THE GMES MISSIONS RELATED TO ATMOSPHERIC COMPOSITION

Paul Ingmann, Jörg Langen, Ellen Brinksma, Ben Veihelmann, Grégory Bazalgette Courrèges-Lacoste, Marco Arcioni

ESA/ESTEC, European Space Agency, Postbus 299, 2200 AG Noordwijk, The Netherlands

Abstract

At the 2008 EUMETSAT Conference the concept of the GMES Sentinels related to atmospheric composition had been introduced (Ingmann et al, 2008). The concept of reliable long-term space-based monitoring of atmospheric constituents with quality attributes sufficient to meet atmospheric chemistry application needs was introduced.

Implementation of atmospheric composition missions is foreseen in the context of the Global Monitoring for Environment and Security (GMES) initiative. This is an activity which was confirmed as the European Union's priority at the 2001 Summit in Gothenburg, where the Heads of States and Governments requested that "the Community contribute to establishing by 2008 a European capacity for Global Monitoring for Environment and Security". The concept was recently confirmed at the ESA Council at Ministerial Level which took place at the end of November 2008 in The Hague. At that meeting it was agreed that, in addition to Sentinels-4 (GEO component) and -5 (LEO component), a Sentinel-5 precursor would get implemented to avoid a data gap between missions like AURA or Envisat and Sentinel-5. The mission would need be to operational as of 2014 with a life-time of the order of 5 to 7 years.

BACKGROUND - GLOBAL MONITORING FOR ENVIRONMENT AND SECURITY (GMES)

Global Monitoring for Environment and Security (GMES) 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 relies largely 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.

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).

ESA's new Sentinel missions will provide information in all domains of GMES, starting with the all-weather, day and night radar imaging from Sentinel-1 (S-1) for land and ocean services. Sentinel-2 (S-2) will deliver high-resolution optical imaging for land services and Sentinel-3 (S-3) will provide services for ocean and global land monitoring. Sentinel-4 (S-4) and Sentinel-5 (S-5) will provide data for atmospheric composition monitoring from geostationary and polar orbits. A Ground Segment, facilitating access to Sentinel and Contributing Mission data, complements the GMES Space Segment.

The acquisition of reliable information and the provision of services form the backbone of Europe’s GMES initiative. Services will be based on data from a host of existing and planned Earth observation satellites from European and national missions, as well as a wealth of measurements taken in situ from instruments carried on aircraft, floating in the oceans or positioned on the ground.

The resulting services will bring a broad range of socio-economic benefits to many sectors of society. Policy makers will have ever-better information on which to base decisions for the protection, preservation and management of the environment as well as benefit from related cost savings.

Services provided through GMES fall into five main categories: services for land management, services for the marine environment, services relating to the atmosphere, services to aid emergency response and services associated with security.

These services have the potential to significantly improve many environmental concerns such as natural resource management, food security, biodiversity and air-quality forecasting. In addition, information through GMES will lead to a better understanding of climate change issues. The services component of GMES is under the responsibility of the EC.

The GMES in situ component is based on an observation infrastructure owned and operated by the large number of national and European stakeholders coordinated, in some cases, within the framework of European and international networks. The in situ component is under the coordination of the European Environment Agency (EEA).

The user needs and requirements for operational atmospheric composition sounding have been carefully evaluated in recent years. This has lead to a concept whereby the baseline foresees that S-4 will be embarked on MTG-S and S-5 will be embarked on Post-EPS. In order to avoid any data gap, a precursor mission (S-5p) would be needed by 2014 to ensure continuity of already existing services. The present baseline would ensure that Europe will be in a position to meet the operational user needs during the second decade of the 21st century.

THE FIVE SENTINELS

Sentinel-1 (S-1)

The S-1 European Radar Observatory is a polar-orbiting satellite system for the continuation of Synthetic Aperture Radar (SAR) operational applications.

S-1 is a C-band imaging radar mission consisting of a pair of satellites aimed at providing an all-weather day-and-night supply of imagery for GMES user services. The first Sentinel-1 satellite is envisaged to launch in 2012 and will be followed by the second satellite a few years later.

