Geometric correction of ECOSTRESS and ASTER data in the framework of SCO THERMOCITY project

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1. Introduction

The THERMOCITY project aims to study phenomena such as urban heat islands and heat losses. A part of the project entails the development of a thermography analysis tools based on satellite imagery. Data and models are then compared in order to understand these phenomena and work towards the ultimate aim: prepare and adapt cities to climate change.

Please refer to the following URL for more detailed information on the project
https://www.spaceclimateobservatory.org/thermocity-toulouse

1.1. ASTER AND ECOSTRESS DATA DOWNLOAD & PREPROCESSING

ASTER and ECOSTRESS data have been downloaded from the following websites:

- https://earthexplorer.usgs.gov
- https://search.earthdata.nasa.gov

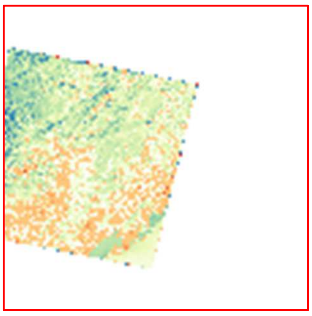
In addition to the metadata and quality masks, the following data have been downloaded :

- For ASTER: top of atmosphere (TOA) radiances, bottom of atmosphere (BOA) reflectances and radiances, land surface temperature and emissivity (LST ad LSE)
- For ECOSTRESS: BOA radiances, LST and LSE

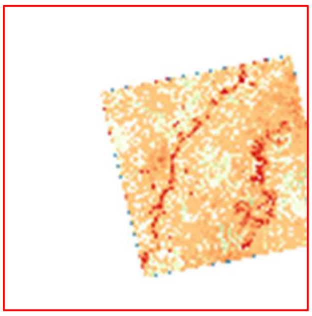
In order to facilitate further processing and distribution, the data has been homogenized through the following process:

- extraction of the raw data over 100kmx100km region of interest (ROI) centered around the target cities
- conversion into a single-band geotiff image (data and metadata)
- re-projection to the local UTM zone.

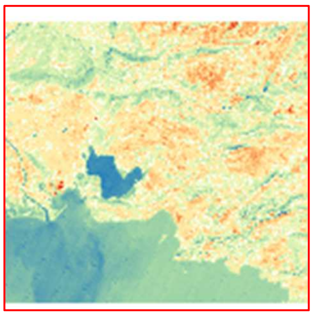
Please be aware that considering ASTER' and ECOSTRESS' data-acquisition properties, the ROI is never fully covered by ASTER (60km field of view) and not always fully covered by ECOTRESS. Besides, the areas covered in between different dates might also not be identical. The following figures illustrate the ROI coverage for selected acquisitions:



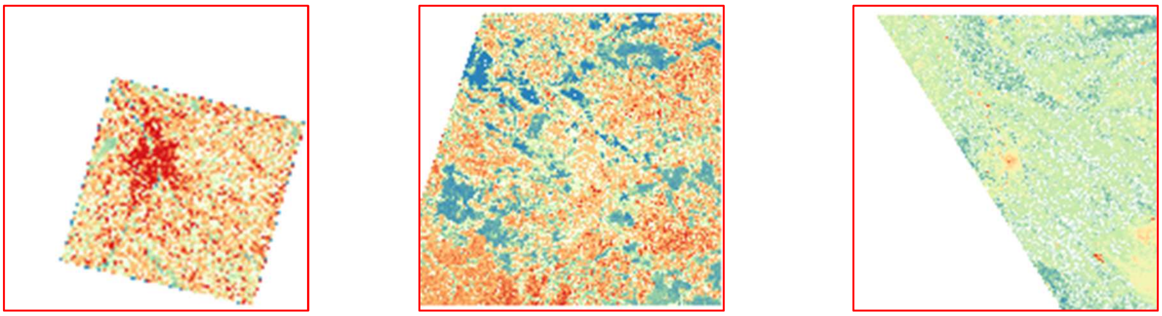
20071102, ASTER, Montpellier



20270126, ASTER, Strasbourg



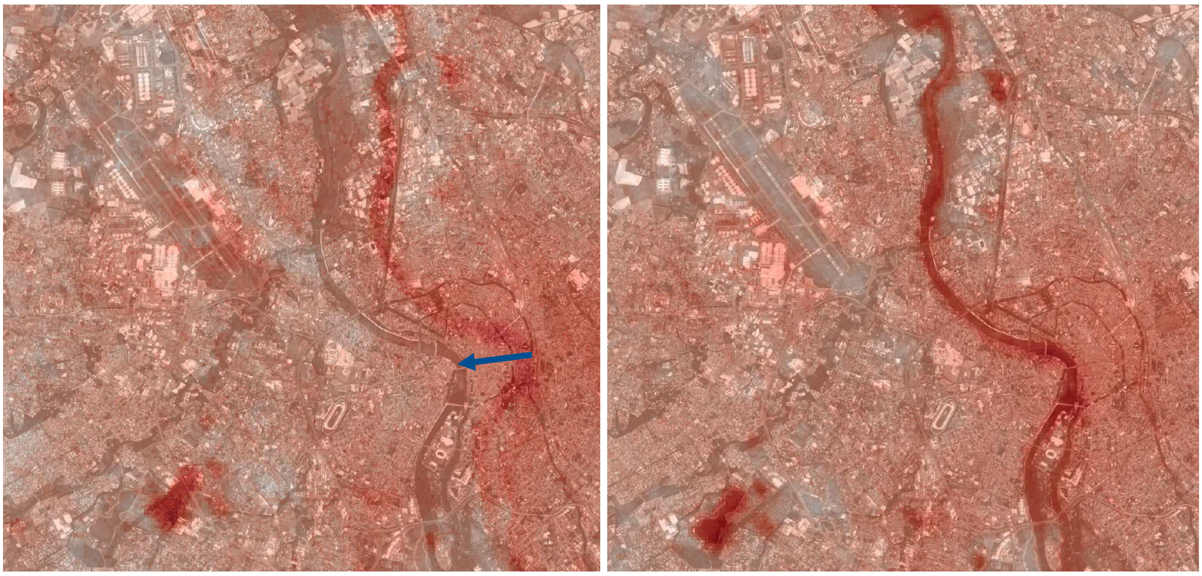
20190227, ECOSTRESS, Marseille



20180623, ASTER, Toulouse 20180828, ECOSTRESS, Paris 20200111, ECOSTRESS, Toulouse

1.2. NEED FOR ASTER AND ECOSTRESS GEOMETRIC IMPROVEMENTS

One of THERMOCITY' ambition is to use thermal data to support the decision making process. In order to confidently support decision making a precise absolute geolocation is required. Hence, the first step was to inspect both ASTER and ECOTRESS data and their geolocation, from which was deducted that the geometric quality is not sufficient for proper homogenization of the dataset. Geolocation errors of about 120m have been found for the ASTER dataset, and reach to more than 1km in some ECOSTRESS images. The following figure illustrates the worst case observed with ECOSTRESS data:



ECOSTRESS_L2_LSTE_08607_004_20200111T225917_0601_01_LST_UTM before (left) and after (right) geometrical correction, on top of a Sentinel-2 visible image. Absolute geolocation error is easily visible on the Garonne river (blue arrow) and is about 1.5km.

To overcome these large discrepancies, a dedicated processing routine was developed to improve of the absolute geolocation and multi-temporal co-registration, using Copernicus Sentinel-2 as a geometric reference. Sentinel-2 has been chosen as a reference considering its rather good and well known geometric quality. In addition it assures and facilitates interoperability between Sentinel-2 and THERMOCITY thermal products.

1.3. DOCUMENT OUTLINE

The next section describes two different methods that have been implemented to improve the initial geometric quality of ASTER and ECOSTRESS data in the frame of THERMOCITY project. Then, the results section explains in a quantitative way to what extent the geometric quality has been improved and describes the residual errors after correction.

2. Methods

To improve the absolute geolocation of ASTER and ECOSTRESS products, all ASTER and ECOSTRESS bands are re-aligned to a Sentinel-2 reference image. More precisely, the red band of Sentinel-2 is used as a reference band given that it is also the reference band for the inter-band registration of the Sentinel-2 products and also considering that the red-band has a similar wavelength available in ASTER products.

Between the reference Sentinel-2 red-band and all other ECOSTRESS and ASTER produces, the method aims to measure offsets between two images using the CNES *Médicis* tool based on a correlation method. In general, correlation needs similar patterns in both images to perform well. *Médicis* allows for a local sub-pixel measurement of the offset of each pixel. For performance reasons, the correlation procedure was carried out not for all pixels but for each 10, 20 or 30 pixels.

2.1. ABSOLUTE OFFSET MEASURMENT

The first step is to measure the absolute offsets between ASTER/ECOSTRESS and the Sentinel-2 reference image. Considering that the correlation performance is linked to similar patterns found in both images and to thus ensure an optimal correlation quality performance, the ASTER/ECOSTRESS band closest to the reference band was selected, see next Table. For ASTER, red spectral band is available. However, for ECOSTRESS there are only bands in the TIR range:

Absolute offsets measurement	**Band number**	**Type**	**Wavelength**	**Resolution**
Sentinel-2 (reference)	Band 4	Red	665 nm	10 m
ASTER	Band 2	VNIR	630 – 690 nm	15 m
ECOSTRESS	Band 2	TIR	8790 nm	70 m

For some images, correlation with another image of the same city at different date was better than with Sentinel-2 and was used as reference.

