calibration references

The need for consistent calibration and traceability to absolute references was pointed out for the Architecture for Climate Monitoring from Space. Furthermore, interoperability and accuracy of observations are important for a whole range of other applications: to support composite imagery, or robust quantitative products, or any product merging different space sensors or space and surface-based sensors. Measurement reference standards should be maintained in orbit in order to support the calibration of operational radiometric measurements and thus to leverage the quality of the whole constellation of sensors which could be compared to these references, providing traceability and enhanced interoperability. 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.

These reference standards should be developed for the full spectrum of passive and active remote sensing instruments from the reflected solar through infrared to microwave wavelengths. Methods to achieve reference standards for orbiting sensors may include space based, suborbital, or surface based references, or may be most effectively achieved using a combination of such approaches.

- a) For passive solar and infrared wavelengths, reference orbiting calibration spectrometers have been proposed for use.
- b) provisions should be made to secure and characterize ground-based reference targets for vicarious calibration.

- c) for solar occultation measurements (e.g. SAGE III), the sun can represent a reference observation just before the occultation event
- d) for dark target passive solar sensors (e.g. ocean color or vegetation) a highly accurate reference characterization of the spectral reflectance of the moon as a function of phase angle and libration may be sufficient.
- e) at wavelengths with very little atmospheric absorption, it may be possible to use surface targets to calibrate space based radars (e.g. precipitation, cryosphere, vegetation radar)
- f) for space based backscatter aerosol and cloud lidar a combination of in orbit calibration using Rayleigh scattering and aircraft reference lidar under flights might be considered

As for SI laboratory standards determined in metrology laboratories, independent reference approaches greatly increase confidence in the achieved uncertainty of standards. In some cases there will be identified needs for further improvement in the underlying SI metrology standards. This is especially true in the passive microwave, and to a lesser extent in the near-infrared and far-infrared portions of the spectrum.

The assimilation process in numerical models can detect outliers and remove individual instrumental bias by a linear correction, however some accurate anchor measurements with absolute traceability are necessary to reduce the possible bias of the model itself and to support instrument monitoring and analysis for a precise error characterization.

These calibration and traceability issues are addressed by the Global Satellite Inter-Calibration System (GSICS) and the CEOS Working Group on Calibration and Validations (WGCV) whose activities should be expanded and strengthened. To date mainly surface and suborbital references have been used: space references have not yet been developed and therefore represent a new opportunity and capability.

3.4. Radio-frequency protection

While noting the considerable potential for expanding MW observations, one should bear in mind the growing concern on the protection of essential passive microwave radiometry frequency bands, as well as the active measurement bands, which are threatened by the strong market pressure and political incentive to expand the frequency allocations for telecommunication services.

3.5. Data management and telecommunications

As every new payload generation is offering higher spectral, spatial and temporal resolution, the resulting average data rates have been growing exponentially over the past 3 decades. This growth was accompanied by a similar evolution of telecom performances (e.g. DVB-S broadcast services in the 90s, now DVB-S2). However this race to ever increasing data rates raises issues of sustainability and affordability. These issues are reviewed in the new Satellite Data Dissemination Strategy (SDDS)⁴ to be submitted to CBS-16.

⁴ http://www.wmo.int/pages/prog/sat/meetings/documents/IPET-SUP-1_Doc_05-01_SDDS.pdf

Furthermore, the technology gap is increasing between the most advanced users and the users in least developed countries. Users with limited communication and processing infrastructure are left along the road, as the data throughput exceeds what they can usefully acquire. Data access solutions should be offered for “advanced users” and “regular users”. In the latter case, we should move products (Environmental Data Records) rather than data (Satellite Data Records), assuming that higher level data means lower data rates and less processing burden.

The expansion of “Cloud” technology will cause a wider use of on-demand online access to data servers as an operational near-real time access strategy for advanced users with high connectivity. As the data offer increases it is of utmost importance to ensure data quality and traceability through comprehensive and standardized metadata. Going one step further, cloud technology may expand the use of remote/distributed processing. Furthermore, increased interconnectivity requires a high attention given to security.

