Earth Observation Quality Control

Landsat frequently asked questions

	name *function* *company*	*date* *signature*
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1. Introduction

1.1 Purpose of this document

The Frequently Asked Questions (FAQ) is a repository of questions processed by the Earth Observation Quality Control service (EOQC – http://www.gael.fr/eoqc). It mainly gathers Users questions that Eurimage or the ESA / ESRIN help desk have submitted to the EOQC service. This document is addressed to the end-users, and its primary function is to explain the basic concept of the Landsat quality control policy carried out by the EOQC service on ESA's behalf.

Its aims are to provide the User with the key points that are involved in handling of the European Landsat products. The main themes such as format definition, radiometric processing and conversion, geometric corrections, resampling and map projection methods are discussed.

1.2 Document overview

- Chapter 2 General aspects,
- Chapter 3 Format,
- Chapter 5 Radiometric,
- Chapter 6 Geometric,
- Chapter 7 Resampling methods,
- Chapter 8 Resources.

1.3 Applicable documents

A-1	15993/02/I-LG	*Rider No. 1 to Contract — Maintenance and Support to Operations of the Multi Mission Quality Control System for the Period March 2003 – March 2005* May 23rd, 2003 European Space Agency – ESRIN

1.4 Reference documents

This section describes the related documents and applied conventions to be considered within the present document.

R-1	GAEL-P157-DOC-001	*Inventory of Landsat product anomalies* Issue 1, Revision 0 – June 06th, 2003 GAEL Consultant

1.5 Deliverables

The present document will be provided to ESA/ESRIN in both “word” and “pdf” format. The document formatted in “pdf” will be made available on the actual ESA Third Party Missions web pages.

2. PRODUCT, ORDERING AND QUALITY CONTROL

Q1. *What are the orbit coverage parameters of the Landsat instruments?*

Landsat 4, 5, 7 operate in circular, sun synchronous, near polar orbit at a nominal altitude of 705 km. The inclination of the orbit is 98.2 degrees, and the satellites circle the earth every 98.9 minutes.

The MSS, TM and ETM+ sensors view the Earth every 16 days with a complete cycle of 233 orbits. This equates to 14 orbits per day.

The local time of equatorial crossing (descending orbits) is approximately 09:45 am (Landsat 4 and 5) and 10:15 am (Landsat 7). Each consecutive orbit is displaced west of the previous orbit by 2752 km, or 24.7 degrees in longitude at the equator. The track of each succeeding days is shifted to the west by 10.8 degrees or 12045 km at the equator.
The descending (daytime) orbit paths run from northeast to southwest, whereas ascending (night time) orbit paths run from southwest to northeast.

Q2. *How do I access Landsat data via ESA?*

Access to a pre-defined, limited collection of Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) archived data acquired by the Landsat 5 and 7 satellites over Europe between 1990 and 2004 is provided by ESA FREE OF CHARGE under the Category-1 scheme. The exact coverage of the dataset can be verified by browsing within the "Landsat Cat-1" collection of the EOLI-SA catalogue (available at http://earth.esa.int/resources/catalogues/).

Data available in the other Landsat collections in EOLI-SA is currently only distributed through the commercial distributor Eurimage SPA, Rome, Italy (http://www.eurimage.com). On demand products from the whole archive are planned to become available in the near future.

Q3. *Which is the format specification document of the actual ESA products?*

The table here after recalls the product format specification document of Landsat product processed at ESA.

Format	Sensor	Level	Format specification
FAST-B	TM	1G	Landsat 5 FAST DFCB Rev. B, July 1993
FAST-B	TM	1T	Landsat 5 TM level 1 DFCB – V 1.0, August 2007
FAST-L7A	ETM+	1G / 1T	Landsat 7 ETM level 1 DFCB – V 11, April 2007
GeoTiff	TM	1G / 1T	Landsat 5 TM level 1 DFCB – V 1.0, August 2007
GeoTiff	ETM+	1G / 1T	Landsat 7 ETM level 1 DFCB – V. 11, April 2007

table 1 - Format specification documents.

Effective date, July 1st, 2009, the HDF format is not proposed anymore.

GeoTIFF format is a TIFF-based interchange format for georeferenced raster imagery. A full description of the format is provided on the GeoTIFF web site and is discussed on a dedicated forum.

Q4. *Why would I order Landsat product processed into the CEOS format?*

The CEOS (Committee on Earth Observation Satellites) format specification provides the finer level of information. It provides key parameters to fully understand the remote sensing data and make the user able to process from the raw product up to the value added or geophysical product.

