TOOL DESCRIPTION AND VALIDATION

TECHNICAL NOTE

	Name	Company	Date	Signature
Prepared by :	O. Amram G. Salgues S. Saunier	Magellium	23/03/2015	
Checked by :	S. Saunier	Magellium	23/03/2015	
Approved by :	S. Saunier	Magellium	23/03/2015	

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1 Purpose

This **Technical note** is prepared by Magellium for the Project "X-Press", which is the subject of the contract "XPReSS-SER-SUB-0003" issued by the **SERCO** Company.

This document is organized in eight sections; in the following a brief description of the content sections is provided, with the relationships between them:

- Chapter 1: Purpose. This is this section.
- Chapter 2: References. This section mentions documents related to this one.
- Chapter 3: Terms and Abbreviations. This section defines terms which are used within this document.
- Chapter 4: Executive Summary. This section presents the high level findings of the test report and proposes some recommendations.
- Chapter 5: SV Generation Process. This section presents the approach that has been adopted to generate SV. The S/W is then described in term of interface, format specification and usage (command line).
- Chapter 6: Delivery details. This section presents the content of the delivery and the packaging (file organization).
- Chapter 7: Validation. This section is focused on the validation of the generated SV by considering basically the geometric accuracy of the resulting L1 products.
- ANNEX 8: Document Annex. It should have been cumbersome for the reader to have all the tables, included in the main sections of this document, hence, it has been decided to put detailed on input data, and also some results in Annex. The most synthetic information is presented in the main part of the document.

2 References

2.1 Applicable documents

The following documents are fully applicable together with this document.

Id.	Ref.	Description
[AD-1]	Constract N : XPReSS-SER-SUB-0003	1.0

Table 1 - Applicable Documents.

2.2 Reference documents

The following documents, though not a formally part of this document, amplify or classify its contents.

Id.	Ref.	Description

Table 2 - Reference Documents.

3 Terms, Definition and Abbreviated Term

3.1 Terms and Definitions

Term	Meaning
Orbital Propagator	Propagation model interpolating the sparse satellite position to restitute continuous SV. In our case, it is SGP4.
SV Type: PREdicted (PRE)	Collected with different means, mainly applicable for old Landsat missions. It involved propagator starting from a known satellite position. It is not clear which kind of propagator has been used. The time sampling of Predictive is very sparse
SV Type: REStitued SV (RES)	Collected by using Telemetry from PCD stream, one ephemeris record is given every two PCD major frames. In one standard TM scene, the s/c position is given at two different times every 12 s. However, the PCD data are sometimes corrupted. Therefore, a dedicated process has been set up by ACS to consolidate data and rescale to a time frequency which is appropriate for processing. The Restitued SVs have been used for near real time data provision. Actually, within 2 days, the observations from external tracker and the full analysis of all past orbits were used to provide more accurate ephemeris (DEF)
SV Type: DEFinitive SV (DEF)	The definitive ephemeris data are consolidated data. It has been generated within two days after recording of the satellite path by ACS. The DEF data has been progressively provided by USGS and therefore ACS DEF data has been replaced by DEF from USGS.
State Vector	Herein, it is the position and velocity of the s/c at a given date /time. The Earth Centered coordinate system of SV position, velocity is mission specific. It is discussed in this document.
TLEs	Two-Line Element sets, position / velocity of s/c is deduced by rusing coordinates expressed in the Keplerian Coordinate system.

Table 3 - Definition.

3.2 Abbreviated Terms

Term	Meaning
ACS	Advanced Computer System (herein designer of the Landsat S/W)
AD	Applicable Document
ESA	European Agency
GCP file	Landsat Product GCP File; listing residuals of geometric model refinement at given

	GCPs.
LS	LandSat, 'LS-01' refers to Landsat 1 mission.
MSS	Multi Spectral Sensor
MTL file	Landsat Product Metadata File
SGP4	Standard General Perturbations 'satellite orbit model 4'
SV	State Vector, 'SV_PRE' standing for PREdicted SV 'SV_RES' standing for REStitude SV 'SV_DEF' standing for DEFinitive SV 'SV_MAG' standing for Magellium's SV.
TDS	Test Data Set
USGS	United States Geological Survey

Table 4 - Abbreviated Terms.

4 Executive Summary

The objective of this work was to generate Definitive State Vector (SV) files for gap filling. This state vector will be used during the operational re processing of Landsat data. To date, a part of the Landsat MSS archive cannot be processed because there is no SV files match with observation periods of given set of WILMA data.

A total of 644 SV Files has been successfully generated. The table below shows a summary of generated SV files broken into categories depending on the Landsat mission number.

	Landsat 1	Landsat 2	Landsat 3	Landsat 4	Landsat 5
Number of SV Files	7	310	172	150	5
Number of Products that can now be processed	16	866	510	720	9
Total Number of products	613	5030	2796	5705	23633
% recovered	**2,610**	**17,216**	**18,240**	**12,620**	**0,038**

Table 5 - Overall Number of generated SV Files.

Note, that the regeneration covers all the WILMAs for which no SV files exist (RES & PRE & DEF).
Also, it is important to note that a different approach consisting in generating SV files even if PRE / DEF SV is available might be proposed. It should be done in case of product geolocation accuracy achieved by using the new SV is better than with existing AUX.
This aspect is to be clearly assessed. In this case, the number of affected WILMA products would be:

- 21698 and 4278 SV files, replacing de facto any RES / PRE SVs;
- 37777 and 9422 SV files, replacing de facto any RES / PRE / DEF SVs.

To validate the SV generation process, a set of items has been defined. The WILMA data for which existing RES data is available has been selected and L1 products, processed both with existing SVs ''SV_PRE' products) and also with new SVs ('SV_MAG' products), have been generated and compared (L1G, L1T processing level).

As consequences, the table below lists depending on these quality items, the main outputs of this validation exercise.

Validation Items	Comments
Filename	GEO – GTC) The file name of the product (main directory) may change because of time differences between the two SVs. The maximum difference observed is 0.2 s for LS01 products. For products from the other missions, results are very corrects but however might show high variability (LS04 case).
MTL / GCP File	GEO/GTC) Excepting geometric information associated with the scene footprint, the content of MTL does not change. The content of GCP file does not change significantly depending on SV used (existing or generated). The quality parameters are the same.
Absolute Geometric registration (GEO)	The absolute geometric accuracy of 'SV_MAG' and 'SV_PRE' can be somehow different in some cases. 1.5 km (RMS) difference found for LS03 with better results given with 'SV_PRE'. In most cases, the results are in the same order.
Geometric co registration accuracy (GTC)	The geometric co registration accuracy of GTC products is within the pixel. The use of a new SV does not impact the absolute accuracy of the GTC. It has been shown that the internal geometry of GTC products is not good. The geometry is changing depending on the SV origin. It results in difficulties for direct comparison of 'SV_MAG' and 'SV_PRE' image grids. It is quality aspect to keep in mind form time series processing.

Table 6: Validation Results, summary.

5 SV Generation Process

The scope of this part is to describe the approach proposed for the generation of Landsat SV files.

5.1 Context

Generally speaking the SVs are used during the geometric processing, in particular for a direct location of the scene before geometric model refinement.

The SV generation process does not intend to extract/correct SVs which available in the L0 telemetry. Actually, depending on the mission, SVs from PCD data might be missing / corrupted / inconsistent / inaccurate. For this reason, the ACS processing sw, used SV stored as auxiliary data. The category of SVs is either PREdictive, REStitued, DEFinitive (refer to definition above, $3.1).

According to literature, depending on the category of the SV, the operational direct location accuracy that might be achieved is from 250 m (DEF) up to 5 km (RES), RMS values.

The SV data at a given observation period is mandatory for the generation of the Level 1 product.

- The direct location accuracy of Level 1 "GEO" is highly correlated with the accuracy of the SVs;
- The planimetric accuracy of Level 1 "GTC" is a priori not correlated with the accuracy of the SVs.

Note that the direct location accuracy of Level 1 "GEO" is important because in some cases, for certain applications, it is important to let the user performing its own terrain relief corrections, in particular with a digital elevation model of a better accuracy than the operational one (SRTM).

5.2 The "TLE Approach"

NORAD Two Line Elements (TLE) records from Celestrak database[1] together with an orbital propagation model [2] are used in order to predict (interpolation / extrapolation) the location and the velocity of the s/c at a given data/ time. The remaining part of the process relied on a

[1] http://www.celestrak.com/NORAD/elements/

[2] SGP4 orbit propagator describes and available here

coordinate system conversion function in order to output values in the appropriate AUX SV format.

Note that, this approach has already been set up in case of missing MMFI file. Any missing MMFI files are blocking for processing of WILMA Level 0 data. An activity of DSI consolidation phase has been to regenerate MMFI. In case of missing SV file, the observation times of the WRS scenes, have been estimated by inferring the theoretical WRS scene location with satellite sub track location at different times. This latter one is the result of the "direct location" as a function of the SV, predicted in this case, by using TLEs data.

5.2.1 Early Evaluation

The early evaluation has been based on comparison between scene center coordinates obtained with different approach and the scene center coordinates as specified in the definition of the theoretical WRS scenes (reference).

The results are shown in both figures below. The 'red' curve is obtained by using 'SV_DEF'. In the next second figure, the 'green' curve depicts locations obtained with the TLE approach.

The first observation is that predication matches with theoretical WRS scenes within an uncertainty within +/-3.8 km (mean offset). It is considered as correct.