Data latency: there is a general request to have data earlier. Near real-time availability is not only expected for operational missions but also is also seen as a strong advantage for R&D missions, when feasible. What technical solutions will be best to achieve the 5 min timeliness goal for non-geostationary satellites? Dedicated Data Relay Satellites are an expensive infrastructure which may be appropriate for certain applications (e.g. human in space) but are not affordable for Earth Observation unless charged at no or marginal cost. The potential contribution of a communication payload on an Earth Observation mission (e.g. PCW) should be investigated, and compared with the impact of a fleet of LEO spacecraft. In the short to medium term, DBNet (formerly named “RARS”) i.e. a distributed network of Direct Broadcast acquisition stations coupled with high-speed data concentration and sharing through a “cloud”, seems a promising, cost-efficient approach. A generalization of this approach to high data rates raises the question of how the cost of high-speed networks should be borne.

Satellite data and products being a driver of the overall data exchange in the meteorological community, this should be part of the prospective considerations of the WMO Information System (WIS) in 2040.

The satellite data management framework must enable seamless merging of data from various satellite operators, which implies an open data policy as well as actual standardization of data and metadata.

Long-term Data Preservation must be planned and included in the design of data management systems and processes. It may have important cost implications, especially if made available for public access, which raises the question of cost recovery – not only to account for the data acquisition, processing and distribution, but rather for its long-term maintenance, anticipating future user demands.

Data downlink to satellite operators ground stations, or user stations (Direct Broadcast) will require higher radio-frequencies to accommodate high data rates. This has a cost impact on users which suggests a continued differentiation between high and low data rate users. It is also essential to preserve the radio-frequency spectrum needed for these communications, including the historical L-Band which is unaffected by weather conditions. (Radio-frequency protection is also a critical issue for passive and active sensing, as mentioned in above.)

4. CHANGES IN THE PROVIDERS' COMMUNITY

4.1. Satellite programme concepts

Classical operational programmes include a prototype and a series of recurrent satellites in order to amortize the development cost over several units, providing a firm planning framework with a validated, affordable, technical baseline and stable operations for the programme life cycle, typically more than a decade. A disadvantage is the lack of reactivity to changing context or user demand, except some incremental payload evolution not affecting the risk (the evolution can be minor or significant depending on the agencies). Evolving needs can best be addressed through other types of programmes such as hosted payload opportunities or small satellites.

For R&D programmes, long-term stability and affordability are normally not the primary requirements.

Achieving transition of a mission concept from the R&D status to a fully operational framework, requires multiple conditions: technology readiness and reliability, identified user community, maturity of applications, affordability meaning that expected operational benefits of these applications to the identified user community will justify the costs, institutional framework enabling programme funding, management and user interaction.

A model of transition to operations is for instance the evolution from TOPEX-Poseidon to the Jason series of oceanographic missions. Pre-operational or transition missions (e.g. Sentinel-5 precursor) can bridge or reduce the gap between successful demonstration and operational missions.

In order to help such a transition, R&D agencies (e.g. NASA with AQUA & TERRA, or ESA with ENVISAT) are more and more in a position to sustain programme operations well beyond their initial scope. As a matter of fact, data from a number of R&D missions are routinely used by the operational community (e.g. TRMM). Several R&D agencies (e.g. CSA, DLR, ISRO, JAXA,) are increasingly encouraged to serve operational applications, thereby not only requested to develop technology but also to promote applications and demonstrate the benefits.

4.1. New operators

Historical satellite operators have developed and implemented programmes for several decades with a goal of technological development and operational demonstration until the activity reaches a fully mature operational stage, which is the case in satellite meteorology. Nowadays since the continuation of these programmes is seen as an operational activity, major programme decisions are subject to the demonstration of the socio-economic benefit of the incurred cost. In contrast, emerging satellite operators who are at the stage of building a national industrial and scientific satellite capacity don't have the same constraint to justify the cost/benefit and may more easily decide on new programmes.

4.2. International coordination

Without being compulsory, agreeing on a shared Vision encourages the convergence of individual national planning towards a globally consistent system. It enables Members to

make international commitments to contribute to the implementation of the Vision. Such international commitments (formally recorded in WMO Technical Regulations) must be guaranteed by governmental entities, or agents entrusted by governmental entities.

