The contribution of the European Space Agency to the ALOS PRISM / AVNIR-2 commissioning phase.

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Abstract

The Advanced Land Observing Satellite (ALOS) was launched on Jan 24th, 2006 by a Japan Aerospace Exploration Agency (JAXA) H-IIA launcher. It carries three remote sensing instruments: Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2), Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) and Phased Array Type L-band Synthetic Aperture Radar (PALSAR). Within the framework of European ALOS Data European Node (ADEN), European Space Research INstitute (ESRIN) as part of European Space Agency (ESA), teamed up with JAXA for contributing to ALOS commissioning phase plan. This paper summarizes the strategy that ESA adopted to define and implement a data verification plan for mission operated by foreign nation, classified as so called ESA *Third Party Missions*. The verification of ALOS optical data from PRISM / AVNIR-2 instruments activities had begun four months after satellite launch on March 2007.GAEL Consultant (French company) has supported ESA / ESRIN for designing and executing the plan. A team of principal investigator's has been put together to provide technical expertise. This paper includes a description of the verification plan and summarizes the methodologies that were used for radiometric, geometric and image quality assessment. Preliminary results indicate that the radiometric calibration of the AVNIR-2 sensor agrees with Landsat 5 (L5) Thematic Mapper and the MEdium Resolution Imaging Spectrometer (MERIS) calibration to within 10%. The geometry accuracy of PRISM and AVNIR-2 product remains within specifications but some recommendations are provided to improve the quality of product. The preliminary results from the PRISM image quality assessment through computation of PRISM Modulation Transfer Function (MTF) raised few questions toward jpeg compression that degrades image.

Keyword: PRISM / AVNIR-2, data verification, radiometric calibration, geometric characterization and calibration, image quality.

I. INTRODUCTION

The Advanced Land Observing Satellite (ALOS) was launched on Jan 24th, 2006 onboard a Japan Aerospace Exploration Agency (JAXA) H-IIA launcher. The planned operational lifetime is 3 years, in a near-polar, Sun-synchronous orbit, at a mean altitude of 691 km. Its payload consists of three sensors: Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2), Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM), Phased Array type L-band Synthetic Aperture Radar (PALSAR). The coverage and distribution of ALOS data is done through the implantation of the ALOS Data European Node (AEDN) concept. The acquisitions performed globally are classified in four regions: Asia, Europe and Africa, America, Australia and Oceania (Figure 1.). Each Data Node is responsible for the provision of level-1 data to the users within the geographical zone covered by the Node. In that framework, the ALOS Data European Node – (ADEN) – is managed by ESA. ESA is supporting ALOS as a "Third Party Mission" which means that ESA uses its multi-mission ground systems of existing national and industrial facilities and expertise to acquire, process and distribute data. In that context, ESA-ADEN verified the ALOS data quality in order to get the approval for operating ALOS as Third party Mission and to report to JAXA on the product quality and calibration as member of the JAXA Cal/Val team.

In this frame, ESA mandated GAEL Consultant for support in the design and implementation of the verification plan for ALOS optical data.

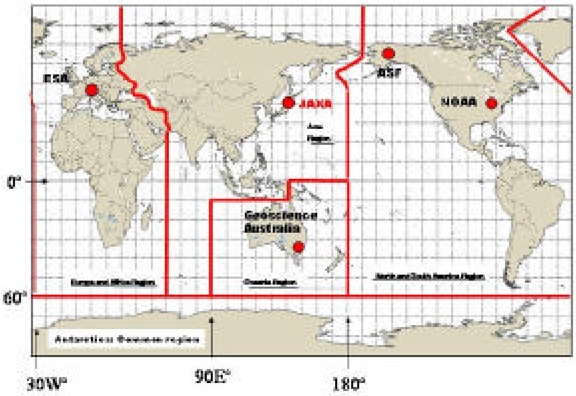

Figure 1. ALOS Data Nodes showing the various processing nodes.

The Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) on board ALOS is a multi spectral sensor operating in four spectral bands in the Visible and Near Infrared (VNIR) bands, with 10 meter spatial resolution and a ground swath of 70 km at nadir.

The Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) is a panchromatic sensor with 2.5-meter spatial resolution and a ground swath depending on acquisition mode; 35 km in triplet mode and 70 km in nadir mode. Its data will be used for extracting highly accurate digital elevation model (DEM). The PRISM has three independent optical systems for nadir, forward and backward looking to achieve along-track stereoscopy [1].
This paper describes the verification plan and proposes a compilation of results collected during the data verification period.

II. VERIFICATION PLAN DESCRIPTION

The plan has been organized according to three major milestones,; quick assessment, in depth assessment and calibration / validation such as depicted in (Figure 2. and has been defined as close as possible to the JAXA schedule.

The first stage was dedicated to quick assessment of products and aimed at providing qualitative results; to validate assessment tool, to demonstrate ALOS mission operates nominally, to check ESA processing chain. The second stage has been oriented towards in-depth control of geometry (geo location), stereoscopic capability and image quality (MTF).

The last stage has focused on radiometric calibration activities.

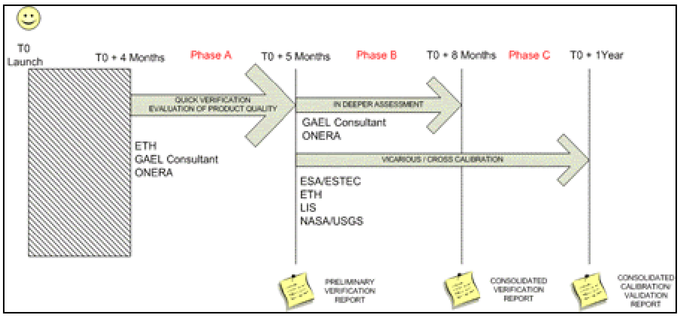

Figure 2. Scheduling of verification plan.

The ESA / ALOS science team gathered a wide panel of skilled actors, experts in the fields of radiometry (ESA, ULCO, and USGS), geometry (ETH, and GAEL Consultant) and image quality (ONERA). During this period, a major concern of ESA has been to ensure an efficient data distribution, to facilitate the sharing of reference equipments and methods. A set of tools has been proposed to support investigators in reading and inspecting ALOS products: the ALOS Expert Tool [1] and the BEAM VISAT toolbox [2].

III. Radiometric Calibration

A major part of methodology and results are explained in [7]. Purpose of this section is to make a synthesis methods and results collected in the frame of radiometric calibration assessment.

Assessments on the radiometric calibration of AVNIR-2 has been carried out through analysis of band to band calibration stability and inter calibration exercises between AVNIR-2 sensor and other Earth observation sensors; PRISM, Landsat-5 Thematic Mapper (TM), and MEdium Resolution Imaging Spectrometer (MERIS).

All radiometric calibration methodologies have been applied to AVNIR-2 dataset acquired over the western Libyan desert site (28.9°N / 23.75°E). Libya site is considered to be an invariant target that is stable and uniform with time..

AVNIR-2 dataset sample included more than 20 products observed from mid of May 2006 to the end of December 2006.

A. AVNIR –2 Band to band calibration and radiometric calibration stability

The purpose of this exercise was to coarsely evaluate the stability of the radiometric calibration and the interband calibration stability.

The methodology is based on time series analysis of band ratio of Top Of Atmosphere (TOA) reflectance. Multi date images are geometrically co-registered to a reference one. A region of interest (ROI) is defined. Digital count values are converted into TOA reflectance based on the extraterrestrial solar irradiance from [4]. The band-to-band ratio and TOA computation are then performed and the statistical mean of pixels belonging to the ROI is computed.