The second observation is that the direct location function applied to SV from the 'TLE approach' or from 'SV_DEF' (the most accuracy ephemeris data) provides very similar results.

Note that in both figures below, the blue curve depicts the two closest (neighboring) satellite tracks.

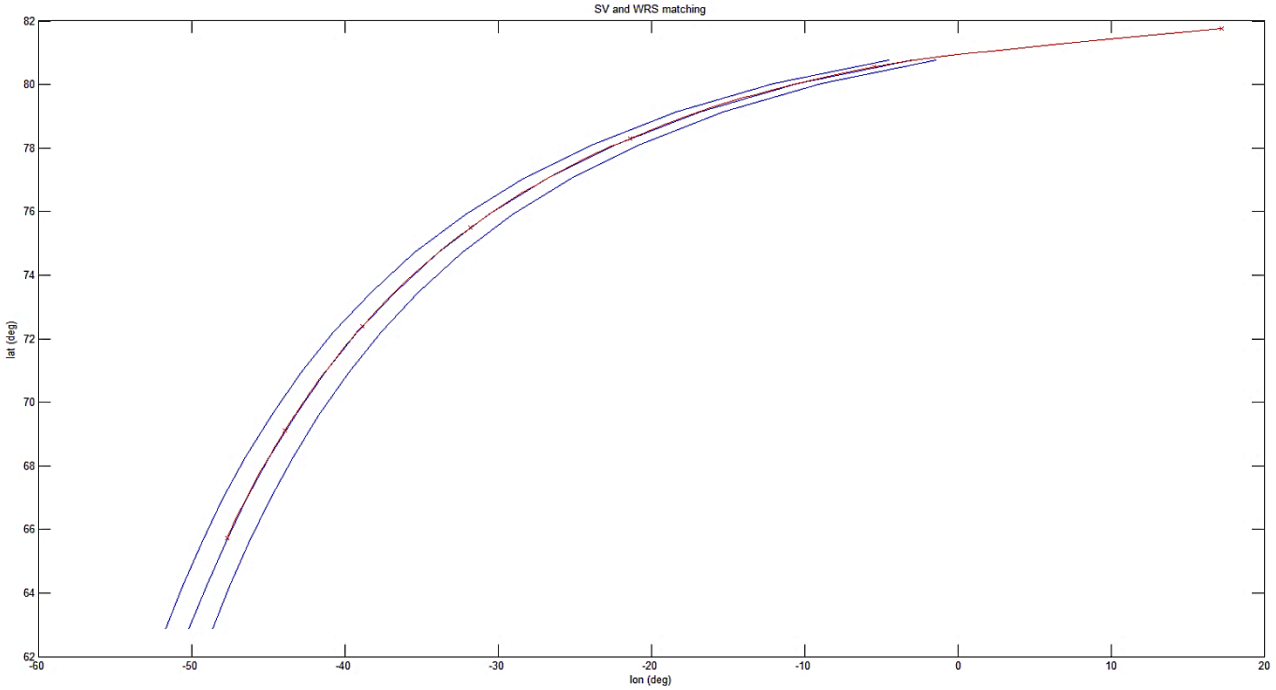


Figure 1 – Comparison of the scene center location by using 'SV_DEF' and WRS theoretical definition.

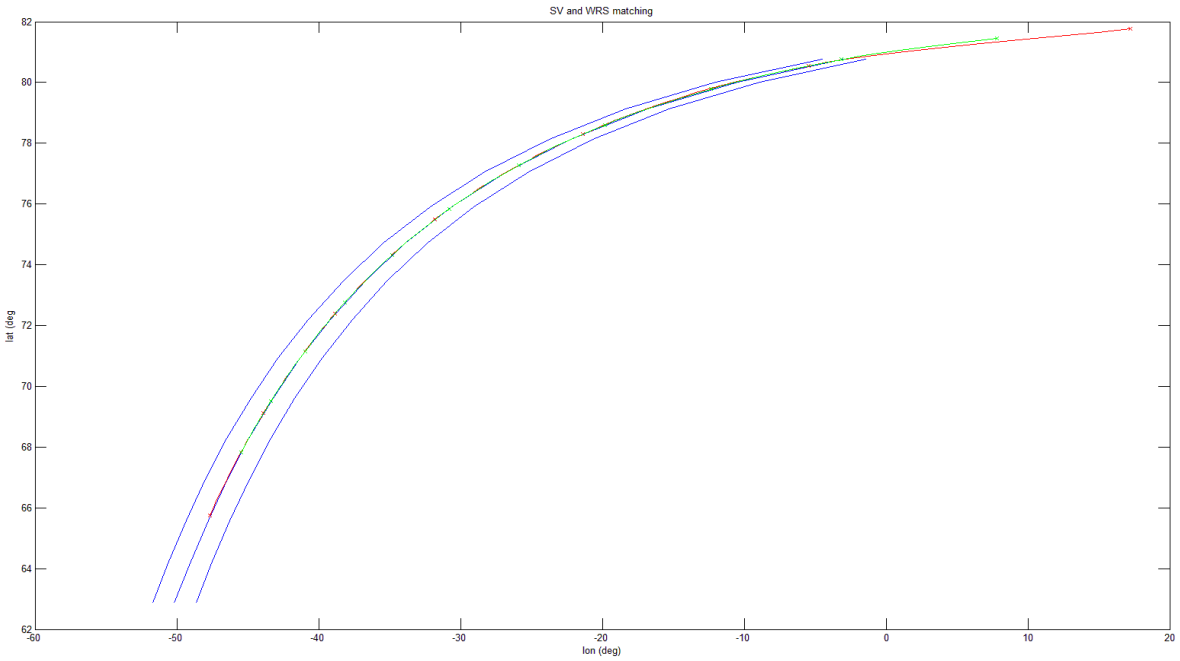


Figure 2 Comparison of the scene center location by using 'SV_MAG' and WRS theoretical definition.

5.3 S/W description

5.3.1 SV File specification

The SV files respect the following naming convention:

[MMMM]_AUX_SV_[TTT]_(ValidyPeriodStart)_(ValidityPeriodEnd)_[OR]_[d]_[dddd].ACSA

- [MMMM] for Mission Id "LS01" "LS02" ….
- [TTT] for SV Category "RES" for restitute , "PRE" for predictive, "DEF" for definitive
- ValidityPeriod [yyyyMMdd]T[HHmmss] (UTC)
- [OR] Originator trigram, "ACS" for "RES" and "PRE" , "ACS" or "ESR" for "DEF"
- [d] & [dddd] set to 0 in the most cases.
- Extension ACSA to indicate that the file has been generated by using the ACS tool in charge of formatting / coordinate conversion – in particular for importing Ephemeris from the USGS.

The SV files generated by Magellium respect fully this naming convention including the ACSA file extension in order to ensure the full compatibility with the processor. We only use "MAG" trigram for the [OR] in order to identify theirs origins and they will be considered as "PRE" SV file for the processing.

Concerning the SV file content, the "MAG" SV files are generated on a daily basis from midnight to midnight with a time sampling of 1 minute. Below an example of the naming of a Magellium SV file:

« LS01_AUX_SV_PRE_19760710T000000_19760711T000000_MAG_0_0000.ACSA »

The SV files respect the following content convention:

SV format, one SV file includes one or several two-line records, with UTC date / time and (Position(X,Y,Z),Velocity(Vx,Vy,Vz)) , expressed in geocentric system, J2000 (depending on the LS mission the coordinate system of the mission is different), (precession / nutation correction applied or not applied)

The first line of a record contains the UTC date/time with the following convention:

UTC=[yyyy-MM-dd]T[HH.mm.ss.SSS]

The second Line contains respectively, X Y Z Vx Vy Vz in the following format:

[+/-]NNNNNNN.NNN [+/-]NNNNNNN.NNN [+/-]NNNNNNN.NNN [+/-]NNNNN.NNN [+/-]NNNNN.NNN [+/-]NNNNN.NNN

Exemple of two-line record:

L1 : UTC=1976-10-16T20:31:05.400
L2 : -6733815.248 +2813606.649 -0000609.421 +00434.636 +01056.354 -07299.676

The three existing types of SV files have different validity periods, time sampling, time coverage:

PRE:
LS04_AUX_SV_PRE_19920701T063248_19920731T212842_ACS_0_0000.ACSA

- Validity +/- 3 d, from time period boundaries (here from 19920701 up to 199207312)
- Time Coverage: It Depends on the SV file, several records might be included; 6 – 35 days
- Time sampling: One record every 1/2 days

RES:
LS01_AUX_SV_RES_19761016T203105_19761016T203106_ACS_0_0000.ACSA

- Validity +/- 3 d, from time period boundaries, here from 19761013 up to 19761019
- Time Coverage: It Depends on the SV file, several records might be included; 6 – 32 days
- Time sampling: One record every 2/3 days

DEF:
LS05_AUX_SV_DEF_20120111T000000_20120113T130000_ESR_0_0000.ACSA

- Validity +/- 3 d, from time period boundaries (here from 20120111 up to 20120113)

- Time Coverage: 7 days as maximum extent – in general one file refers to 1 / 2 days
- Time sampling: One record every minute

5.3.2 **Tools packaging**

The tool is developed in java language and consists in an executable JAR file to which is associated a 'ReadMe.txt' file. The arguments of the executable are

1. A text file containing the list of dates for which an SV file must be generated;
2. An output folder in which processing results ('SV_MAG') will be written.

