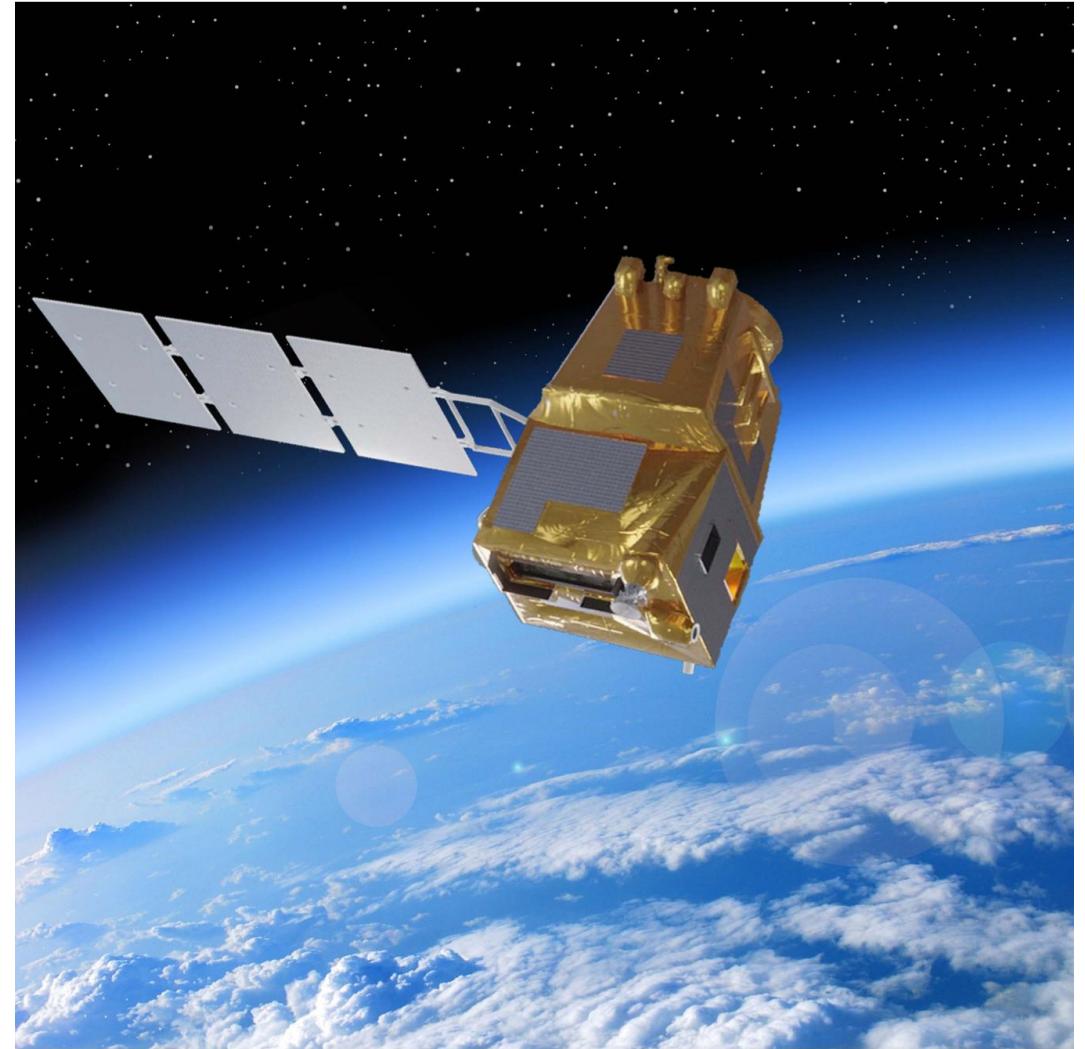


MASTER X

M4.8 PAYLOAD MISSION AND APPLICATIONS

PROFESOR: LUCIA SOTO SANTIAGO

ASIGNATURA: PAYLOADS AND MISSIONS APPLICATIONS (PLMA)



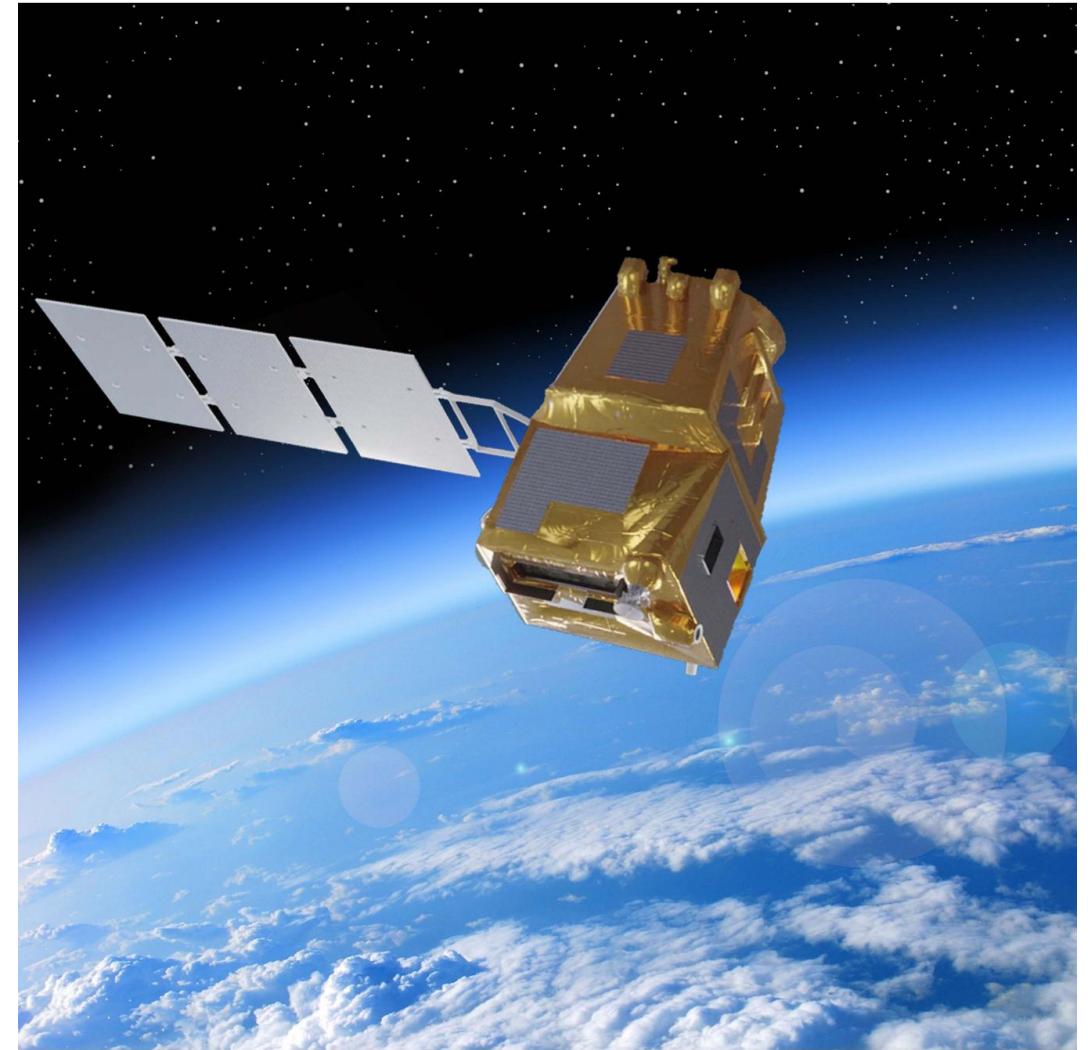
ON-GROUND DATA PRODUCTS

- Data extraction
- Levels of data processing
- Description of the Payload Data Ground Segment (PDGS)
- End-to-End Simulators (E2ES)
 - Instrument Data Simulators (IDS)
 - Ground Processor Prototypes (GPP)
- Operational processors



*In this topic we will introduce **Earth Observation Data Processing**, a fundamental activity in the Space domain.*

