Noveltis

User Requirements for Future Earth Observation Laser Altimeter Missions

Final Review

ESTEC Noordwijk, The Netherlands

January 21st 2011

Agenda

- 9:30 – 9:45 Welcome
- 9:45 – 10:45 Review of science requirements
- 10:45 – 11:00 Coffee Break
- 11:00 – 12:30 Review of L1B/instrumental requirements
- 12:30 – 13:00 Conclusions and perspectives
- 14:00 – 15:00 Contractual issues

- **User requirements for future Earth Observation Laser Altimeter Missions**
  - ✓ Express the needs of the scientific community in the frame of a future Laser Altimeter mission

- **The fields of expertise in the consortium**
  - ✓ Cryosphere
  - ✓ Ocean
  - ✓ Land Topography
  - ✓ Vegetation
  - ✓ LIDAR
  - ✓ Engineering and Project management

Noveltis team

- Stéphane Bourgogne (project manager)
- Quentin Chenevier
- Eric Jeansou
- Pascal Prunet
- Bernard Tournier
- Carsten Standfuss

Noveltis partners

- Kim Partington (Polar Imaging Limited)
- Ian S. Robinson, Colette Robertson (NOCS)
- Norbert Pfeifer (TU Wien)
- Felix Morsdorf, Michael Schaepman (Univ. Zurich)
- Patrick Vrancken, Gerhard Ehret (DLR)

Science task

- ✓ Define innovative applications
- ✓ Define Level-2 products
- ✓ Define user requirements for Level-2 products

Instrument task

- ✓ Convert the Level-2 requirements in terms of observables requirements (Level-1B requirements)
- ✓ Provide instrumental characteristics
- ✓ Provide one or two main instrument concepts

Feedback task

- ✓ Precisions and clarifications to industry

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- **General overview**
  - ✓ Overview of applications
  - ✓ Overview of products
  - ✓ Overview of requirements

- **Focus on:**
  - ✓ Priority applications
  - ✓ Priority products
  - ✓ Numerical results of the most constraining requirements

- **Steps: in the frame of a future LA mission**
  - ✓ Search for innovative scientific applications
  - ✓ Search for Level-2 products
  - ✓ Definition of user requirements for Level-2 products

- **Spirit of the task**
  - ✓ Start from the science needs. Wishes from users in the scientific community.
  - ✓ No restriction by existing technology. Thinking out of the box.
  - ✓ Be as open as possible and as complete as possible (innovation + improvements to existing applications)

Cryosphere

- ✓ Monitoring of ice and snow (mass balance, state, dynamics)
- ✓ Sea ice
- ✓ Land ice: ice sheets, ice shelf
- ✓ Land: snow and frozen water over continents (glaciers, rivers)

Ocean

- ✓ 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

Land Topography

- ✓ Digital terrain modelling: global or regional
- ✓ Land surface parameterization: specific surface features (roughness, geomorphology)
- ✓ Natural hazards: avalanche, rockfall

Vegetation

- Forest monitoring:
  - Structure
  - Change (deforestation and regrowth)
  - Productivity
- CO_2 monitoring: sequestration and stocks
- Natural hazards (wildland fires)

- **Common areas for cryosphere and ocean**
  - ✓ Polar seas
  - ✓ Coastal zones, limits between ice and water
  - ✓ Marginal Ice Zone (MIZ) and polynyas

- **Common background of the scientists**
  - ✓ Radar altimetry: over seas and polar regions

- **Common areas for land topography and vegetation**
  - ✓ Land cover
  - ✓ Objects heights

- **Common background of the scientists**
  - ✓ Airborne LIDAR

- **Several types of products**
  - ✓ Typical, and common to all application fields
  - ✓ Very specific to the application field

- **With a distinction between:**
  - ✓ Basic products (roots products)
  - ✓ Derivated products, coming simply from basic products
  - ✓ More elaborated products (even some L3 for completeness)

Common Level-2 products

- ✓ Surface elevation
- ✓ Surface roughness
- ✓ Surface height distribution

Specific products

- ✓ Cryosphere: flags ice/snow/water
- ✓ Ocean: wind speed, bathymetric depth, chlorophyll conentration
- ✓ Land Topography: slope maps, curvature maps
- ✓ Vegetation: LAI, fPAR, NDVI, PRI, AGB

Overview 2: Level-2 products

- **Basic products**
  - ✓ Surface elevation
  - ✓ Surface roughness

- **Derivated products**
  - ✓ Surface displacement, derived from surface height
  - ✓ Wind speed, derived from surface roughness
  - ✓ Curvature map, derived from terrain model

- **More elaborated products**
  - ✓ Above ground biomass: needs modelling of forest

Overview 3: Requirements

- **Level-2 products requirements**
  - ✓ Geophysical parameter is function of x, y (and possibly z for 3D applications). Parameter = f(x,y,z)

- **Requirements on x,y,z**
  - ✓ Sampling: along and across-track
  - ✓ Resolution: footprint size
  - ✓ Across-track coverage: swath width
  - ✓ Geolocation requirements

- **Requirements on the measured geophysical parameter**
  - ✓ Typical range of observations
  - ✓ Precision and accuracy
  - ✓ Stability

Overview 3: Requirements

- **Scientific requirements**
  - ✓ Region of interest / latitude coverage
  - ✓ Time of observation
  - ✓ Revisit frequency
  - ✓ Geophysical corrections
  - ✓ Mission lifetime

- **Additional comments**
  - ✓ User requirements: expected users, delivery requirements
  - ✓ Instrumental recommendations
  - ✓ Open part with free comments

- **Tables** with values for Threshold / Breakthrough / Objective
  - ✓ **Threshold:** minimum performance level useful for a particular application.
  - ✓ **Breakthrough:** performance would give a significant delta impact on the targeted user service and would justify new instrument developments.
  - ✓ **Objective:** performance is level beyond which any improvement does not bring a clear advantage in a cost effective way
- **Written comments** and scientific justifications