Global coordination seeks overall optimization – reducing overlaps to the level of redundancy necessary to ensure robustness -, interoperability and sharing. It should also promote participation of other countries in a coordinated framework. The Coordination Group for Meteorological Satellites (CGMS) is the primary technical coordination body of satellite operators contributing to WMO programmes, which is why the CGMS Baseline is included into the Manual on WIGOS (as Attachment to Section 4).

4.3. New business models

Can we engage with commercial initiatives and what should be the conditions to make it successful?

The future observing system may be affected by the emergence of different business models. Commercial initiatives or public-private partnerships are an opportunity to enhance the observing system, taking advantage of the agility of the commercial sector either to provide observing capabilities (e.g. thousands of observing platforms by Google) or hosting such capabilities as piggyback on platforms operated for different primary purpose (e.g. hundreds of sensors aboard Iridium satellites).

Private information sources were traditionally outside the scope of meteorological activity, however, as we move towards a more integrated Earth system monitoring, a more open approach may be needed.

The related risks should be considered in depth by the relevant WIGOS body. In particular:

- Risk of loss of total transparency of the observation and processing chain, and loss of control over the integrity and reliability of the data. This may happen if some information cannot be disclosed because they involve proprietary knowledge, or in case of conflict of interests. This risk has to be fully controlled through contracts.
- Risk of limitations to data access. Maintaining and expanding international data sharing is a fundamental goal of WMO. Resolution 40 (Cg-12)⁵ defines “essential data” and “additional data”, whereby “essential data” must be exchanged openly without any restrictive condition, while the exchange of “additional data” may be subject to conditions and possibly charged. Therefore, Resolution 40 aims to enable a commercial activity on “additional data” without hampering the free and open exchange of essential data. This only happens if “additional data” are a true *addition* to the essential data, and not associated with any decrease of “essential data”.
- Risk of endangering international mission coordination. Such coordination aims to maintain an agreed Vision, to promote its implementation, to address contingency situations to fill potential gaps, and to ensure interoperability. It is at the heart of the

⁵ http://www.wmo.ch/pages/about/Resolution40_en.html

space-based observing system. By definition, commercial initiatives have to pursue economic interests driven by market priorities. They may benefit from participating in international consultations but would not commit to provide a service complying with agreed standards unless this is specified in a contract with a customer entity.

Because of these risks, we must be very careful and avoid weakening the decision process of those governmental/intergovernmental programmes which constitute the backbone of the system and must be under full control of the governments, and in coordination by WMO, to secure “essential data”.

As an illustration, assuming that it is essential to maintain a backbone capability of infrared and microwave sounding on 3 orbital planes and at least 20,000 radio-occultation soundings per day, these data should be considered as “essential data” and made freely available as per Resolution 40; meanwhile, a commercial operator may wish to host other radio-occultation sensors on its own platforms in order to market radio-occultation “additional data”.

Several models can be explored to accommodate public benefit and commercial interests.

- A commercial entity can operate under a “data-buy” contract with a governmental customer. In this case the public customer participates in international coordination, it would seek to purchase a service compliant with the internationally agreed standards and commit to share the “essential data” internationally. A variant of this model is a public-private partnership where the commercial operator would commercialize “additional data” in addition to the “essential data” data purchased by the public customer (e.g. Radarsat Constellation Mission).
- Another model worth to be investigated would be a private entity owned and managed by several government entities. A first example is ARGOS, a system founded by CNES, NASA and NOAA, now extended to EUMETSAT and ISRO; it is operated by CLS, which is a subsidiary of CNES under private law; it complies with a charter under control of the governmental agencies through an Operations Committee. A second example is the Disaster Monitoring Constellation (DMC) which is an international consortium of governmental interests; it is operated by a private entity, DMC International Imaging (DMCii) linked with the UK Space agency; it delivers free data through the International Charter on Space and Major Disasters, serves its governmental stakeholders, and commercializes “additional data” on top of that.

The business models in the latter examples can foster international contribution to a global system, since they are accessible to countries with little or no space experience and does not even require having established a space agency. The control performed by governmental entities ensures compliance with international requirements, although the private legal status offers much more agility than an intergovernmental decision process, and the possibility of combining openly available “essential data” and commercialized “additional data”.

5. CONCLUSIONS

5.1. Opportunities for an ambitious vision

The satellite community is very active: 10 satellites were launched in 2014, contributing to the WMO Global Observing System, 5 have already been launched in the first 3 months of 2015 and more than a dozen is planned for the rest of the year. Ambitious plans have been developed by several agencies for the coming decade.

