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*G. Bazalgette Courrèges-Lacoste*

*M. Arcioni*

*Y. Meijer*

*J.-L. Bézy*

*et al.*



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## SENTINEL-4: THE GEOSTATIONARY COMPONENT OF THE GMES ATMOSPHERE MONITORING MISSIONS

G. Bazalgette Courrèges-Lacoste, M. Arcioni, Y. Meijer, J.-L. Bézy, P. Bensi, J. Langen.

*Earth Observation Programmes Directorate, ESA / ESTEC, P.O. Box 299, 2200 AG Noordwijk (the Netherlands)*

[gregory.bazalgette@esa.int](mailto:gregory.bazalgette@esa.int)

[marco.arcioni@esa.int](mailto:marco.arcioni@esa.int)

[yasjka.meijer@esa.int](mailto:yasjka.meijer@esa.int)

[Jean-Loup.Bézy@esa.int](mailto:Jean-Loup.Bézy@esa.int)

[paolo.bensi@esa.int](mailto:paolo.bensi@esa.int)

[joerg.langen@esa.int](mailto:joerg.langen@esa.int)

### ABSTRACT

The implementation of operational atmospheric composition monitoring missions is foreseen in the context of the Global Monitoring for Environment and Security (GMES) initiative. Sentinel-4 will address the geostationary observations and Sentinel-5 the low Earth orbit ones. The two missions are planned to be launched on-board Eumetsat's Meteosat Third Generation (MTG) and Post-EPS satellites, respectively.

This paper presents an overview of the GMES Sentinel-4 mission, which has been assessed at Phase-0 level. It describes the key requirements and outlines the main aspects of the candidate implementation concepts available at completion of Phase-0. The paper will particularly focus on the observation mode, the estimated performance and the related technology developments.

### 1. INTRODUCTION

Atmospheric chemistry observations from space have been made for nearly 30 years. They have been motivated by the concerns about a number of environmental issues. However, most of the space instruments have been designed for scientific research, e.g., to improve the understanding of processes that govern stratospheric ozone depletion, climate change and the transport of pollutants. Long-term continuous time series of atmospheric trace gas data have been limited to stratospheric ozone and a few related species. Meteorological satellites will maintain the latter observations over the next decade. They will also add some measurements of tropospheric climate gases. As their measurements are motivated by operational meteorology needs, they fall short in meeting requirements for atmospheric chemistry applications. Reliable long-term space-based monitoring of atmospheric constituents with quality attributes sufficient to serve atmospheric chemistry applications still need to be established.

### 2. MISSION BACKGROUND

In December 2007, the GMES Atmospheric Service Implementation Group, set up and coordinated by the European Commission, issued its preliminary recommendations for the development of the GMES Space Segment operational capabilities in regard of atmospheric missions. In particular, it recommended implementing the Sentinel-4 mission as a UV/Visible/Near-InfraRed (UVN) sounder to be deployed on the two MTG Sounding (MTG-S) satellites.

"MTG" is the generic name identifying the future European Operational Geo-Stationary Meteorological system that will replace the Meteosat Second Generation System (MSG) at the end of its operational life, currently expected by 2015.

The ESA study on "Operational Atmospheric Chemistry Monitoring Missions" ("CAPACITY") has been used to gather all the various inputs, including those of the GMES Service Element project PROMOTE [1], of the EC-funded projects GMES GATO, GEMS and others, as well as inputs from the IGOS IGACO report. The study generated comprehensive observational requirements (by environmental theme, by user group, and by observational system, i.e. ground and airborne vs. spaceborne) and assessed the contributions of existing missions to the fulfilment of these requirements. Finally, it identified observational technique priorities for GMES missions.

The corresponding mission requirements have been gathered in the GMES Sentinel-4/-5 in the Mission Requirements Document (MRD) [2] and are largely based on the results of the CAPACITY study. The mission requirements generated within that study are based on the mentioned inputs as well as a user consultation workshop.

A detailed overview of the targeted atmospheric services in the framework of GMES is given in [3].

### 3. SENTINEL-4 PRELIMINARY CONCEPT AND PERFORMANCE

#### 3.1. Sentinel-4 Requirements Overview

##### Spectral and Observation Requirements

The Sentinel-4 mission is implemented with a high spatial and spectral resolution instrument (called GEO-UVN in the following) operating from the UV to the NIR bands in the range 290-500 nm and 750-775 nm. Table 1 gives an overview of the characteristics of the Sentinel-4 UV to NIR bands. The specified spectral sampling ratio is 3.