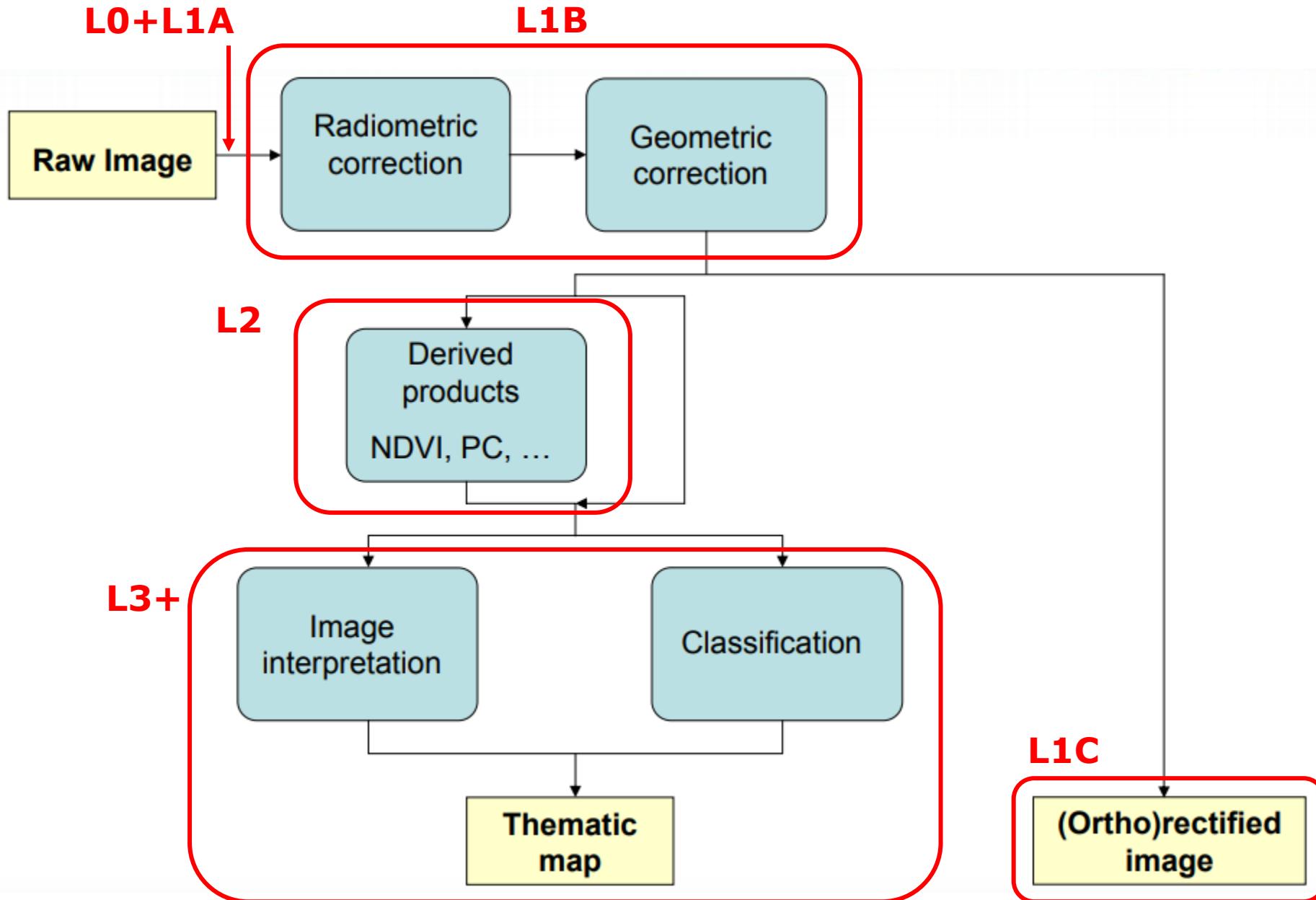
DATA EXTRACTION



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Data processing steps

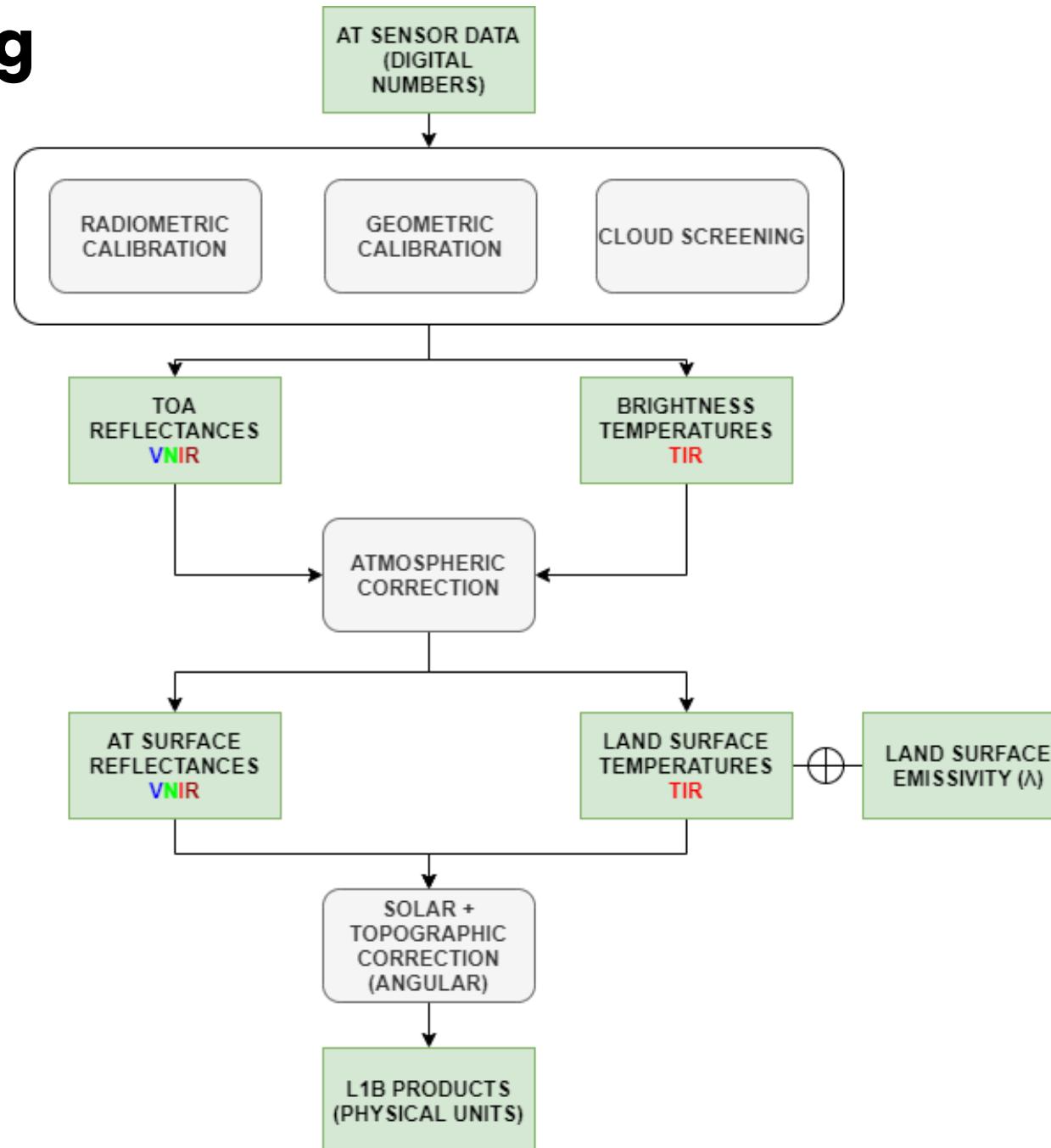
- The satellite sends to Earth a stream of data.
- That data, which is formatted and compressed, needs to be processed to retrieve the information we are looking for (e.g., the weather forecast).
- Essentially, the steps that we need to do are:
 - **Uncompress the data and check** that it is not corrupted, has gaps, etc. → L0.
 - Translate the digital numbers to **physical units** (e.g., radiances) → L1A
 - **Calibrate** the data (geometrical, radiometrical, spectrally) → **Appended in L1A and applied in L1B** processing. Obtain the „best possible data” as measured by the sensor.
 - **Regrid.** Interpolate to a common orthorectified grid → L1C
 - Process to obtain the desired derived **variables** (e.g., Land Surface Temperature, soil moisture) → L2
 - Process to obtain **maps**, evolution of parameters, statistics, trends → L3+



Terminology

- **Processing** → The satellite stores the data in the on-board memory (in „digital numbers”). Processing is all of the steps applied to this digital number in order to retrieve what we actually want to measure (for example „the salinity of the ocean”).
- **Calibration** → Any instrument, and each of its detector elements, responds in a not-ideal way due to a number of effects. This response is measured against a standard in the laboratory on-ground (before launch) and during the satellite's operation. This response is used to remove the errors introduced by the response of the instrument, to try to achieve the best possible knowledge of the physical variable being measured.

L1B processing steps



Radiometric & Spectral Calibration

- The instrument is *not* ideal in the following ways:
 - **Imperfect optics** (telescope, spectrometer, lenses, any optical element) ☐ straylight, smile/keystone effects
 - **Imperfect detection:**
 - Each detector element responds differently to the same input radiance ☐ Photo Response Non-Uniformity.
 - Electronic noise ☐ Dark-noise, dark signal.
 - Readout errors ☐ Cross-talk

→ Radiometric & spectral calibration

① Photon Response Non-Uniformity



(a) Input Y

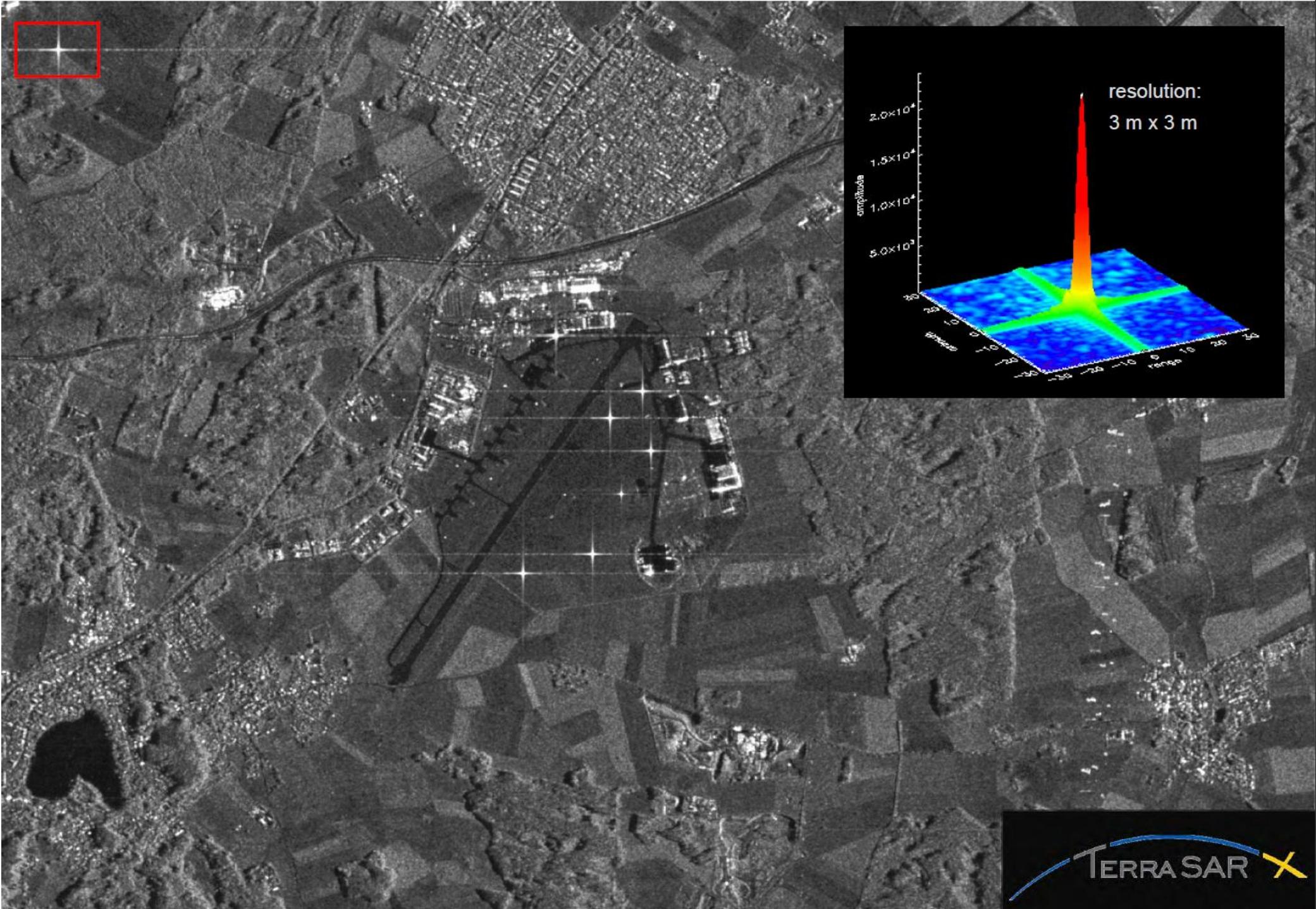


(b) r_a (values increased by $\times 10^4$)

① Calibration Devices

- Examples of calibration targets with well-known reflectivity (Radar Cross Section) for external calibration of the SAR system





Source:
http://seom.esa.int/landtraining2015/files/Day_1/D1T2a_LTC2015_Younis.pdf

Correction to obtain Surface properties (τ , ρ)

- After correcting the radiances for the instrument effects (calibration), we are interested in retrieving the surface properties:
 - **VNIR:** Surface reflectances — ρ
 - **TIR:** Surface temperatures — T
- For this we need to:
 - Correct for the **Atmospheric** propagation — we use the Radiative Transfer Models to estimate the atmospheric effects of absorption and scattering (see #3 Passive Optical instruments).
 - **TIR:** Correct for the **Emissivity**
 - **Cloud** screening.
 - Correct for the **topography** (angular corrections) and **Solar** conditions

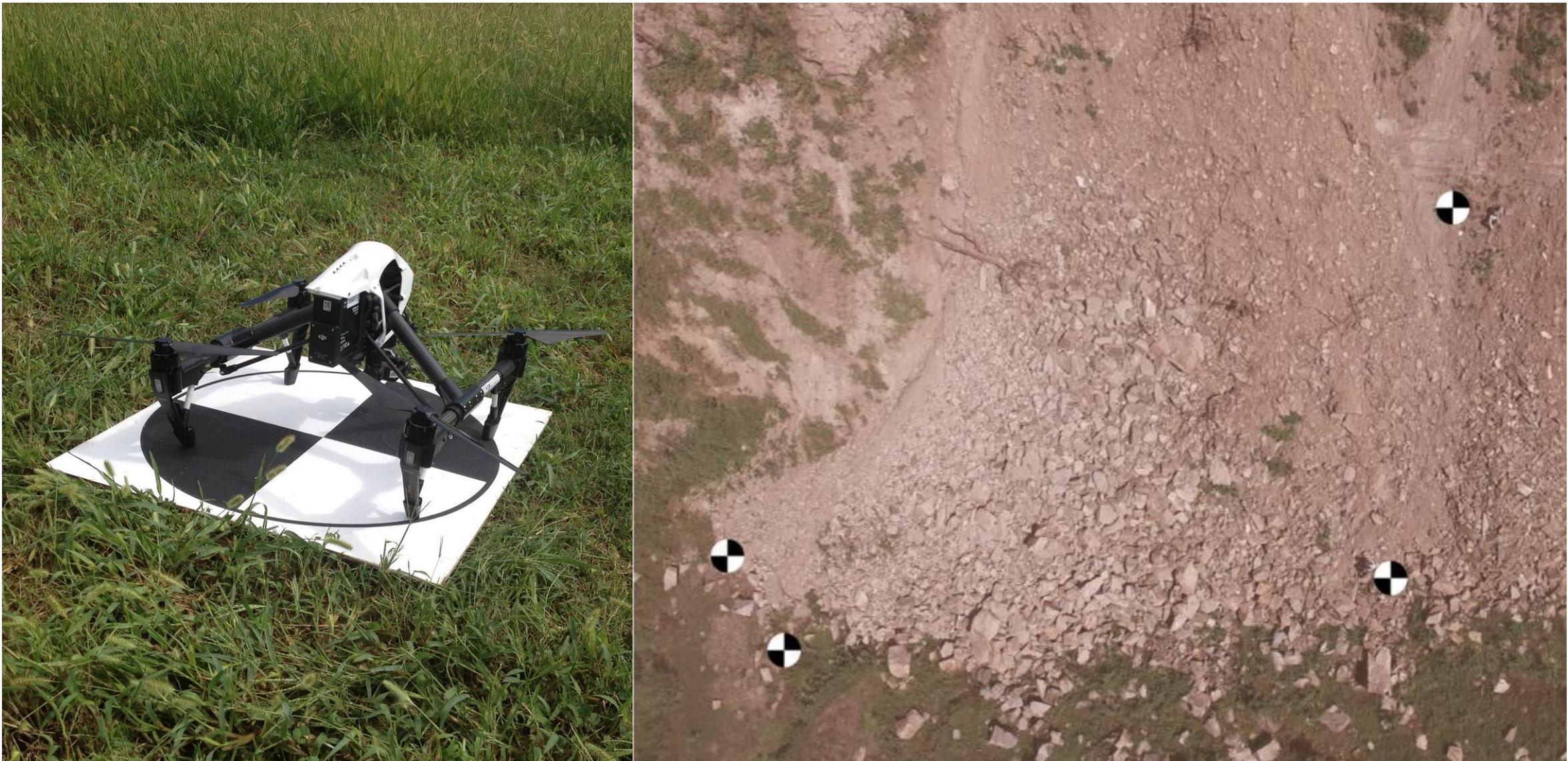
Geometrical Calibration

- The satellite records its own ephemeris:
 - **Position:** with **GNSS** sensors (Galileo, GPS)
 - **Attitude:** with **accelerometers/star-trackers.**
- The instruments that record the position/attitude have associated knowledge errors, which we try to compensate.
- This is quite an elaborate processing and can be done in several ways:
 - With ground control points.
 - Feature matching

→Geometrical calibration

1. In your image, you are calculating the geolocation for all the pixels based on your knowledge of the satellite position, attitude and line-of-sight.
2. Additionally, you know the location on ground (lat,lon,alt) of certain features (a building, or any feature with enough contrast) – the **ground control points**.
3. You compare the position of your geolocation with the real position of the GCPs. You use this to correct the location of all your pixels.

