MISSION OBJECTIVES OF THE ATMOSPHERIC COMPOSITION RELATED SENTINELS S5P, S4, AND S5

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ABSTRACT

Atmospheric chemistry observations from space have been made for over 30 years, in the beginning mainly by US missions. These missions have always been motivated by the concern about a number of environmental issues. At present European instruments like GOME-2 on MetOp/EPS-A and -B and OMI on NASA's Aura are in space and, despite being designed for research purposes, perform routine observations. The space instruments have helped improving our understanding of processes that govern stratospheric ozone depletion, climate change and the transport of pollutants. However, long-term continuous time series of atmospheric trace gas data have been limited to stratospheric ozone and a few related species.

According to current planning, meteorological satellites will maintain these observations over the next decade. They will also add some measurements of tropospheric trace gases critical for climate forcing. However, as their measurements have been motivated by meteorology, vertical sensitivities and accuracies are marginal for atmospheric chemistry applications. With the exception of stratospheric ozone, reliable long-term space-based monitoring of atmospheric constituents with quality attributes sufficient to serve atmospheric chemistry applications still need to be established.

The need for a GMES atmospheric service (GAS), its scope and high level requirements were laid down in an orientation papers organised by the European Commission and then updated by an Implementation Group (IG) [1], backed by four working groups, advising the Commission on scope, architecture, in situ and space requirements. The goal of GAS is to provide coherent information on atmospheric variables in support of European policies and for the benefit of European citizens. Services cover air quality, climate change/forcing, stratospheric ozone and solar radiation.

To meet the needs of the user community atmospheric composition mission concepts for GEO and LEO have been defined usually referred to as Sentinel-4 for GEO and Sentinel-5 for LEO.

Proc. 'ESA Living Planet Symposium 2013', Edinburgh, UK
9–13 September 2013 (ESA SP-722, December 2013)

1. BACKGROUND – THE ATMOSPHERIC COMPOSITION RELATED GMES/COPERNICUS MISSIONS

Global Monitoring for Environment and Security (GMES)/Copernicus has been established to fulfil the growing need amongst European policy-makers to access accurate and timely information services to better manage the environment, understand and mitigate the effects of climate change and ensure civil security.

Under the leadership of the European Commission (EC), GMES/Copernicus largely relies on data from satellites observing the Earth. Hence, ESA – in accordance with the European Space Policy – is developing and managing the Space Component for the initiative. The EC, acting on behalf of the European Union (EU), is responsible for the overall initiative, setting requirements and managing the services.

To ensure the operational provision of Earth-observation data, the Space Component includes a series of five space missions called 'Sentinels', which are being developed by ESA specifically for GMES/Copernicus.

In addition, data from satellites that are already in orbit, or are planned will also be used for the initiative. These so-called 'Contributing Missions' include both existing and new satellites, whether owned and operated at European level by the EU, ESA, EUMETSAT and their Member States, or on a national basis. They also include data acquired from non-European partners. The Space Component forms the European contribution to the worldwide Global Earth Observation System of Systems (GEOSS).

More background related to the atmospheric composition related Sentinels-5p/-4 and -5 can be found in [2] and [3].

2. THE ATMOSPHERIC SENTINELS: SENTINEL-5P, SENTINEL-4 AND SENTINEL-5

The general framework for spaceborne atmospheric composition measurements in synergy with ground-based and airborne measurements and integration with atmospheric models and data assimilation schemes has been outlined in the IGOS Integrated Global Atmospheric Chemistry Observation (IGACO) Theme Report [4]. That document included quantitative observation requirements, summarised for scientific and operational applications. Several other efforts have been made to identify the needs of long-term atmospheric composition data, such as the Eumetsat position paper on observation requirements for nowcasting and very short range forecasting in 2015-2025 [5], and the results of EUMETSAT requirements processes for operational atmospheric chemistry monitoring in the EPS second generation time frame [6].

An ESA study on Operational Atmospheric Chemistry Monitoring Missions (CAPACITY) [7] gathered all available inputs and generated comprehensive observational requirements by environmental theme, by user group, and by observational system (ground / satellite) primarily at product level, i.e. Level-2. This included an extensive assessment of the capabilities of spaceborne atmospheric chemistry instrumentation, either already existing or proposed for Sentinels-4, -5 and -5p, It also addresses observational requirements, a prioritisation of observational capabilities per application as well as further references justifying individual specifications for suggested space instruments.

