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URBANFLUXES

URBAN ANTHROPOGENIC HEAT FLUX FROM EARTH OBSERVATION SATELLITES

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1 INTRODUCTION

1.1 Purpose of the document

This document aims at describing the activities carried out in the framework of URBANFLUXES for collecting and pre-processing Sentinel data to be used by the Consortium for estimating the spatiotemporal patterns of QF along with all other UEB fluxes. In particular, alternatively to what done in the first phase of the project with Landsat and SPOT imagery, the improved data quality, coverage and revisit time of Sentinel data is expected to further improve the quality of QF estimations. Moreover, the Sentinels long-term observational commitment and the variety of instruments with different spectral bands and spatial resolutions with global coverage and high revisit times (Berger et al. 2012), well fit an operational application of QF product time series estimation.

In the following, after introducing how Sentinel-1 (S1), Sentinel-2 (S2) and Sentinel-3 (S3) data of interest for the project are collected at DLR, details are provided for their specific pre-processing activities. Technical details are provided based on the information reported in corresponding user handbooks and technical guides available from ESA and listed in Section 1.3.

1.2 Definitions and acronyms

Acronyms

AATSR	Advanced Along Track Scanning Radiometer
AOI	Area Of Interest
AOT	Aerosol Optical Thickness
BOA	Bottom Of Atmosphere
CGS	Collaborative Ground Segment
CODE-DE	Copernicus Data and Exploitation Platform – Deutschland
DEM	Digital elevation Model
ESA	European Space Agency
EO	Earth Observation
ENL	Equivalent Number of Looks
ETM	Enhanced Thematic Mapper
EW	Extra Wide swath
GRD	Ground Range Detected
GSD	Ground Sampling Distance
HR	High Resolution
IW	Interferometric Wide swath
LAI	Leaf Area Index
LST	Land Surface Temperature
MSI	Multispectral Instrument

MWR	Microwave Radiometer
NDVI	Normalized Difference Vegetation Index
NIR	Near InfraRed
OGC	Open Geospatial Consortium
OLCI	Ocean and Land Color Instrument
OLI	Operational Land Imager
PAC	Processing and Archiving Centers
RADAR	Radio Detection and Ranging
RGB	Red-Green-Blue
S1	Sentinel-1
S2	Sentinel-2
S3	Sentinel-3
S5	Sentinel-5
SAR	Synthetic Aperture Radar
SLC	Single Look Complex
SLSTR	Sea and Land Surface Temperature Radiometer
SM	Stripmap
SPOT	Satellite Pour l'Observation de la Terre
SRAL	Synthetic Aperture Radar Altimeter
SRTM	Shuttle Radar Topography Mission
SWIR	Short Wave InfraRed
TIFF	Tag Image File Format
TOA	Top Of Atmosphere
UEB	Urban Energy Budget
URBANFLUXES	URBan ANthropogenic heat FLUX from Earth observation Satellites
UTM	Universe Transverse Mercator
VHR	Very High Resolution
WGS	World Geodetic System
WV	Wave

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2 SENTINEL DATA COLLECTION

The gap between the Sentinel space element and the users is closed by the ground segment, which - next to mission operations - is built by distributed entities to ensure the reliable and timely access, processing and distribution of data and products.

The ground segment consists of dedicated data acquisition stations (augmented with the European Data Relay Satellite capability) and a series of Processing and Archiving Centers (PACs) aimed to process, archive and distribute the ingested Sentinel data. Among these, DLR operates PACs responsible for S1, S3 and the upcoming Sentinel-5 (S5). However, solely for internal use, also the entire S2 archive is stored and made available for in-house activities. All S1, S2 and S3 data of interest for URBANFLUXES are then directly available and accessible from DLR via the novel Copernicus Data and Exploitation Platform – Deutschland (CODE-DE), i.e. the German Collaborative Ground Segment (D-CGS) for Copernicus.

CODE-DE is currently being finalized in order to support also higher level data processing and provides a platform for Earth-Observation data users (e.g., research centers, government agencies, public users) as well as for other entities of the national (or European) CGSs. Specifically, it offers access to the following data sources:

- ESA Collaborative Data Hub;
- Sentinel Long-Term-Archive;
- Several receiving stations of the national CGS;
- Third-Party data (e.g., ESA Data Warehouse and commercial data from Airbus and BlackBridge).