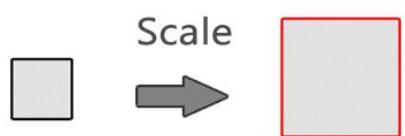
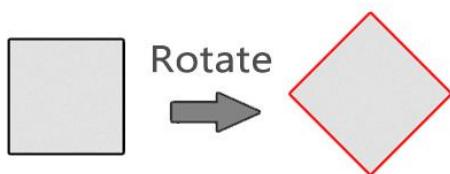
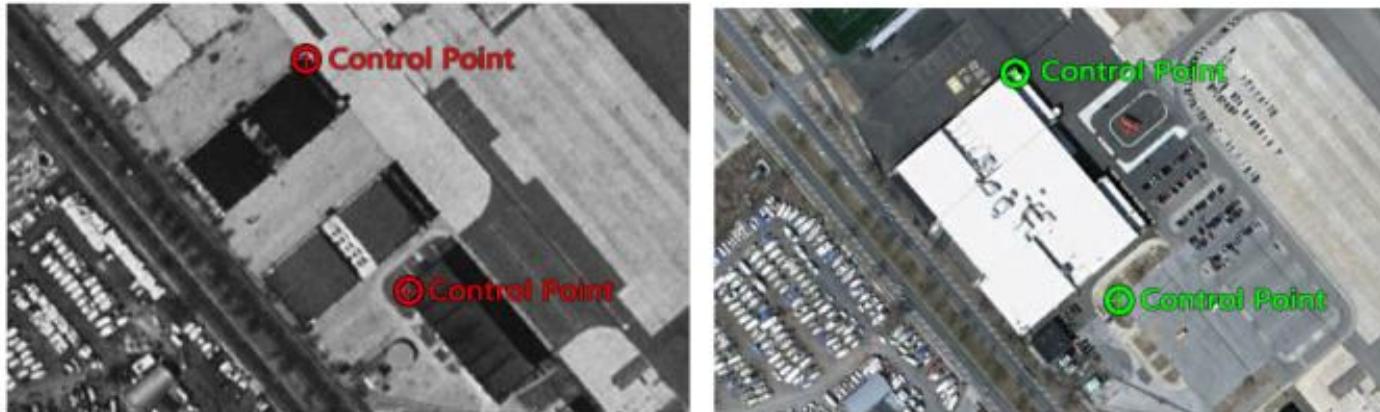
Example of calibration: Ground Control Points



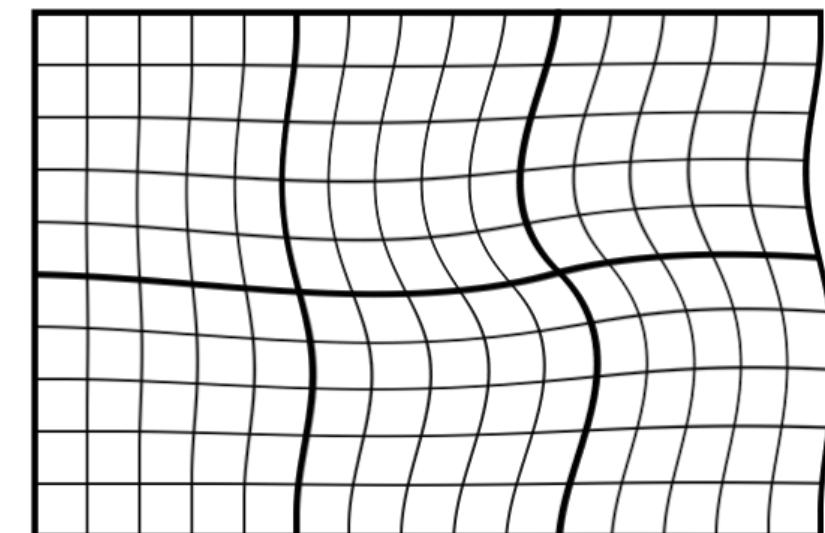
Example of Calibration Ground Control Points on Reference Image



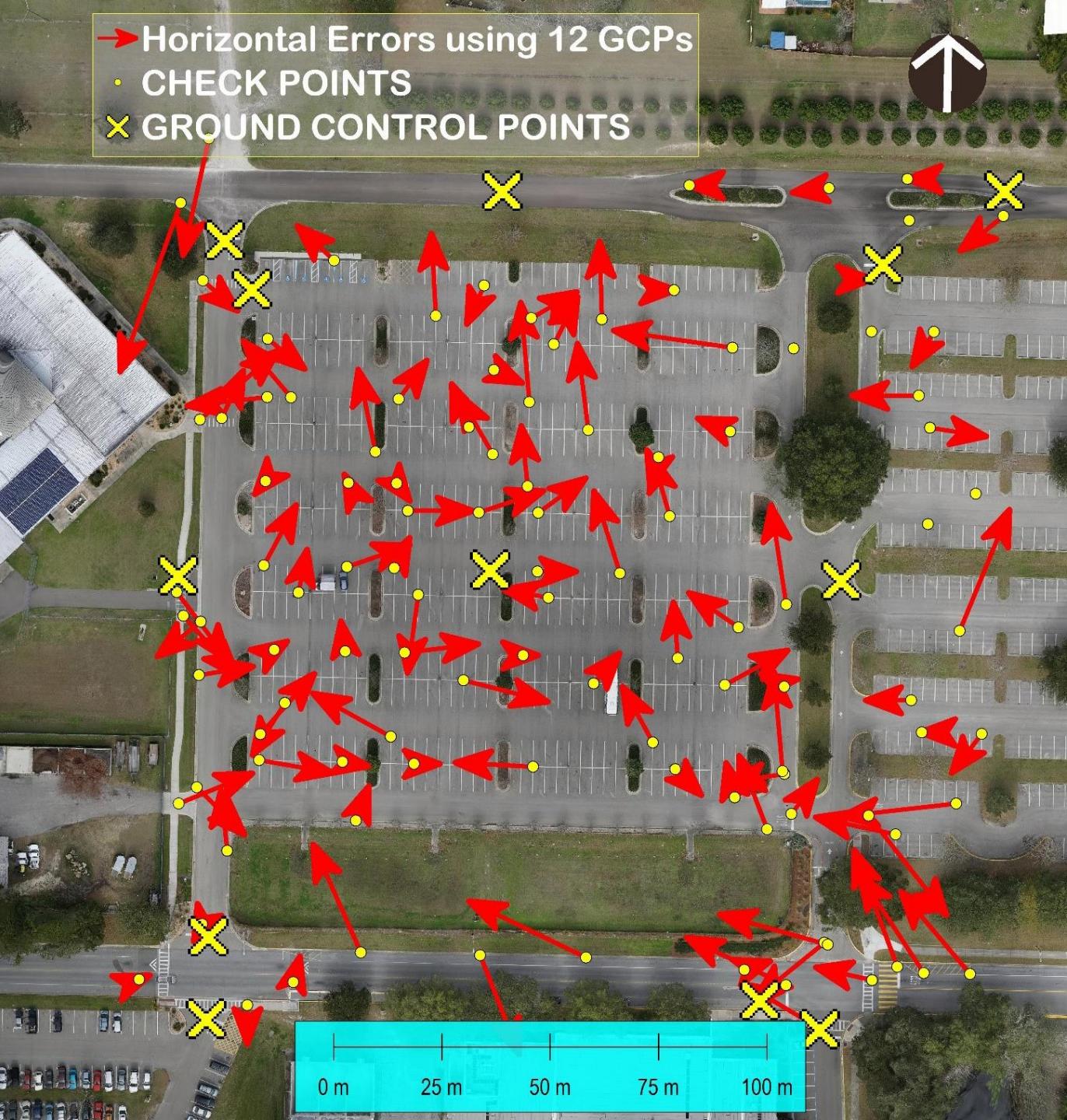
Example of Calibration Ground Control Points on Reference Image



Often enough with affine
transformations



In other cases, it may
need rubbersheeting



Source: <http://v-map.net/wp-content/uploads/2015/09/HorizontalErrors12GCPs1.jpg>

① FLEX L0+L1B processing steps →

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 - 7.4 GPP-ATB-L0-1: Mathematical Description
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 - 8.3.1 FIPS-ATB-L1PP-1: L1b Geolocation Process
 - 8.3.2 GPP-ATB-L1PP-2: Identification of defective pixels
 - ▲ 8.4 L1b Corrections
 - 8.4.1 GPP-ATB-L1PP-3: Offset correction (TBC)
 - ▷ 8.4.2 GPP-ATB-L1PP-4: Non-linearity correction
 - ▷ 8.4.3 GPP-ATB-L1PP-5: Dark signal removal
 - ▷ 8.4.4 GPP-ATB-L1PP-6: Smearing signal correction
 - ▷ 8.4.5 GPP-ATB-L1PP-7: Stray-light correction
 - ▷ 8.4.6 GPP-ATB-L1PP-8: Flat Field correction
 - ▷ 8.4.7 GPP-ATB-L1PP-9: Absolute Radiometric Gain application
 - 8.4.8 GPP-ATB-L1PP-10: L1b classification flag derivation
 - 8.4.9 GPP-ATB-L1PP-11: L1b Formatting
- ▲ 9 Calibration Processing module (CPM)
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 - 9.2 Module Output
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 - ▲ 9.5 Geometric Calibrations
 - 9.5.1 GPP-ATB-CAL-3: Geometric Calibrations
 - ▲ 9.6 Spectral Calibrations
 - 9.6.1 GPP-ATB-CAL-4: Spectral Calibrations
 - ▲ 9.7 Radiometric Calibrations
 - 9.7.1 GPP-ATB-CAL-1A: Absolute radiometric gain calculation using the solar port and instrument radiometric degradation model
 - 9.7.2 GPP-ATB-CAL-1B: Absolute radiometric gain validation and instrument radiometric degradation model validation using the Moon (TBC)
 - 9.7.3 GPP-ATB-CAL-1C: Radiometric measurements using deep convective clouds (TBC)
 - 9.7.4 GPP-ATB-CAL-2: Dark signal calculation (at each pixel)
 - 9.7.5 GPP-ATB-CAL-5: MTF evaluation using the lunar disc
 - 9.7.6 GPP-ATB-CAL-6: Non linearity assessment
 - 9.7.7 GPP-ATB-CAL-7: SL correction validation
 - 9.7.8 GPP-ATB-CAL-8: Flat Field calculation using the deserts (TBC)
 - 9.8 On-line Calibrations

① Sentinel-3 MWR
(radiometer) L1B
processing steps →

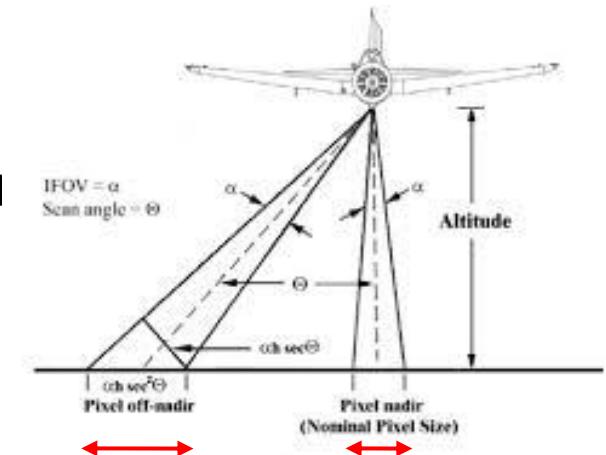
 CLS COLLECTE LOCALISATION SATELLITES	Sentinel-3 MPC Level 1b MWR Algorithm Theoretical Baseline Definition	Ref.: S3MPC.CLS.PRB.004 Issue: 1.0 Date: 01/07/2019 Page: ii
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Orthorectification and co-registration (L1C)

- The L1B product is in sensor geometry. The satellite is in an SSO orbit (probably, or any other orbit), looking with a certain angle Θ the position on ground of the detectors is **not** regular
- **Orthorectification** is projecting the L1B product to a regular grid.
- **Co-registration** is an ample term to describe the processing of \geq two images into a final product. These images can come from different passes of the satellite over a given area, or from different detector lines from an instrument.

