

RE-DESIGNING THE SPACE-BASED GLOBAL OBSERVING SYSTEM

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Abstract

The WMO Space Programme supports global planning of space-based missions contributing to the WMO Global Observing System (GOS), with the aim to ensure that the efforts of WMO Members through their national space agencies, as well as EUMETSAT and ESA, will optimally satisfy the observation requirements of WMO and co-sponsored programmes.

The WMO Commission for Basic Systems (CBS) initiated an action to update the present baseline of the GOS and to develop a new “Vision for the GOS to 2025”. The main motivations for this update are:

- the scope for optimization of current geostationary (Geo) and Low-Earth Orbit (LEO) constellations,
- the potential benefit to be taken from newly demonstrated instruments, and from various observation strategies departing from the classical geostationary and polar-orbiting sun-synchronous constellations and,
- the need to observe all Essential Climate Variables for climate monitoring, in response to GCOS Implementation Plan, instead of limiting the GOS to serving the needs of operational weather forecasting.

The draft vision that is being developed calls upon optimizing the existing operational Geo and LEO components, consolidating the altimetry measurement strategy, enhancing atmospheric sounding with an operational Radio Occultation Sounding (ROS) constellation, refining sea surface wind observation, and bringing several new missions to an operational status: global precipitation, Earth Radiation Budget (ERB), atmospheric composition, specific imagery for ocean colour and vegetation, as well as possible missions on Molniya orbits for high latitudes.

Implementing such a new vision would require enhanced cooperation and coordination among operational and R&D agencies in order to optimize the effort, and to ensure timely availability and consistent quality of data worldwide. This new vision, which contributes to the integration of the WMO Global Observing systems, would further reinforce the importance of the space-based GOS as a major component of the Global Earth Observation System of Systems (GEOSS).

BACKGROUND

The WMO Space Programme provides a framework facilitating global planning of space-based missions contributing to the WMO Global Observing System (GOS) with a goal of harmonization and optimization. This optimization should ensure that the heavy investments made by WMO Members through their national space agencies, as well as EUMETSAT and ESA, will satisfy, as far as possible, the observation requirements of WMO and WMO co-sponsored programmes.

In 2002, the WMO Commission for Basic Systems (CBS) had defined a “Vision for the GOS to 2015” and agreed on an “Implementation Plan for the Evolution of the Surface and Space-based Subsystems of the GOS”. Progress towards this goal is regularly assessed by relevant CBS Expert Teams. In 2006 the WMO Space Programme, through the Expert Team on Satellite Systems, performed a preliminary review of mission plans for the next decades and of their adequacy for satisfying requirements of the Global Climate Observing system (GCOS) as expressed in the GCOS Implementation Plan and its Satellite Supplement [GCOS, 2006]. This review was shared with the

Coordination Group for Meteorological Satellites (CGMS) and adopted by CGMS as a joint CGMS-WMO preliminary response to GCOS. It was further refined in 2007 in consultation with GCOS and with the Committee on Earth Observation Satellites (CEOS). This response analyzed opportunities and gaps in current satellite plans and stressed the need to recognize climate monitoring as one of the main objectives of the Global Observing System. Based on this outcome, and noting that several satellite operators were discussing plans for the 2020s, CBS recommended at its extraordinary session in 2006 to initiate a review and update of the present GOS baseline, taking 2025 as a new horizon.

Several factors give a particular dimension to this review of the space-based GOS:

- There is an increasing scope for optimizing the space-based GOS since it involves now a larger number of missions and contributing agencies than in the previous decade. This provides opportunities for a better response to the observation requirements, but it also reinforces the need for global coordination and optimization of mission plans, in order to address in priority the gaps and deficiencies while avoiding unnecessary redundancies. Technical coordination is achieved within the CGMS.
- Such an optimization goes well beyond the agreement on regularly spaced longitudes for the geostationary constellation or equally distributed Equatorial Crossing Times for the polar-orbiting sun-synchronous satellites. Optimization must take advantage of the potential of diverse measuring techniques and orbital systems, including low inclination orbits, constellations of radio-occultation sensors, formation-flying in Low Earth Orbit (LEO), highly elliptical orbits, or combined LEO and Geo systems.
- Given the need for sustained observations of climate variables, climate requirements shall now be an integral part of the requirements to be satisfied by the GOS, in addition to the weather forecasting requirements. The incorporation of climate monitoring objectives is one important step towards full integration of the various WMO observing systems and reinforcing the importance of the GOS as a major contribution to the GEOSS.