Overview 3: Requirements

3.2.2.3. Surface elevation requirements for marginal ice zone and polynya processes (C-4)

3.2.2.3.1 Table description

Product Ref and Title	C-A: surface elevation (sea ice)
Geophysical parameter (units)	Surface elevation (m)
Region of interest	Polar and sub-polar seas
Latitude coverage	> 60°N
Inter-track spacing at equator	Should be as dense spatial sampling as possible within the revisit frequency, taking into account across-track sampling
Along-track sampling (m)	100 / 50 / 10 m
Across-track coverage (width)	Footprint diameter / sufficient to provide 10% coverage at 70°N in revisit period / sufficient to provide no gaps in revisit period
Across-track sampling	1 / sufficient to provide 10% coverage at 70°N in revisit period / same as along-track sampling
Horizontal resolution (footprint size)	50 m / 25 m / 10 m
Revisit frequency	30 days / 10 days / 1 day
Time of observation	Depends on daily cloud statistics, preference local a.m.
Typical range of observations	0 (sea level) to 10 m a.s.l.
Accuracy	+/- 5 cm minimum
Precision	3 cm / 2 cm / 1 cm
Stability	Not critical
Geophysical corrections	Atmospheric (thin cloud, forward scattering,...); snow thickness and density (to convert freeboard to ice thickness)
Geolocation	< 15% of footprint (at least)
Additional comments	
Related applications	C-1, C-2, C-8 (latter in iceberg areas)
Expected users	Polar scientists, oceanographers, atmospheric scientists, biologists, operational interest if near real time
Delivery requirement	Near real time very useful operationally if spatial sampling is at breakthrough level.
Minimum mission lifetime	5 yrs / 7 yrs / 10 yrs+
Mission/orbit comments (optional)	No exact repeats needed because the ice is moving
Instrumental comments (optional)	Good dynamic range needed for specular returns from leads
Other comments / issues	Availability of coincident high resolution imagery very useful (for lead/ice discrimination and ice type assessment); snow thickness information essential.

3.2.2.3.2 Related applications

Related applications include O-9 (oceanography at high latitudes) and C-1. There may also be some overlap with requirements associated with C-8 (icebergs).

MIZ laser altimetry would be used in conjunction with SAR and other moderate to high resolution sensors.

3.2.2.3.3 Scientific justifications

Polynyas and the marginal ice zone are biologically rich areas (polynyas have been referred to as "polar oases"), but complex in their mix of meteorological, oceanographic, cryospheric and biological processes, and not very well understood. Laser altimetry offers a method to coincidently measure several key parameters and high spatial resolution which can be linked to additional observations such as SAR to help with observations from other sensors – in effect, to help tie together multiple sensor observations. Algorithms from several sensors tend to break down close to the ice edge. There are also strong operational interests in understanding and monitoring the marginal ice zone more successfully.

3.2.2.3.4 Written requirements

Product C-D: Additional requirement for surface type flag (sea ice / land ice / land / lead / open water / iceberg) with the same sampling as the primary product.

3.2.2.3.5 References

Comiso, J. and Drinkwater, M., 2007, in King, M., Parkinson, C., Partington, K. and Williams, R., 2007, "Our Changing Planet: the View from Space", pub. Cambridge University Press.

Kwok, R., G.F. Cunningham, H.J. Zwally, and D. Yi, 2006: ICESat over Arctic sea ice: Interpretation of altimetric and reflectivity profiles. J. Geophys. Res., 111, C06006.

Timothy Urban, Roberto Gutierrez, Bob Schutz, "Analysis of Icesat laser altimetry elevations over ocean surfaces: sea state and cloud effects", IGARSS 2008, pp.

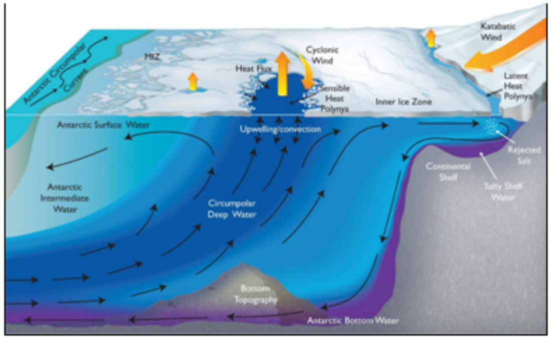

Figure 8: The marginal ice zone represents a complex interaction of oceanographic, sea ice and atmospheric processes. This schematic from Comiso and Drinkwater (2007) focuses on processes taking place in polynyas.

- General overview
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  - ✓ Overview of requirements

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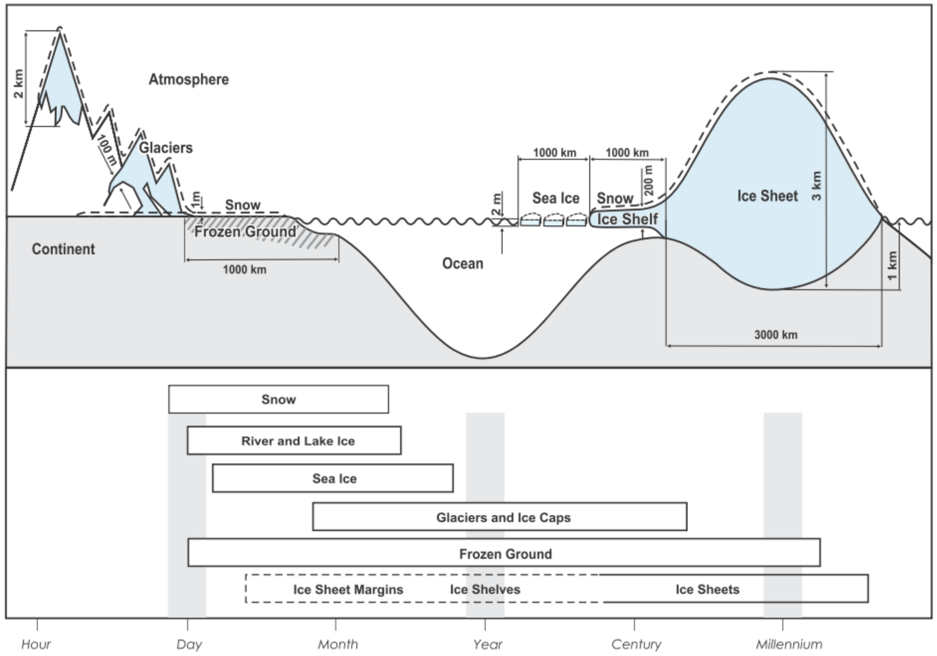
Priority applications : Cryosphere



- C-1 : Sea ice mass balance assessment
  - ✓ Hydrological cycle
  - ✓ Reducing ice cover
- C-4 Marginal ice zone and polynya process
  - ✓ Ocean Biology
  - ✓ Ocean & Atmosphere interaction
  - ✓ Operational interest
- C-5 Land ice mass balance and dynamics
  - ✓ Global see level change
  - ✓ Seasonal features, snow dynamics

Priority applications : Ocean

- **O-1 : Ocean Altimetry at fine spatial resolution**
  - ✓ With radar : data fusion and improvement of algorithms
  - ✓ Parameterisation of Air-Sea fluxes of gas and heat

- **O-4 : Transferring sea level between ocean and land**
  - ✓ Radar data not available
  - ✓ Comparison with high precision tide gauge data

Priority applications : Ocean

- **O-5 : Enhanced coastal altimetry**
  - ✓ Coastal hydrodynamics
- **O-9 : Ocean surface topography in Ice covered seas**
  - ✓ Ocean currents under the ice : constraining circulation models
- **O-13 : Extreme waves**
  - ✓ Monitoring strong currents
  - ✓ Better detection of isolated waves than radar

- **L-2 : Global DEM and GSDI** (Global Spatial Data Infrastructure)
  - ✓ Need global datasets for the GSDI
  - ✓ Intercalibration between national datasets.

