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ALTIKA : A MICRO-SATELLITE Ka-BAND ALTIMETRY MISSION

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Abstract.

Ka-band altimetry has been proposed by Verron et al. (2001) to complement the altimetry reference missions of the Jason class. The goal of this paper is to provide information on the so-called "AltiKa" proposal in terms of science requirements, responsive technical specifications, and a priori performances. Besides the fact that the feasibility of embarking an AltiKa payload on a microsatellite has already been assessed, there is also the information that a small launcher may have the capability of launching several microsatellites simultaneously (up to three) in a number of configurations that may be adapted to the space time requirements of high resolution altimetry.

Introduction

The development of altimetry has been steady and the benefits outstanding. There has been a quasi-continuous series of missions, starting with GEOSAT (1985), and then ERS-1/2 (1991 and 1995), and TOPEX-POSEIDON (1992). These will continue from Year 2000 with Jason-1 and ENVISAT, that are respectively scheduled for launch in 2001.

More generally, the heritage of past and current oceanographic space missions has paved the way for the incremental implementation of the space component of the Global Ocean Observing System. Because they have already demonstrated their "pre-operational" maturity, in terms of end-to-end performances, value to users and affordability, altimeter and scatterometer missions are the first immediate candidates for operational transition. Short-term decisions are therefore required to secure continuity and enhancement of the current altimeter and scatterometer systems in the GODAE (Global Ocean Data Assimilation Experiment) timeframe and beyond.

In the short term, the future looks secure with a two-satellite altimeter system being maintained for the next five years with Jason-1 and ENVISAT. It is foreseen that the combined use of their data with measurements from independent gravity missions such as CHAMP (2000), GRACE (2001) and possibly GOCE (2004) will be another breakthrough. It should enable absolute estimates of ocean currents, to be obtained by subtracting an independent estimate of the geoid from individual altimeter height measurements.

A first firm decision is however needed in the very short term to secure continuity through Jason-2 measurements in the GODAE window. Further decisions will be needed to maintain a multi-satellite system providing the required accuracy, coverage and sampling beyond the GODAE window, after the end of life of ENVISAT. Such a system should provide an affordable service equivalent to one Jason-class mission and one or two medium accuracy missions of the ENVISAT class. Several options need to be evaluated, taking into account results of R & D and demonstration missions aimed at validating new candidate observing techniques.

The goal of this paper is then to provide the reader with the status of Ka-band altimetry, considering the embarkment of the system on a microsatellite platform.

1. The AltiKa proposal : about science objectives

The science objectives of the AltiKa mission are described in Verron et al. (2001) and in Remy et al. (1999) in very details.

Hereafter, we only recall those of the objectives that most impact the design of the altimeter instrument and the payload.

1.1 Ocean Mesoscale variability

Based on the need to resolve the mesoscale variations and to study the effect of these fluctuations on the energetics of the mean circulation, the spatial and temporal resolution required is set by the need to directly observe the mesoscale variability to a degree that allows, in conjunction with assimilative numerical models, a proper description of the oceanic eddy field and the interactions of this field with the mean field.

In 1999, G. Mitchum et al. summarized some of the requirements for a well adapted sea-surface height system: The section below partly derives from Mitchum et al.' statements concerning space altimetry. The constraint concerning the spatial and temporal resolution of a sea-surface height system means that we must be able to resolve signals that occur at spatial scales on the order of several oceanic Rossby radii, and on time scales of days to weeks, which cannot presently be done with a single altimeter. The important question is how many altimeters must be available at any given time, and what orbits should these satellites occupy? Jacobs et al. (1999) have estimated that three altimeters are needed to directly observe the mesoscale variations without additional statistical or dynamical model input. If assimilative models are used, however, two satellites may be adequate. In a different set of simulations, Le Traon and Dibarboure (1999)

conclude that most of the improvement in reproducing the mesoscale variability is obtained in going from a single altimeter to two flying simultaneously. Adding further altimeters improves the results, but to a lesser degree.
It is clear that at least two altimeters are required, and that additional altimeter would still improve the science return, but the optimal number is still under study.
Other ocean topics may also add spatial and temporal requirements that will impact the number of altimeters needed to get high space-time resolution.

