COMMITTEE ON EARTH OBSERVATION SATELLITES

STRATEGIC IMPLEMENTATION TEAM

WOODS HOLE, MASSACHUSETTS, USA, 23-24 APRIL 2008

VISION OF THE SPACE-BASED GLOBAL OBSERVING SYSTEM TO 2025

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Summary

A new vision of the Global Observing System (GOS) is being developed by relevant Expert Teams within WMO. Its time horizon is set to 2025 instead of 2015 for the current vision. The vision proposes a high-level architecture of the GOS that WMO Members should agree to maintain, ensuring its long-term continuity through voluntary commitments for contributions, in accordance with established practices regarding current GOS and GTS.

The primary reasons for developing a new vision are :

- to ensure that the future GOS serves the needs of climate monitoring, as expressed by GCOS, and of other WMO programmes in addition to the historical objective of supporting weather forecasting,
- to optimize the GOS taking into account updated user requirements and recently demonstrated observing capabilities that could be operational by 2025.

While confirming the need for the core GEO and LEO components of the current vision, the draft new vision calls upon enhancements and additional elements including:

- IR hyperspectral sensors aboard operational GEOs,
- IR and MW sounding on early morning orbit (in addition to mid-am and pm orbits)
- Operational radio occultation sounding constellation,
- Ocean altimetry missions for high accuracy reference measurements and dense coverage
- Ocean surface wind missions with scatterometry and microwave imagery
- Global precipitation measurement by active and passive sensors
- Earth radiation budget
- Atmospheric composition
- Specific imagery for ocean colour and vegetation monitoring
- High-resolution IR/VIS land surface imaging
- Synthetic Aperture Radar observation
- Lightning detection on some geostationary satellites

Other elements are under consideration, such as missions in Molniya orbits.

Implementing the new vision would require enhanced cooperation and coordination among operational and R&D agencies for global long-term mission planning, data sharing, data inter-comparability, and transition of relevant R&D missions to an operational status. It will reinforce the space-based GOS as the space component of the WMO Integrated Global Observing Systems (WIGOS) as well as a major component of the GEOSS, supporting a number of GEO Societal Benefit Areas.

The new vision will be refined until end of 2008 and presented for endorsement to the WMO CBS in March 2009. During this process, space agencies, CEOS and CGMS are invited to comment on the new vision and to consider how their programmes could contribute to its implementation. In particular, the CEOS SIT may wish to comment on the role of CEOS constellations with respect to the implementation of the future GOS.

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1. The GOS definition process

Defining a vision for the Global Observing System (GOS) is one step in an iterative process involving user communities, scientific working groups, implementing agencies, coordination groups, and WMO bodies. This process can be schematized as follows:

- Collecting ***User Requirements*** from all application areas that the GOS is supposed to support. This is performed on a recurring basis through the Rolling Review of Requirements, which currently addresses 12 applications; this process is theoretically technology-free.
- Translating observing requirements (in terms of geophysical variables) into a high-level ***architecture of observing capabilities*** (in terms of sensors) to be established within the coming decades, as a goal or future planning; this is called the ***Vision***.
- Developing recommendations for implementing the vision, taking into account existing capabilities. This is done through an ***Implementation Plan*** for Evolution of the GOS that is kept under review and regularly updated by the Commission for Basic Systems (CBS) through its Expert Team on Evolution of the Global Observing System (ET-EGOS). Its space-based aspects are reviewed by the Expert Team on Satellite Systems (ET-SAT) involving representatives of space agencies.
- As space agencies of WMO Members (i.e. countries or territories) develop programmes responding to these recommendations, their representatives with WMO can make ***voluntary commitments*** to provide theses programmes as contributions to the GOS; these commitments are recorded by the CBS and ultimately by the WMO Executive Council and WMO Congress.
- The agreed configuration as adopted by the WMO CBS is described in the ***Manual for the GOS*** and the ***Guide on the GOS***, which are part of WMO regulatory material.
- Space Agencies ***implement the programmes*** contributing to the GOS, either individually or through joint undertaking involving several operational or R&D agencies.
- A ***gap analysis*** is performed on a regular basis to compare the available or planed capabilities with the requirements, and update the Implementation Plan accordingly.

While user requirements and Implementation Plans are updated on a regular basis, annually if possible, the Vision and the corresponding regulatory material are in a long-term perspective. The Vision for 2015 was adopted in 2002 and the new Vision for 2025 is being developed for endorsement by CBS in March in 2009.

