LASER ALTIMETER

Executive summary

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1. INTRODUCTION

1.1 Scope

The present document has the goal of illustrating the activities performed in the frame of the "Laser Altimeter for Earth Observation and Planetary Exploration" study. Initial requirements evaluation, scenarios definition, trade offs for the scenario selection and related P/L architecture definition are briefly described.

1.2 Applicable and Reference Documents

The following documents are directly applicable to Laser Altimeter study and have provided guidelines for the definition of mission requirements and system design drivers.

[AD 1] User Requirements for Future Earth Observation Laser Altimeter Missions – Final Report, NOV-3899-NT-10841, Issue 1, 28/01/11

2. STUDY INPUTS

At kick off of this study, the user requirements have been provided by ESA. They have been developed by Noveltis in the frame of another study and not considered mandatory, i.e. modifications and corrections can be suggested if there are suitable justifications for this. The attempt is to "think out of the box" without imposing limitations related to the current technology, although in some cases improvements to existing applications will be sufficient to satisfy the requirement while in other cases innovation will be necessary.
A set of domains for altimetric measurements have been provided (cryosphere, land topography, ocean and biosphere) identifying possible applications (Figure 2-1).

-Cryosphere (from C1 to C11) • Monitoring of ice and snow • Sea ice • Land ice: ice sheets, ice shelves • Land: snow and ice over continents (glaciers, rivers)	- Land Topography (from L1 to L13) • Open ocean: ocean altimetry at fine spatial resolution • Coastal applications: coastal altimetry, sea level change, beach processes, windspeed • Biological parameters: chlorophyll, phytoplankton, marginal ice zone and polynyas in polar regions • Miscellaneous: extreme waves, ocean temperature, material detection at sea surface
- Ocean (from O1 to O14) • Digital terrain modelling: global or regional • Land surface parameterization: specific surface features (roughness, geomorphology, etc.) • Natural hazards: avalanche, rockfall	- Biosphere (from V1 to V7) • Forest monitoring: Forest structure Forest change (deforestation and regrowth) Forest productivity • CO2 monitoring: sequestration and stocks • Natural hazards (wildland fires)

Figure 2-1 : Applications for the four domains

Applications require measurement of products, directly or indirectly (e.g. surface elevation and roughness, vegetation indices, wind speed on oceans), by means of a lidar. Among the 63 products it is possible to identify 17 basic products (Figure 2-2) from which all the other can be derived, that are thus considered the drivers for the study.

Basic Products

Domain	Product	Description	Derivables	Observable
Cryosphere	CA	Surface elevation	CC	TOF
	CB	Surface rms roughness	-	WF
Ocean	OA	Sea surface height above reference ellipsoid	OH OJ	TOF
	OB	Sea surface roughness (from amplitude of surface reflection)	OD	CE-RC
	OC	Sea surface height distribution within footprint	-	WF
	OE	Chlorophyll concentration from fluorecence	-	LIF-RC
	OF	Turbidity (suspended particulates) within the water column	-	WF-RC
	OG	Height of sea bed relative to reference ellipsoid	OH	TOF
	OI	Green surface reflectance	OJ	WF-RC
Land Topography	LA	Global terrain model, featuring the elevation of the ground surface	LE LF LG LH LI LJ	TOF
	LB	Regional terrain model	LA LE LF LG LH	TOF
	LC	Waveform parametrization	LD	WF-RC
Biosphere	VA	Vegetation height	VB VC VE	WF
	VF	Fraction of Photosynthetically Absorbed Radiation (fPAR)	VC	CE-RC
	VG	Normalised Difference Vegetation Index (NDVI)	VD	CE-RC
	VH	Photochemical Reflectance Index (PRI)	-	CE-RC
	VL	Fluorescence	-	LIF-RC

Figure 2-2 : List of the 17 basic products

Often, 3 different requirement levels are given:

- **Threshold** is the minimum performance level;
- **Breakthrough** performance would give a significant delta impact on the targeted user service and would justify new instrument developments (used asreference in our study);
- **Objective** performance is level beyond which any improvement does not bring a clear advantage in a cost effective way.

3. MISSION REQUIREMENTS AND CONCEPTS

Preliminary review of existing lidar altimetry techniques, with reference to mission goals and requirements, has led to identify three main candidate options:

- Full waveform (FW) analogue detection lidar
- Single Photon Counting (SPC) detection lidar
- Pseudo-Random Noise (PRN) lidar with CW laser

The two former options are pulsed instruments. Their main difference is the detection technique. PRN performances have shown to be too influenced by the presence of atmosphere, thus this technique has been discarded for the continuation of the study.

3.1 Selected Scenarios

The first phase of the study has culminated with the presentation of a set of mission scenarios with different architecture and performances. The proposed missions have been intended as representative of missions' classes which can be successively tuned for more specific scientific targets, still to be defined at that time.

In the frame of the innovation content of the study, ESA has expressed particular attention in the study of vegetation height using the photon counting technique, because of its higher efficiency.

The selected baseline scenario is characterized by:

- Single platform

- Dual techniques / dual wavelengths approach
- Multi domains (but with at least one priority).

