Earth Explorer 7 Candidate Mission PREMIER: Addendum to the Report for Mission Selection
APPROVAL

Title  EE7 Candidate Mission PREMIER - Delta Report

Issue  1  Revision 1

Author  See Report for Mission Selection  Date  17/01/2013

Approved by

M. Drinkwater (EOP-SM)  18/1/13
P. Silvestrin (EOP-SF)    18/1/13
P. Bensi (EOP-SF)        18/1/13

CHANGE LOG

<table>
<thead>
<tr>
<th>Reason for change</th>
<th>Issue</th>
<th>Revision</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revision 1 including final corrections and addition of Exec. Summary</td>
<td>1</td>
<td>1</td>
<td>17/1/13</td>
</tr>
</tbody>
</table>

CHANGE RECORD

<table>
<thead>
<tr>
<th>Issue 1</th>
<th>Revision 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reason for change</td>
<td>Date</td>
</tr>
<tr>
<td>D/EOP request for addition of Executive Summary</td>
<td>17/1/13</td>
</tr>
</tbody>
</table>
Table of contents:

EXECUTIVE SUMMARY ........................................................................................................ 4

1 INTRODUCTION ............................................................................................................... 6

2 BACKGROUND AND SCIENTIFIC JUSTIFICATION ...................................................... 6

3 RESEARCH OBJECTIVES ............................................................................................. 9

4 OBSERVATIONAL REQUIREMENTS ............................................................................. 9

5 SYSTEM CONCEPT ........................................................................................................ 9

6 SCIENTIFIC DATA PROCESSING AND VALIDATION CONCEPT ........................... 19

7 PERFORMANCE ESTIMATION ...................................................................................... 19

8 MISSION CONTEXT ......................................................................................................... 28

9 PROGRAMMATICS ......................................................................................................... 28

10 REFERENCES ................................................................................................................ 32
EXECUTIVE SUMMARY

This report summarises the results of the activities performed in the context of the extension to the preparatory activities at Phase A level for the PREMIER mission, which have been completed since the publication of the PREMIER Report for Mission Selection (RfMS) (ESA SP-1324/3, May 2012).

The findings are presented as an Addendum to the respective sections of the Report for Mission Selection and are numbered identically for allowing the reader to cross-reference the text to the relevant parts of the Report.

The activities performed for the PREMIER mission produced the following main results:

- Confirmation of the importance and urgency of the PREMIER science objectives as highlighted in newly published scientific studies;
- Detailed error analysis for the retrieval of IR extinction coefficient profiles in atmospheric windows, proving that cirrus and aerosols information will be derived with sufficient accuracy to meet the objectives of the mission;
- Definition of several independent procedures (in-flight calibration or retrieval) to increase the determination accuracy of key instrument parameters, leading to improved error budgets of vertical profiles retrieval;
- Demonstration of the unprecedented horizontal and vertical resolution of the observation technique and of its capability to observe e.g. small scale filamentary trace gas structures with limited (500 m) vertical extent from the results of the ESSenCe campaign where the GLORIA airborne prototype of the PREMIER IRLS was flown;
- Demonstration of the capability to provide important constraints on the vertical distribution of Ozone in the troposphere and the stratosphere via simultaneous assimilation of limb and nadir Ozone data from concurrent satellite instruments;
- Technical consolidation of the STEAMR instrument design and subsequent optimization of the satellite configuration allowing to increase the clearance with the launcher fairing;
- Consolidation of different elements of the IRLS design depending on the concept (mechanical/thermal architecture, front optics, cryostat, pointing mirror);
- Progress on technology pre-developments relevant to the IRLS instrument to demonstrate the maturity of key technologies (pointing mirror, front telescope, interferometer) prior to the start of the implementation phases;
- Start of the IRLS breadboard development to reduce the development risks and consolidate the instrument performance assessment;
- Consolidation of an option for the IRLS detectors based on the re-use of MTG detectors with the aim of reducing the development schedule and cost, subject to the acceptability of the reduced instrument performance;
- Execution of environmental test on selected STEAMR components/sub-assemblies to remove concerns about the space qualification.

The intent of this Addendum to the Report is to provide ESAC and the User Consultation Meeting participants with an overview of the key findings from the Phase A extension in preparation of the User Consultation Meeting deliberations and the subsequent ESAC’s recommendation for the selection of the 7th Earth Explorer mission.
1 INTRODUCTION

The PREMIER Report for Mission Selection (RfMS) published in June 2012 (ESA 2012) provides detailed information on the scientific, technical and programmatic outcome of the PREMIER Phase A activities. The time between the deadline for the Report and the User Consultation Meeting scheduled for March 2013 has been used for an extension of the Phase A, including the system level activities, the Swedish studies on STEAMR, the end-to-end performance simulator, and some of the scientific studies performed during Phase A. Also, the IRLS breadboard activities have started.

This addendum to the Report summarises the most significant results obtained during the extension phase. Section numbers refer to the sections in the original report affected by the new findings.

2 BACKGROUND AND SCIENTIFIC JUSTIFICATION

Since publication of the RfMS, new scientific studies have been published that highlight the importance and urgency of the PREMIER science objectives. A prime example is the study of Jiang et al (2012), which demonstrates that current understanding of processes in the Upper Troposphere and Lower Stratosphere (UTLS) severely limits state-of-the-art climate models participating in the CMIP5 (Coupled Model Intercomparison Project) in support of the IPCC 5th assessment (to be published in 2013). The overall performance of the climate models was evaluated against a combination of A-train satellite observations at different altitudes in the troposphere (Figure 1).