2. Background

After GCOS had issued in 2006 the Satellite Supplement to the GCOS Implementation Plan [Ref. A], an analysis was performed of the suitability of the space-based GOS to satisfy these updated GCOS requirements. The response to GCOS that was prepared by WMO and the Coordination Group for Meteorological Satellites (CGMS) in October 2006 [Ref. B], highlighted that some of the observations needed by GCOS were beyond the current scope of the GOS (e.g. ocean colour, greenhouse gases) and suggested that the scope of the GOS be re-defined in order to encompass all observations needed for GCOS.

At its extraordinary session in November 2006 (CBS Ext. 06) the CBS subsequently decided "*to commence an update of the baseline of the space-based GOS up to 2025 as a new horizon, and expand its scope beyond the World Weather Watch in order to include sustained observations of additional variables required for climate monitoring, and ultimately to address the needs of other WMO Programmes.*"

Since CBS Ext. 06, the following actions have been taken:

- The capabilities of current and planned instruments were analyzed, with their planned availability, and compared to World Weather Watch and GCOS requirements. This resulted in a "Gap Analysis" document [Ref. C].
- The Workshop on the Re-design and Optimization of the Space-based Global Observing system" (OPT-2) was convened on 21 and 22 June 2007. It involved participants from operational and R&D space agencies: CMA, CNSA, ESA, EUMETSAT, JAXA, JMA, NASA, NOAA, USGS, as well as representatives of GCOS, of the Committee on Earth Observation (CEOS), the Chairman of OPAG-IOS, the Chairman of ET-EGOS, and the WMO Space Programme. CEOS provided an important contribution to the OPT-2 Workshop, through participation of the Ocean Surface Topography and Atmospheric Composition Constellation leads. The OPT-2 Workshop report is available on-line [Ref. D].
- Based on the outcome of the OPT-2 Workshop, the CBS ET-EGOS initiated in July 2007 drafting a new "Vision for the GOS to 2025", that was reviewed in September 2007 by ET-SAT [Ref. E].
- The draft vision was presented at the joint EUMETSAT-AMS Conference in Amsterdam, Netherlands in September 2007 [Ref. F] and to CGMS-XXXV in November 2007; in January 2008, the eighth session of Consultative Meetings on High-level Policy on Satellite Matters (CM-8) welcomed the draft vision, it encouraged further refining it in an ambitious manner and noted that several space agencies represented at the meeting had expressed readiness to contribute to its implementation.

3. New elements of the vision of the GOS to 2025

This section summarizes the changes contained in the draft vision, compared with the current "Vision to 2015" as agreed by CBS in 2002. It includes enhancements or refinements of some current components; it also includes additional missions to provide long-term continuity of observation of Essential Climate Variables (ECV) that were not initially identified as operational requirements in the previous vision for the GOS.

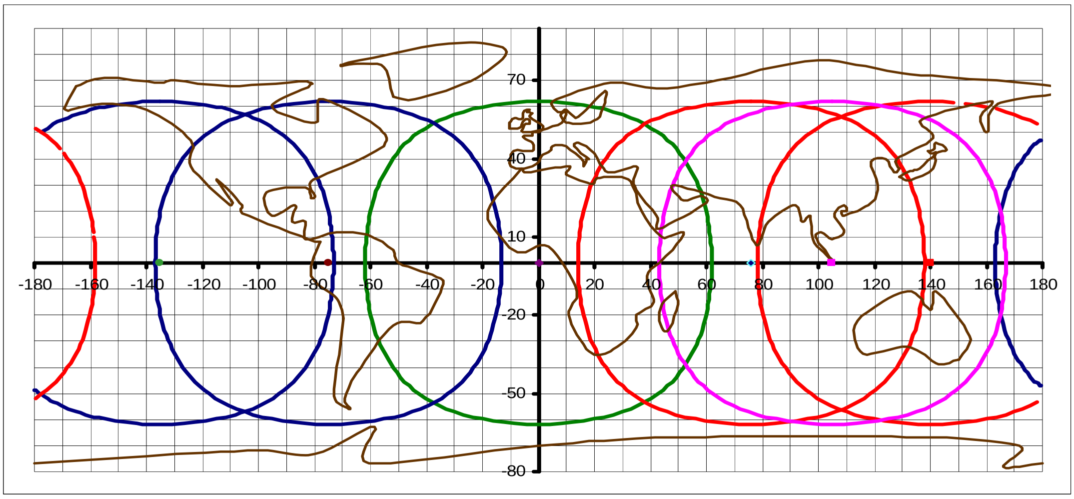
(a) Hyperspectral IR sounding on geostationary orbit

The geostationary component of the space-based GOS should be enhanced through systematically including IR hyperspectral sounding in the baseline payload.