The CODE-DE architecture is highly modular and composed of individual services, which form a general-purpose system, largely based on existing software components, to serve as a high-performance and scalable platform that fulfils the service requirements.

Apart from being a gateway for low level products, CODE-DE is going to serve as exploitation platform. This requires additional functionalities such as "Search and Access" (e.g. modules for discovery, visualization, download, past product retrieval, subscription, distribution, catalogue services) and "Processing" services (application provisioning, workflow orchestration, scheduler, resource management).

To guarantee interoperability CODE-DE mostly relies on Open Geospatial Consortium (OGC) services, which are a *de facto* standard in the spatial data community or even more generic standards used throughout the internet.

3 SENTINEL-1 DATA PRE-PROCESSING

The S1 mission is a constellation of two satellites - namely S1A and S1B launched on 3rd April 2014 and 22nd April 2016, respectively – mounting on board a C-band Synthetic Aperture Radar (SAR) sensor which can transmit and receive in both horizontal (H) and vertical (V) polarizations. In particular, SAR sensors have the advantage of operating at wavelengths not impeded by cloud cover or lack of illumination, hence allowing to observe the Earth's surface at any time of the day or night, regardless of weather and environmental conditions.

It is worth noting that in the first phase of the project no radar data have been used for generating any of the selected EO-based products supporting the estimation of the UEB terms. Nevertheless, all S1 scenes available for the three selected case studies have been yet downloaded and pre-processed as described in the following since they might be of support for the estimation of some morphological parameters in case no VHR height information dataset is accessible. Eventually, such aspect shall be further investigated in the second phase of URBANFLUXES compatibly with the available remaining resources.

The S1 SAR instrument supports four acquisition modes:

- **Stripmap (SM):** standard SAR stripmap imaging mode where the ground swath is illuminated with a continuous sequence of pulses, while the antenna beam is pointing to a fixed azimuth and elevation angle;
- **Interferometric Wide swath (IW):** data is acquired in three swaths using the Terrain Observation with Progressive Scanning SAR (TOPSAR) imaging technique. **IW is the primary operational mode over land**;
- **Extra Wide swath (EW):** data is acquired in five swaths using the TOPSAR imaging technique. EW mode provides very large swath coverage at the expense of spatial resolution;
- **Wave (WV):** data is acquired in small stripmap scenes called "vignettes", situated at regular intervals of 100 km along track. The vignettes are acquired by alternating, acquiring one vignette at a near range incidence angle while the next vignette is acquired at a far range incidence angle. **WV is the operational mode over open ocean**.

S1 data products acquired in SM, IW and EW mode are distributed at three levels of processing, i.e. Level-0, Level-1 and Level-2 (instead, for WV mode only Level-2 products are provided).

Table 1: Spatial resolution, pixel spacing, number of looks and Equivalent Number of Looks (ENL) for different resolutions and acquisition modes supported by the S1 SAR sensor.

Resolution	Mode	Resolution rg x az	Pixel spacing rg x az	Number of looks	ENL
Full	SM	9x9 m	4x4 m	2x2	3.9
High	SM	23x23 m	10x10 m	6x6	34.4
	IW	20x22 m	10x10 m	5x1	4.9
	EW	50x50 m	25x25 m	3x1	2.9
Medium	SM	84x84 m	40x40 m	22x22	350-398
	IW	88x87 m	40x40 m	22x5	105.7
	EW	93x87 m	40x40 m	6x2	12.7
	WV	52x51 m	25x25 m	13x13	123.7

Level-0 products contain the compressed and unprocessed instrument source packets, with additional annotations and auxiliary information to support processing. Level-1 products are intended for most data users and can be of two different types: Single Look Complex (SLC) or Ground Range Detected (GRD). Level-2 consists of geo-located geophysical products derived from Level-1 supporting ocean wind, wave and currents applications.

Among these, products most suitable for the analysis of urban morphology are Level-1 GRD which consist of focused SAR data which have been detected, multi-looked and projected to ground range. In particular, these are available at three different spatial resolutions (dependent upon the amount of multi-looking performed):

- Full Resolution for SM mode;
- High Resolution for SM, IW and EW modes;
- Medium Resolution for SM, IW, EW and WV modes.

All related details are reported in Table 1.