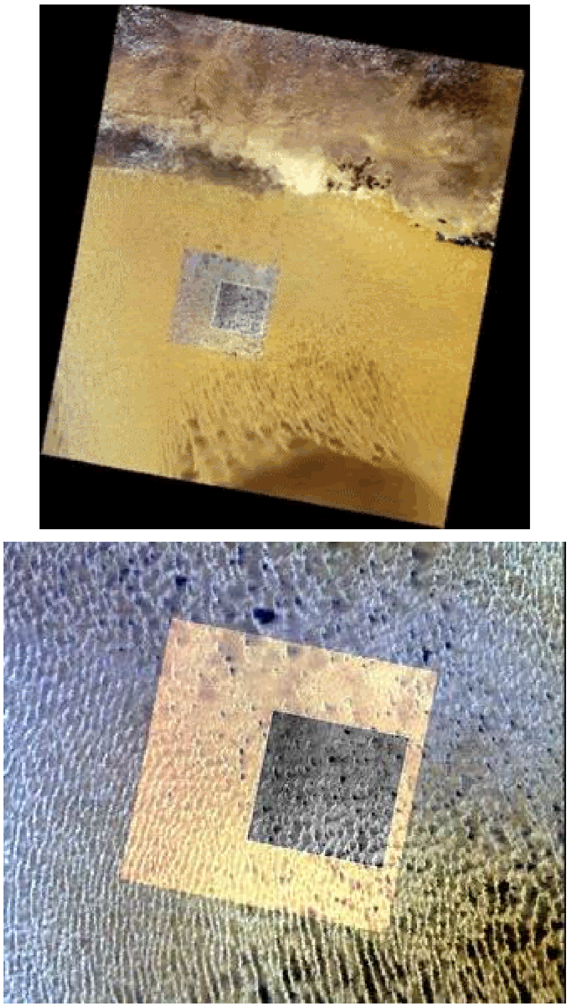

Figure 3. Libya site view with MERIS, AVNIR-2 and PRISM sensors.

TOA reflectance time series for band 1, 2, 3, 4 remains stable. Variations are respectively up to at 8.6%, 3.76%, 2, 2% and 1.82%. These results are in agreements with those obtained from band to band calibration.

This method is suitable in first stages of verification period to appreciate quality of radiometric calibration. Influence of atmosphere and Bidirectional Reflectance Distribution Function (BRDF) are not account for by this method.

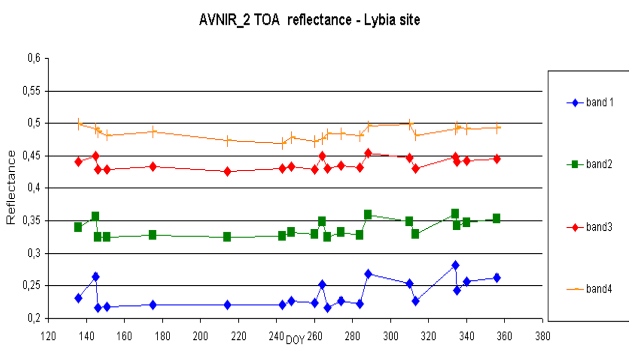

Figure 4. - AVNIR-2 toa reflectance time series.

B. AVNIR-2 data vs PRISM

The purpose of this exercise was to assess the consistency of the radiometric calibrations of PRISM and AVNIR-2 sensors.

The methodology for intercomparison between PRISM and AVNIR-2 sensors relies on simulation of PRISM TOA reflectance using AVNIR-2 measurements.

The both images are geometrically co-registered. An ROI is defined and the mean of digital counts are extracted for each band. The digital counts are converted to spectral radiance and TOA reflectance based on the extraterrestrial solar irradiance from [4]. These results are used as input for simulating the TOA reflectance as recorded with PRISM panchromatic channel. AVNIR-2 TOA reflectance at 5nm step is deduced using 'cubic-spline' interpolation. AVNIR-2 TOA reflectance spectrum is convolved with PRISM spectral sensitivity and then compared to the one directly computed using the PRISM panchromatic channel.

The PRISM and AVNIR-2 images were acquired simultaneously over Libya site on October, 1st, 2007.

The simulated PRISM TOA reflectance using the AVNIR-2 TOA reflectance spectrum is equal to 0,4384 and is very close to the value 0,4407measured in the PRISM panchromatic channel. There is a relative difference of +0.5 % between the simulated PRISM reflectance and the measured PRISM reflectance. Based on the results, it can be concluded that the two optical ALOS instruments are well inter-calibrated and provide consistent measurements.

Because method does not account for effects due to atmosphere, geometry and terrain relief, a same exercise with MERIS does not provide reliable results.

C. AVNIR-2 data vs. Landsat 5 Thematic Mapper data

The purpose of this verification item was to perform cross-comparison between measurements from ALOS AVNIR-2 and Landsat-5 (L5) Thematic Mapper (TM).

The methodology involves comparison of nearly simultaneous TOA reflectances over areas observed by the two sensors and the challenge relies on a good selection of two co-incident image pairs with comparable atmospheric conditions and observational geometries [1].

The first stage of this methodology is the conversion from digital counts to radiances using the rescaling coefficients embedded within the products. The data are eventually converted to TOA reflectances. The comparison between the two sensors is based on common areas observed near-simultaneously from which are computed reflectance relative differences.

The cloud-free L5 TM scene acquired on May 15, 2006 (9:10:12 AM) has been selected and compared to an AVNIR-2 scene acquired a day later on May 16, 2006 (8:47:16 AM).

Due to inappropriate gain setting, AVNIR-2 band 3 is partially saturated over the region of interest. However, results for the other bands are illustrated with Figure 5. and Figure 6.

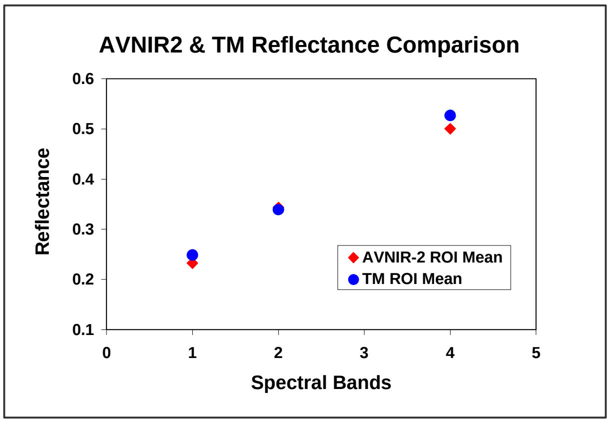

Figure 5. TM and AVNIR-2 radiance comparison..

The average relative differences in reflectance obtained from the comparison are shown in Table IV. In band 1, the average percentage difference is -6.55%; in band 2, 1.24%; and in band 4, -4.99%.

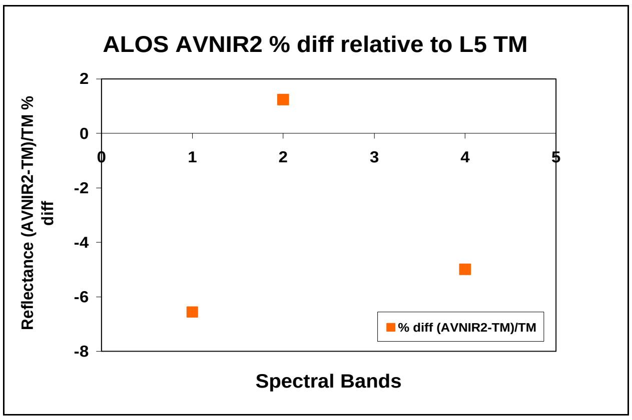

Figure 6. TM and AVNIR-2 radiance comparison., % difference.

D. Intercomparison 2: AVNIR-2 datas vs. Simulated AVNIR-2 data using AATSR, A-MODIS, POLDER-3 and MERIS data

The purpose of the verification item was to perform inter comparison of AVNIR-2 measurements and the simulated ones using multi sensor data set observations, namely, POLDER-3, Aqua MODIS (A-MODIS), AATSR and MERIS [6].