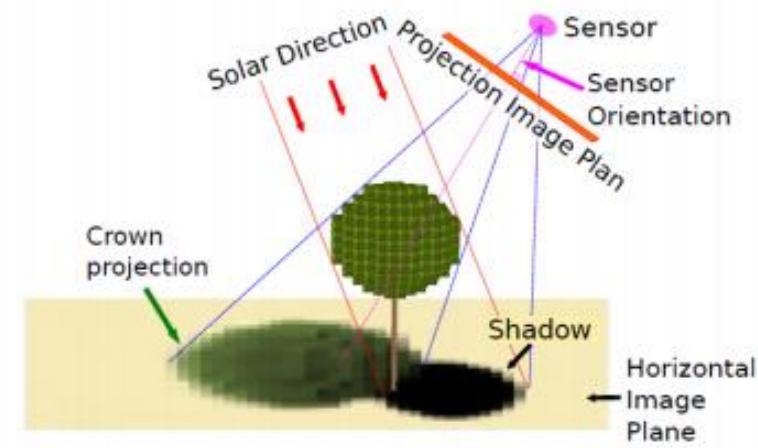
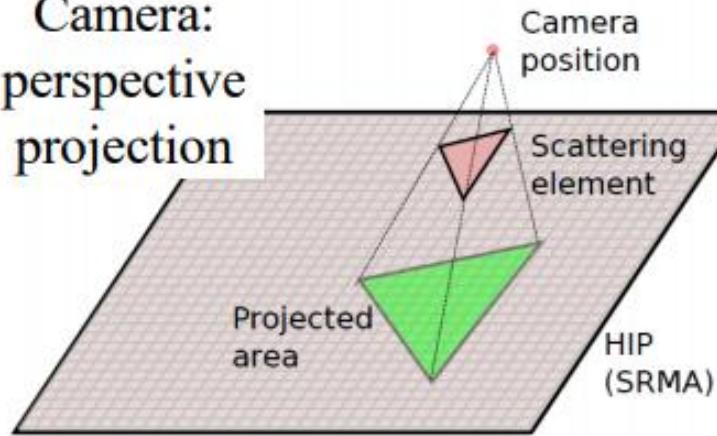


The ground sampling distance off-nadir is larger than in nadir (& lower spatial resolution, higher distortions).

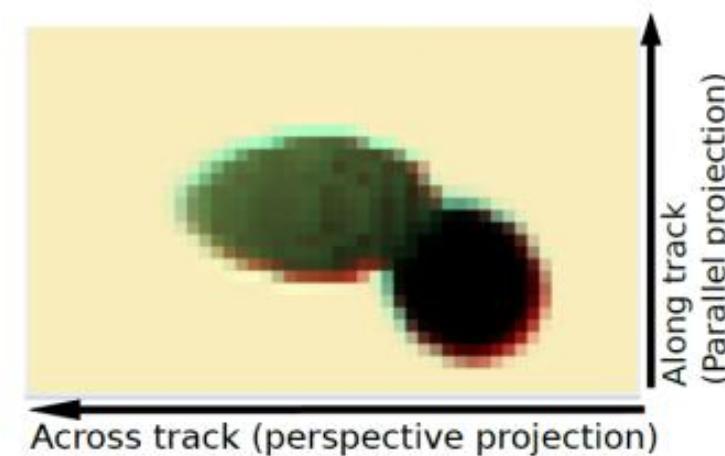
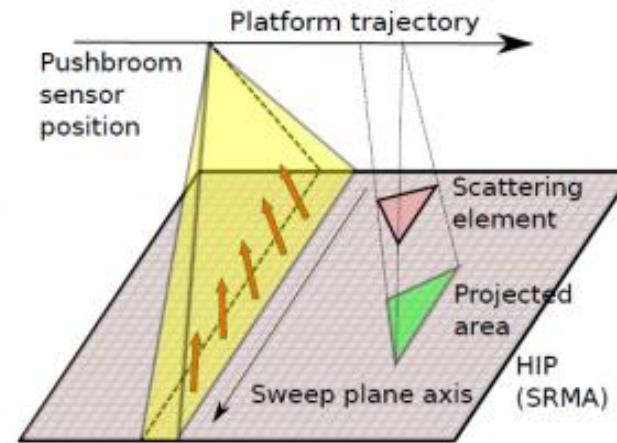


Source:
https://link.springer.com/chapter/10.1007%2F978-1-4020-3100-7_3

**Camera:
perspective
projection**

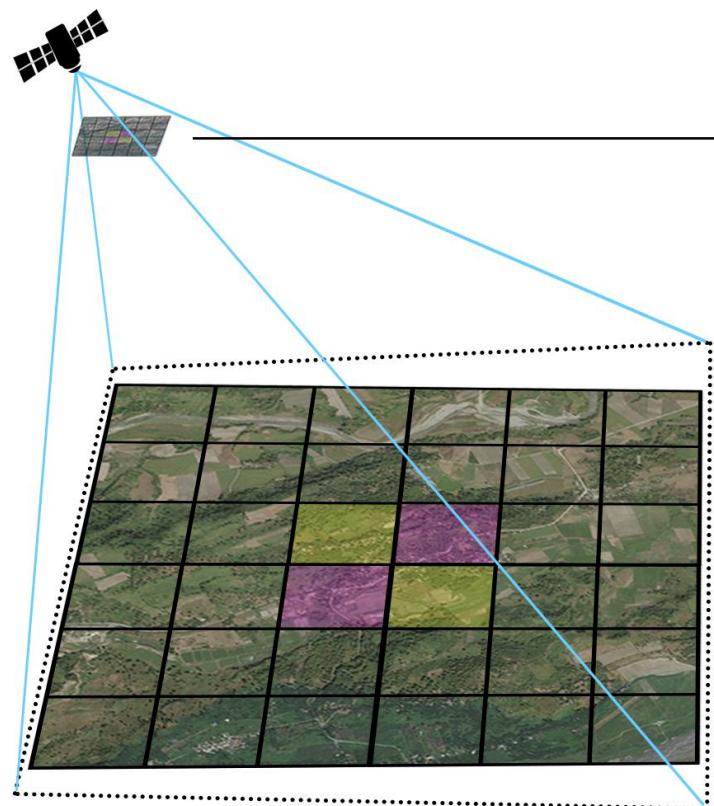


**Pushbroom: parallel-
perspective projection**



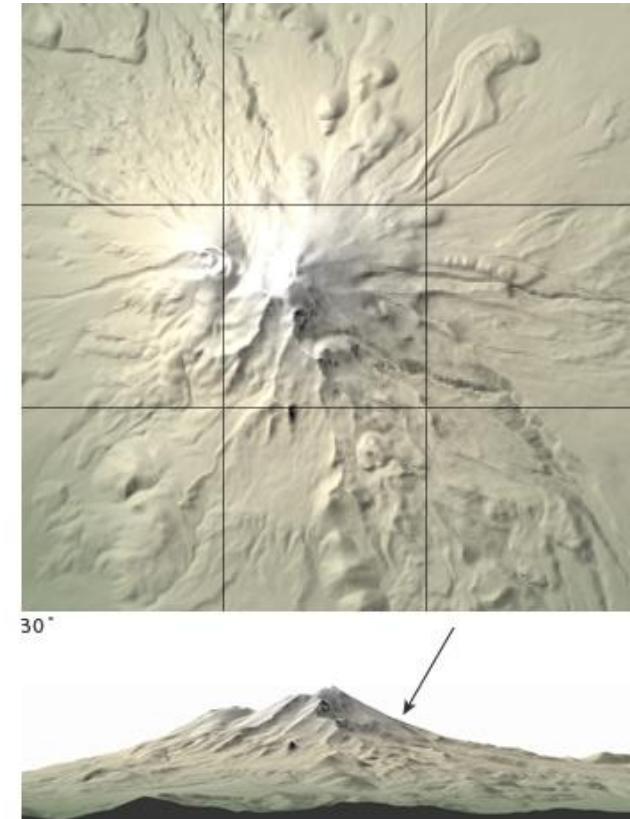
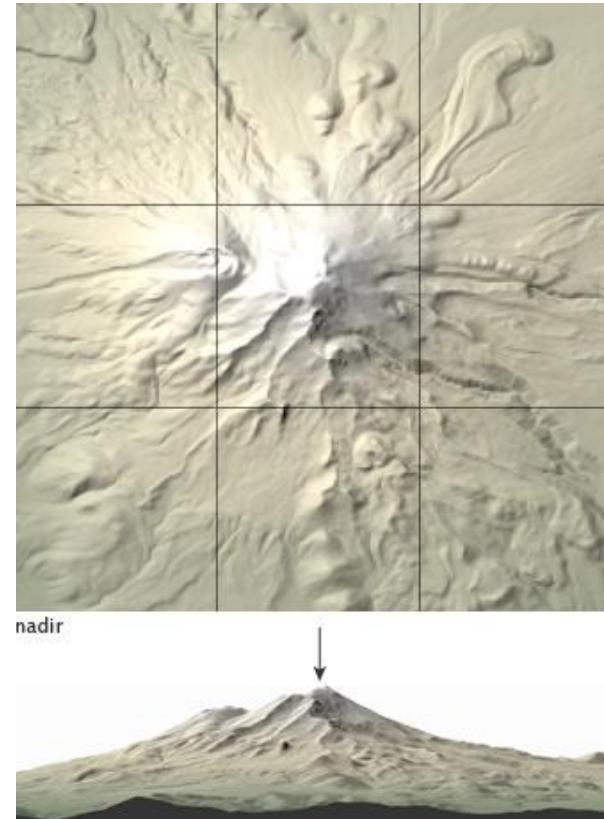
Non-zero FOV impacts RS data: geometric distortion + view direction difference