1.2 Contribution in coastal altimetry and continental waters

The initial single satellite AltiKa proposal did not have the goal to answer the space-time requirements corresponding to a fully adapted sampling of the coastal dynamical features. We'll come to the possibility of flying a multisatellite AltiKa constellation in the conclusion.

However, coastal altimetry has been a driver to derive new instrumental spcecifications to answer new performance requirements both in terms of noise and along-track space resolution.

At the same time, we also considered how a new altimetry system may answer requirements dealing with the observation of continental waters (lakes, reservoirs, rivers) such as the requirements listed in the HYDRASAT proposal. Once again, besides the time sampling issue, we looked at the orbit pattern that may be useful to have in complement of Jason to sample the major continental water areas; we also tried to focus on space resolution requirements avoiding to design an instrument that would be specific to the altimetry of lakes and rivers keeping in mind that the main driver is ocean altimetry.

Some main technical features of the Ka-band altimeter that is part of the AltiKa payload are directly derived from the coastal and continental water requirements : they are described in more details in sections 2 and 3.

1.3. Ice sheet ice monitoring

As the AltiKa payload has been foreseen to also continue the ERS/ENVISAT series of altimeter measurement of ice sheets, we also considered some basic features of ice altimetry that may impact the technical specifications of AltiKa.
The monitoring of the ice-sheet height over Antarctica and Greenland is of primary importance for climate studies. However, one of the major limitations of the ice sheet mass balance study, is presently the poor knowledge of the radar wave penetration within the snowpack, in Ku-band for the ERS1/2 altimeters. The induced volume echo is of the same magnitude as the surface echo, yielding to a critical situation. The induced effect is twofold: it directly acts on the surface elevation accuracy and, due to the temporal change in the snow characteristics from daily to yearly scales, it produces a long term analysis error that can hide the long term trend.
Then, the objective was to try specifying the altimeter so that penetration effects would be minimized with respect to Ku-band altimetry.

2. Ka-band payload characteristics

2.1. General requirements and proposed payload

The above objectives were translated into some main features of the Ka-band payload :

- get an altimeter instrument whose range noise performance may be so that the recovery of the ocean short wavelength features is improved,
- get an altimeter instrument with an improved space resolution along-track and a better performance when approaching or leaving coastal boundaries,
- get an altimeter instrument that will minimize the penetration effects over media such as continental ice,
- embark an orbitography system that will ensure a high level of accuracy in terms of orbitography and that will ease the connection of historical altimetry series within a common well surveyed geodetic reference frame,
- embark a microwave radiometer that will help correcting altimeter measurements for wet troposphere effects.

To answer the previous requirements, it is proposed to compose an AltiKa payload with :

- A single frequency Ka-band (35 GHz) altimeter instrument (see Phalippou et al. (2000) for details)
- A two-frequency radiometer,
- A DORIS receiver,
- A passive laser retroreflector array.

2.2. Summary of some characterisitics of the Ka-band altimeter

From the above requirements, we derived altimeter instrument specifications that are compared with the POSEIDON-2 specifications in the table below :

	AltiKa	POSEIDON2
Altitude	500 to 800 km	1340 km
Inclination	~98°	66°
Lifetime	2 years (objective : 3 years)	5 years
Frequency	35.75 GHz	13.65 GHz
Bandwidth	480 MHz	320 MHz
PRF	4000 Hz	~2000 Hz
Signal to noise ratio	> 10dB	> 10dB
Spectral analysis	128 gates	128 gates
Integration duration	25 to 50 ms	50 ms
Mass	<20 kg	70 kg (C+Ku)
Consumption	< 50 W	78 W (C+Ku)

To comment the above table, we can add the following :

- At Ka-band, the ionosphere effects are much lower than at Ku-band and may be considered as negligible, except for some exceptional ionospheric situations (in the latter cases, the embarkment of DORIS may provide a backup solution to retrieve the ionospheric correction). This is one reason for the choice of such a frequency band for a single frequency altimeter.
- The decorrelation time of sea echoes at Ka-band is shorter than at Ku-band. This gives the possibility to significantly increase the number of independent echoes per second compared with Ku-band altimeters. The instrument is designed for a high Pulse Repetition Frequency (PRF) around 4000 Hz.
- The antenna beamwidth is smaller for the Ka-band altimeter than for Ku-band POSEIDON 2. This gives a Brown echo which is sharper than the echo obtained with altimeters such as POSEIDON 2 ; the echo power is also lower due to larger gain variation in the pulse limited footprint.
- The 480 MHz bandwidth that may be used at Ka-band will provide a high vertical resolution (0.3 m) which is improved with respect of all flying altimeters (including Jason and ENVISAT)
- It is known that Ka-band EM waves are sensitive to rain. In addition to attenuation effects, perturbation of echoes by rain has to be analyzed in terms of the retrieval of the 3 geophysical parameters to be estimated from waveforms (to be discussed in a decicated section).