- **L-8 : Surface roughness mapping**
  - ✓ Improvement of radar backscatter treatment
  - ✓ Geological age of landscape
  - ✓ Input for different models

Priority applications : Biosphere

- **V-1: Forest Structure**
  - ✓ Ecosystem processes
  - ✓ Indicator of biodiversity
  - ✓ Risk assessment :fire, wind-related damages

- **V-2: Forest productivity**
  - ✓ Dynamics of carbon uptake
  - ✓ Input for climate modelling

- **V-5: Deforestation, degradation and regrowth**
  - ✓ Global monitoring of deforestation

Level 2 products: priorities

- **Mostly basic products**
  - ✓ These products are the threshold

- **Type of data**
  - ✓ Elevation
    - Maximum
    - Gaussian fitting + centroid calculation
  - ✓ Waveform characteristics
    - Distribution
    - Amplitude

Most constraining requirements :

- ✓ Along-track sampling
- ✓ Across-track sampling (number of beams)
- ✓ Swath width (across-track coverage)
- ✓ Footprint (horizontal resolution)
- ✓ Accuracy, Precision, Stability
- ✓ Revisit frequency
- ✓ Minimum mission lifetime

Along-track sampling

- Smaller along-track sampling = better
- Vegetation requirements :
  - ✓ Used to have few data : only 2.5% of the vegetated surface covered by ICEsat.
  - ✓ Compliant requirements but to take with a grain of salt
- Others: harsher requirements

- **Threshold**
  - ✓ 50 m (topography)
- **Target**
  - ✓ 20 m (topography & ocean)

Across-track sampling

- **Different requirements for across-track sampling**
  - ✓ Number of beams : vegetation & oceanosphere
  - ✓ Geometry of a regular data grid (m) : topography & cryosphere
  - ✓ Enough to achieve coverage in revisit time (%) : cryosphere

- **Threshold**
  - ✓ 1 beam but 50 m grid achieved during mission lifetime
- **Target**
  - ✓ At least 5 beams
  - ✓ Grid : same as across-track (during mission lifetime)
  - ✓ 10 % coverage of cryosphere during revisit time

Swath width (across-track coverage)

- **Different requirements for swath width**
  - ✓ Enough to achieve coverage in revisit time and regular data grid (cryosphere & land topography)
  - ✓ Geometric (in km) : larger = better (ocean & vegetation)
- **Threshold**
  - ✓ No swath (ocean, vegetation, cryosphere
  - ✓ Regular grid : no gap between tracks (topography)
- **Target**
  - ✓ 10 km of width
  - ✓ Regular grid (during mission lifetime)
  - ✓ Enough to achieve 10% coverage of cryosphere in revisit time

Footprint (horizontal resolution)

- Smaller footprint = better
- Almost the same requirements in the four domains

- **Threshold**
  - ✓ 50 m
- **Target**
  - ✓ 20 m
- **Breakthrough**
  - ✓ 5 m

Accuracy, Precision, Stability

- Dependent of the geophysical parameter and the L2 product
- Influence on pulse width and temporal sampling
- Precision = Accuracy / 2

- **Accuracy for the simplest products (T/B/O)**
- Surface elevation for topography & Vegetation height distribution:
  - ✓ 1 m / 0.5 m / 0.1 m
- Surface elevation for oceanosphere & cryosphere (gaussian fitting & centroid retrieval) :
  - ✓ 5 cm / 2 cm / 1 cm

Revisit frequency, minimum mission lifetime

- **Many temporal scales to apprehend**

- Land Topography (practically : no temporal constraint)
  - ✓ ~5 year (mostly Not Critical)
  - ✓ 1 year (land cover change detection)

- Cryosphere, Vegetation, Ocean
  - ✓ Target: 30 days
  - ✓ Breakthrough: 5 days
  - ✓ Many revisit requirements not so harsh

- **Minimum mission lifetime :**
  - ✓ >3 years for vegetation , ~7 years (Ocean & Cryosphere)
  - ✓ « Until global coverage is reached » (Land topography)

Conclusion on Science task

- **Many products and applications**
  - ✓ 63 tables and 45 products
  - ✓ Scientific priorities defined by the science team

- **Transition towards the instrumental task**
  - ✓ Analysis of basic products and derived products
  - ✓ Instrumental requirements concern basic products
  - ✓ Grouping of products according to the detection method

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User requirements for future Earth Observation Laser Altimeter missions

Pt II: Level 1B requirements and instrumental recommendations

Final Review

January 21st 2001

ESTEC Noordwijk

Patrick Vrancken (DLR) for the Noveltis Consortium

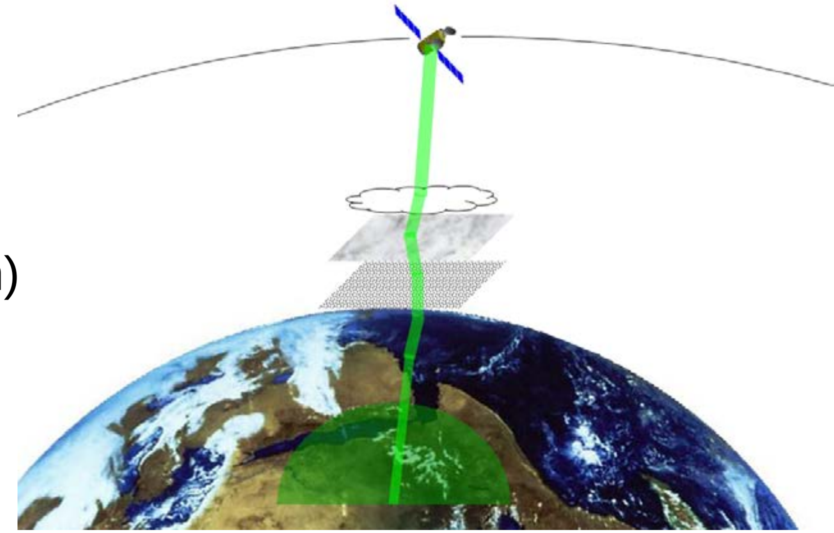
Synopsis

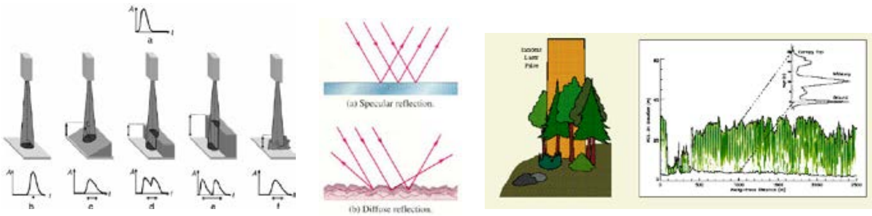
- Scope
- Summary of level 2 products / requirements
- Grouping of products/requirements w.r.t. detection method
- Implications on level 1b requirements
- Possible instrument concepts
- Recommendations