And the following scientific guidelines have been agreed:

Scenario A (Full coverage)

- Primary target: Vegetation Height with photon counting technique multi-beams at 532 nm
- Secondary target: Not given
- Reduction of inter-track distance and reduction of revisit frequency (e.g. 10 km and 132 days)

Scenario B (Monthly revisit)

- Primary target: as for scenario A
- Secondary target: Ocean dynamics
- Increment of revisit frequency and increment of inter-track distance (e.g. 30 days and 43 km)

It's important to stress the innovative content of the proposed approach, with the use of SPC for targets which are traditionally domain of FW.

Performances are assessed by means of dedicated performance models which simulate the signal emission by the transmitter, its propagation through atmosphere, its backscattering from the target (land, ocean, vegetation…) and its collection by the receiver. The return signal waveform is then processed to extract the measure.

Since measurement at water surface with SPC channel suffers reflection inefficiency at 532 nm, it is agreed the inclusion of a second altimeter channel Full Waveform at 1064 nm, single beam, which shall be mainly devoted to the new requirements for scenario B.

Enclosing both a Full Waveform altimeter and a Photon Counting altimeter with two different wavelengths on the same platform is challenging for spacecraft resources but it provides also interesting perspective in terms of synergy between the two instruments. This is can be interpreted in two ways:

- Measurements from one channel improves the other (e.g. cross-calibration, differential measurements)
- Measurements from one channel complete the other, addressing different observables and products: time of flight, waveform or intensity.

The option of an additional camera for stereo 3D imaging has been considered but not selected as the optical design for the requested resolution would be quite complex, large and massive.

3.2 The 800-nm option

It was already known that the vegetation reflectance at 532 nm, although located near a peak in the visible range, is considerably lower than what is achievable working in the NIR range, above 750 nm (Figure 3.2-1).

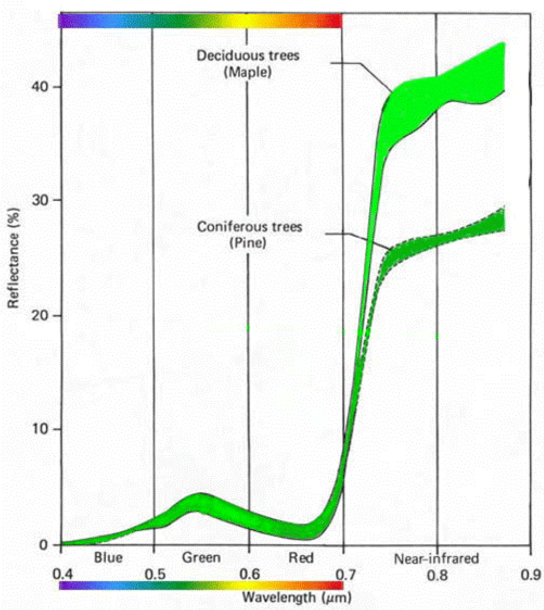

Figure 3.2-1 : Reflectance from deciduous and conifer trees

After a discussion, in December 2011, about the first promising results of a study carried on by Midaz and Hovemere about the Alexandrite laser (fundamental harmonic in the range 760 – 860 nm), it has been agreed that the wavelengths obtainable from alexandrite lasers are better suited for vegetation applications than those offered by Nd:YAG technology and that it was worthwhile to evaluate the possible performances with compared simulation runs. It is evident from simulations that return at 532 nm is not high enough to deliver enough information for the signal waveform reconstruction and more than 300 µJ are required to build count histograms comparable to 800 nm.

The Alexandrite study has shown that this laser has the potentialities to achieve the performances required for the laser altimeter. Therefore the functional analysis and the reference instrument design configuration presented in the following section have been defined according to this option. Anyway, backup solutions are considered and their impact evaluated:

- Source at 800 nm with Nd:YAG and OPO
- Source at 532-nm with Nd:YAG SHG (original baseline).

3.3 Science Requirements

The vegetation height requirements are summarized in the following table:

Product V-A (Priority) **Requirement**	**Vegetation height** **Value**
Latitude coverage	World / Tropical regions / Boreal regions (-70°/ 70°)
Inter-track spacing at equator	100 km / 10 km / 1 km
Along-track sampling (m)	1 km / 500 m / 100 m
Across-track coverage (width)	0 / 10 km / 30 km
Across-track sampling	1 / 5 / 10 samples
Footprint size	30 m / 20 m / 5 m

Revisit frequency	< 180 days (seasonal cycle would give an idea on phenology effects -e.g. leaf on vs. leaf off tree heights)
Typical range of observations	0 – 115 m
Accuracy	2 m / 1 m / 0.5 m
Precision	1 m / 0.5 m / 0.1 m
Vertical sampling (3D apps)	1 / 0.5 / 0.1 m
Vertical resolution (3D apps)	1 / 0.5 / 0.1 m
Geolocation	10% of footprint
Minimum mission lifetime	> 5 years (for change detection), 1 year for vegetation map

Table 3-1 Primary target (vegetation height) requirements

After a critical review of this requirement, the team considers geolocation requirement (corresponding to 1.4”/1.0”/0.2”) extremely severe. For comparison ICESat1 made use of a dedicated Stellar Reference System to achieve 1.5" of laser pointing knowledge. Instead, one-third of a footprint is considered sufficient for the mission purposes, thus relaxing the requirement to (corresponding to 4.7”/3.3”/0.7”), challenging but achievable.