The present paper summarizes the results of the discussions on reviewing and optimizing the space-based GOS. It reflects an intermediate status, based on the outcome of the most recent meetings.

SUMMARY OF THE CURRENT BASELINE

The current baseline for the space-based GOS, as described in Chapter 4 of the WMO Manual on the GOS [WMO No 544], calls for:

- A constellation of at least six geostationary satellites, near-equally spaced around the equator, ensuring observations typically at 30 to 15 minutes intervals throughout a field of view between 60° S and 60° N; they should perform several missions including visible and infrared imagery, infrared sounding, data collection, dissemination and other missions as appropriate e.g. radiation budget.
- A constellation of operational polar-orbiting satellites including typically two sun-synchronous in ante-meridian (a.m.) orbit and two in post-meridian (p.m.) orbit providing global coverage at least eight times per day for instruments with horizon-to-horizon scanning; they should perform several missions including visible, infrared and microwave imagery, infrared and microwave sounding, data collection, direct broadcast and other missions as appropriate, e.g. sea surface wind measurement by scatterometry, sea surface altimetry, etc.
- Research and Development (R&D) satellites acquiring data for research purpose or testing new or improved sensor technology; R&D satellites provide, when possible, information of great benefit for operational use, however without any guarantee of long-term continuity.

The nominal locations of the geostationary satellites are coordinated within the CGMS. In the current baseline the six locations are not regularly distributed around the globe, with longitude intervals ranging between 29 degrees to 85 degrees, as illustrated in Figure 1.

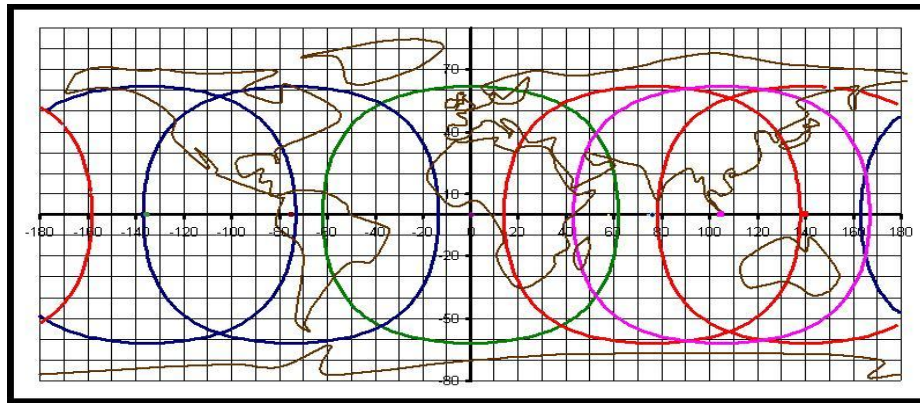


Figure 1: Illustration of the current baseline for the geostationary constellation of six satellites. Fields of view are indicated here for a maximum zenith angle of 70 degrees. Intervals between adjacent locations are ranging from 29 degrees over Asia to 85 degrees over the Pacific. The actual constellation includes currently more satellites than this baseline, however the respective spacecraft do not all have equivalent payload capabilities.

TOWARDS A NEW VISION FOR THE GOS TO 2025

This section summarizes the changes contained in the new “Vision to 2025” compared with the current “Vision to 2015” of the space-based GOS.