Comment: There are plans or considerations for hyperspectral sounders on the future generations of geostationary satellites to be first flown in 2015-2020 by China (FY-4-O), Eumetsat (MTG-S), Japan (MTSAT-FO), and NOAA (GOES-S or –T). Furthermore a candidate IGeoLab project to fly a demonstration mission beforehand has been discussed but not confirmed.

(b) Optimizing the geostationary locations

It is recommended to optimize geostationary coverage of the globe in ensuring no more than 60° longitude separation between consecutive locations of geostationary satellites equipped with the full baseline payload as shown in Figure 1.



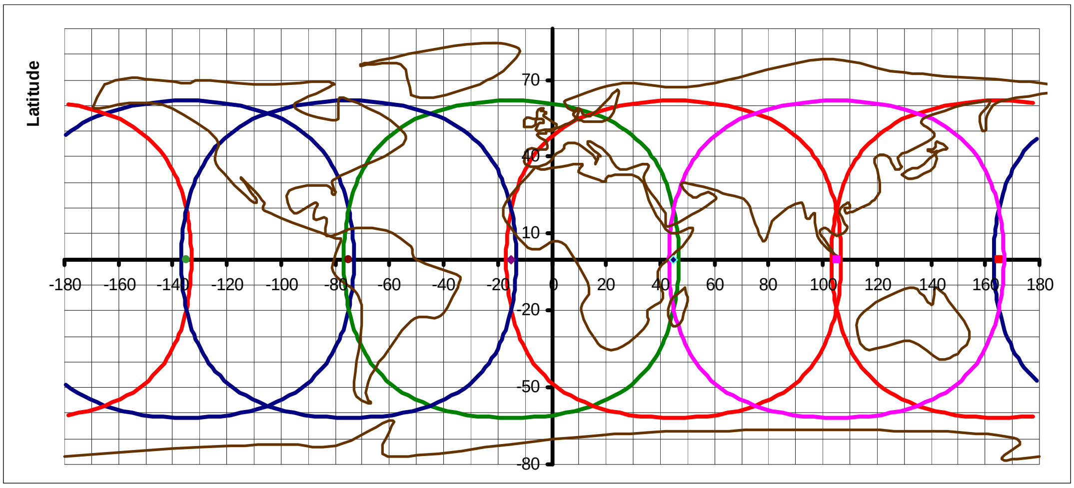


Fig.1. Top: Current baseline, where longitude intervals are spreading between 29 deg and 85 deg. Bottom: Theoretical example of a sixty deg equidistant constellation, ensuring better coverage over the Pacific and Atlantic oceans at high latitudes.

Comment: At the thirty-fifth session of Coordination Group for Meteorological Satellites (CGMS-35) in Cocoa Beach, Florida on 5-9 November 2007, CGMS satellite operators agreed to evaluate the possible flexibility to adjust the nominal locations of their baseline geostationary satellites, taking into account their operational requirements and technical constraints such as spacecraft control, orbital slot and frequency planning. A new nominal configuration is not considered earlier than 2015.

(c) Optimizing the core LEO sun-synchronous constellation

The core operational payload in sun-synchronous LEO orbit should systematically include VIS-IR-MW imagery and microwave and Hyperspectral IR sounding.

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 these core sun-synchronous missions be deployed over three orbital planes around 13:30, 17:30 and 21:30 Local Solar Time at ascending equatorial crossing. This should ensure regular sampling of the atmosphere avoiding too large a temporal gap around dawn and dusk, as required by Numerical Weather Prediction (NWP) and GCOS. Some redundancy should be available around these orbital planes, to the extent possible. Figure 2 illustrates a 2-orbital plane configuration with redundancy on two of them.

