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Final calibration/validation report

AVNIR-2

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TABLE OF CONTENT

DISTRIBUTION LIST	2
DOCUMENT CHANGE LOG.....	2
TABLE OF CONTENT.....	3
LIST OF FIGURES.....	3
LIST OF TABLES.....	4
1 INTRODUCTION.....	5
1.1 PURPOSE.....	5
1.2 DOCUMENT PLAN	5
1.3 APPLICABLE DOCUMENTS.....	5
1.4 REFERENCE DOCUMENT	5
1.5 SUMMARY	7
2 PRODUCT FORMAT	8
3 PRODUCT GEOMETRY	9
3.1 THE GEODETIC ACCURACY OF 1B2G PRODUCT LEVEL	9
3.2 THE ACCURACY IMPROVEMENT OF 1B2R PRODUCT LEVEL	10
3.3 THE GEO LOCATION ACCURACY STABILITY FOR A LONG TERM ACQUISITION PERIOD	14
3.4 BAND TO BAND REGISTRATION.....	16
4 PRODUCT RADIOMETRIC CALIBRATION.....	17
4.1 AVNIR –2 BAND TO BAND CALIBRATION AND RADIOMETRIC CALIBRATION STABILITY	17
4.2 AVNIR-2 DATA VS PRISM.....	20
4.3 AVNIR-2 DATA VS. LANDSAT 5 THEMATIC MAPPER DATA.....	21
4.4 INTERCOMPARISON 2: AVNIR-2 DATAS VS. SIMULATED AVNIR-2 DATA USING AATSR, A-MODIS, POLDER-3 AND MERIS DATA.....	22
4.5 INTERCOMPARISON 3:AVNIR-2 DATA VS. SIMULATED AVNIR-2 DATA USING MERIS DATA.....	24
4.6 RESULTS SYNTHESIS FROM THE THREE INTER-COMPARISON METHODS.....	25

LIST OF FIGURES

fig. 1 - Multi date evolution of the 1B2R product geolocation accuracy.....	11
fig. 2 Multi date analysis of across track Shift wrt pointing angle (metre unit).	12
fig. 3 - Error dX along with altitude.	13
fig. 4 - CE90 graphic plots.	14
fig. 5 - Scene Shift observed over Turkey site.....	16
fig. 6 - Libya site view with MERIS, AVNIR-2 and PRISM sensors.	17
fig. 7 - TOA reflectance and diffusion.	18
fig. 8 - AVNIR-2 multi date TOA reflectance series.....	18
fig. 9 - AVNIR-2 multi date interband ratio series.....	19
fig. 10 - MERIS and ALOS PRISM / AVNIR-2, TOA comparison.	21
fig. 11 - AVNIR-2 and simulated PRISM data.....	21
fig. 12 - TM and AVNIR-2 radiance comparison.....	22
fig. 13 - TM and AVNIR-2 radiance comparison., % difference.	22
fig. 14 - Linear interpolation between the 5 day narrow band TOA reflectances.....	23
fig. 15 - The simulated AVNIR-2 data using the MERIS data.	24



LIST OF TABLES

table 1 - The 1B2G data set for the assessment of the geodetic accuracy.	9
table 2 - The results of assessment on the geodetic accuracy of 1B2G dataset (metre unit).	9
table 3 - The 1B2R data set for the assessment of the geodetic accuracy.....	10
table 4 - The results of assessment on geo- location accuracy of 1B2R product level (metre unit).	11
table 5 - ALAV2A03625380 product; geo-location accuracy results (metre unit).....	13
table 6 - ALAV2A03625380 product; geo-location accuracy results (with correction).....	14
table 7 - The 1B2R data set for the assessment of the geolocation accuracy stability.....	15
table 8 - The results of assessment on the geolocation accuracy stability (metre unit).	15
table 9 - Dataset used for assessment of interband registration accuracy.	16
table 10 - ALAV2A03579270 product; Band to band registration results.	16
table 11 - Multi date TOA reflectance analysis, linear interpolation results.	19
table 12 - The comparison of AVNIR-2 TOA reflectances and the simulated AVNIR-2 reflectances.	24
table 13 - Synthesis of radiometric calibration results.....	25

1 INTRODUCTION

1.1 Purpose

Purpose of this document is to report to ESA consolidated results collected during ALOS / AVNIR-2 data verification.

1.2 Document plan

- Chapter 1 Introduction and results summary,
- Chapter 2 Proposed some comments on product format,
- Chapter 3 Presents results from product geometry accuracy; absolute location, relative location,
- Chapter 5 Presents results from activities regarding radiometric relative and absolute calibration accuracy.
- Chapter 4 Results on image quality, especially from modulation transfer function computation,

1.3 Applicable documents

- A-1 Contract - AMALFI Multi-Mission Facility
19284/06/I-LG
14 February 2006
ESA-ESRIN

1.4 Reference document

- R-1 GAEL-P224-DOC-003 *ALOS optical data verification*
Verification and Implementation Plan
Issue 1, Revision 3 – March 16th, 2006
GAEL Consultant
- R-2 *NEB 00016* ALOS/AVNIR-2 Level 1 product format description
Rev G - August, 2005
JAXA
- R-3 GAEL-P224-DOC-003 *ALOS optical data verification*
Verification and Implementation Plan
Issue 1, Revision 3 – March 16th, 2006
GAEL Consultant.
- R-4 GAEL-P224-DOC-004 *ALOS Consolidated verification report*
AVNIR-2
Issue 1, Revision 0 – November 23th, 2006
GAEL Consultant.
- R-5 Saunier S, Goryl P, 2006
Meris Absolute Geo location status,
ESA PCS documentation
<http://earth.esa.int/pcs/envisat/meris/documentation/>



- R-6** Cross Calibration of the Landsat 7
ETM+ and EO ALI Sensor
Gyanesh Chander, David J Meyer, and Dennis L Helder
IEEE TOGARS – December, 2004.
- R-7** Bouvet M, 2006,
Intercomparison of multispectral imagers over natural targets,
IGARSS 2007 proceedings.
- R-8** Bouvet M., Goryl. P., Santer R., Chander G., Saunier S,
Preliminary radiometric calibration assessment of ALOS
AVNIR-2,
IGARSS 2007 proceedings.
- R-9** Saunier S., Goryl. P and al
The contribution of ESA to the ALOS PRISM / AVNIR-2
commissioning phase
IGARSS 2007 proceedings.
- R-10** Thuillier, G., M. Hersé, P. C. Simon, D. Labs, H. Mandel, D.
Gillotay, and T. Foujols, 2003, "The solar spectral irradiance
from 200 to 2400 nm as measured by the SOLSPEC
spectrometer from the ATLAS 1-2-3 and EURECA missions,
Solar Physics, 214(1): 1-2

1.5 Abbreviations and Acronyms

This section controls the definition of all abbreviations and acronyms used within this document. Special attention has been paid to adopt abbreviations, acronyms and their definitions from international standards as ISO, ANSI or ECSS.