Dedicated to GMES, S-1 will ensure the continuity of C-band SAR data and build on ESA's and Canada's heritage with SAR systems carried on ERS-1, ERS-2, Envisat and Radarsat. At the same time, the mission parameters have been greatly improved to meet GMES user requirements, especially in areas such as revisit time, geographical coverage and rapid data dissemination.

Sentinel-2 (S-2)

S-2 polar-orbiting satellites will provide systematic global acquisitions of high-resolution multispectral imagery with a high revisit frequency. This mission is tailored towards the needs of operational land monitoring and emergency services with a first launch in 2013.

S-2 will provide enhanced continuity of multispectral imagery provided by the French SPOT (Satellite Pour l'Observation de la Terre) series of satellites (for resolution of typically 10 metres and above).

In order to meet the user requirements, Sentinel-2 satellites will provide imagery for the generation of high-level operational products such as land-cover maps, land-change detection maps, and geophysical variables, for example, leaf area index, leaf chlorophyll content and leaf water content.

Data from S-2 will benefit services in areas such as land management by European and national public institutes, the agricultural industry and forestry as well as disaster control and humanitarian relief operations. Images of extreme events such as floods, volcanic eruptions and landslides will also be acquired by S-2.

Sentinel-3 (S-3)

S-3 is primarily a mission to support services relating to the marine environment, with capability to serve numerous land-, atmospheric- and cryospheric-based application areas. The first S-3 satellite is expected to launch in 2013, followed by a second so that they work together to provide maximum coverage.

The mission's main objective is to determine parameters such as sea-surface topography, sea- and land-surface temperature as well as ocean- and land-surface colour with high-end accuracy and reliability.

Benefiting from a proven heritage, S-3 carries several instruments:

- A topography system, which includes a dual-band Ku- and C-band altimeter based on technologies used on ESA's Earth Explorer CryoSat mission, a microwave radiometer for atmospheric correction and a DORIS receiver for orbit positioning.

- An Ocean Land Colour Instrument (OLCI), which is based on heritage from Envisat's Medium Resolution Imaging Spectrometer MERIS instrument. The OLCI operates across 21 wavelength bands from ultraviolet to near-infrared and uses optimised pointing to reduce the effects of sun glint.

- A surface temperature system called Sea Land Surface Temperature Radiometer (SLSTR), which is based on heritage from Envisat's Advanced Along Track Scanning Radiometer (AATSR). The SLSTR uses a dual viewing technique and operates across eight wavelength bands providing better coverage than AATSR because of a wider swath width.

Sentinel-4 (S-4), Sentinel-5p (S-5p) and Sentinel-5 (S-5)

The basic scientific rationale behind the atmospheric composition missions S-4 and S-5 had been explained in quite some detail in Ingmann et al (2008) and will not be repeated here. However, the recently finished CAMELOT study (Levelt et al, 2009) revealed a number of issues which are worth considering. The objectives of the CAMELOT study had been:

- The establishment of auxiliary (meteorological) data requirements
- Trade-off's between measurement principles for several species
- The quantitative derivation of Level 1b requirements
- The quantification of cloud sensitivity per species
- Performing orbit trade-off

The main results in terms of species and spectral bands are:

For Ozone (O_3):

- For the derivation of O_3, both UV and TIR have limited sensitivity in the PBL
- The iterative synergistic retrieval of O_3 remains to be demonstrated
- Observation of the diurnal variation of O_3 in the PBL remains challenging

For Nitric Dioxide (NO_2):

- The retrieval of NO_2 will strongly benefit from the O_2-A band in cloudy conditions
- It has been demonstrated based on OMI and ground-based observations that there is a good correlation between them with respect to NO_2
- The observed diurnal variation is convolved with PBL dynamics

For Methane (CH_4):

- The direct retrieval of CH_4 is highly sensitive to cloud and aerosol
- Calibration of air mass factor requires using CO_2 (1.6 μm band) and is sensitive to the assumed CO_2 abundance and requires a combination of 1.6 and 2.3 μm bands

And for aerosol:

- Proper characterisation of aerosol requires multi-spectral, multi-directional, multi-polarisation imager (3MI)
- Both UV and SWIR channels are desirable in 3MI

For the thermal infrared:

- Requirements have changed following the success of IASI, namely from 2-3 narrow bands (O_3, CO) to a wide-band instrument with target species like O_3, CO, CH_4, H_2O, NH_3, HNO_3, CH_3OH, PAN, volcanic SO_4, C_2H_4, C_2H_2, HCN, CFC-11, CFC-12
- The spectral resolution required shall be in the range 0.075 – 0.3 cm^{-1} unapodised
- The implementation requires a combined meteorology – chemistry instrument on Post-EPS

The S-4 and S-5 payloads will be embarked on meteorological satellites operated by EUMETSAT.