Q5. *Which product level and format the ESA processing chain proposed?*

The Landsat products can be processed into the CEOS CEOS, FAST or GeoTIFF format.
The product levels proposed are L1G, L1R and L1T. The ESA level 4 and ESA level 5 are both L1G (US standard) products, with the Level 4 being 1G SYS corrected and the Level 5 being 1G GEO Georeferenced/Geocoded.

Landsat TM L1R products [RADCOR] (with radiometric correction applied but NOT geometric correction) are NOT available at ESA, however Landsat ETM+ L1R products [RADCOR] (with radiometric correction applied but without geometric correction) ARE available at ESA.

Level processing nomenclature (L1R-L1G L1T) agrees with the one given by EURIMAGE.

Note that the level 0 cannot be proposed. The L0R product level, with radiometric correction applied but no geometric correction, is not available from the ESA catalogue.

Q6. *How to get Landsat product at ESA?*

In using the EOLI interface for the users that use the data in the framework of category one or two project. Eurimage is the official distributor in all the other cases.

Q7. *I order Landsat product, and note that a quality control report is associated to it. What are the quality control tests performed at the ESA stations?*

As part of the Multi Mission Quality Control System (MMQCS), a quality control application, is installed downstream of the processing chain. The application routinely checks around one on ten of the generated products, and thereby controls format consistency, geometric and radiometric quality.
For more information on the definition of the tests involved, the User is invited to download the MMQCS user's manual.
The table below summarizes the test sequence that the quality control application applies to the European Landsat 5 and 7 products.

Test / Format	CEOS			FAST			GEOTIFF		
Processing Level	1R	1G	1T	1R	1G	1T	1R	1G	1T
Saturated pixels	L5	L5	L5	L5	L5	L5	L7	L7	L7
Interband alignment	L5	L5	L5	L5	L5	L5	L7	L7	L7
Striping	L5	L5	L5	L5	L5	L5	L7	L7	L7
Fields control	L5	L5		L5	L5				
Ephemeris and attitude	L5	L5	L5						
Gain and offset stability	L5	L5	L5						
Swath and line	L5								

table 1. - QUISS operational test against product format and level.

Q8. *What is the actual software version and its properties?*

Effective date July 1st, 2009 products are now processed based on an improve software that embeds several major modifications and improvements.

The TM / ETM+ products are now processed based on the USGS Calibration Parameter File (CPF). The TM product takes benefit of improved radiometric calibration accuracy which is demonstrated to be in agreement with the most of reference optical instruments.

The past software versions and the associated changes are listed in the table just here after.

Software Code	*Release Date*	*Software release note*
TMVFR 1.7.0		*The ephemeris flag of the supplemental file is set to null value if the state vector is not used*
TMVFR 1.8.0		*CEOS radiance to reflectance factor corrected* *The imagery file of the CEOS map oriented product is processed with the prefix data added.*
TMVFR 1.8.1		*Geometric corrections of TM products due to failure of mirror wear; switch to bumper mode.*
TPM PL	*Effective July 1st 2009*	*TM products systematically processed based on LUT 07Level 1T products*

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Q9. *which algorithms the Landsat ESA processing is based*

The processing applied in the processor for Landsat 7 ETM+ but also for Landsat 5 TM is based on the USGS specifications presented in the "Landsat 7 IAS Geometric Algorithm Theoretical Basis Document" issue 3.2 July 1998 [ATBD] and the "Landsat 7 ETM+ IAS Radiometry Algorithms" issue 2.0, describing the geometric and radiometric corrections applicable to raw data, see the USGS pages.

Q10. *I have ordered a European Landsat product. However, I am unable to tell if it is an NLAPS or LPGS product. What is the difference in the two products, and how can I tell what my product is?*

NLAPS and LPGS are two different US processing systems that are used for level 1 product generation. Lot of information on these two separates system is given by USGS. From a radiometric and geometric viewpoint, the European Landsat products generation system is more closely aligned to the LPGS system. However, the user must be aware of differences on the radiance conversion rules: an LPGS product has a minimum digital number value set to ‘1’ whereas for the European products it is set to ‘0’

(for expansion of this topic, please refer to questions below).

Q11. *What is the calibration file?*

The Calibration Parameter File (CPF) includes a set of radiometric, geometric and artefact removal parameters used during Level 1 processing of Landsat 7 / 5 data.