ALOS	Advanced Land Observing Satellite
ANSI	American National Standards Institute
AUIG	ALOS User Interface Gateway
AVNIR-2	Advanced Visible and Near Infrared Radiometer type 2
CAL/VAL	Calibration and Validation
CCD	Couple Charge Device
CEOS	Committee on Earth Observation Satellite
DEM	Digital Elevation Model
DSM	Digital Surface Model
ECI	Earth Center Inertial coordinates
ECR	Earth Centered Rotating coordinates
ECSS	European Cooperation for Space Standardization
ESA	European Space Agency
GCP	Ground control point
GPS	Global Positioning Satellite
GPSR	GPS Receiver

ISO	International Organization for Standardization
JAXA	Japan Aerospace Exploration Agency
MTF	Modulation Transfer Function
NASDA	National Space Development Agency of Japan
PCD	Payload Correction Data
PI	Principal Investigator
PRISM	Panchromatic Remote-sensing Instrument Stereo Mapping
TKSC	Tsukuba Space Center
UTC	Universal Time Coordinated

1.6 Summary

This document is the final report related to ESA contribution to ALOS PRISM/ AVNIR-2 calibration / validation activities. The last results from geometric and radiometric activities are reported here, for more details on method applied and image quality results, the reader is invited to refer to [R-4].

Geometric activities demonstrate that the pointing accuracy has improved over time and processing software update. **The orbit shift in time has been significantly reduced and is now below the pixel.** The geo location accuracy of the **1B2R product reaches 50 metres (RMS)**. The internal accuracy which reflect **the image geometry is evaluated to be around 18 metres (RMS)** .

Regarding the 1B2G product level, the geolocation accuracy of the map oriented products are in the same order of the one computed for 1B2R product level.

The geo-location remain stable for a long acquisition period (one orbit). It means that the geolocation model embed within product format account for the pointing accuracy variation that occurs for a long acquisition period.

Indeed, some assessments to compute the interband registration have been done; results are agreeing together to report that **the band-to-band registration remains mainly 0.5 pixel.**

Radiometric activities performed on stable and invariant test site demonstrated that the radiometric band to band calibration and **radiometric calibration remains very stable over one Year**. In addition, the sensor inter comparison procedures have been set up and applied to a same dataset. The conclusions of these three methods are also agreeing together; the radiometric calibration of AVNIR-2 is satisfactory, given the error bar of the methodologies which is estimated to be around 5 %.

2 PRODUCT FORMAT

The AVNIR-2 products are processed into CEOS format, and external ASCII file ('summary.txt') is embedded within the product.

Some of remarks listed just here below have been previously raised and are more documented into the previous document ([R-4]).

Encoding

- A mixing between "little endian" and "big endian" encoding system is observed from some values stored into the product such as those stored into the ancillary information files map projection.

Radiometric transformation

- The rescaling gain and offset are not directly written into 'summary file' but only into scene header record. The rescaling gain and offset is changing along with time and geographical position. It is not ease to convert from AVNIR-2 digital number to radiance values,
- AVNIR-2 product is proposing sun zenith and azimuth angles. No information is provided on satellite zenith and azimuth angles. High pointing angle of AVNIR-2 instrument makes the correspondence between satellite heading and satellite azimuth values not reliable anymore,
- The time information is not preserved with 1B2 product level. To rebuild a viewing geometry of one observation, it is mandatory to use twice the 1B1 and 1B2 product level,
- Band solar spectral irradiance values are not proposed with the standard L1B2 AVNIR-2 product as done with Landsat CEOS format.

Geometric transformation

- The product resampling grid is not build with regard to the pointing angle; the whole of AVNIR-2 products we investigated were processed using a geometric sampling step of 10 meter. For observations taken with an important pointing angle, the 10-meter resolution hypothesis is not reliable anymore.
- A polynomial transformation for geo coding purpose is proposed with the both 1B1 and 1B2 levels. From a line/pixel position the geographic coordinates of the pixel can be retrieved. Coordinates are given at ellipsoid level and so that do not embed altitude parameter. AVNIR-2 observations performed with high de-pointing angle induces parallax effect. The polynomial transformation does not account for parallax effect.
- Geographic information, scene center and corner coordinates express into decimal degree unit are given within 'summary file'. Theses values are given to within 10 e-3 degrees. It to an accuracy of about 110 meters.

3 PRODUCT GEOMETRY

This sections presents the assessment results regarding the product geolocation accuracy. This final stage of verification period has focused on following items:

- To check the accuracy of geocoded product (1B2G product level),
- To appreciate the improvement of geo location accuracy along with processing software update,
- To monitor the geo location accuracy for a long term acquisition period.

Except for the first point, the geographic information is retrieved from a geo location model based on polynomial coefficients embedded within product format.

3.1 The geodetic accuracy of 1B2G product level

The 1BG product level is free from geometric distortions. The image orientation is 'North up', a geo coding procedure has been applied; the geographic information is derived from the upper left geographic coordinates and is associated to each image pixel. The terrain elevation is not taking into account.

The working data used for performing this verification item are listed in table just here after.

Observation date	Scene Id	Pointing angle	Path	Orbit data Precision	Attitude data Precision	Site
27-mars-07	ALAV2A035792720	0	348	Precision	AOCS Precision	La Crau

table 1 - The 1B2G data set for the assessment of the geodetic accuracy.

The method for geo location assessment is semi-automatic; an operator sets Ground Control Points (GCP) manually on the working data. GCP geographical coordinates are matched with the ones belonging to the reference data. Operator adjusts the GCP location for ensuring the best matching between the both views. To discard error due to terrain relief, GCP are belongs to low elevated areas.

For observation made over Piemont, reference data are from GPS measurements. On the other hand, for observation of La Crau, reference data are from post-processed SPOT 4 data.

Scene Id	ALAV2A035792720
GCP number	7
Mean X	-44,395
Mean Y	-5,529
Mean	45,261
Std X	11,35
Std Y	6,368
Std	11,062
RMS X	45,823
RMS Y	8,433
RMS	46,601

table 2 - The results of assessment on the geodetic accuracy of 1B2G dataset (metre unit).

The 1B2G product has been prepared on January 2007 with software version 36453060752. table 2 lists the assessment results expressed in meter unit.. For a same observation, the geo location accuracy of 1B2G product level is in the same order of the one computed using **1B2R product level**.

On December 2006, parameters of geometric model changed significantly to improve pointing accuracy. To assess the impact of such modification on product quality, the same products have been re-ordered on January 2007 and processed with software version 45003070020. The verification procedure has been played back, **the assessment results highlighted that the geo location accuracy is remained similar although an update of processing software has been done.**

3.2 The accuracy improvement of 1B2R product level

Input dataset

The 1BR product level is free from geometric distortions. Image product is 'path oriented'. Products are not corrected from effects due to terrain relief. The computation of RMS is based on results from low altitude (<50m) GCP dataset sample located over flat area.

Some details on input dataset are listed in table just here after (table 3). The preparation date is from September 06' (Launch + 9 Months) up to April 07' (Launch + 15 Months).

