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ASSESSMENT BY ESA OF GCOS CLIMATE MONITORING PRINCIPLES FOR GMES

The ESA Sentinel missions are being designed for the GMES services, with special emphasis on the European Commission's fast track services recently defined.

The operational requirements of the Sentinels such as robustness, timeliness, high revisit frequency, data quality and reliability makes the system more than adequate for climate monitoring.

The Sentinels design, and more generally the ESA usual practices for EO missions' development and operation, are to a large extent compatible with the GCOS climate monitoring principles.

ASSESSMENT BY ESA OF THE GCOS CLIMATE MONITORING PRINCIPLES FOR THE GMES SENTINELS

1 INTRODUCTION

The ESA Sentinel missions are being designed for the GMES services, with special emphasis on the European Commission's fast track services recently defined. Therefore it is not evident that Sentinels should be fit for the purpose of climate monitoring following GCOS principles, even if a number of these services will contribute to climate monitoring.

Nevertheless the operational requirements of the Sentinels such as robustness, timeliness, high revisit frequency, data quality and reliability makes the system more than adequate for climate monitoring. In view of this, it is of interest to explore to which extent the design of the Sentinels complies with the GCOS recommendations.

As evidenced below the Sentinels design, and more generally the ESA usual practices for EO missions' development and operation, are to a large extent compatible with the GCOS climate monitoring principles.

2 PRINCIPLES FOR EFFECTIVE CLIMATE MONITORING SYSTEMS[1]

2.1 The impact of new systems or changes to existing systems should be assessed prior to implementation.

The ESA Sentinel missions are being designed primarily to continue the provision of critical measurements for current GMES services which have been established and built up over the past years. A number of these activities are relevant to climate monitoring. Most notably, these observations are provided today by ENVISAT, ERS, Jason, Landsat, SPOT and other European and third party missions.

2.2 A suitable period of overlap for new and old observing systems is required.

This is indeed an essential requirement and is in line with ESA practice in the past (transition from ERS-1 to ERS-2, and from ERS to Envisat). For the Sentinel missions, the political, programmatic, contractual and technical preparations have been advanced as much as possible to avoid a data gap between the above

1 * *The ten basic principles (in paraphrased form) were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. This complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.*

mentioned missions and the Sentinels. The lifetime of the missions listed in point 1 above and the actual launch date of the Sentinels will ultimately determine whether an overlap of observations or a data gap will occur.

2.3 The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.

The plans for GMES are in line with this requirement and consistent with operational and maintenance procedures as well as configuration control policies currently applied to ESA EO missions (e.g. ERS and Envisat) regarding mission operations, cataloguing and metadata, data products information contents, algorithms and processor maintenance/evolution, re-processing activities, etc.

Auxiliary data enhance processing and utilisation of remote sensing payload data that are not captured by the same data collection process as the instrument data. This may include calibration data measured on-board, external calibration files from sources other than the satellite, processor configuration files, and any other files needed by the instrument processors such as orbit state vectors, time correlation files, operational meteorological data (e.g. coming from ECMWF), etc. Auxiliary data files can be classified as mandatory or non-mandatory to a specific ground processing level. All auxiliary data are documented and accessible, some auxiliary data sets are included in the data products themselves and accessible through the catalogues.

In addition, for specific data like ortho-rectified products, the characteristics of the Digital Elevation Model used for the ortho-rectification process must be adequately documented. This will be in particular the case for the related GMES Sentinel-2 land products.

2.4 The quality and homogeneity of data should be regularly assessed as a part of routine operations.

The plans for the GMES space segment are in line with this requirement and consistent with data quality procedures currently applied to ERS and Envisat and Earth Explorer missions in the future.

Quality Control (QC) activities are carried out operationally on a routine basis. Historically, these activities were performed off-line. In order to avoid that near real time products or large products are delivered without any QC, a subset of basic QC activities is exported to and fully integrated in the processing centres. These activities are run either in automatic mode or by non-expert operators. This type of setup is being re-enforced with the development of specific tools and will become the nominal setup in the future for the Sentinel missions in particular. The monitoring by these tools may either have an impact on the production data flow (e.g. by interrupting the product dissemination) or not (e.g. by setting a flag in the inventory).