The Image Assessment Team, based at USGS, continuously reviews and updates the file parameters. The USGS distributes the CPF file to the international ground stations. The files can also be loaded on the related web site.
The CPF is used as auxiliary information during the processing from raw level to upper leve1. The CPF is released for a one month period and can be reviewed during the period. The validity of the CPF with regards to the observation date is crucial in order to achieve the expected geometric and radiometric accuracy

Q12. *Is the CPF file name used to process the TM / ETM+ data is written within the product format?*

For FAST L7A and TM / ETM+ GeoTIFF products, the CPF file name is described in the metadata file ("*.mtl"); line 55, field "CPF_FILE_NAME" where group is "PRODUCT METADATA".

For CEOS products, the same information is provided in the volume directory file of the calibration file. The exact location is the field 13 of the text record.

The TM Fast B format is not designed to add the description on the CPF file name used during the processing.

3. RADIOMETRIC PROCESSING

Q13. *How are European Landsat products (radiometric corrected or above) calibrated from radiometric corrections point of view?*

Basically three kinds of calibration methods could be used for the radiometric correction of TM / ETM+ products:

- pre-flight or pre launch (PL),
- in-flight,
- using lifetime model,

Any calibration algorithm computes the calibration gain and bias (offset) of each detector band. It determined the detector Look Up Tables (LUT's) to be applied for the generation of the radiometric corrected image.

For TM instrument, the pre-flight calibration procedure uses heuristic look up table estimated in laboratory before the launch in order to estimate the calibration gain. The analysis of the dark current as part of Internal Calibration (IC) data is used to estimate the calibration offset.

Obviously, after 25 years of TM instrument operation, the value defined before the flight do not account for the detector ageing. So that, the pre flight calibration is not valid anymore.

The IC system is a part of the TM and ETM+ instruments. The response of the detector to a Lamp signal for which the radiance is well known is collected at the end of every scan (mirror sweep). The analysis of the detector response leads to the determination of the calibration gain. The in flight calibration is based on this principle. The lamp signal considered as a reference has varying with time and decrease without any control. So that, any estimate based on the calibration signal is not reliable anymore.

The new calibration method based on gain and offset values derived from a detector lifetime model has been set up in order to overcome the loss of accuracy raised by the use of pre flight and in flight calibration method. A potential drawback of the lifetime model is the dependence with the auxiliary parameter that does not depends on the flight segment.

The documentation on pre-flight calibration algorithms used for processing of the ESA TM / ETM+ Full resolution system corrected data is proposed at the ESA Earthnet Online website.

The documentation on the lifetime model applied for an up to date calibration of TM products is also available at the ESA Earthnet Online website. The scientific exercise of the USGS calibration team is summarized into the following document;

Gyanesh Chander, Brian L.Markham, Julia L Barsi
Revised Landsat-5 Thematic Mapper Radiometric Calibration
IEEE GEOSCIENCE AND REMOTE SENSING LETTERS,
VOL. 4, NO. 3, JULY 2007

Q14. What is the radiometric processing applied by default on TM products

Effective date, July 1st, 2009, the TM/ETM+ products are processed using the USGS calibration parameter file. Then; the default calibration mode for the TM products is based on the lifetime model of Year 06.

Q15. *How much the TM calibration accuracy is improved when product is processed in using the lifetime model?*

The revised calibration of L5 TM sensors will improve absolute calibration accuracy, consistency over time, and consistency with Landsat-7 (L7) Enhanced Thematic Mapper Plus (ETM+) data.The absolute accuracy of TM instrument with the lifetime look-up-table (LUT) gain model is now estimated to be within 5% for all solar reflective bands. This compares very favourably in comparison to the 20% accuracy achieved previously using pre-launch based calibration.

Q16. *Is the consistency between the old and new generated product preserved?*

From a radiometric point of view, the TM products generated with pre flight method are obviously not aligned on the ones generated using the coefficients derived from the lifetime model.

Q17. *I would like to improve the radiometric calibration of the TM products I ordered before the TPM PL SW . Is there any solution?*

On the processing side, the radiometric correction applied to TM product **before** TPMPL SW used heuristic look up table (LUT). The LUT is derived from the PREFLIGHT one Goddard Space Flight Center proposed (refer to TM ICD document[1].).

The USGS and CCRS proposed recalibration algorithm[2]. This offline algorithm makes the user able to correct the calibrated data. When applied to the ESA products, the product accuracy did not take benefits of the recalibration procedure.