The ocean height requirements are summarized in the following table

Product O-A (Priority) **Requirement**	**Sea Surface Height** **Value**
Latitude coverage	70°S - 70°N to cover most seas and oceans. Inclusion of polar seas desirable but not essential
Inter-track spacing at equator	Not critical
Along-track sampling (m)	100 m / 20 m / 10 m
Across-track coverage (width)	0 / 5 km / 10 km
Across-track sampling	1 / 5 / 20
Footprint size	100 m / 20 m / 5 m
Revisit frequency	10 - 35 days (preferred but not critical)
Typical range of observations	Ellipsoid +/- 50 m
Accuracy	0.05 m / 0.02 m / 0.01 m
Precision	0.02 m / 0.01 m / 0.005 m
Stability	0.05 m / 0.02 m / 0.01 m
Geolocation	Not critical
Minimum mission lifetime	3 years

Table 3-2 Secondary product (ocean height) requirements

The interest in high spatial resolution doesn’t justify the stringent requirements provided by scientists, suggesting that vertical height accuracies can be larger for such applications (e.g., 5-10 cm average over 1 km). Consider also that the requirement, as it is provided by Noveltis, would require orbit knowledge at sub-centimetre level, which is not realistic in the near future.

Also roughness measurement is addressed by the performance model.

The inter-track spacing at equator and the temporal revisit are not independent variables. Indeed, they are linked through the orbital dynamics: once the repeat cycle is fixed, the minimum distance at the equator between two adjacent ground tracks is fixed. 132 days of revisit frequency is compatible with seasonal cycles in order to identify phenology effects. It corresponds to 10 km of inter-track distance. When combined with 10 km track width, it allows achieving full coverage for scenario A with complete mapping within one year and detecting changes throughout the mission lifetime. The monthly revisit is required for the study of ocean dynamics in scenario B. The inter-track spacing at equator shall be consequently 43 km.

Across-track coverage and across-track sampling define the beam topology within each track. With multi-beams configuration, the altimeter shall cover the requested width with the requested number of samples. This is not applicable to the FW instrument for which a single beam has been agreed. The requested size corresponds to a FOV of 1.34º, which can already become challenging when combined with additional instrument constraints (e.g. compact design, fast mirrors and compression ratio for afocal configurations).

A graphical representation which correlates these requirements is in Figure 3.3-1. The four application domains are represented with four different colours: cryosphere (light blue), ocean (blue), vegetation (green) and land (brown). For each of them, the three levels of requirements (Threshold, Breakthrough and Objective) are plotted. Faded spots are used to include the parameters flexibility for different applications or scientific targets. The number of beams required by the sampling is identified with the gray bands. A shaded green box has been added to represent the region of the sampling/coverage space which is covered by a mission having breakthrough requirements for vegetation as primary target.

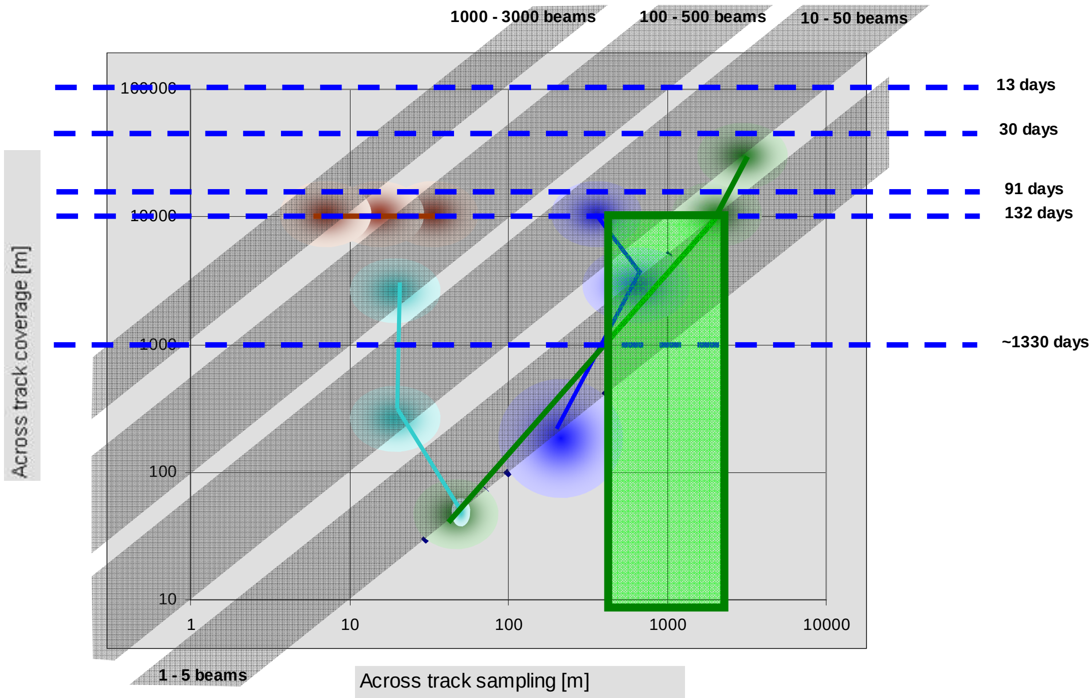

Figure 3.3-1 : Across-track and coverage requirements combined with revisit frequency (dotted blue lines) for full coverage

The highly sparse sampling required by the product V-A is not compatible with other products. Anyway, the same architecture can, with only some modifications, extend its domain to oceans and cryosphere by moving to a denser sampling, either by increasing the number of beams or by reducing the field of view, thus exploring the portion of the plot laying below and left of the vegetation target.