Observation date	Scene Id	Pointing angle	Path	Orbit data Precision	Attitude data Precision	Processing date	SW version
15-juil-06	ALAV2A025142730	-21,5	317	Precision	OnSite Precision	19-sept-06	36007060006
21-juil-06	ALAV2A026022690	41,5	344	Precision	AOCS Precision	19-sept-06	36007060006
23-juil-06	ALAV2A026312710	21,5	331	Precision	OnSite Precision	19-sept-06	36007060006
14-août-06	ALAV2A029522700	34,3	338	Precision	OnSite Precision	19-sept-06	36007060006
30-août-06	ALAV2A031852730	-21,5	317	Precision	AOCS Precision	19-sept-06	36007060006
15-oct-06	ALAV2A038562730	-21,5	tbd	Precision	OnSite Precision	16-janv-07	36453060752
27-mars-07	ALAV2A062342620	0	tbd	Precision	OnSite Precision	24-avr-07	45003070020
17-avr-07	ALAV2A065402730	-21,5	tbd	Precision	OnSite Precision	24-avr-07	45003070020

table 3 - The 1B2R data set for the assessment of the geodetic accuracy.

AVNIR-2 1B2R product geo location

The product geo location accuracy has improved along with time and processing chain SoftWare version (table 4). The across track and along track shift have been reduced significantly when processing software update has occurred in December 06' (fig. 1).

JAXA team adjusted instrument alignment parameters in order to reduced bias occurring between observations made with different pointing angles.

The product dated of March 24, 07' has been acquired with 0 pointing degree. In this case, the parallax effect is strongly reduced, the shift according to pixel direction reaches 3.5 metres. The shift in time is about 8 metres, again below the pixel. The magnitude of this shift is close to the one measured for product dated of April 17, 2007. **It demonstrated the stability of the orbit and attitude determination system.**



Acq Date	15-juil-06	21-juil-06	23-juil-06	14-août-06	30-août-06	15-oct-06	27-mars-07	17-avr-07
Processing Date	19-sept-06	19-sept-06	19-sept-06	19-sept-06	19-sept-06	16-janv-07	24-avr-07	24-avr-07
GCP number	65	68	16	5	49	5	12	12
Pointing angle	-21,5	41,5	21,5	34,3	-21,5	-21,5	0	-21,5
Mean X	-712,85	-986,388	-326,509	-221,083	-448,551	-247,554	3,506	-67,049
Mean Y	-199,07	-1482,526	-721,053	-923,874	-173,347	34,66	-8,273	-8,15
Mean	740,455	1781,196	791,771	955,891	481,554	250,399	43,693	68,207
Std X	45,069	44,838	20,223	100,067	46,901	55,377	48,031	3,956
Std Y	13,705	7,167	7,927	42,747	14,403	19,183	6,216	9,446
Std	41,76	21,470	10,429	23,262	42,021	56,732	22,743	3,831
RMS X	714,273	987,406	327,135	242,675	450,996	253,6722	48,159	67,165
RMS Y	199,541	1482,544	721,097	924,862	173,944	39,61443	10,348	12,478
RMS	741,632	1781,326	791,839	956,174	483,384	256,7468	49,258	68,315

table 4 - The results of assessment on geo- location accuracy of 1B2R product level (metre unit).

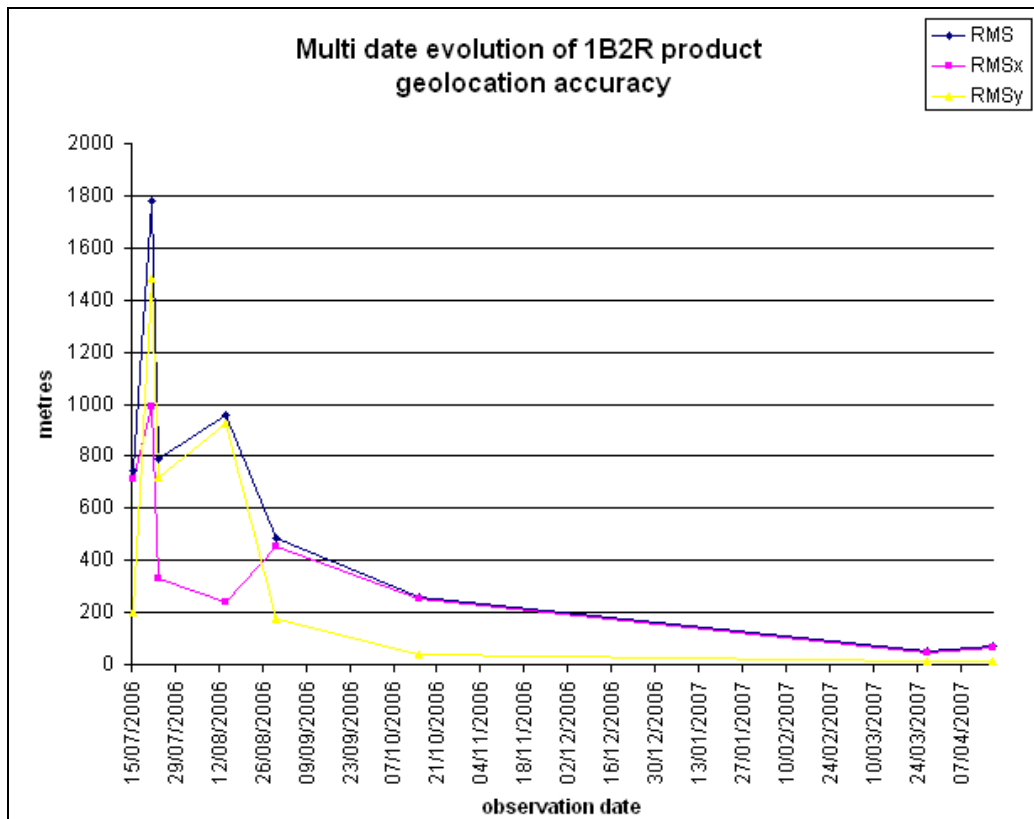


fig. 1 - Multi date evolution of the 1B2R product geolocation accuracy.



Alignment parameter

One observed during calibration/validation period, that the product geo location is strongly varying according the instrument pointing angle. JAXA corrected the linear relationship between pointing angle and ground range location¹. For data from the last AVNIR-2 observations, **the assessments demonstrated that errors due to alignment have been corrected**, such as illustrated with figure just here after (fig. 2).

