AQUALIS: ADVANCING INFLIGHT CALIBRATION TO ACHIEVE AFFORDABLE QUALITY

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ABSTRACT

AQUALIS intends to improve the quality and cost-efficiency of very high-resolution Earth Observation image acquisition from small platforms, by developing innovative calibration technologies. Key issues preventing this are: limited pointing accuracy and stability which makes geometric calibration more challenging. Radiometric consistency is challenged by thermal variations, limited coverage, low SNR and the need for cross-calibrating constellations.

Novel geometric and radiometric calibration methodologies are developed to address these issues. On geometry, we aim to improve geolocation accuracy by minimising distortions considering the total geometry of viewing. To achieve this we are testing different optimization strategies on real satellite data to identify the most suitable approach.

To improve radiometric accuracy we investigated lunar calibration: we performed Monte Carlo simulations to investigate the impact of platform stability and orbital behaviour on the accuracy of the retrieved lunar irradiances. The results yield estimates which are useful for optimizing practical lunar calibration activities. To reduce angular effects. we created a simulation environment to study the effects of BRDF on retrieved radiances. With the result, we created a prototype BRDF disaggregation model, which allows to understand and predict the impact of BRDF effects, which in turn can improve calibration based on ground targets.

1 INTRODUCTION:

AQUALIS stand for ‘Affordable Quality Images from Space’, and it is a strategic basic research project, funded by the Flemish Research Foundation (FWO) and carried out by a consortium (KULeuven, VITO and imec). The goal is to develop and demonstrate innovative technologies which enable the acquisition of very high-resolution Earth Observation images from small platforms at reduced cost while maintaining high image quality.

The AQUALIS project intents to address some key issues that prevent affordable high-quality data acquisitions. One issue is the limited pointing accuracy and stability, resulting in image blur and geometrical shifts, making geometric calibration more challenging.

Radiometric consistency is being challenged by different characteristics which are typical for small missions: absence of on-board calibration instruments, larger thermal variations; limited coverage and lower SNR due to smaller optical systems which gather less light. The increased use of constellations of small satellites makes it necessary to cross-calibrate them accurately as well.

Novel solutions to these issues are being researched in the areas of geometric and radiometric calibration methodologies which are being developed specifically to address the issues found with small satellites. The goal is to improve relative and absolute geolocation accuracy, absolute and relative radiometric accuracy and independence of angular effects. In the following sections, we describe the progress that has been made on these three aspects.

2 GEOMETRIC CALIBRATION

Environmental monitoring and land cover management applications (e.g. change detection) require a high geometric performance (subpixel accuracy). In-flight processing and calibration strategies can greatly improve the image quality, especially since SmallSat missions typically do not have very stable pointing. A limiting factor of CubeSats for EO missions is their geometric instability (> 0.1 deg).

Despite the efforts to precisely correct the alignment before launch, on-orbit geometric calibration is mandatory as additional errors may be introduced after launch. Consequently, it is common for EO satellite programs to calibrate the alignment during commissioning.

In-flight geometric calibration is essential to correct for the distortion caused by :

- platform altitude variation in combination with sensor focal length which can change the pixel spacing;
- platform attitude variation (roll, pitch and yaw) inducing a change of the orientation and the shape of acquired images;
- calibration parameter uncertainty such as in the focal length, principal point and sensors line of sight
- topographic relief, which generates a parallax in the scanner direction.

A common approach for on-orbit geometric calibration is based on the usage of ground control points (GCPs) and a rigorous 2D/3D physical sensor model which reflects the physical reality of the viewing geometry (platform, sensor, earth). Other 2D/3D empirical models such as 2D/3D polynomial or 3D rational polynomial functions are also very common as replacement to the georeferencing models.

