Modeling the oceanic gravity field by a high resolution altimetric satellite mission

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NEEDS ANALYSIS

Abstract

Although gravity measurements are acquired over the oceans since the 60's, our knowledge of the oceanic gravity field has been mostly improved by the advent of altimetric and gravimetric satellites. Global models of mean oceanic surface or their derived items (gravity, topography) have brought a wealth of new information and lead to an acceleration of research in geophysics on the oceans. Nevertheless, the resolution of the gravity models derived from altimetric measurements is still not high enough.

The limits of these models are partly due to the altimetric technology itself, which limits measurements close to the coastlines and to the spatial resolution along the satellite tracks (with a footprint diameter close to 16 km). In addition, the strategy of measurements adopted for altimetric missions generally favours the study of oceanographic processes and their temporal variability (i.e. repeated orbits) rather than a complete spatial coverage needed for high resolution geophysical studies. Gravity satellite missions such as GRACE and CHAMP are able to resolve 300 km wavelength anomalies. The gradiometer on the GOCE project will give access to the 100 to 150 km wavelengths whereas altimetric missions detail 18 km wavelength anomalies.

We have investigated the contribution of existent and future satellite missions to fulfill the needs expressed during the "High Resolution Gravity field by Altimetry" meeting held in CNES (Paris) in June 2007 for a high resolution gravity field. Moreover we have been working on the design of an altimetric mission dedicated to provide 10 km resolution and 1 mGal accuracy to improve the global geoids model. The upcoming fulfilment of SWOT concept brings hopes that may become reality as well about resolution, than accuracy and coverage. Its expected performances will be analyzed to get an idea on the final improvement it can imply to the geophysics community.

In 2006, the SHOM (French Hydrographic and Oceanographic Office) associated to IFREMER (French Institute of sea research and exploitation) and the IUEM (European marine academic Institute), started a work on the limitations of altimetry for geophysical and hydrographic purposes. They compared the precise marine data and altimetry derived models, to get their limitations as resolution and accuracy.
A workshop on high resolution altimetry attended the French community shows that present derived altimetry models are not sufficient to improve the knowledge on global bathymetry or geodynamics objects.

Main constraints on altimetric measurements:

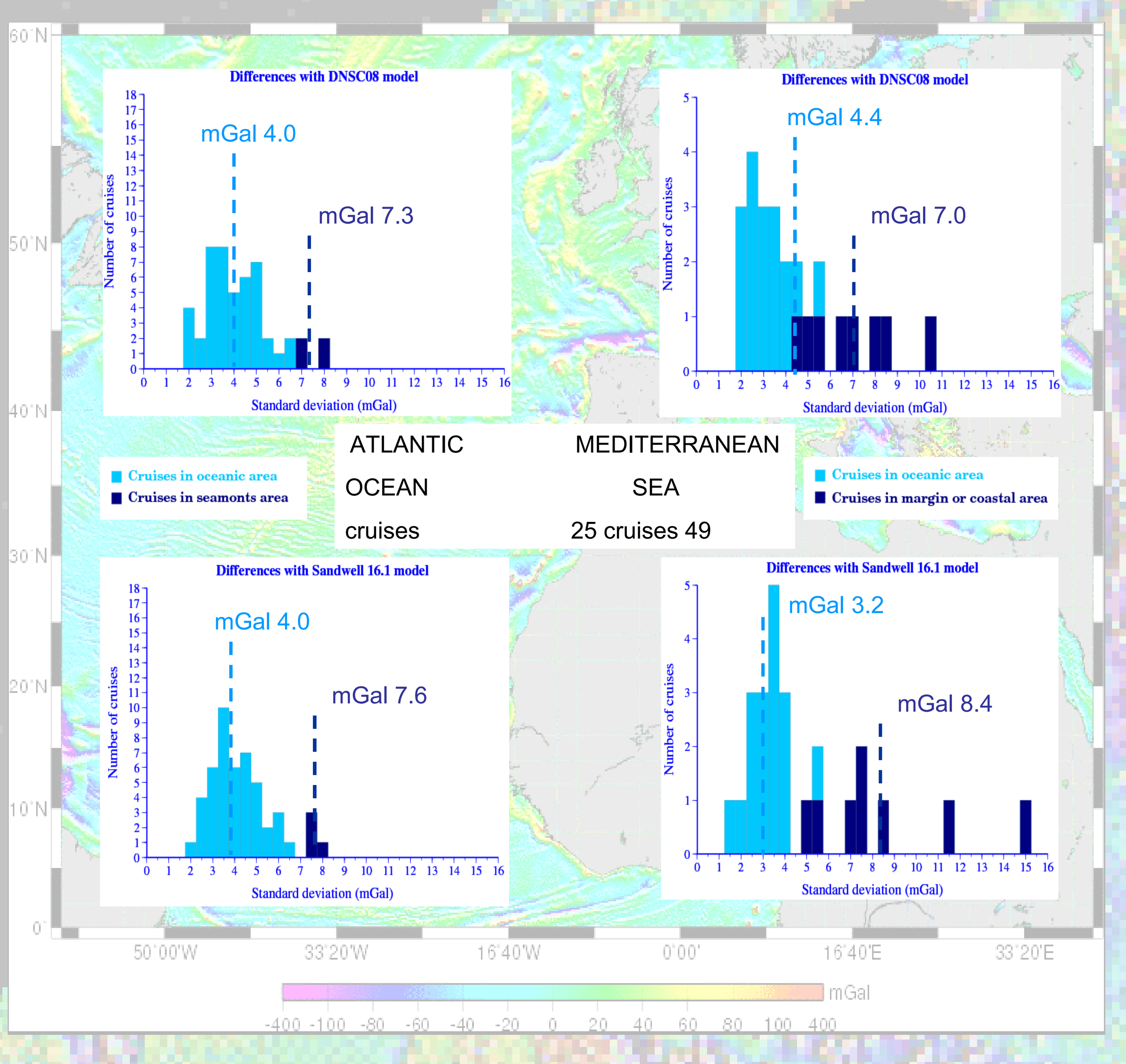
The satellite orbit, the spatial resolution (footprint effects), the corrections models and the land/sea altimeter handover do highly constraint the quality of models.