Horizontal resolution is the smallest area on ground that can produce a measurement. In this sense it usually corresponds to the footprint size of the laser beam. When the multi-kHz altimeter is concerned, this becomes the length on which all the fires shots can be summed. The actual laser spot is usually smaller. With this assumption, there's no immediate link between science requirement and system requirement, but it shall be the performance model to suggest possible combination of pulse energy, length, frequency and wavelength able to achieve the expected performance within the requested horizontal resolution.

The along-track sampling refers to the on ground spatial separation between two consecutive altitude measurements. For a Full Waveform altimeter this requirement imposes a limit to the minimum Pulse Repetition Frequency (PRF) of the laser. 20-m sampling requires a PRF of 360 Hz. Although not typical, this PRF with the requested power is achievable and has been demonstrated at even higher powers. In the multi kHz altimeter, the compliance with the horizontal resolution requirement is sufficient to assess the performance in terms of along track sampling. A 10 kHz PRF is deemed sufficient to build histograms compatible with measurement performances within the required horizontal resolution

3.4 Preliminary altimeter design

The preliminary design is based on functional analysis whose objective is to derive top level system (mission, platform and instrument) requirements (internal functions) from scientific requirements (external functions). For some functions derivation require some preliminary allocation between different contributors and must be consolidated. Performances are linked to the system functions in a complex manner through the results of simulation runs on the performance model. Thus the proposed laser pulse (energy, length) derive from a possible combination of laser and detection parameters which allows building a histogram, within the horizontal resolution length, containing a number of photon counts sufficient to allow the algorithm retrieving results in line with the expected accuracy.

The final selection of the wavelength (800 nm) has come after the results of the simulations for the specific scientific target. Simulations have been performed with 60 µJ pulses and 2 ns FWHM. Shorter pulses are possible but they have not been simulated (limited by memory allocation).

The use of a nearby Fraunhofer line has also been taken into consideration in order to further reduce the background contributions and avoid the use of etalons (a line at 800.116 nm has been individuated with ~20% reduction of background). Nevertheless the option has been rejected since analysis has shown that the line, a few tens of pm wide, contributes in negligible way to background reduction. Moreover, preliminary simulations at 800 nm have shown that the etalon filter could be removed without performance degradation.

Simulations on the FW channel have been performed with 30 mJ energy and 10 ns FWHM (but shorter pulses are possible)

Proposed energies are compatible with eye safety analysis

At receiver, the SPC channel shall include an ultra-narrow interference filter (FWHM < 160 GHz), while the high resolution filter (etalon) is not mandatory and the necessity in each case needs to be verified through specific target simulations.

The SPC receiver channel is equipped with SPAD array detector with QDE (Quantum Detective Efficiency) ≥ 30% and negligible dead time. Simulations have shown that good detection efficiency is much more effective than the higher noise. The spot size can be adjusted to cover several pixels of the array essentially equal to the angular size of the laser spot and thus no additional background is introduced. The other significant benefit is that the adjacent pixels which are not used provide margin for misalignment tolerance. This is an alternative to the classical architecture (e.g. ICESat-2) with optical fibres which gives flexibility in reconfiguring the geometry but reduces the tolerance on spot stability which can move the signal out from the fibre core thus requires frequent alignments.

The simulation of the FW channel are based on an APD detector with quantum efficiency ~40% (reference from Krainak M. et al, NASA Goddard Space Flight Center, MD, “Wide-Bandwidth Near-Infrared Avalanche Photodiode Photoreceiver”).

Timing resolution of 1 ns is used in the profile retrieval algorithm of both channels to asses performances.

The following picture shows the identified preliminary P/L architecture.