Within AQUALIS, we mainly focus on studying the different strategies to optimise the physical models. Refinement of the physical model can be done step by step with mathematical function modelling each source of distortions or simultaneously by performing a global and combined optimisation. It is better to consider the total geometry of viewing (platform, sensor, projection) as some of their distortions are strongly correlated and lead to the same impact on the ground. Different optimization strategies are being tested (including different modelling approaches for the exterior and interior distortions) Tests are carried out on real satellite imagery allowing to select the appropriate geometric corrections approach that is suitable and applicable to SmallSats.

3 LUNAR CALIBRATION

Small satellites are usually not equipped with on-board devices, so they rely entirely on vicarious calibration to establish radiometric quality. One of the preferred targets is the Moon as it has no atmosphere, which introduces an increased uncertainty for most of the calibration methods. The moon is highly stable in terms of irradiance and quite predictable in function of the phase angle.
As shown in Figure 1, the irradiance follows a highly predictable pattern. With LIME, a new model to predict lunar irradiance was developed under the ESA contract 4000121576/17/NL/AF/hh. This model has an estimated uncertainty level of maximum 2% over its complete spectral and phase angle range [1] [2]

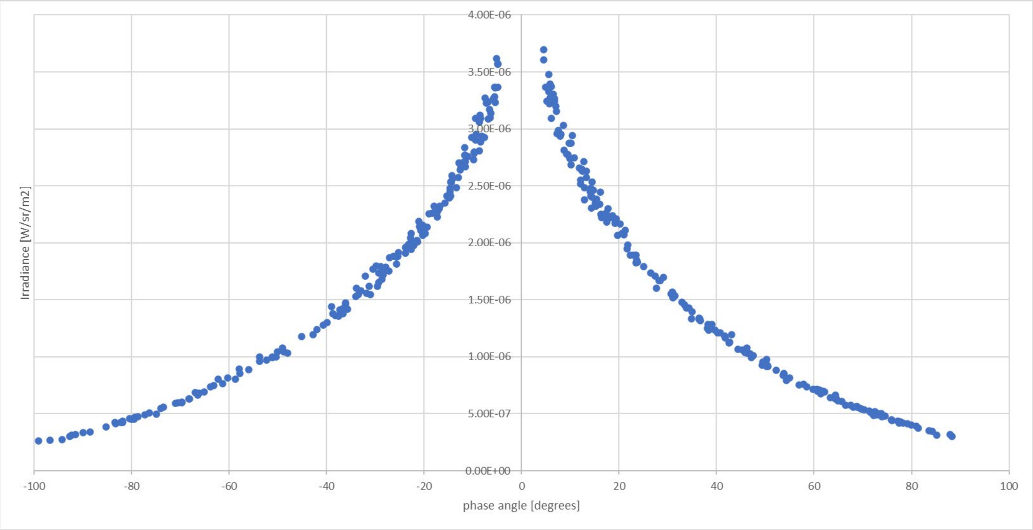

Figure 1 Lunar irradiance as a function of phase angle

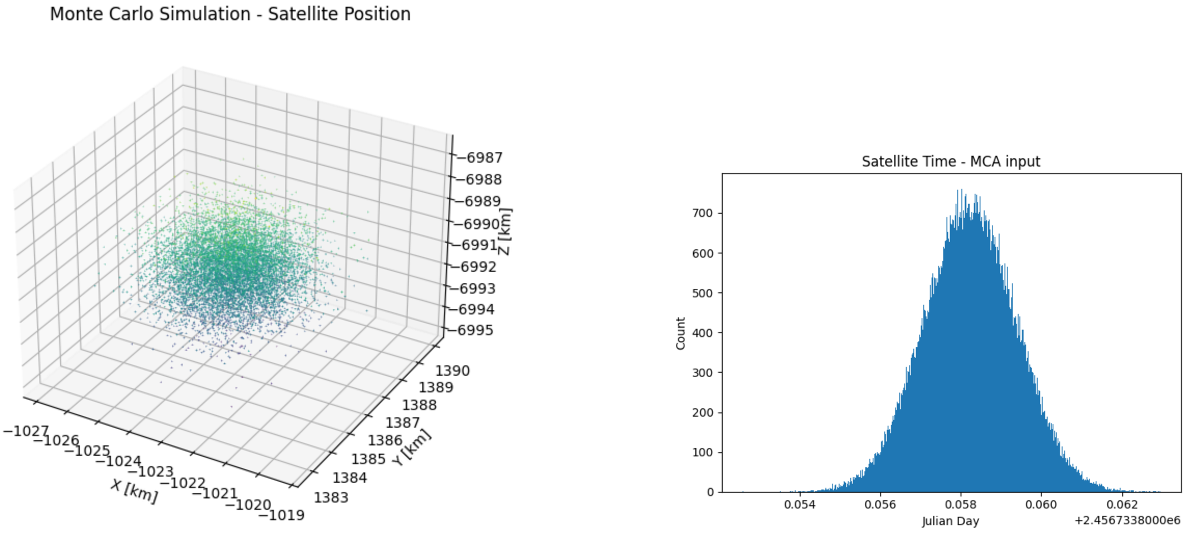

Figure 2: Perturbations: left: Platform XYZ position, right: timestamp

To improve smallsat radiometric calibration, we performed a detailed study on lunar calibration. We have simulated the impact of platform position stability and time measurement on the output of LIME irradiance levels. Simulations were done using Monte-Carlo techniques, to estimate the impact of platform stability on the model irradiance output. The LIME model output is influenced by both the absolute timestamp (in UTC) and the exact platform XYZ position (in J2000 coordinates). Perturbation of both inputs was done separately, to be able to assess them in a separate way.

An absolute position error of 5m up to 100km was introduced to the input. The exact timestamp (expressed in Julian Days) was perturbated as well. Results of the simulation are shown graphically in Figure 2 and numerical results in Table 1. The results of this study show that the impact of the orbital behaviour is very small, and it gives a useful estimation of the effects of platform stability. This is a valuable result which forms a solid basis for optimizing practical lunar calibration activities.