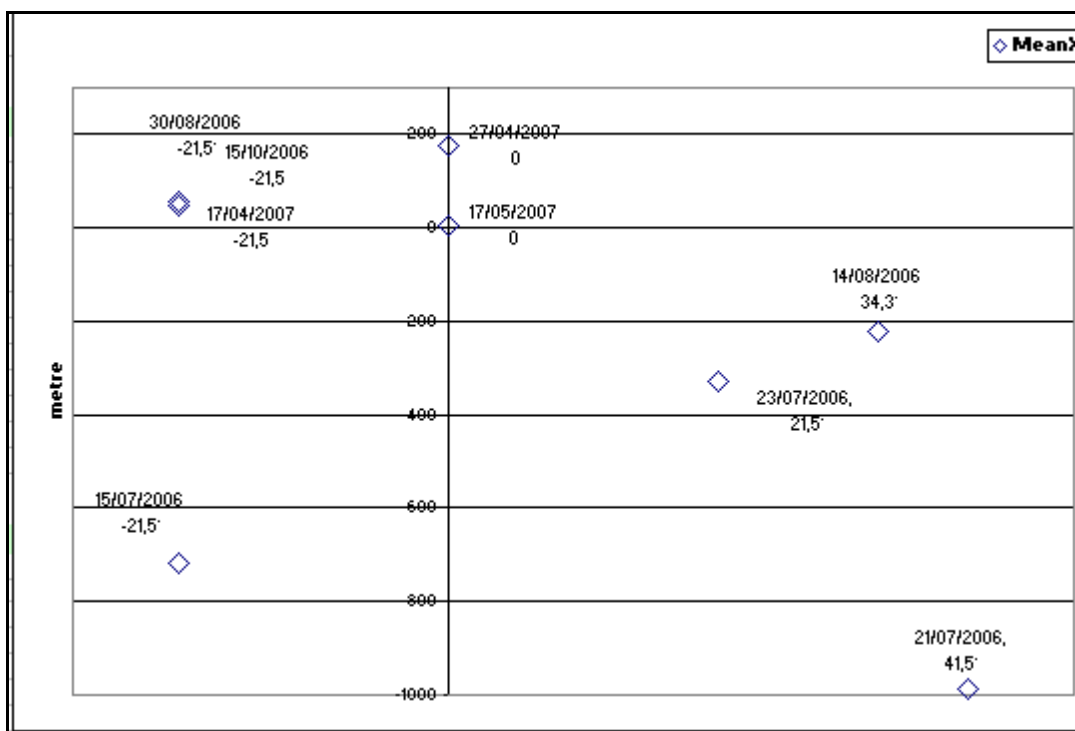


fig. 2 Multi date analysis of across track Shift wrt pointing angle (metre unit).

AVNIR-2 geometry

In the previous document (R-4), a methodology to assess the geometry of AVNIR-2 instrument has been explained. The objective of the method was to take into account image deformation due to ephemeris and attitude variations and to correct image from error due to polynomial coefficient. The product geographic grid is predicted using polynomial transformation from coefficient embed within product. The pixel geo location values is at ellipsoid level and then does not reflect the reality of terrain relief.

For the first observation dated of July 5, 07', two reference points have been added to remove deformation due to translation and rotation. In doing so, the error due to shift in ephemeris and inaccurate attitude are partially removed.

¹ Takeo TADONO, Masanobu SHIMADA, Takanori IWATA, and Junichi TAKAKU, 2007: Accuracy assessment of geolocation determination for PRISM and AVNIR-2, Proc Optical 3D Conference, Zurich

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GCP number	0.GRP	1.GRP	2.GRP
Mean X	-716,2	-41,781	9,722
Mean Y	-189,997	14,510	-4,906
Mean	740,58	44,229	40,091
Std X	42,285	42,509	42,334
Std Y	14,077	14,078	14,246
Std	39,361	44,780	22,503
RMS X	717,269	59,605	43,436
RMS Y	188,253	20,217	15,067
RMS	741,64	62,940	45,975

table 5 - ALAV2A03625380 product; geo-location accuracy results (metre unit).

The results of this methodology are listed in table 5. the final accuracy is very close to the one obtained on product dated of March 24, 07' and acquired over La Crau as well. The shift according to pixel direction remains about 45 metres whereas the shift according to the line direction remains about 15 meters.

The linear dependency (correlation about 86% confidence) between altitude and error according to pixel direction is used to remove the effect due to terrain relief (fig. 3). In doing so, the residual error is analysed.

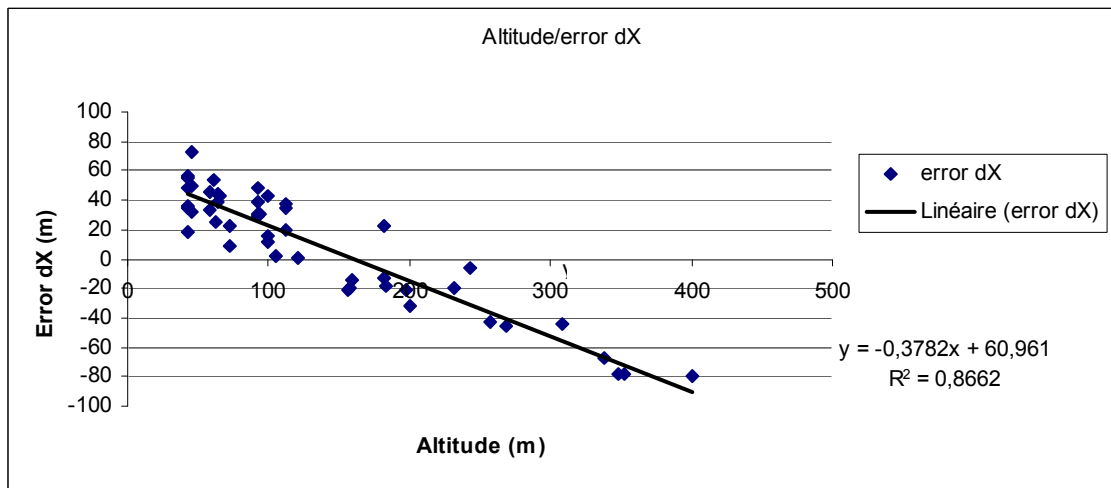


fig. 3 - Error dX along with altitude.

Correlation between error dY and altitude is less important (65% confidence) . So that; no correction are applied to dY error results. After correction, **the geo location accuracy of 18 metres (RMS) is reached (table 6). The circular error at 90 percent (CE90) is about 26.7 metres (fig. 4).**

GCP number	0.GRP	1.GRP	2.GRP	2GRP + parallax correction
Mean X	-716,2	-41,781	9,722	0,27
Mean Y	-190	14,510	-4,906	-7
Mean	740,58	44,229	40,091	17,240
Std X	42,285	42,509	42,334	14,250
Std Y	14,077	14,078	14,246	9,890
Std	39,361	44,780	22,503	6,870
RMS X	717,269	59,605	43,436	14,253
RMS Y	188,253	20,217	15,067	12,117
RMS	741,64	62,940	45,975	18,707

table 6 - ALAV2A03625380 product; geo-location accuracy results (with correction).

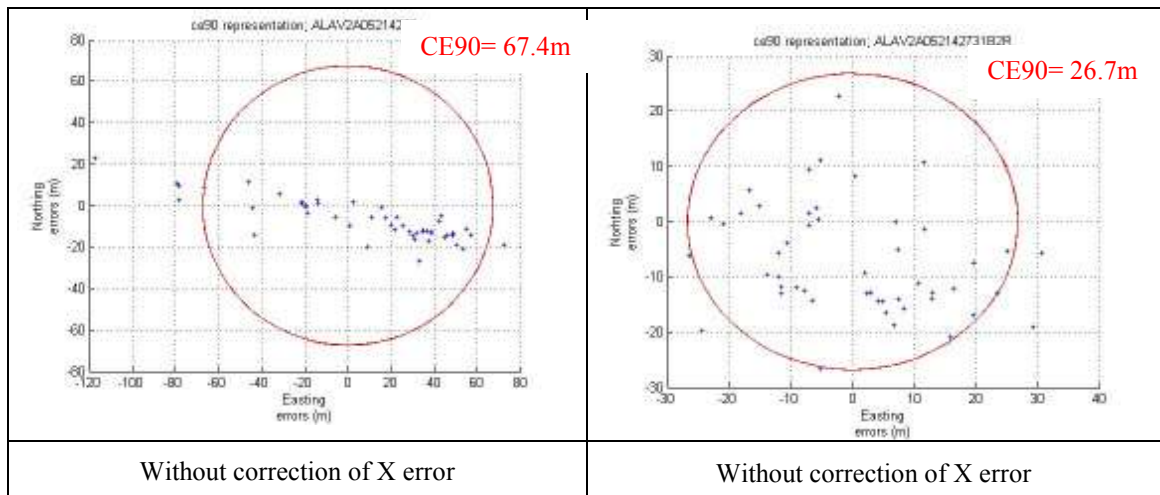


fig. 4 - CE90 graphic plots.