![Figure 1. Colour-coded summary of performance scores, running from 0-1, based on the individual model scores at 100, 215, 600, and 900 hPa for H2O, ice water content (IWC) and liquid water content (LWC) against A-train satellite observations. M: spatial mean performance scores; V: spatial variance performance scores; C: spatial correlation performance scores. Water vapour and ice cloud parameters in the upper troposphere, i.e. at the 100 and 215 hPa levels, show the largest spread among state-of-the-art climate models and the largest differences from A-Train satellite observations (figure based on Jiang et al., 2012, courtesy of J. Jiang).](image-url)
The poor scores (red colours) at the 100 and 215 hPa levels underline the need to improve understanding of processes governing water vapour and cirrus in the UTLS region, and also reflect the insufficient spatial resolution of many state-of-the-art climate models in the UTLS region.

With respect to PREMIER Science Objective A (impact of UTLS processes on surface climate), Ravishankara (2012) restates the need for more accurate measurements and fuller understanding of water vapour transport mechanisms in the lower stratosphere because of the importance of (stratospheric) water vapour in modulating surface climate. The study by McLandress et al. (2012) demonstrates the importance of potentially missing gravity wave drag for the break-up of the southern hemisphere polar vortex in spring, which continues to be inaccurately parameterized in climate models, with consequences for Southern Ocean heat and carbon uptake.

Riese et al. (2012) report that uncertainties in small-scale mixing of water vapour and ozone in the UTLS (Objective B, quantification of stratosphere-troposphere exchange) have significant effects on the simulated radiation budget of the atmosphere. The results of their study reinforce the importance of a quantitative model representation of physical and chemical processes influencing UTLS greenhouse gases with steep spatial gradients, a prerequisite for obtaining improved climate projections. Glatthor et al. (2012) have further documented the impact of the strong pyroconvective uplift on UTLS composition (Objective C). Gerber et al. (2012) review the advances in weather and climate research that demonstrate the role of the UTLS region impacting the lower troposphere across a wide range of temporal and spatial scales (Objective D, links to lower tropospheric pollution). Finally, Miyazaki et al. (2012) have performed an in-depth analysis of the mutual benefit of combining present-day MLS limb observations of O₃ and HNO₃ together with those from nadir sounders of CO, O₃ and NO₂ in a chemical data assimilation framework. This study reinforces the potential of combining PREMIER limb measurements with temporally and spatially co-located MetOp/MetOp-SG nadir observations.

2.3 Chemistry-Climate Interactions

2.3.4 Processes Linking the UTLS to the Lower Troposphere

The synergistic assimilation of limb-profile ozone data together with tropospheric information on ozone (provided by IASI), as discussed in the RfMS (p. 28 and 29), has also been investigated further. Complementing the example shown on Figure 2.10 (p. 28) against an ozonesonde, there is strong evidence confirming that the simultaneous assimilation of both types of instrument data provides important constraints on the vertical distribution of ozone in both the troposphere and stratosphere. This new result is illustrated on Figure 2. The joint assimilation of IASI (nadir) and MLS (limb) data in the Météo-France Chemistry-Transport Model results in very realistic total ozone columns as measured against the independent reference provided by the OMI instrument, while correcting for most of the shortcomings of the free-running model and providing important information on the ozone profile as well as the total column. It is attractive to assimilate jointly instruments that have very different sensitivities in the vertical, since this allows the important issue of inter-instrument bias to be overcome (fully in this example). The addition of PREMIER to the Global Observing System for atmospheric composition would be of great benefit by providing detailed profile information in the UTLS and stratosphere, complementing the nadir instruments that are expected to fly at the same time (see in particular section 8.3 of the RfMS).
Figure 2. Average total ozone columns over Europe for July 2009 from Météo-France free-running Chemistry-Transport Model (left), from the analyses obtained by simultaneous assimilation of tropospheric ozone data from IASI and of MLS ozone profiles (middle) and as observed independently by OMI. Figure courtesy of J. Barre and V.-H. Peuch.

2.4 Improving Medium-range to Seasonal Meteorological Forecasts

The Observing System Simulation Experiments (OSSEs) performed at Environment Canada (see RfMS p. 31 and Figure 2.11 p. 30) have been further exploited to provide quantitative insight into the capability of both PREMIER instruments, MWLS (=STEAMR) and IRLS, to reduce short-term forecast errors of specific humidity and ozone in the Canadian operational NWP system. Their capabilities are compared with the current MLS instrument on Aura, which provides a more robust answer than the absolute values. Zonally-averaged results for July 2005 are shown as latitude-pressure cross-sections on Figure 3. The top row displays 6-hour forecast errors for water vapour. While MWLS, IRLS and MLS exhibit similar improvements in terms of the spatial pattern of error reduction in the lower troposphere and mid- to upper stratosphere, both PREMIER instruments have significantly improved skill in reducing the magnitude of the errors in the UTLS with the best performance at mid-latitudes. IRLS presents the best results overall, with errors in this altitude range being 2 to 3 times smaller than those estimated for MLS. The results for ozone are presented on the bottom row of Figure 3. While similar improvements in the UTLS are obtained for both PREMIER instruments compared to the Aura MLS reference, the IRLS also shows a significantly increased skill in reducing errors in the troposphere at southern (winter) high latitudes. These results confirm the strong impact that PREMIER instruments will have on NWP and Atmospheric Composition applications, leading to substantial improvements in this field compared to current limb-sounding instruments.
RESEARCH OBJECTIVES
(unchanged)

OBSERVATIONAL REQUIREMENTS
(unchanged)

SYSTEM CONCEPT

5.4 Space segment
5.4.1 Overview
The main improvement of the system concept consists of the STEAMR envelope optimisation as a result of the reconfiguration of its primary and secondary reflectors. This update has led to an increase of the complete PREMIER satellite clearance with respect to the dynamic envelope of the Vega fairing. Other relevant updates are the replacement of the original pointing mirror of the IRLS Concept B by a simpler and more performing one and the optics and cryostat optimisation in Concept A. The solar array and Solar Array Drive Mechanism (SADM) have also been revisited in both concepts together with a more detailed analysis of EMC and safe mode scenarios.