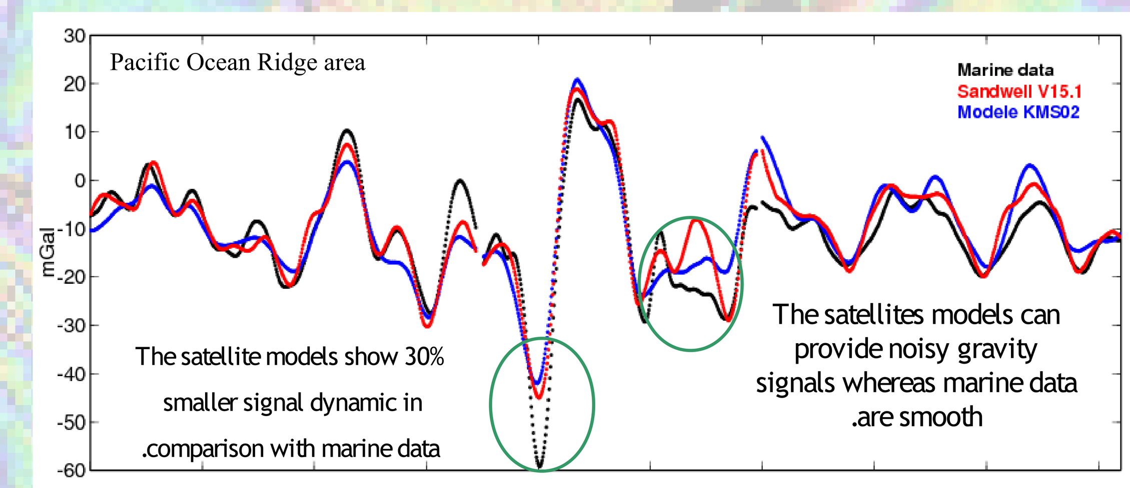
The needs for geophysical purposes are :
-the best spatial resolution (from 10km for offshore bathymetry to 1km for small wavelength structures)
-the best quality to rise 1 mGal on Free Air Anomaly and 1 cm on the sea surface height.