Q18. *How do I know that my CEOS product is processed using the Lifetime model for radiometric corrections?*

The CEOS catalogue file is a text file associated to the product format and is detailed into the ESA CEOS format specification. When products are processed using radiometric correction based on LifeTiMe, the LTM acronym replaces the PRE acronym. The PRE acronym indicates that the product is processed using PRE LAUNCH methods.

```
LS5THM NN  GAIN LTM     LEVEL4 19841009082515082515 181 040STDFUL00001234567NR0000.1A1
```

Example of CEOS catalogue file with radiometric LifeTiMe processing

```
LS5THM NN  PRE   LEVEL4 19841009082515082515FucinoMatera 181 040STDFUL00001234567NRFS2387.1A     1
```

Exemple of CEOS catalog file with radiometric PRE LAUNCH processing

Moreover, within the CEOS format, *the leader file/scene header record/Radiometric calibration designator* field indicates 'Lifetime gain model'. This format tags within the CEOS format is internal calibration 'N', pre flight data 'N'.

Q19. *How can spectral radiances be computed from radiometric values?*

Digital Numbers (DN) are converted to spectral calibrated radiances (L) using the following formula:

$$L = Gain * DN + Offset$$

[1] LANDSAT TO GROUND STATION INTERFACE DOCUMENT, REV9.0, January 1986
[2] A definitive calibration record for the Landsat-5 thematic mapper anchored to the Landsat-7 radiometric scale P.M. Teillet, D.L. Helder, T.A. Ruggles, R. Landry, F.J. Ahern, N.J. Higgs, J. Barsi, G. Chander, B.L. Markham, J.L. Barker, K.J. Thome, J.R. Schott, and F.D. Palluconi , Canadian Journal of Remote Sensing, v 30, No4, pp 631-643, 2004.

Where:

L	is the Spectral calibrated radiance, with units of $w.m^{-2}.sr^{-1}.\mu m^{-1}$ (“*Luminance” in French*),
DN	is the Digital Number (0, 255),
(L_{max}, L_{min})	is the upper and lower spectral radiance limit, with units of $w.m^{-2}.sr^{-1}.\mu m^{-1}$,
$Offset = L_{min}$	is the rescaled offset, with units of $w.m^{-2}.sr^{-1}.\mu m^{-1}$,
$Gain = \frac{(L_{max} - L_{min})}{(Q_{max} - Q_{min})}$	is the rescaled gain, with units of $w.m^{-2}.sr^{-1}.\mu m^{-1}$.

The lower and upper radiance limits are related to their correspondent DN, where the lower digital number (Q_{min}) and the upper digital number (Q_{max}) are respectively equal to 0 and 255.

Q20. *What are the lower and upper DN values for European products?*

For European products (CEOS, FAST, GeoTIFF, formats), the lower DN value is 0 and the upper DN value is 255. An image pixel value set to 0 has a radiance value equal to the lower radiance limit (L_{min}) and an image pixel value set to 255 has a radiance value equal to the upper radiance limit ((L_{max}).

In the case of Landsat, misunderstandings can occur during the computation of gain value because other (non-European) processing systems use the 0 image pixel value to flag background pixels. In this scenario, $Q_{max} - Q_{min}$ is therefore equal to 254 rather than 255.

Furthermore, Some misunderstandings can arise due to information provided by the format.

The CEOS format does not provide the lower and upper DN values, because these never change (0,255). However the radiometric ancillary record of the leader file informs on the gain, the offset and the lower and upper spectral radiances of every band.

Through the metadata file, The FAST and GeoTIFF formats provide lower and upper DN values which are NOT 0 and 255 respectively. These values differ from the standard because they are the boundaries (min, max) of the image histogram, and the spectral radiance limit values are computed on this basis.

The formula:

$$Gain = \frac{(L_{max} - L_{min})}{(Q_{max} - Q_{min})}$$

remains applicable and gives gain and offset values as illustrated here below.

Q21. *What are the commonly-used ESA recalling gain and offset coefficient to be used to convert Landsat TM digital number value into radiance value?*

For the ESA TM products, it is important to check the calibration method used during the processing and the observation date of the scene.
The two tables just here after list the rescaling coefficients in case of pre flight calibration and in case of calibration based on lifetime model.