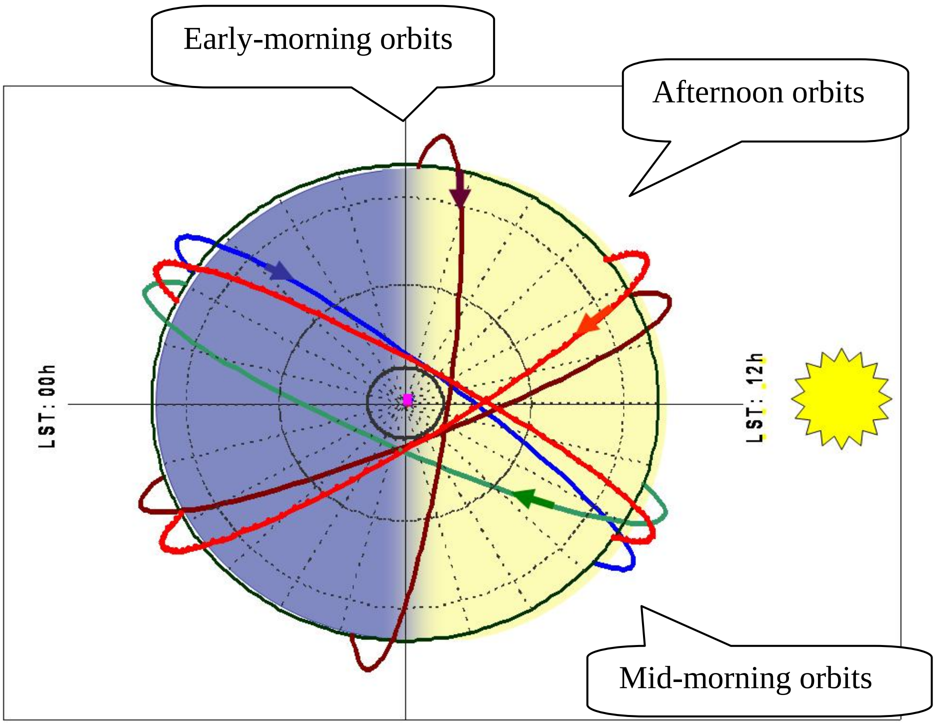


Figure 2: Example of 3-orbit configuration for IR/MW sounding and core imagery missions, with redundancy for two of the nominal orbital planes (mid-am and pm). View of the Northern hemisphere, North Pole being in the centre.

Comment: CGMS-35 supported the new baseline with 13:30, 17:30 and 21:30 nominal equatorial crossing times with redundancy, while noting that this recommendation calls for a change with respect to current plans since no full sounding package is currently planned on the early morning orbit.

(d) Ocean altimetry observation strategy

While the current Vision to 2015 includes provisions for altimeters on two LEO satellites without particular details on the orbital and payload configuration, the oceanographic community is now in a position to specify its need more precisely, as promoted by the CEOS Ocean Surface Topography Constellation. The recommended observation strategy relies 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 inclined orbit)
- At least two additional altimetry systems flying on higher inclination orbits to maximize global coverage (e.g. ENVISAT/RA or Sentinel-3).

Comment: The OPT-2 Workshop also stressed the need for data accessibility; it expressed interest for the future HY-2B ocean monitoring mission announced by CNSA and wished more information on data availability from this mission.

Continuity of the reference altimetry mission beyond Jason-2 as of 2012 is still subject to confirmation. The observation strategy was further confirmed and refined by the Strategic Workshop on Ocean Surface Topography Constellation convened by EUMETSAT and NOAA in Assmannshausen, Germany on 29 to 31 January 2008.

(e) 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 temperature sounding performance in the high troposphere and the stratosphere. A high number of instruments are 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 more precise needs shall be assessed through OSSEs.

Radio-Occultation Sounding (ROS) should not necessarily be included in the core sun-synchronous constellation. On the contrary, a dedicated constellation with diverse orbit inclinations should be envisaged for the ROS mission. 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.

Comment: Contacts have been made by the Joint Centre for Satellite Data Assimilation (JCSDA) with the view to perform OSSEs in 2008/2009, in order to provide objective guidance for defining the optimal size of the constellations and orbital scenarios.

(f) Refining the Ocean Surface Wind observation strategy

Experience gained on Ocean Surface Wind observations now provides firm ground to recommend an observation strategy based on two components:

- Two scatterometers on well separated orbits shall ensure the provision of wind vectors (speed and direction) around the global ocean with typically a six-hour refresh cycle;
- Two conical scanning microwave imagers with full polarization shall contribute to a denser coverage of the globe; it is noted that microwave imagery cannot provide reliable direction information in low wind areas but support the observation of a range of other variables.

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.