Scope of Part II of study

- “be very creative and absolutely free from considerations of existing technology!“ [dixit ESA]
- Only mission characteristic: Laser altimeter

- What characterises a laser altimeter:
  - ✓ Instrument:
    - ➢ Emitter
    - ➢ Receiver:
      Observables (envelope, frequency, polarisation, spatial power distribution)
  - ✓ Atmospheric channel
  - ✓ Ground interaction
    = subject of scientific interest
- Identify needed observables along with their characteristics (= Level 1b requirements)





Summary of Level 2 products

- Task: determine needed observables along with characteristics in order to derive Level 2 products defined by science groups
- Summary of 'basic' products
  - Cryosphere
    - C-A: Surface elevation (ice)
    - C-B: Surface rms roughness
  - Ocean
    - O-A: Sea surface height above reference ellipsoid
    - O-B: Sea surface roughness (from amplitude of surface reflection)
    - O-C: Sea surface height distribution within footprint ~ Ocean wave height
    - O-E: Chlorophyll concentration from fluorescence
    - O-F: Suspended particulates within the water column
    - O-G: Height of sea bed relative to reference ellipsoid
    - O-I: Green surface reflectance
  - Land Topography
    - L-A: Global terrain model, featuring the elevation of the ground surface
    - L-B: Regional terrain model, as L-A, but higher resolution than L-A
    - L-C: Waveform parameterization, showing radiometric properties and height distributions of surfaces within footprint
  - Biosphere
    - V-A: Vegetation height
    - V-F: Photosynthetically absorbed radiation (fPAR) (L2, only for multi-spectral)
    - V-G: Normalised difference vegetation index (NDVI) (L1c or L2, only for multi-spectral)
    - V-H: Photochemical reflectance index (PRI) (L2, only for multi-spectral)
    - V-L: Laser and sun induced Fluorescence

Grouping of products ↔ detection method

- Grouping of these identified ‘driver’ products in view of detection method, starting from ‘minimum’ observable (basically only laser pulse envelope)
  - ✓ **TOF**: Time-of-flight measurement
    - ➢ Rising edge of analogue signal, timing
    - ➢ Single-photon detection, timing
  - ✓ **CE-RC**: Contained energy with radiometric correction (lidar signal of atmosphere)
    - ➢ Integration of analogue signal
    - ➢ Photon counting
  - ✓ **WF / WF-RC**: Waveform w/o or with radiometric correction:
    - ➢ Fast sampling of analogue signal
    - ➢ (Photon counting)
  - ✓ **LIF-RC**: Laser induced fluorescence, similar to CE-RC but different wavelength
    - ➢ Photon counting

Grouping of products ↔ detection method

- Grouping:

Product	Along-track sampling			Swath width (m)			Across-track sampling			Footprint size (m)			Accuracy			Precision			Methods	Comments	Prio ?
CA Surface elevation (m)	170	50	10	footprint 10% cov.		no gap	1	10% cov.me as ald		50	20	5	0,05	0,05	0,05	0,03	0,02	0,01	TOF		X
OA Sea surface height (m)	100	20	10	0	5 km	10 km	1	5	20	100	20	5	0,05	0,02	0,01	0,02	0,01	0,005	TOF	λ IR	X
OG Height of sea bed (m)	100	20	5	100 m	2	10 km	1	5	20	100	20	5	0,1	0,05	0,02	0,1	0,05	0,02	TOF	λ blue/green	
OH Bathymetric depth below sea surface (m)	100	20	10	100 m	2	10 km	1	5	20	100	20	5	0,1	0,05	0,02	0,1	0,05	0,02	TOF	λ blue/green	
LA DEM Surface height above geoid (m)	50	30	15	no gap	betw	tracks	50m	30m	15m	30	20	10	1	0,5	0,1	1	0,5	0,1	TOF		X
LB Regional Terrain Model Surface Height (m)	20	10	5	no gap	betw	tracks	50m	10	5	10	5	3	1	0,5	0,1	1	0,25	0,05	TOF		
OB Sea surface roughness (dB)	100	20	5	0	5	10	1	5	20	100	20	5	NFS	NFS	NFS	NFS	NFS	NFS	CE - RC		X
OF Water Turbidity	100	20	5	0	2	10	1	5	20	100	20	5	NFS	NFS	NFS	NFS	NFS	NFS	CE - RC	λ blue/green	
OI Green surface reflectance (dB)	200	100	50	0	5	10	1	10	40	400	200	100	NFS	NFS	NFS	NFS	NFS	NFS	CE - RC	λ blue/green	
VD Leaf Area Index (m²/m²)	1 km	500 m	100 m	0	10	30 km	1	5	10	30	10	5 m	1	0,5	0,1	0,5	0,25	0,1	CE - RC		
VF fPar (%)	1 km	500 m	100 m	0	10	30 km	1	5	10	70	20	5	10%	5%	2%	5%	2%	1%	CE - RC	# of wavelengths?	
VH PRI	1 km	500 m	100 m	0	10	30 km	1	5	10	50	20	5	0,01	0,005	0,002	0,005	0,002	0,001	CE - RC		
CB Surface RMS roughness (m)	170	50	10	footprint 10% cov.		no gap	1	10% cov.me as ald		50	20	5	10%	5%	2%	5%	2%	1%	WF		X
OC Surface height distribution (m)	100	20	10	0	5	10	1	5	20	100	20	5	0,5	0,2	0,1	0,1	0,05	0,02	WF		X
VA Vegetation height (m) distribution (3D)	1 km	500 m	100 m	0	10	30 km	1	5	10	30 m	20 m	5 m	2	1	0,5	1	0,5	0,1	WF		X
VC Vegetation understorey (%)	1 km	500 m	100 m	0	10	30 km	1	5	10	30 m	20 m	5 m	0,20	0,10	0,05	0,05	0,03	0,01	WF		
VE Surface roughness	1 km	500 m	100 m	0	10	30 km	1	5	10	30 m	20	5	1	0,5	0,2	0,5	0,25	0,1	WF		
LC Waveform parametrisation	20	10	5	no gap	betw	tracks	20m	10m	5m	15	10	5	0,6	0,4	0,2	0,3	0,2	0,1	WF-RC		X
OE Chlorophyll from fluorescence (mg/m3)	100	50	10	2	5	10	1	10	40	100	25	10	50%	20%	5%	2 sig. fig.	2 sig. fig.	2 sig. fig.	LIF - RC		
VL Fluorescence (mW/m²/steradian/nm)	1 km	500 m	100 m	0	10	30 km	1	5	10	50	20	5	10%	5%	2%	5%	2%	1%	LIF - RC		
CC Surface displacement (m/yr)	170	140	TBD	TBD	TBD	TBD	> 5	> 5	> 5	75	50	TBD	5%	TBD	10 m/yr	TBD	TBD	TBD	derived from other	from CA	
OD Surface wind speed (m/s)	100	50	10	2	10	20 km	5	20	40	50	25	10	10%	5%	2%	1 m/s	1 m/s	0,5m/s	derived from other	from OB	
LD Roughness map (m)	50	20	5	no gap	betw	tracks	50	20	5	20	10	5	1m	50 cm	10 cm	1	0,5	0,1	derived from other	from LC	
LE Object height map (m)	50	10	5	no gap	betw	tracks	50	10	5	20	10	5	2m	1m	50 cm	1	0,5	0,25	derived from other	from LC	
LF Slope (°) and aspect map (°)	20	10	2,5	no gap	betw	tracks	20	10	2,5	10	5	1	15°	10°	5°	15°	10°	5°	derived from other	from LC	
LH Profiles of elevation	100	50	10	NA	NA	NA	TBD	TBD	TBD	50	25	5	50 cm	10 cm	5 cm	0,5	0,1	0,05	derived from other	from LC	X
LI Histograms of slopes	250	50	25	no gap	betw	tracks	250	50	25	150	30	15	2°	1°	0,25°	2°	1°	0,25°	derived from other	from LC	
LJ (Local) relief energy (m/km²)	50	20	10	no gap	betw	tracks	50	20	10	1km²	1km²	1km²	5 m/km²	1 m/km²	0,1 m/km²	1 m/km²	0,5	0,1	Level 3		
VB Fractional vegetation cover (%)	1 km	500 m	100 m	0	10	30 km	1	5	10	30 m	20 m	5 m	10%	5%	1%	5%	1%	0,10%	derived from other	from VA	X
VI Above Ground Biomass (kg/m²)	1 km	500 m	100 m	0	10	30 km	1	5	10	50	20	5	20 ton/ha	10 ton/ha	5 ton/ha	12	6	3	Level 3		
VJ Timber Volume (m3/ha)	1 km	500 m	100 m	0	10	30 km	1	5	10	50	20	5	20 m3/ha	10	5	10	5	2	Level 3		
VK Fuel load (kg/m²)	1 km	500 m	100 m	0	10	30 km	1	5	10	50	20	5	20 ton/ha	10 ton/ha	5 ton/ha	10	5	2	Level 3		