Several agencies indicated in ET-SAT that a WMO Vision will help in orientation and support of future programmes.

In the previous sections we have identified some user needs, as well as a wealth of technical opportunities and system concepts which may even go beyond the users' dreams. It is hoped that such ideas can help users to project their requirements in the future context of space-based observations and facilitate further dialogue between users and providers.

5.2. A narrow path

The Vision shall however not only explore a range of possibilities but should be focused enough to provide guidance. Firstly to the agencies – on how their future programmes can best contribute to the global picture – and secondly to the users – on what observing capabilities can be expected in the long term and what research could be undertaken to take advantage of them for improved operations. The goal set by the Vision should be shaped enough to drive an Implementation Plan with concrete and measurable actions.

This is a delicate exercise.

A first risk would be to consider the whole collection of traditional and alternative concepts without any selection or prioritization. It may give the illusion that everything is possible, although what is technically conceivable is not always affordable. It may be confusing instead of providing useful guidance.

The opposite risk would be for the Vision to be over-specified and restrictive, limiting its scope to those systems that can easily be identified and monitored, with well-known implementing agents. It would be easy to translate into an implementation plan, however would not take advantage of the most novel approaches which are not yet technically mature or relying on well-established partners.

5.3. Way forward

It is suggested that the future space-based observing system should strike a balance between the following three components:

- A backbone component largely based on the current Vision-2025 with some incremental enhancements, which would be the subject of firm commitments by the contributing WMO Members, with specified minimum sensor characteristics and orbital features, in order to guarantee an observation base to generate “essential data”;
- A distributed component which would augment the backbone with a variety of capabilities, which would be specified in terms of variables to be measured, with minimum requirements to be met and the planned contributions of WMO Members to the global coverage, also contributing to “essential data”;

- Opportunities for “additional data” provided by private entities, with purely indicative planning.

Having regard to the processes mentioned in Section 2.3, the Vision should address the planning process, ensure comparability, stability, continuity, and traceability. The Gap Analysis approach would need to be adapted to the type of planning of each component. The analysis should explore in more depth particular priority areas, comparing what we plan to have by 2020 and what we can have by 2040.

5.4. User engagement

User can request capabilities that they are aware of, but have difficulty to anticipate the potential use of future technology. Space agencies must thus demonstrate and promote the new technologies. A balance must be found between user pull and technology push, through active dialogue between space agencies, research, and operational communities.

WMO can play a unique role in facilitating such a dialogue with user communities from a range of application areas and providers of observing capabilities – ground or space-based. This role should be further exploited through existing WMO mechanisms in addition to the respective user consultation mechanisms of each agency:

- Expert Teams and Statements of Guidance
- WMO impact assessment workshops
- Regional user requirements coordination groups
- Consultation of WMO-sponsored science groups (e.g. ITWG, IPWG, IROWG...)
- Users should be involved in socio-economic benefit studies, which are essential to inform the decision process of new programmes.

A workshop should be convened to foster this dialogue with key application communities represented by major WMO programmes, in order to expose space agencies to the projected needs of these communities, and improve the understanding of these needs. It would stimulate thoughts on possible scenarios to be evaluated further in the development of the WIGOS Vision for 2040.

Appendix 2:

« **WIGOS SPACE 2040 WORKSHOP** »