5.4.2 Satellite configuration
Figure 4 shows the updates in the sunshield and payload module to accommodate the optimised STEAMR. The basic system configuration remains unchanged, but the minimum margins with respect to the Vega
envelope have increased from 2 cm to about 5 cm for both concepts. Further optimization is considered possible in later phases.

**Figure 4.** Sunshield and payload module updates in Concept A (left) and Concept B (right).

### 5.4.3 Payload

#### 5.4.3.3 IRLS

#### 5.4.3.3.1 IRLS Overview

The size of the IRLS in Concept A has increased as a result of the optimisation of the optics and the cryostat. Nevertheless, the instrument still fits with sufficient margins in the available envelope, as shown in Figure 5 (left). The total mass has marginally increased by 1 kg, while power consumption and data rate production remained constant.

**Figure 5.** Maximum envelope allocated to IRLS Concept A and instrument fitting inside after optimisation (left). IRLS Concept B including the new pointing mirror (right)

#### 5.4.3.3.3 Instrument subsystems

**Mechanical and thermal architecture**

Concept B has undergone a detailed thermal analysis that provides further evidence of the robustness of the baseline thermal design. The worst-case temperature of the blackbody is 241 K, in line with requirements. The worst-case thermal stability of any optical element is 0.13 K, well within the allocations made to meet the radiometric requirements. Figure 5 (right) shows a CAD model of the IRLS with the radiators on top and the new scan mechanism implemented.
**Entrance aperture and pointing mirror**

Figure 6 (left) shows the updated design of the pointing mirror in Concept B, which has evolved from a two-axis gimbal mechanism to a single-axis one. It implements a bigger mirror requiring a larger entrance aperture, which imposes a deployable sun cap to prevent sunlight contamination inside the instrument (see Figure 6 right). Straylight, although increased by about 66% in the new design, is still within acceptable levels. The total mass of the pointing mirror remains almost constant since the increase of mass of the bigger mirror is compensated by the use of a single motor. The pointing accuracy is improved by one order of magnitude and its complexity is largely reduced. A new patent on the kinematics of this concept has been registered.

![Figure 6. Concept B new pointing mirror concept (left) and the sun cap once deployed (in red) at the IRLS entrance aperture (right)](image)

**Front optics and camera system**

The optical design of Concept A has been updated using inputs from the on-going pre-developments. As a result, the clearance between the optics (front and back) and the interferometer and the cryostat is larger, leading to an improved performance in terms of MTF, wavefront error and ghosting. The new design has led to an increase in the size of the instrument in the Y-direction as shown in Figure 5 (left), which is compatible with the available envelope.

**Back optics and cryostat**

The distance between the imaging optics and the detectors inside the cryostat has increased in Concept A. This has required an update of the mechanical layout of the cold optical bench, which has resulted in a small enlargement and broadening of the cold optical bench. These updates are compatible with the current design. The heat load of the cryostat has not changed significantly.

5.4.3.4. STEAMR

5.4.3.4.3 Instrument subsystem description

**Mechanical and thermal architecture**

The size and shape of STEAMR has been optimized to increase the margins with respect to the Vega fairing. Figure 7 shows a side (left) and a top (right) view of the updated design and compares it with the previous STEAMR envelope. The size has decreased in the Y direction by a maximum of 13.2 cm as a result of the
decrease in distance between the primary (M1) and the secondary (M2) reflector. The internal optical design (from M3 to M7) remains unchanged, whereas the M1-M2 supporting structures have been shortened keeping the original design and the back side of the STEAMR outer structure has been rounded. The three attachment points between STEAMR and the platform remain unchanged, together with the complete hexapod support structure to minimize the impact in the mechanical behavior. The mass of STEAMR has decreased by about 0.7 kg.

![Figure 7](image)

**Figure 7:** Side (left) and top (right) view of the STEAMR instrument after the size reduction. The top view also shows the old contour (dashed line) of the outer structure behind the primary mirror and the instrument box. The two original corners have been rounded to better fit the shape of the Vega envelope allowing a size reduction in the Y-axis between 13.2 cm and 9.4 cm.

**Optical design**

The modification of the STEAMR antenna optics consists of the shortening of the M1 to M2 inter-mirror propagation distance while maintaining the effective focal length (EFL). The resultant updates were generated with optimization routines implemented in the optics design tool ZEMAX. Figure 8 presents a graphical comparison of the M1 and M2 mirror combinations for the previous design (brown) and new design (green). The distance between reflectors M1 and M2 along the optical axis chief ray has been shortened by 8.4 cm and the curvature of the M1 and M2 has been updated. The modified design shows low sensitivity to alignment errors between the primary and the secondary mirrors.
**Front-end electronics**

Work on the integration and test of a demonstration receiver array with four complete RF chains from horn to the autocorrelation spectrometer output is progressing as planned. Initial results confirm the present baseline design. The demonstrator is modular in order to simplify the design and testing, and is fully representative of the STEAMR design.

**Figure 8:** Comparison of STEAMR M1 and M2 reflectors from previous design (brown) and the new design (green).

**Figure 9:** One completed frontend with, on the left side, the horn mounted on the mixer. The local oscillator input at 14 GHz is at the right. In between, the active six-times multiplier and frequency doubler.

The measured sensitivity is shown in Figure 10, which is compliant to the requirement at room temperature.

The doubler design was optimised for low output power and shows very similar performance for all four breadboards. Figure 10 (right) shows the output power of a completed local oscillator chain with varying bias.
**Figure 10:** Double sideband receiver noise (K) as function of the intermediate frequency (GHz) with 1.2 $mW$ local oscillator power (left). The output power at the input to the mixer and from the multiplier is on the left hand axis. Multiplier efficiency is shown on the right hand. Optimum LO power to the mixer is around 1.2 $mW$ (right).