PERSPECTIVE DISTORTION

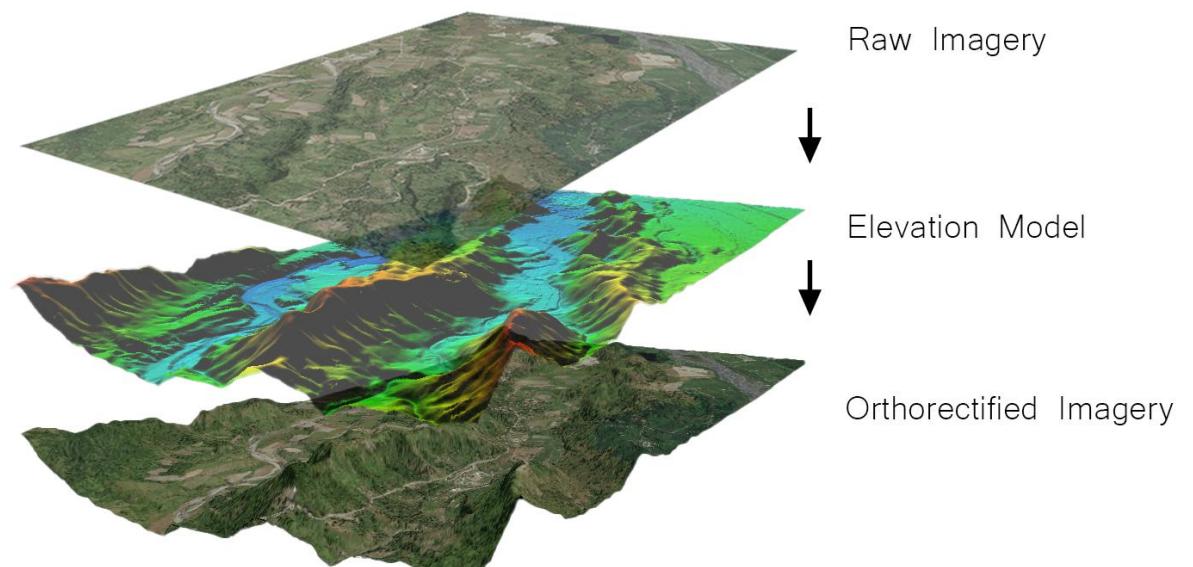
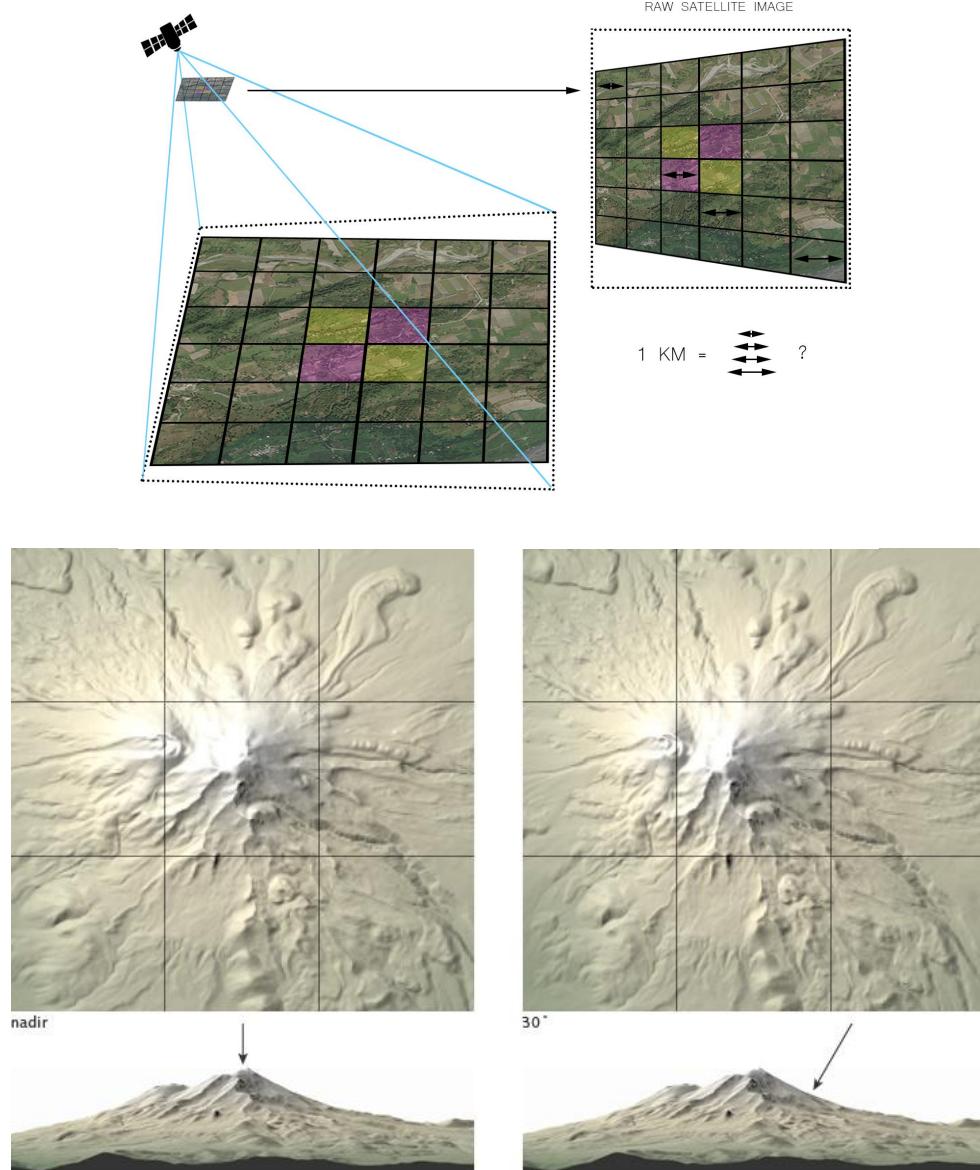


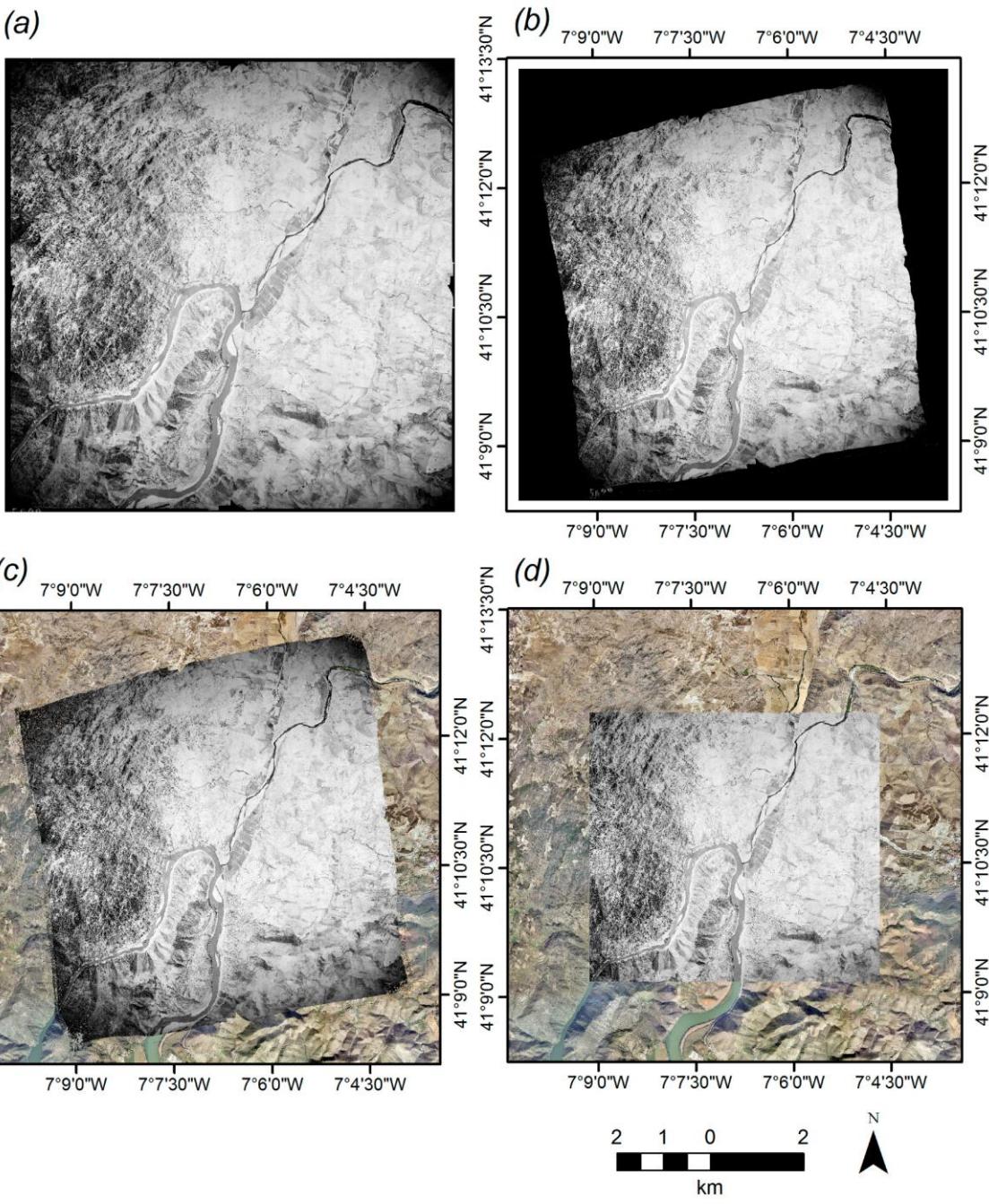
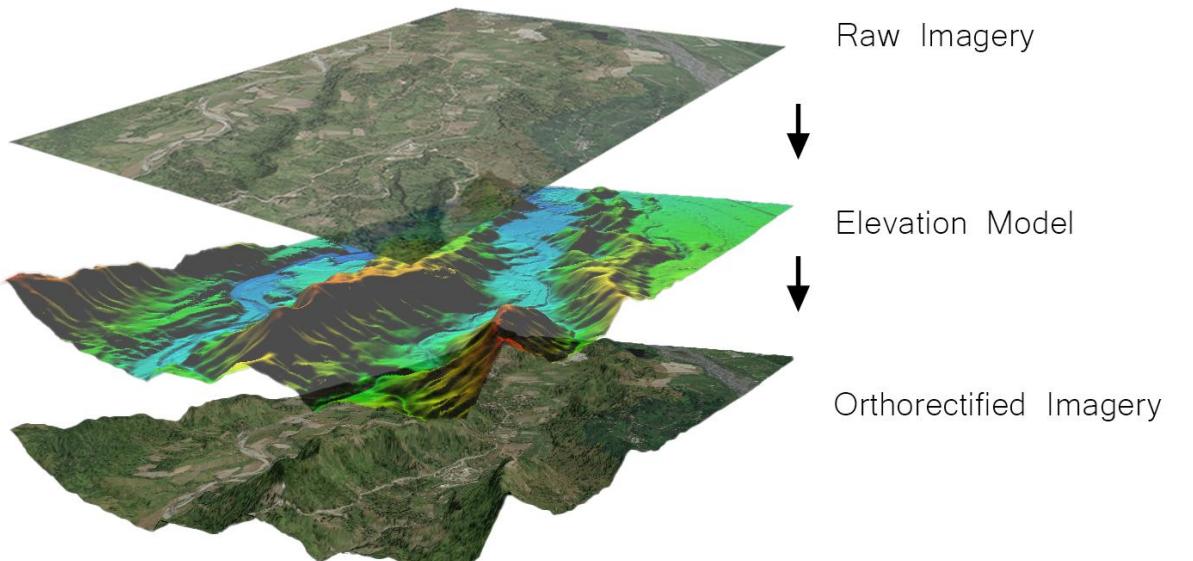
RAW SATELLITE IMAGE

$$1 \text{ KM} = \begin{array}{c} \leftrightarrow \\ \leftrightarrow \\ \leftrightarrow \end{array} ?$$

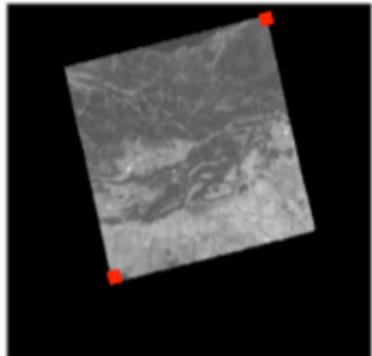


PERSPECTIVE DISTORTION

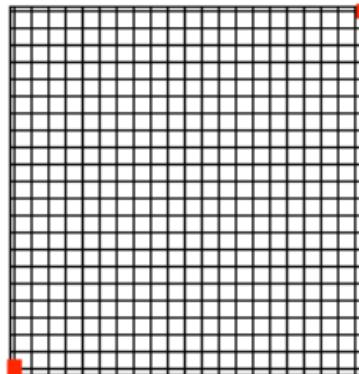
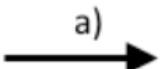




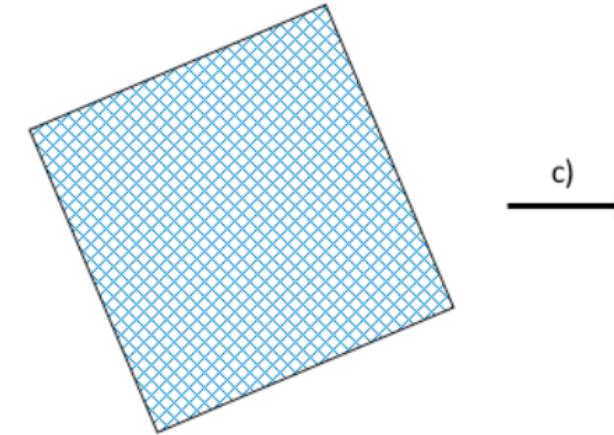
L1B → L1C. Orthorectification



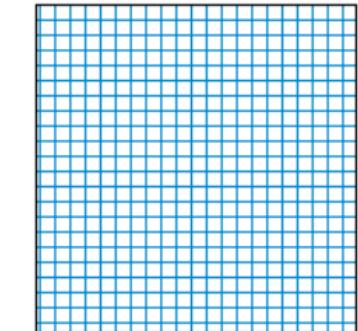
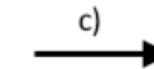
Geodetic Level-1b image



