ALTIUS as an element of the
European Earth Watch Programme

Excerpt from the ALTIUS Mission Proposal as submitted to the ESA-EFP Programme Board No.27

Summary

ALTIUS is an element of ESA’s European Earth Watch Programme that aims at the development of a limb sounder mission based on a small satellite. Its main objective is the monitoring of the 3-D distribution and evolution of stratospheric ozone at high vertical resolution. The versatile instrument, which is intended to image the Earth’s limb in the near UV, Visible and Near Infrared spectral regions, in combination with the agility provided by the spacecraft platform can allow measurements of concentration profiles of other species as well as of aerosol extinction vertical profiles. The Programme Proposal covers the phases B2/C/D including the development of the space segment, up to Flight Acceptance Review and of the Ground Segment up to the Ground Segment Acceptance Review. It does not cover the procurement of the launch service, nor the phase E1/E2 which will be subject of a separate programme proposal to be issued during phase C/D.

1. Background

1.1 Limb Sounding Ozone Missions

The depletion of stratospheric ozone due to anthropogenic emissions of substances containing chlorine and other halogens was first identified in the mid-1970s and has received increasing attention since the mid-1980s after the discovery of the ozone hole. Today, the atmospheric halogen load is still enhanced substantially above natural levels and will remain so for decades. Monitoring of stratospheric ozone remains extremely important, as the ozone layer has yet to recover and since climate change is having an increasing influence on stratospheric ozone and the influence of changing ozone levels on climate change has manifested itself. Over the last decade operational services using stratospheric ozone observations have been developed in response to user requirements. For instance, in Europe, the Copernicus Atmosphere Monitoring Service (CAMS) has been set up. The World Meteorological Organisation has a mandate by the Parties of the Montreal Protocol to regularly report on the status of the ozone layer.

A series of nadir sounders is planned in order to continue the measurement of ozone and some trace gases. These range from ESA’s (in collaboration with the EU) Copernicus Sentinel-5 precursor mission and the Sentinel-4 (on MTG) and Sentinel-5 (on MetOp-SG) instruments to NOAA/NASA missions within the JPSS programme, which will host the OMPS nadir ozone sounder. The nadir sounders deliver information on the ozone total column and on stratospheric ozone profiles at coarse vertical resolutions of about six kilometres at best. Limb observations, on the other hand, provide detailed stratospheric
profile information, which has been shown to provide a valuable addition to ozone total ozone in data assimilation systems used by operational centres. However, there will be a lack of adequate limb measurements of ozone in the future, starting towards the end of this decade with the end of the lifetime of SAGE-III and OMPS-limb on Suomi-NPP, and with the only subsequently planned limb-sounder currently planned to be launched on JPSS not earlier than 2022.

Belgium expressed the desire to develop ALTIUS in the frame of a small operational mission to monitor ozone. Under PRODEX, ESA funded an “OPEROZ” study (Operational Ozone Profile Requirements) to establish user requirements for monitoring the evolution of stratospheric ozone at high vertical resolution, calling for operational, i.e. sustained long-term monitoring from space of ozone profiles (and possibly related observables) in the stratosphere in limb geometry at high vertical resolution. Requirements were split into an ozone only, “minimum mission” and several potential “mission extensions” with different priorities.

1.2 ALTIUS Background

Anticipating the gap in limb sounding missions, BISA defined and has worked on the ALTIUS mission as a limb scattering mission based on the ESA PROBA small platform. Various inter-leaved activities related to the ALTIUS mission have been performed mainly with Belgian funding, either through GSTP or PRODEX, since 2006, and some Finnish funding through PRODEX in relation to the use of the Fabry Perot technology. These covered the definition of instrument concepts for the different spectral channels and assessment of their feasibility, as well as the preliminary design of an evolution of the PROBA platform (PROBA-NEXT) embarking the ALTIUS instrument as one of its reference missions. ALTIUS was initially defined as an in-orbit demonstration of an innovative limb imager, based on a series of technical requirements, and with the goal to fulfill scientific objectives defined by BISA (derived from scientific literature and recommendations of several international organizations).

During November 2015 to January 2016, the potential of ALTIUS to comply with the minimum operational mission as defined by the OPEROZ study was reviewed during a Preliminary System Requirements Review, which concluded that “... at this stage of the development, no showstopper has been identified that could prevent ALTIUS from fulfilling the OPEROZ requirements for the “minimum mission”.

ALTIUS also has potential to contribute significantly to the mission extension into the mesosphere. However significant additional work is required to demonstrate compliance to the end-to-end performance requirements for the minimum mission, focusing especially in the instrument performance, retrieval, completion of end-to-end error budget, adaptation of the observation scenario to 200km along track sampling requirement, and delivery of L2 data within 3 hours from sensing...”.

1.3 Short description of the ALTIUS mission

ALTIUS is a mission based on an innovative instrument concept and on features offered by the PROBA bus, ensuring a small autonomous multi-mode mission, i.e. allowing for atmospheric observations in multiple sounding geometries. Development and operations costs are optimized by maximal re-use of facilities and experience gained in the development and operation of previous PROBA missions. Mission lifetime of minimum 3 years is envisaged.