3.3 The geo location accuracy stability for a long term acquisition period

The purpose of this verification item is to observe if a drift in ephemeris and attitude dataset occurs along with satellite orbit. This assessment is based on the comparison of the accuracy of two products observed from a same satellite orbit path but belonging on one hand to the northern hemisphere (Turkey site) and on the other hand to the southern hemisphere (South Africa site).

Indeed, all along one orbit the platform / instrument is exposed to the Sun. It results in increasing on board temperature and may induce thermal effect that contaminates the sensor and lead to image artifact

The assessment is based on 1B2R product level and the dataset sample used is listed into table 7. The methodology applied for the geo location control remains similar to the ones applies for the previous assessment. The reference data are post processed SPOT 4 data.



Observation date	Scene Id	Pointing angle	Path	Orbit data Precision	Attitude data Precision	Processing date	SW version	Site
07-oct-06	ALAV2A037382870	-21,5	257	Precision	OnSite Precision	17-janv-07	36453060752	Turkey
07-oct-06	ALAV2A037384300	-21,5	257	Precision	AOCS Precision	17-janv-07	36453060752	South Africa
07-oct-06	ALAV2A037382870	-21,5	257	Precision	OnSite Precision	17-janv-07	4500307002	Turkey
07-oct-06	ALAV2A037384300	-21,5	257	Precision	AOCS Precision	17-janv-07	4500307002	South Africa

table 7 - The 1B2R data set for the assessment of the geolocation accuracy stability.

GCP number	ALAV2A037382870 Turkey	ALAV2A037384300 South Africa
Mean X	-175,232	-213,699
Mean Y	-51,283	-69,834
Mean	182,687	224,920
Std X	5,032	12,920
Std Y	5,98	5,031
Std	4,815	12,126
RMS X	175,304	214,090
RMS Y	51,631	70,015
RMS	182,75	225,247

table 8 - The results of assessment on the geolocation accuracy stability (metre unit).

The assessment results are listed in table 8, they demonstrates that the along and across track shift varies respectively on the order of 18 metres and 40 metres between the both observations. **The geo location error increases from 182.75 metres to 225.247 metres.** So that **the pointing accuracy all along one orbit is not confirmed.**

On the other hand, the standard deviation increases, it means that the image geometry is became less accurate for South Africa scene. It can also be due to terrain relief in South Africa, Le Cap, and the effect of parallax.

No new improvement is observed when playing back verification on product processed with the new processing software (4500307002). It would be interesting to do the same study but applied on a new dataset acquired after December 06'.

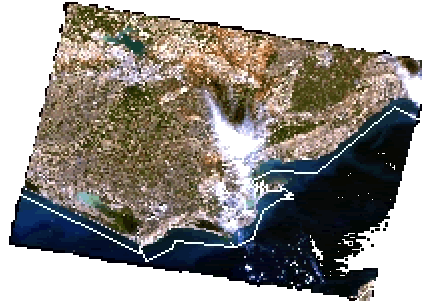


fig. 5 - Scene Shift observed over Turkey site.

3.4 Band to band registration

Purpose of this verification is to check that AVNIR-2 bands of L1B2G 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. The AVNIR-2 observation taken as working dataset has been done with a 0 pointing degree angle.

Main results are summarized in table 10.

Observation date	Scene Id	Pointing angle	Path	Orbit data Precision	Attitude data Precision	Processing date	SW version	Site
26-sept-06	ALAV2A035792720	0	324	Precision	OnSite Precision	19-janv-07	36453060752	LA Crau

table 9 - Dataset used for assessment of interband registration accuracy.

Results demonstrate that **interband accuracy remains** mainly within 0.4 and 0.6 pixels for band 1, 2, 3. Some inconsistencies (between 0.9 pixel) are observed when band 4 is compared with band 2 are involved into computation.

Results are expressed in pixel unit to within 0.01 pixel.

	band1		band2		band3		band4	
	x	y	x	y	x	y	x	y
band1	x	x	0,62	0,55	0,41	0,34	0,56	0,27
band2	0,62	0,55	x	x	0,41	0,60	0,49	0,87
band3	0,41	0,34	0,41	0,60	x	x	0,64	0,43
band4	0,56	0,27	0,49	0,87	0,64	0,43	x	x

table 10 - ALAV2A03579270 product; Band to band registration results.

4 PRODUCT RADIOMETRIC CALIBRATION

A major part of methodology and results are explained in [R-8]. Purpose of this section is to make a synthesis on 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.

4.1 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 R-10. The band-to-band ratio and TOA computation are then performed and the statistical mean of pixels belonging to the ROI is computed.

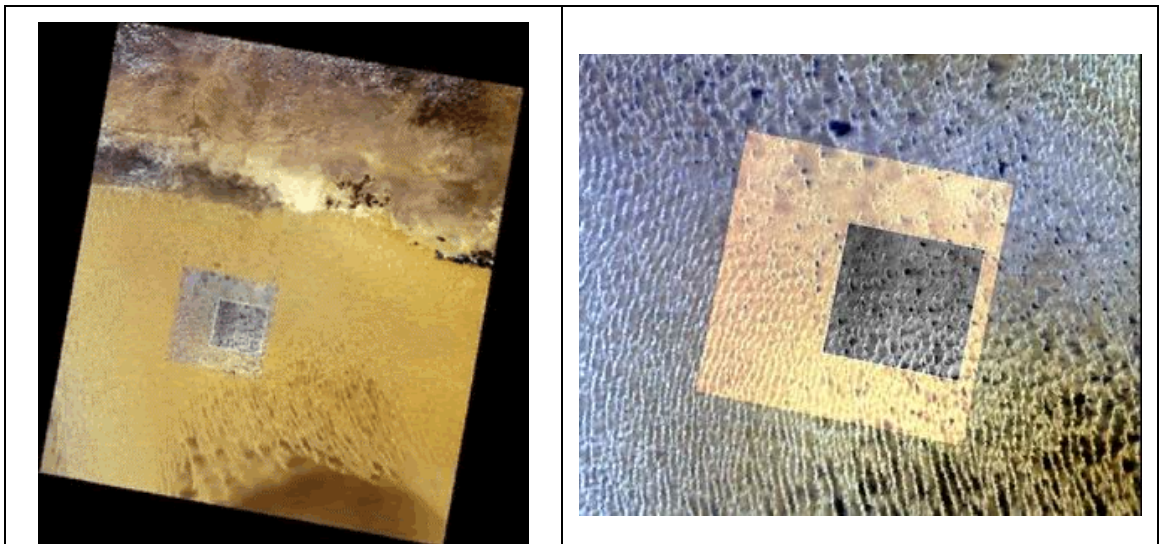


fig. 6 - Libya site view with MERIS, AVNIR-2 and PRISM sensors.