**Developing the vision of space-based Earth observation
in the WMO Integrated Global Observing System (WIGOS) in 2040**

organized by the WIGOS Project Office and the WMO Space Programme

- Place** World Meteorological Organization (WMO) Headquarters, Geneva
- Dates** 18 to 20 November 2015
- Scope** Dialogue among space agencies and major user communities in weather, climate, water, and related environmental areas, to stimulate the development of a long-term vision for space-based capabilities and applications.
- Background** WMO regularly reviews its Vision of future global observing systems to support weather, climate and related environmental applications. The Vision provides a shared, high-level goal to guide the efforts of WMO Member states in the evolution of observing systems. The current WMO [“Vision”](#) is defined for 2025, which is “to-morrow” for satellite programmes, given the usual lead time of defining, approving, designing and developing a new programme. As the Vision’s purpose is to help shape the future, it should address primarily satellite programmes that are still at the mission concept phase and will be implemented in maybe two decades from now, building on currently emerging technology. The WMO Commission for Basic Systems therefore agreed to undertake an update of the WMO Vision, with 2040 as a new horizon. This effort was initiated by the Expert Team on Satellite Systems (ET-SAT) at its 9th session and will be pursued throughout 2015 and early 2016 together with other teams involved in space or surface-based observations. The Vision should aim to respond to the future user needs. It is however a challenge to anticipate these needs 25 years ahead. While space agencies have a good grasp on the range of novel technologies that could or will be operationally available in the next two decades, such a projection to the future is more difficult on the application side, and application programmes are generally not aware of the potential capabilities in this time range. Most of the “Statements of Guidance” from application areas are expressing needs for improving the performance of existing services, if not maintaining existing services. Such a conservative approach is likely to miss the opportunities of future space capabilities.

Objectives The aim of the workshop will thus be to reconcile “technology push” and “user pull” to outline a prospective view of space capabilities and applications, with three main objectives:

- Expose representatives of major user communities in weather, climate, water and related environmental applications, to the opportunities enabled by current or future space technologies (for instance sensors, orbit and constellation concepts, telecommunications, and satellite systems in general)
- Expose space agencies to the projected needs of the application communities represented by major WMO programmes, and improve the understanding of these needs in a dialogue.
- Stimulate thoughts on possible scenarios for alternative approaches to be evaluated further in the development of the WIGOS Vision for 2040.

Target participants

The workshop (limited to 30 participants) will gather:

- Satellite providers including ET-SAT member agencies, and representatives of CGMS, CEOS, and industrial associations
- Representative users of major WMO application areas, including Numerical Weather Prediction (NWP), nowcasting, climate monitoring and modeling, cryosphere monitoring, ocean applications, Global Atmospheric Watch (GAW), Hydrology, Disaster Risk Reduction.
- Representatives of the Inter-Programme Expert Teams on Satellite Utilization and Products, on Observing System Design and Evolution, and of the Task Team on Observing System Network Design.

Programme committee

Jack Kaye (NASA), Anthony Rea (BoM), John Eyre (MetOffice), Kenneth Holmlund (EUMETSAT), Wenjian Zhang, Lars Peter Riishojgaard, Jérôme Lafeuille, and Stephan Bojinski (WMO)

Milestones

16 April	First Programme Committee meeting, draft concept
10 May	First announcement
15 June	Confirmed speakers, background document (from ET-SAT)
10 Sept	Provisional programme, additional documents

Draft Programme

Day 1, AM: Introduction and future opportunities in satellite observation

- 20' Opening, objectives of the meeting
- 20' Introduction to WIGOS, RRR, Vision, and WMO/CBS framework
- 30' Current Vision and actual plans for space-based observing systems
- 20' Existing international prospective efforts
- Break*
- 30' Prospective view on space sensors and measurable parameters
- 30' Novel orbit and constellation concepts
- 30' Industry perspective: technology prospects
- 20' Satellite programmatic framework – classical and alternative

Day 1, PM: Application thematic presentations

- 30' Outlook on future NWP capabilities and data assimilation needs
- 30' Major challenges in satellite observation of climate
- 30' Ocean and cryosphere observation needs
- Break*
- 20' Atmospheric Composition from space
- 20' Observation challenges for Nowcasting
- 20' Space-based Hydrology
- 30' Presentation of discussion themes for Day 2

Day 2, AM: Cross-cutting issues

- 30' Future surface-based observation and space/surface complementarity
- 20' Calibration and traceability of space-based observations
- 20' Data circulation and distributed information concept
- 20' Interoperability, continuity, and international coordination
- Break*
- 20' Identification of key issues and formation of breakout groups
- 60' Breakout groups discussing questions such as:
 - What key measurements shall be made from space in 2040?
 - What sensors should be promoted ?
 - Sampling priorities and implications on orbital configurations ?
 - International coordination and programmatic framework

Day 2, PM: Break-out Groups (Continued)

Day 3: AM Consolidation of outcomes

Day 3: PM Conclusions

Recommendations including missions that should be further evaluated, through joint work among users and satellite community, as input to the Vision of WIGOS space-based component in 2040.