AATSR, A-MODIS and POLDER-3 data were radiometrically rescaled to the MERIS data radiometric scale following a methodology described in [4]. The rescaling to the MERIS reference sensor is based on doublets selection of concomitant identical and reciprocal observations. Such processing results into a radiometrically homogeneous dataset of AATSR, A-MODIS, POLDER-3 and MERIS data.

The homogeneous dataset is in turn used to invert a spectral BRDF model of the target on a 5-day basis. BRDFs are used to simulated narrow band TOA reflectances at 443 nm, 490 nm, 560 nm, 670 nm and 865 nm. Simulated AVNIR-2 reflectances can be obtained by convolution of the 5-day simulated spectra with the relative spectral responses of AVNIR-2 bands. To fully simulate the AVNIR-2 measurements from the 5-day spectra, a correction for O_2 and H_2O is applied by computing the gaseous transmission of these gases, in the AVNIR-2 bands, along the downwelling and upwelling optical path and using auxiliary water vapour data.

The error budget of the methodology is estimated to be about 5 %. AVNIR-2 appears to be 7.0 %, 1.1 %, 2.5 % (saturated band) and 3.5 % below the radiometric scale of MERIS in respectively band 1, 2, 3 and 4. ANVIR-2 band 3 suffers from saturation and the results for this specific band are to difficult to interpret. All AVNIR-2 bands but band 1 are within the error budget.

A degradation appears to be detected in each band. When modeled as an exponentially decrease, the time constants are respectively 13.2 %.year-1, 8.8 %.year-1, 5.9 %.year-1 and 0.1.year-1 % in band 1, 2, 3 and 4 (with respect to the radiometric scale of MERIS). The degradation figures can however only be confirmed after one full year of AVNIR-2 data over the Libyan site have been processed to ensure that such degradation is not an artifact induced by the methodology itself. Again, due to saturation in band 3, the degradation figure obtained for this band should not be considered as valid.

TOA reflectances, for all sensors AATSR, POLDER-3, MODIS, MERIS and AVNIR-2, in all bands from the UV to the NIR, over the Libyan desert, show a seasonal variation. In winter, TOA reflectances, for a given band, are higher than in summer. Our dataset of simulated AVNIR-2 data only extend over about 4 month. The degradation trends are thus to be confirmed over a period of at least a year to ensure that the degradation measured over 4 months do no result from an artifact due to the seasonal variation in the TOA signal.

TABLE I. THE COMPARISON OF AVNIR-2 TOA REFLECTANCES AND THE SIMULATED AVNIR-2 REFLECTANCES. THE INTERPRETABILITY OF RESULTS FOR BAND 3 SUFFER FROM THE SATURATION OCCURING IN THIS BAND

	Mean relative difference with simulated TOA reflectances (in %)	Standard deviation to the mean (in %)	Degradation in %.year-1
Band 1	-7.0	1.7	13.2
Band 2	-1.1	1.4	8.8
Band 3	-2.5	2.0	5.9
Band 4	-3.5	1.4	0.1

E. Intercomparison 3:AVNIR-2 data vs. Simulated AVNIR-2 data using MERIS data

The purpose of the last inter comparison exercise was to simulate the AVNIR-2 TOA reflectances using MERIS data over the Libyan desert. The methodology is based in the identification of the linear relationship between the TOA reflectance and the scattering angle.

In order to compare MERIS and AVNIR-2 data, the concept of effective wavelength is introduced.

The linear fit of the simulated AVNIR-2 data with scattering angle provides linear BRDF models associated to each AVNIR-2 spectral band. AVNIR-2 data are then reconstructed and compared with simulated values.

It is assumed here that the most significant effects of absorption are caused by water vapour absorption and that the most affected band is the AVNIR-2 band 4. When applied to the simulated AVNIR-2 data, these absorption values, we observe result of differences between actual data and simulated data derived from MERIS, in band 1, 2, 3 and 4. Their magnitude are the following ones -4.6 %, -1.4%, -5.9% and -10.3 % respectively for band 1, 2 , 3, and 4. The intercomparison in band 3 is also affected by the saturation in ANVIR-2 band 3.

F. Conclusion

The different approach notice saturation occurring in AVNIR-2 band3 which make difficult to fully appreciate radiometric calibration. AVNIR-2 switch its gain setting automatically, the procedure has been improved along with commissioning phase to avoid saturated data.

TABLE II. listed final radiometric calibration results obtained with different methods. We observe that uncertainties mainly remain regarding the radiometric calibration accuracy of AVNIR-2 band 1. Band ratio method and intercomparison 2 seems to indicate that a degradation occurs in band 1 and 2. These results concerning the degradation are still to be confirmed with longer time series since they are not confirmed by other intercomparisons. ESA/ALOS science team recommends using another vicarious calibration approach and the so-called Rayleigh calibration is an alternative.

	Inter comparison1	Inter comparison 2	Inter comparison 3
Band 1	-6.55%	-7%	-4.6%
Band 2	1.24%	-1.1%	-1.4%
Band 3	Saturation	Saturation	Saturation
Band 4	-4.99%	-3.5%	-10.3%

TABLE II. SYNTHESIS OF RADIOMETRIC CALIBRATION RESULTS.

IV. GEOMETRIC CALIBRATION

The geometric verification/calibration activities of PRISM/AVNIR-2 products encompass various items; band to band registration, absolute geo location and stereoscopic capability. This section aims at providing a short description of methodology applied and main results collected during the verification plan.

A. AVNIR-2 Band to band registration

Purpose of this verification is to check that AVNIR-2 bands of L1B2 product processed with cubic convolution re-sampling kernel can be perfectly superimposed.

Methodology applied is the sub-pixel correlation of several small images. The selection of sub-images should be done carefully in order to discard influence of vegetation and makes efficient correlation processing. Results from the whole of sub images are compared statistically. TABLE III. summarizes results.

Results demonstrate that accuracy remains within 0.4 and 0.5 pixels for band 1, 2, 3. Some inconsistencies (between 0.5 and 1 pixel) are observed when band 4 is involved into computation. Visually, Figure 7. illustrates that impact of cubic convolution on band to band registration accuracy should not be neglected.

	band1		band2		band3		band4	
	x	y	x	y	x	y	x	y
band1	x	x	0,43	0,44	0,51	0,35	0,87	0,75
band2	0,43	0,44	x	x	0,53	0,39	0,72	0,57
band3	0,51	0,35	0,53	0,39	x	x	0,71	0,54
band4	0,87	0,75	0,72	0,57	0,71	0,54	x	x

TABLE III. AVNIR-2, BAND TO BAND REGISTRATION RESUTLS.

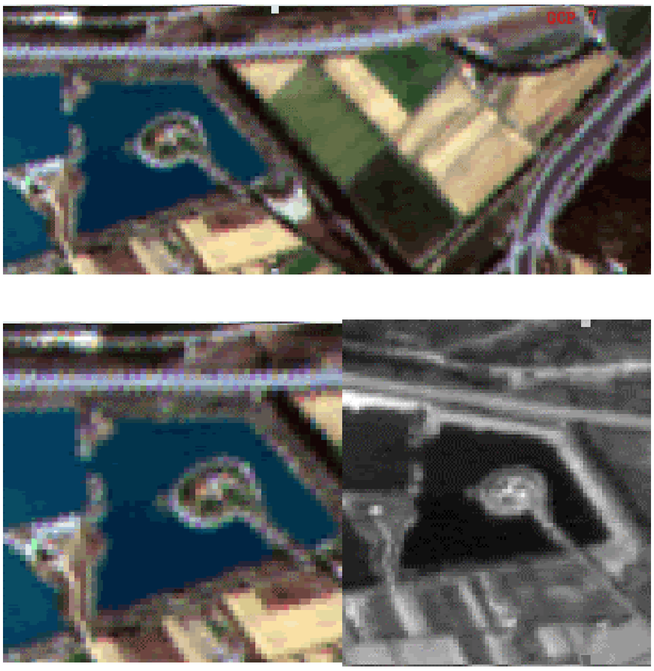

Figure 7. Upper image is a color composition of AVNIR-2 band 1,2,3. Edge response from one band to the other one is not perfectly aligned. Problem with cubic convolution and noise resulting in errors with band to band registration are observed. The bottom image, is a visual comparison between the same area views with SPOT 4 (right) and AVNIR-2 (left), it magnifies that the image edge contaminated are perfectly straight.