In the framework of URBANFLUXES available full-resolution SM as well as high-resolution IW and EW data have been selected and processed to backscattering coefficient σ°. Specifically, it represents the target backscattering area (radar cross-section) per unit ground area and

Table 2: Spatial resolution, pixel spacing, number of looks and Equivalent Number of Looks (ENL) for different resolutions and acquisition modes supported by the S1 SAR sensor.

Case Study	Pass	SM	IW	EW
Basel	Ascending	0	146	0
	Descending	5	111	0
Heraklion	Ascending	0	143	12
	Descending	0	148	11
London	Ascending	1	208	4
	Descending	4	215	14

depends on the physical characteristics of the terrain (primarily the geometry of the terrain elements and their electromagnetic characteristics).

To derive σ°, a dedicated processing chain has been implemented which includes:

- orbit correction;
- thermal noise removal (which allows excluding dark strips near scene edges with invalid data);
- radiometric calibration (performed by exploiting specific sensor calibration parameters provided in the GRD metadata);
- terrain correction (i.e., orthorectification to the UTM projection specific to the investigated study region carried out by using the SRTM 30 meter DEM).

Finally, since σ° can vary by several orders of magnitude, as commonly done with radar data, we convert it to dB as 10*log10(σ°); moreover, afterwards values are clamped to the 1st and 99th percentile for preserving the dynamic range against anomalous outliers and conversion to GeoTIFF format is performed.

Table 2 reports for the three investigated case studies the number of pre-processed VV-VH S1 scenes intersecting the corresponding AOI which have been acquired between 3rd October 2014 and 18th January 2017 in SM, IW and EW modes either in ascending or descending pass.

Furthermore, Figure 1, Figure 2, and Figure 3 report the backscattering coefficient σ° product derived from IW GRD high-resolution VV imagery acquired by S1B over Basel on 23rd December 2016, by S1A over Heraklion on 5th January 2017, and by S1B over London on 1st January 2017, respectively.

Figure 1: Basel – backscattering coefficient σ° product derived from S1B IW GRD high-resolution VV imagery acquired on 23rd December 2016.

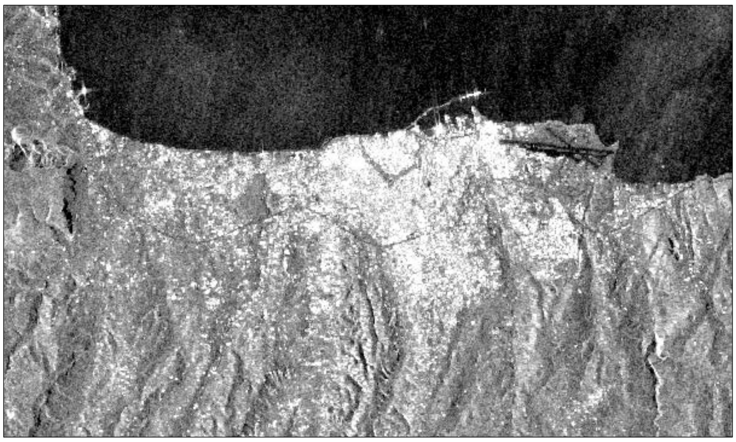


Figure 2: Heraklion – backscattering coefficient σ° product derived from S1A IW GRD high-resolution VV imagery acquired on 5th January 2017.

Figure 3: London – backscattering coefficient σ° product derived from S1B IW GRD high-resolution VV imagery acquired on 1st January 2017.

4 SENTINEL-2 DATA PRE-PROCESSING

The S2 mission is a constellation of two twin polar-orbiting, wide-swath, high-resolution, multi-spectral imaging satellites (i.e., S2A and S2B) supporting Copernicus Land Monitoring studies. Specifically, S2A has been launched on 23rd June 2015, whereas S2B is scheduled to lift off on 7th March 2017.

The S2 mission provides systematic coverage over:

- all continental land surfaces (including inland waters) between latitudes 56° South and 83° North;
- all coastal waters up to 20 km from the shore;
- all islands greater than 100 km^2;
- all EU islands;
- the Mediterranean Sea;
- all closed seas (e.g. Caspian Sea).

As soon as S1B is operational, all areas indicated above will be revisited every five days under the same viewing conditions (however due to overlap between swaths from adjacent orbits, the revisit frequency increases with different viewing conditions).

S2 satellites mount on board the Multispectral Instrument (MSI) which acquires in 13 different spectral bands: 4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m spatial resolution. All the corresponding details are given in Table 3.