**Calibration**

A calibration system for radiometric tests of the demonstrator was developed, as shown in figure 11 (left). It consists of a load selector mirror with control electronics and three external loads; one ambient, one hot, and one LN2 (not shown). In the figure, one complete frontend connected to the IF-unit power and power splitter to feed the upper and lower frequency band autocorrelation sections can also be seen.

**Figure 11:** Lab test setup with warm and ambient calibration sources of ALMA design. In the front is one frontend connected to the four-band IF unit followed by power splitter and the completed four-band autocorrelation spectrometer (left). DM control board, connected to a PC and to the test set-up (right).

**IF and back-end electronics**

The outputs from the integrated low noise amplifiers are further amplified in a dedicated IF unit before bringing the signals to the back-end spectrometers. One such integrated four-channel device is shown in Figure 12 (left).

Figure 5.32 in the RfS shows a block diagram of the basic building block autocorrelation spectrometer for receiver channels. This is part of the demonstration receiver built, currently undergoing testing and shown in Figure 12 (right).
Figure 12: Integrated IF amplifier unit (left). One half frequency band autocorrelation spectrometer with four inputs from the left followed by filtering and IQ-converters, the HIFAS autocorrelation chips and further processing (right).

Control system
A first iteration of the instrument controller was built. A board for motor control and thermal control, shown in Figure 11 (right), is used in the current test set-up. At this stage, the overall control functionality is built in a PC, but the real-time functions, such as controlling the chopper and start / stop of integration cycles, are carried out with this board.

5.4.4 Platform
5.4.4.3 Mechanisms
As shown in Figure 13 (left), the SADM of Concept A has been moved from the bottom floor of the platform to one of the side panels to mitigate the impact of shocks. Nevertheless, they are still slightly higher than the specification and either a shock damper has to be placed at the SADM interface with the platform or specific qualification programme has to be planned during the development phase.

5.4.4.8 Electrical power generation and energy storage.
The Concept A reused the EarthCARE solar panels, however a change in its design has made them unsuited for PREMIER. Figure 13 (right) shows the updated solar array design in Concept A. It consists of four panels of $1.81 \times 1.425 \text{ m}^2$, instead of the original three, using triple-junction Gallium-Arsenide cells with Beginning of Life (BOL) efficiency of 28%. The new design is based on the next generation of solar array (NGSA) developed in the frame of the NEOSAT telecom satellite. It is a hybrid solar array concept consisting of a rigid backbone of two panels in combination with lightweight lateral panels. Figure 13 (centre) shows the new solar array deployment sequence.

A detailed FEM analysis has been performed on the solar array of Concept B to assess its impact on the satellite pointing performance, the impact is low and allows to meet the required performance.
5.4.4.10 Attitude and Orbit Control System (AOCS)
Several Monte-Carlo simulations on worst-case scenarios have been performed for both concepts to further guarantee that the STEAMR secondary reflector is not illuminated by the sun for more than 35 s during the transition to safe mode. Figure 14 shows the results of a simulation of a Safe Mode entry due to an OBC failure after launch separation. In all cases the sun illumination on the secondary reflector lasts less than 16 s and therefore the specification is met.

Figure 14. Results of a Monte-Carlo simulation with 1000 runs for a case of transition to safe mode.

5.4.4.11 Radio frequency and electromagnetic compatibility
A detailed EMC analysis, using the Phase-A configuration, has been performed to assess the electric field created by the X-band and S-band antennas at the focal plane of STEAMR. Figure 15 shows the results for the X-band antenna (left) and S-band antenna (right). The conclusions are that the X- and S-band antennas create a maximum field of 0.25 V/m and 0.55 V/m respectively at the STEAMR focal plane, which satisfies the 1 V/m specification.
5.4.5 Budgets

Table 1 shows the updated mass budget. The wet mass in Concept B has increased by 7 kg as a result of the updates in solar array, IRLS and STEAMR. The wet mass of Concept A has decreased by 38 kg as a result of the update of the platform mass maximizing the reuse of existing AstroTerra equipment (i.e. SPOT 6), the redesign of the solar array, an update in the harness mass, the results of a more detailed FEM at satellite level including the sunshield and the update of the propellant mass.

<table>
<thead>
<tr>
<th></th>
<th>Concept A</th>
<th></th>
<th>Concept B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase-A</td>
<td>Extension</td>
<td>Phase-A</td>
<td>Extension</td>
</tr>
<tr>
<td>Dry Mass Total</td>
<td>894</td>
<td>848</td>
<td>844</td>
<td>848</td>
</tr>
<tr>
<td>System margin</td>
<td>134</td>
<td>127</td>
<td>127</td>
<td>127</td>
</tr>
<tr>
<td>Dry Mass</td>
<td>1028</td>
<td>975</td>
<td>971</td>
<td>975</td>
</tr>
<tr>
<td>Propellant</td>
<td>97</td>
<td>112</td>
<td>84</td>
<td>87</td>
</tr>
<tr>
<td>Wet Mass</td>
<td>1125</td>
<td>1087</td>
<td>1055</td>
<td>1062</td>
</tr>
<tr>
<td>Launcher performance</td>
<td>1240</td>
<td>1240</td>
<td>1240</td>
<td>1240</td>
</tr>
<tr>
<td>Launcher adapter</td>
<td>88</td>
<td>88</td>
<td>76</td>
<td>76</td>
</tr>
<tr>
<td>Launch margin</td>
<td>27</td>
<td>65</td>
<td>109</td>
<td>102</td>
</tr>
</tbody>
</table>

Table 1. Mass budgets for concepts A and B [kg]

5.5. Launcher

The minimum clearance of both concepts with respect to the Vega fairing has increased from 2 cm to about 5 cm as a result of the optimization of STEAMR. Figure 16 shows the accommodation and clearance of Concepts A and B in the Vega fairing.
Figure 16. Accommodation of PREMIER in Vega after optimization of STEAMR size and shape. Concept A (left) and Concept B (right).