Based on [7] the following implementation priorities had been recommended:

1. A satellite with UV-VIS-NIR (UVN), SWIR and TIR observational capabilities, also using auxiliary cloud and aerosol data, which serves air quality and climate protocol monitoring in LEO. This satellite complies with all temporal sampling / geographical coverage requirement scenarios and will provide continuity and improvement with respect to the OMI and Sciamachy missions. From the considered orbit scenarios, namely sun-synchronous or low inclination, the sun-synchronous option was chosen.

2. An extension of this mission is to obtain regularly ≤ 1 hour revisit time as required for air quality applications. This extension would consist of a G EO platform carrying instrumentation with similar Level-1b performance specifications. It was decided to implement this mission, in addition to one LEO platform as specified under item 1.

3. A limb-sounding mission observing the UTLS in the mm-wave and/or infrared region to serve stratospheric ozone / surface UV and climate near real time and assessment applications. This mission will not be part of the Sentinel-4/-5 system and is not further considered in the GMES/Copernicus context at present.

Following recommendations expressed in [1] and based on high level agreements, Sentinel-4 and -5 will get implemented as additional payloads on Eumetsat platforms, as follows.

Sentinel-4 (S4) will be a realised as

- addition of a UVN spectrometer on the MTG-S platforms;
- utilisation of thermal infrared (TIR) data from the IR sounder (IRS) onboard the same platforms; and
- utilisation of imager data from the MTG-I platforms (FCI).

Sentinel-5 (S5) will consist of

- a UVNS spectrometer embarked on the EPS Second Generation platforms;
- the implementation of the Sentinel-5 IR sounding requirements within the EPS Second Generation IR atmospheric sounder (IAS);
- utilisation of EPS Second Generation VIS/IR imager data (VII); and
- utilisation of EPS Second Generation Multi-Viewing Multi-Channel Multi-Polarisation Imager (3MI).

Another ESA study addressed the consolidation of requirements at radiance level, i.e. Level-1, namely Observation Techniques and Mission Concepts for Atmospheric Chemistry (CAMELOT, [8]). The key objective of the CAMELOT study was to contribute to the definition of the air quality and climate protocol monitoring parts of GMES/Copernicus Sentinels 4 and 5 in the time frame 2012-2020. In particular the user requirements derived in CAPACITY were in scope of the CAMELOT study addressing the user requirements for air quality protocol monitoring, air-quality near-real-time applications, and climate protocol monitoring.

3. SENTINEL-5P, SENTINEL-4 AND SENTINEL-5 MISSION REQUIREMENTS

A thorough discussion of the S4, S5, and S5p mission requirements can be found in the S-4/S-5 mission requirements traceability document, MRTD [3].

3.1 LEO and GEO UVNS Requirements

Ultraviolet, Visible, Near Infrared and Shortwave Infrared (UVNS) bands are used to measure several trace gas species, and gain information on aerosols and clouds. In Tab. 1 these data products are listed together with the required spectral ranges in the context of GMES/Copernicus service requirements for both LEO and GEO orbits.

Table 1: Data Products derived from observations in the Ultraviolet, Visible, Near Infrared and Shortwave Infrared, required spectral ranges and priorities for both LEO and GEO (N/A = not applicable, i.e. no requirement). Species have been ordered by wavelength.

Level-2 data product	Wavelength range [nm]	LEO	GEO
Ozone vertical profile (O_3)	270 – 330	X	X[1]
Sulphur dioxide (SO_2)	308 – 325	X	X
Albedo	310 – 775	X	X
Total ozone (O_3)	325 – 337	X	X
Aerosol	336 – 340	X	X
Formaldehyde (HCHO)	337 – 360	X	X
Bromine monoxide (BrO)	345 – 360	X	N/A
Rayleigh scattering (cloud), aerosol absorption	360 – 400	X	X
Aerosol	400 – 430	X	X
Nitrogen dioxide (NO_2)	405 – 500	X	X
Glyoxal (CHOCHO)	430 – 460	X	X
Aerosol	440 – 460	X	X
Cloud (O_2-O_2)	460 – 490	X	X
Water vapour and cloud	685 – 710	X	N/A
Cloud (O_2-A band)	750 – 775	X	X
Aerosol profile (O_2-A band)	750 – 775	X	X
Methane (CH_4) [& CO_2]	1590 – 1675	X	N/A
Carbon monoxide (CO) [& CH_4]	2305 – 2385	X	N/A

[1] But only using wavelengths above 305 nm (tropospheric ozone)

3.2 LEO-TIR - Spectral Requirements

In order to cover all target species in the TIR, several spectral bands and with specific resolutions are required as indicated in Tab. 2. Spectral bands are defined in terms of measurable species. The species highlighted in bold are primarily targeted in the spectral bands. A wider wavenumber coverage is strongly preferred over narrower independent windows, allowing numerous species and also aerosol to be probed simultaneously.