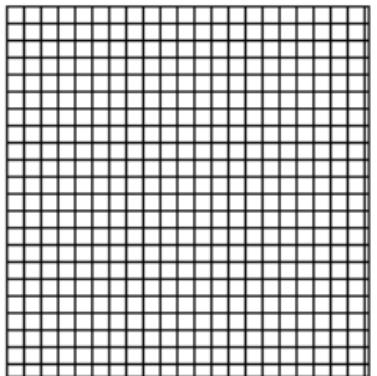
Tile Grid limited by the Level-1b image coordinates in UTM coordinates



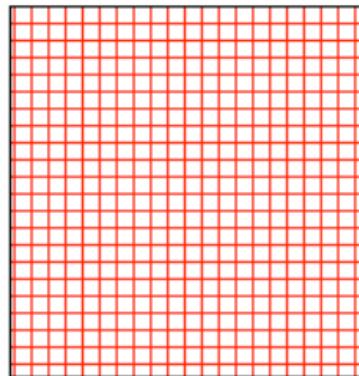
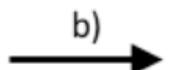
Geodetic Level-1b image



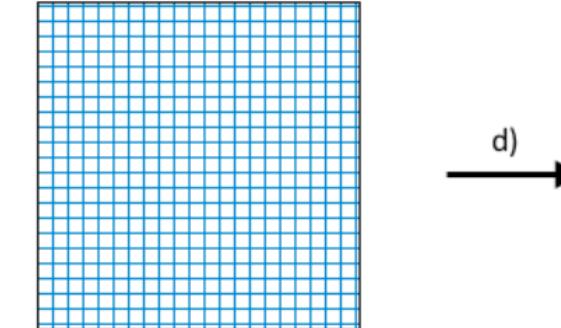
Projection of the Level-1b image onto the Tile Grid in longitude and latitude coordinates



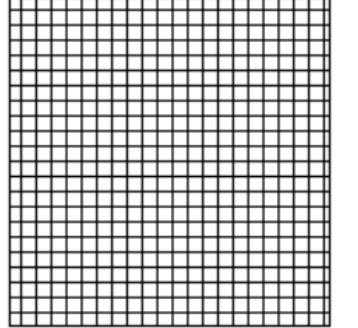
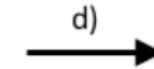
Tile Grid in UTM coordinates



Tile Grid in longitude and latitude coordinates in degrees



Level-1b image projected onto the Tile Grid in longitude and latitude coordinates. Level-1c image in latitude and longitude



Final Level-1c image in UTM coordinates

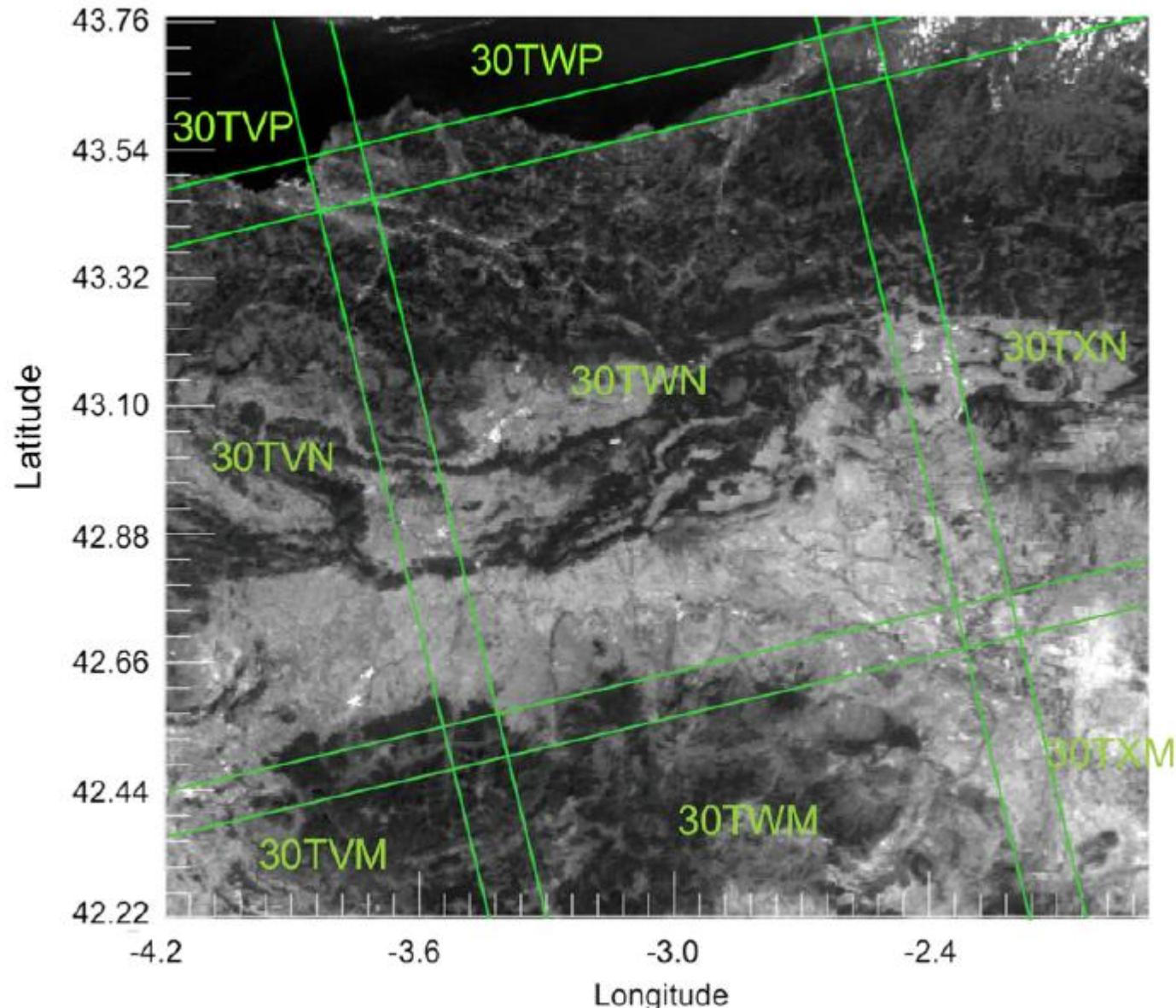
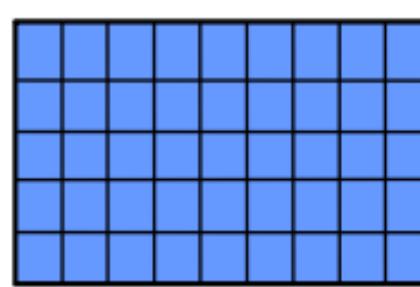
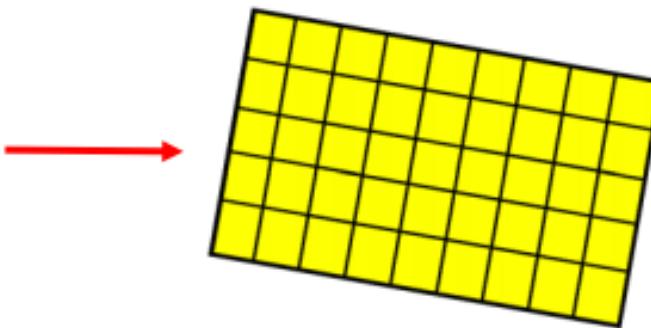


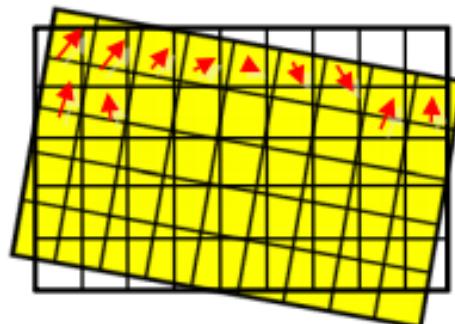
Figure 7: Sentinel-3a SLSTR image with the MGRS tiles over plotted.