Table 1: GEO-UVN observation requirements (G = Goal value, T = Threshold value)

Band ID	Spectral range [nm]	Spectral resolution [nm]	SSD at Sub-Satellite Point [km]	Priority
GEO-UV-1	290-308	1	50 km (T) 5 km (G)	1
GEO-UV-2	308-400	0.5	5 km	1
GEO-VIS	400-500	0.5	5 km	1
GEO-NIR	750-775	0.5 (T) 0.06 (G)	5 km	1 2

This instrument shall be embarked on the MTG-S mission. As such, a main driver for the instrument design is to be compatible with the MTG-S resource envelope allocated to this instrument. In particular, a maximum mass of 140 kg has to be targeted.

According to current ESA-EUMETSAT Working Assumptions on GMES and following recommendations expressed by the GMES Atmospheric Service Implementation Group (GAS) in March 2008 [4], the GEO-UVN instrument will mainly cover Europe (latitudes 30° N/ 65° N and longitudes 30°W/ 45°E at 40°N latitude) from a GEO-stationary orbit at 0° longitude (MTG-S satellite). This corresponds to a solid angle of 8.8 ° E-W x 3.4° N-S. Fig. 1 shows the Field of View of the GEO-UVN instrument.



Fig. 1 GEO-UVN instrument coverage requirements: the yellow rectangle is the required coverage over Europe.

##### Radiometric Requirements

The SNR requirements are presented in Fig. 2. The absolute radiometric accuracy for Earth reflectance measurements is specified to be < 3% (T) and < 2% (G). Note that this absolute radiometric requirement includes all instrumental error sources, in particular straylight. The use of an on-board calibration unit is compulsory to achieve such demanding requirements.

It is also worth noting that additional requirements related to the presence of unwanted spectral features originating from the on-board diffuser [5, 6] or polarization scrambler [7] have been set, specifying the relative spectral radiometric accuracy of the Earth reflectance measurements over any spectral range of width 0.1 to 3 nm to be < 0.05 % (T)/0.01% (G) peak-to-peak for  $\lambda > 310$  nm and < 0.1% for  $\lambda < 310$  nm.

Finally, the instrument polarization sensitivity shall either be < 0.01 (G) or the polarization components shall be measured (T) as a function of wavelength.

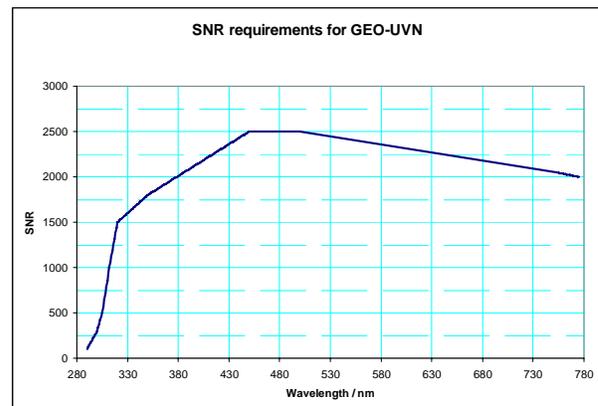


Fig. 2 SNR requirements for the GEO-UVN instrument.

Note that in the particular case of the GEO-UVN instrument the SNR requirement applies per spectral resolution element.

##### Sentinel-4 Preliminary Concept

The Sentinel-4 GEO-UVN instrument is a wide-field push-broom imaging spectrometer that scans Europe in the East-West direction with a repeat cycle of 60 min. As mentioned in the previous Section, the Field of View of the GEO-UVN instrument is about 9 degree in the East-West direction and about 3.4 degree in the North-South direction, centred on Europe.

Regarding Considering the severe polarization sensitivity requirement and considering the mass and volume constraints, the concept that has been selected is

a polarization scrambler to make the instrument insensitive to polarization. The concept of measuring polarization with high spectral resolution has not been retained due to the increased complexity and mass.

The following paragraphs focus on the main subsystems of the Sentinel-4 payload:

Scanning mirror: It needs to be able to rotate around two axis, i.e. E-W scan of the field of view and N-S scan (step) to access to vicarious calibration targets situated in the Sahara region (area between 20°–30° N and 15°W–35°E). The mirror tilt and coating have to be optimized in order to minimize polarization sensitivity.

Telescope assembly and polarization scrambler: the telescope images from infinity to an entrance slit with a large FOV in N-S direction. The polarization scrambler implemented in the telescope assembly has to minimize the sensitivity to polarization of the incoming light and has particularly to correct for the effect of the scanning mirror.

Spectrometer(s): after the telescope, the light is directed to several (concept dependant) spectrographs using conventional gratings as dispersive elements. The main driver for the number of spectrographs is the minimization of the straylight. For the NIR band, it is the threshold spectral resolution that has been selected as baseline. Indeed the only way to achieve an improved spectral resolution with respect to the threshold value in the NIR (targeting the goal spectral resolution of 0.06 nm) is to use grating immersion technology. As the corresponding technology is not available yet, and thus considered as a high risk, the goal resolution for the NIR band is not considered in the current GEO-UVN instrument baseline.