The S-4 payload will be accommodated on the two Meteosat Third Generation–Sounder (MTG-S) satellites in geostationary orbit planned to launch in 2017 and 2024. The payload is a UVN spectrometer with bands in the UV (305-400 nm), visible (400-500 nm) and in the near-IR (750-775 nm). The IR sounder on-board will be utilised to get the TIR data required to meet the overall S-4 mission requirements. Figure 1 shows a typical accommodation of the UVN instrument on-board MTG-S.

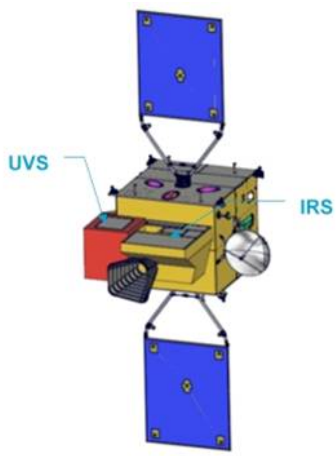

Figure 1: **Possible implementation of the UVN instrument on-board MTG-S. It is assumed that the UVN spectrometer is accommodated in the vicinity of the Infrared sounder (IRS) for a good registration of the two instruments. The latter is required to meet the requirements for synergetic products retrieval.**

However, as the UVN instrument was added late to the payload, the sounder is optimised for NWP use. Therefore, the performance provided will be sub-optimal for meeting the overall S-4 requirements. It is also planned to make use of the imagers on the MTG-I platforms in order to get information about clouds.

The S-5 payload, a UVNS spectrometer, will be carried on the Post-EPS spacecraft series planned to launch starting in 2020. The payload is a UVNS spectrometer with two bands in the UV, three bands in the visible and in the near-IR complemented by two band s in the SWIR between 1600 and 2400 nm. Similar to the S-4 concept, it will utilise the IR sounder on-board to get the TIR data required to meet the overall S-5 mission requirements. Again, it is planned to make use of the imager on the Post-EPS platforms in order to get information about clouds.

The expected launch dates for MTG-S (2017) and Post-EPS (2020) imply a data gap following the end of life of the Envisat mission (< 2014, including Sciamachy) and the EOS-Aura mission (< 2014, including OMI and TES), affecting in particular short-wave measurements with sufficient quality for tropospheric applications. A precursor for S-5 is needed to bridge between current research missions.

A thorough discussion of the S-4, S-5, and S-5p mission requirements can be found in the S-4/S-5 MRD (ESA, 2009). The spectral bands required to meet the mission objectives can be found in Figures 2 for the short-wave and Figure 3 for the long-wave part of the spectrum together with the species driving the choice of spectral bands.

STATUS

At present, the UVN instrument concept for S-4 is getting consolidated in the context of the MTG-S satellite project, within a dedicated S-4 phase A study and parallel scientific studies. Instrument design as well as issues like calibration concept have been addressed. Accommodation of the UVN instrument in terms of physical size and interfaces, e.g. data rate, are crucial for the overall MTG system.

On the scientific side, various studies have been performed to analyse the impact of Sentinel-4 based on the envisaged implementation. Although the instrumental specifications for MTG-IRS are not optimized for