Table 2: Species and spectral band requirements for LEO-TIR. The species highlighted in bold are the primary targets in the spectral bands. Species have been ordered by wavenumber.

Species	Spectral range (cm^{-1})
Ethyne (C_2H_2), Hydrogen cyanide (HCN)	650-750
Peroxyacetyl Nitrate (PAN) (HONO, C_2H_6, NH_3, CFC11)	750-850
Nitric Acid (HNO_3) (NH_3, CFC11)	850-920
Ammonia (NH_3), C_2H_4 (CFC12)	920-980
Methyl Alcohol (CH_3OH) (NH_3)	980-1080
Ozone (O_3) profile	1030-1080
Formic Acid (HCOOH) (SO_2, NH_3, CFC12)	1080-1130
Sulphur Dioxide (SO_2) in PBL & Free Troposphere (PAN, NH_3, CFC12)	1130-1200
Methane (CH_4), Water vapour (H_2O) (N_2O, HNO_3, SO_2-UT)	1200-1350
Sulphur Dioxide (SO_2) in the Upper Troposphere (H_2O)	1350-1400
Carbon Monoxide (CO)	2140-2180
Methane (CH_4)	2700-2760
Methane (CH_4)	2760-2900

3.3 GEO-TIR - Spectral Requirements

The Sentinel-4 system shall make use of data from the TIR sounder on the MTG-S platform. The required spectral bands, together with the target species, are listed in Tab. 3. A wider wave number coverage is strongly preferred over narrower independent spectral windows.

Table 3: Spectral bands and target species in the thermal infrared

Band ID	Spectral Range [cm^{-1}]	Species
GEO-TIR-1	700 - 1210	H_2O, O_3, CO_2, Surface, Clouds, Aerosols, HNO_3, NH_3, CH_3OH, HCOOH
GEO-TIR-2	1600 - 2175	H_2O, CO, N_2O

3.4 The Sentinel-5 Precursor

The expected launch dates for MTG-S (2019) and post-EPS (2020) imply a data gap following the end of life of the EOS-Aura mission (< 2014, including OMI and TES), affecting in particular short-wave measurements with sufficient quality for tropospheric applications. Hence, the need for an additional mission was identified, i.e. Sentinel-5p.

The payload of Sentinel-5 Precursor, TROPOMI, shall satisfy the requirements provided above for the Sentinel-5 UV-VIS-NIR-SWIR spectrometers with the following exceptions:

- the time frame of the precursor mission being 2015-2020;
- the precursor shall include the UV-VIS-NIR and one SWIR spectral band. Considering the transitional nature of the precursor and the availability of TIR data - albeit with reduced quality - from IASI, is acceptable not to consider the Sentinel-5 TIR instrument for the precursor;
- auxiliary data from the VII and 3MI will not be available.

The Sentinel-5 Precursor shall be flown on a sun-synchronous low Earth orbit with an equator crossing mean local solar time of 13:30h.

The local time of the Sentinel-5 orbit is determined by the need for collocation with the IR sounder and the imager of the EPS SG mission and will therefore be 9:30h. For the Sentinel-5 Precursor, an early afternoon orbit (13:30h equator crossing mean local solar time (MLST)) is required for the following reasons:

- an afternoon orbit is favourable to pick up the main daily pollution signal which is the information needed for air quality forecast and protocol monitoring, and to support decisions on possible traffic or emission regulations for the next day;
- an afternoon orbit will allow a start into observation of diurnal variability in synergy with data from GOME-2 and IASI on Metop; this would hardly be possible in the reverse case of a morning orbit and synergy with NPP/JPSS, due to the specification values of the relevant NPP/JPSS instruments which are not designed for chemical measurements in the troposphere;
- early afternoon provides better observation conditions in solar channels than late afternoon, due to more favourable solar zenith angles;
- in a 13:30h orbit, advantage can be taken by synergetic exploitation of simultaneous measurements of stratospheric ozone profiles by OMPS on the NPP/JPSS platform and of imager data of VIIRS on NPP/JPSS. The time delay between observations of a scene by NPP/JPSS and Sentinel-5 precursor is recommended to be less than 15 s econds (goal) / 5 minutes (threshold) (TBC).
- an early afternoon orbit will be most suitable for continuation of the long term record of short-lived tropospheric species from OMI, which has been started in 2004, at 13:45 equator crossing MLST.