B. Absolute geo location accuracy

1) Methodology

The purpose of this approach is to appreciate geo location accuracy of 1B2 product such as seen by user. For this reason no sensor model is used, error is not directly link with the estimation of external and internal parameters.

The methodology relies on visual identification between a Ground Control Point (GCP) set on working data and the corresponding one set on reference data. Error in geo location are deduced from difference between GCP location and GCP location predicted with AVNIR-2 image model [8].

AVNIR-2/PRISM image model is defined according to polynomial coefficients embedded within product format and stored into the leader file. This model is planimetric and does not account for altitude; geo location values are predicted at ellipsoid level.

2) AVNIR-2, multi-date analysis

The verification exercises of geometric accuracy of AVNIR-2 L1B2 products have been performed on a multi date dataset acquired over La Crau site (43.513°N,4.875°E),and processed on September 15, 2006, Figure 10.

Reference dataset sample is a SPOT4 one. Data validation and geometric correction procedures using reference cartographic map have been performed at GAEL Consultant.

Figure 8. depicts the evolution of the root mean square from July 15 up to August 30; 2006. Accuracy tends to improve

along with time. Shift occurs mainly along with the pixel direction Figure 10. magnifies that its magnitude strongly depends on acquisition date and pointing angle. Shift in pixel direction varies from –200 m to - 1000 m.

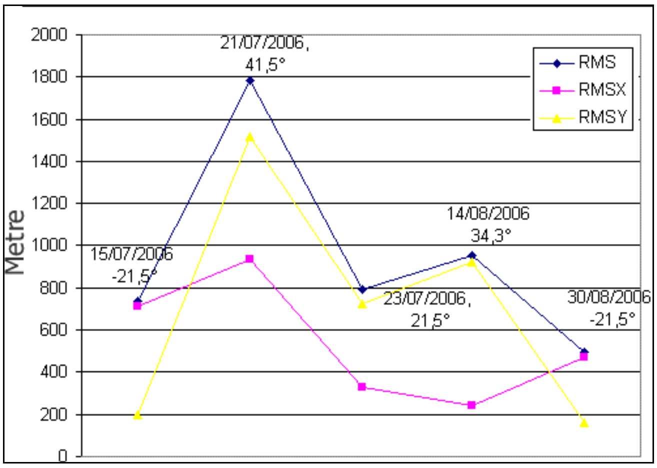

Figure 8. Geo location accuracy along with acquisition date and pointing angle. Geo locatin accuracy is strongly corrected with pointing angle.

On checking correlation (0,8578) between pointing angle and line displacement, a linear dependency is observed and a bias of about -490 m is highlighted Figure 9. . The dependency with pixel displacement needs more dataset acquired with different pointing angle to be characterized.
At the beginning of the verification period, the geo location accuracy of the first AVNIR-2 products was about 5000 m RMS. This assessment based on product processed just after processing chain improvement demonstrates that geo location accuracy has improved to be within 1000 m RMS. The study regarding dependency between pointing angle and displacement magnifies that a change of sensor alignment parameters may lead to improve significantly the accuracy. Hopefully, operational goal of 300 m (RMS) for data acquired with 0 degree of pointing angle will be reached. This verification is planned to be done in the future.

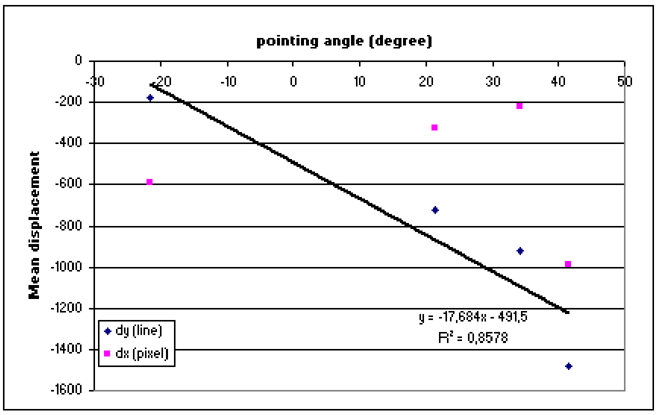

Figure 9. Mean displacements along with pointing angles. A linear dependy is observed between pointing angle and line displacement.

The depedency with pixel displacement need more data to be characterized. A biais of about 490 m will be corrected when applying correction of alignment parameter.

3) *AVNIR-2, verification of internal geometry*

Using results obtained with previous methodology, purpose of this verification was to estimate geo location error when the standard polynomial model is refined; displacements due to translation and rotation are removed using Ground Reference Points (GRP). Then, terrain relief is account using linear interpolation. With one GRP, model is refined and geo location accuracy improves from 741m (RMS) to 62 m (RMS). The use of a second GCP increases accuracy to 46 m (RMS). Displacements are mainly due to a linear shift.

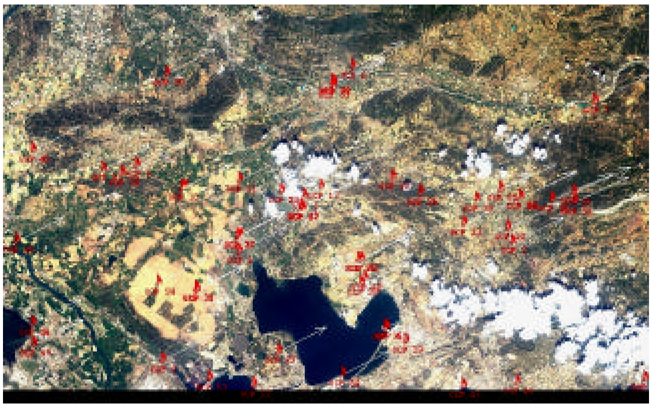

Figure 10. AVNIR-2, product geo location and error vector fields.

Linear dependency of altitude with error in pixel direction is demonstrated with Figure 12. The correlation reaches 90%. When correcting previous dx displacements from terrain relief effect, RMS reaches 18m (RMS) and 26.70m (CE90).

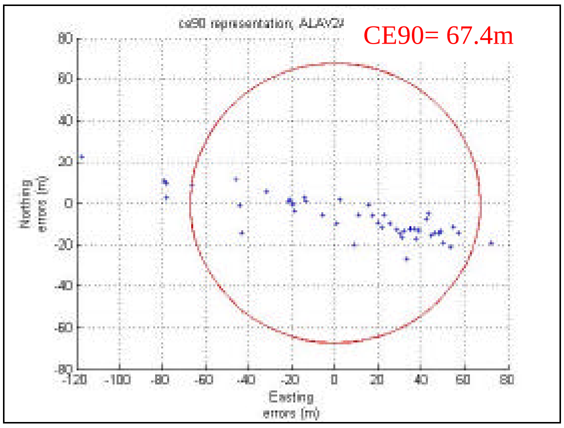

Figure 11. AVNIR-2, product geo-location, if dataset corrected from across and along track shift CE90 reach 67.4 metre.