Radiometric calibration stability

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.



The geometry of AVNIR-2 acquisition should be taken into account for a better appreciation of TOA reflectance values. As illustrated with fig. 7, TOA reflectance measurements varies along with diffusion angle.

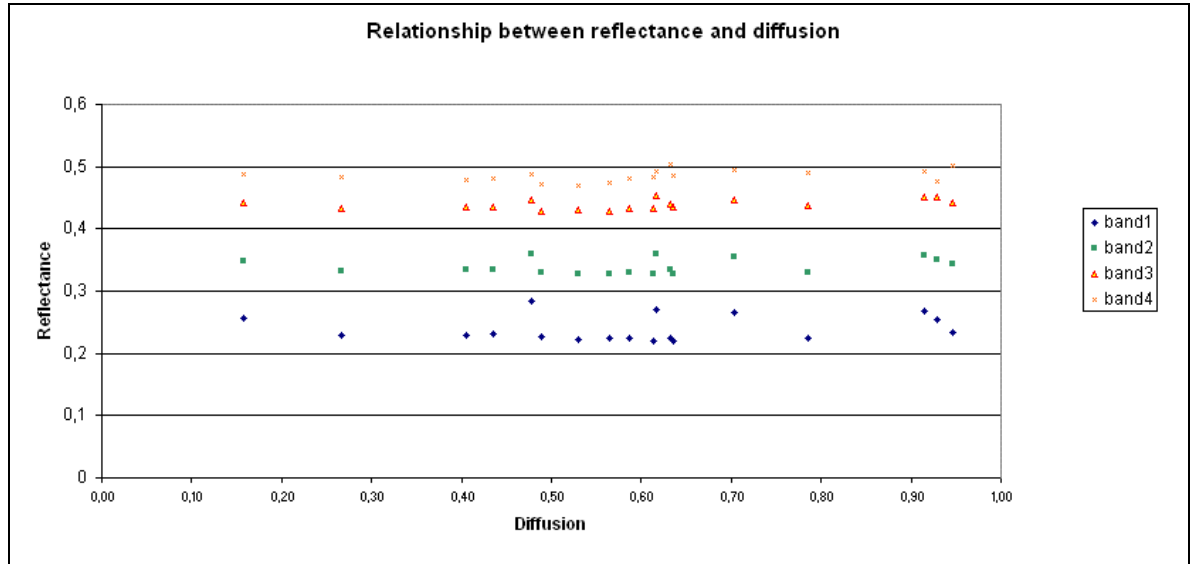


fig. 7 - TOA reflectance and diffusion.

The computation of diffusion is based on solar and instrument zenith / azimuth angles. We observed that some TOA measurements look not consistent with regards to the overall tendency. These measurements have been discarded from multi date analysis. These inconsistencies are more likely due to water vapor content that disturb the signal.

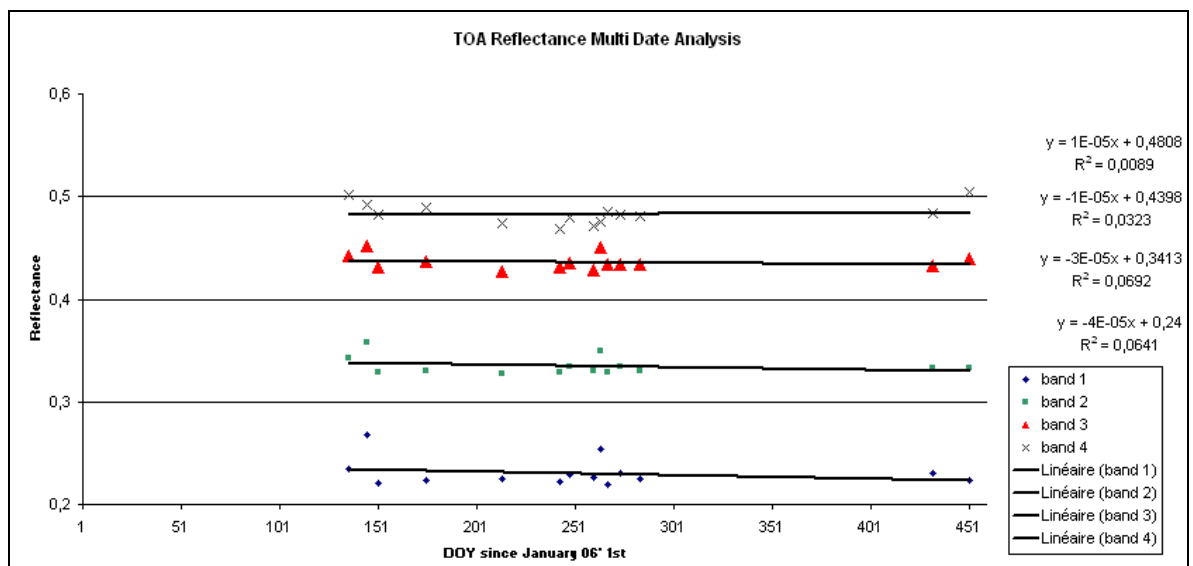


fig. 8 - AVNIR-2 multi date TOA reflectance series.



Band number	Linear interpolation results
1	$y = -4E-05x + 0,24$ R2 = 0,0641
2	$y = -3E-05x + 0,3413$ R2 = 0,0692
3	$y = -1E-05x + 0,4398$ R2 = 0,0323
4	$y = 1E-05x + 0,4808$ R2 = 0,0089

table 11 - Multi date TOA reflectance analysis, linear interpolation results.

Band to band calibration stability

Prior to band ratio operation, digital numbers are converted into band radiance measurement. From a large sample dataset, 50 % of working data has been discarded. A part of them were contaminated with saturation that made difficult band-to-band ratio. In addition, we do not take into account product discarded for radiometric calibration stability time series due to water vapor content.