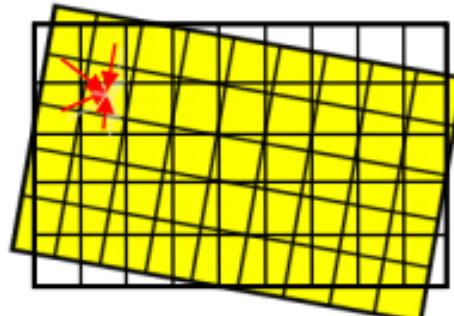
Original image



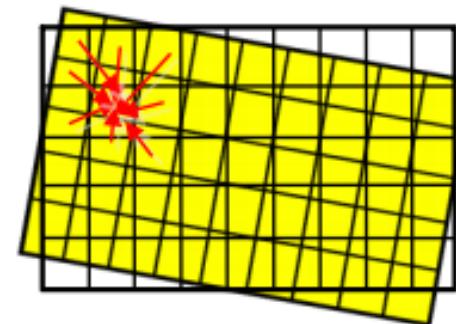
Corrected Image



Nearest neighbour



Bilineal interpolation

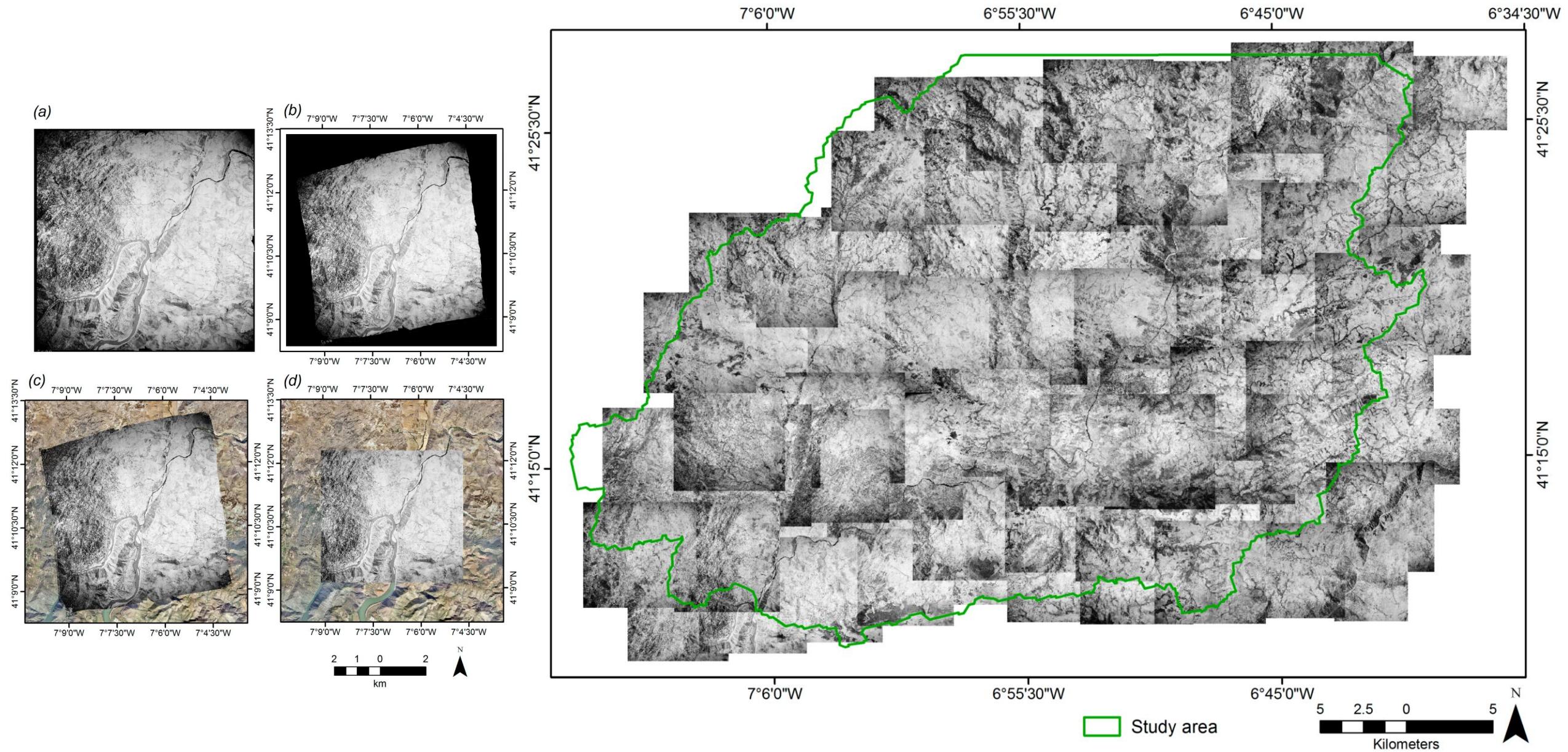


Cubic convolution

Co-registration

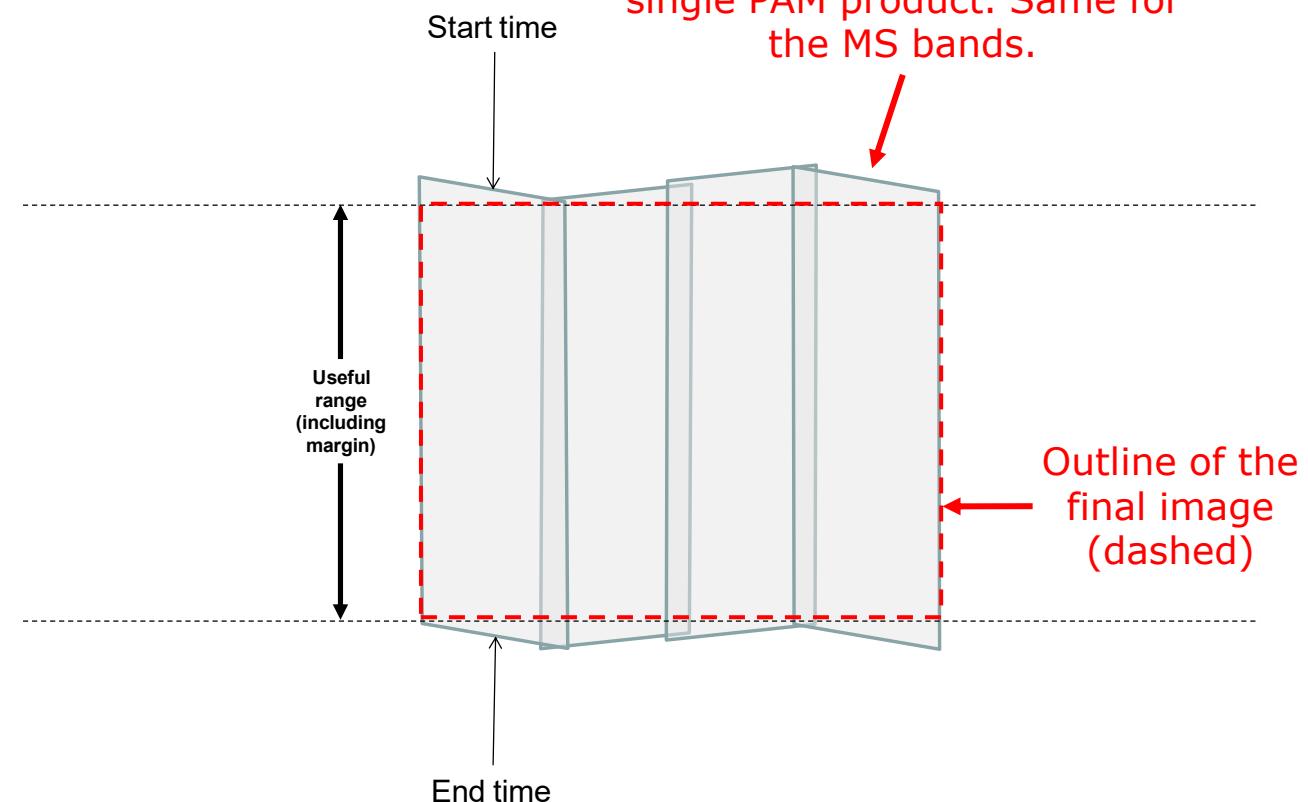
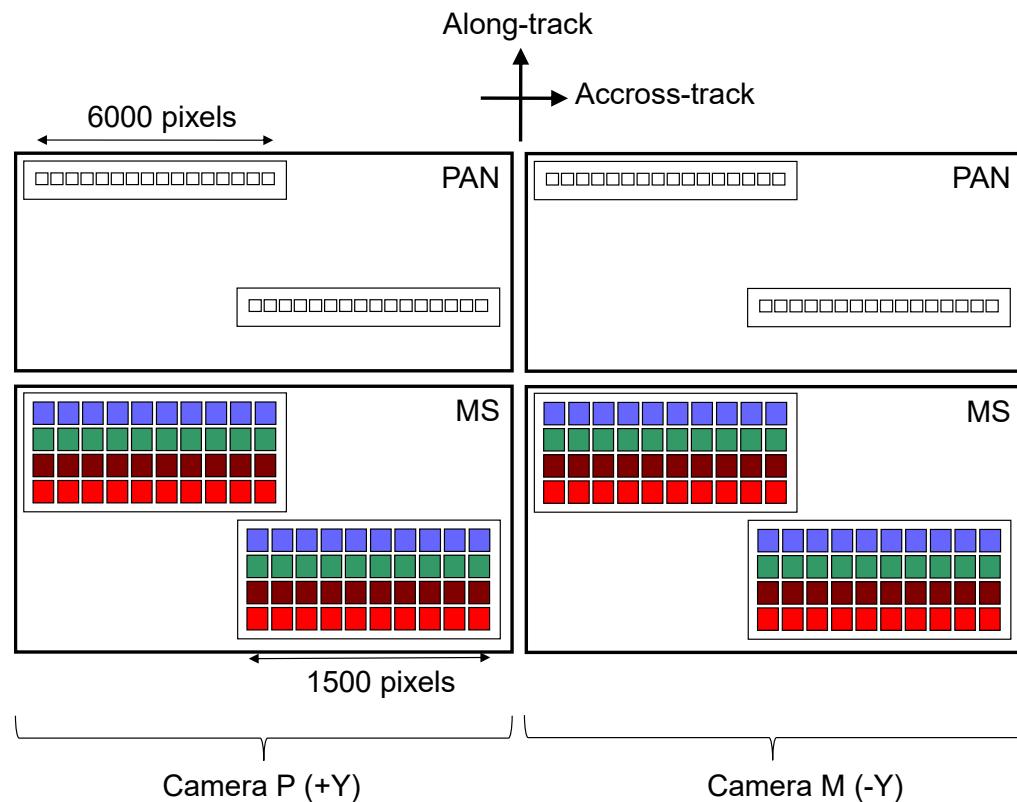
This example shows the composition of two Sentinel-2 images from different satellite passes (different temporal acquisitions).





Inter channel co-registration

Diagram showing the coregistration for SEOSAT, which has four detector lines each for the PAN and MS blue, green, red and NIR.



Each of the detector lines produces an image, so there will be 4 PAN images, 4 MS BLUE images, etc. The 4 PAN images will be co-registered to produce a single PAM product. Same for the MS bands.

Outline of the final image (dashed)

LEVELS OF DATA PROCESSING



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Levels of data processing

There is only a loose convention of the data processing levels, so each mission & instrument tweaks and defines its own levels. However, the conventions follows approximately the following data levels for **ESA** projects.

- **Level-0**

Uncompressed, time sorted and annotated data from Instrument Source Packet (ISP).

Missing and duplicate packets removed. Some quality checks are performed.

- **Level-1A**

The **digital values** are transformed into **physical units** (for example radiances).

Calculation of the geolocation for each pixel appended to the product. Orthorectification (geometrical calibration) can be calculated at this stage or in Level-1B.

Radiometric calibration calculated and appended (not applied). Some calibration steps can also be performed at L1B.

Levels of data processing

- **Level-1B**

The **calibration** coefficients are applied. This is generally the highest level of „true” physical variables that can be obtained.

This is usually the level of data the scientists want because it has not been interpolated or further processed. This is also the lowest level of data commercially available (Landsat, Sentinel, etc.)

- **Level-1C**

Resampling to a reference equally-spaced grid.

Co-registration of the bands (if there are several sensors, compose the whole image).

Levels of data processing

- **Level-2**

Geophysical variables, the goal of the mission (for example „evapotranspiration”).

- **Level-3+**

Level-3 and higher products are derivatives, for example, time series, global maps, etc.

Example L0 to L1C of the LSTM

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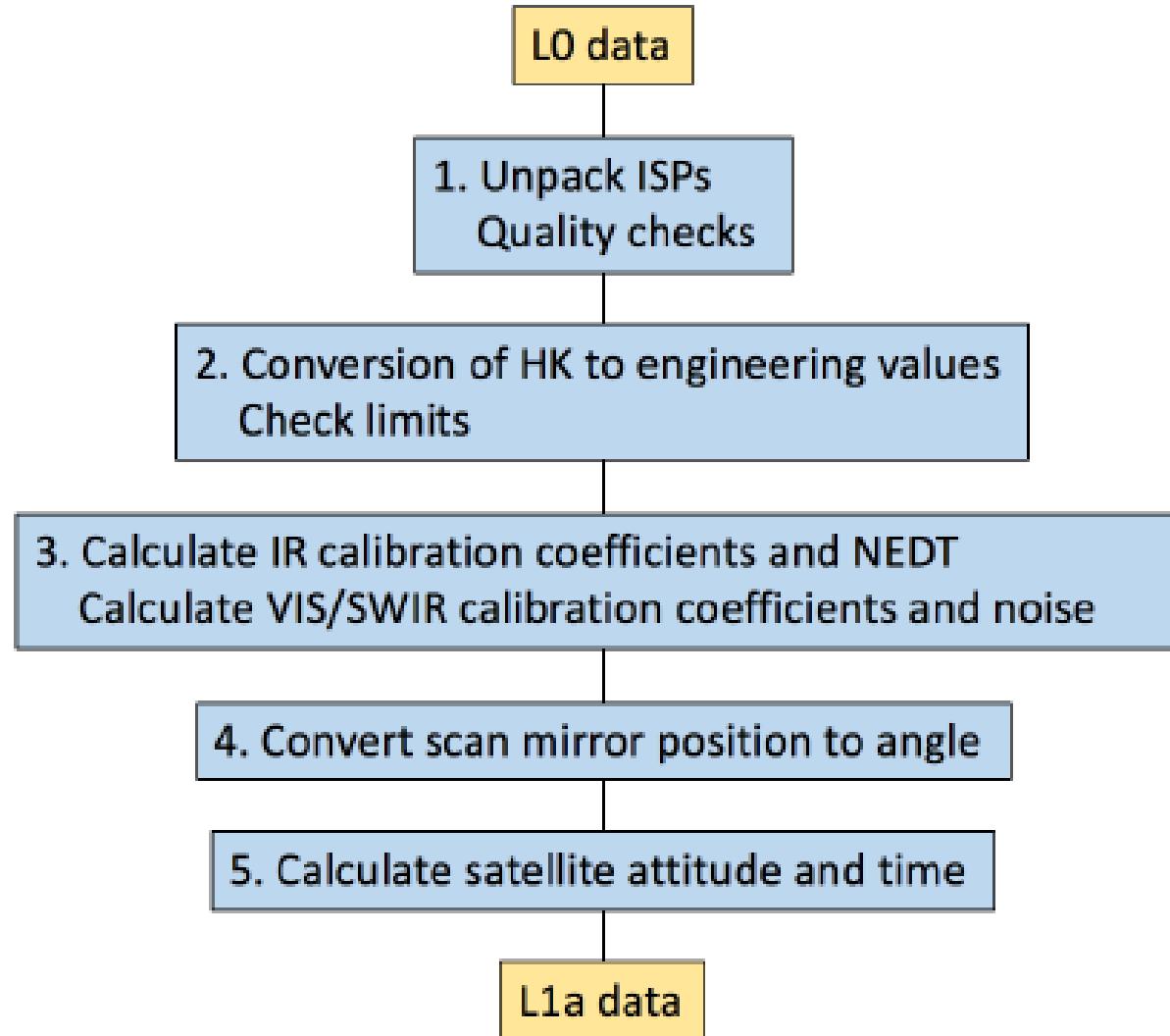


Figure 1: Level-0 to Level-1a processing steps.