5.3.3 **Command Line**

In order to generate 'SV_MAG', the following command line is to be used:

```
>java –jar aux-sv-generator.jar "./list.txt" "./outputFolder/"
```

The input text file ("list.txt") is an ASCII file. It contains several lines. Each line corresponds to a date and a mission number separate by the character ";". The format of the date is [dd/MM/yyyy] and the mission number is the Landsat Mission number from 1 to 5.

An example of the input text file is given below.

```
24/07/1978;2
30/07/1978;2
31/07/1978;2
06/08/1978;3
07/08/1978;3
08/08/1978;3
09/08/1978;3
10/08/1978;3
01/08/1978;4
02/08/1978;5
03/08/1978;5
04/08/1978;5
```

6 Delivery details

6.1 Processed data

	Landsat 1	Landsat 2	Landsat 3	Landsat 4	Landsat 5
Number of SV Files	7	310	172	150	5
Number of Products that can now be processed	16	866	510	720	9
Total Number of products	613	5030	2796	5705	23633
% recovered	2,610	17,216	18,240	12,620	0,038

Table 7 - Processed data.

Note that, the regenerated SV are independent from the acquisition station (KSE, FUI, MTI…).

6.2 Packaging format

The format of the package delivers to the customer is depicted with the figure below.

The folder 'aux-sv-generator' includes the following items:

1. aux-sv-generator-1.0.jar the executable jar;
2. ReadMe.txt the command line usage notice.

The folder 'Generated-SV-Files' includes the generated 'SV_MAG' files. These files are sorted depending on the Landsat mission and also on the date. It complies with the commonly used structure format involved in the consolidation.

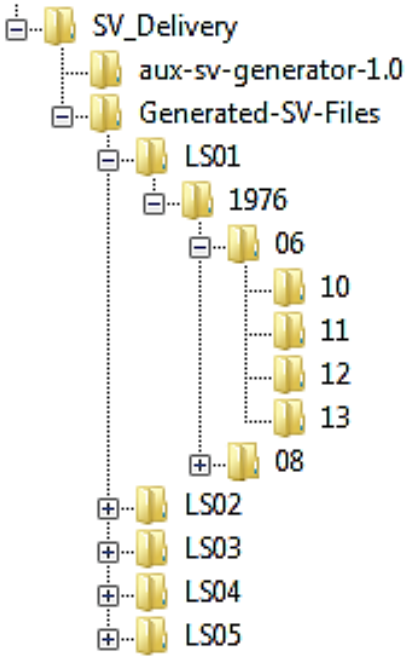


Figure 3 - File breakdown structure of 'SV_MAG' delivery.

7 Validation

The scope of this part is two folds; the description of the validation approach and also the validation results.

7.1 Methodology

The validation of generated SV can be cumbersome and it is not possible to validate any generated SVs. Our interest has been focused on observation periods of several days for which no SV data exist. These periods are characterized as a strong SV data gap. And our objective has been to validate the 'SV_MAG' at the period boundary for which there is existing SV data to be considered as reference. Hence, the following dates have been kept:

- The D0-date defined as to be one day before the starting date of the gap;
- The D1-date defined as to be one day after the ending date of the gap.

Landsat 01, 02 , 03, 04, 05 MSS WILMA image have been inspected, and the most appropriate twin dates (D0, D1) have been selected for each one of the missions.

File Name	Mission	Satellite Path	Nb. WRS scenes
LS01_MSS_MSS_0P_19760602T072348_19760602T073619_FUI_19674_7AC0	LS01	193	31
LS01_MSS_MSS_0P_19760831T071833_19760831T072904_FUI_20929_BBEF	LS01	193	27
LS02_MSS_MSS_0P_19761201T084913_19761201T090103_FUI_9467_C829	LS02	204	29
LS02_MSS_MSS_0P_19771021T083116_19771021T084427_FUI_13985_53B0	LS02	204	32
LS03_MSS_MSS_0P_19781125T101610_19781125T102603_FUI_3695_FF84	LS03	217	24
LS03_MSS_MSS_0P_19820911T102113_19820911T102841_FUI_23022_70DA	LS03	217	19
LS04_MSS_MSS_0P_19820926T062923_19820926T063805_KSE_1046_F33D	LS04	165	22
LS04_MSS_MSS_0P_19830711T063230_19830711T064051_KSE_5240_CC46	LS04	165	22
LS05_MSS_MSS_0P_19851002T091344_19851002T091911_KSE_8445_7C35	LS05	191	15
LS05_MSS_MSS_0P_19860530T090855_19860530T091420_KSE_11940_B2C3	LS05	191	15

Table 8 - WILMA TDS.

Images of L0 WILMA from TDS are shown in table below. Missing image data anomaly is observed. The TDS has been selected under the following constraints:

- D0 date, D1 date definition, see above;
- At D0 date, D1 date it is the same path number;
- The terrain elevation is reduced (flat), to facilitate the assessment of GEO products
- The number of GTC/GEO twins (D0, D1) is maximized.

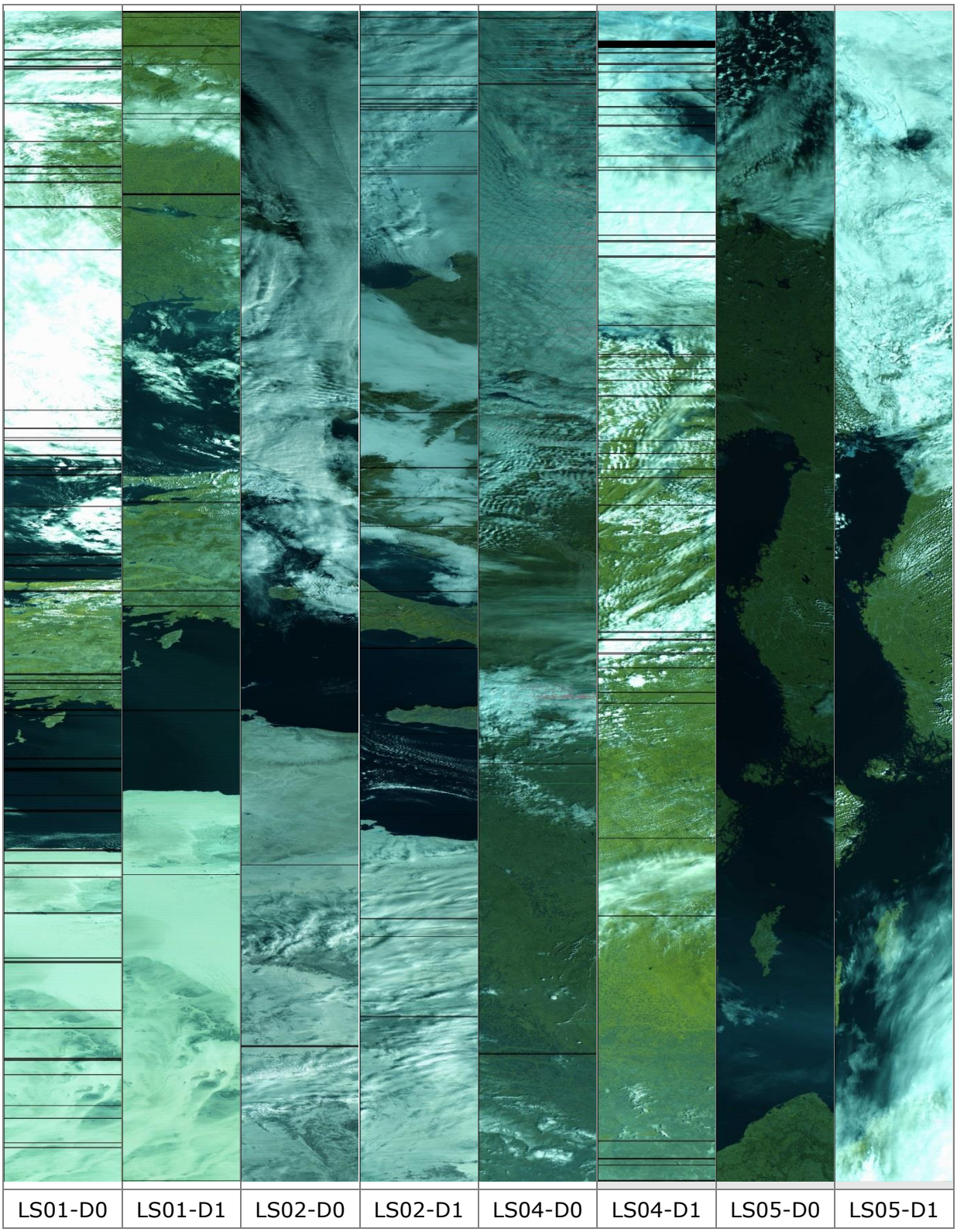


Figure 4 - WILMA Level 0 images.

The reference of WILMA has been communicated to Serco (Marco Meloni), and corresponding Level 1 products have been generated. Depending on the path, the Level 1 product sample includes a variable number of GEO or GTC products.

We did not get capabilities to force the ACS s/w in way to process only GEO products. The consequences have been: to get more operational difficulties for accurately assessing the accuracy of GEO products, notably because of cloud contamination in the input scene.

The methodology has been based on the following validation Items. These ones strongly depend on the processing level of the input products.

The baseline approach has been, at WRS reference level, the comparison between products generated with 'SV_RES' and products generated with 'SV_MAG'.

For a given mission, at DO and D1, whenever possible, a same WRS reference has been considered in view of performing the validation of the product geometry and discern problem if necessary. The five Landsat Missions have been considered.