Vega is the baseline launcher and PSLV the back up launcher. During the extension of Phase-A an exercise has also been made to verify the compatibility of PREMIER with a dual launch with Soyuz, considering that the orbital parameters and the launcher flexibility may be suitable for a range of co-passengers. Figures 17 and 18 show Concepts A and B respectively in the available envelope of Soyuz in a dual launch configuration. The Concept A platform has to be modified to fit in the lower module (left) but is marginally compatible with the upper module (right). The Concept B is fully compatible with the upper module without any change in the configuration and marginally compatible with the lower module. For the latter an adaptation of the solar arrays size should be performed. Overall it is considered that both concepts, possibly with minor updates, would be suited for a dual launch with Soyuz, should a co-passenger satellite be identified.

Figure 17. Accommodation of Concept A in the lower (left) and upper (right) Sylda module of Soyuz
6 SCIENTIFIC DATA PROCESSING AND VALIDATION CONCEPT

(unchanged)

7 PERFORMANCE ESTIMATION

7.2 L1b performance
There are no significant changes in the IRLS performance besides the improvement on the PSF knowledge. Regarding STEAMR, the updated optical design shows no major difference in performance.

7.2.3 IRLS
7.2.3.2.2 Spatial resolution and PSF
The PSF has been modeled based on the variation of the positions of the optical elements according to the expected alignment tolerances. It was found that the PSF knowledge, based on modeling only, is better than required outside +/- FWHM, but partially compliant inside. As a consequence, an on-ground calibration of the PSF is still foreseen to guarantee the required knowledge accuracy.

7.2.4 STEAMR
7.2.4.3 Antenna performance
The results of a Gaussian beam mode and ray tracing analysis show that the updated M1-M2 reflector arrangement has maintained the imaging capabilities of the STEAMR antenna optics. The motivation of this...
rearangement was to decrease the size of STEAMR to increase the clearance of PREMIER with respect to the dynamic envelope under the fairing of Vega. Comparison of Gaussian beam parameters and pointing of the individual beams at the focal plane show extremely minor differences. A more accurate representation of performance of the updated optical design was performed through a full physical optics (PO) modeling of the system, using GRASP. The results of these PO simulations show relatively good agreement between the concept reported in the RIMS and the updated one.

### 7.2.6 End-to-End Simulator Description and Results

The End-to-End performance Simulator (E2ES) detailed verification up to Level 1b for the IRLS has been concluded while the Level 2 one is still on-going. The E2ES is designed to assess the impact at Level 1b and 2 of instrumental parameters and errors. It is also able to assess the fulfillment of certain requirements and model the complete instrument baseline design.

The following Figures show three examples of performance simulations at Level 1b. The first simulation addresses the impact of changes in the focal length on the Instrument Line Shape. The following graph shows a spectrum in DM, for which the nominal focal length has been changed by ±25 and ±50 µm.

![Figure 19. Spectrum (upper graph) simulated for dynamics mode at the centre FoV and the corresponding changes as generated by focal length changes (lower graph).](image)

Figure 19 shows that the instrument line shape is affected by change in focal length however the effect is limited to variations of less than 1 nW / cm² sr cm⁻¹. The effect is small and could be compensated by a phase shift calibration.

The second simulation addresses the effect of cross talk at Level 1b. The cross-talk is a driving requirement, which demands a certain image quality and PSF shape. The effect of cross-talk can be tested by applying it to a spectrum to show the spectral effects. Figure 20 shows the ideal spectrum and the comparison to the spectrum perturbed with goal and threshold cross talk values. The differences are in the order of a few nW / cm² sr cm⁻¹, which is comparable to the noise. Once the Level 2 simulations are verified, the simulator can be used for further studies on the effect of instrument errors on the Level 2 performance.

The third simulation shows the impact of micro-vibrations at Level 1b. Figure 21 shows the spectrum variations generated by LOS perturbation at three different altitudes (i.e. 62.3 km, 12.8 km and 9.2 km). The
LOS perturbation is considered in this test as the only instrumental error and is generated in form of a time series, as already reported in the RfMS in Chapter 7.2.6. The first spectrum at 62.3 km has almost no radiation content. Despite of that, there is a noise floor of about 0.3 nW / cm² sr cm⁻¹. It can be seen that the LOS perturbation generates a random error for all spectra at all altitudes with a magnitude decreasing with the altitude but in a range which is below 1 nW / cm² sr cm⁻¹ as is here the case for the spectrum at 9.2 km. The perturbation generates also a background at the lower altitudes, which is significant only at altitudes below 12 km in the case considered, where the radiance spectra are generated for the atmosphere at mid-latitude in summer. Once the complete verification campaign is finished, the E2ES will be able identify critical frequencies and simulate the effect of measured perturbations on the Level 2 performance.

Figure 20. Spectrum in CM and the corresponding difference spectrum generated by the instrument cross-talk (blue line: threshold values, red line: goal values).
7.3.2 Estimated Errors on Retrieved Profiles

A quantitative assessment of PREMIER’s performance was presented in the RfMS (Chapter 7), based on retrieval simulations for representative atmospheric profiles and error estimates consistent with L1b requirements (Chapter 4). This assessment has now been consolidated through extension to the CORSA study (Kerridge et al. 2013) in two respects: firstly, performance estimates have been added for extinction coefficient profiles and, secondly, further attention has been given to L1b requirements of significance to estimated retrieval accuracies (Figures 7.19 and 7.20).