Table 1 Uncertainties of phase angle and model irradiance resulting from introduced position and timestamp perturbations

	position perturbations [km]				time perturbation [s]		
	100	10	1	0.005	100	10	1
uncertainty phase [%]	0.599	0.06	0.006	3.01E-05	0.5376	0.054	0.0054
uncertainty irradiance [%]	0.161	0.016	0.002	2.29E-05	0.1482	0.0149	0.0015

4 DATA HARMONIZATION

The several elements in the AQUALIS satellite formation can ensure a daily coverage of the Earth at the expense of varying observation and illumination geometries between successive orbit overpasses for a given target located on the ground. Due to the land surface reflectance anisotropy, such angular variations infer saw-like patterns on time series of surface reflectance and derived products. These artefacts are commonly known as directional effects.

The effect of land surface anisotropy on VNIR satellite imagery has been primarily investigated at a coarse spatial resolution (e.g. [3][4]). Previous efforts [6] have shown that the robust methodologies employed to correct directional effects on coarse spatial resolution Earth observation products are not directly applicable to high spatial resolutions because the adjacency effects are more significant at high spatial resolutions.

Therefore, within the AQUALIS project, we are working on a methodology to enable the modelling and removal of directional effects on high spatial resolution images. Our framework is based on realistic 3D radiative transfer modelling Earth observation scenes using DART [2].

The acquisition geometry for the DART simulations of a cultivated region in Italy is displayed in the polar plot of Figure 1. In the central polar plot displays, an orange five-pointed star represents the Sun's position. A subset of the different acquisition geometries simulated with DART for the Grosseto site are shown as black circles. The dashed lines link this the corresponding DART simulated surface reflectance images. The images are downsampled to a pixel size of 10 m and convoluted with the Sentinel-2 MSI-A band 8A (865nm) spectral response function. It is worth noticing that the highest level of simulated reflectance is observed for the viewing directions closest to the Sun's direction, which is a manifestation of the hot-spot effect.