The ALTIUS instrument consists of three independent spectral imagers capable of observing the atmospheric limb in the UV (250-400 nm), VIS (400-800 nm) and NIR (800-1800 nm) with a spectral resolution better than 10 nm for VIS and NIR and better than 2.5 nm for UV. A distinct spectral tuneable filter element will perform observations in each of these three wavelength ranges, being an acousto-optic tuneable filter (AOTF) in the VIS and NIR and a setup of cascading Fabry-Perot interferometers in
the UV. In combination with the platform pointing agility, observations of the bright limb in forward, backward and sideward looking configurations are possible on the bright side of the Earth, as well as solar occultations, providing very high signal-to-noise ratio observations, and stellar/planet/Moon occultations in the dark side. Launched into a Sun-synchronous orbit (< 800 km altitude) with an equator crossing node at the local time 10:00-10:30, this enables observations of the limb to an altitude of 100 km with high vertical resolution (considerably better than 1 to 2 km, up to 0.5 km in VIS) and dense spatial sampling (200 km along-track sampling). Flexibility provided by the payload and platform operations allow for global and regional observations of ozone vertical profiles as well as observations of profiles of several other atmospheric species relevant for ozone chemistry and climate studies.

2. Programmatic rationale and objectives

The main mission objective of ALTIUS is the monitoring of the 3-D distribution and evolution of stratospheric ozone at high vertical resolution in support of operational services and for long term trend monitoring. Compliance with the “minimum mission” as defined by the OPEROZ study will be the target. For the lower and middle stratosphere a vertical resolution of 1 to 2 km, and a horizontal resolution better than 200 km is required and slightly relaxed resolution for the upper stratosphere. A targeted 3-day repeat cycle ensures coarse daily global sampling and denser sampling every 3 days.

A number of secondary mission objectives are also foreseen, even if the targeted performances need to be consolidated by a more detailed appraisal of the performance of the selected instrument technology and retrieval algorithms. Expected to be included are a selection of specific mission extensions defined by the OPEROZ study such as mission extension into the mesosphere, measurements of concentration profiles of other species such as NO$_2$, H$_2$O, CH$_4$ as well as of aerosol extinction profiles. Furthermore, the flexibility of the ALTIUS instrument combined with the agility of the spacecraft enable the use of ALTIUS for a number of scientific observations relevant for the understanding of observed ozone evolutions, atmospheric chemistry and climate change, as well as the use of ALTIUS in campaigns related to explosive volcanic events and inter-validation with other atmospheric missions.

In order to ensure achievement of primary and secondary objectives, the aim of the ALTIUS development is the implementation of a versatile, multimode flight segment in combination with a ground segment offering flexible mission planning capabilities, systematic and timely production, archiving and dissemination of Level 2 products for the primary objective complemented with a flexible ground segment processing and product delivery infrastructure in support of the secondary objectives.

3. Programme content and implementation approach

This Programme Proposal covers phases B2/C/D of:

- the development, manufacturing testing and calibration of the ALTIUS space segment up to and including demonstration of flight readiness at the Flight Acceptance Review (FAR),
- the development, implementation, preparation and acceptance of the ALTIUS Ground Segment, consisting of the flight operations centre (FOS) in charge of the satellite TT&C and located in Redu (Belgium), the Payload Data Ground Segment (PDGS) in charge of generation of the mission planning, in line with established mission planning rules (as discussed below), and acquisition stations (through the procurement of relevant services from Data Ground Receiving
Station(s) possibly in Northern latitude such as Kiruna, Svalbard, etc... still to be selected in line with the mission needs), up to and including the Ground Segment Acceptance Review (GS AR).

- The confirmation and verification of the end-to-end mission performance, including development of required simulators.
- The identification of launcher opportunities, selection of target launcher and management of the launcher interface to the level needed to ensure compatibility of the ALTIUS space segment with the target launcher.

In view of the need for a short development time in order to minimise interruptions in limb measurements of ozone at the beginning of the next decade and in order to limit the cost of the mission, a design based on selected core instrument technologies (AOTF, Fabry-Perot, detector) and core platform technologies is proposed. Spacecraft elements (such as Fabry-Perot interferometer, instrument electronics, platform equipment, satellite structure etc.), and ground segment elements can be proposed by participating states and will be incorporated in the design early in the project, pending confirmation of compatibility with the core technologies and overall spacecraft concept. The development of the space segment will continue as fast as possible, capitalizing on pre-developments already completed and some still to be initiated outside the scope of the current proposal, namely in GSTP and/or PRODEX. The detailed capabilities of the technology will be established early in the project, during phase B2. In parallel, a detailed definition of the mission and ground segment will be established, exploiting in the best way the capabilities of the flexible flight segment, in order to meet the needs of the users and consolidate the detailed mission objectives. As a result, the proposed programme structure and plans for the ground segment presented below shall be considered at this stage as less mature than the space segment plans and will be consolidated during phase B2 of the project.

4. Rationale for an Earth Watch approach and link with other EO programmes

The overall objective of the Earth Watch programme is to secure an independent sustainable European capability in operational Earth Observation.

Limb observations of ozone, providing detailed stratospheric profile information at high vertical resolution are a valuable addition to ozone total column in data assimilation systems based on nadir sounders used by operational centres. In addition, instruments capable of delivering high-resolution ozone profiles are of high importance for the atmospheric modelling community, especially for climate models lacking chemistry modules as well as for validation purposes and performance increase of chemistry-based climate models. However, limb measurement became rare with the failure of the ENVISAT mission in 2012 and will further decrease when several Canadian and US limb missions will end at the end of this decade.

The ALTIUS programme element will reduce the gap in high-resolution limb observation data of ozone, in support of operational services and for long term trend monitoring. ALTIUS data has the potential to contribute to the GCOS (Global Climate Observing System) ozone profile ECV (Essential Climate Variable).

In addition, off-line ALTIUS products are relevant for the validation of the CAMS model, for instance as a potential element of the quarterly validation of CAMS. ALTIUS measurements can be complementary to Sentinel-4, Sentinel-5 and 5P missions, having the potential to help validate and improve tropospheric ozone, tropospheric NO₂ and tropospheric methane columns from these nadir sounders.