Performance estimates for aerosol IR extinction profiles

A detailed error analysis for retrieval of extinction coefficient profiles in atmospheric windows has now been performed on the same basis as for temperature and trace gas profiles. Figure 22 presents the breakdown of error components and their root-sum squared totals for the dynamics mode at three example wavenumbers (833, 942 and 1207 cm\(^{-1}\)). Target requirements are seen to be met in these atmospheric windows. Information on cirrus and aerosol will be derived with sufficient accuracy to address PREMIER’s scientific objectives.
Performance estimates for temperature and trace gases

In the case of the infrared limb sounder (IRLS), several independent procedures (in-flight calibration or retrieval) have been devised to determine key instrumental parameters (pointing offset between spectral bands, pixel-to-pixel variations in array vertical spacing, FOV shape, radiometric gain and offset, and instrument lineshape) with greater accuracy, with improvements to error budgets. In Figure 23, consolidated error budgets are presented for several examples for which this is significant.

Figure 22. Error budgets for retrieval of extinction coefficient profiles in dynamics mode in three atmospheric windows, 833 cm\(^{-1}\) (left), 942 cm\(^{-1}\) (centre) and 1207 cm\(^{-1}\) (right). Full and dashed red lines are L2 target and threshold requirements, respectively. Spectral dependence of extinction coefficient will also provide information to derive cirrus particle size and aerosol composition. Figure courtesy of A. Dudhia.

Figure 23. Consolidated error budgets for IR retrieval of individual mid-latitude profiles of temperature (left), \(\text{H}_2\text{O}\) (centre) in dynamics mode and \(\text{CH}_4\) in chemistry mode (right). These may be compared with original estimates in Figure 7.19 (a) and (b) of the RfMS). Full and dashed red lines are L2 target and threshold requirements, respectively. Figure courtesy of A. Dudhia.
In the case of the mm-wave limb sounder (STEAMR), performance has now been estimated for the same mid latitude profiles as for IRLS, with antenna patterns calculated for a more compact instrument configuration (see Section 5.4.3.4.3), with updated information on L1b performance and considering in-flight calibration or retrieval procedures to determine more accurately several instrumental parameters (knowledge of spectral baseline, side-band responses, linearity and receiver-to-receiver variations in vertical spacing). In Figure 24, consolidated error budgets are presented for water vapour and ozone, examples for which the consolidation is significant.

**Figure 24.** Consolidated error budgets for mm-wave retrieval of mid-latitude profiles of \( \text{H}_2\text{O} \) (left) and \( \text{O}_3 \) (right). For \( \text{H}_2\text{O} \), these may be compared with original estimates for tropical profiles in Figure 7.20(a) of the RfMS. Full and dashed red lines are L2 target and threshold requirements, respectively. Figure courtesy of J. Urban, A. Dudhia.

L2 threshold requirements are now met by STEAMR for the representative mid-latitude profiles of \( \text{H}_2\text{O} \) and \( \text{O}_3 \) down to 12km and also for \( \text{HNO}_3 \), \( \text{CO} \) and \( \text{HCN} \) (not shown here).

### 7.4 Scientific Impact

#### 7.4.2 Stratosphere-Troposphere Trace Gas Exchange (Objective B)

In this section of the RfMS, results of an airborne campaign using the IR limb-sounder CRISTA-NF and the mm-wave limb-sounder MARSCHALS had been reported. Another campaign (ESSenCe) flying the new GLORIA limb-imaging FTIR had taken place just before publication of the Report. The data of this new campaign have now been analysed and are presented here.

**First field campaigns utilizing the IRLS prototype GLORIA**

The Gimballed Limb Radiance Imager of the Atmosphere (GLORIA) is a newly developed airborne prototype of the PREMIER IRLS. This is realised by combining a classical Fourier transform spectrometer (FTS) with a 2-D detector array tailored to the FTS needs. GLORIA is designed to operate on various high altitude research platforms (aircraft and stratospheric balloons). The instrument is a joint development of the Helmholtz Large Research Facilities Karlsruhe Institute of Technology (KIT) and Research Centre Jülich.
GLORIA builds upon the heritage of KIT and FZJ in developing and operating IR limb sounders (CRISTA, MIPAS).

The GLORIA spectrometer (Figure 25) consists of a classical Michelson interferometer combined with an infrared camera. Essential features of the instrument are a spectral range (currently) extending from 780 cm\(^{-1}\) to 1400 cm\(^{-1}\) with high spectral resolution and instantaneous altitude coverage from 4 km up to flight altitude with an extremely high spatial sampling of typically 100 m in the vertical domain. To ensure accurate scene acquisition and stabilisation the spectrometer is mounted in a gimballed frame that permits 3-axes-agility (with respect to elevation, azimuth and image rotation). Scene acquisition and scene stabilisation in the gimballed frame are accomplished by a control system based on an inertial measurement unit. Like the PREMIER IRLS, GLORIA is operated in a high-spectral and medium-spatial resolution ('chemistry') mode and a medium-spectral high-spatial resolution ('dynamics') mode. In the latter, the line of sight is panned from about 45° to 135° with respect to the airplane flight direction. Measurement time for one image (one interferometer sweep) is 2.8 s. Individual images contain 128x48 pixels (spectra).