Comment: The recommendation goes beyond current plans for scatterometry since only one scatterometer mission with operational continuity is planned over the next decade. The proposed CEOS constellation on Ocean Surface Wind would contribute to fill this gap.

(g) Global Precipitation Measurement (GPM).

The GPM concept, based on a core spacecraft with dual frequency radar on an inclined orbit (e.g. 65 degree inclination) combined with a wide constellation of microwave imaging sensors on several higher inclination orbits, should become an integral part of the GOS design;

Comment: The NASA-JAXA GPM mission augmented by a constellation of microwave imagers is expected to provide initial response to this recommendation on 2014 onwards but continuity shall be planned in due time.

(h) Earth Radiation Budget (ERB)

ERB should be measured through a constellation of sensors including at least one cross-track scanning broad-band radiometer and a Total Irradiance Sensor in LEO. These instruments shall be used in combination with contextual measurements in LEO to enable calculation of the radiative fluxes (temperature and humidity profiles, aerosols, surface albedo, etc.) and with geostationary imagers accounting for the diurnal cycle.

Comment: The observation strategy is being further refined with the radiation community in order to provide more precise guidance on the required capabilities.

(i) Atmospheric composition

While the need to include appropriate payload for measuring atmospheric composition is clearly acknowledged, namely 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 prioritized observation strategy that could be used as a guidance for future planning;

Comment: Collaboration between the Atmospheric Composition Constellation and the WMO Atmospheric Research and Environment Branch (ARE), in charge of the Global Atmosphere Watch (GAW), should allow refining WMO recommendations in this respect.

(j) Specific imagery missions

Narrow-band sensors are necessary for ocean colour and vegetation monitoring (Leaf Area Index and fraction of Absorbed Photosynthetically Active Radiation) on an operational basis. High-resolution VIS/IR imagers are also necessary e.g. for land use monitoring and support to disaster reduction. Synthetic Aperture Radar (SAR) provides unique information in support of some disaster reduction activities, ice shelf and iceberg detection.

Comment: The proposed CEOS constellation on ocean colour is expected to respond to part of these needs.

(k) Lightning detection

Lightning detection is recommended on at least some of the geostationary satellites in order to monitor severe weather and the impact of lightning on chemical processes in the upper atmosphere.

Comment: Lightning detection is currently considered as an option for geostationary satellites, because of the complementary capabilities of ground and space-based systems. Actually these two approaches do not detect the same events. Such sensors are planned for GOES-R and FY-4O satellite series and are being discussed for MTG. It would be an advantage to have quasi-global coverage of geostationary lightning detectors.

(l) Highly Elliptical Orbits

As an option, satellites in Highly Elliptical Orbits would be a valuable complement for quasi permanent coverage of the high latitudes including the polar ice shelf, subject to successful demonstration.

Comment: A demonstration mission based on the Arctica project is currently being discussed by the Russian Federation and other partners in the framework of IGeoLab.

4. Cross-cutting aspects

International coordination

Implementing such a new vision with its diverse components would enhance the observing capability to its required level, but would require more investments and operating expenses. This can only be achieved through increased cooperation among satellite operators, including 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.

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. These aspects are being addressed through the Global Space-based Inter-calibration System (GSICS) and the Integrated Global Data Dissemination Service (IGDDS) project.

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.

Architecture summary

For LEO missions, the proposed vision is a change of paradigm where the classical pairs of operational sun-synchronous satellites with core imagery and sounding payload would be complemented by diverse constellations of instruments, some of them flying on these sun-synchronous satellites, others flying on different operational spacecraft with possibly non-sun-synchronous orbits. This is summarized in the table below.

	Mission addressed	Typical orbit type	Comment
1	Core multispectral imagery and IR-MW sounding	sun-synchronous, 3 orbital planes (13:30-17:30 -21:30)	"Core constellation" Heritage of current mission
2	Radio Occultation Sounding	Clusters with different orbit inclinations a priori not sun-synchronous	New constellation, COSMIC heritage
3A	Ocean altimetry (2-component constellation)	Precise non sun-synchronous (e.g. 1336 km, 66° inclined orbit)	Jason follow-on
3B		Sun-synchronous, 2 well separated orbital planes	Envisat/RA, or GFO heritage
4	Ocean surface wind vector (2 scat + 2 MWI)	Sun-synchronous (TBC)	Can be flying with mission 1 satellites
5A	Global Precipitation	65° inclination	GPM Core spacecraft
5B		Various (sun-synchronous and low-inclination)	GPM MW imager constellation
6	Earth Radiation Budget	Solar irradiance and cross-track scanning Earth radiation broadband sensor (complemented by GEO)	Includes Acrimsat and CERES heritage
7	Atmospheric composition	(TBD, and complemented by GEO))	
8	Specific Imagery	For Ocean colour, for vegetation	