Band	1	2	3	4	5	6	7
Lmin (W/m²*sr*µ)	-1,500	-2,800	-1,200	-1,500	-0,370	1,238	-0,150
Lmax (W/m²*sr*µ)	152,1	296,8	204,3	206,2	27,19	15,6	14,38
Offset = Lmin, (A0)	-1,5	-2,8	-1,2	-1,5	-0,37	1,238	-0,15
Gain = (Lmax-Lmin)/255, (A1)	0,6024	1,1749	0,8059	0,8145	0,1081	0,0563	0,0570

table 2 - TM-4 and TM-5 spectral range values and rescaling coefficient (processing with Pre launch calibration method).

There are two samples of rescaling gain/offset coefficients for TM products processed using the lifetime model.
The first set of gain/offset coefficients covers a period from the satellite launch to December 31st 1991.
The second set gain/offset coefficient covers a period from January 1st 1992 through to the present.
The table below lists the TM products scaling coefficients with regards to the observation period.

Band	1	2	3	4	5	*6*	7
	LUT 07 - Acq Mar,1, 1984 -> Dec, 31, 1991						
Offset (A0)	-1,52	-2,84	-1,17	-1,51	-0,37	*1,2378*	-0,15
Gain	0,668706	1,31702	1,03988	0,872588	0,119882	*0,055158*	0,065294
	LUT 07 - Since Acq Jan,1, 1992 -> present						
Offset (A0)	-1,52	-2,84	-1,17	-1,51	-0,37	*1,2378*	-0,15
Gain	0,762824	1,44251	1,03988	0,872588	0,119882	*0,055158*	0,065294

table 3 - TM-5 spectral range values (processing with Life Time Model).

Note that the coefficients given for the TM band number 6 (thermal band) are not reliable because the ESA TM thermal band is not calibrated during the processing.

Q22. *What are the commonly-used ESA recalling gain and offset coefficients to be used to convert Landsat ETM + digital number value into radiance value?*

A set of lower and upper spectral radiances is provided for each band. In the case of Landsat 7 ETM+, this set differs from one gain state to the other one. In tables here below are illustrated the spectral radiance limits as well as their correspondent gain and offset.

Band	1	2	3	4	5	6	7	8
Lmin (W/m²*sr*µ)	-6,2	-6,4	-5	-5,1	-1	0	-0,35	-4,7
Lmax (W/m²*sr*µ)	293,7	300,9	234,4	241,1	47,57	17,04	16,54	243,1
Offset = Lmin, (A0)	-6,2	-6,4	-5	-5,1	-1	0	-0,35	-4,7
Gain = (Lmax-Lmin)/255, (A1)	1,1761	1,2051	0,9388	0,9655	0,1905	0,0668	0,0662	0,9718

table 4 - ETM+-7 spectral range values in low gain mode.

Band	1	2	3	4	5	6	7	8
Lmin (W/m²*sr*µ)	-6,2	-6,4	-5	-5,1	-1	3,2	-0,35	-4,7
Lmax (W/m²*sr*µ)	191,6	196,5	152,9	157,4	31,06	12,65	10,8	158,3
Offset = Lmin, (A0)	-6,2	-6,4	-5	-5,1	-1	3,2	-0,35	-4,7
Gain = (Lmax-Lmin)/255, (A1)	0,7757	0,7957	0,6192	0,6373	0,1257	0,0371	0,0437	0,6392

table 5 - ETM+-7 spectral range values in high gain mode.

Q23. *We are conducting a study on numerous European Landsat 5 and 7 products acquired between 1984 and 2003. We would like to work with spectral radiance values. Could you let me know if the calibration values for each band (Gain and offset) have been changed during these scenes acquisition period?*

For the whole European Landsat 5 and 7 products, the gain and offset values to be applied are unchanged. On September 1,1986, EOSAT adjusted look-up tables (LUT) for TM bands 5 and 7. Adjustment methods and results are fully explained in the following document:

Markham, B.L., and J.L. Barker, 1986,
Landsat MSS and TM post-calibration dynamic ranges,
exoatmospheric reflectances and at-satellite temperatures.
EOSAT Technical Notes, August 1986.

Q24. *In "Landsat ETM/TM CEOS/ESA products format definition" spectral radiance units are expressed in 10*W m^{-2} sr^{-1} um^{-1}. Could you confirm?*

I confirm in the CEOS specification spectral radiance values are expressed in 10*W m^{-2} sr^{-1} um^{-1} units. However, clarification must be done only for US processed data. The common used spectral radiance units for MSS and TM product is mW*(cm^{-2} sr^{-1} um^{-1}) while it is W*(m^{-2} sr^{-1} um^{-1}) for ETM+. The conversion factor is 10 when going from the one to the other.