Filename Checking	To assess the impact of the new SV on the file name, particularly in term of sensing time. It has been done for all scenes in the delivered dataset (95 scenes)
MTL File (GEO)	To assess impact of the new SV regarding the information written into the MTL, in particular scene footprint coordinates. It has been done for all scenes in the delivered dataset (25 scenes)
MTL / GCP File (GTC)	To assess impact of the new SV regarding the information written into MTL / GCP files information. It has been done for all scenes in the delivered dataset (70 GTC scenes)
Geometric co registration (GEO)	To evaluate the accuracy of the geometric co-registration for products observed both at D0 and at D1. It is performed against a reference (ortho reference). The scope is to discern if by 'using SV_MAG', the geolocation accuracy is degraded or improved. Visual inspection has been done for all GEO scenes in the delivered dataset. Quantitative analysis for 5 image twins.
Geometric co registration (GTC)	To evaluate the accuracy of the geometric co-registration for products observed both at D0 and at D1. In doing so, it is expected that the internal geometry of images does not change whatever SV origin. Visual inspection has been done for all GTC scenes in the delivered dataset. Quantitative analysis for 10 image twins.
Absolute accuracy	To evaluate the absolute accuracy of the registration, this

geometric accuracy	validation step is triggered not conclusive results obtained in the context of the previous validation item (Geometric co registration (GTC)).

7.2 File Name

Objective

The use of a different SV, from a same source or external source may have an impact on the scene footprint definition, and as consequences results in a change in the product file name, in particular regarding the start / end data / time of the scene.

Results

There are 76 LS01, LS02, LS03 products and 53 LS04, LS05 products that have been investigated.

Based on the product file name, broken into Landsat Mission category it has been observed that

- Regarding LS01, LS02 and LD03, for 26 products (52 twins), there is "within a 1 second shift" (34 %);
- Regarding LS04 and LS05, for 6 products (3 twins), there is a "within a 1 second shift (5 %).

For a given WRS scene, a "within a 1 second" shift occurs; the file name is changing as follow:

- LS01_RFUI_MSS_GTC_1P_19760831T0720**43**_19760831T072113_020929_0193_0027_477F.TIFF ('SV_PRE' product);
- LS01_RFUI_MSS_GTC_1P_19760831T0720**44**_19760831T072113_020929_0193_0027_9D6C.TIFF ('SV_MAG' product).

The scene "start time" is changing but the "ending time" does not. The shift is more likely within ½ second.

A "one second shift" means as a rough approximation about 6.5 km on the ground. Hence, the shift between 'SV_MAG' and 'SV_PRE' products might be up to 13 km. It is not the case for products that have been analyzed.

Note that shift does not mean a wrongly geo located product. It is the difference of scene coordinates between two products; it is not exactly the same area that is delivered to the user.

With this approach, it is not possible to distinguish which location predicted with 'SV_MAG' and 'SV_PRE' is the best one and also it is not the scope.

However, it is possible to compare the two scene center coordinates from the 'SV_MAG' product & from the 'SV_PRE' products. The table below lists the results.

	LS01	LS02	LS03	LS04	LS05
Nb Reference	16	6	1	6	9

	Delta Lon (m)	Delta Lat (m)	Delta Lon (m)	Delta Lat (m)	Delta Lon (m)	Delta Lat (m)	Delta Lon (m)	Delta Lat (m)	Delta Lon (m)	Delta Lat (m)
Mean	-876,66	-699,01	-3,16	38,74	-18,13	0,21	-636,39	-527,32	11,37	27,04
Standard Deviation	925,28	1253,88	305,87	194,73	n/a	n/a	1007,23	818,14	136,25	51,86
Minimum Value	-4050,45	-5081,77	-329,82	-238,45	-18,13	0,21	-2234,25	-1647,84	-153,58	-0,42
Maximum Value	664,25	604,04	485,97	240,22	-18,13	0,21	1,68	0,42	231,74	118,76
Median Value	-741,72	-487,71	-96,22	55,81	-18,13	0,21	-0,84	-0,10	15,47	0,21

Table 9 - Impact of SV on scene center determination (m).

According to our TDS,

- LS01 products are more likely subject to get a significant shift: above 1 km (RMS). Over 16 products the mean of the shift in time is about 0.2 second.
- LS02, LS03 and LS05, the shift is not significant
- For LS04, the shift appears to be extremely high but it is due to three products for which differences are very high and as a result overall variability very high.

We may have expect to observe a shift more pronounced in the time direction, it is not the case, error in both latitude, longitude direction is almost the same.

7.3 MTL / GCP File (GTC)

Objective

As part of Landsat Product GCP file information, the residuals error of geometric model refinement at given GCPs are given. The objective is to compare the RMS, RMSX, RMSY accuracy values depending on the SV origin. Differences between product accuracy parameters are computed for any products and then statistics are derived.

Results

The following conclusions are formulated and results listed in the table below:

- The use of 'SV_MAG' does not degrade significantly the accuracy of the model geometric refinement.
- The statistics vary depending on the missions, from 0.9 m (RMS) for LS05 up to 5 m (LS03).

We might have conjectured to get the almost same results (below 2 m RMS). It is not the case. The choice of SV impacts on the definition of the scene bounding box (geographical extent). As consequences, the GCP set involved might be different and as a result the residual errors of geometric model are different.

		RMS (in MTL)	RMSX (in MTL)	RMSY (in MTL)
LS01	MeanDx	-0,72	-1,43	0,09
	stdDx	2,45	5,19	2,10
	RMS	2,55	5,39	2,11
LS02	meanDx	-0,34	-0,04	-0,45
	stdDx	2,88	1,33	3,67
	RMS	2,90	1,33	3,70
LS03	meanDx	0,41	-0,35	0,91
	stdDx	1,85	1,11	1,67
	RMS	1,89	1,16	1,90
LS04	meanDx	-3,24	-1,54	-2,87
	stdDx	3,24	1,93	3,75
	RMS	4,58	2,47	4,72
LS05	meanDx	-0,37	-0,02	-0,51
	stdDx	0,79	0,22	1,00
	RMS	0,87	0,23	1,12

Table 10 - 'SV_RES' / 'SV_MAG', accuracy difference (meter).

A this point, to go further, and still regarding the residual errors of the ortho rectification process, the figure below covers any GTC products of the TDS and shows the matching between RMS, RMSX and RMSY parameters. It can be stated that the agreement between 'SV_MAG' and 'SV_PRE' product is reached. There are some outliers that need to be investigated more in depth.

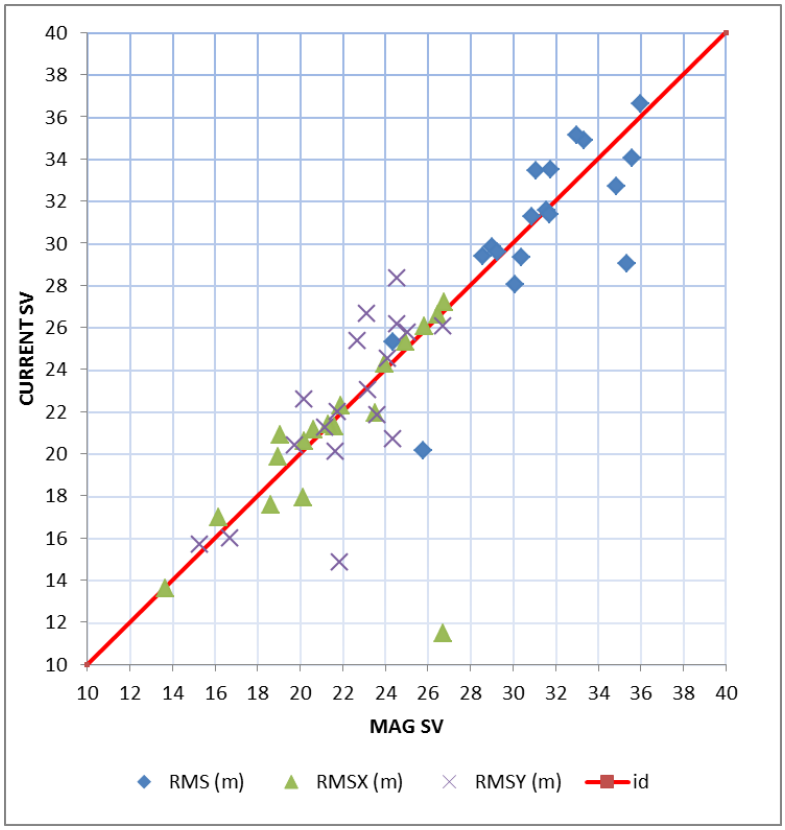


Figure 5 - LS01, LS02 and LS03, Matching of geometric model accuracy.