2.2. INTER-BAND OFFSET MEASURMENT

The second step is to measure ASTER/ECOSTRESS' inter-band offset. The absolute offset is then computed as the sum of first and second step for each band.
For ASTER, this involved checking the Intra-Telescope Registration geometric performances mentioned in **Erreur ! Source du renvoi introuvable.**. An analysis of the results confirms that offset between the VNIR bands, SWIR bands and TIR bands was negligible. Consequently the offsets between VNIR and SWIR and between VNIR and TIR were measured (Inter-Telescope Registration in **Erreur ! Source du renvoi introuvable.**) and these offsets are considered non-negligible.

ASTER inter-band offsets measurement	**Band number**	**Type**	**Wavelength**	**Resolution**
ASTER (reference)	Band 2	VNIR	630 – 690 nm	15 m
ASTER	Band 4	SWIR		30 m
ASTER	Band 10	TIR		90 m

For ECOSTRESS, the aim was to measure the offset between the TIR bands.

ECOSTRESS inter-band offsets measurement	**Band number**	**Type**	**Wavelength**	**Resolution**
ECOSTRESS (reference)	Band 2	TIR		70 m
ECOSTRESS	Band 4	TIR		70 m
ECOSTRESS	Band 5	TIR		70 m

2.3. GEOLOCATION OFFSET CORRECTION

The final step is to correct the measured offsets. For this purpose, two solutions described below have been implemented, resulting in two versions of the geolocation corrected data. After the geolocation correction of all bands, a final measurement allows us to verify the correct alignment and gives the residual offsets.

2.3.1. SIMPLE BIAS CORRECTION (V1)

The first method is rather straightforward and consists in assimilating the measured offsets to a global bias. This bias is the average of the measured offsets. A simple bias translation (offsets in line and column) is then applied to the image.
For practical reasons, the final image is then resampled on the same grid as Sentinel-2
Considering a single bias correction for the entire image, one has to bear in mind that this method does not correct for local offsets.

2.3.2. REFINED GEOMETRIC CORRECTION (V2)

The second method corrects the offsets more accurately with a dense resampling grid taking into account generalised local differences so that each grid-element uses the local offset measurement to correct the image. The density of the grid is related to the sampling step used in the offset measurement phase. At certain points a correlation is not found, resulting in a wrong or absent offset measurement. One can imagine that using the local correction method, missing or false data perturbs the overall performance and hence, it was necessary to filter those anomalies. For this purpose, an FFT pass-band filter was applied in order to only keep the low frequencies and eliminate high-frequency measurement noise. The example below illustrates this process:

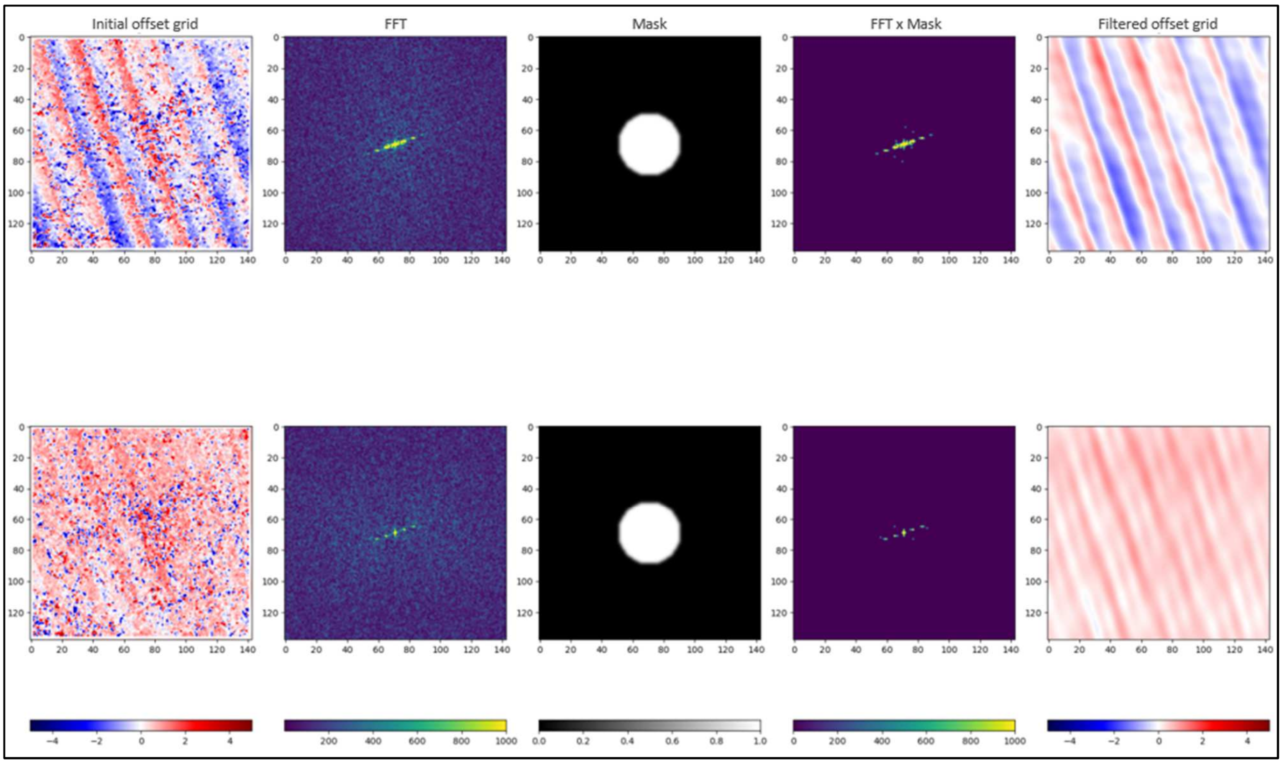


Figure 1 : FFT filtering of resampling grid for horizontal (top) and vertical (bottom) shifts. From left to right: Initial noisy offset measurements, initial FFT, filter mask, filtered FFT, final resampling grid.

The filtered resampling grid is then applied to correct geometric offset and resample the images using the CNES *Orion* tool with a bi-cubic resampling procedure so that the image is directly resampled on the same grid as Sentinel-2.
This method requires a sufficiently dense grid of the initial offset measurement in order to obtain a suitable resampling grid. Unfortunately, it was not always the case for ECOSTRESS data, which performs accordingly during daytime.

3. Results

3.1. ASTER

Once the corrections are applied, a final measurement of the residual shifts allows to verify remaining residual errors. Below is an example of the registration for an ASTER image of Montpellier with V1 and V2:

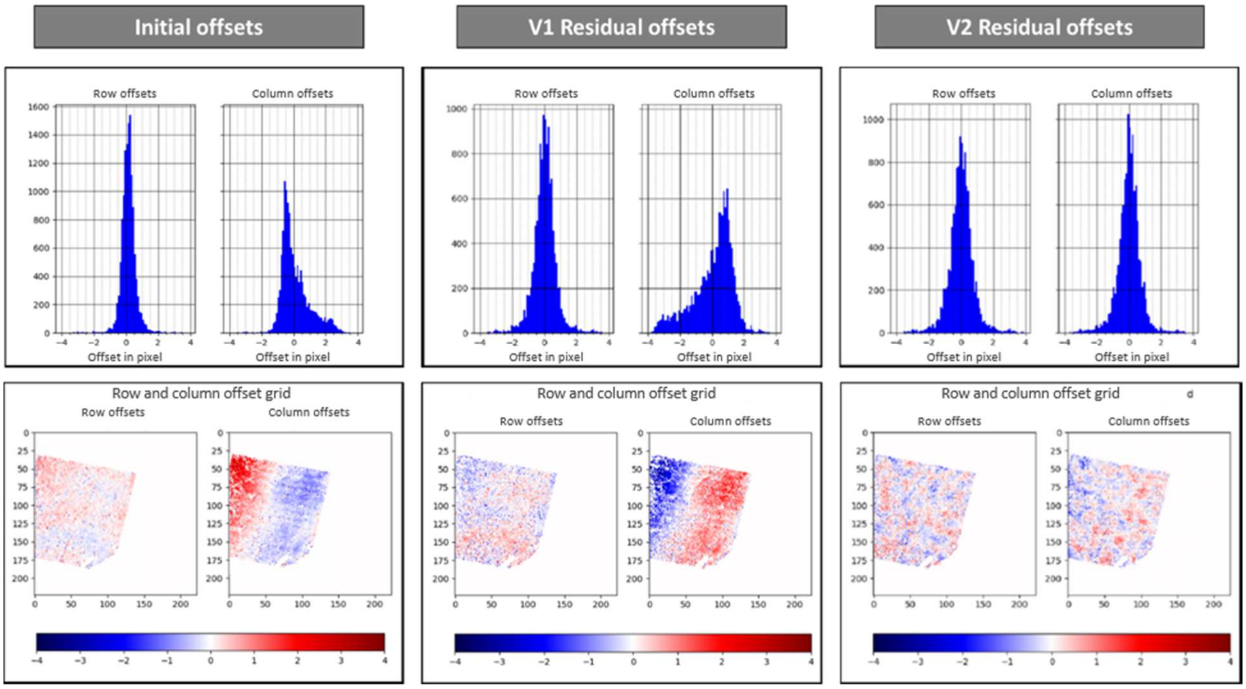


Figure 2: Offsets measurements histogram (top) and map (bottom).