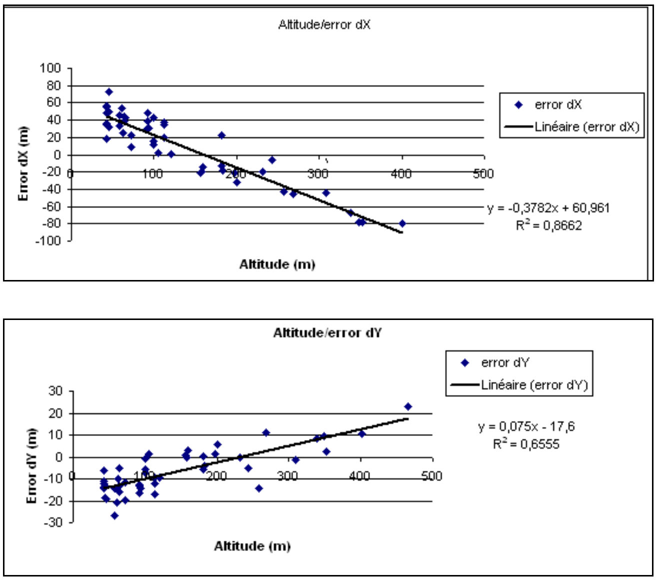

Figure 12. These plots illustrate depency of altitude with pixel error (upper) and with line error (bottom).

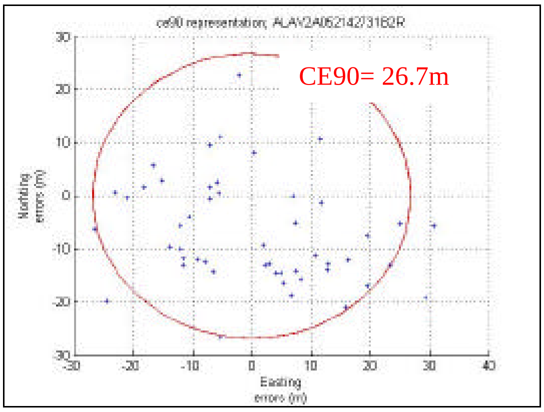

Figure 13. AVNIR-2, product geo-location (CE90), if data corrected from terrain relief effect

This exercise has been done to appreciate geo location accuracy when refining model with two ground reference points and when accounting for parallax effect. Results make us confident; these geo-location accuracy results that partially reflect internal geometry of image is below two pixels.

C. PRISM product, "dense" and "along track" study

The methodology for the assessment of product absolute geo location remains the same as the one done for AVNIR-2. The primary objectives were different and following exercises were planned to be done:

- to evaluate the alignment between CCD ("dense" study),
- to appreciate if thermal effects occurring between the begin and the end of the orbit result in distortion into the three camera ("along track" study).

"Dense" study is focused on 1B1 product level and needs to be performed in using as reference data a large sample of very accurate GCPs. For one PRISM view, GCPs should spatially cover the whole of image from one CCD. One view is the concatenation of data from four to five CCDs. This study requires a sub-pixel approach and the accuracy of image model based on polynomial coefficient is not sufficient to re estimate internal parameters of camera. So that, "Dense" study has been refocused on the assessment and monitoring of 1B1 and 1B2 product for the backward, nadir and forward views.
"Along track" study is based on comparison of geo location accuracy of two products acquired in northern and southern hemisphere. The both scenes are observed at the same date and belong to the same satellite path.

1) *Dense study*

The associated test site (44.42°N, 2.68°E) is located at the eastern part of Paris suburb area. After several GPS campaigns about 30 GCPs with an accuracy of 10 cm have been collected. The site displays mean size urban areas, agricultural fields and forest landscape.
Acquisition date of the dataset is June, 7, 2006 and processing date is September, 5, 2006

	CCD1	CCD2	CCD3	CCD4
GCP number	1	12	3	2
Mean X	52,86	48,41	51,56	62,83
Mean Y	149,07	154,56	165,49	187,45
Mean	158,17	161,98	173,34	197,71
Std X	0,00	3,12	5,50	5,04
Std Y	0,00	3,91	13,30	8,31
Std	0,00	4,52	14,39	9,48
RMS X	52,86	48,51	51,86	63,03
RMS Y	149,07	154,61	166,03	187,63
RMS	158,17	162,04	173,94	197,93

TABLE IV. GEO LOCATION ACCURACY RESULTS OF 1B1PRODUCT LEVEL, BACWARD VIEW.

	CCD1	CCD2	CCD3	CCD4
GCP number	15	8	3	
Mean X	38,893	43,688	43,43	
Mean Y	153,167	156,915	163,071	
Mean	158,0278	162,883	168,755	
Std X	2,649	4,245	1,426	
Std Y	3,197	4,519	2,909	
Std	4,151868	6,20011	3,23972	
RMS X	38,98311	43,8938	43,4534	
RMS Y	153,2004	156,98	163,097	
RMS	158,0824	163,001	168,786	no data

TABLE V. GEO LOCATION ACCURACY RESULTS OF 1B1PRODUCT LEVEL, NADIR VIEW.

	CCD3	CCD4	CCD5	CCD6
GCP number	14	7	1	5
Mean X	0,812	4,651	-0,635	-1,767
Mean Y	-0,274	4,686	-2,003	-0,69
Mean	0,856983	6,6023	2,10125	1,89694
Std X	1,375	7,27	0	0,636
Std Y	4,843	10,63	0	6,678
Std	5,034409	12,8783	0	6,70822
RMS X	1,596862	8,63045	0,635	1,87797
RMS Y	4,850745	11,617	2,003	6,71355
RMS	5,106828	14,472	2,10125	6,97127

TABLE VI. GEO LOCATION ACCURACY RESULTS OF 1B1PRODUCT LEVEL, FORWARD VIEW.

Results for each camera are not consistent. Image data from forward view offers a good geo location quality whereas it is not the case for the backward and nadir view mainly contaminated with shift along with line direction. If are considered only results with a sufficient quantity of GCPs (superior to 10), interpretation is then focused on CCD 2 of backward view and CCD 1 of nadir view and CCD 3 of forward view. For backward and nadir, displacements along the line direction is about 154 m RMS and 4,85 m (RMS) for forward view. Regarding displacement in pixel direction, the shift observed for backward view (48.51 m (RMS)) is 10 m above the one observed for nadir view, whereas no shift is observed on forward view. These deviations are probably due to rotation effect that are not corrected with image model. Nadir should offer the best geo location accuracy; hypothesis according to which the image model is misaligned may be formulated.

For PRISM product controlled at the beginning of the commissioning phase, the geo location displacement could reach 11 km. Error in line (Along Track (AT)) and pixel (aCross Track (CT)) were both about 8 km RMS for nadir view and lead to a geolocation accuracy above 10 km.

The various processing chain updates with for instance correction of 1s time delay (also seen on AVNIR-2 product) and across track misalignment have impact favorably in the improvement of product quality, as depicted in Figure 14.

Product geo location accuracy using polynomial coefficient is now below 200 m RMS. JAXA is planning new improvement, we are now waiting new products for determination of geo location accuracy specification of the 'operational' PRISM 1B1 and 1B2 products.

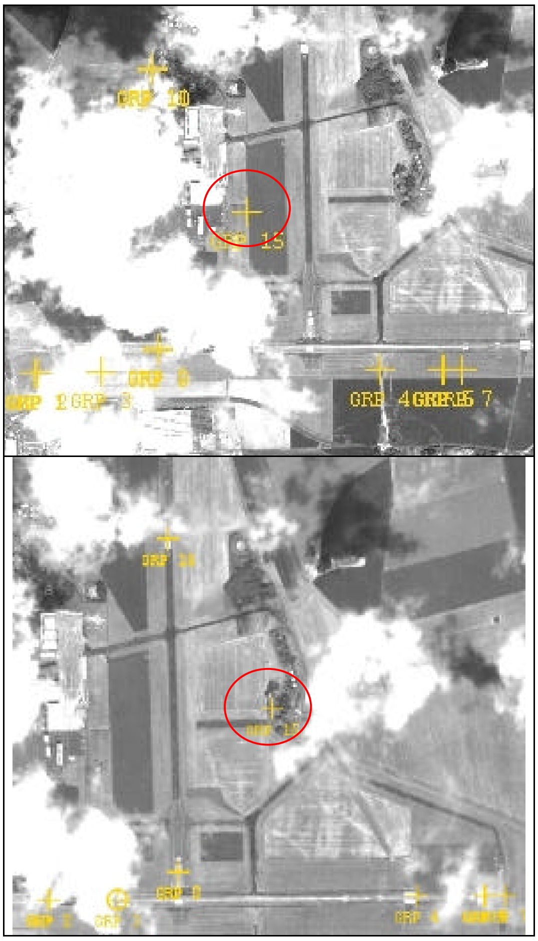

Figure 14. The upper image is from product processed prior to correction of across track and along track errors. The bottom image is from product processed after processor update. Ground control point pattern overlaid the both image. GCP 15 surrounded with red circle matches the exact geo location on the bottom image, this is not the case for the upper image.