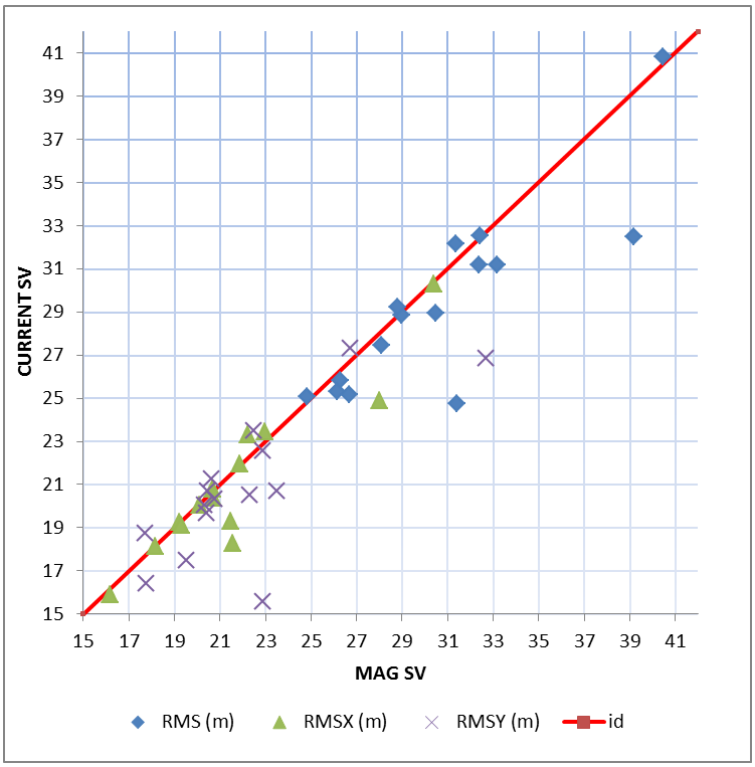


Figure 6 - LS04 and LS05, Matching of geometric model accuracy.

7.4 Absolute Geometric registration (GEO)

Objective

The objective is to assess the absolute geolocation accuracy of GEO products and assess if by using 'SV_MAG', the geolocation accuracy is improved.

The Shortcomings and Input Data

The geo location accuracy of GEO products is known to be degraded. It is not possible to apply, as for GTC products, evaluation procedure based on dense matching. Hence, for each mission, a reference data is selected. Each image of the twin is assessed against this reference by using a set of Ground Control Points, picked up manually in both the working and the reference images.

Due to s/w limitation, it has been difficult to find cloud free GEO scene for any Landsat missions. The selected TDS is listed in table below. Unfortunately, there is no data for LS04 and LS05 missions.

Product File Name	Identifier
LS01_RFUI_MSS_GEO_1P_19760831T072313_19760831T072342_020929_0193_0033_A88D	LS 01 - 'SV_MAG'
LS01_RFUI_MSS_GEO_1P_19760831T072312_19760831T072342_020929_0193_0033_8CB9	LS 01 - 'SV_PRE'
LS02_RFUI_MSS_GEO_1P_19761201T085500_19761201T085529_009467_0204_0034_07F3	LS 02 - 'SV_MAG'
LS02_RFUI_MSS_GEO_1P_19761201T085500_19761201T085529_009467_0204_0034_E43E	LS 02 - 'SV_PRE'
LS03_RFUI_MSS_GEO_1P_19820911T102121_19820911T102151_023022_0217_0025_A49E	LS 03 - 'SV_MAG'
LS03_RFUI_MSS_GEO_1P_19820911T102121_19820911T102151_023022_0217_0025_E861	LS 03 - 'SV_PRE'

Table 11 - Test data set for absolute geometric registration.

Overall Results

The absolute accuracy results are shown in the table below. X, Y directions are respectively referring to easting and northing directions. It cannot be concluded that the 'SV_MAG' improved significantly the accuracy of GEO products. Moreover, in the LS03 case, the results are degraded.

Identifier	MeanX	MeanY	StdX	StdY	RmsX	RmsY	RMS
LS 01 - 'SV_MAG'	-13783,80	-12372,25	104,15	118,22	13784,19	12372,81	18522,70
LS 01 - 'SV_PRE'	-13999,29	-10212,28	136,13	124,91	13999,95	10213,04	17329,31
LS 02 - 'SV_MAG'	-94,48	-319,36	2889,59	861,78	2891,13	919,05	3033,69
LS 02 - 'SV_PRE'	-1142,71	218,33	3202,18	878,42	3399,96	905,15	3518,39
LS 03 - 'SV_MAG'	**-1918,87**	**-5299,32**	**568,46**	**298,63**	**2001,30**	**5307,73**	**5672,50**
LS 03 - 'SV_PRE'	-1402,96	-2784,17	571,22	291,37	1514,79	2799,37	3182,94

Table 12 –Absolute accuracy results, 'SV_MAG', 'SV_PRE' comparison (m).

Visual inspection

From visual inspection point of view, the geolocation checking of images from any Landsat MSS missions has been done. The geolocation accuracy is always above 2000 m (mean). It is not possible to anticipate on the bias direction / magnitude that will be observed. Each case is different. Some illustrations are shown below.

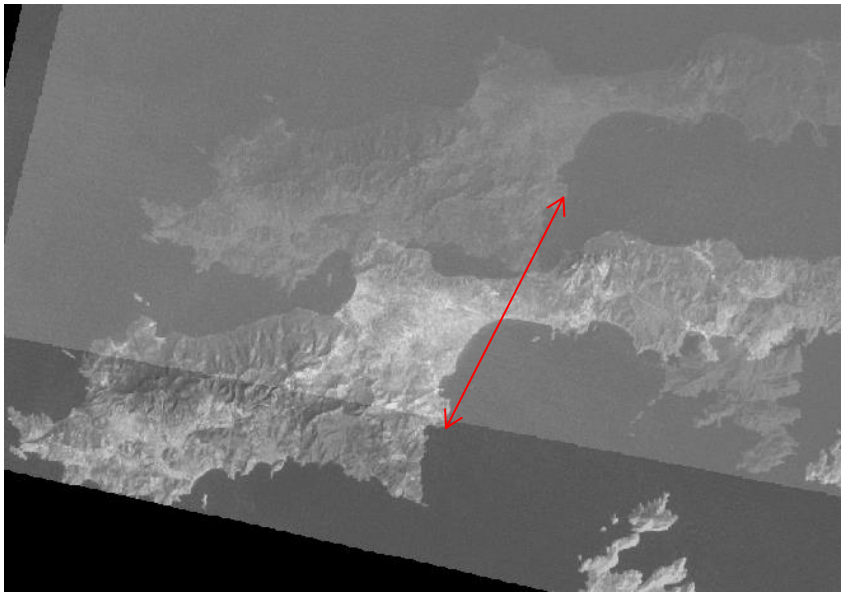


Figure 7 – Co registration of LS01 GEO images (19760831).

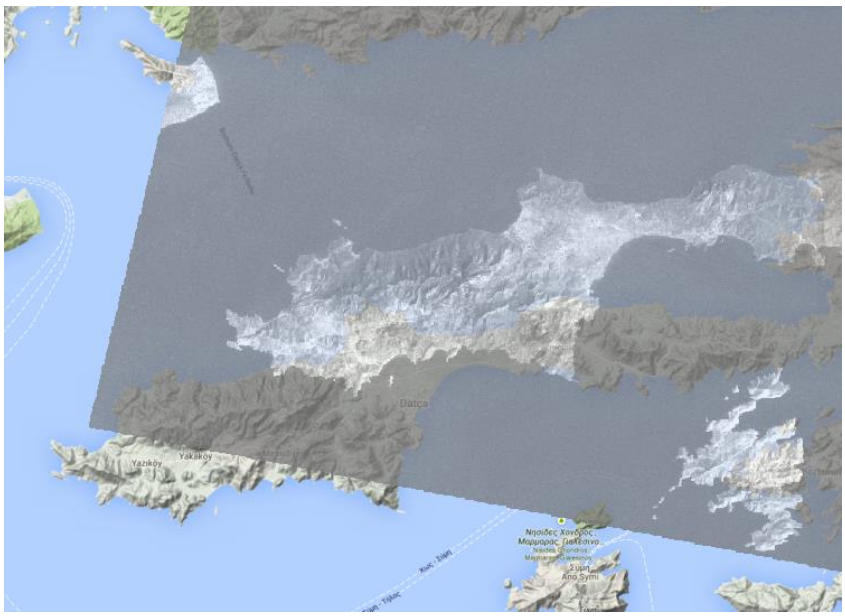


Figure 8 - LS01 GEO image ('SV_MAG') over reference map image (19760831).

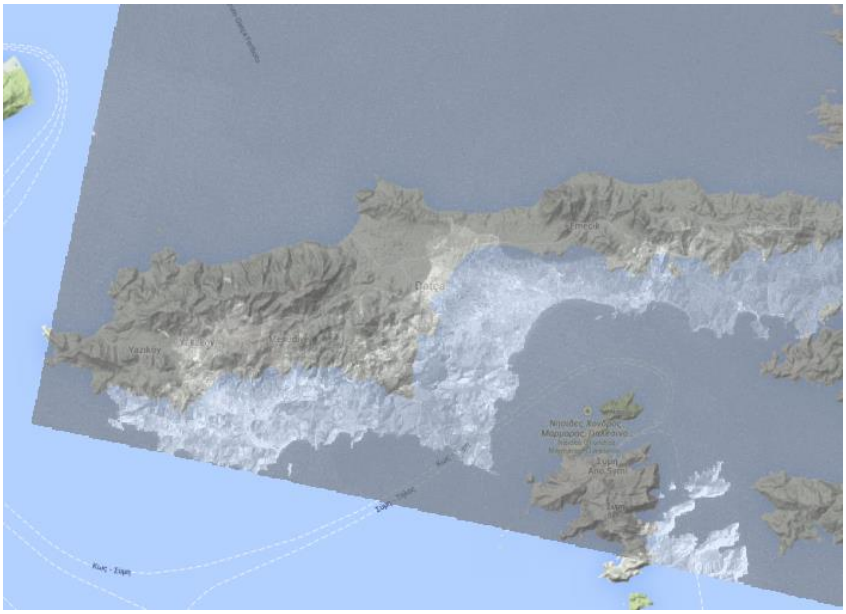


Figure 9 - LS01 GEO image ('SV_PRE') over reference map image (19760831).