2.3. About the dual frequency radiometer

The selection of the radiometer type has been driven by :

- the basic science requirement, that is to perform the measurements necessary to get the wet troposphere correction with a sufficient accuracy ;
- the willingness to embark the AltiKa payload on a microsatellite, which requires a compact and simple instrument.

Frequencies have been selected to be optimal for the case of a dual frequency radiometer, that is 23.8/36.5 GHz. A three-frequency radiometer would be more difficult to embark because the lowest frequency (19 GHz) would impact the system on the microwave and antenna point of views. In addition, it is possible to overcome this drawback by adapting a wet troposphere retrieval algorithm incorporating the relationship between the wind and the altimeter backscatter coefficient (for instance, such a solution is used for the ENVISAT altimetry).

The 23.8 GHz frequency will use the full width of the allocated bandwidth, that is 400 MHz. Concerning the 36.5 GHz frequency, the fact that it is near from the altimeter frequency does not allow the use of the whole allocated bandwidth which is 1 GHz. In addition, the accuracy of the wet tropospheric correction does not much depend on this bandwidth. Then, it is envisaged to use a 400 to 700 MHz bandwidth with a high probability to select a 400 MHz band (so that the high frequency of the radiometer is centered at 36.8 GHz).

After comparing the known radiometer concepts, we selected a so-called « Total Power » radiometer which has the most simple architecture and that also provides the best radiometric sensitivity. The counterpart is the necessary frequent radiometric calibrations because of the high sensitivity to the gain variations.

2.4. An integrated Altimeter + Radiometer instrument

One of the initial requirements to design the AltiKa payload was that it should be possible to embark it on a microsatellite and that it could also be provided as a whole to become a passenger on an apportunity platform.
This has lead us to define an integrated instrument that allows for interface optimization and reduction of the number of units (boxes). Indeed, the integrated instrument is composed of :

- One microwave unit that gathers all microwave functions of the altimeter and the radiometer, including the calibration functions of the radiometer and the sources of the antenna.
- One processing unit that gathers all functions dedicated to the altimeter and radiometer processing, as well as a global management unit.

3. Performances and impact on some science objectives

3.1. Minimizing the range noise of the altimeter measurement

The Ka-band (35 GHz) is more interesting than the Ku-band for the altimeter since it improves the link budget and allows larger bandwidth (up to 500 MHz) and pulse repetition frequency (4 kHz).
The selected 480 MHz bandwidth provides a 0.3 m vertical resolution.
Due to the smaller antenna beamwidth, the Brown echo has a sharper shape in Ka-band than that what is obtained with conventional altimeters in Ku/C-band (e.g. POSEIDON 2).
The proposed architecture for the Ka-band altimeter is based on the classical deramp technique for pulse compression and it takes benefits of French experiences from the realisations of POSEIDON 1 & 2. A wide band chirp (~480 MHz) of about 107 µs duration is emitted. The digital processing includes the real time FFT, echo integration and radiometer processing (power averaging). The main limitation of Ka-band is the non-operationality for rain rate higher than several mm/h (5 to 10% of time for AltiKa depending on the geographic area).
Range noise comparison with POSEIDON 2 altimeter shows that AltiKa will provide excellent performances (see Figure 1 where the Ku/C and Ku curves correspond to the dual and Ku-band-only frequency estimates of POSEIDON 2 range noise).