2) Along track study

The both test fields associated to this study are Tarsus (Turkey) and Le Cap (South Africa).

Tarsus site (36.9830°N, 35.635°E,) is located between Tarsus and Adama in the southern part of Turkey, and close to the Mediterranean sea. The site displays two mid size cities and lot of open areas; agricultural fields, bare soil…

Le cap site (34.034°S, 18.391°E,) is located at Le Cap city in South Africa. The site mainly displays urban and residential areas with very well defined limits between made man features. The site is flat (60 m) very close to the sea. PRISM dataset is from observations belonging to ALOS satellite track number 257, Figure 15. Products have been acquired on the October 07, 2006.

Reference data used for this validation exercise is a dataset from IKONOS sensor. Product is orthorectified using digital elevation model (20 m grid).

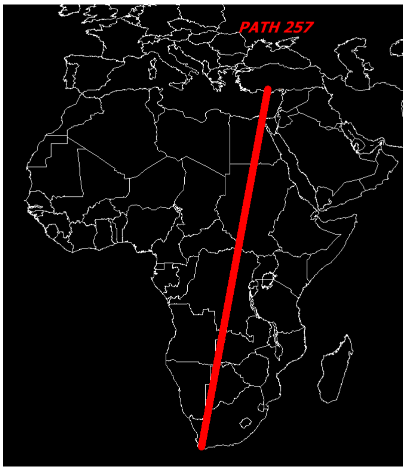

Figure 15. Northern hemisphere test field is located in Turkey (Tarsus) whereas southern hemisphere test field is location in South Afriqua (Le Cap). This both areas belong to the same satellite sub-track (path 257).

Results listed in TABLE VII. , demonstrate that with time, pixel and line displacements change significantly for the three views. The magnitude of the AT shift occurring for nadir view (absolute difference between results from northern and southern hemisphere) is quite low (26 m) in comparison with the ones occurring on backward and forward views (70 m, 136 m). For the three view, a change in CT accuracy is also observed. With time the geo location accuracy of product from backward and forward views is degrading. The pointing stability of the three radiometers is not preserved between the northern and southern hemispheres.

(Unit km)	ErrorX (CT)	Error Y (AT)	RMS
PSM F	0.022461	-0.00191	0.022633
PSM N	0.026112	-0.05929	0.064872
PSM B	-0.001280	-0.17020	0.170266

(Unit km)	Error X (CT)	Error Y (AT)	RMS
PSM F	-0.050175	-0.13725	0.14662
PSM N	-0.034037	-0.08532	0.091930
PSM B	-0.0232880	-0.10932	0.112

TABLE VII. GEOLOCATION ACCURACY RESULTS FOR PRISM 1B2 PRODUCTS ACQUIRED OVER TURKEY (UPPER) SOUTH AFRICA (BOTTOM) TESTFIELDS.

(Unit km)	Error X (CT)	Error Y (AT)	RMS
AVNIR-2 NH	-0,175232	-0,05128	0,18275
AVNIR-2 SH	-0.213699	-0.06983	0.22524

TABLE VIII. GEOLOCATION ACCURACY RESULTS FOR AVNIR-2 1B2 PRODUCTS ACQUIRED OVER NORTHERN AND SOUTHERN HEMISPHERE TEST FIELD.

(Unit km)	Error X (CT)	Error Y (AT)	RMS
Prior to August 06	1.82689	7.66134	7.87632
After August 06	-0.034037	- 0.08532	0.091930

TABLE IX. GEOLOCATION ACCURACY RESULTS FOR PRISM 1B2 PRODUCTS (NADIR VIEW) ACQUIRED OVER SOUTHERN HEMISPHERE TEST FIELD. TABLE COMPARE S ACCURACY BETWEEN TWO DIFFERENT PROCESSING VERSIONS.

D. Stereoscopic capabilities

1) DSM production with PRISM stereo views

ETH Zurich Laboratory managed the verification stage dealing with the evaluation of PRISM stereoscopic capability.

The reference data used for this validation exercise are from ESA geometric test field based in Italy, Piemont (44.5°N ,7.3°E) and located at the edge of Mont Vizo (Alpes).

Such as seen previously, image orientation procedure based on polynomial method does not offer a good quality.

Prior to digital surface model (DSM) generation, an accurate image orientation procedure must be applied through the estimation of internal and external orientation parameters.

The external orientation modeling takes into account physical properties of the sensor and satellite position.. As part of adjustment, the Direct GeoReferencing (DGR) Model (DGR) and the Piecewise Polynomial Model (PPM) (with stochastic exterior orientation) approaches are adopted for modeling the sensor trajectory. Camera interior orientation parameters are not given to the community. Estimation of these parameters is performed through self-calibration procedure during bundle adjustment.

A part of 39 the Ground Control Points (recorded with differential GPS techniques) are used as check points, and the other ones as control points for refinement of bundle adjustment procedure and estimation of exterior (and possibly) interior orientation parameters. GCP coordinates are introduced as observations into the adjustment and constrained stochastically, according to their measurement and definition accuracy.

ETH methodology and results for calibration validation of PRISM sensor model are more detailed in [9]. TABLE X. listed results of exterior and interior orientation procedures according to sensor model used.

GCP no	5	5	9	9
Model	DGR	PPM-2	DGR	PPM-2
RMSExy	2.34	2.58	2.22	2.30
RMSEz	1.05	2.36	1.03	2.35

TABLE X. RESULTS FROM EXTERIOR AND INTERIOR ORIENTATION WITH DGR AND PPM-2 MODEL FOR 5 AND 9 GROUND CONTROL POINTS. THE RESULTS ARE IN METER.

An overview of the accuracy results is given in TABLE X. With the DGR model, the RMSE values in planimetry are at sub pixel level (below 2.5m) with five GCPs. The use of nine GCPs do not improve results.
The accuracy in height (RMSEz) from DGR model is about 1 m with five GCPs and the use of nine GCPs do not improve accuracy. With PPM-2 model results, orientation procedure using five GCPs provides accuracy in height on the order of 2.3 m. The use of nine GCPs do not improve the accuracy.

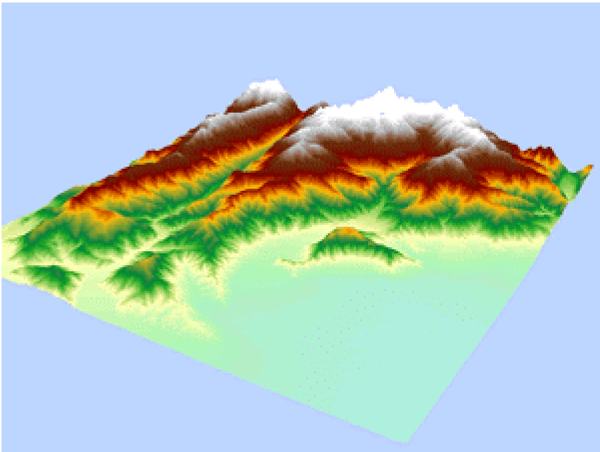

Figure 16. DSM Piemonte (Italy), generated by ETH.