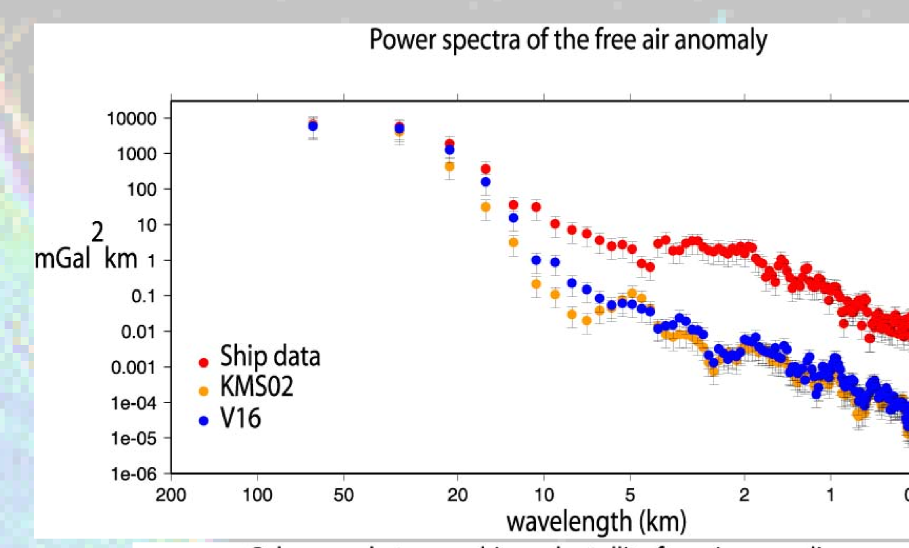
We first study the bathymetric purposes as describe by Sandwell (Ref 1) in the ABYSS project (Ref 2). The slope accuracy and spatial resolution requirements expressed by Sandwell were 1µRad accuracy and 4km resolution. Of course he gave a priority to the complete coverage.

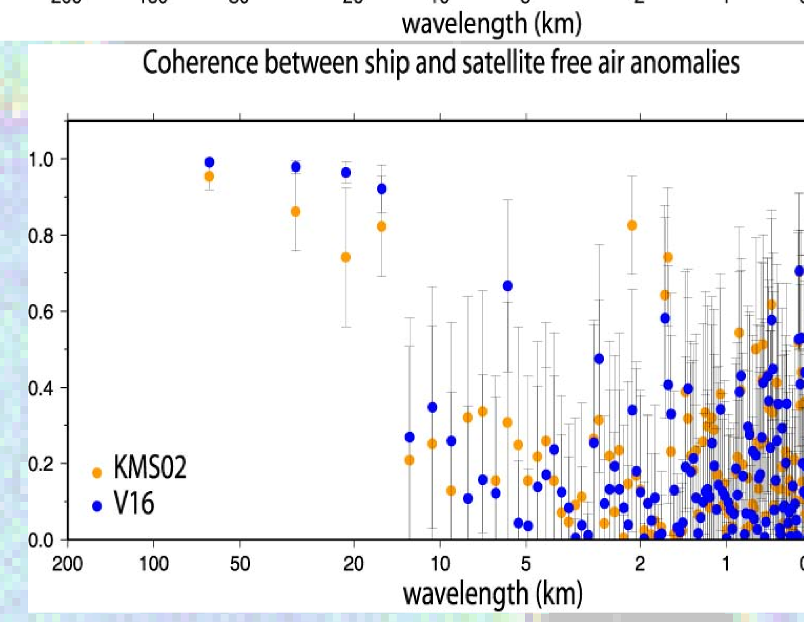
Marine & spatial gravimetry can not fulfill the requirements

Despite its high resolution and accuracy, the marine gravimetry is out because covering the whole sea surfaces by ships will take about 100 years. Gravimetric satellites as CHAMP, or GRACE, reached at best a 400Km resolution. Even the future GOCE mission which aim a better resolution near 100km. Nevertheless, such measurements will provide very accurate reference data at long wavelength on the oceans.
A good way to provide global high resolution gravity models on oceans will be to use the altimetry technologies . The present global gravity models derived from altimetry involve the most quality of altimetric current data (retracked for GEOSAT and ERS, last models of climatology). We tested such models (Ref 3 & Ref 4) and shows that even with these new improved processing they can't rise the spatial resolution and accuracy needed for local geophysical works (see diagrams on the left and right sides).
We selected the models from Sandwell and Smith and those of Andersen and Knudsen. On our examples the last models DCNS08 (Ref 6) and the V16 (Ref 4) are used. The previous model KMS02 is shown to illustrate the improvement of such models.