Optimizing the geostationary constellation

As concerns its geographical distribution, it is proposed to set as a target that the global coverage be optimized in ensuring no more than 60 degrees separation between adjacent locations of geostationary satellites equipped with the full instrument suite. With six satellites, such a 60-degree interval would ensure full coverage of all latitudes between 57 S and 57 S with a zenith angle not exceeding 70 degrees. Figure 2, below, illustrates the proposed baseline. This proposal will be submitted to the CGMS as a basis for discussion, while recognizing that it would be difficult for CGMS satellite operators to implement such a vision in the short term, since each satellite operator has to consider the requirements of its own stakeholders in priority.

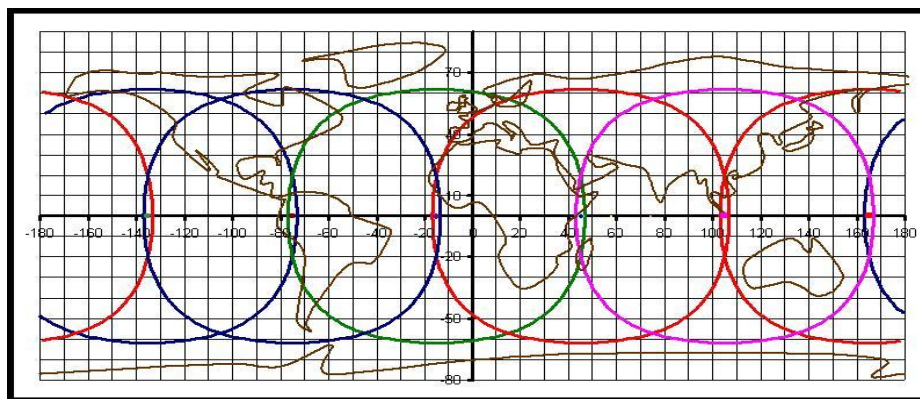


Figure 2: Example of suggested distribution of the geostationary locations. Fields of view are indicated here for a maximum zenith angle of 70 degrees.

It is furthermore considered that the geostationary baseline payload should systematically include IR hyperspectral sounding in addition to VIS-IR imagery.

Optimizing the core LEO sun-synchronous constellation

First of all, the payload of the core VIS-IR-MW imagery and IR-MW temperature and humidity sounding mission in sun-synchronous orbits should systematically include IR Hyperspectral sounding.

As concerns the distribution of this constellation in space/time, instead of recommending “four operational LEO sun-synchronous satellites optimally spaced in time, two in a.m. and two in p.m.,” it is recommended that this constellation be deployed over 3 orbital planes around 13:30, 17:30 and 21:30 Equatorial Crossing Time (ECT). This should ensure regular sampling of the atmosphere avoiding too large a temporal gap around dawn and dusk, in accordance with the requirements from NWP and climate monitoring as concerns atmospheric soundings. In addition, it is recommended to provide in-orbit redundancy around these orbital planes, to the extent possible.

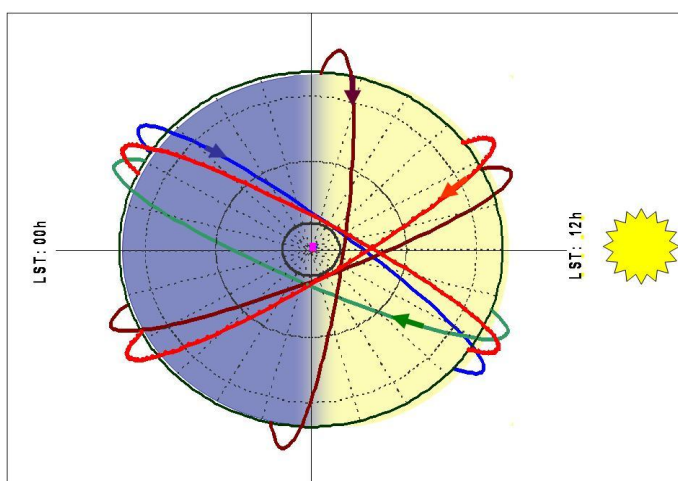


Figure 3: Example of 3-orbit configuration, with in-orbit redundancy, for IR/MW sounding and core imagery missions (Northern hemisphere view)

Reviewing the ocean altimetry observation strategy

While the current Vision to 2015 includes provisions for altimeters on two LEO satellites without particular considerations of the orbital and payload configuration, the community is now in a position to specify its need more precisely, as promoted by the CEOS Ocean Surface Topography Constellation, which leads to recommending an observation strategy relying on two components:

- at least one high-precision reference altimeter mission with orbit and coverage ensuring that data are free of tidal aliasing (e.g. Jason-type non-sun synchronous 66° inclined orbit)
- at least two additional altimetry systems flying on higher inclination orbits to maximize global coverage (e.g. ENVISAT/RA or Sentinel-3).