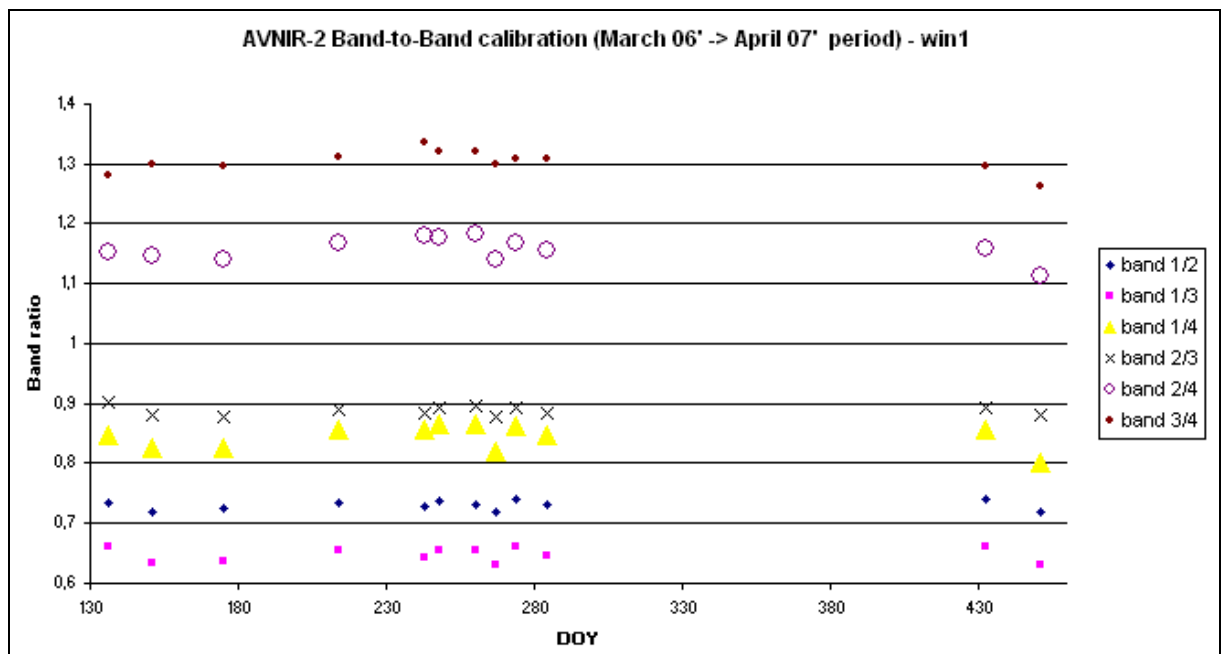


fig. 9 - AVNIR-2 multi date band to band ratio series.

These two methods are suitable to verify calibration stability and to appreciate quality of radiometric calibration. Influence of atmosphere and Bi-directional Reflectance Distribution Function (BRDF) are not account for by this method.



Following conclusions from radiometric calibration stability can be done

- Radiometric calibration of **band 1 and 2 is slightly decreasing**,
- Radiometric calibration of **band 3 is stable**,
- Radiometric calibration of **band 4 is slightly increasing**.

The tendency for band 1 and band 4 is more pronounced and the confidence coefficient remains very low. The linear interpolation performed on multi date TOA reflectance for every band (table 11) provides quantitative results.

4.2 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 means 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 [R-10]. 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 0,4407 measured in the PRISM panchromatic channel (fig. 10, fig. 11).

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 instruments on board ALOS 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.

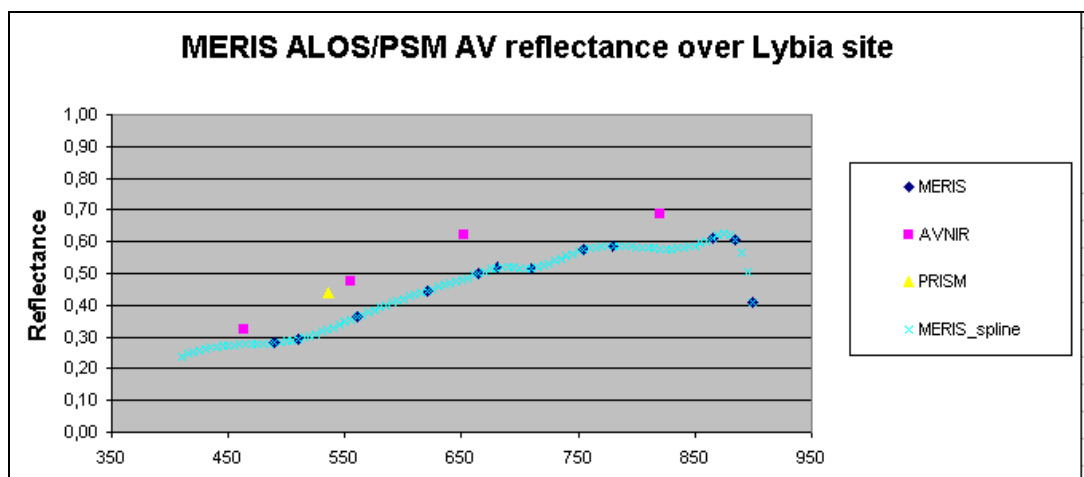




fig. 10 - MERIS and ALOS PRISM / AVNIR-2, TOA comparison.

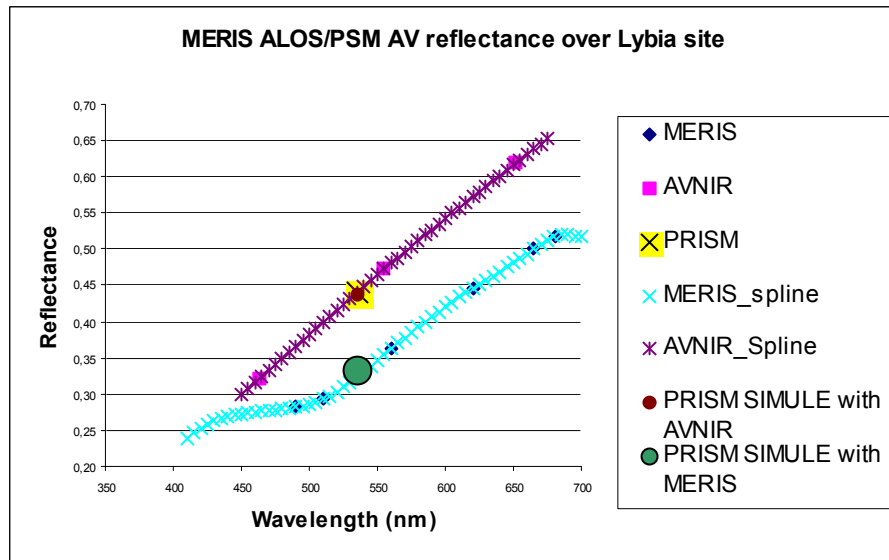


fig. 11 - AVNIR-2 and simulated PRISM data.

4.3 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.

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 fig. 12 and fig. 13.

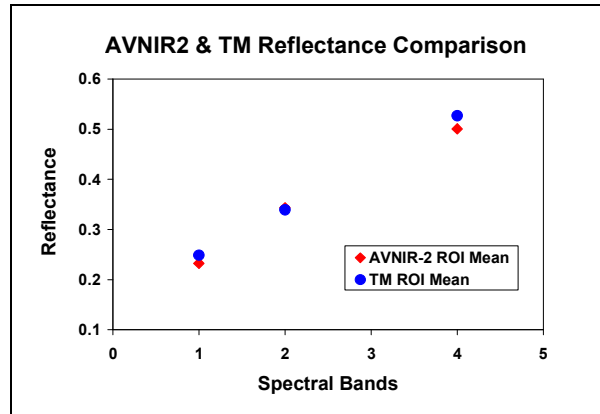


fig. 12 - TM and AVNIR-2 radiance comparison..

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%.