From Figure 4, we can deduct that the V1 offset histogram are mean-centred around 0 but there remains a spatial gradients in the residuals that is corrected for in V2 (narrower offset histograms).
The table below details the versions available for the ASTER data:

	v1	v2
Marseille	OK	OK
Montpellier	OK	OK
Paris	OK	OK
Toulouse	OK	OK
Strasbourg	OK	Not enough well correlated points

3.2. ECOSTRESS

Once the corrections had been applied, a final measurement of the residual shifts allows to verify remaining residual errors. Below is an example of the registration for an ECOSTRESS image of Paris with V1 and V2:

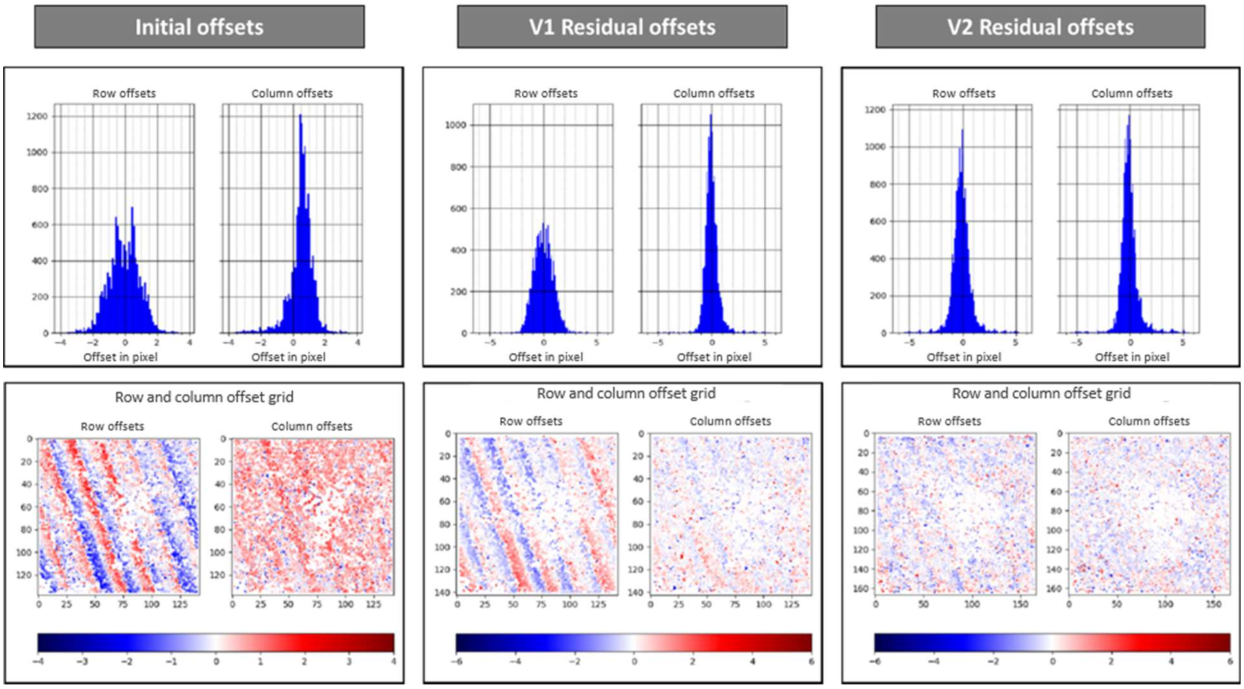


Figure 3: Offsets measurements histogram (top) and map (bottom).

We observe that V2 eliminates high-frequency offsets, incorrect correlation measurements and improve local geolocation.

The correlation between ECOSTRESS and S2 is more difficult than in the case of ASTER because there is no band in the visible range. The well-correlated point density for V2 was only sufficient for some cases mainly during the day in summer.

The table below details the versions available for the ECOSTRESS data:

	v1	v2
Marseille	OK	**Only** for : 20180827T112530 20200807T120137
Montpellier	OK	**Fait** pour : 20180827T112530 20200105T012131 20200807T120137
Paris	OK	**Only** for : 20180828T103302 20200807T133846
Toulouse	OK	**Only** for : 20180820T092448 20200807T120045
Strasbourg	OK	**Only** for : 20180822T123248 20200808T125213

4. Conclusion

The methodology outlined in this document enabled the ASTER and ECOSTRESS data to be geometrically re-aligned to Sentinel-2. These data were resampled to correct the offsets and to be superimposable with the Sentinel-2 data in a single step in order to limit the impact on the radiometry due to multiple resampling. The main limiting factor in our methodology is in the quality of the correlation of thermal images with a visible (red-band) reference.
The initial geometric offsets were up to 120 m for ASTER and 1500 m for ECOSTRESS. The residual offsets after geometric corrections are about meters and are available in the annexes.

5. Annexes

5.1. ASTER RESIDUAL OFFSETS

Residual offsets are measure for each image (Image 2) with best reference (Image 1) according to well correlated points.