S2 data is complementary to existing optical missions like SPOT and, especially, Landsat. In the latter case one can notice from Figure 4 how, between the visible and SWIR portion of the spectrum, there is a high correspondence between spectral bands of S2 MSI and those of Landsat-7 ETM+ and Landsat-8 OLI sensors. This is particularly important in the framework of URBANFLUXES since Landsat and SPOT data have been used as input for deriving all biophysical parameters of interest (i.e., surface reflectance, NDVI, LAI, LST and AOT) as well as land-cover maps in the first phase of the project.

All data acquired by the MSI instrument are systematically processed to Level-1C, which is the only one released to the users. Level-1C products are composed of 100x100km^2 elementary granules, which consist of JPEG2000 ortho-images in UTM/WGS84 projection containing all 13 spectral bands. Per-pixel radiometric measurements are provided in Top Of Atmosphere (TOA) reflectances along with the parameters to transform them into radiances. Products are resampled with a constant GSD of 10, 20 and 60 m depending on the native resolution of the different spectral bands.

Level-1C products also include cloud and land/water masks; however, concerning the former

Table 3: Spatial resolution, central wavelength and bandwidth of different S2 MSI spectral bands.

Band n.	Spatial Resolution (m)	Central Wavelength (nm)	Bandwidth (nm)
1	60	443	20
2	10	490	65
3	10	560	35
4	10	665	30
5	20	705	15
6	20	740	15
7	20	783	20
8	10	842	115
8a	20	865	20
9	60	945	20
10	60	1375	30
11	20	1610	90
12	20	2190	180

it is worth noting that actually in its current version it often exhibits poor quality (just very dense clouds are generally detected). To this purpose, a new version of the Fmask algorithm (which has been employed in the first part of the project for masking all analyzed Landsat scenes for the investigated case studies) has been released which also supports S2 data (Zhu et al., 2015). Such module is currently being included into the dedicated pre-processing chain at DLR and shall be operational within the next few weeks.

Starting from Level-1C, Level-2A products can be derived providing Bottom Of Atmosphere (BOA) reflectance images. However, Level-2A products are not systematically generated at the ground segment; rather, such task is left to the users through the employment of the S2 Toolbox. In particular, this can be carried out by means of the Sen2Cor processor, which performs atmospheric-, terrain and cirrus correction of Top-Of- Atmosphere Level 1C input data. Sen2Cor (which embeds DLR's ATCOR software) creates BOA, and optionally terrain- and cirrus corrected reflectance images; moreover, AOT, water vapor, scene classification maps and quality Indicators for cloud and snow probabilities can be also generated.

However, Sen2Cor is currently under development (latest available version 2.3.0 released on 25th November 2016) and might still result in artifacts or poor quality corrections in many cases. In this context, the DLR ATCOR team is currently working for fixing existing bugs and an updated version is expected by February/March 2017.

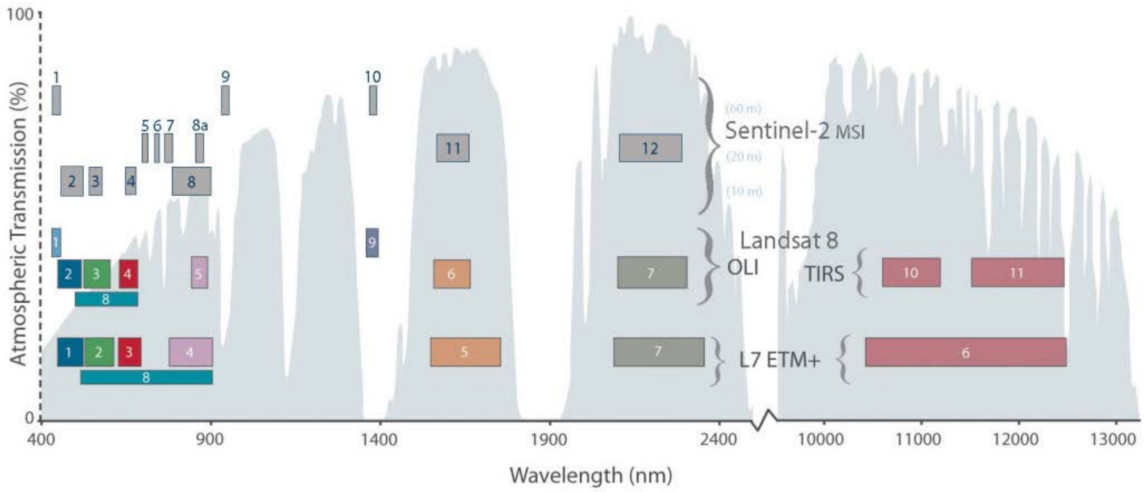


Figure 4: Comparison of Landsat 7 ETM+, Landsat 8 OLI/TIRS and Sentinel-2 MSI spectral bands (source: NASA).