7.5 Geometric co registration (GTC)

Objective

The objective is to assess geometric co registration between two GTC products processed with either 'SV_MAG' or 'SV_RES'. It is done by dense matching of the two images from NIR spectral bands.

Overall Results

As results, the registration accuracy obtained for the 10 image twins, at D0 and at D1, remains within the pixel. However, from one date to the other date, the accuracy is not stable.

We might have expected accuracy of about 30 m (RMS) but finally the results are above, except for 'LS04-D0' and 'LS05-D0.' By investigating this issue, it has been observed that the internal geometry of two Level 1 images, originated from the same Level 0 by using different SV file does not have the internal geometry. It results in difficulties to explain the accuracy differences.

product_Id	meanx	meany	stdx	stdy	rmsx	rmsy	rms
LM11930341976154ESA00	-10,60	12,97	22,26	12,91	24,66	18,30	30,71
LM11930271976244ESA00	38,30	-8,06	13,91	25,22	40,75	26,47	48,59
LM2**204037**1976336ESA00 (D0 Tunisia)	-21,50	0,96	38,17	27,18	**43,81**	27,20	51,57
LM2**204031**1977294ESA00 (D1 Italy)	-3,30	-21,34	7,90	37,79	8,56	**43,40**	44,24
LM32170271978329ESA00	-10,01	0,23	15,27	7,41	18,26	7,41	19,70
LM32170271982254ESA00	-30,56	1,08	13,34	21,52	33,34	21,55	39,70
LM41650241982269ESA00	1,23	-1,89	7,83	4,62	7,92	4,99	9,36
LM41650231983192ESA00	-14,20	2,15	33,68	18,92	36,55	19,04	41,22
LM51910151985275ESA00	3,43	-0,30	6,61	8,61	7,45	8,62	11,39
LM51910151986150ESA00	11,61	-11,52	21,41	25,98	24,35	28,42	37,43

Table 13 - Geometric co registration results (m).

Deformation of the Image Internal geometry

The figures below, illustrate typical geometric deformations observed on the LS02 image twins at D0 and at D1. The figures are post processed images obtained from dense matching procedures. It is the results of a geometric comparison between GTC 'SV_MAG' image and GTC 'SV_PRE' image.

The following observations can be formulated:

1. The D0 / D1 images are not of the same WRS reference (Tunisia / Italy).
2. In both cases, strong geometric deformations are observed.
3. In both cases, it is not the same deformation that has been observed

- (D0) – Strong deformation according to pixel direction
- (D1) – Strong deformation according to line direction

4. The SV type (‘MAG’ / ‘PRE’) impacts on the internal geometry of the image.

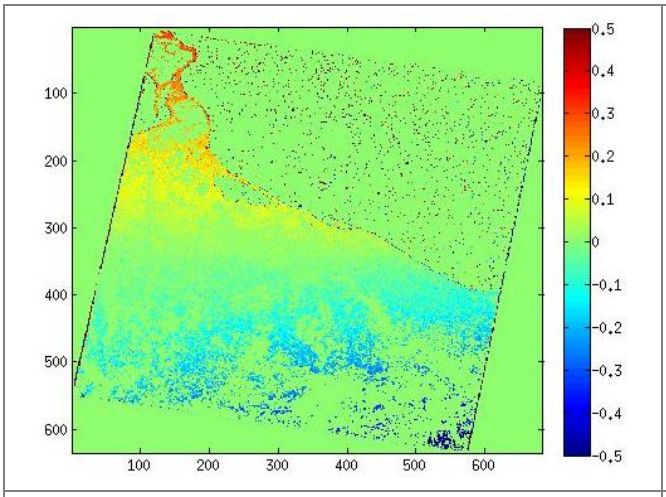
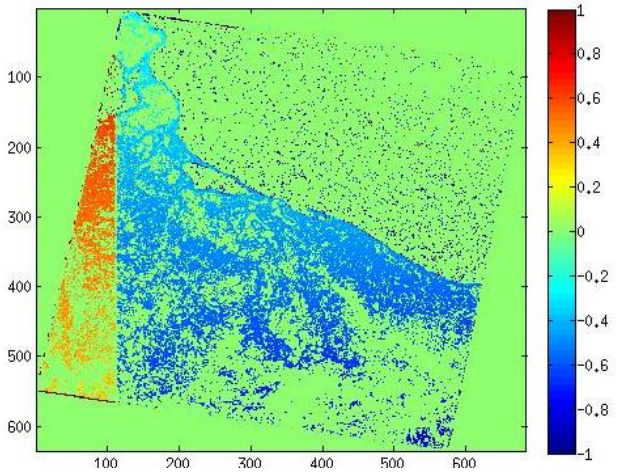
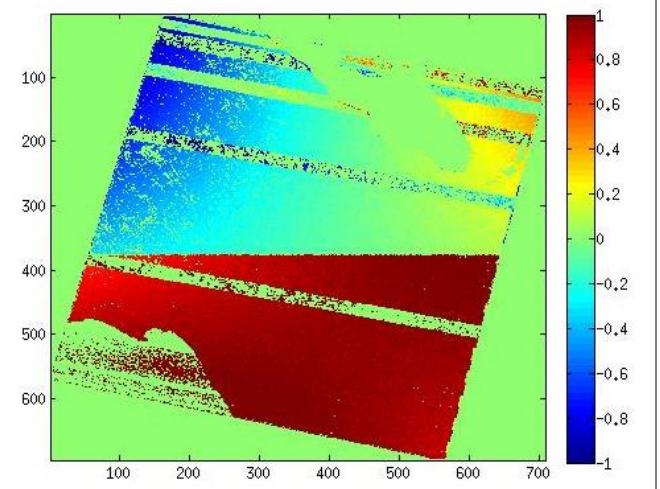
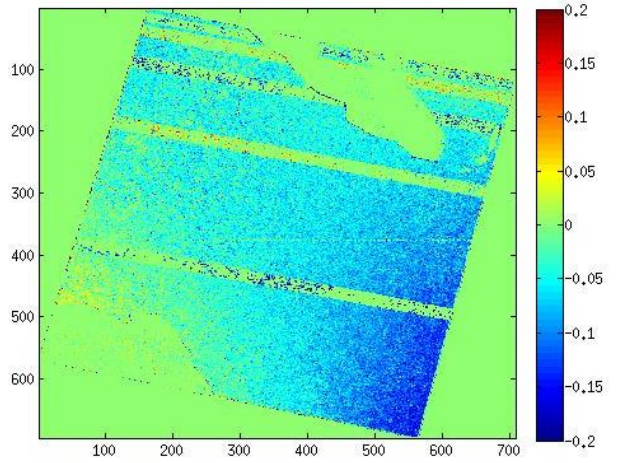
	
D0) Line direction Displacement (Dx) A very small rotation is observed, the lines are shifted depending on the location in the map. The magnitude of the deformation is within 0.7 pixel, which is considered to be ‘nominal’.	D0) Pixel direction Displacement (Dx) Geometric shift from -1 up to 1 pixel, right – left direction.
	
D1) Line direction Displacement (Dx) The horizontal band are actually image swath that are shifted depending on the image origin, e.g ‘SV_MAG’ or ‘SV_PRE’/ The image is cut in two parts with a sharp transition between and a step edge at 1 pixel in the bottom part of the image.	D1) Pixel direction Displacement (Dx) As shown in the figure, the geometric deformation in pixel direction does not exceed 0.2 pxiel in absolute. It is nominal.

Figure 10 - LM22040371976336ESA00, GTC products, ‘SV_MAG’ / ‘SV_PRE’ image comparison.

Note that an external raster reference (Landsat 8) has been considered, and procedure played back. It is a way to really assess which one of 'SV_MAG' or 'SV_PRE' products provides the worst results.

Visual inspection

From visual inspection point of view, the geolocation checking of images from any Landsat MSS missions has been done. For any twins, the co-registration of GTC is mainly within 1 pixel. Nonetheless, Local deformations are likely to be observed.

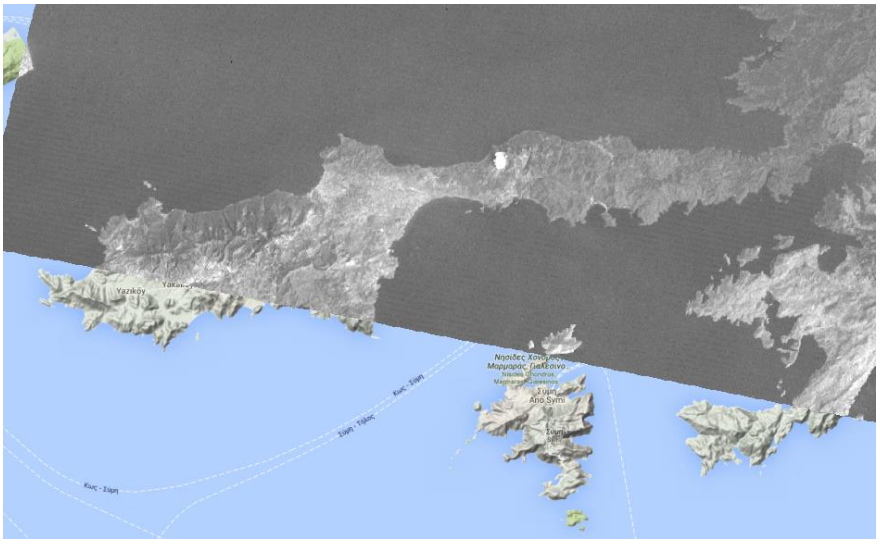


Figure 11 – 1 pixel Matching between two GTC products (LS01_GTC_19760602_MAG).