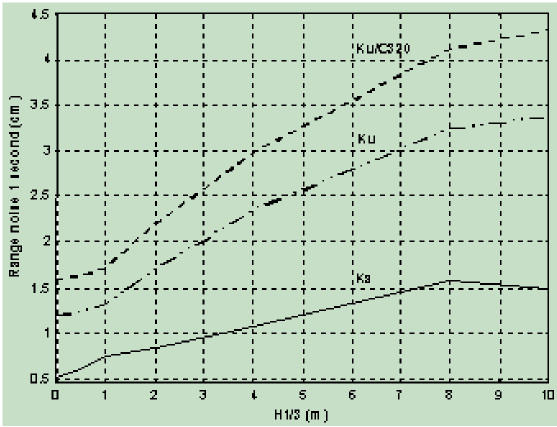

Figure 1: Comparison of AltiKa (at 800 km) and POSEIDON 2 (at 1340 km) performance

Since no ionospheric correction is required for AltiKa (DORIS might indeed provide a correction in extreme, rare ionospheric conditions), the expected improvement is close to a factor of 3 (for example, 1-s range noise at 2-m SWH would be less than 0.8 cm for AltiKa vs 2.2 cm for POSEIDON 2).

3.2. Space resolution improvement wrt classical Ku-band altimetry

This very good range performance will be associated with reduced footprints and better coastal performance as well.

Performance for coastal applications depends :

(i) on waveform / footprint relationship
(ii) on antenna diagram / footprint relationship (to obtain attenuation of land contribution to echo
(iii) on tracking performance for complex (coastal or in-land) echoes.

AltiKa characteristics have been optimized for these 3 issues :

- AltiKa is close to a beam limited altimeter : there is no ‘plateau’ in the echo, since it strongly attenuates shortly after leading edge due to the small antenna aperture. This will greatly reduce the pollution of ‘land gates’ into ‘ocean gates’.
- Tracking loops were designed at the same time as SIRAL/CRYOSAT altimeter for which continuous tracking in ocean/land/ice conditions is required. Thus, AltiKa is supposed to provide data in most coastal zones and in-land water areas. Moreover, in case of loss of track, acquisition/locking phase is required to be shorter than 500 ms, allowing a quick return to

nominal tracking conditions (about 3 km along track).

These values will be associated with small footprints for the radiometer as well since altimeter and radiometer will share the same antenna. In addition to the altitude reduction, which is the main contributor to the radiometer

footprint reduction, it may also be noticed that the absence of an additional 19-GHz channel to the radiometer is also an advantage since this low frequency would give the largest footprint.

	Leading edge (2-m SWH)	128-gate echo (2-m SWH)	Footprint diameter at 3-dB attenuation
POSEI- -DON2 (Ku-band)	5.3	19.1	19.5
POSEI- -DON2 (C-band)	5.3	19.1	49.5
AltiKa (800 km)	4.1	12.7	7.2
AltiKa (500 km)	3.4	10.3	4.6

Table : Footprint diameter for different criteria (values given for a 75-cm antenna for AltiKa)

This is why it is expected that AltiKa will give useful data as close as 5 km from a majority of coastal areas. Associated with a shorter data cycle (probably 500 ms instead of 1 s), it will probably represent a major improvement in mesoscale and coastal applications of radar altimetry.

3.3. Minimizing penetration effects over continental ice

An empirical analysis of the temporal variability of the satellite radar altimetric observation demonstrates that the Ku-band radar penetration above the dry snowpack of Antarctica is between 5 m in the interior to 14 m at a lower altitude, before decreasing due to wetness near the coast. The absorption coefficient of dry snow being 0.05 m^{-1}, it induces a scattering coefficient comprised between 0.05 and 0.16 m^{-1}, depending on ice the grain size which varies from 0.2 to 3 mm.
In Ka-band, Mie scattering can be assumed, then the scattering coefficient is inversely proportional to the radar wavelength at a power 4. From Ku to Ka bands, the scattering coefficient will increase by a factor 55: the volume scattering will then be clearly dominant over the surface scattering. Inversely, the radar wave extinction will also increase to values comprised between 2.75 and 8.75 m^{-1}, leading to a penetration depth over snow surface between 0.3 and 0.1 m. The altimetric observation and height restitution will thus correspond to a thin subsurface layer. The accuracy will then be considerably improved.
Moreover, ice grain size, that is one of the pertinent climatological snow parameters, could be directly derived from Ka-band scattering coefficient, which is not possible from present day Ku measurements that also highly depend on surface roughness.
However, the major benefit will lie in the reduction of the induced long term bias due to the temporal change in the snowpack surface. Indeed, a strong temporal variability of the altimetric observations over Antarctica ice sheet has been recently exhibited with the help of the ERS-1 three day orbit mission. These temporal variations are linked to meteorological events and consequently play a role on a large band of the temporal spectrum, from few hours to few decades. They are due to changes in surface roughness induced by change in wind, which modifies the echo surface part and then, both the waveform shape and the elevation recovery. Even with a dedicated correction, the residual correction yields to a raw noise estimate of 10 cm.