Table 1: Summary of the LEO components of the GOS in the draft vision to 2025

Transition from R&D to operations

An important feature of the proposed vision is that several missions that have been provided for a long time in the framework of R&D missions would in the future be performed on an operational basis. The transition from relevant R&D missions to operations includes two aspects. 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 which is linked with the change of purpose and its consequences on the need for long-term commitment and compliance with different user requirements. 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, a mature and affordable mission concept, suitable data distribution and processing plans, the availability of implementing agencies or consortium of agencies that must have adequate expertise, relevant operational mandate, sufficient funding and maintain an active user relationship.

5. Conclusions

The vision for the space-based GOS to 2025 that is being developed will contribute to the integration of the WMO Integrated Global Observing Systems (WIGOS) and would further reinforce the importance of the space-based GOS as a major component of the GEOSS.

Some early feedback was provided by CGMS-35 that stressed developing such a new vision was important to help each individual agency develop its own planning as a contribution to the whole system, and welcomed the fact that the new vision was clearly addressing several GEO Societal Benefit Areas. The vision was also presented to CM-8 who encouraged refining further the vision in an ambitious manner and noted the readiness of several agencies to contribute to its implementation.

CEOS Member agencies are invited to note the new vision and to consider how their programmes could contribute to its implementation. It is anticipated that CEOS constellations will play an important role as pilot initiatives in this respect.

References

Ref. A. Satellite supplement to the GCOS Implementation Plan: Systematic Observation Requirements for Satellite-based Products for Climate, GCOS-107, September 2006 (WMO/TD No. 1338).

Ref. B. Response to GCOS requirements for space-based observations (CGMS XXXIV WMO-WP-37)

Ref. C. Gap analysis: http://www.wmo.int/pages/prog/sat/documents/CGMS-35WMO-WP-05.pdf

Ref. D. Final Report of the Workshop on the re-design and Optimization of the GOS: http://www.wmo.int/pages/prog/sat/documents/OPT-2FINAL-Report.pdf

Ref. E. Vision for the GOS in 2025, Initial draft proposal from ET-EGOS-3 (July 2007) (Provided as an appendix)

Ref. F. Lafeuille,J.,2006, Re-designing the GOS, EUMETSAT-AMS Conference, Amsterdam http://www.wmo.int/pages/prog/sat/documents/Article_Lafeuille_2007_RedesigningGOS_Amsterdam.pdf

VISION FOR THE GOS IN 2025

Initial draft proposal from ET-EGOS-3 (July 2007)

Role of the GOS

In 2025, the GOS will continue to provide effective global collaboration in the collection and exchange of observations to meet the needs of Members. It will continue to be implemented through a composite and increasingly complementary system of observing systems.

1. In terms of broad general trends:

- The WWW/GOS is expected to evolve to a WIGOS that will integrate its current functionalities together with other observing systems which are not dedicated to the weather forecasting (climate monitoring, oceanography, chemistry, hydrology, weather and climate research). Provision shall be made for continuity of observations of all operational weather variables and Essential Climate Variables, adhering to GCOS climate monitoring principles.
- This implies that more meteorological observing platforms will be shared by instruments for different applications, then more meteorological observations will be performed on “platforms of opportunities”, or using some infrastructures which have been set up for non-meteorological purposes (like GPS surface stations, or the possibility to measure the rainfall rate from the attenuation of the mobile phone radio electric signals).
- The trend to develop fully automatic observing systems will be confirmed (for example likely to affect the radiosondes as well).
- Some level of targeted observations should be achieved in 2025, but there is still a lot of uncertainty on what level can be achieved. Targeting will not be just “putting more observations in sensitive areas or around special weather events”: it will involve a close interaction between “observation performing” and “assimilation” (for example an adaptative data selection scheme taking into account the local meteorological situation and all the available satellite data, before deciding what to use in the assimilation process). It may also involve an earlier selection during the data collection process.
- In 2025, a much larger amount of surface observations is expected to be exchanged globally (such as radar or GPS surface network data).
- An improved calibration ensuring data consistency and reference to absolute standards is expected.
- Sustainability of essential components of the GOS will be secured with many of the R&D systems integrated as operational systems