- Determination of requirements on
  - ✓ Detection method / observable
  - ✓ Instrumental constant (transmitter side)

Implications: TOF-based products

Threshold TOF

Parameter	Needed?	associated parameters
Laser pulse envelope:		
Time of flight (range)	*Yes*	Resolution: **3 GHz** SNR: TBD Number of pulses: One for ocean products and more than one for topographic products (TBC) Dead time (for multiple pulses): 3 ns (for distinguishing between different surfaces etc, TBC)
Frequency / Wavelength:	*no requirement*	
Polarisation:		
Polarisation-insensitive detection	*Yes*	
Spatial distribution of optical power (per beam):	*no requirement*	

Parameter	Options	Comment
Laser pulse envelope:		
Form / shape	irrelevant	
Length (FWHM) for analogue detection	10 – 30 ns	Depends on the SNR, but typically it is possible to time far better than the pulse rise time. The distortion due to ground (slope, surfaces etc) is probably more constraining.
Length (FWHM) for single photon detection	300 ps	The single detected photon represents the whole laser pulse envelope.
Frequency / Wavelength:		
Wavelength (first surface) *CA, OA, LA and LB*	NIR, IR	The aim is to have an optimum reflectance for all applications. The reflectances of the different surfaces may differ a lot. This aspect has to be studied further.
Wavelength (second surface, penetrating first, i.e. water) *OG and OH*	VIS (blue/green)	
Polarisation:	*no requirement*	
Spatial distribution of optical power:	*no requirement*	

Target TOF

Parameter	Needed?	associated parameters
Laser pulse envelope:		
Time of flight (range)	*Yes*	Resolution: **30 - 60 GHz** SNR: TBD Number of pulses: One for ocean products and more than one for topographic products (TBC) Dead time (for multiple pulses): 3 ns (for distinguishing between different surfaces etc, TBC)
Frequency / Wavelength:	*no requirement*	
Polarisation:		
Polarisation-insensitive detection	*Yes*	
Spatial distribution of optical power (per beam):	*no requirement*	

Parameter	Options	Comment
Laser pulse envelope:		
Form / shape	irrelevant	
Length (FWHM) for analogue detection	~200 ps	Depends on the SNR, but typically it is possible to time far better than the pulse rise time. The distortion due to ground (slope, surfaces etc) is probably more constraining.
Length (FWHM) for single photon detection	20 ps	The single detected photon represents the whole laser pulse envelope.
Frequency / Wavelength:		
Wavelength (first surface) *CA, OA, LA and LB*	NIR, IR	The aim is to have an optimum reflectance for all applications. The reflectances of the different surfaces may differ a lot. This aspect has to be studied further.
Wavelength (second surface, penetrating first, i.e. water) *OG and OH*	VIS (blue/green)	
Polarisation:	*no requirement*	
Spatial distribution of optical power:	*no requirement*	

Implications: CE-RC based products

- CE-RC

Parameter	Needed?	associated parameters
Laser pulse envelope:		
Amplitude / contained energy	*Yes*	Resolution: 1% SNR = 100
Frequency / Wavelength:	*no requirement*	
Polarisation:		
Polarisation-insensitive detection	*Yes*	respecting above precision
Spatial distribution of optical power (per beam):	*no requirement*	

Parameter	Options	Comment
Laser pulse envelope:		
Form / shape	irrelevant	
Length (FWHM)	*no requirement*	
Frequency / Wavelength:		
Wavelength (OB)	NIR / IR	Water surface
Wavelength (NDVI)	2 wavelengths: best: 650-680 nm and 760-850 nm compromise according to Vegetation scientist: 1064 nm and 532 nm (e.g.)	Optimally, NDVI is determined the same way as with a passive imagery, i.e. on the two given channels. However, it may also be determined using Nd:YAG harmonics, for instance (or any similar combination)
Polarisation:	*no requirement*	
Spatial distribution of optical power:	*no requirement*	

- Analysis difficult:
  - ✓ Sea surface roughness (OB): Various empirical models
  - ✓ fPAR (VF) and PRI (VH) not considered further due to specific λs
  - ✓ NDVI (VG) unique driver
    - ➢ high demands on precision, thus SNR → to be discussed