3.4. Propagation losses

3.4.1. Attenuation effects

It is known that propagation of EHF waves through the troposphere may suffer from severe attenuation due to the interaction of the electromagnetic wave with the atmospheric contents. As far as the Ka-band altimeter is concerned, current requirement is that the instrument provides nominal performance 90% of time, with an objective as high as 95%. An extensive study has been made to analyze the contributions from :
(i) gazes : attenuation is calculated for oxygen and water vapour. Even if the allocated frequency range is nearly ideally chosen with respect to the water propagation spectral window, strong attenuation may result from moderate to high humidity contents. Values may vary from 0.4 to 2.1 dB when humidity varies from 7.5 to 50 g/m3.
(ii) clouds : 7 types of clouds are taken into account for the propagation models. Attenuation is estimated from their liquid vapour contents and depths. As expected, cumulus and cumulonimbus are generally

the main contributor (0.2 to 0.7 dB) to the total loss, and sometimes stratocumulus (0.05 to 0.2 dB).
(iii) rain : attenuation by rain, and possibly snow, is computed from rain rate and rainfall thickness.
Other possible contributors (ice, fog) have been shown to have no significant influence (order of 0.1 dB for the fog).
As far as rain is concerned, maximum precipitation rates are known as less than 1.5 mm/hr everywhere (95% through time) or even 1.0 mm/hr (90% through time) over ocean and polar areas, except in a region off the Philippines islands for which previous figures have to be doubled. Following accepted statistical distributions, one can associate some classical layering distributions with the previous rates. Then, total attenuation due to rain may be computed. Results show that attenuation is lower than 1.8 dB (95%) or even 1.2 dB (90%). Given these figures, we can conclude that :

- Case 1 : no rain or very low rain rates, then a nominal functioning of AltiKa is ensured,
- Case 2 : rain rates greater than 1.5 mm/h, then altimeter measurements will be degraded or even not acquired for the largest rain rates,
- Case3 : moderate rain rates less than 1.5 mm/h, then the echoes will have to be corrected using a specific algorithm modeling the perturbation of the echoes by rain cells.

To refine the previous statements, 7 years of TMR data from TOPEX/POSEIDON have been used to check some seasonal effects and to analyze the effect of local time which may be an important parameter to select in the case of a sun-synchronous orbit for AltiKa. Translation of TMR measurements into rain attenuation has been performed using dedicated algorithms and results have been mapped versus location, local time, month in the year, and on a multi-year time scale. On the one hand, the study has confirmed that Ka-band data availability will be greater than 90% over the world ocean and even greater than 95% for some areas such as the North Atlantic. On the other hand, it appeared that local times from 6 am to 12 am, and from 6 pm to 12 pm are the worst cases for rain, which may provide a « light » constraint for the optimization of the link budget of the instrument and select the most adequate local time for a sun-synchronous orbit.

3.4.2. Impact of rain cells on waveform analysis

Following considerations are derived from Tournadre (1999).
Approximations made in previous studies to estimate the effect of rain cells on Ku-band altimeter waveforms are no longer valid ; a second new method has thus been developed based on the true integration of rain attenuation.
It may be shown that the difference between the two methods is significant even for low rain rates (few tenths of mm/hr). The method can be used to compute the altimeter waveform for any rain field. It shows that a precise retrieval of altimetric parameters (significant wave height, wind speed and sea surface topography) will require to take into account corrections for rain cell perturbations even for low rain rates.
The sensitivity of Ka band measurements to rain may also lead to a way of estimating very light rainfall over the oceans, for which we dramatically lack of information and which could lead to a great improvement of our knowledge of the oceanic rain climatology.

3.5. Anticipated radiometer performances

The following figures present the major elements of the radiometer performance budget :

-resolution : about 0.3 K for the 23.8 GHz frequency, and 0.4 K for the 37 GHz frequency

-sensitivity : better than 1K

-accuracy : better than 3K (worst case estimate).