2. In terms of space-based observing systems:

At least 6 operational geostationary satellites:
- With no more than 60° longitude difference between neighbouring locations
- All with IR/VIS multi-spectral imager
- All with IR hyper-spectral sounder

Operational polar-orbiting sun-synchronous satellites on 3 orbital planes (around 13:30, 17:30, 21:30 ECT) with redundancy
- All with IR/VIS multi-spectral imager
- All with MW sounder
- All with IR hyper-spectral sounder

Other satellites on appropriate orbits (not excluding the geostationary and polar orbits above) contributing to operational observations for weather and climate on a long-term basis:

- Two sun-synchronous satellites with scatterometer
- Two sun-synchronous satellites with conical scanning full polarimetric MW imager
- At least two sun-synchronous satellites with narrow-band VIS/NIR imagers for ocean colour and vegetation
- Constellation of high-resolution VIS/IR imagers for Land Surface Imaging
- Constellation of clusters of small satellites for radio occultation (RO)
- A constellation for altimetry including two altimeters on sun-synchronous orbits and a high-precision reference altimeter system avoiding tidal aliasing
- Constellation of LEO satellites for precipitation measurements through combined use of active instrument in a low inclination orbit and passive microwave instruments on several high-inclination orbit
- Constellation of sensors for Earth Radiation Budget including at least one broad-band multi-angle viewing radiometer in LEO and a Total Irradiance sensor, together with auxiliary LEO measurements and geostationary sensors (TBD)
- A constellation of instruments/missions to address atmospheric compositions
- Optionally geostationary lightning detection
- Optionally satellites in Highly Elliptical Orbit (HEO) ensuring Polar Regions coverage

Several R&D satellites and operational pathfinders including

- LEO with wind Doppler lidar
- GEO microwave
- LEO Low-frequency microwave radiometer addressing salinity and soil moisture

Improved availability and timeliness through operational cooperation among agencies.

3. In terms of surface-based observing systems:

- **Radiosondes**: Optimized utilization, especially in terms of horizontal coverage, which will decrease in data dense areas; supplemented by AMDAR ascent/descents for most of the airports worldwide; supplemented also by profilers for some atmospheric layers. Radiosonde data disseminated at higher vertical resolution than now.
- **GUAN**: A subset of radiosonde stations to be maintained for climate monitoring. A GCOS Reference Upper Air Network (GRUAN) to serve as a reference network for other radiosonde sites, calibration and validation of satellite records and other applications.
- **Aircraft data**: Aircraft instruments able to observe humidity in addition to temperature and wind; available from most airports worldwide and able to replace radiosondes near most of these airports. Data available also on small aircrafts flying on short distances. Could be supplemented by UAVs, but not on a regular basis (maybe to help targeting strategies).
- **Surface observations**: Larger variety of surface networks (e.g.: road network); multi-applications networks; higher level of reliability and availability.
- **GSN**: A subset of surface stations to be maintained for climate monitoring.
- **Radar**: Observing systems will produce the same products as now but with increased data coverage; used by more applications (even global NWP may assimilate radar data with some benefits).
- **Profilers** will be developed and used by more and more applications; a large variety of techniques to be used (lidars, radars, microwave instruments…); these observing techniques to be developed into a consistent network of remote-sensing observations, integrated with other surface networks.
- **GPS** receiver networks will be developed, and locally used (by tomography techniques) to measure also the vertical structure of the humidity field (complementing then radiosondes and aircraft).

- **Long range lightning detection systems** will provide cost-effective, homogenized, global data with a location accuracy of about 2 km, significantly improving coverage in data sparse regions including oceanic and polar areas.
- **Marine observations**: Sustained systems providing high temporal and vertical (sub-surface) resolution data using two-way high data rate satellite data telecommunication systems to collect the in situ observational data; cost-effective multi-purpose in situ observing platforms; new observing technology (e.g. ocean gliders)
- **Atmospheric composition**: Surface-based observations of atmospheric composition (including balloon-borne and aircraft measurements) will be provided by an integrated three-dimensional global atmospheric chemistry measurement network, with a complementary satellite component. New measurement strategies will be combined to provide near real time data delivery.
- **Hydrology**: The surface based observations of hydrological parameters at the global level are expected to diminish, however the exchange of data within the river basins would substantially increase.