Implications on WF-based products

- Waveform

Parameter	Needed?	associated parameters
Laser pulse envelope:		
Full waveform	*Yes*	Resolution (time/range): **6 GHz** Resolution (amplitude): TBD (in particular for LC)
Frequency / Wavelength:	*no requirement*	
Polarisation:		
Polarisation-insensitive detection	*Yes*	
Spatial distribution of optical power (per beam):	*no requirement (TBC)*	

Parameter	Options	Comment
Laser pulse envelope:		
Form / shape	Gaussian, $sech^2$ or similar	for ease of calculation (deconvolution)
Length (FWHM)	1 ns	
Frequency / Wavelength:		
Wavelength	NIR / IR	
Wavelength II (OF and OI)	blue/green	Water penetration
Polarisation:	*no requirement*	
Spatial distribution of optical power:	*no requirement*	

- based on ‘target’ of OC/LC, attaining ‘breakthrough’ for CB and VA

One waveform rules them all

- Waveform

Parameter	Needed?	associated parameters
Laser pulse envelope:		
Full waveform	*Yes*	Resolution (time/range): **6 GHz** Resolution (amplitude): TBD (in particular for LC)
Frequency / Wavelength:	*no requirement*	
Polarisation:		
Polarisation-insensitive detection	*Yes*	
Spatial distribution of optical power (per beam):	*no requirement (TBC)*	

Parameter	Options	Comment
Laser pulse envelope:		
Form / shape	Gaussian, sech² or similar	for ease of calculation (deconvolution)
Length (FWHM)	1 ns	
Frequency / Wavelength:		
Wavelength(s)	different, see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**	
Polarisation:	*no requirement*	
Spatial distribution of optical power:	*no requirement*	

- All previous observables may be provided by a waveform
  - ✓ TOF: scaling factor of ~10 between range resolution and waveform sampling (ICESat)
  - ✓ CE: intrinsically included - SNR issue to be discussed

Implications on LIF-RC – based products

- LIF

Parameter	Needed?	associated parameters
Laser pulse envelope:		
Amplitude / contained energy (photon counting)	*Yes*	Resolution: 1- 5 % SNR > 20
Frequency / Wavelength:	*different from transmitter, 685 nm for chlorophyll, other tbd*	
Polarisation:		
Polarisation-insensitive detection	*Yes*	*tbd (polarisation of fluorescent signal?)*
Spatial distribution of optical power (per beam):	*no requirement*	

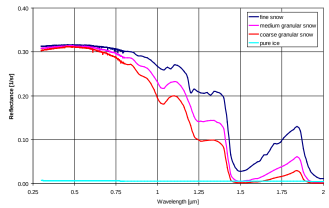
Parameter	Options	Comment
Laser pulse envelope:		
Form / shape	irrelevant	
Length (FWHM)	*no requirement*	
Frequency / Wavelength:		
Wavelength	VIS ??(TBC/TBD exact optimum wavelength)	Chlorophyll excitation?
Polarisation:	*no requirement*	
Spatial distribution of optical power:	*no requirement (TBC)*	

- Low signal (TBD!)
- SNR issue as for CE-RC, to be discussed with scientists

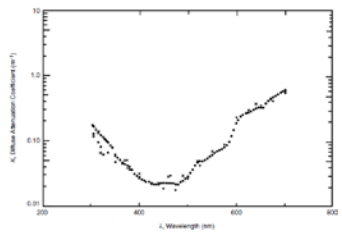
- Considered as an additional option (add. channel w/ different wavelength)

Instrumental constant: Wavelength

- Cryosphere

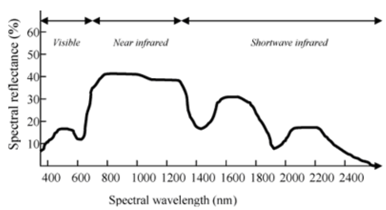


- Ocean



- Land

- Vegetation



Product	Wavelength	Comments
CA Surface elevation	Vis/NIR	Best reflectance in the visible and near infrared
CB Surface RMS roughness	Vis/NIR	
OA Sea surface height	NIR/IR	Best reflectance beyond the visible range, thus NIR and IR
OB Sea surface roughness	NIR/IR	
OC Surface height distribution	NIR/IR	
OE Chlorophyll from fluorescence	Vis	Chlorophyll excitation frequency TBC
OF Water Turbidity	blue/green	Best transmission in water in the blue/green range
OG Height of sea bed	blue/green	
OI Green surface reflectance	blue/green	
LA DEM Surface height	all	Reflectance over land is very diverse (depending on vegetation and ground). A further analysis and trade-off is necessary.
LB Regional Surface Height	all	
LC Waveform parametrisation	all	
VA Vegetation height	all	
VF fPar	550 AND 570 nm	Precisely these wavelengths are needed
VG NDVI	650 - 680 nm AND 760 - 850 nm or 532 nm AND 1064 nm	Either from the given intervals (determination of NDVI as with passive instruments) or a compromise
VH PRI	550 AND 570 nm	Precisely these wavelengths are needed
VL Fluorescence	Vis	Chlorophyll excitation frequency TBC

- !! Definition of a wavelength figure-of-merit $F = \rho \cdot T_{atm}^2 \cdot \eta_{SHG} \cdot \eta_q$

  ➔ Visible wavelengths more advantageous due to better detector characteristics

Instrumental constant: Wavelength

- Further study needed to detail this figure-of-merit and consolidate wavelength(s) choice and thus laser technology
- Issues:
  - ✓ Ground reflectance
  - ✓ Detector quantum efficiency
- For now:
  - ✓ Single wavelength – **NIR**: This version would only partly fulfil the given requirements (CA, CB, OA, OB, OC, LA/LB, LC and VA)
  - ✓ Single wavelength – **Vis**: This version would fulfil the requirements CA, CB, OA, OB, OC, OE, OF, OG, OI, LA/LB, LC, VA, VL
  - ✓ Two wavelengths – **NIR & Vis**: This version would fulfil all requirements except VF and VH
  - ✓ Three wavelengths – **NIR & 2x Vis** (550 and 570 nm): This version would be able to further provide VF and VH

Instrumental constant: Laser repetition rate

- Following out of 'along-track' (spatial) resolution requirements
  - ✓ Single-shot measurement (for one specific data point)
  - ✓ Averaging over multiple shots (for one data point)

- Interdependency with orbit altitude
  - ✓ Single-shot needed rep rate:

$$\Delta s \cdot f_{rep} = \sqrt{\mu \cdot \frac{R^2}{(R+h)^3}}$$

f_{rep} [Hz]	Orbit altitude h [km]			
Δs [m]	500	600	700	800
50	141	138	135	132
20	353	345	338	331
5	1412	1382	1352	1324

- !! High demands on rep rate:
  - ✓ Individual pulse energy lower (for comparable power)
  - → necessarily photon counting (for high along-track resolution)