Implementing a Radio-Occultation Sounding constellation

The potential of ROS has now been demonstrated as a complement to passive IR/MW radiometric sounding, which is necessary in particular to enhance the performance in the stratosphere. ROS should not necessarily be included in the core sun-synchronous constellation, since a high number of instruments is required to achieve the required coverage and temporal sampling. An order of

magnitude of 12 or 24 satellites has been suggested on the basis of preliminary considerations, but this needs to be refined through Observing System Simulation Experiments (OSSEs.)

It is considered that the required configuration would best be implemented through a constellation based on several clusters of similar or comparable instruments deployed across different inclined orbits. The modular aspect of such a constellation and the possibility to share the use of ground support equipment (time references) provide scope for international cooperation to share the effort of implementing and operating this constellation.

Refining the ocean surface wind observation strategy

Experience gained on ocean surface wind observations provides now some ground to recommend an observation strategy based on two components:

- Two scatterometers on well separated orbits ensuring the provision of wind vectors (speed and direction) over the global ocean with typically a 6-hour refresh cycle;
- Two conical scanning microwave imagers with full polarization ensuring a wider coverage of the globe, although bearing in mind that microwave imagery cannot provide reliable direction information for low winds.

Additional microwave imagers with only two-channel polarization, which would be implemented to address other observation needs such as precipitation, or sea surface temperature, would not provide wind direction information but would provide useful wind speed information to be assimilated in addition to the two components mentioned above.

Additional missions to observe Essential Climate Variables

Additional missions shall be considered on an operational basis in order to provide long-term continuity of observations for Essential Climate Variables (ECV) that were not initially identified as operational requirements for the GOS. In some cases these observations are relying on sensors that are fully "operational" from a technology point of view; however steps still need to be taken in order to secure their long-term continuity.

This includes the following observation missions:

- i) Global Precipitation Measurement (GPM): The GPM concept, based on a core spacecraft with dual frequency radar on a 65 degree inclination orbit combined with a wide constellation of microwave imaging sensors on several higher inclination orbits, should become integral part of the GOS design;
- ii) Earth Radiation Budget (ERB): ERB should be measured through a constellation of sensors including at least one broad-band multi-angle viewing radiometer in LEO and a Total Irradiance Sensor, together with auxiliary measurements in LEO to facilitate contextual interpretation of the measurements, and some geostationary sensors allowing accounting for the diurnal cycle. It is recommended to further refine the observation strategy with the ERB community in order to provide more precise guidance on the required capabilities;
- iii) Atmospheric composition: While the need to include appropriate payload for measuring atmospheric composition is clearly acknowledged, for example for stratospheric ozone, other greenhouse gases and aerosol monitoring (profile and total column), and for air quality in the low troposphere, further analysis is needed to define a recommended observation strategy that could be used as a guidance for future plans;
- iv) Specific imagery missions are also needed on an operational basis. Narrow-band sensors are necessary for ocean colour and vegetation monitoring (namely Leaf Area Index and fraction of Absorbed Photosynthetically Active Radiation). High-resolution VIS/IR imagers are also necessary e.g. for land use monitoring and support to disaster reduction. Synthetic Aperture Radars (SAR) provide unique information in support of some disaster reduction activities, as well as ice shelf and iceberg detection.
- v) Satellites in Highly Elliptical Orbits would complement the GOS for quasi permanent coverage of

the high latitudes including the polar ice shelf, subject to successful demonstration. Plans for such a demonstration mission are being developed in the framework of the International Polar Year.