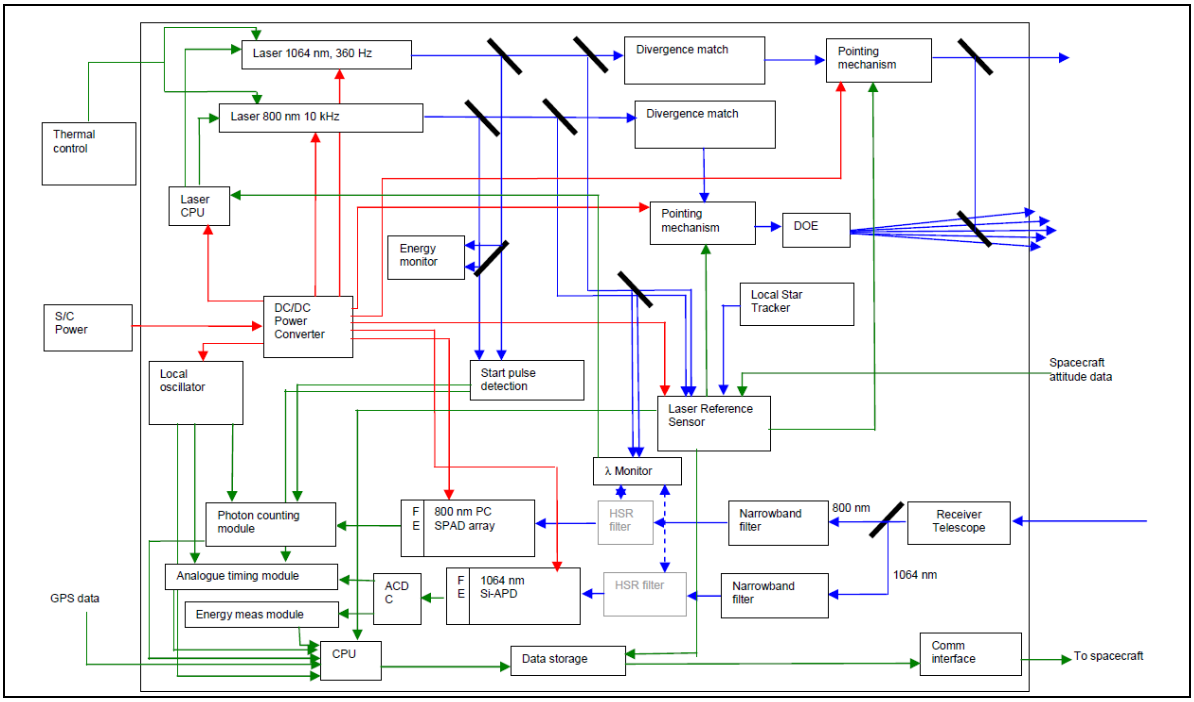

Figure 3-2 instrument physical architecture. Electrical signal (green), Power lines (red), Optical signal (blue)

The bistatic architecture is the recommended one.

The proposed configuration, which depends on the specific scientific target, is based on a focusing telescope (Figure 3.4-3) with long focal length (5 metres) with primary aperture of 1050 mm, providing acceptable quality without too stringent tolerances. The secondary obstruction reduces the equivalent diameter of the collecting area to 93 cm. The long focal length produces slow beams on the focal plane, spaced enough to allow separation of the beams through small optics (Figure 3.4-3). This solution is suitable in our application where vegetation requirements ask for sparse sampling (5-10 spots across 10 km FOV).

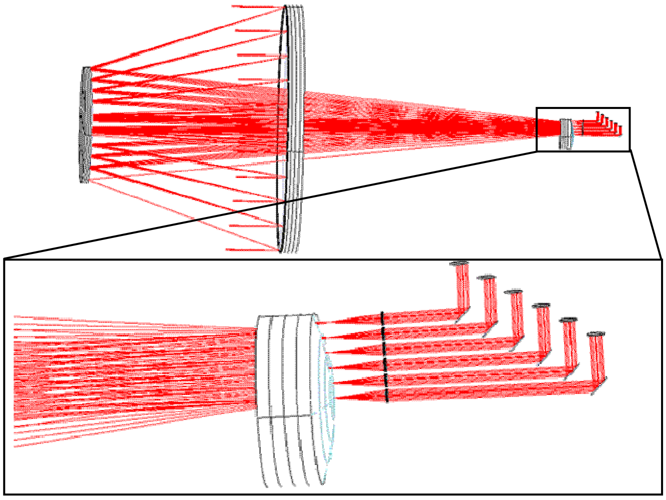

Figure 3.4-3 : Proposed principle for receiver architecture

The example simulated in Figure 3.4-3 is a two-dimensional sketch of the principle, with all the spots aligned. In practice the layout will be optimized if:

- the pattern of footprints is designed to maximise inter-distance within the 10-km FOV (Figure 3.4-4)
- the collimated beamlets are guided by small mirror/prism assembly also out of the plane (Figure 3.4-5)

Once they are collimated and the paths separated, they can be guided through the filtering and detection section. Filters can be manufactured in small size and work with a near-zero acceptance angle.

A dichroïc mirror is used to separate the 1064-nm beam from the central beamlet.