2.5 Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.

The GMES services and related user requirements are derived from European policies covering various domains, including environment and climate monitoring. Some of these requirements will particularly serve climate monitoring aspects. GMES is based on an operational system aiming at providing robust, reliable data source with high observation frequency, and as such its contribution to climate-monitoring products is expected to be considerable. This aspect will need further attention during the development of information products (level-2 and up). As far as the link with the IPCC is concerned, important parameters like Sea Surface Temperature and Sea Level Height are currently measured with great accuracy by (A)ATSR and Radar Altimeter instruments and these measurements will be continued by the GMES Sentinel missions.

2.6 Operation of historically-uninterrupted stations and observing systems should be maintained.

This is definitely the plan. Part of the mandate of ESA is to ensure preservation of and access to historical data archives from all EO missions handled by ESA in order to support and facilitate the use of long time series of data in particular. This will also be applicable to GMES data.

2.7 High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.

The rationale of the so-called background mission for ERS-2 and Envisat is, among others, to satisfy the above requirement. The instrument design, performance and operations concept for the Sentinels will even more favour and better fulfil the requirement.

By their nature, the Sentinel-3, -4 and -5 instrument missions will ensure global (or regional for Sentinel-4 in case of the choice of a geostationary mission) and systematic routine observations with a high degree of repetitiveness over both ‘data-rich’ and ‘data-poor’ regions.

The Sentinel-1 mission (C-Band SAR) has been designed to satisfy user requirements in terms of data availability, coverage & revisit, timeliness and quality of its data products. The platform and instrument performance (e.g. high data rate, large swath in high resolution mode, etc) will allow consistent and reliable conflict free mission operations, daily coverage of critical areas and a global coverage in 14 days. These performances and the mission operations concept will facilitate the fulfilment of the above requirement, avoiding operational conflicts and priority assignment.

In line with the above, the Sentinel-2 mission (VNIR-SWIR, 10m-20m-60m spatial resolution) will also ensure high revisit and global land coverage (except Antarctica) in a short time (5 days with 2 spacecrafts). The sensor will be continuously operated in the illuminated part of the orbit.

In addition to Sentinel-3, -4 and -5, also Sentinel-1 and -2 missions will therefore produce data products over both 'data-rich' and 'data-poor' regions in a routine and systematic way.

2.8 Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.

These requirements have been considered in the elaboration of the Mission Requirements Document (MRD) of Sentinel-1, -2, -3, -4 and -5, responding to the related GMES user requirements.

2.9 The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.

The Sentinels are the result of such a process that started with ERS, Envisat, Spot and similar sensors.

2.10 Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.

The Agency facilitates access, use and interpretation of the data by climate monitoring systems by providing a consistent, long-term archive of the mission products, supported by multi-mission catalogues. In addition, some relevant products are ingested in assimilation models on an operational basis (e.g. ECMWF).

3 PRINCIPALS FOR SATELLITE SYSTEMS FOR MONITORING CLIMATE

Steps that operators of satellite systems for monitoring climate are two-fold:

(a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and
(b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.

Thus satellite systems for climate monitoring should adhere to the following specific principles:

3.1 Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained

This is in line with ESA practice (ERS-1, ERS-2, Envisat). For the ERS and Envisat satellites sun-synchronous orbits are used, thereby ensuring constant local time of observations with an orbit accuracy of the order of 1 km. Sun-synchronous orbits will also be used for Sentinel-1, -2 and -3 satellites (and most probably for Sentinel-5).

3.2 Overlapping observations should be ensured for a period sufficient to determine inter-satellite biases

Data continuity is indeed an essential requirement and in line with ESA practice (ERS-1, ERS-2, Envisat), thus allowing inter-satellite measurements and monitoring activities.

Where similar or identical sensors are deployed on separate satellites, careful inter-comparison is performed. This is the case for sensors on the ERS and Envisat satellites, like synthetic aperture radars, radar altimeters, the ATSR instruments and some atmospheric chemistry instruments. This requirement is also supported through the extensive calibration and validation activities undertaken as part of new satellite missions and will be the case for the Sentinels.