GLORIA has been flown for the first time in December 2011 on board the Russian M55-Geophysica research aircraft (see Figure 26, ceiling altitude of ~20 km) from Kiruna/Sweden during the ESA Sounder Campaign (ESSenCe). In spite of very harsh conditions during this first deployment of this complex instrument, GLORIA was able to collect useful data in both nominal modes. The full chain of data processing from the raw data to scientific products has proven the power of the instrument concept. The trace gas retrieval is performed on a filtered and averaged 128x1 pixel grid. This yields a typical vertical resolution of trace gas fields of 300-500 m. The horizontal extent of the averaged pixel rows is about 7.5 km at 10 km tangent height. The horizontal sweep of the dynamics mode (45° to 135° with respect to flight direction) provides a horizontal coverage of 300 km at 10 km tangent height, sampled by 15 tangent points. Thus, a very good correspondence with the PREMIER IRLS dynamics mode horizontal sampling pattern is obtained. Figure 27 illustrates cloud observations of an individual GLORIA image taken during the ESSenCe field campaign in December 2011. Cloud structures can be resolved at horizontal (across line of sight) and vertical scales of 150 m at 10 km tangent altitude (and even smaller scales at higher tangent heights).
Atmospheric fields of ozone, CFC-11, and HNO$_3$, measured in the dynamics mode, indicate a thin vertical structure at about 14 km extending about 500 m vertically (Figure 28). The excellent vertical resolution of GLORIA data is key to identify such structures. This filament is observed for a few minutes, only. It is most likely an intrusion of deeper stratospheric air, as indicated by relatively large ozone and HNO$_3$ values together with small CFC-11 values. The existence of the fine layer observed by GLORIA at ~14 km is corroborated by results obtained from a MARSCHALS ozone profile retrieval as well as a MIPAS-STR HNO$_3$ profile retrieval for altitude scans close to the GLORIA dynamics mode segment shown in Figure 28. In addition, the HNO$_3$ enhancement at ~14 km could be qualitatively reproduced by GEM-AQ simulations with very high horizontal and vertical spatial resolution.

In summary, the ESSenCe campaign demonstrated the technical readiness and advancement of the infrared limb-imaging technique. The horizontal and vertical resolution of GLORIA is unprecedented. The observation technique allowed observations of small scale filamentary trace gas structures extending about 500 m in altitude at unprecedented horizontal sampling.

In 2012, GLORIA was flown successfully in more than 120 flight hours on the new High Altitude and Long Range Research Aircraft (HALO). Qualification and certification flights with GLORIA - mounted in the bellypod underneath the fuselage of the HALO aircraft - were successfully undertaken in April 2012. In August and September 2012 GLORIA was an integral part of the extremely successful first large HALO atmospheric mission. The data base, which spans latitudes from 80°N to 65°S (Svalbard to Antarctica), forms a unique treasure which is being used to study a number of scientific questions related to PREMIER, such as outflow of biomass burning products from Africa to the Atlantic Ocean, filamentation at the edge of the Antarctic vortex, signals of pollution in air outflowing from Asia on the flight leg from the Maldives Islands to Cyprus, and validation of Chemistry Climate Models (CCMs). In the time period from 2013 to 2015, GLORIA will participate in three subsequent scientific HALO campaigns dedicated to UTLS science. In addition, a project proposal including an Asian Monsoon aircraft campaign (M55-Geophysica) was recently submitted to EC (FP7).

Figure 27. GLORIA direct current signal (arbitrary units) for the detector plane, before the Fourier transformation is applied. Exposure time is 40 ms and the horizontal extent is about 7.5 km at 10 km tangent altitude. High values are indicative for continuous emissions from clouds or aerosol layers. Note the very thin layer at 10 km altitude. Figure courtesy of T. Guggenmoser.
7.4.4 Processes Linking the Composition of UTLS and Lower Troposphere (Objective D)

7.4.4.1 Assessment of combined sensor performances in the lower troposphere

The co-flight of PREMIER with MetOp/MetOp-SG will enable operational retrieval products from the nadir-viewing spectrometers IASI/IASI-NG (IR) and GOME-2/Sentinel-5 (shortwave) in the lower troposphere to be improved by providing more accurate prior constraint of profiles above 6 km. The quantitative assessment of the combination of MetOp-SG with PREMIER presented in the RfMS has now been consolidated for lower tropospheric (0-6 km) CH₄, O₃ and NO₂.

The variability of methane 0-6 km column-average mixing ratio has been estimated from MACC-II and GEM-AQ analyses in the southeast Asian monsoon region, of particular interest to PREMIER. Adopting 100 ppbv (2-sigma) dynamic range in this region as prior uncertainty combination with PREMIER improves the retrieval uncertainty for MetOp-SG alone by about a factor of 2, which will benefit surface flux inversion. Similarly, for lower tropospheric ozone the retrieval precision will be improved by about a factor 2. The assessment of NO₂ has been consolidated by quantifying explicitly the reduction in uncertainty in 0-6 km column average mixing ratio expected from the addition of PREMIER observations in the range from 6 to 12 km (mid-latitude tropopause) as well as in the stratosphere. The addition of PREMIER information in the 6-12 km interval reduces the 0-6km column average uncertainty to ~0.1 ppbv, which thereby meets the 0.2 ppbv target requirement. This holds even when large a priori uncertainty of 2 ppbv is assumed in the 6-12 km layer, representing variability due to lightning production and convective uplift. By comparison, a
stratosphere-only NO₂ constraint from a model, even at the 1% level, still results in ~0.5 ppbv uncertainty on the 0-6 km column average NO₂.

The consolidated performance for lower tropospheric CH₄, O₃ and NO₂ confirms the value of PREMIER to reduce sensitivity to prior constraints used in retrievals, and to reduce significantly uncertainties estimated for MetOp-SG alone for these three operational products.

8 MISSION CONTEXT
(unchanged)

9 PROGRAMMATICS

9.2 Scientific maturity, critical areas and risks
Residual effects of uncertainties in radiometric, spectral and spatial calibration upon the retrieval have been investigated. Mitigation via in-flight calibration and refinements of the retrieval schemes led to significant reductions in total errors and much improved compliance to Level 2 requirements.

An airborne campaign was conducted with the newly developed limb-imaging FTIR instrument GLORIA. This campaign demonstrated the ability of the limb-emission sounding technique to detect very thin and horizontally limited atmospheric layers with modulated chemical composition.

Further evidence has been gathered for the need for UTLS composition data of high vertical and horizontal resolution.

The value of this type of measurements in data assimilation context, both research and operational applications, has been further demonstrated.