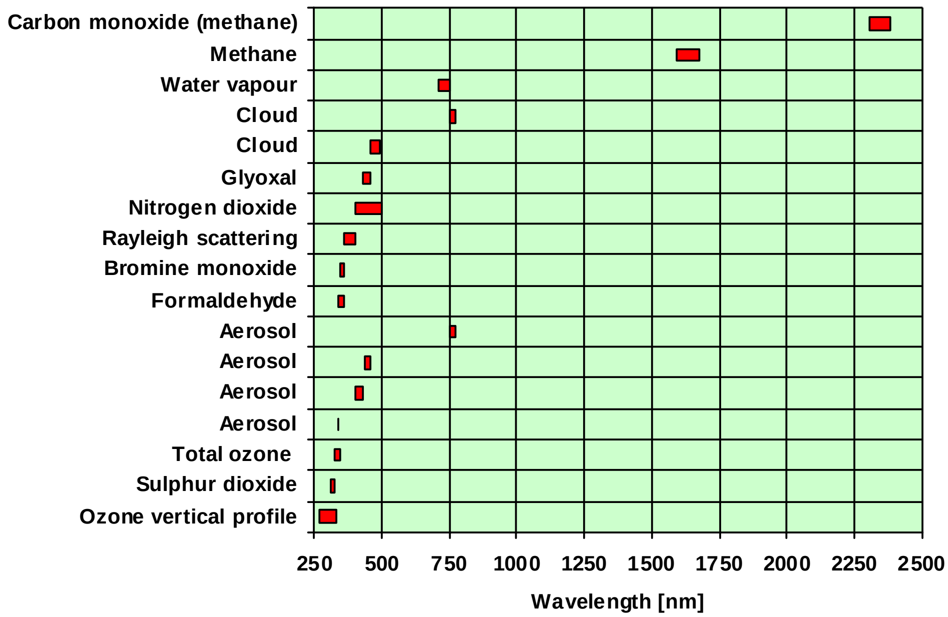

Figure 2: **Spectral bands required to meet the mission requirements with respect to species expected to be derived from Sentinels-4, -5p and -5 in the ultraviolet, visible, near-infrared and short-wave infrared part of the spectrum.**

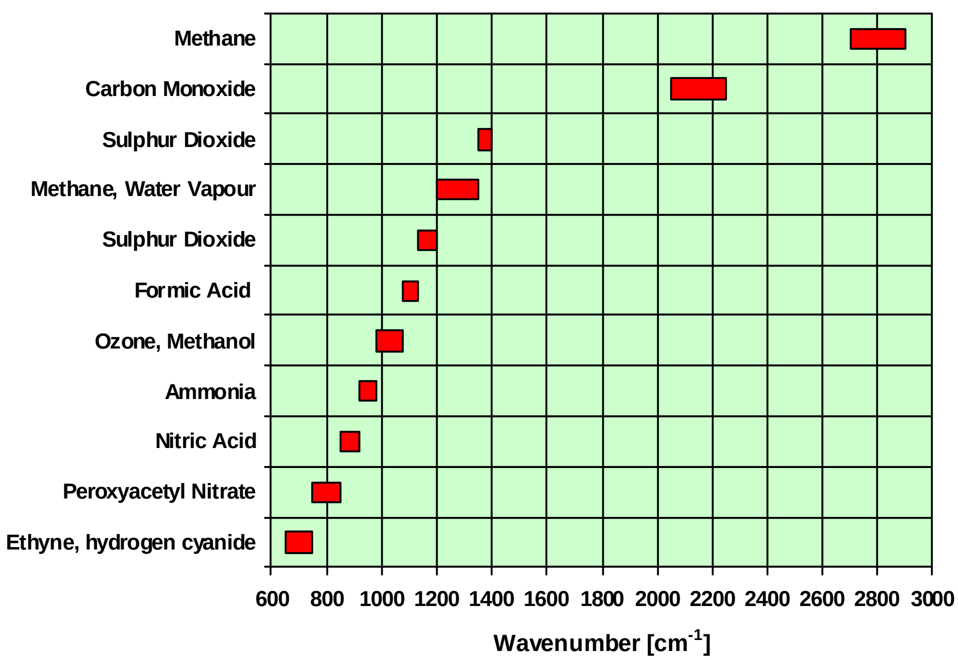

Figure 3: **Spectral bands required to meet the mission requirements with respect to species expected to be derived from Sentinels-4, -5p and -5 in the thermal infrared part of the spectrum. Only S-5 addresses all spectral bands.**

chemistry, the instrument will provide tropospheric columns of O_3 and CO, with significant improvement on our prior knowledge, most remarkably for high pollution events, i.e. photochemical pollution in the case of ozone and fires in the case of CO. The diurnal variability will be difficult to capture. As ozone pollution mainly occurs along with high temperatures, pollution peaks will likely be monitored. However, it is expect to take benefit of the high sampling rate of the GEO sounders (0.5 to one hour) in order to set-up a specific retrieval strategy that would use the information at different times of the day (hence different thermal contrast) to extract peak pollution events at the right time and place. Moreover the smaller MTG-IRS pixel size (3 to 6 km) would allow to average data in order to increase accuracy. More details can be found in Clerbaux et al (2008).