At present, we have yet gathered and pre-processed all available Level-1C products intersecting the AOIs of the three URBANFLUXES case studies (excluding those exhibit full cloud coverage). In particular, we cropped all scenes to the corresponding AOI extent, and converted each of them to GeoTIFF format resampling all bands to 10m spatial resolution.

Table 4 reports for each investigated city the number of currently pre-processed S2A Level-1C images (acquired between the beginning of the mission and 18th January 2017) sub-divided into three different categories determined by visual inspection and depending on the corresponding amount of cloud coverage. In particular:

- Category I corresponds to cloud-free or reduced-cloud-covered scenes;
- Category II corresponds to scenes where cloud cover is not negligible but lower than 50% of the AOI;

Table 4: Number of currently pre-processed S2A Level-1C images (acquired between the beginning of the mission and 18th January 2017) sub-divided into the three selected categories.

Case Study	Category I	Category II	Category III
Basel	14	8	5
Heraklion	33 (18)	16 (7)	21 (8)
London	6	12	17

- Category III corresponds to scenes with major cloud cover (>50% of the AOI).

Since for Heraklion one of the available S2A orbits intersects only the left portion of the AOI, we report in brackets, for each category, the number of scenes actually covering the entire study region.

Figure 5, Figure 6, and Figure 7 show the RGB true color composition (bands 4, 3, 2) derived from S2A MSI imagery defined as Category I acquired on 1st November 2016 over Basel, 29th January 2016 over Heraklion, and 15th August 2015 over Landsat, respectively.

Based on the experience gathered while deriving the EO-based products in the first phase of the project, only scenes belonging to Category I and II will actually be of practical use (i.e., so far overall 26 for Basel, 25 for Heraklion and 18 for London). Accordingly, for each of them the corresponding Level-2A products are scheduled to be generated in February/March 2017 using the most up-to-date version of the Sen2Cor/ATCOR tools.

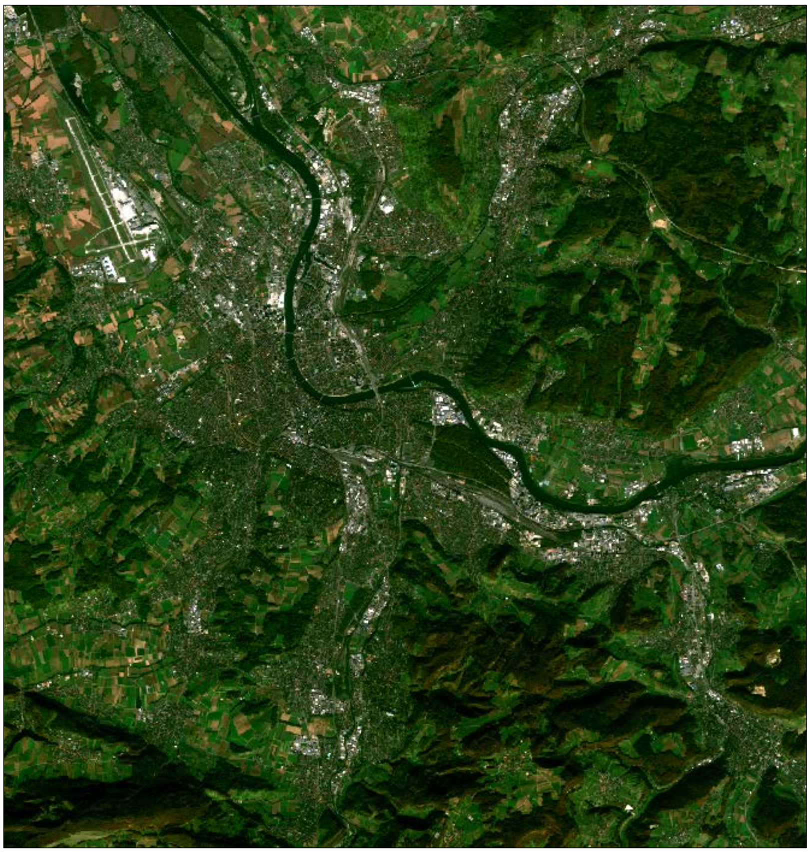


Figure 5: Basel – RGB true color composition (bands 4, 3, 2) derived from S2A MSI imagery acquired on 1st November 2016.