4. Conclusion : Status of the Ka-band altimetry studies

The Ka-band altimetry concept that is proposed exhibits enhanced performances in terms of vertical resolution, time decorrelation of echoes, space resolution, range noise. In addition, an adapted tracker algorithm has already been designed to perform near-continuous altimetric tracking above all surfaces, which is especially important when approaching or leaving coasts. Also, it appears that, even if Ka-band measurements are more sensitive to rain than Ku-band measurements, rain does not prevent from acquiring a fairly high percentage of measurements (objective is up to 95%) except for strong rain rates : nevertheless, the development of new algorithms taking into account rain perturbations of the altimeter echoes is necessary and presently under study.

Of course, even if not presented in this note, the presence of the DORIS system and of a laser retroreflector array in the AltiKa package ensures that the classically required orbitography performances will be reached and that the AltiKa altimeter series may be linked to TOPEX/POSEIDON, Jason and ENVISAT series in a well monitored geodetic reference frame.

Preliminary studies have shown that a microsatellite platform such as the MYRIADE series under development at CNES is well suited to embark the AltiKa payload (Figure 2). A recent study has been performed considering a classical sun-synchronous 35 day ENVISAT-type orbit (6 am ascending node) at an altitude of 800 km and a 98 degree inclination, also requiring a +/- 1km repeatability for the ground track. The main issues relating with the accommodation of the AltiKa payload on the microsatellite platform have been analyzed : mass, power, pointing, fields of view of the various instruments, TM/TC rate, thermal and electromagnetic environment, etc. A detailed report is still under writing at the present time, the conclusion of it being that AltiKa is a valid candidate for the embarkment on such a microsatellite.

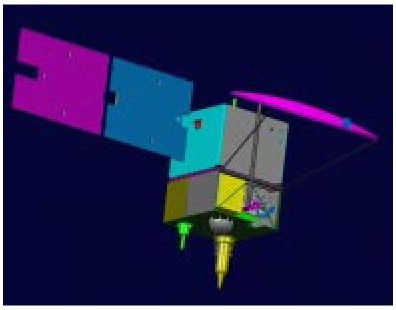

Figure 2 : Artist view of AltiKa satellite

During the same study, a very preliminary analysis of possibly launching several (up to 3) AltiKa microsatellites with the same small launcher has been performed (Figure 3). The feasibility of such an approach has been assessed for 2 configurations : one is to have 3 satellites flying in the same orbit plane with a 120 degree lag in terms of position on the orbit (classical constellation type), the second one being to have the 3 satellites flying on different orbit planes that would be separated up to 0.24 degree corresponding to one third of the typical 35 day ground track spacing (formation flying). These 2 configurations may of course answer differently space time requirements of high resolution ocean altimetry and maybe inputs for ocean simulation to illustrate their relative interest in terms of science return.

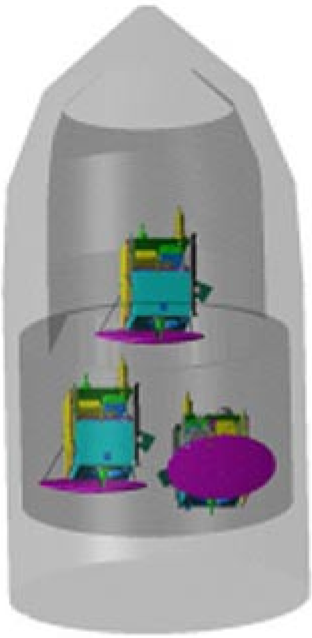

Figure 3 : Example of accommodation of 3 AltiKa microsatellites inside a DNEPR fairing

It shall be noticed that the technical studies that are referred to are preliminary ; they need to be consolidated by more detailed analysis including the possibility of considering other microsatellite platforms and launchers. However, the results that are presented demonstrate the potential of Ka-band altimetry both in technical and performances aspects, validating the AltiKa concept for a high performance continuation of ENVISAT altimetry and to potentially contribute in high resolution altimetry.

Finally, it may be stressed that the Ka-band altimeter payload defined above may be embarked as a passenger of opportunity missions as a complement to existing altimeters such as the POSEIDON ones :

we would then get multi-frequency measurements that may be of much use for all applications mentioned above.

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