Q25. *How can I convert DN to radiance and reflectance value?*

According to the ESA document *Full Resolution System Corrected data*, the formula is:

$$Rea = \frac{(\pi * L_{cal}(\lambda))}{(E_\lambda * \cos(\theta_s) * d^2)}$$

Where:

Rea is the reflectance at the Top of the Atmosphere (“*Reflectance exo atmosphérique”*) for a given Spectral calibrated radiance.

$L_{cal}(\lambda)$ is the spectral calibrated radiance at the TOA.

E_λ is the Solar spectral irradiance at the TOA atmospheric irradiances, units $w.m^{-2}.\mu m^{-1}$.

θ_s is the Solar zenith angle, degrees units.

d is the radius vector (ratio of mean to actual sun-earth distance) which can be computed using the following formulae:

$$d = \frac{1}{(1 - 0.016729 * \cos(0.9856(DOY - 4)))} \text{ and } d = \frac{1}{d_0}.$$

Where:

DOY is the Julian day number, from 1 to 365-366.

d_0 is the Earth-Sun distance in astronomical units.

Then, the formula to compute the reflectance is:

$$\text{Re}a = \frac{(\pi * L_{cal}(\lambda) * d_0^2)}{(E_\lambda * \cos(\theta_s))}$$

Q26. *Why does Landsat 7 ETM+ change its gains?*

For every band, ETM+ instrument can operate in either high (H) or low (L) gain state. Gain state strongly depends on the illumination (sun elevation) at ground level and on cover type. The gain mod system consists of an on-board pre amplifier which acts as a filter; the low gain mod prevents the sensor's saturation but reduces the histogram dynamic. The two modes differ by about a factor of 1.5 for the seven reflective bands and 2.0 for the emissive band 6.

As an example, Landsat 7 image bands acquired over snow areas in high gain mode can show sensor saturation for bands 1 (blue), 2 (green), 3 (red) and less frequently 4 (near infrared). However, the same bands acquired in low gain mode do not show sensor saturation, but their poor dynamics are sometimes the cause of a striping defect.

Q27. *What are the gain setting rules?*

The basis concept on the gain setting strategy applied by USGS is well explained in the Landsat Handbook. However, two points must be underlined:

- Landsat ETM+ instrument switches its gains by group of bands:

Four bands groups can be discerned since the thermal bands are acquired simultaneously in a low and high gain state and as a result, never switch their gain. The four groups of bands are;

- Bands 1-2-3
- Band 4
- Bands 5-7

  Band 8

For instance, HLHL is the same as HHH L H LH H L.

- In addition, the gain setting strategy has taken effect the day 195 of 200 (July 13th). This strategy is based on other parameters including the sun elevation angle, cloud cover rate and earth cover type. IUt should be noted that this strategy is not absolute and also not always respected.

Q28. *Can we detect product contaminated by a gain change while checking its quick look in the Eurimage catalogue?*

The Eurimage Quicklook is a composition of bands 2,5 and 7. As has been mentioned earlier. any gain change on band 4 or 8 is undetectable.

Q29. *Does radiometric calibration is applied to the TM thermal band of the ESA product?*

There is no radiometric calibration procedure applied for the TM thermal band.

Q30. *Is the banding correction applied to the ESA products?*

The memory effect produces light and dark bands in the imagery and is most obvious in homogeneous regions following a sudden transition in intensity, such as at a cloud–land boundary. It is also known by other names, including "banding", "bright target recovery", "bright target saturation", "scan-to-scan striping", and "radiometric hysteresis". Every image pixel is affected and the magnitude of the effect can reach as high as two digital counts. The memory effect has not been observed in bands 5, 6, and 7, which are in the cold focal plane and use preamplifiers that are designed differently compared to those used in TM bands 1–4.

Helder et al. (1997) trace the memory effect to the preamplifiers that amplify the analog signal from each individual detector element. Following saturation by a bright target, the output of the preamplifier undershoots the desired level and recovers exponentially with a time constant of 10 ms, which corresponds to 1040 pixels.

4. GEOMETRIC

Q31. *What is the ESA product level of the terrain corrected products?*

The ESA product level is 7.

This information is written into:

- The catalog file 'LEVEL 7'
- The leader file / leader file/scene header record/product ID – correction applied , tag '07'

Q32. *Why are ephemeris data used?*

Ephemeris data is a component part of the information downloaded in the telemetry data and is used during geometric corrections of the image. The data describes the conditions under which the data has been collected, and may also be used to correct the data before it is analysed.