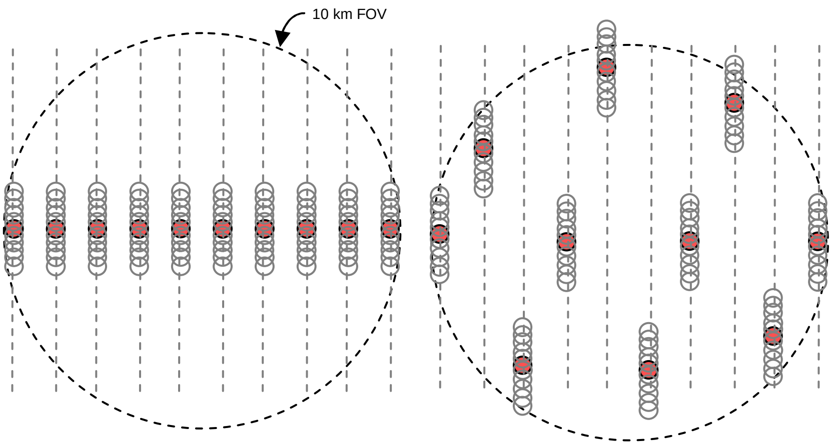

Figure 3.4-4 : 10 footprints aligned (left) or sparse (right) within the10-km FOV

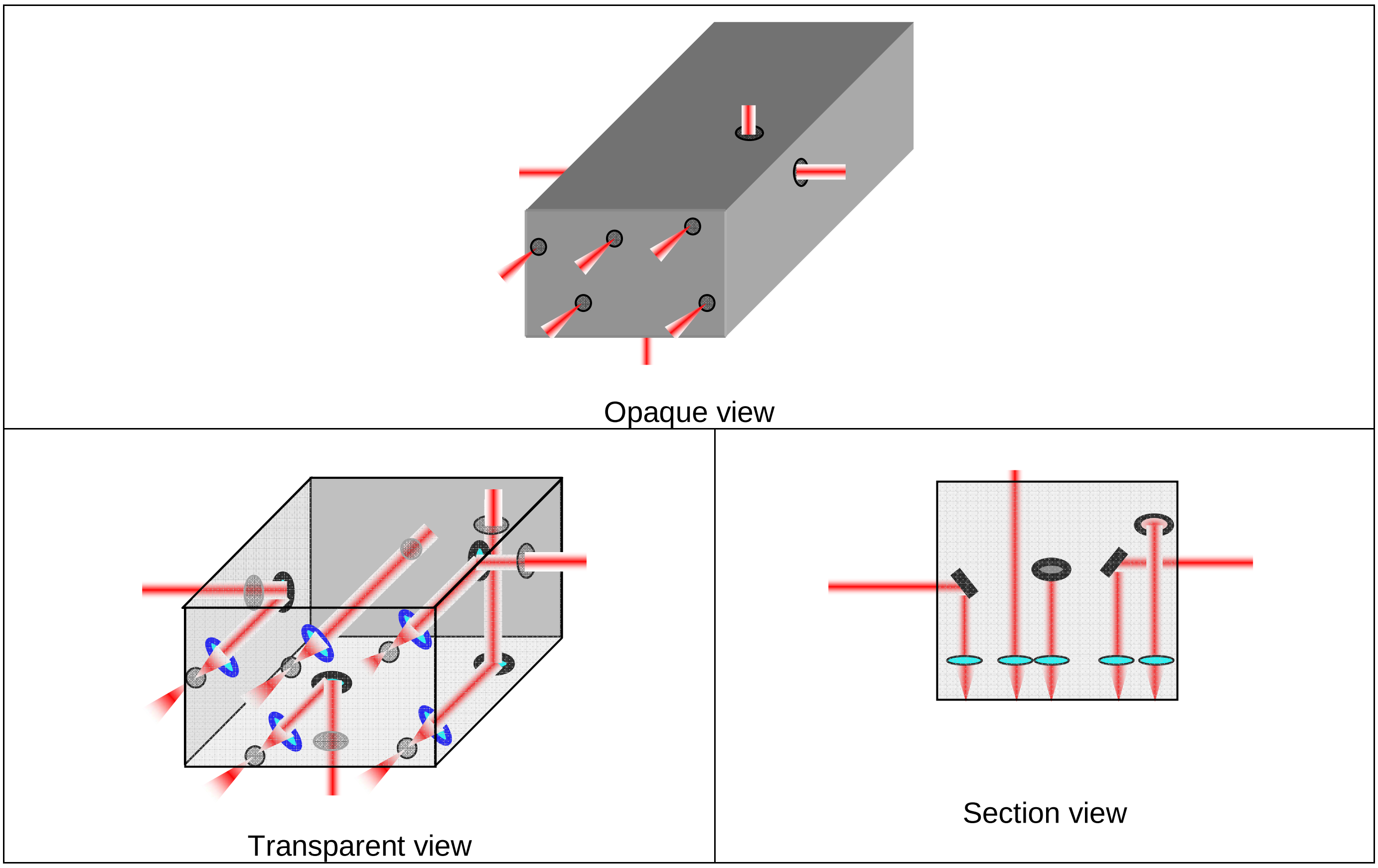

Figure 3.4-5 : Hypothesis of beamlets 3D layout

3.5 Budgets

The mass budget is based on a preliminary data available for sources and detectors.

	Qty	Unit mass [kg]	Mass [kg]
Laser source with electronics (FW)	1	80	80
Laser source with electronics (SPC)	1	80	80
Transmitter optical chain	2	5	10
Receiving telescope with baffle	1	20	20
Detection chain	6	6	36
Data Processing and Control Unit	1	15	15
Beam Pointing Monitor	1	15	15
Optical bench, Thermal H/W, harness and mounting interfaces	1	42	42
Total [kg]			298
Margin			20%
Total w margin [kg]			357.6

Table 3-3: Mass budget

A comparison of power budgets is presented for:

- Alexandrite laser
- Estimation of the future evolution of the Alexandrite laser

- 800-nm provided by a Nd:YAG + OPO system,
- The original baseline of the 532-nm provided by the second harmonic of a Nd:YAG source. Note that in this case, the energy-per-beam requirement is so high that multiple single-beam lasers would be required to perform multi-beams measurement, with an increment of the laser mass of a factor 5.