Follow this procedure, a DSM of Piemont has been produced (Figure 16.).

2) Verification of PRISM DSM generated by ETH

Purpose of the verification exercise was to evaluate the z accuracy of generated PRISM DSM.
Reference altitudes retrieved have been retrieved from ground control point recorded with Differential Global Positioning System.. On the other hand, a DSM generated using SPOT 5 HRS has been used.
The methodology used this both reference dataset independently. At the end of the altitude accuracy estimation, results from the two methodologies are compared.
Statistical comparison have been performed according to altitude class; class 1 < 400 m, 400 <Class 2 <800 m; 800 <class3<100 m, 100 < class 4.
Firstly, a visual inspection of altitude curves computed on the both DSM (PRISM and SPOT), highlight that the both altitude curves perfectly match. Figure 17. illustrates that more details are provided with altitude curves computed using PRISM DSM than using SPOT one.

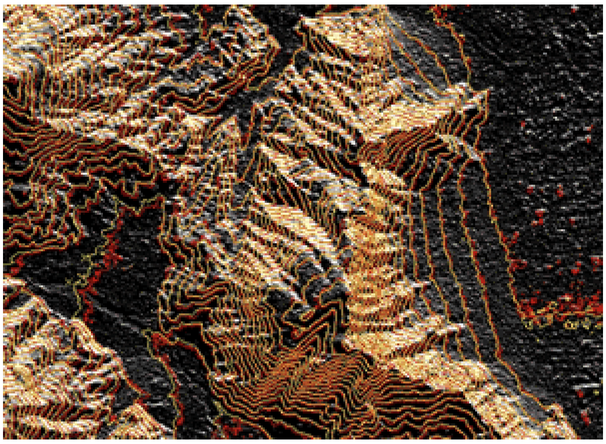

Figure 17. DEM Piemonte (Italy) in background, altitude curves, PRISM (red), SPOT (yellow).

An overview of results is given in TABLE XI. Obvisouly, the accuracy in height is varying according to altitude class. For a flat terrain relief , we observed that first approach provides an accuracy of about 1.5 m.
The second comparison confirms that DSM accuracy of PRISM remains within specification. Because SPOT DSM is of lower resolution, results do not reflect the real accuracy of PRISM DSM (3.6 m for altitude class 1)

	Altitude Class		
Données	1	2	3
Moyenne Delta-GPS-ETH	-0,83	-0,906331438	-8,85
Ecartype Delta-GPS-ETH	1,242801495	1,656057706	10,71991915
Min Delta-GPS-ETH	-2,2	-2,7	-24,6
Max Delta-GPS-ETH	1,7	3,471	-0,6
RMS	1,49447501	1,88784634	13,90104912

	Altitude Class			
Données	1	2	3	4
Moyenne Delta-SPOT-ETH	-0,908333333	-1,65695	-7,82375	-5,5526
Ecartype Delta-SPOT-ETH2	3,462095065	5,206658727	2,266569563	10,44844753
Min Delta-SPOT-ETH3	-8,015	-11,302	-10,59	-23,099
Max Delta-SPOT-ETH4	2,953	12,733	-5,646	3,854
RMS	3,579269714	5,463952636	8,14545282	11,83221968

TABLE XI. PRISM DSM VERIFICATION WITH REFRENCE ALTITUDE VALUES FROM GPS (UPPER) SPOT 5 DATA (SPOT5).

V. IMAGE QUALITY EVALUATIONS

Image quality evaluation of PRISM and AVNIR-2 images have been done through visual inspection task and the measurement of absolute Modulation Transfer Function estimation (MTF).

A. Visual inspection

Visual inspection has been performed systematically on dataset received from JAXA.
Image quality problems have been mainly observed when inspecting PRISM image. Figure 18. , Figure 19. , Figure 20. illustrates image quality problem found.

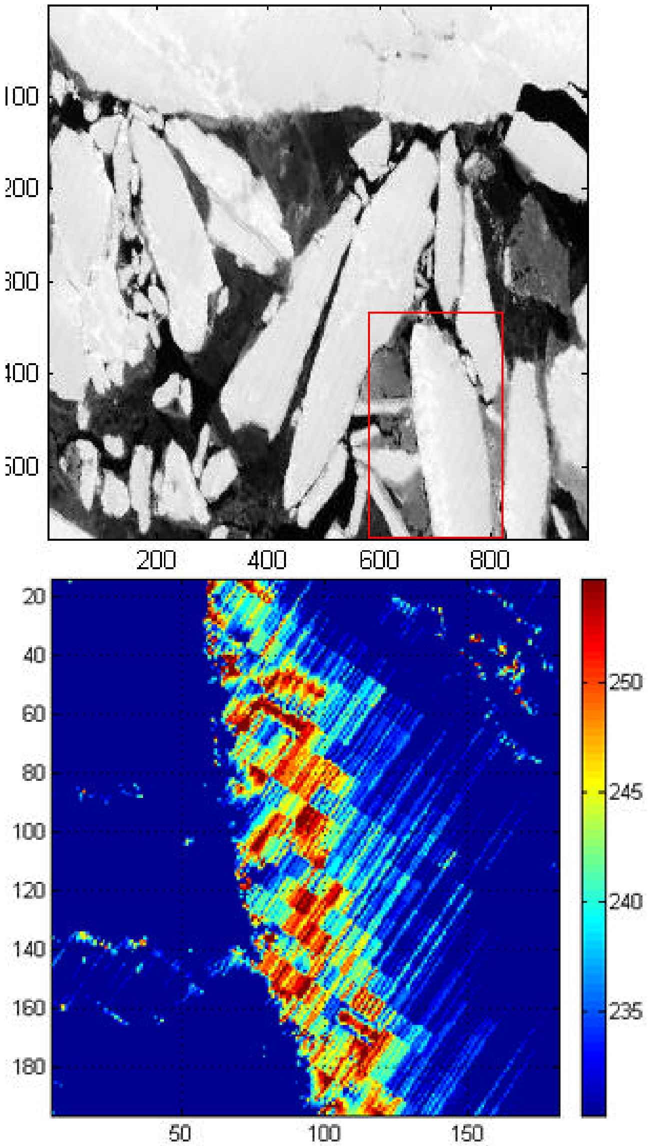

Figure 18. PRISM; compression effect. Upper image is a part of the scene, saturation and blocking artefacts are oberved close to white gray level. The bottom image, is a part of the first image with a threshold of 230 applied. Compression kernel is highlites (block) and pixel from odd and even detectors are not compressed separately.

Figure 19. PRISM Relative calibration problem due to optical black. Altenare brighter and darkrt

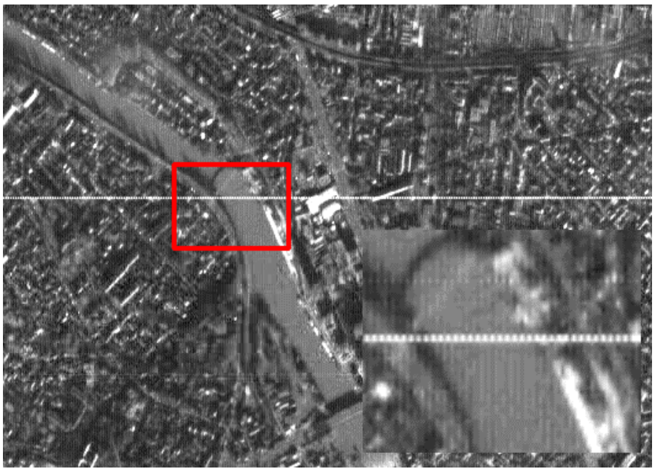

Figure 20. Image artifact know as 'detector over saturation'; the width in accros track direction depends on the size of bright source, it makes vary up to 15 pixels and the saturation can contaminate the whole of odd or even detectors.