Geometric correction involves modelling the relationship between the image and systems of ground coordinates. Two kinds of geometric errors can be discerned:

- **systematic** geometric errors
- **non-systematic** geometric errors.

Data on sensors and ephemeris information are modelled and applied to the raw imagery as part of systematic corrections. Thus, Eurimage systematic corrected (L1 G) products are free of **systematic errors**.
Non-systematic errors caused primarily by satellite altitude and attitude require image to map rectification, and this process can use Ground Control Points (GCPs) to tie image pixel coordinates to their corresponding map coordinates.

A sub pixel registration can necessitate a non-systematic errors removal process. This can be done using an accurate post processing (http://www.eurimage.com/).

Q33. *Why does the supplemental file of my CEOS product include two ephemeris groups?*

On the ground, the first ephemeris group computation is made using the state vector coming from the PCD (Payload Control Data) stream. This first ephemeris group is made on raw ephemeris data, and includes missing and corrupted values. Before it can be used for a set of geometrical corrections, the quality of this data must be improved. Interpolations and corrections are therefore performed on the first ephemeris groups, and results are stored in the second ephemeris group. This second group is ALWAYS involved in the geometry model computation, and its quality influences absolute scene location accuracy.

Q34. *What is the difference between products processed with PCD Ephemeris group and products processed with Definitive Ephemeris group?*

Corrections and interpolations of first ephemeris group are based on whether the external ephemeris data is used or not. The computation of the second ephemeris group relies on definitive or predicted data.

In the first case, the product will be defined as processed with consolidated or definitive ephemeris (DEF product) or otherwise is as processed with predicted one (PCD product). Usually, for a same scene (same acquisition date), the PCD product will have absolute location accuracy weaker than the DEF one.

Definitive ephemeris data can be downloaded on the following URL link

http://landsat7.usgs.gov/ephemeris.html

Q35. *We are ready to order a Landsat 7 systematic corrected product. How can we know if it will be a PCD or DEF product?*

The definitive or consolidated ephemeris data spans a period from June 29, 1999 through to the present So, products acquired prior to June 29, 1999 are systematically processed with predicted ephemeris (PCD product). The Landsat Handbook entry for Landsat 7 Definitive Ephemeris notes:

> *"The Landsat 7 Mission Operations Center receives tracking data on a daily basis that shows the position and velocity of the Landsat 7 spacecraft. This information comes from the three US operated ground-receiving stations and is augmented by similar data from NASA's Tracking and Data Relay Satellites. The Flight Operations Team processes this information to produce a refined or "definitive" ephemeris that shows the position and velocity of Landsat 7 in one minute intervals. Tracking data are used to compute the actual spacecraft position and velocity for the last 61 hours and to predict these values for the next 72 hours. The predicted ephemeris data are uploaded to the spacecraft daily. On-board software interpolates from this data to generate the positional information contained in the Payload Correction Data (PCD)."*

Furthermore, a product is processed using predicted ephemeris data if the definitive ephemeris data is unavailable; i.e. if the delay between the acquisition date and the processing date does not exceed 2 days.

NOTE: For the Landsat 5 systematic corrected products, ESA's European products are only produced using PCD data.

Q36. *What is the geodetic accuracy of the Landsat 7 systematic corrected product?*

An extract from the following document:

Barker, J. L., Dolan, S. K., Sabelhaus, P. A., Williams, D. L., Irons, J. R., Markham, B. L., Bolek, J. T., Scott, S. S., Thompson, R. J., Rapp, J. J.,Arvidson, T. J., Kane, J. F.,& Storey, J. C. (1999). Landsat-7 Mission and Early Results. EUROPTO Conference on Sensors, Systems, and Next-Generation Satellites V, vol 3870 (pp. 299– 311). Florence, Italy: SPIE.

notes that:

> *"The geodetic accuracy of the systematically corrected image using the routinely supplied PCD-ephemeris will usually be better than 50 meters. In those cases where there is an excursion in geodetic accuracy greater than 50 meters, it appears that the use of post-processed "definitive" ephemeris will bring systematically corrected geodetic accuracy to within 50 meters again."*

In 2002, ESA/ESRIN carried out a study with the aim of assessing the impact of PCD/DEF ephemeris on product geodetic accuracy. This study confirmed the assertions made by Barker et al (above).