The ESA radar calibration approach based on absolute calibration of individual sensors proved successful. Negligible radiometric inter-sensor biases were demonstrated by independent verification using natural stable targets and inter-satellite radar interferometry was developed demonstrating controlled phase behaviour.

3.3 Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured

Although ESA is not in a position to ensure continuity of observations from scientific or pre-operational satellites in general, this is an important element, and indeed a driver, for the planned GMES satellites. A long term scenario for the GMES space component is currently being defined with the related strategy for satellite replenishment, with some similarities with operational meteorological missions.

3.4 Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured

All new instruments are characterised and calibrated before launch, and during the commissioning phase immediately following the launch, calibration is one of the primary goals. In addition regular calibration activities take place during the lifetime of the instruments in order to account for ageing effects. Depending on the instrument, both onboard and vicarious calibration activities are maintained throughout the mission lifetime. This is the standard practice for all ESA EO missions and will be continued for GMES.

It should be noted that the reference to radiance in principle 14 is not necessarily applicable to non-optical sensors (for instance SAR). The level-1b product for Sentinel-1 is radar echo and not radiance. The principle 14 should be viewed in a wider context.

3.5 On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored

See response to item 14.

3.6 Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate

All products are based on user requirements from outside the Agency. New products are being developed in close cooperation with the different users.
A number of products generated by the ESA managed ground segments are used in medium- to long-term modelling centres.

ESA maintains extensive programmes where new applications and corresponding products are being developed. In the GMES framework, products relevant for climate monitoring will be defined similarly to any GMES product, based on close coordination with (and review by) the GMES service providers and user community.

3.7 **Data systems** needed **to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained**

This is standard practice in ESA and in particular for atmospheric chemistry products. ESA has a web-based user interface for browsing and ordering data. An extensive archive of data is maintained, from which all data is available to users, also after the end of a mission. This includes a number of products from raw data to higher level products. For many instruments, toolboxes are available for users, and reprocessing of archived data sets is done when needed.
See also response to item 3.

3.8 Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on de-commissioned satellites

When launched ESA satellites have a nominal lifetime. Both ERS satellites have continued functioning well beyond their nominal lifetime, and in both cases operation of the missions has been maintained. When the gyros on ERS-2 failed, new algorithms were developed for the scatterometer in order to allow the operational use of the scatterometer products to be continued in spite of the lower pointing accuracy.

The Agency has not yet decommissioned Earth observation satellites and prefers to maintain data continuity with operational satellites. This recommendation seems targeted at Agencies that have decommissioned fully functioning satellites.

3.9 Complementary in-situ baseline observations for satellite measurements should be maintained through appropriate activities and cooperation

The Agency has a key track record of such collaborations in the framework of geophysical validation and it is expected that the GMES operational entities will maintain the activities and collaboration.
ESA is allocating significant resources to perform validation both through in-situ and airborne data collection activities. In-situ and airborne measurement data are being maintained in databases.
ESA is also involved in GEO task DA-06-02, which aims to "Develop a GEO data quality assurance strategy, beginning with space-based observations and evaluating expansion to in-situ observations, taking account of existing work in this arena". ESA contribution to this task is to assist in the development of standards for quality assurance and to assist in the harmonisation activities towards accessible databases for sensor and in situ data.

3.10 Random errors and time-dependent biases in satellite observations and derived products should be identified

This is planned for the Sentinels and in line with ESA practice (ERS-1, ERS-2, Envisat) related to quality control. See response to item 4.
In addition, for derived products data assimilation is considered a very powerful tool for the determination of error statistics. This would necessitate continuation of the fruitful collaboration with partner organisations (e.g. ECMWF for wind/wave products).

The results of QC activities and in particular the biases are accessible to users by various means (e.g. as part of the products, the inventory, on-line through dedicated web sites, e.g. http://earth.esa.int/pcs).

4 CONCLUSIONS

The GMES Sentinels are generally compliant with all the GCOS Climate Monitoring Principles. For Sentinels 1, 2 and 3 data continuity with ERS, Envisat, Spot, etc., will be ensured by launching the first satellites early in the next decade. During the development and operational phases of the GMES space segment ESA will aim at maintaining the compliance with the GCOS Climate Monitoring Principles.