	Power [W]
with Alexandrite Laser	443.1
with the possible future evolution of Alexandrite Laser	365.1
with OPO source at 800 nm	533.1
with Nd:YAG 532 nm laser	762.8

Table 3-4: Comparison of the different power budgets

The following data rates are estimated:

Total data per second	24.832	Mbps
Total data per second (compressed)	9.9328	Mbps
Total data per day	858.19392	Gb
Mean ground contact time	427	s
N. of contacts per day	10	
Total contact time per day	4270	s
Mean accumulated data between downloads	85.819392	Gb
Mean required data rate capacity	0.200982183	Gbps
Maximum time without contacts	28500	s
Maximum accumulated data	283.0848	Gb
Maximum data rate to ground	0.662962061	Gbps

Table 3-5 overall data rate

The quantity of interest in mapping Earth surface, and whose requirement is explicitly set by science, is the knowledge of the laser spot location on the Earth's surface, or *geolocation* of the laser spot.

The geolocation measurement budget is reported in the following table.

Contributor	Error	Geolocation error
Altimeter Errors (modulus of vector l)	50 cm	< 1 mm
Payload Errors (orientation in the STRF of the vector l)	1.5"	3 m
Platform Errors (vector $\mathbf{\Delta}$)	0.5 cm	0.5 cm
AOCS Errors (M_{ECI_STRF})	1"	2 m
GNSS Errors (satellite position)	1 cm	1 cm
RSS		**3.6 m**
Requirement R-SCI-A-10		***10 m / 6.67 m / 1.67 m***

Table 3-6 geolocation measurement budget

In the reconstruction of the altitude of a given point of the Earth surface from a reference surface (like the WGS-84 reference ellipsoid) not only the instrument performance, but also the knowledge of the satellite position and attitude, hence the geolocation, play an important role.

An example of measurement budget is presented in the following (adapted from ICESat-1).

	Target: vegetation	Target: ocean
Error from TOF evaluation	50 cm	10 cm
Error knowledge correction time triggers	< 1 cm	< 1 cm
Measurement Reference Point distance from centre of mass	0.5 cm	0.5 cm
Errors from POD	1 cm	1 cm
Errors from PAD	5 cm	5 cm
Geolocation	< 1 cm	< 1 cm
Atmospheric delay correction	2 cm	2 cm
Other corrections (tides, atmospheric scattering, post-glacial rebound)	< 1 cm	< 1 cm
RSS Total	**50.3 cm**	**11.5 cm**

Table 3-7 Example of altimeter single shot error budget

3.6 Performances summary

3.6.1 Performances on Vegetation

Simulation cases have been defined by considering all the possible combinations of the following parameters:

- Tree type: coniferous or deciduous tree, with different reflectivity
- Tree density: 0.05 m^{-2} or 0.1 m^{-2}
- Tree DBH: 0.1 m or 0.3 m, a parameter linked to the tree size h, d and w (see next picture)

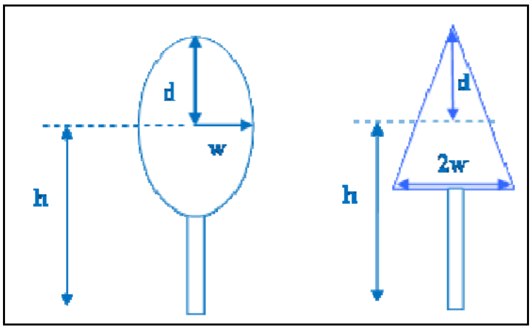

Figure 3-6 trees descriptive parameters

Performances are summarized in Table 3-8. Height estimate is the main output of the algorithm. The columns CRLB (= Cramer Rao Lower Bound) is the precision estimate.

Input parameters						Outputs			
Tree type	Tree density [1/m^2]	DBH [m]	h [m]	d [m]	w [m]	CRLB [m]	Height [m]	Empirical formula for height [m][4]	Difference
Conifer	0.05	0.1	7.75	4.31	2.42	1.15	9.67	9.91	0.24
Conifer	0.05	0.3	19.23	10.69	6	1.53	28.11	28.90	0.79
Deciduous	0.05	0.1	11.87	5.34	2.28	4.93	14.13	14.48	0.35
Deciduous	0.05	0.3	26.93	12.12	5.17	3.69	36.73	36.57	-0.16
Conifer	0.1	0.1	7.75	4.31	2.42	1.26	9.95	9.91	-0.04
Conifer	0.1	0.3	19.23	10.69	6	1.19	28.48	28.90	0.42
Deciduous	0.1	0.1	11.87	5.34	2.28	2.32	14.78	14.48	-0.30
Deciduous	0.1	0.3	26.93	12.12	5.17	2.8	37.01	36.57	-0.44

Table 3-8: Measurement performance for vegetation height

The following table reports a synthesis and a comparison with requirements:

	Required	SPC800	Statistics on Table 3-8
Height Accuracy	1 m	NA	0.79 m
Height Precision	0.5 m	4.93 m (CRLB)	0.41 m

Table 3-9 Synthesis of measurement performances for vegetation height

Simulations have also demonstrated that: the use of higher PRF (up to 20 kHz) doesn't bring advantages, if the average power is kept constant. It can even have a negative impact since it is required to open more gates for detection with the risk of increasing background noise (but not the signal).