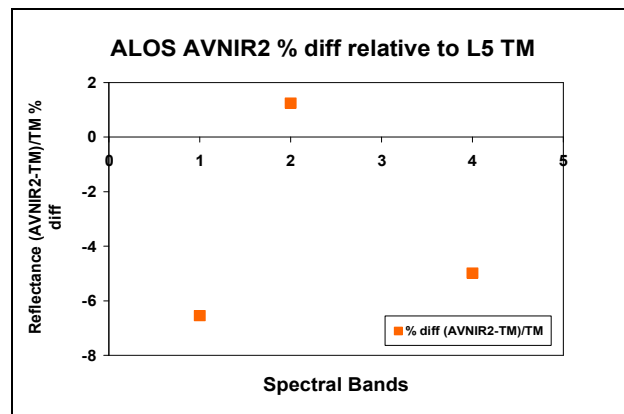


fig. 13 - TM and AVNIR-2 radiance comparison., % difference.

4.4 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. The full methodology is explained in [R-8].

AATSR, A-MODIS and POLDER-3 data were radiometrically rescaled to the MERIS data radiometric scale following a methodology described in [R-7]. 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.

Such simulated AVNIR-2 reflectances are however not completely representative of the actual AVNIR-2 measurements although both the spectral and directional properties of the target have been taken into account. Indeed, because the AVNIR-2 bands extend over spectral region where the gaseous absorption is significant, the measured reflectances differ from the ones simulated using the homogeneous dataset.

The narrow bands of the homogeneous dataset are almost unaffected by water vapour absorption and dioxygen absorption. Conversely, the AVNIR-2 bands 3 and 4 are significantly affected by absorption from the two gases. The influence of absorption on the AVNIR-2 data is illustrated in fig. 14.

This figure shows the 5-day spectrum (black line) obtained from linear interpolation between the 5-day narrow band TOA reflectances of the homogeneous dataset (black stars). Superimposed, in red, the relative spectral response of AVNIR-2 in its 4 bands from which the AVNIR-2 reflectance are simulated. and the 6S gaseous transmission of O₂ and water vapour (2.14 g/cm). These are the 5-day spectrum and the transmission corresponding to the AVNIR-2 acquisition of the day of the year 136 of 2006.

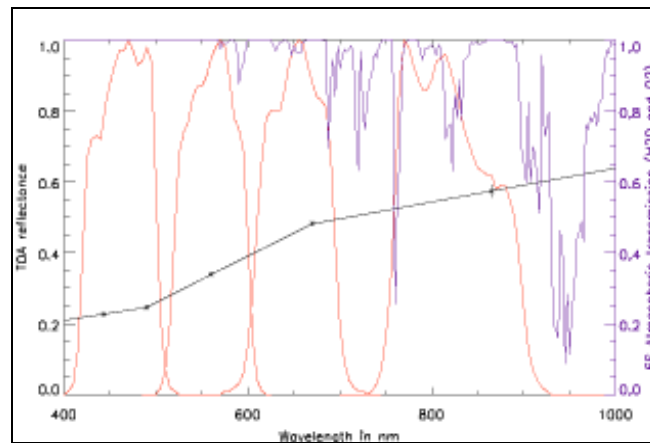


fig. 14 - Linear interpolation between the 5 day narrow band TOA reflectances.

Concerning the influence of ozone, it is here assumed that the influence of ozone is relatively well mapped by the 5-day simulated spectra based as the spectral sampling of the narrow bands of the homogeneous dataset is sufficient to follow the spectral variations of the absorption induced by ozone.

To fully simulate the AVNIR-2 measurements from the 5-day spectra, a correction for O₂ and H₂O is applied by computing the gaseous transmission of these gases, in the AVNIR-2 bands, along the downwelling and upwelling optical path. Such direct transmission computation in the 4 AVNIR-2 bands, for each AVNIR-2 acquisition is computed with 6S [3]. Using the direct transmission along the optical path to correct for the absorption is not rigorous when multiple scattering occurs. However, because these gaseous absorption corrections are significant only in AVNIR band 3 and 4 where important surface brightness induces that the single scattering of photons at the surface is predominant in the TOA signal, the assumption of a gaseous transmission reducing to the direct transmission can be justified.

O₂ absorption is driven by pressure and temperature profiles. Both are considered constant (mid-latitude summer profile) for each AVNIR-2 acquisition.

Water vapour data were obtained from the Aqua-MODIS level 3 daily atmospheric products. The total columnar water-vapor MODIS level 2 product from which the daily level 3 product are derived is claimed to have an accuracy of 5-10% (<http://modis-atmos.gsfc.nasa.gov>).

	Mean relative difference with simulated TOA reflectances (in %)	Standard deviation to the mean (in %)
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Band 1	-5.6	3.9
Band 2	-0.1	2.7
Band 3	-1.1	3.0
Band 4	-2.7	2.2

table 12 - The comparison of AVNIR-2 TOA reflectances and the simulated AVNIR-2 reflectances.

The error budget of the methodology is estimated to about 5 %.

AVNIR-2 appears to be 5.6 %, 0.1 %, 1.1 % (saturated band) and 2.7 % below the radiometric scale of MERIS in respectively band 1, 2, 3 and 4. Band 3 suffers from saturation and the results for this specific band are too difficult to interpret. All AVNIR-2 bands but band 1 are within this error budget.

4.5 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 and is fully detailed in [R-8]. 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 (fig. 15). AVNIR-2 data are then reconstructed and compared with simulated values.

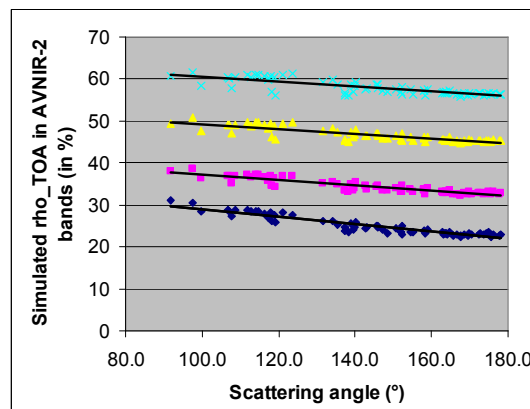


fig. 15 - The simulated AVNIR-2 data using the MERIS data.

It is assumed here that the most significant effects of absorption are caused by water vapor 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.



4.6 Results synthesis from the three inter-comparison methods

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

The results of sensor intercomparisons presented in table 13 indicate that the radiometric calibration of AVNIR-2 is satisfactory, given the error bar of the methodologies which is estimated to be around 5 %.

All results are consistent across the intercomparisons and bands but for intercomparison 1 and 2 – band 1 indicating an underestimation of AVNIR-2 in the blue part of the spectrum.

Intercomparison 3 , in band 4, indicates a significant underestimation of AVNIR-2 that is not confirmed by other intercomparisons. This could also be explained **by the water vapour correction applied**, which is directly inherited from intercomparison 2 (although the AVNIR-2 data series differ between the two intercomparisons).

	Inter comparison 1	Inter comparison 2	Inter comparison 3
Band 1	-6.55%	-5.6%	-4.6%
Band 2	1.24%	-0.1%	-1.43%
Band 3	Saturation	Saturation	Saturation
Band 4	-4.99%	-2.7%	-10.3%

table 13 - Synthesis of radiometric calibration results.