Figure 6: Heraklion – RGB true color composition (bands 4, 3, 2) derived from S2A MSI imagery acquired on 29th January 2016.

Figure 7: London – RGB true color composition (bands 4, 3, 2) derived from S2A MSI imagery acquired on 15th August 2015.

5 Sentinel-3 Data Pre-processing

The main objective of the S3 mission is to measure sea and land surface temperature, sea surface topography and ocean and land surface color with high accuracy and reliability in support of ocean forecasting systems, environmental monitoring and climate monitoring.

As in the case of S1 and S2, also the S3 mission is a constellation of two satellites, namely S3A and S3B. S3A, originally scheduled to lift off in late 2014, has finally been launched only on 16th February 2016 and it is still in its pre-operational phase. S3B is scheduled for launch in 2017.

The S3 scientific payload includes four main instruments, namely:

- OLCI (Ocean and Land Color Instrument);
- SLSTR (Sea and Land Surface Temperature Radiometer);
- SRAL (Synthetic Aperture Radar Altimeter);
- MWR (Microwave Radiometer).

Among these, the one of highest support to URBANFLUXES is SLSTR since it features thermal infrared bands which are instead not available from S2. In particular, SLSTR is based on Envisat's Advanced Along Track Scanning Radiometer (AATSR) and aims at deriving sea (SST) and land (LST) surface temperatures globally with high degree of accuracy (better than 0.3 K for SST). Moreover, the SLSTR sensor improves the along track scanning dual-view technique of AATSR, hence providing advanced atmospheric correction.

SLSTR measures in nine spectral channels (denoted as S1-S9) with spatial resolution in the visible and shortwave infrared channels of 500 m and 1 km in the thermal infrared channels. Moreover, two further features (i.e., F1 and F2) dedicated to active fire detection are additionally derived based on the same detectors as S7 and S8 but with an increased dynamic range to prevent saturation over fires. All related technical specifications are reported in Table 5.

Given the very short revisit time (currently with the only S3A in orbit on average 1 day for nadir view and 1.9 days for dual view) but the low spatial resolution (i.e., 1 km) for the three bands suitable for LST retrieval (i.e., S7, S8 and S9) the idea within URBANFLUXES is then to downscale thermal bands information for retrieving high spatial and temporal resolution urban surface temperature by means of spatial-spectral unmixing techniques (Mitraka et al. 2013).

To this purpose, SLSTR Level-1B data are then analyzed as they provide geolocated TOA radiances for visible/NIR/SWIR channels and, especially, TOA brightness temperatures for

Table 5– Spatial resolution, central wavelength and bandwidth of different S3 SLSTR spectral bands.

Band Id	Spatial Resolution (m)	Central Wavelength (nm)	Bandwidth (nm)
S1	500	0.555	0.02
S2		0.659	0.02
S3		0.865	0.02
S4		1.375	0.015
S5		1.61	0.06
S6		2.25	0.05
S7	1000	3.74	0.38
S8		10.85	0.9
S9		12	1
F1	1000	3.74	0.38
F2		10.85	0.9

thermal IR and fire channels. Moreover, Level-1B products also include additional information as – among others - cloud flagging, surface pixel classification information and meteorological annotations.

S3A SLSTR Level-1B data are available for the three case studies from 17th November 2016; in particular, 151, 119 and 184 scenes have been collected intersecting the AOI of Basel, Heraklion and London until 18th January 2017, respectively.

A dedicated pre-processing chain has been implemented so far using the S3 toolbox where products gathered at DLR can be directly ingested. In particular, bands S7, S8 and S9 are extracted, reprojected to the UTM system specific to the investigated study region, cropped to the selected AOI and finally saved in GeoTIFF format. Given the very high number of available input data, final products will be generated for the dates of interest to be chosen by the project consortium during the second phase of the project.

Figure 8.a and 8.b depict the S7 band of the S3A SLSTR Level-1B scenes acquired on 1st December 2016 covering Basel in nadir and dual view, respectively. Corresponding zooms over the selected AOI are given in Figure 8.c and 8.d, respectively.