3.6.2 Performance on Ocean

	Mission	Requirement	Comments
Revisit Frequency	30 days	35 days	OK
Inter-track spacing at equator	43 km	-	OK
Across-Track Coverage (only for SPC)	10 km	5 km	OK
Across Track Sampling (only for SPC)	2.5 km	1 km	Increase n. of beams
Horizontal Resolution (for FW)	20 m	20 m	OK
Along-Track Sampling	20 m	20 m	OK
Geolocation	3.6 m	-	OK

Table 3-10 Mission and measurement parameters for ocean products

The following parameters for ocean simulation have been used:

- Mean wind speed: 10 m/s

- Surface roughness: 1.6 m

	Required	FW1064	Comments	SPC800
Height Accuracy	0.02 m	0.13 m	Marginal according to §3.2	0.39 m
Height Precision	0.01 m	0.07 m		0.47 m
Roughness Accuracy	0.2 m	0.19 m	OK	NA
Roughness Precision	0.05 m	0.01 m	OK	NA

Table 3-11 Measurement performances for ocean products

3.6.3 Performance on Cryosphere

	Mission	Requirement	Comments
Revisit Frequency	30 days	30 days	OK
Inter-track spacing at equator	43 km	-	OK
Across-Track Coverage (only for SPC)	10 km	300 m	OK
Across Track Sampling (only for SPC)	2.5 km	20 m	No
Horizontal Resolution	20 m	20 m	OK
Along-Track Sampling	20 m	50 m	OK
Geolocation	3.6 m	3 m	OK w.r.t. threshold requirement

Table 3-12 Mission and measurement parameters for cryosphere products

Across track sampling is not adequate since the mission is sized on the vegetation target which requires very sparse sampling.

The performance on ice is superior to ICESat-1 Full Waveform instrument, but marginally non compliant with the user requirement.

	Required	SPC800	Comments
Height Accuracy	0.05 m	0.08 m	No
Height Precision	0.02 m	0.24 m	Too high
Roughness Accuracy	0.2 m	NA	
Roughness Precision	0.05 m	NA	

Table 3-13 Measurement performances for cryosphere products

The SPC performance model has been designed on the study of the vegetation height. Thus, a dedicated routine for the computation of the roughness is not included.

3.6.4 Performance on Land

	Mission	L-A	L-C	Comments
Revisit Frequency	132 days	-	1 year	OK
Inter-track spacing at equator	10 km	-	-	
Across-Track Coverage (only for SPC)	10 km	10 km	10 km	OK
Across Track Sampling (only for SPC)	2.5 km	30 m	10 m	No
Horizontal Resolution	20 m	20 m	10 m	DEM OK, regional model no
Along-Track Sampling	20 m	30 m	10 m	DEM OK, regional model no
Geolocation	3.6 m	3 to 4.5 m	1.5 m	DEM OK, regional model no

Table 3-14 Mission and measurement parameters for land applications products

	Required	SPC800	Comments	FW1064
Height Accuracy	0.05 m	0.06 m	No	0.07 m
Height Precision	0.02 m	0.15 m	No	0.04 m
Roughness Accuracy	0.2 m	NA		NA
Roughness Precision	0.05 m	NA		NA

Table 3-15 Measurement performances for land applications products

For comparison, the FW1064 channel achieves similar accuracy (with 10 times the resources!) but better precision. Consider anyway that the precision is evaluated by means of theoretical models rather than repeated measurements. Moreover, the histogram building-up depends on the Poisson statistic and it is intrinsically non-deterministic. This probably contributes to enlarge the statistic of the measurement process, especially for fainter signals.

4. CONCLUSIONS

The present document has illustrated the activities performed in the frame of the “Laser Altimeter for Earth Observation and Planetary Exploration” study. The scenario of interest is the dual technique mission multi-domain on a single platform, with highest priority product Vegetation Height (V-A) with photon counting technique; synergetic use of the FW technique at wavelengths where highest efficiency is expected; SPC channel with multiple beams, FW channel with single beam.

Two scenarios A and B, targeting full coverage and frequent revisit respectively led to the definition of preliminary instrument architecture and design (and related preliminary budgets). Largely innovative is the use of photon counting technique for the retrieval canopy height and the proposal to use the evolution of Alexandrite laser to achieve performance. Results are encouraging and the system performs also quite well in domains different from vegetation, for which the design has been optimized.

In all critical areas - detectors, lasers and electronics, European products and developments exist. These are presently driven by commercial markets or by existing research projects supported by a range of research institutions, and could be used as solid basis for future development projects supported by ESA.

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