7.6 Investigate on absolute geometric accuracy (GTC)

Starting from conclusions of the previous section, the objective of the work has been to investigate on the absolute geometric accuracy. An external reference, Landsat 8 data has been considered as raster reference (LC81890312014357LGN00).

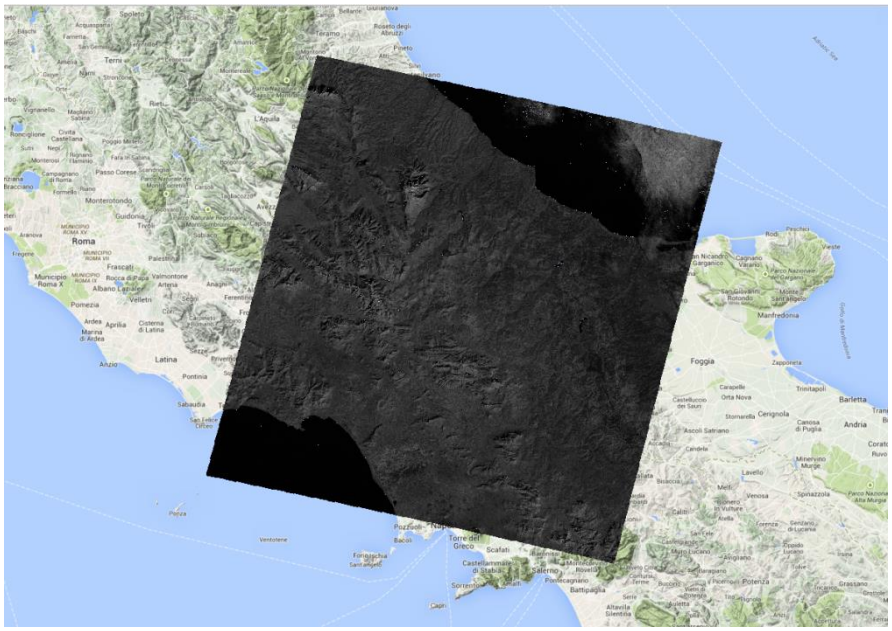


Figure 12 - Location of investigated scene.

Context

By comparing the two input images 'SV_MAG', 'SV_RES', image distortions are observed. Alternative brighter (-2.5 pixel) and darker image line (2.5 pixels) are visible in the line displacement image. In addition, a sharp change at the bottom part of the displacement image is also visible. At this point it is not possible, to state on the root causes of the problem, and in particular, which image is contaminated with distortions, probably both.

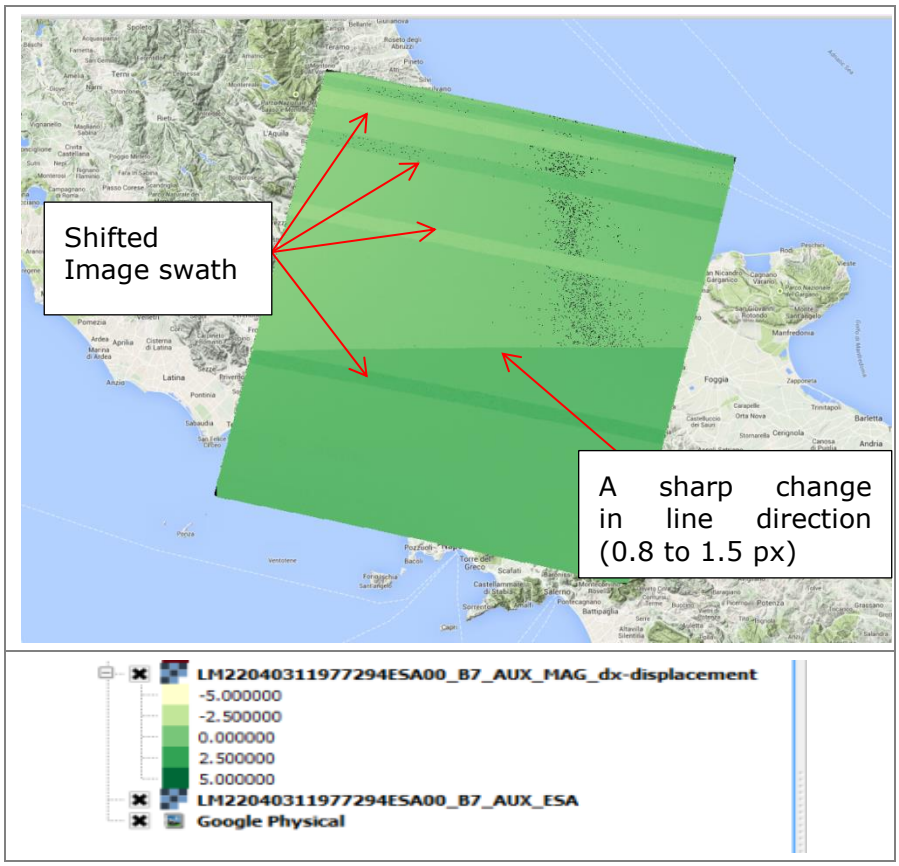


Figure 13 – LS02 Image deformations ('SV_MAG' and 'SV_PRE'), LM22040311977294ESA00.

Comparison with a reference image

In order to better explain errors depending on the product origin ('SV_MAG', 'SV_PRE'), dense matching with L8 image has been done.

- The location of the shifted Image Swath depends on the SV origin ('SV_MAG' or 'SV_PRE');
- No step observed in the 'SV_MAG' image;
- Step observed in the 'SV_PRE' image but at a different location in the image;
- The internal geometry of 'SV_MAG' and 'SV_PRE' images are different, the magnitude of the deformation remains on the same order.

Figure 14 shows line displacement image from comparison between L8 and 'SV_PRE' images. The line displacement image from comparison between 'SV_PRE' and 'SV_MAG' has been added beyond.

The step edge is visible, but lower in the image. This is probably due to an artifact of the correlator that gives no very accurate results when comparing L8 and MSS (method to be improved). The patterns of the shifted image swath are observed.

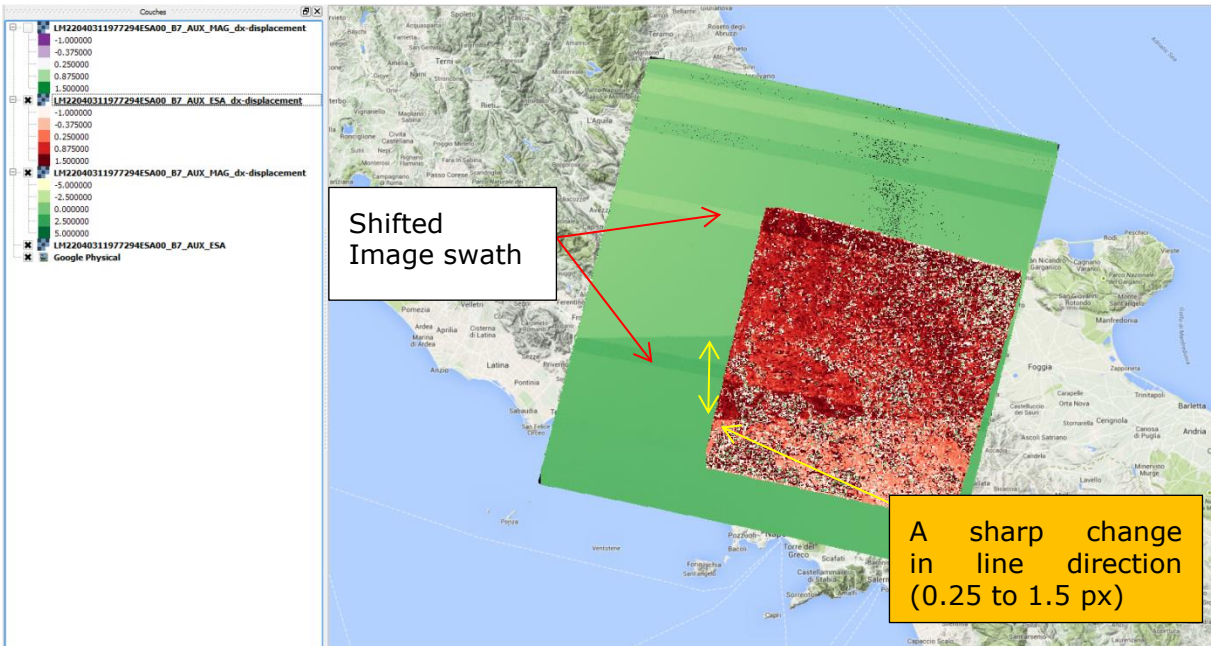


*Figure 14- LS02 Image deformations (L8 and 'SV_PRE'), LM2204031**1977294ESA00.***

Figure 15 shows line displacement image from comparison between L8 and 'SV_MAG' images. The line displacement image from comparison between 'SV_PRE' and 'SV_MAG' has been added beyond.

The step edge is not visible. The location of the second shifted swath (bottom part of the image) corresponds to the limit from which error a greater (step @ 1.5 pixel) to decrease at -1 pixel around bottom right corner. The influence of the relief, above 200 m might be considered for in depth analysis. Because we see that the limit is not straight but depends on mountain delineation.