Performance and other aspects of the S4 UVN instrument are addressed in an on-going study performed by IUP/Bremen (Bovensmann, et al, 2009). Issues investigated include spatial coverage, co-registration, the spectral resolution in the Near-IR (Oxygen A-band) driven by the derivation of aerosol optical thickness in the PBL, radiometric requirements, polarisation sensitivity and spectral calibration concepts. The latter requires close interaction with industry.

While Sentinel-4 has been approved by the ESA Council in 2008, the final approval of MTG-S by the EUMETAT Council is expected in the 2010/11 time-frame.

For S-5p implementation activities have started. Most of the instrument is based on work performed in the Netherlands in the context of TROPOMI (e.g. Voors et al, 2008). Getting this mission implemented within a rather stringent cost envelope is a major challenge. Issues like the identification of key operational data products and the overall ground segment structure meeting the standard of an operational mission are essential for meeting the mission objectives. A S-5p Mission Advisory Group (MAG) has been set up to ensure overall consistency between the Sentinel-4/-5 MRD and Sentinel-5p taking into account that the precursor mission will be a mission ‘designed-to-cost’. Elements addressed by the group include geophysical product identification and the structure of the ground segment including data latency.

S-5p has been approved by the ESA Council in 2008. The development will be co-funded by the Netherlands.

In the context of the Post-EPS preparation atmospheric composition requirements for the 2020’s are getting refined. The satellite system is undergoing feasibility study. Two activities have been performed in parallel. Of paramount importance is to establish a system which (a) can continue MetOp/EPS services but is (b) innovative enough for embarking mission opening new avenues of applications including atmospheric composition monitoring. Similar to MTG, it is highly probable that the missions get distributed over two satellites to meet all requirements.

So far only the preparatory activities have been approved for S-5. Final approval and funding is expected both by EUMETSAT and ESA in 2011.

CONCLUSIONS

The preparations of S-4, S-5p and S-5 are well underway. However, due to the nature of the programme and related to programmatics, the missions are in various stages of development. S-4 is in a rather advanced status in line with the maturity of the MTG programme. The situation is rather similar for S-5p due to the preparatory work performed nationally in the Netherlands. For S-5, the situation is much more open as the mission complement is still in the selection phase.

Overall, the atmospheric composition element of GMES, i.e. S-4, S-5p and S-5, is in a rather advanced stage seeing a successive implementation of the various elements in the period 2014 to 2020.

REFERENCES

Bovensmann, H. et al (2009) Retrieval Sensitivity Analysis for Sentinel 4, ESA Contract No. 22293/09/NL/EL

Clerbaux, C., P.-. Coheur, O. Scharf, D. Hurtmans, A. Boynard (2008) The potential of MTG-IRS and S4-TIR to detect high pollution events at urban and regional scales, ESA Contract No. 20839/06/NL/HE, CCN-1, 58p

European Space Agency (ESA), (2009) GMES Sentinels 4 and 5 Mission Requirements Document, EOP-SMA/1507, issue 3 rev.1

Ingmann, P., J. Langen, Y. Meijer, G. Bazalgette Courrèges-Lacoste and M. Arcioni (2008) GMES Sentinels 4 and 5 - Atmospheric Composition Monitoring from Space in **EUMETSAT P. 52**, '2008 EUMETSAT METEOROLOGICAL SATELLITE CONFERENCE', Darmstadt, Germany 8 - 12 September 2008

Levelt, P. et al, (2009) Observation Techniques and Mission Concepts for Atmospheric Chemistry (CAMELOT), ESA Study, Contract no. 20533/07/NL/HE

Voors, R., J. de Vries, P. Veefkind, A. Gloudemans, A. Mika, P. Levelt (2008) TROPOMI end-to-end performance studies, in 'Sensors, Systems, and Next-Generation Satellites XII', edited by R. Meynart, S. Neeck, H. Shimoda, S. Habib, Proceedings of the SPIE, **7106**, pp 71061D-1 to 71061D-7