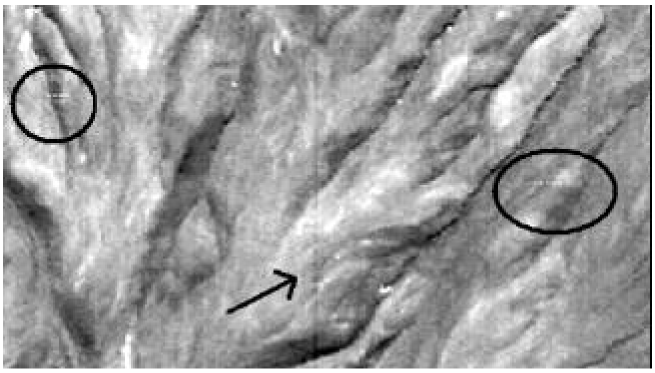

Figure 21. Missing data problem (circle) detected on AVNIR-2 image more likely due to the lost of data during do<wnlink. A dark column at the scne center of the quick look higkitht mis calirated or inoperant detecor.

B. MTF

The purpose of modulation transfer function is to evaluate and quantify capability of PRISM instrument discern ground features. Various methods are usually applied to measure MTF; point source, step edge and bi-resolution methods [10].

ONERA team applied step edge method on artificial target for PRISM MTF measurements. On the other hand, AVNIR-2 MTF measurements have been derived using the bi resolution method.

1) PRISM MTF

The artificial target used in the frame of step edge method is a checkerboard target located at Salon-de-Provence (4.875°E, 43.513°N) and sized 60x60 m has been laid out. The computation have been performed on PRISM/AVNIR-2 scenes acquired on June and September 09, 2006. Product level for which no geometric correction such resampling has been applied to the image has been selected (1B1 product level).

Unfortunately, for observation dated September only the PRISM backward view was suitable.

MTF results computed on the both backward images have been compared to determine; if MTF remained stable along with time, if the model applied is suitable and to determine a way of overcoming saturation.

The main conclusions of this exercise were that the model applied was suitable. ONERA team observed PRISM cross track MTF was stable whereas the along track MTF was changing between the both observations. When applying model to nadir and forward images dated of June, cross track MTF results remained consistent with previous ones whereas along track MTF results differed surprisingly from one PRISM view to the other one.

Figure 22. Illustrates along and across MTF measurements curves along with normalized spatial frequencies. Again, along track results are below across track ones.

ONERA team made hypothesis according to which compression may disturb MTF assessment. Its value at Nyquist frequency (Fe=0.5) is very low and out of pre flight specifications (>0.2).

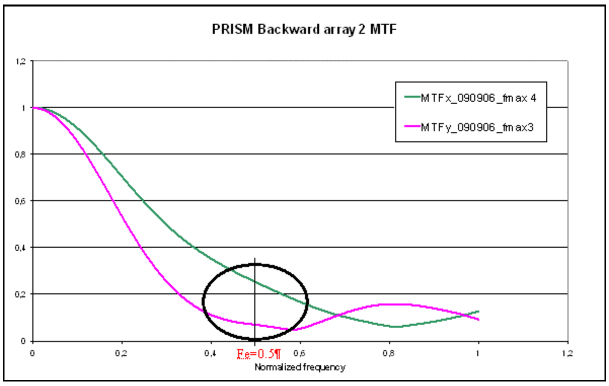

Figure 22. PRISM Backward view, MTF curve along with normalized spatial frequency, cross/along track MTF are estimaed to be 0.25 and 0.07. Along track MTF is falling down more faster than across track MTF.

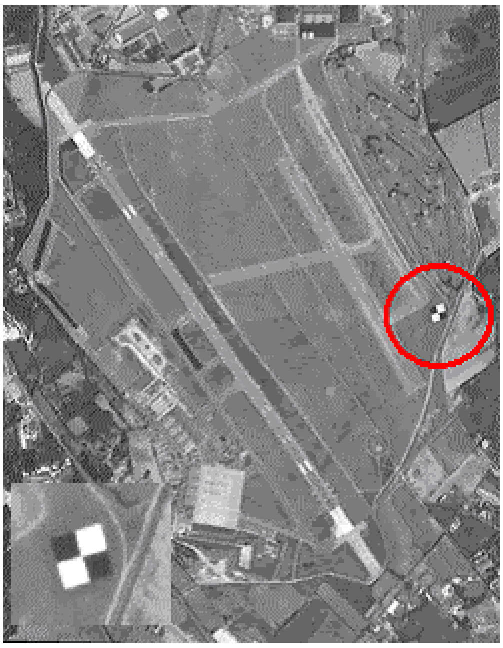

Figure 23. PRISM view of Salon –de-Provence airport and checkerboard used for measuring PRISM / AVNIR-2 MTF.

	Cross track MTF	Along track MTF
Measured	0.25	0.07
Pre flight	0.29	0.23

TABLE XII. PRISM MTF MEASUREMENTS AT NYQUIST FREQUENCIES AND COMPARISON WITH PRE FLIGHT SPECIFICATIONS.

2) AVNIR-2 MTF

The bi resolution method has been applied to a couple of PRISM/AVNIR-2 scenes acquired on June 07, 2006 over ONERA / Pirrene test field.

The staggered alignment of AVNIR detectors makes difficult to compute MTF on level 1B1. A dedicated processing has been implemented to re align image pixels without resampling and so that conserve a raw geometry.

As far as AVNIR Ground Sampling Distance (GSD) is close to 10 m; it is very difficult to use adequate artificial target to measure MTF. For such GSD, an adequate method is the Low Resolution/High Resolution method.

LR/HR method, so called bi-resolution method, LR is AVNIR-2 and HR is PRISM, requires two images of the same landscape taken in the same spectral band with two GSD. Similar radiometries are required between spectral bands.

Results of the methodology are listed in TABLE XIII. ,. They are globally in agreement with the pre-flight measurements and within the specifications (marginally for band 1 in along-track direction).

Due to the measurement method and saturation observed on image band number 4, no MTF assessment has been performed.

MTF at Nyquist frequency	Band 1	Band 2	Band 3
CT MTF (x)	0.51	0.50	0.48
AT MTF (y)	0.24	0.30	0.32
CT MTF (pre-flight)	0.54	0.51	0.48
AT MTF (pre-flight)	0.35	0.34	0.36
Specification	>0.25	>0.25	>0.25

TABLE XIII. AVNIR-2 BAND 1 2 3 MTF AT NYQUIST FREQUENCY WITH BI RESOLUTION METHOD AND COMPARISON WITH PRE FLIGHT MEASUREMENT AND SPECIFICATIONS.

3) *Conclusions*

A lot of work has been done for on orbit MTF of ALOS optical sensors. Nevertheless, the PRISM MTF should be consolidated and completed. For PRISM, methodology needs to be played back on image free from cloud and acquired with a suitable gain setting to avoid saturation. Hypothesis according to which compression may disturb MTF has been formulated. For AVNIR-2, the on orbit MTF measurements are in agreement with the pre flight measurement for band 1,2, 3 and specification are globally met.

VI. CONCLUSIONS

We have described methods used to implement the ESA verification plan of the ALOS optical data. The ESA ALOS science team has benefited from a large body of research on radiometric calibration, geometric calibration and image quality. A fruitful cooperation and synergy have been created. The study presents early results on PRISM / AVNIR-2 data quality. It forms a good point to exchange with JAXA and to highlight the accuracy ESA users may expect. More data and research are now needed to confirm trend in radiometric and geometric calibration and to characterize image artifacts.

This paper demonstrates major improvements have already been accomplished since the launch of ALOS spacecraft. In the future, our methodologies will be refined and played back.

ACKNOWLEDGMENT

The authors acknowledge JAXA for data provision and support.

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