ASTER	Data						Metadata		Offset in pixel				Offset in meter			
	Image 1 (reference)			Image 2			Resolution in meter	Correlated point %	Mean		Standard deviation		Mean		Standard deviation	
	Data	Date	Band	Data	Date	Band			Row	Column	Row	Column	Row	Column	Row	Column
MARSEILLE V1	Sentinel-2	20200615	4	VNIR	20030812T104031	2	15	6%	-0.01	0.05	0.36	1.12	-0.10	0.77	5.38	16.83
	Sentinel-2	20200615	4	VNIR	20050130T103425	2	15	14%	0.01	-0.05	0.55	1.20	0.09	-0.68	8.23	17.97
	Sentinel-2	20200615	4	TIR	20190114T213551	10	90	5%	0.03	-0.01	0.51	0.51	2.80	-0.92	45.59	45.81
MARSEILLE V2	Sentinel-2	20200615	4	VNIR	20030812T104031	2	15	6%	-0.06	0.01	0.36	0.46	-0.95	0.08	5.45	6.88
	Sentinel-2	20200615	4	VNIR	20050130T103425	2	15	15%	-0.06	-0.03	0.48	0.62	-0.91	-0.52	7.21	9.32
	Sentinel-2	20200615	4	TIR	20190114T213551	10	90	5%	0.02	-0.06	0.50	0.50	1.85	-5.27	44.84	44.76
MONTPELLIER V1	Sentinel-2	20200615	4	VNIR	20071102T104702	2	15	25%	-0.02	-0.03	0.47	0.90	-0.36	-0.41	7.12	13.47
	Sentinel-2	20200615	4	VNIR	20150829T104208	2	15	31%	-0.02	-0.04	0.41	1.13	-0.28	-0.53	6.21	17.00
	TIR	20150829T104208	10	TIR	20150829T214908	10	90	4%	0.03	0.14	1.35	1.18	2.37	12.70	121.69	106.36
	TIR	20150829T104208	10	TIR	20151101T214848	10	90	6%	0.02	0.00	1.11	1.00	2.13	0.03	100.23	90.06
MONTPELLIER V2	Sentinel-2	20200615	4	VNIR	20071102T104702	2	15	25%	-0.02	-0.03	0.50	0.48	-0.26	-0.39	7.49	7.16
	Sentinel-2	20200615	4	VNIR	20150829T104208	2	15	32%	-0.03	-0.02	0.44	0.53	-0.46	-0.29	6.60	7.92
	TIR	20150829T104208	10	TIR	20150829T214908	10	90	4%	0.03	0.03	1.36	1.15	2.62	2.57	122.34	103.14
	TIR	20150829T104208	10	TIR	20151101T214848	10	90	6%	0.01	0.01	1.09	0.95	0.49	0.59	98.53	85.18
PARIS V1	Sentinel-2	20200615	4	VNIR	20030801T105721	2	15	23%	0.00	0.05	0.77	0.83	0.03	0.68	11.50	12.44
	Sentinel-2	20200615	4	VNIR	20041022T105711	2	15	21%	-0.04	-0.04	0.86	0.89	-0.64	-0.61	12.88	13.39
	Sentinel-2	20200615	4	TIR	20151101T215007	10	90	12%	-0.02	-0.02	0.49	0.45	-1.41	-1.95	44.26	40.35
	Sentinel-2	20200615	4	TIR	20151101T215016	10	90	9%	-0.05	-0.01	0.57	0.53	-4.28	-0.82	51.44	47.44
	Sentinel-2	20200615	4	VNIR	20180803T105334	2	15	24%	-0.03	0.04	0.67	0.89	-0.41	0.63	10.05	13.38
	Sentinel-2	20200615	4	VNIR	20180803T105343	2	15	29%	0.02	0.03	0.64	1.01	0.24	0.43	9.57	15.18