The USGS specifications concerning the geodetic accuracy of the Landsat 7 systematically corrected images is 250 meters for low-relief areas at sea level. This latter value is a maximum threshold. Even if the mean of geodetic accuracy is centred on 50 meters, a specification of 250 meters is more careful.

Q37. *What are consequences of the wrong ephemeris data on a product?*

If the ephemeris data is wrong, then the systematic corrections are not correctly applied, and as a consequence, geometrical errors can arise. During processing, any wrong and missing values are corrected; however an ephemeris group shift could remain.
Usually, the shift, inherent to estimated spacecraft positions, is more important in along track (AL) direction than in across track (AC) direction. For instance, a wrong onboard counter induces a shift in time which means the Landsat scene is shifted in the AL direction..

Q38. ***I am presently conducting a project using a pixel-by-pixel change detection method. Could I superpose two systematic corrected products? What are the specifications concerning the temporal registration?***

Bands of similar resolution coming from systematic corrected products of a same location and with same output map projection parameters can be superimposed.

The satellite is held from +/-5 km from its repeat of the ground track, and therefore satellite altitude may be different from one image to another. This difference could cause a scale difference between images acquired at different dates and therefore some pixel mismatching may be present.

You could check the specifications of the temporal registration in the IAS web site.

Q39. ***I have a systematic corrected product and I want to perform an image classification. What kind of bands combination could I choose to improve discrimination of features such as roads, land and water?***

You can try using the following band combination: 4,5,3 (RGB). It should improve discrimination of the land/water interface. If roads have a sufficient width and are not obscured by vegetation, it would match your request.

The Table below gives some basic clues about the Landsat 7 channels properties. From an image interpretation point of view, it highlights each Landsat ETM feature that can be discerned.

Channel	Description
1	Coastal water mapping, soil/vegetation discrimination, forest classification, man-made feature identification
2	Vegetation discrimination and health monitoring, man-made feature identification
3	Plant species identification, man-made feature identification
4	Soil moisture monitoring, vegetation monitoring, water body discrimination
5	Vegetation moisture content monitoring
6	Surface temperature, vegetation stress monitoring, soil moisture monitoring, cloud differentiation, volcanic monitoring
7	Mineral and rock discrimination, vegetation moisture content

table 6 - Landsat 7 Channel wavelengths: Usage for varying monitoring requirements

The following URL links point to the Eurimage Landsat gallery. Coastal areas ,Deserts, Agriculture, Tropics, Mountains .

Q40. ***The ordered products show a high rate of duplicated lines. What are root causes of duplicated lines?***

On the one hand, the curvature of the Earth curvature coupled with the satellite motion induces a partial addition to the image line during the map projection.

On the other hand, if the amount of duplicated lines in Landsat 4&5 imagery are too important, these are due to inoperable or bad detectors. Also called line dropout, this is corrected by interpolating between the next adjacent lines, above and below the dropped line. This procedure is done at the L1 stage of processing. In the format, an appropriate flag is set to "Y" to notify to the user that such corrections have been performed.

Q41. *What is the "bumper" mode on Landsat 5?*

Early in 2002, The TM instrument onboard Landsat 5 lost synchronization between the scan mirror and calibration shutter, resulting in "caterpillar tracks" on imagery. In order to fix this problem, the USGS switched the TM instrument from the scan angle monitor (SAM) mode to backup "bumper" mirror mode in order to extend the useful life of the TM instrument.

In SAM mode the telemetry data reports three time values;

- the active scan start time,
- the first (scan start to mid-scan)
- second (mid-scan to scan stop) time.

While in bumper mode, the telemetry data contains values for the total scan mirror travel time between successive bumper impacts.

The USGS team has developed an emulated SAM mode using the bumper mode (bumper mode theoretical basis). A check has already been engaged by ESA/ESRIN to assess the impacts of such change on the product quality. The European Landsat 5 products acquired in bumper mode, are processed in SAM mode. Thus, information written in the CEOS format (imagery file) and related to the mirror time error would remain unchanged. Unlike the previous model, the new model necessitates the use of an updated Calibration Parameter Files (CPF).

5. Resources

5.1 Technical information

Landsat USGS website

Landsat 7 Science Data Users Handbook

Eurimage, Landsat products specification

5.2 Applications and end user forums

USGS - Landsat project - Frequently Asked Questions

Geosystems Gmbh - Atmospheric Corrections - Forum

Landsat GSFC - education - training