Figure 9.a and 9.b show the S8 and S9 bands of the S3A SLSTR Level-1B scenes acquired on 5th January 2017 and 13th January 2017 covering London and Heraklion in nadir view,

respectively. Corresponding zooms over the selected AOI are given in Figure 9..c and 9.d, respectively.

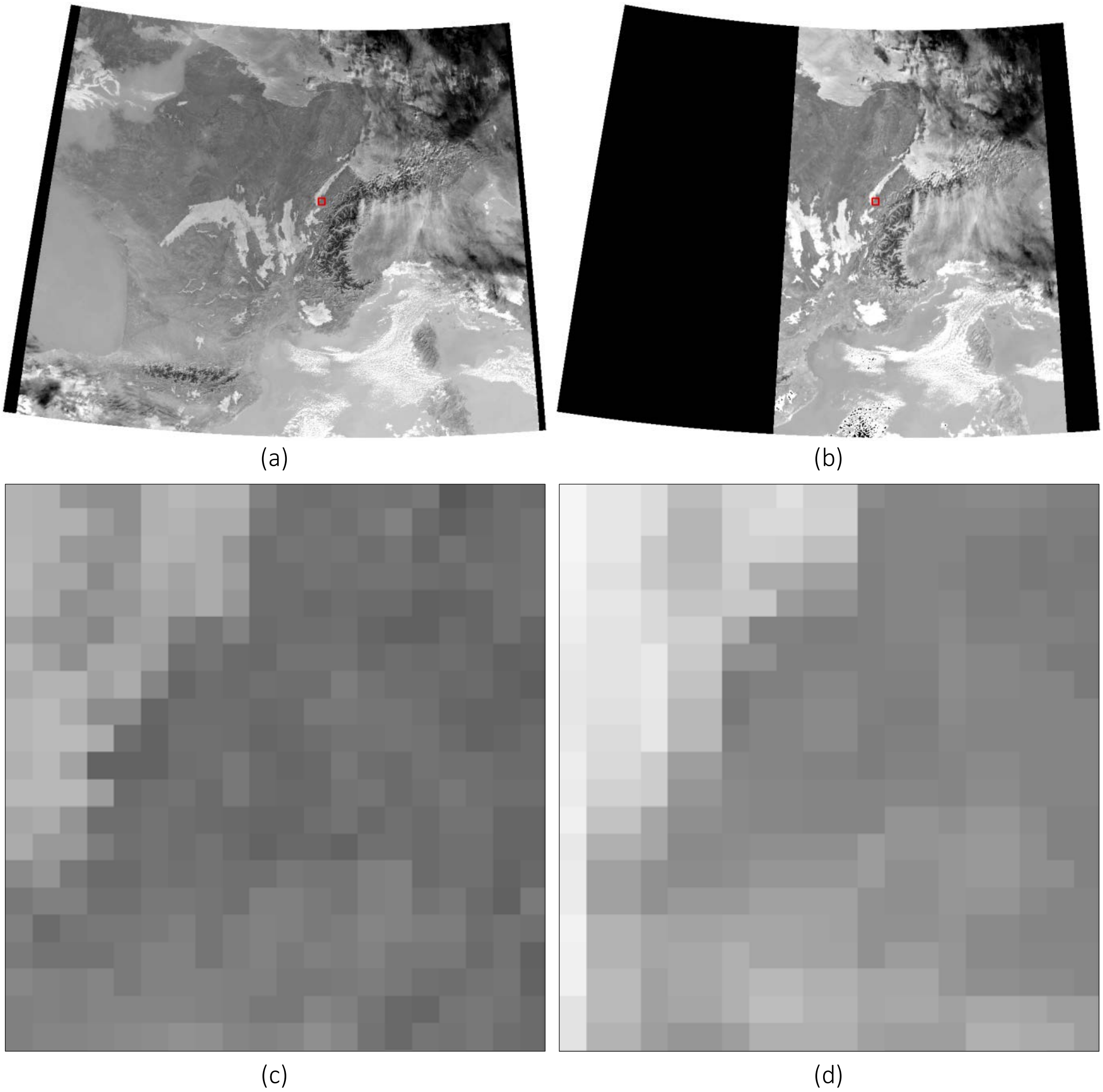
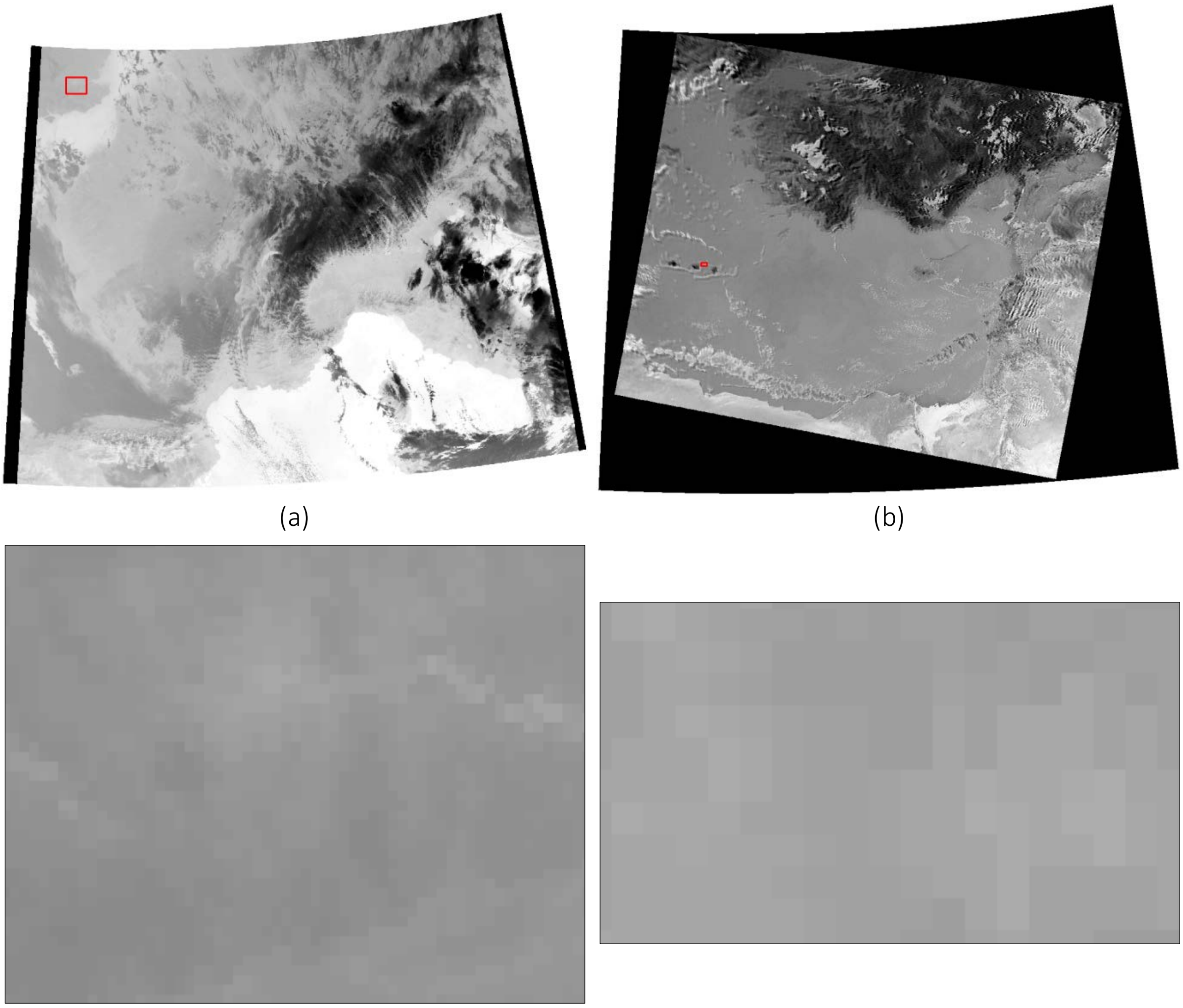


Figure 8: S7 band of the S3A SLSTR Level-1B scenes acquired on 1st December 2016 covering Basel in nadir (a) and dual (b) view, respectively, along with corresponding zooms (c and d) over the selected AOI.



(a) (b) (c) (d)

Figure 9: S8 and S9 bands of the S3A SLSTR Level-1B scenes acquired on 5th January 2017 and 13th January 2017 covering the London (a) and Heraklion (b) in nadir view, respectively, along with corresponding zooms (c and d) over the selected AOI.