FAA derived from Altimetry MODELS ANALYSIS

The Free Air Anomaly derived from altimetry models show weaknesses when describing high magnitude signal and interferences with the noise due to the measures.
In two different geodynamic areas, the Atlantic Ocean and the Mediterranean Sea, we compared marine gravity data with altimetry derived models (pic on the left). We can identify as shown from standard deviation values of the differences: an oceanic area , an oceanic rough area (ridge, seamounts), a coastal area. The altimetry derived models don't allow to recover the gravity signal with sufficient resolution and accuracy in rough and coastal areas.
As shown on the left side, the current FAA models differ from around 4 mGal on oceanic areas and 7.5 mGal on rough areas in the Atlantic Ocean and from 3.2/4.4 mGal to 7.0/8.4 mGal on coastal area in the Mediterranean Sea (Ref 7).
On the right side, you can see the energy dispersion at wavelength less than 16 km for the Sandwell V16.1 and 20 km for the KMS02 (former model of Andersen and Knudsen upgraded as DNSC08) (Ref 8). The Foundation Seamount take place in the Pacific Ocean and its rough structures fluctuate considerably.

THE PLANNED ALTIMETRIC MISSIONS AND PROJECTS

JASON-2, after Topex-Poseidon and Jason-1, provide great accurate data thanks to its high repetitiveness. Such choice of orbit derived from a wish to get better accuracy at the expense of a more complete coverage. In fact Jason-2 with its 315 km intertrace at the equator has been designed for a different mission in the way to complete a data set in time.
The constraints are the same as previous missions (Topex-Poseidon and Jason-1). There are requirements of regular time sampling too but this doesn't fit ours in term of spatial resolution for example. The missions design depends on wishes which could be different from one department to an other, we also are obliged to consider an other design to complete our mission

CRYOSAT-2 (2009) has been designed to study the ice volume evolution. Its near polar orbit could have been useful to complete the coverage to the high latitudes as much than its SAR altimeter but on the oceans, CRYOSAT-2 has been designed for low resolution measure. Despite its well accuracy, this mission can not provide measures with higher resolution than 16 km.
CRYOSAT-2 use a double antennae and thanks to the interferometry technology can measure the slopes across track of ice sheets. Its Baseline is not long enough to determine soft slopes (Ref 9). Whereas this mission will improve the knowledge of the gravity field particularly thanks to its polar orbit, it won't fulfill all the needs of the geophysics community.

SARAL (2010) looks as the altimeter mission with the best resolution but its footprint diameter is still more than 10 km large. Above the oceans, **AltiKa** will get measure on the Low Resolution mode corresponding to the 13 km large integral footprint diameter. Moreover its Sun synchronous orbit does not allow it to distinguish tidal components.
The use of the Ka Band can improve the accuracy of the altimeter and the resolution of the measurements on coastal areas and rough structures but the coverage on wet climate area looks to be uncompleted if the rain rate is to important (Ref 10). The improvements brought by AltiKa are significant but not enough considering our requirements.

We could have talk about **SENTINELLE-3** (2013) which a Digital Terrain Modeling (DTM) has been added at, in the goal to improve the coverage close to coastlines, but all the other planned altimetric satellite missions except SWOT mission can not reach better resolution than 13 km if it is not higher frequency reprocessed. The altimeter SRAL (SAR Altimeter) with the micro-waves radiometer (MWR) will allow an accuracy of about 3.5 cm rms and an along-track high spatial resolution (Ref 11). Unfortunately, we are looking for the same resolution along- and across-track.

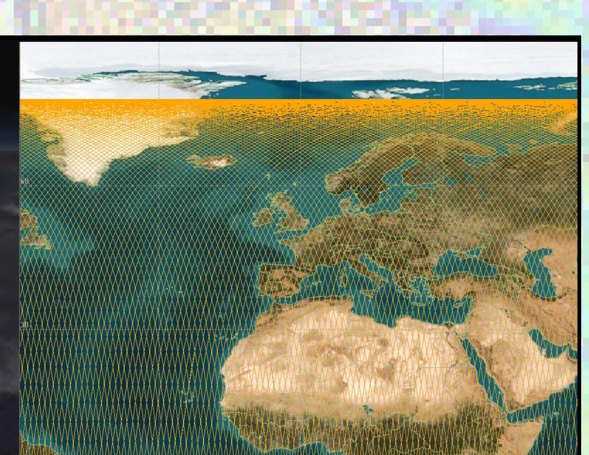
Every mission has been designed for justified and precise goals and we are looking for a complementary mission which can fulfill the needs of searchers in terms of high resolution and accurate altimetric data. A dedicated mission should be the only way but the actual planning and expected performances of SWOT looks to be interested as well.