4. STATUS

The status of Sentinel-4 and Sentinel-5p will be reviewed in more detail in subsequent papers in this volume.

For Sentinel-5 supporting scientific studies are in progress focusing on the requirements in the NIR and SWIR.

Another study will address requirements on the UV-Vis. Synergetic products are another topic as some of the identified Level-2 products require synergetic retrievals based on various bands with the UVNS instruments but also observations from other instruments on-board of MetOp-SG, namely:

- ozone (O_3) from a combination of the UV and TIR bands,
- carbon monoxide (CO) from combination of the SWIR and the TIR bands,
- methane (CH_4) from combination of the SWIR and the TIR bands,
- cloud information from the NIR (i.e., O_2-A) band used in UV-VIS and SWIR retrievals,
- cloud information from VII used in UV-VIS, SWIR and TIR retrievals,
- refined cloud characterisation from the combination of all instruments,
- aerosol information from UVN and 3MI, also used in trace gas retrievals in UV-VIS
- aerosol information from UVN and TIR, also used in trace gas retrievals in UV-VIS

5. CONCLUSIONS

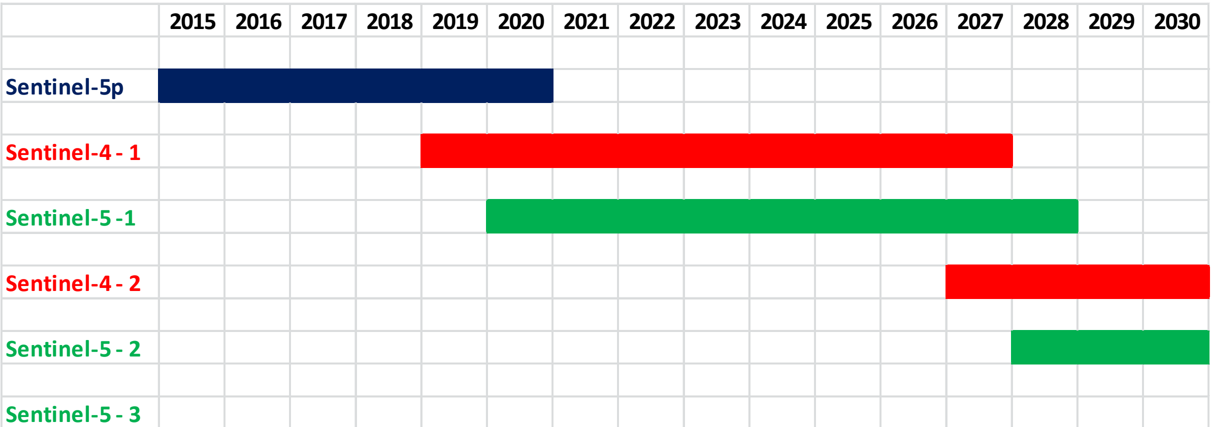
The preparations of S5p, S4 and S5 are well underway. However, due to the nature of the programme and related to programmatics, the missions are in various stages of development. S4 is in a rather advanced status in line with the maturity of the MTG programme. The situation is rather similar for S5p due to the preparatory work performed at national level in the Netherlands. For S5, the situation is more open as the mission is in the detailed design phase.

Tab. 4 summarises the implementation scenarios for Sentinel-5p, -4 and -5. Fig. 1 provides an overview over the launch schedule of the atmospheric sentinels.

Table 4: Summary of the implementation scenarios of the Atmospheric Composition Sentinels.

	UV-VIS- NIR, SWIR			**TIR**	
Orbit	LEO		GEO	LEO	GEO
Temporal sampling	daily		hourly	daily	hourly
Instrument	UVNS	TROPOMI	UVN	IAS	IRS
(Host) Satellite	EPS-SG	Free flyer	MTG-S	EPS-SG	MTG-S
Synergy	VII, 3MI	VIIRS+OMPS+CRIS/ NPP, /JPSS	FCI/MTG-I	VII	FCI /MTG-I
Sentinel-5p ➔		**X**			
Sentinel-4 ➔			**X**		**X**
Sentinel-5 ➔	**X**			**X**	

Figure 1: Launch Schedule of the Atmospheric Sentinels; the third Sentinel-5UVNS instrument is expected to be launched after 2030



Overall, the atmospheric composition element of GMES/Copernicus, i.e. S5p, S4 and S5, is in a rather advanced stage seeing a s uccessive implementation of the various elements in the period between 2015 and 2020.

6. REFERENCES

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