Focal Plane Assembly: Because of the lack of UV sensitive CMOS devices, CCD detectors have been chosen as the baseline. The main driver for the selection is the required format of the detector, which is larger than 1000x1000 pixels.

Calibration unit: For the radiometric calibration an approach with redundant solar diffusers is proposed. One diffuser used frequently (typically daily to weekly) and a reference diffuser used infrequently (typically monthly) to monitor the degradation of the first one. Implementation of a White Light Source (WLS) is also considered for the purpose of meeting the relative radiometric requirements. In the proposed baseline the wavelength calibration will rely on the observation of the Fraunhofer line via the on-board diffuser.

### Sentinel-4 Preliminary Performance

The two proposed baseline instrument designs meet the radiometric requirements except for the GEO-UV2 band, specifically in the spectral range 308 nm to 320 nm (with some variation depending on the proposed concept). As can be seen in Table 1, this range corresponds to a change of the required spectral resolution (from 1 to 0.5 nm) and spatial resolution (from 50 km (T) to 5 km). Consequently, although further optimisation of detector and optical system throughput might help, a full compliance in the spectral range between 308 and 320 nm appears to be challenging within the current mass constraints. This (local) non-compliance has been acknowledged by the scientists.

The GEO-NIR band is, to a lower extent, also critical particularly if an improved spectral resolution with respect to the threshold value is targeted. The other bands (GEO-UV1 and GEO-VIS) are compliant with the GEO-UVN requirements with margins.

The critical issues that have been identified during the Phase-0 study of Sentinel-4 are as follows:

- **Straylight level:** Because of the nature of the instrument (large-field) and the rather large signal dynamic of the spectral range to be covered, the straylight ratio is expected to jeopardize (part of) the absolute radiometric accuracy budget (< 2 % goal, < 3 % threshold) in the spectral range below 350 nm. Consequently, it is expected that dedicated efforts will have to be made to reduce the straylight levels in the detail design phase of the instrument. For instance, on-ground characterisation and appropriate baffle design will have to be considered, although the efficiency of baffles is practically limited since the crucial straylight contributions are mostly “in-field”. An alternative approach will be to split the considered wavelength range into smaller ranges using appropriate band-pass filters. This will however result in a more complex instrument. This issue will have to be addressed in detail in the coming Sentinel-4 Phase-A studies.
- **The other critical issue** that has been identified is the polarization sensitivity. Sentinel-4 is a pushbroom instrument with a scanning mirror allowing to scan the E-W Field of View. This mirror will introduce some polarization effect that needs to be corrected with the use of a polarization scrambler. Finding the optimum location of the scrambler is however rather complex as one has the choice between its implementation in the rather large pupil (typ. 100 mm) of the instrument, implying the use of a very large scrambler, or in an intermediate pupil within the telescope assembly, which implies to operate the scrambler in

convergent beams, which may not be optimum. Consequently, the implementation and performance of the scrambler will have to be reviewed in detail during the Phase-A studies of the instrument.

#### Technology developments for Sentinel-4

Only a few technology developments have been identified during the Sentinel-4 Phase 0 studies. First, the availability of grating immersion technology in the NIR range would allow bridging the gap between goal and threshold spectral requirements of Sentinel-4. It is however worth noting that, although this technology may allow achieving a higher spectral dispersion while keeping the volume of the spectrometer limited, it will likely not allow reaching the specified goal spectral resolution of 0.06 nm (0.2 nm seems a more appropriate target). Furthermore, it is also expected that a SNR compliancy issue will arise (i.e., less photons per resolution element will be collected) for such improved spectral resolution.

The second technological development proposed relates to the detectors. As mentioned, customised CCD have been proposed in the framework of both industrial studies. Although the development risk of such CCD is limited (there are already space qualified devices close to the Sentinel-4 needs on the European market), the specifications for these devices can still be considered challenging and sufficient development time needs to be accounted for in the development planning. Alternatively, CMOS/APS type detectors can also be considered, but they will imply a stronger development effort to make this technology available for Sentinel-4 on-board MTG-S (launch planned for 2017).

#### 4. CONCLUSION

The implementation of atmospheric composition missions is foreseen in the context of the Global Monitoring for Environment and Security (GMES) initiative. Sentinel-4 will address the geostationary and Sentinel-5 the low Earth orbiting part. The two missions are planned to be launched respectively on-board METEOSAT Third Generation Sounder (MTG-S) and Eumetsat's Post-EPS platform.

This paper presents an overview of the GMES Sentinels-4 mission, as it was assessed at Phase 0 level. The mission has been reviewed in detail and a preliminary instrument concept discussed including the achievable performance. Critical technologies have been highlighted.

The results achieved from this preliminary study have allowed ESA to consolidate the mission, system and programmatic requirements and to narrow down the architectural options prior to more detailed feasibility studies in phase A.

#### 5. ACKNOWLEDGEMENTS

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