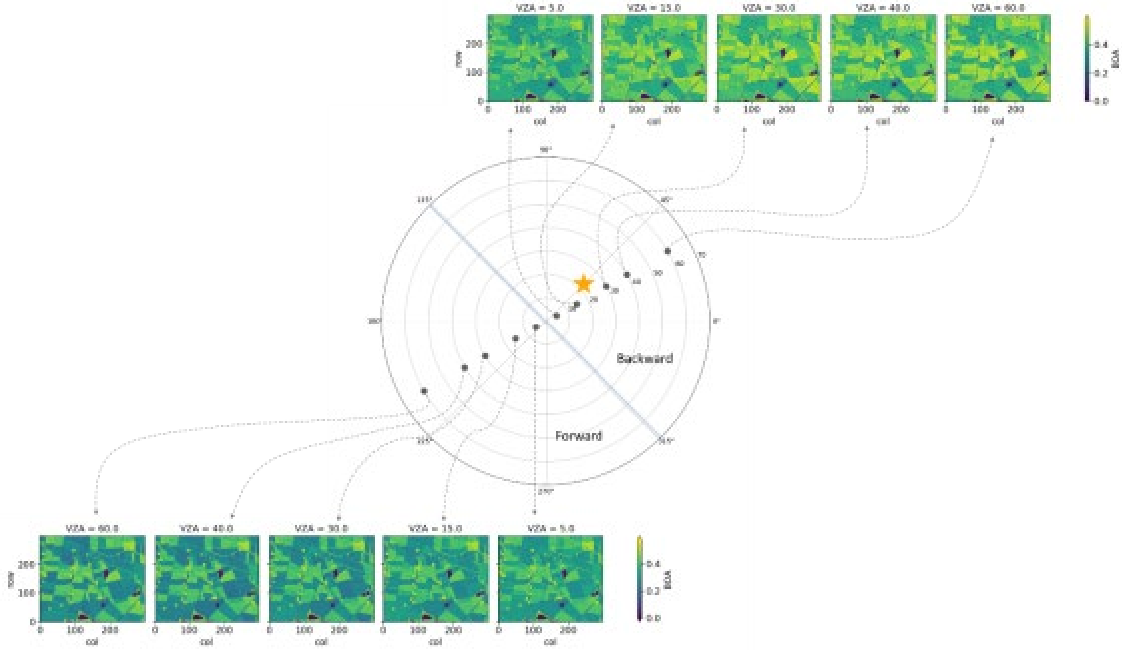

Figure 3: illustration of radiance variations depending on acquisition geometry (simulations)

While the surface and illumination conditions remain constant throughout the DART simulation run, the simulated surface reflectance significantly depends on acquisition geometry. More specifically, the surface reflectance obtained in the backward scatter direction (above the blue line in Figure 1) is higher than sensing geometries in the forward scatter direction (below the blue line in Figure 1). As is apparent from Figure 1, of the simulated acquisitions in the backward region, the one closer to the Sun position shows the highest level of surface reflectance. The latter manifests the well-known hot-spot effect [1][5].

The realistic radiative transfer simulations generated with DART shall allow us to have a controlled environment to assess the modelling of directional effects in the imagery delivered by the AQUALIS constellation. Moreover, our simulation framework shall enable us to develop for the first time a methodology to correct for directional effects on VNIR high spatial resolution imagery and to operate at a global scale to perform a harmonisation of surface reflectance among AQUALIS constellation satellites.

5 CONCLUSION

Within the AQUALIS project, important issues are being investigated to resolve limitations on the radiometric and geometric accuracy that can be obtained from smallsats. On geometry, the goal was to identify the best optimisation strategy for minimising distortions. Investigation are still ongoing, but an important learning is that the optimisation is best performed on the total geometry of viewing, because the different distortions are often strongly correlated.

On lunar calibration we established results on the impact of platform stability and orbital behaviour on the accuracy of the retrieved lunar irradiances. These are useful for optimizing lunar calibration activities. On the study of BRDF effects, we created a simulation environment and a prototype BRDF disaggregation model. This which allows to understand and predict the impact of BRDF effects, which in turn can improve calibration based on ground targets.

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