PROPOSALS

The future : SWOT Project

The upcoming execution of SWOT project forced us to not consider it any more as a technological utopia and take into account that it will one day be launch. SWOT mission is the first new generation radar altimeter mission. Its predecessor, WSOA, has been canceled in 2004 due to budget's problems after 6 years of application and technology development. Today a large community of searchers in oceanography and hydrology support this program from the USA to the EUROPE. We all wish that this project one day will be launch and believe in supporting it as a priority project fulfilling the needs of geophysists about high resolution, coverage and precision, which expectations are better than what we can do with the traditional altimetry.

SWOT will be launch on a 22 days repetitive and 78° inclined orbit at a 800 km altitude (Ref 12) to get the best compromise between the coverage and the repetitiveness. Gaps are minimized and data quality and coverage optimized.



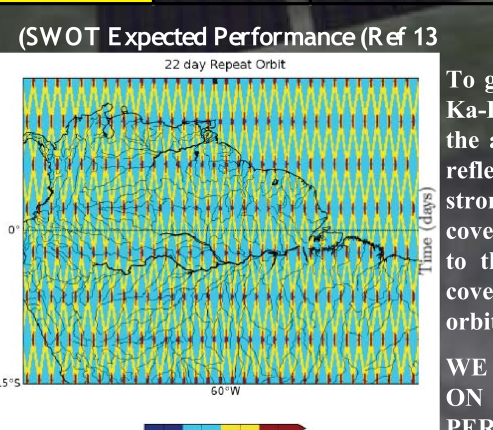
SWOT GROUNDTRACE

	Height Error	Slope error
Phase error	1cm @ 1km² area	0.7mrad @ 5km 0.15mrad @ 10km
Roll errors	2cm (max) at swath edge	0.1mrad (max)
Wet Troposphere	1cm (Ocean)	0.1mrad
Dry Troposphere	<1cm	0.01mrad
Ionosphere	1cm	0.2mrad
EM Bias	1-2cm	0.1mrad
Orbit	1cm	/
RMS error	3.5cm max at 1km² area	0.75mrad at 5km

(SWOT Expected Performance (Ref 13

Thanks to its width swath and interferometry antennas, it is able to cover from 10 to 60 km on both sides and detail 1 km large cells. Such performances couldn't have been dreamt before and here is the revolution of such a technology. The nominal cell is about 2x10m but the measure on it is to noisy to allow such a resolution. Nevertheless integrating the measures on bigger cells permit to minimize the errors and improve the accuracy. Above the Ocean, the data compression will be done onboard and provide 1 km large pixel, what differs from land data which will not be compressed before being transmitted.

We are here looking for slopes measurement . The better resolution we could have for 1 µRad implied at least a 10 km large resolution. Thanks to SWOT we can reach a 0.75 µRad for a 5 km large cell or 0.3 µRad fro 10 km (pic on the right down corner). The correlation due to similarities on measurements conditions will reduce the media delay error and we will get a better accuracy on slopes than on Sea Surface Height. Moreover these slopes measures are already orthogonal and their accuracy will not vary with latitude.



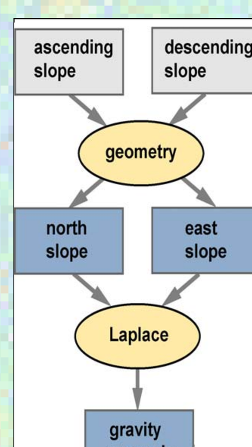
Coverage rate with the 22 day repeat (orbit (Ref 13

To get such resolution and keep using a huge mast length, the use of Ka-Band could not have been a choice. This frequency Band improve the accuracy but may bring problems on the coverage because of its reflectivity with the water. In fact the signal attenuation will be to strong at rain rates higher than 3mm/hour (pic on the right side). The coverage on tropical climate area looks to be uncompleted but thanks to the 22 days repetitiveness, we shall complete the global oceans coverage several times and better than with a long period repetitive orbit mission such as GRAL mission.