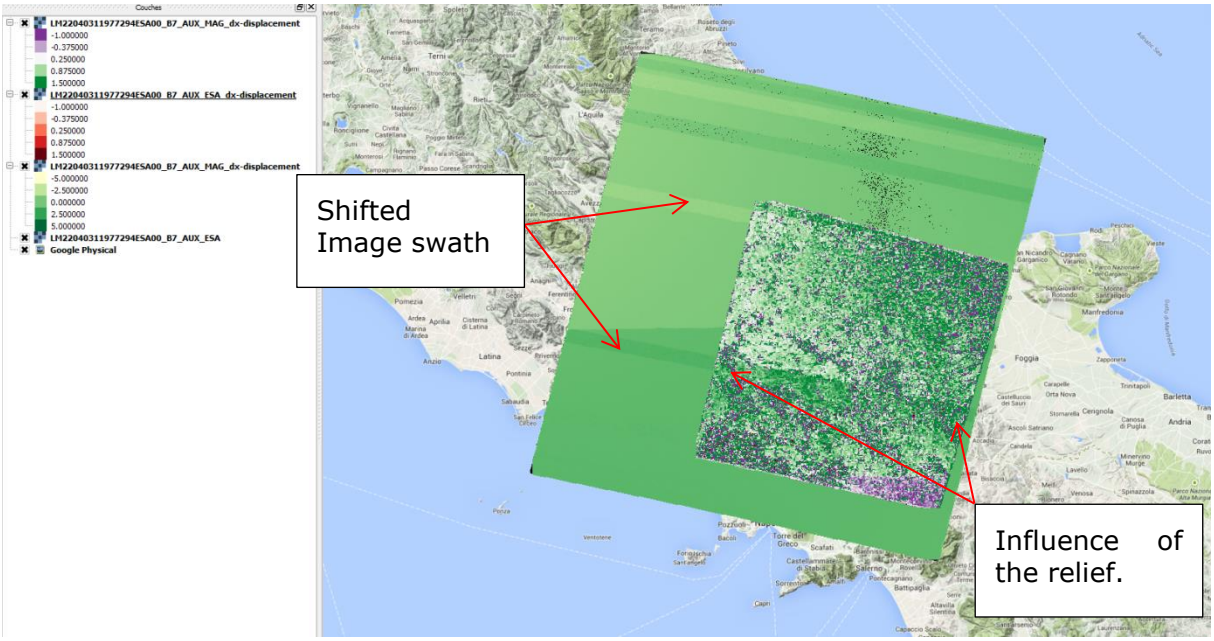


*Figure 15 - LS02 Image deformations (L8 and 'SV_MAG'), LM2204031**1977294ESA00.***

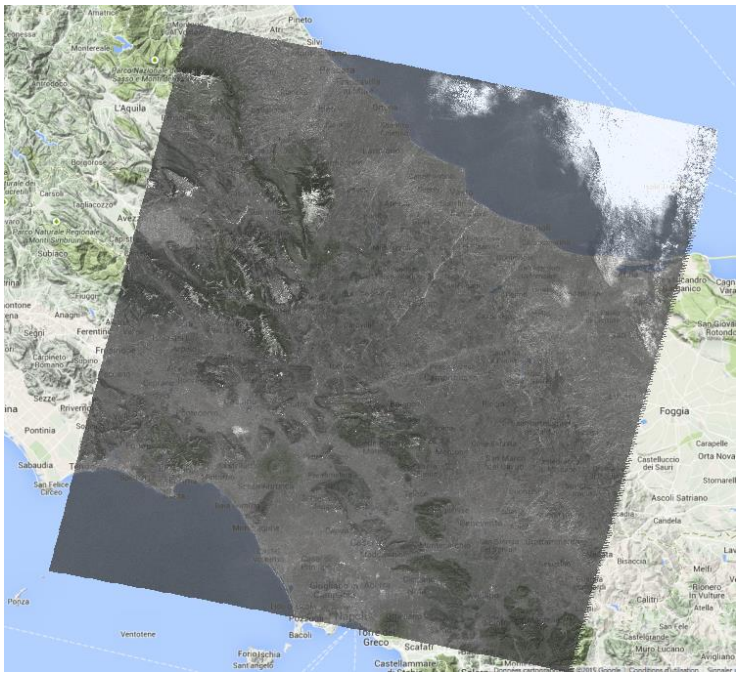


Figure 16 - LS03_GTC_19771021_MAG.

8 ANNEX

Annexe A GTC/GEO TDS

Below is the TDS used for the following validation exercises:

1. Absolute geometric registration (GEO),
2. Geometric co registration (GTC).

Otherwise 76 LS01, LS02, LS03 products and 53 LS04, LS05 products have been investigated (MTL, Visual check).

ID	Product
LS01_GTC_19760602_MAG	LS01_RFUI_MSS_GTC_1P_19760602T073049_19760602T073121_019674_0193_0034_C56F.ZIP
LS01_GTC_19760602_ESA	LS01_RFUI_MSS_GTC_1P_19760602T073049_19760602T073121_019674_0193_0034_2F01.ZIP
LS01_GTC_19760831_MAG	LS01_RFUI_MSS_GTC_1P_19760831T072044_19760831T072113_020929_0193_0027_9D6C.ZIP
LS01_GTC_19760831_ESA	LS01_RFUI_MSS_GTC_1P_19760831T072043_19760831T072113_020929_0193_0027_477F.ZIP
LS01_GEO_19760831_MAG	LS01_RFUI_MSS_GEO_1P_19760831T072338_19760831T072408_020929_0193_0034_1D78.ZIP
LS01_GEO_19760831_ESA	LS01_RFUI_MSS_GEO_1P_19760831T072337_19760831T072407_020929_0193_0034_13B6.ZIP
LS02_GTC_19761201_MAG	LS02_RFUI_MSS_GTC_1P_19761201T085615_19761201T085644_009467_0204_0037_ED45.ZIP
LS02_GTC_19761201_ESA	LS02_RFUI_MSS_GTC_1P_19761201T085615_19761201T085644_009467_0204_0037_15F6.ZIP
LS02_GEO_19761201_MAG	LS02_RFUI_MSS_GEO_1P_19761201T085500_19761201T085529_009467_0204_0034_07F3.ZIP
LS02_GEO_19761201_ESA	LS02_RFUI_MSS_GEO_1P_19761201T085500_19761201T085529_009467_0204_0034_D5E2.ZIP
LS02_GTC_19771021_MAG	LS02_RFUI_MSS_GTC_1P_19771021T083750_19771021T083819_013985_0204_0031_6BCC.ZIP
LS02_GTC_19771021_ESA	LS02_RFUI_MSS_GTC_1P_19771021T083750_19771021T083820_013985_0204_0031_84E0.ZIP
LS03_GTC_19781125_MAG	LS03_RFUI_MSS_GTC_1P_19781125T101928_19781125T101957_003695_0217_0027_5F63.ZIP
LS03_GTC_19781125_ESA	LS03_RFUI_MSS_GTC_1P_19781125T101928_19781125T101957_003695_0217_0027_3046.ZIP
LS03_GEO_19781125_MAG	LS03_RFUI_MSS_GEO_1P_19781125T101813_19781125T101842_003695_0217_0024_BFF4.ZIP
LS03_GEO_19781125_ESA	LS03_RFUI_MSS_GEO_1P_19781125T101813_19781125T101842_003695_0217_0024_18B9.ZIP

LS03_GTC_19820911_MAG	LS03_RFUI_MSS_GTC_1P_19820911T102211_19820911T102240_023022_0217_0027_9E2E.ZIP
LS03_GTC_19820911_ESA	LS03_RFUI_MSS_GTC_1P_19820911T102210_19820911T102240_023022_0217_0027_87B1.ZIP
LS04_GTC_19820926_MAG	LS04_RKSE_MSS_GTC_1P_19820926T063655_19820926T063724_001046_0165_0024_0635.ZIP
LS04_GTC_19820926_ESA	LS04_RKSE_MSS_GTC_1P_19820926T063655_19820926T063724_001046_0165_0024_0904.ZIP
LS04_GTC_19830711_MAG	LS04_RKSE_MSS_GTC_1P_19830711T064017_19830711T064047_005240_0165_0026_CCB3.ZIP
LS04_GTC_19830711_ESA	LS04_RKSE_MSS_GTC_1P_19830711T064017_19830711T064047_005240_0165_0026_00FD.ZIP
LS04_GEO_19830711_MAG	LS04_RKSE_MSS_GEO_1P_19830711T063306_19830711T063337_005240_0165_0008_4559.ZIP
LS04_GEO_19830711_ESA	LS04_RKSE_MSS_GEO_1P_19830711T063307_19830711T063338_005240_0165_0008_1939.ZIP
LS05_GTC_19851002_MAG	LS05_RKSE_MSS_GTC_1P_19851002T091552_19851002T091621_008445_0191_0015_037C.ZIP
LS05_GTC_19851002_ESA	LS05_RKSE_MSS_GTC_1P_19851002T091552_19851002T091621_008445_0191_0015_7710.ZIP
LS05_GTC_19860530_MAG	LS05_RKSE_MSS_GTC_1P_19860530T091100_19860530T091130_011940_0191_0015_1DCD.ZIP
LS05_GTC_19860530_ESA	LS05_RKSE_MSS_GTC_1P_19860530T091100_19860530T091130_011940_0191_0015_4546.ZIP