9.3 Technical maturity, critical areas and risks

9.3.2 Satellite and platform
The clearance of the satellite with respect to the dynamic envelope of Vega is still considered to require careful monitoring during the development phases, even if the risk has decreased due to the increase of the minimum clearance from 2 cm to 5 cm.

9.3.3 IRLS

9.3.3.1 Summary
In the RfMS, the IRLS is considered a complex and high-performance instrument. To reduce the risk on the integration and to verify critical requirements, two representative breadboards are under development. Procurement, integration and test will be finished by Q1 2014. The breadboards consist of an interferometer mechanism, a beamsplitter, a laser metrology system, front optics, camera or re-imaging system and a detection system. All items except the detection chain are representative in function and performance of the PREMIER IRLS configuration. The fulfillment of some of the driving requirements at Level 1b will be validated using the on-going IRLS breadboards (see Figure 29) in addition to the already performed analysis, modeling and simulation. Among others activities, the following will be performed on the breadboard once developed:

- Characterization of the interferometer performance by measurement of the field-dependent ILS in CM and DM
- Investigation of the influence of the interferometer lateral jitter on the ILS and compliance of 1D metrology with pseudo-noise requirements
- Investigation of the sensitivity to micro-vibrations
- Verification of the spectral calibration concept
- Measurement of the interferometer and instrument field dependent transmission
- Characterization of the instrument’s PSF knowledge and the comparison with its analytical model
- Verification of the WFE
- Verification of the straylight sensitivity
- Investigation of instrument stabilities (spectral, spatial, interferometer jitter as function of time)
- Verification of the emissivity / radiometric model

Figure 29. Breadboard design of Concept A (left) with telescope in blue, interferometer in green and detection device. Breadboard design of Concept B (right) includes source, control electronics, optics, interferometer, laser metrology and detection chain

9.3.3.2 Mechanical and thermal
In the RfMS, thermal stability and thermal design were identified, specifically for Concept B, as key to achieve the required radiometric and pointing performance. Results from a coupled thermal analysis of IRLS, STEAMR and the platform shows that the current design performance is better than the one estimated during Phase-A. Although particular attention is needed during the development phase, latest results prove the robustness of the PREMIER thermal concept.

9.3.3.3 Scan Mechanism/Pointing mirror
The scan mechanism in Concept B was considered to be on the critical path due to its inherent complexity (two axes of rotation) and possible accommodation issues. The on-going predevelopment activities have shown that a simpler and better performing scan mechanism, based on a single axis of rotation, is feasible and compatible with the available envelope. The estimated TRL of this new design is still 3–4, but it is not considered anymore to be on the critical path. A breadboarding activity is planned to take place after selection for implementation, which allows to be confident to reach TRL 5 at the end of Phase-B1.

9.3.3.5 Front optics
The development of a semi-monolithic front-telescope for Concept A is ongoing. A performance analysis of the wavefront error showed the compatibility of the manufacturing technology with the requirements, pending verification at breadboard level. In addition, a detailed structural analysis was carried out to verify the flight compatibility of the design. It was also shown that the telescope is lighter than originally estimated. The assessment of compliance of the surface quality at breadboard level is expected to be concluded in April 2013. It is expected to achieve TRL 5 by the end of Phase-B1.
Figure 30. Semi-monolithic front telescope design.

9.3.3.6 Interferometer
The verification of the performance and the adaptation of the IASI (Concept B) and GOSAT (Concept A) interferometers to the PREMIER operating characteristics are ongoing. As an intermediate result, for Concept B the control law of the IASI corner cube mechanism has been established and it has been shown by analysis and simulations that the interferometer can be control as required. This will be further verified at breadboard level by Q3 2013.

9.3.3.8 Back optics
The camera system of Concept A relies on the same technology as the front-telescope.

9.3.3.10 Cryocooler
A detailed analysis has been performed to assess the impact at system level of accommodating two fully redundant cryocoolers for both concepts. The results show that this is feasible in terms of accommodation, but implies an increase in mass, power consumption and thermal power evacuation that will deplete current system margins and put the design to its limits, while the assessed reliability of the instrument at 4.25 years will only increase from 0.884 to 0.902. This option is not retained and the baseline reported in the RfMS is confirmed.

9.3.3.11 Detector
The reuse of MTG detectors has been identified as a possible option to be considered during the detector selection activities foreseen to start during the phase B1. Such option will simplify and possibly shorten the development of the detector and be a more cost effective solution, but it will also decrease the performance of the IRLS, increase its mass and power requirements and force a redesign of the cryostat in Concept A. The scientific impact of the decrease in performance is still under assessment. As a consequence, the baseline reported in the RfS is maintained.

9.3.4 STEAMR
Status of the test on the STEAMR prototypes
A set of environmental tests are being conducted by Omnisys on the prototypes described in chapter 5 of this report to address the concerns on the space qualification of certain STEAMR key components. This is a first step towards a TRL5 demonstration using the existing demonstrator. It so far shows that the components can sustain a direct dose of radiation of 15 krad, three times what expected in orbit. Complementary vibration testing and thermal vacuum cycling will be performed shortly, with the components mounted in the updated design used by the Demonstration Model.
9.4 Development approach and schedule.
Unchanged.

9.5 Conclusion
The consolidated performance results at Level 2 provide confidence in the compliance to geophysical requirements. The data collected during the new airborne campaign demonstrate impressively the capabilities of the limb-sounding technique to resolve small scale structures in the UTLS.
At system level, the results of the Phase-A extension confirm the maturity and robustness of the design baseline. On-going work on technology pre-developments is progressing satisfactory, reducing the risks of the mission and increasing the confidence on their successful outcome at the end of B1. Overall, the results of the Phase-A extension confirm the performance, baseline design and feasibility of PREMIER according to what originally was reported in the RfMS.
REFERENCES