CROSS-CUTTING ASPECTS

Implementing such a new vision with its multiple and diverse components would enhance the observing capability up to its required level, but it would inevitably require more investments and operating resources. This can only be achieved through increased cooperation among operational and R&D agencies, taking advantage of the growing community of space-faring nations that are able to contribute to the space-based GOS. Partnerships should also be encouraged among agencies for extending the operation of functional R&D and other satellites beyond their nominal lifetime to the maximum useful period.

Cooperation should aim at optimizing the effort, through global planning facilitating the definition of individual agencies' plans. It should ensure timely availability of data worldwide, and consistent data quality and comparability through harmonized calibration and cross-calibration practices.

An important feature of the proposed vision is that some missions that have been provided for a long time in the framework of R&D missions would in future be performed on an operational basis. As a matter of fact, observations of a number of climate variables have been relying so far on R&D missions because they initially implied the development of new sensors and since much of the activity was triggered by the scientific community involved in research on climate processes. Nowadays, while R&D activities continue to play an essential and leading role, climate monitoring has developed as a mature routine activity and GCOS, through its GCOS Climate Monitoring Principles, requires long-term continuity of measurements for all the GCOS Essential Climate Variables. In addition to R&D missions, there is a need to recognize essential climate observations as operational programmes. In parallel, there has been an expansion in the scope of operational meteorology; parameters related to the upper ocean, land or ice surface, and atmospheric chemistry are now ingested in NWP models. There is thus a significant convergence between „climate“ and „weather“ requirements, which reinforces the need to address the transition of R&D missions to operational status.

As illustrated in a schematic way in Figure 4, two aspects may be identified in this transition from R&D missions to operation. On one hand a technological aspect, since the relevant instruments must reach the proper technology readiness level in order to be able to support operational missions. On the other hand, the transition has a strategic dimension that includes the change of purpose and its consequences on the need for long-term commitment and compliance with different user requirements.

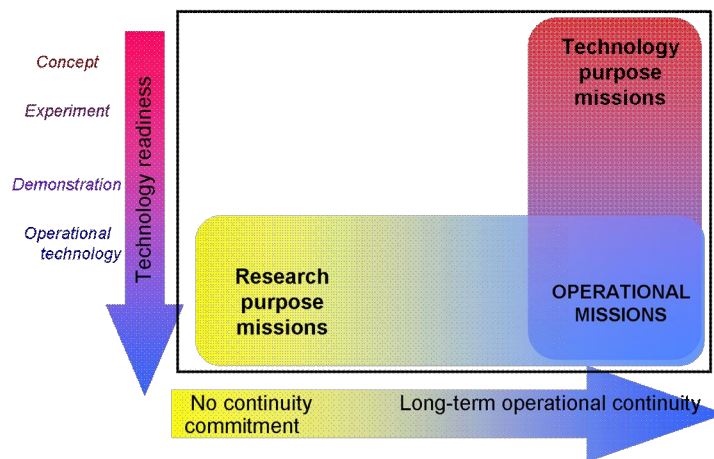


Figure 4: Schematic illustration of two dimensions of the transition from R&D to operational status

This change of status has a number of pre-requisites, such as the identification of a user community with clear requirements, the demonstration of an expected benefit that provides rationale for long-term funding, the availability of implementing agencies or consortium of agencies, with adequate expertise, mandate, funding and user relationship. Within its area of responsibility, the WMO should facilitate such a transition in supporting the identification of user requirements, confirming the societal benefit of the operational missions while recalling the needs for continuing R&D activities, promoting the use of newly demonstrated instrument data and the emergence of applications.

CONCLUSIONS

The Vision to 2025 that is being developed will serve as a goal for the evolution of the space-based GOS; it will provide a global framework facilitating the development of individual agencies' plans in a complementary fashion. Addressing the needs and challenges of climate monitoring it will contribute to the integration of the WMO Global Observing systems and will further reinforce the importance of the space-based GOS as a major component of the GEOSS.

ACKNOWLEDGEMENTS

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