Noveltis

Geometry

- Across-track sampling:
  - ✓ Single track (per revolution) = ‘threshold’ scenario
  - ✓ Multiple tracks means system multiplication for single-beam analogue waveform altimeter
  - ✓ Transversal resolution may be achieved by multi-beam photon counting system (to be iterated with scientists)

- Geolocation and pointing:
  - ✓ Knowledge of actual pointing → AOCS, alignment
  - ✓ Steering to a specific target (for revisit)

  - ✓ Error budget to be set up
  - ✓ For now: Harsh requirement on pointing (µrad level)

Possible LA concepts

Alternative I: Moderate rate, full (analogue) waveform system

Parameter	Value	Comment
Laser pulse:		
Envelope shape	Gaussian, $sech^2$ or similar	needed for efficient deconvolution
Length (FWHM)	1 ns	needed for temporal resolution
Energy	TBD	*Has to be determined for attaining required SNR, specific orbit altitude and type, expected sun noise level, telescope diameter, specific detector type and wavelength (Industry study)*
Frequency / Wavelength:		
Option I:	NIR (such as 1064 nm)	see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**, fulfilling requirements CA, CB, OA, OB, OC, LA/LB, LC and VA
Option II:	Vis (such as 532 nm)	see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**, fulfilling requirements CA, CB, OE, OF, OG, OI, LA/LB, LC, VA, VL
Option III:	NIR + Vis	see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**, fulfilling all requirements except VF and VH
Polarisation:		
State	irrelevant	may be any polarised state
Laser beam:		
Number of beams	1	single fixed beam to nadir
Divergence and beam quality (M^2)	TBD	*So a s to meet the required footprint size (50m – 20m – 5m) for selected orbit altitude and wavelength, considering further eye safety and atmospheric beam spread (Industry study)*
Repetition rate:		
Repetition rate	140 Hz	Compare to **Fehler! Verweisquelle konnte nicht gefunden werden.**, Higher rates probably yield unfeasible laser powers.

Parameter	Value	Comment
Telescope and optics:		
Telescope diameter	TBD	*Has to be determined for attaining required SNR, laser pulse energy, specific orbit altitude and type, expected sun noise level, specific detector type and wavelength (Industry study)*
Telescope / optics FOV	TBD	*Has to be determined based on laser beam divergence, accommodating for atmospheric beam spread and beam wander, mechanical integration error and mechanical stability while respecting the noise budget (Industry study)*
Sensitivity to polarisation state	none (low)	The receiving optics must not be sensitive to the polarisation state, comparable to the overall noise level
Spectral filter(s): Width	TBD	*Has to be determined for attaining required SNR, at expected sun noise level and respective wavelength (Industry study)*
Detection:		
Option I – NIR:	APD (TBC)	*To be identified in industry study, bandwidth coherent with sample frequency*
Option II – Visible:	APD or PMT (TBD)	*To be identified in industry study, bandwidth coherent with sample frequency*
Option III – NIR and Vis:	APD, PMT (TBD)	*To be identified in industry study, bandwidth coherent with sample frequency*
Additional option (for II or II)	Photon counting detector (PMT or APD) at TBD wavelength	*Has to be studied further by scientific partners if a) excitation level may be reached and b) provoked signal is sufficiently strong*
Sampling and data:		
Sample rate:	6 GHz	For altimetric signal resolution
Data acquisition:	6 GSamples/s < 100 MSamples/s	For altimetric signal resolution (e.g. ±60m around expected ground hit) For atmospheric signal (in order to lower data rate)

Possible LA concepts

- Alternative I: Moderate rate, full (analogue) waveform system

  ✓ Would fulfil most requirements except spatial resolution

Product	Precision [m]			Along-track sampling (m)			Across-track sampling			Footprint size (m)			Priority
CA Surface elevation (m)	0,03	0,02	0,01	170	50	10	1	10% cov.	ame as alon	50	20	5	X
CB Surface RMS roughness (m)	0,5	0,2	0,05	170	50	10	1	10% cov.	ame as alon	50	20	5	X
OA Sea surface height (m)	0,02	0,01	0,005	100	20	10	1	5	20	100	20	5	X
OB Sea surface roughness (dB)	NFS	NFS	NFS	100	20	5	1	5	20	50	20	5	X
OC Surface height distribution (m)	0,1	0,05	0,02	100	20	10	1	5	20	100	20	5	X
OE Chlorophyll from fluorescence (mg/m3)	2 sig. fig.	2 sig. fig.	2 sig. fig.	100	50	10	1	10	40	100	25	10	
OF Water Turbidity	NFS	NFS	NFS	100	20	5	1	5	20	100	20	5	
OG Height of sea bed (m)	0,1	0,05	0,02	100	20	5	1	5	20	100	20	5	
OI Green surface reflectance (dB)	NFS	NFS	NFS	200	100	50	1	10	40	400	200	100	
LA DEM Surface height above geoid (m)	1	0,5	0,1	50	30	15	50m	30m	15m	30	20	10	X
LB Regional Terrain Model Surface Height (m)	1	0,25	0,05	20	10	5	50m	10m	5m	10	5	3	
LC Waveform parametrisation	0,3	0,2	0,1	20	10	5	20m	10m	5m	15	10	5	X
VA Vegetation height (m) distribution (3D)	1	0,5	0,1	1000	500	100	1	5	10	30	20	5	X
VF fPar (%)	5%	2%	1%	1000	500	100	1	5	10	70	20	5	
VG NDVI (from -1 to 1)	0,02	0,01	0,01	1000	500	100	1	5	10	70	20	5	
VH PRI	0,005	0,002	0,001	1000	500	100	1	5	10	50	20	5	
VL Fluorescence (mW/m²/steradian/nm)	5%	2%	1%	1000	500	100	1	5	10	50	20	5	

Legend
ok
with restrictions
no
unclear

Alternative II: High rate multi-beam photon counting system

Parameter	Value	Comment
Laser pulse:		
Envelope shape	irrelevant	Since only one photon is expected to return from the pulse, the exact shape is not important
Length (FWHM)	150 ps	needed for temporal resolution
Energy	TBD	*Has to be determined for attaining required SNR, specific orbit altitude and type, expected sun noise level, telescope diameter, specific detector type and wavelength (Industry study)*
Frequency / Wavelength:		
Option I:	NIR (such as 1064 nm)	see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**, fulfilling requirements CA, CB, OA, OB, OC, LA/LB, LC and VA
Option II:	Vis (such as 532 nm)	see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**, fulfilling requirements CA, CB, OE, OF, OG, OI, LA/LB, LC, VA, VL
Option III:	NIR + Vis	see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**, fulfilling all requirements except VF and VH
Polarisation:		
State	irrelevant	may be any polarised state
Laser beam:		
Number of beams	TBD (start value: 16x16)	pattern
Pattern, size and orientation	TBD	*Advantages and disadvantages of pattern type and orientation has to be studied in detail*
Divergence and beam quality (M^2)	TBD	*So as to be coherent with pattern for selected orbit altitude and wavelength, considering atmospheric beam spread and degradation due to pattern-generating optical element (Industry study)*
Repetition rate:		
Repetition rate	TBD (5 – 10 kHz)	*So as to be coherent with requirements concerning along-track resolution and single pulse power needs for sufficient photon rate per pixel (Industry study)*