WE ARE NOW WAITING TO COMPLETE OUR INFORMATIONS ON SWOT MISSION AND BE SURE ABOUT ITS EXPECTED PERFORMANCE BEFORE TO JOIN ITS COMMUNITY BUT NEVERTHELESS SWOT PROJECT NEED TO BE FINALIZED. A NEW AGE FOR ALTIMETRY IS UPCOMING AND WITHIT NEW HIGH QUALITY DATA TYPE.

Rain rate mm/hr	35 GHz Attenuation (5-km path)
3	6 dB
5	11.5 dB
10	24 dB
20	50 dB
30	73 dB
100	215 dB

Effects of the rain on Ka-band (signal (Ref 10

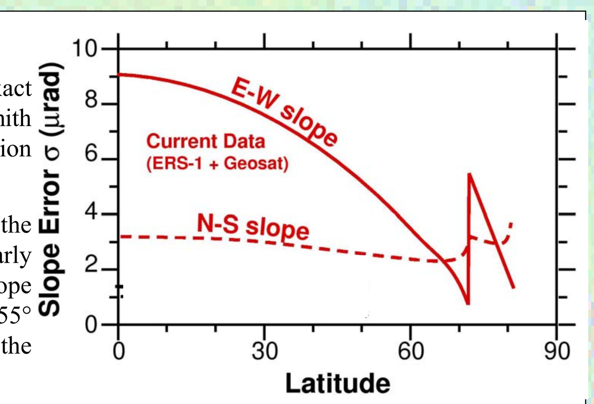


ABYSS mission, a missed opportunity

Sandwell's method instead of using Sea Surface Height, provides an exact theory to convert slopes to vertical gravity deflection. Sandwell and Smith (Ref 1) already studied the needs above and designed the Abyss mission project and dedicated it to provide detailed free air anomaly models.

Launch on a geodetic orbit, Sandwell aimed to make crosses of the satellites as orthogonal and at highest latitudes they could be. A nearly polar orbit would provide a good coverage but a bad East-West slope accuracy as shown on the picture on the right side. An inclination of 55° looked the best compromise between the coverage and the quality of the data. (Ref 2)

The mission would improve the gravity field knowledge but unfortunately the project was not accepted by the USA agencies.

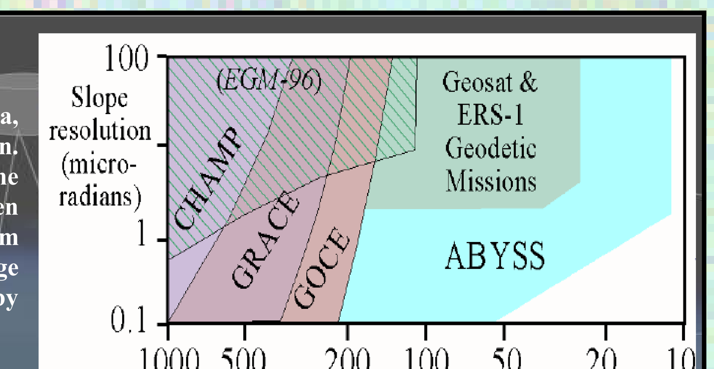


Slope error on ERS-1 and Geosat combined data (Ref 1)

Conclusion

The GRAL Team was looking for a mission able to provide high resolution data, none of the current or planned missions will fulfill at least the 10 km resolution. Cooperating with ThalesAleniaSpace and considering Sandwell's method as the best way to convert altimetric data in Free Air Anomaly models, we have been working on some mission design and studied how to fulfill the minimum requirements of 1µRad slope accuracy, 10 km resolution and a global coverage including at high latitudes. The purpose is to complete the blank unfulfilled by the past and actual missions and in response of ABYSS project abandonment .

An other mission will be studied for geophysical and bathymetric applications. The fresh news coming from E. Rodrigo let us expect great performance (Ref 13). We need know to study how SWOT configuration and technology can respond to our request by imitating the Free Air Anomaly model output with expected SWOT data.



Role of the past mission in the development of gravity field model in term of slope accuracy and spatial resolution

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