	Sentinel-2	20200615	4	TIR	20180805T215100	10	90	6%	0.02	0.04	0.64	0.63	1.86	3.92	57.19	56.38
	Sentinel-2	20200615	4	TIR	20180805T215109	10	90	4%	0.05	0.00	0.53	0.53	4.25	0.02	47.28	47.63
PARIS V2	Sentinel-2	20200615	4	VNIR	20030801T105721	2	15	23%	0.02	0.06	0.76	0.78	0.28	0.96	11.35	11.74
	Sentinel-2	20200615	4	VNIR	20041022T105711	2	15	21%	-0.06	-0.08	0.85	0.80	-0.92	-1.23	12.79	11.98
	Sentinel-2	20200615	4	TIR	20151101T215007	10	90	12%	-0.02	-0.02	0.49	0.45	-1.41	-1.95	44.26	40.35
	Sentinel-2	20200615	4	TIR	20151101T215016	10	90	9%	-0.05	-0.01	0.57	0.53	-4.28	-0.82	51.44	47.44
	Sentinel-2	20200615	4	VNIR	20180803T105334	2	15	24%	-0.04	0.00	0.67	0.70	-0.57	0.05	10.04	10.53
	Sentinel-2	20200615	4	VNIR	20180803T105343	2	15	30%	-0.01	-0.03	0.64	0.68	-0.10	-0.41	9.66	10.23
	Sentinel-2	20200615	4	TIR	20180805T215100	10	90	6%	0.02	0.04	0.64	0.63	1.86	3.92	57.19	56.38
	Sentinel-2	20200615	4	TIR	20180805T215109	10	90	4%	0.05	0.00	0.53	0.53	4.25	0.02	47.28	47.63
STRASBOURG V1	Sentinel-2	20200615	4	VNIR	20030217T104041	2	15	6%	-0.03	-0.05	0.64	0.64	-0.50	-0.79	9.53	9.58
	Sentinel-2	20200615	4	VNIR	20030812T103854	2	15	13%	-0.01	-0.05	0.50	0.63	-0.10	-0.68	7.53	9.48
	Sentinel-2	20200615	4	TIR	20170126T212447	10	90	4%	0.15	-0.05	0.50	0.49	13.15	-4.41	45.07	44.34
	Sentinel-2	20200615	4	TIR	20180622T212619	10	90	3%	-0.05	-0.04	0.52	0.46	-4.53	-3.38	46.80	41.35
TOULOUSE V1	Sentinel-2	20200615	4	VNIR	20030114T105428	2	15	22%	-0.01	-0.03	0.94	0.90	-0.22	-0.49	14.08	13.47
	Sentinel-2	20200615	4	VNIR	20030810T105242	2	15	25%	0.01	0.01	0.74	0.92	0.18	0.08	11.07	13.74
	Sentinel-2	20200615	4	VNIR	20180623T110115	2	15	36%	0.02	-0.01	0.52	1.02	0.36	-0.21	7.73	15.29
	TIR	20161228T215433	10	TIR	20180623T110115	10	90	3%	-0.01	-0.01	0.61	0.59	-0.82	-0.57	54.75	53.36
TOULOUSE V2	Sentinel-2	20200615	4	VNIR	20030114T105428	2	15	22%	-0.01	-0.02	0.93	0.84	-0.19	-0.36	13.93	12.59
	Sentinel-2	20200615	4	VNIR	20030810T105242	2	15	25%	-0.04	0.00	0.74	0.79	-0.56	-0.03	11.15	11.92
	Sentinel-2	20200615	4	VNIR	20180623T110115	2	15	36%	0.02	-0.01	0.49	0.54	0.28	-0.22	7.35	8.06
	TIR	20161228T215433	10	TIR	20180623T110115	10	90	3%	0.02	0.02	0.61	0.59	2.04	1.64	55.14	53.51