Parameter	Value	Comment
Telescope and optics:		
Telescope diameter	TBD	*Has to be determined for attaining required SNR, laser pulse energy, specific orbit altitude and type, expected sun noise level, specific detector type and wavelength (Industry study)*
Telescope / optics FOV	TBD	*Has to be determined based on individual beam divergence, accommodating for atmospheric beam spread and beam wander, mechanical integration error and mechanical stability while respecting the noise budget (Industry study)*
Photon router	TBD (fibre array, e.g.)	*Optical element that collects the individual photons in the telescope focal point and guides them on the respective detectors (Industry study)*
Sensitivity to polarisation state	none (low)	The receiving optics must not be sensitive to the polarisation state, comparable to the overall noise level
Spectral filter(s): Width	TBD	*Has to be determined for attaining required SNR, at expected sun noise level and respective wavelength (Industry study)*
Detection:		
Option I – NIR:	APD array (TBC)	*To be identified in industry study, bandwidth coherent with counter frequency*
Option II – Visible:	APD or PMT array (TBD)	*To be identified in industry study, bandwidth coherent with counter frequency*
Option III – NIR and Vis:	APD, PMT arrays (TBD)	*To be identified in industry study, bandwidth coherent with counter frequency*
Counting rate and data:		
Counter rate:	6 GHz	For altimetric signal resolution and construction of synthetic waveform
Data acquisition:	date modulo 150 ps	For the photon counting system, only the individual arrival date of a photon (along with the detector matrix position ij) has to be stored.

Possible LA concepts

- Alternative II: High rate multi-beam photon counting system
  - ✓ Would fulfil most requirements (incl. spatial resolution)
    - ➢ TBD if digital waveform satisfies requirements (scientists)

Product	Precision [m]			Along-track sampling (m)			Across-track sampling			Footprint size (m)			Priority
CA Surface elevation (m)	0,03	0,02	0,01	170	50	10	1	10% cov.	ame as alon	50	20	5	X
CB Surface RMS roughness (m)	0,5	0,2	0,05	170	50	10	1	10% cov.	ame as alon	50	20	5	X
OA Sea surface height (m)	0,02	0,01	0,005	100	20	10	1	5	20	100	20	5	X
OB Sea surface roughness (dB)	NFS	NFS	NFS	100	20	5	1	5	20	50	20	5	X
OC Surface height distribution (m)	0,1	0,05	0,02	100	20	10	1	5	20	100	20	5	X
OE Chlorophyll from fluorescence (mg/m3)	2 sig. fig.	2 sig. fig.	2 sig. fig.	100	50	10	1	10	40	100	25	10	
OF Water Turbidity	NFS	NFS	NFS	100	20	5	1	5	20	100	20	5	
OG Height of sea bed (m)	0,1	0,05	0,02	100	20	5	1	5	20	100	20	5	
OI Green surface reflectance (dB)	NFS	NFS	NFS	200	100	50	1	10	40	400	200	100	
LA DEM Surface height above geoid (m)	1	0,5	0,1	50	30	15	50m	30m	15m	30	20	10	X
LB Regional Terrain Model Surface Height (m)	1	0,25	0,05	20	10	5	50m	10m	5m	10	5	3	
LC Waveform parametrisation	0,3	0,2	0,1	20	10	5	50m	10m	5m	15	10	5	X
VA Vegetation height (m) distribution (3D)	1	0,5	0,1	1000	500	100	1	5	10	30	20	5	X
VF fPar (%)	5%	2%	1%	1000	500	100	1	5	10	70	20	5	
VG NDVI (from -1 to 1)	0,02	0,01	0,01	1000	500	100	1	5	10	70	20	5	
VH PRI	0,005	0,002	0,001	1000	500	100	1	5	10	50	20	5	
VL Fluorescence (mW/m²/steradian/nm)	5%	2%	1%	1000	500	100	1	5	10	50	20	5	

ok
with restrictions
no
unclear

Recommendations

- Further studies to be implemented:
  - ✓ Surface reflectance for different (candidate) wavelengths (literature study & airborne campaigns)
  - ✓ Technology for high rate multi-beam photon counting laser altimeter
    - Laser
    - Detector arrays
    - Multi channel counters
    - Beam division optics (transmit) and photon router (receive)
    - Pattern layout
  - ✓ Competence in Europe:
    - Geodetic Observatory Wettzell, Observatoire de la Côte d'Azur, University of Prague, DLR BELA-team…
    - Becker&Hickl, FAST ComTech, sensL, SiliconSensor…

Agenda

- 9:30 – 9:45 Welcome
- 9:45 – 10:45 Review of science requirements
- 10:45 – 11:00 Coffee Break
- 11:00 – 12:30 Review of L1B/instrumental requirements
- **12:30 – 13:00 Conclusions and perspectives**
- 14:00 – 15:00 Contractual issues

In brief

- ✓ 45 L2 products (63 tables)
- ✓ 10 priority L2 products
- ✓ 17 basic L2 products
- ✓ 2 instrumental concepts

An overview of the european state of the art:

- ✓ Assets
  - Strong scientific community around LIDAR data
  - Innovative applications and products
- ✓ Weaknesses
  - Definition work and feasability test needed for new products
  - Retrieval algorithm and physics to study into detail

Perspectives: L2

- O-B: Sea surface roughness.
  - ✓ mean square slope <=> reflected energy of the waveform.
  - ✓ studying sample echoes from ocean at 1050 nm.
- O-F: Turbidity.
  - ✓ field experiments : achievable degree of depth, resolution and accuracy.
- O-I: Green Surface Reflectance.
  - ✓ studying ICEsat data : initial green echo which is reflected.
- O-E and V-L: Laser induced fluorescence and chlorophyll concentration.
  - ✓ New product. Feasibility not yet proven : airborne field experiment needed.
  - ✓ Optimal wavelengths for the laser and the detection system : need end-to-end simulation.
- V-E: Surface roughness.
  - ✓ Not yet fully defined.

Perspectives: L1

- Reflectances and wavelength influence : link budget
- Photon counting & KHz LIDAR : waveform quality
  - ✓ Influence on L2 products retrieval
  - ✓ Pattern of the beams and alignment on the track
  - ✓ Number of averaged pulses