5.2. ECOSTRESS REDISUAL OFFSETS

Residual offsets are measure for each image (Image 2) with best reference (Image 1) according to well correlated points.

ECOSTRESS	Data						Metadata		Offset in pixel				Offset in meter			
	Image 1 (reference)			Image 2			Resolution in meter	Correlated point %	Mean		Standard deviation		Mean		Standard deviation	
	Data	Date	Band	Data	Date	Band			Row	Column	Row	Column	Row	Column	Row	Column
MARSEILLE V1	Sentinel-2	20200615	4	Radiance	20180827T112530	2	70	39%	0.00	0.00	1.04	0.98	-0.33	-0.21	72.55	68.41
	ASTER v2	20050130T103425	10	Radiance	20190227T101314	2	70	19%	-0.03	0.03	0.95	0.78	-2.19	1.87	66.44	54.80
	ASTER v2	20190114T213551	10	Radiance	20190715T215627	2	70	4%	-0.07	-0.04	2.24	2.26	-4.92	-2.60	156.79	157.97
	Sentinel-2	20200615	4	Radiance	20200105T012131	2	70	17%	0.01	0.02	1.42	1.39	0.45	1.32	99.08	97.31
	Sentinel-2	20200615	4	Radiance	20200807T120137	2	70	44%	0.03	-0.03	0.91	0.88	2.28	-2.02	64.00	61.49
MARSEILLE V2	Sentinel-2	20200615	4	Radiance	20180827T112530	2	70	40%	-0.02	0.01	1.08	1.07	-1.06	0.71	75.82	74.63
	Sentinel-2	20200615	4	Radiance	20200807T120137	2	70	45%	-0.04	-0.04	0.96	0.93	-2.54	-2.65	67.01	65.25
MONTPELLIER V1	Sentinel-2	20200615	4	Radiance	20180827T112530	2	70	41%	0.03	0.04	1.12	0.97	1.92	2.72	78.09	67.97
	ASTER v2	20071102T104702	10	Radiance	20190227T101314	2	70	27%	-0.04	0.01	0.82	0.76	-2.95	0.48	57.19	53.26
	ASTER v2	20150829T214908	10	Radiance	20190715T215627	2	70	21%	0.04	0.09	1.50	1.42	2.90	6.65	105.25	99.22
	Sentinel-2	20200615	10	Radiance	20200105T012131	2	70	25%	0.00	0.00	1.26	1.32	-0.05	0.32	88.24	92.25
	ASTER v2	20151101T214848	4	Radiance	20200111T225917	2	70	26%	-0.10	0.01	1.42	1.40	-6.96	0.45	99.62	98.17
	Sentinel-2	20200615	4	Radiance	20200807T120137	2	70	49%	-0.02	-0.01	0.91	0.87	-1.41	-0.88	63.38	60.60
MONTPELLIER V2	Sentinel-2	20200615	4	Radiance	20180827T112530	2	70	40%	-0.01	0.05	0.98	0.95	-0.77	3.73	68.47	66.31
	Sentinel-2	20200615	10	Radiance	20200105T012131	2	70	25%	0.00	0.07	1.31	1.31	-0.03	4.72	91.44	91.61
	Sentinel-2	20200615	4	Radiance	20200807T120137	2	70	49%	-0.02	0.06	0.88	0.88	-1.07	4.11	61.49	61.64
PARIS V1	ASTER v2	20180803T105334	4	Radiance	20180828T103302	2	70	60%	-0.01	0.00	0.60	0.45	-0.94	-0.16	41.72	31.78
	ASTER v2	20041022T105711	10	Radiance	20190215T104909	2	70	23%	0.01	0.00	1.22	1.20	0.44	0.09	85.57	83.97
	ASTER v2	20180805T215100	10	Radiance	20190715T233319	2	70	38%	0.04	0.01	2.03	1.08	2.65	0.81	142.07	75.48
	ASTER v2	20151101T215007	10	Radiance	20200121T230359	2	70	36%	0.03	-0.01	1.36	1.22	1.90	-0.93	94.91	85.59
	Sentinel-2	20200615	4	Radiance	20200807T133846	2	70	56%	0.01	0.01	0.96	0.76	0.89	1.03	67.33	53.45
PARIS V2	Sentinel-2	20200615	4	Radiance	20180828T103302	2	70	44%	-0.06	0.06	0.83	0.87	-3.99	4.23	58.38	60.94
	Sentinel-2	20200615	4	Radiance	20200807T133846	2	70	56%	0.00	0.03	0.71	0.72	-0.23	2.45	49.85	50.11
STRASBOURG V1	Sentinel-2	20200615	4	Radiance	20180822T123248	2	70	26%	-0.04	0.04	0.98	0.89	-2.97	3.11	68.75	62.48
	ASTER v2	20071102T104702	10	Radiance	20180917T224710	2	70	28%	0.03	0.00	1.34	1.07	2.41	-0.31	93.69	74.67
	ASTER v2	20150829T214908	10	Radiance	20190215T105001	2	70	18%	0.01	0.05	1.46	1.37	0.73	3.62	102.12	95.89
	Sentinel-2	20200615	4	Radiance	20200808T125213	2	70	29%	-0.04	-0.01	1.05	0.88	-2.48	-0.84	73.69	61.55
STRASBOURG V2	Sentinel-2	20200615	4	Radiance	20180822T123248	2	70	25%	-0.10	0.09	1.01	0.96	-6.98	6.52	70.83	67.14
	Sentinel-2	20200615	4	Radiance	20200808T125213	2	70	29%	-0.06	0.00	0.98	0.94	-3.88	0.25	68.68	65.59
TOULOUSE V1	Sentinel-2	15062020	4	Radiance	20180820T092448	2	70	17%	-0.01	0.02	1.06	0.95	-0.54	1.30	74.44	66.48
	ASTER v2	20030114T105428	10	Radiance	20190213T105426	2	70	8%	-0.05	0.07	1.10	1.07	-3.42	4.64	76.69	74.94
	ASTER v2	20161228T215433	10	Radiance	20190715T215535	2	70	20%	-0.09	0.02	1.41	1.15	-6.60	1.29	98.88	80.54
	ASTER v2	20161228T215433	10	Radiance	20200111T225917	2	70	10%	-0.06	0.07	0.91	0.87	-4.12	4.71	63.48	60.86
	Sentinel-2	15062020	4	Radiance	20200807T120045	2	70	14%	-0.04	0.01	0.80	0.81	-2.64	1.04	55.93	56.54
TOULOUSE V2	Sentinel-2	15062020	4	Radiance	20180820T092448	2	70	17%	-0.08	-0.01	1.07	1.02	-5.70	-0.37	74.86	71.16
	Sentinel-2	15062020	4	Radiance	20200807T120045	2	70	15%	-0.09	0.00	0.84	0.78	-6.36	0.33	58.85	54.43