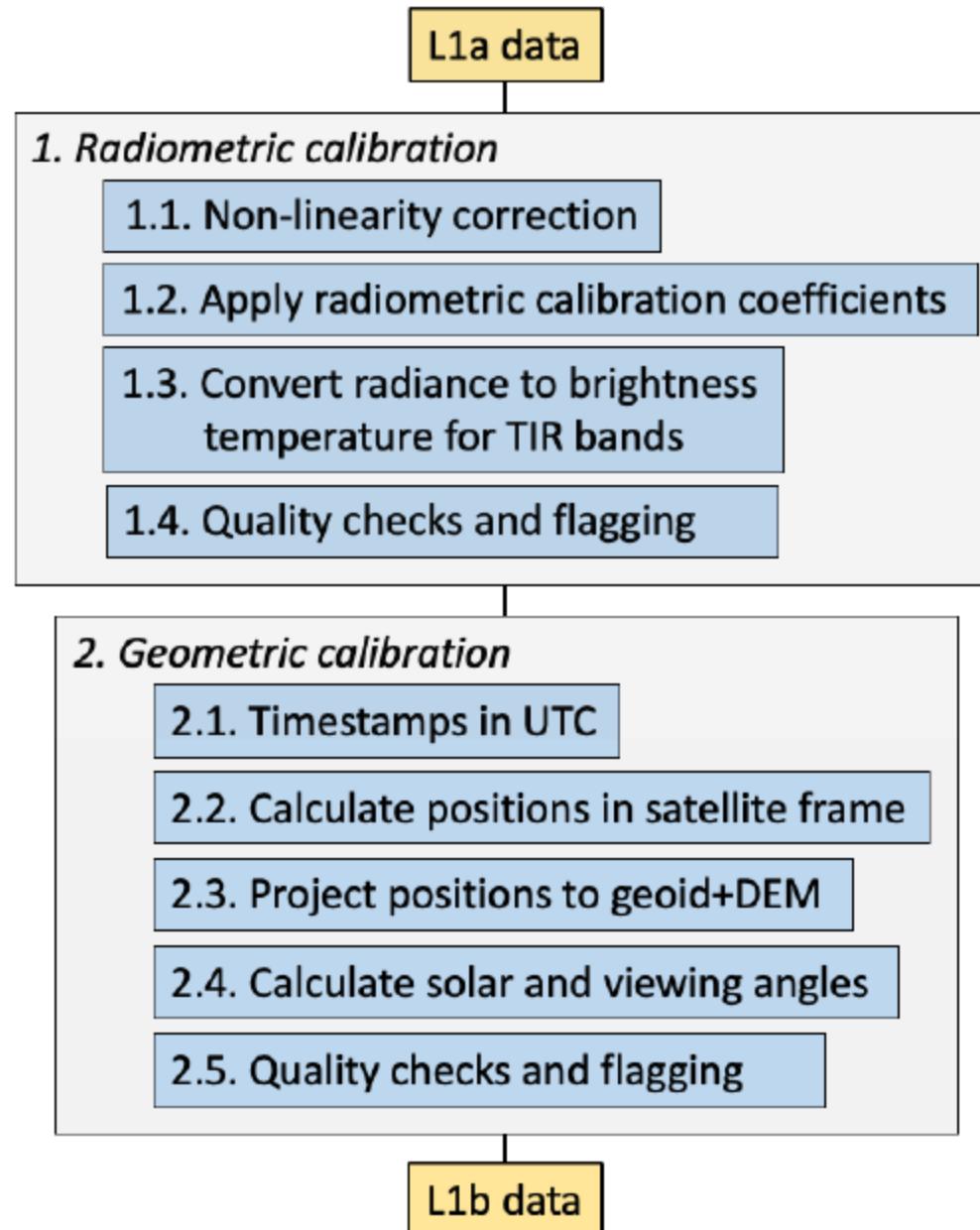


Figure 2: Level-1a to Level-1b processing steps.

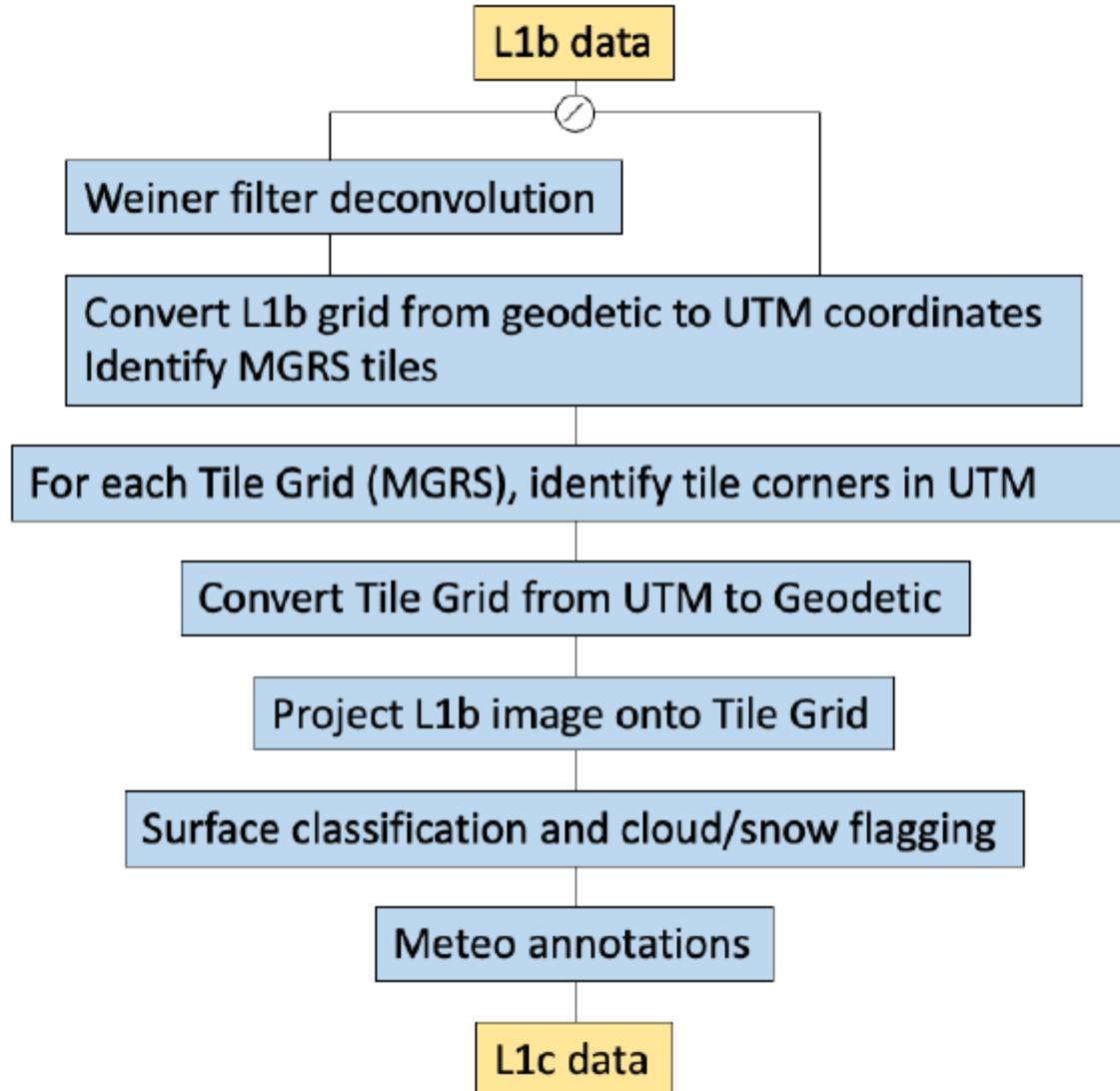
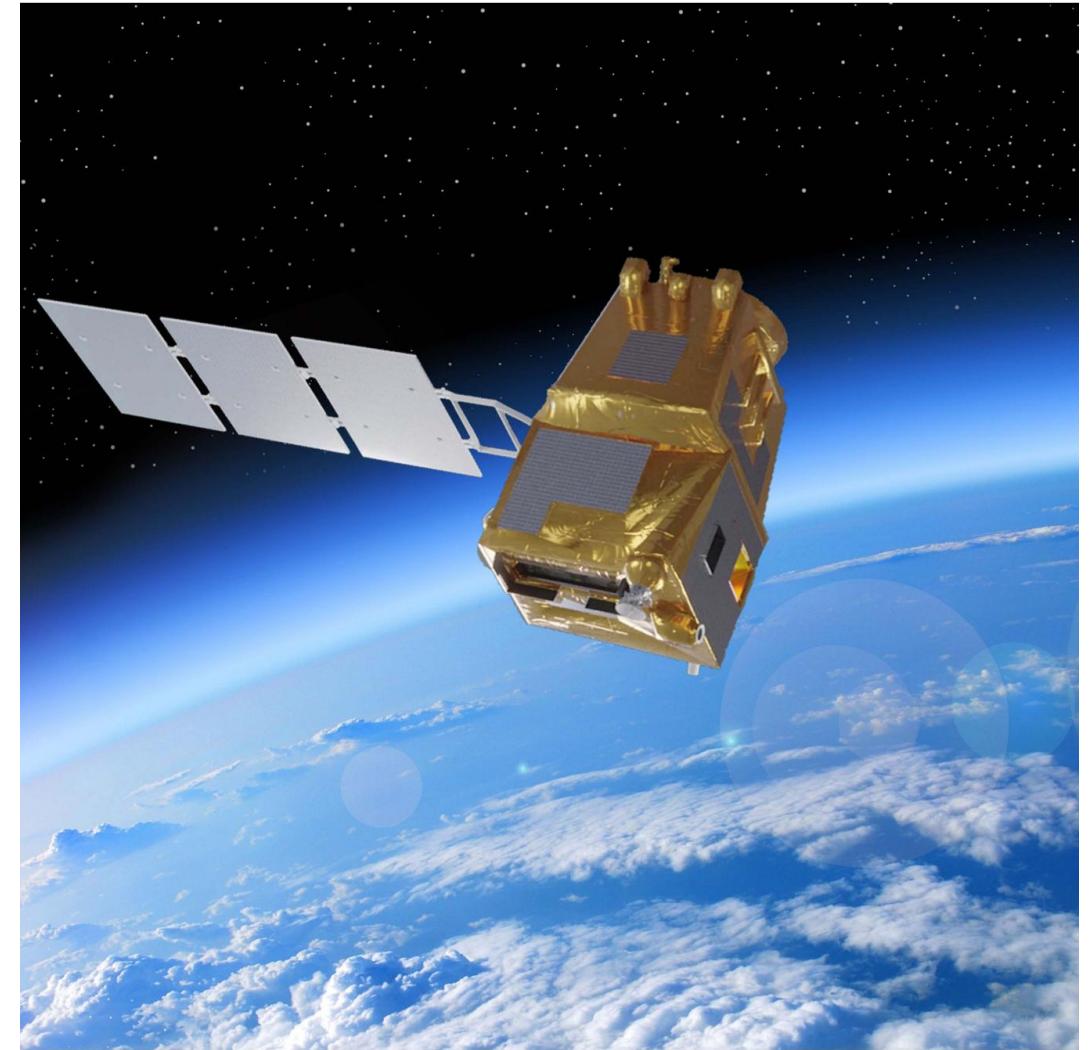


Figure 3: Level-1b to Level-1c processing steps.

ⓘ NASA's data levels

Data Level	Description
Level 0	Reconstructed, unprocessed instrument and payload data at full resolution, with any and all communications artifacts (e.g., synchronization frames, communications headers, duplicate data) removed. (In most cases, NASA's EOS Data and Operations System [EDOS] provides these data to the Distributed Active Archive Centers [DAACs] as production data sets for processing by the Science Data Processing Segment [SDPS] or by one of the Science Investigator-led Processing System [SIPS] to produce higher-level products.)
Level 1A	Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (e.g., platform ephemeris) computed and appended but not applied to Level 0 data.
Level 1B	Level 1A data that have been processed to sensor units (not all instruments have Level 1B source data).
Level 2	Derived geophysical variables at the same resolution and location as Level 1 source data.
Level 3	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
Level 4	Model output or results from analyses of lower-level data (e.g., variables derived from multiple measurements).

PAYLOAD DATA GROUND SEGMENT



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Ground Segment

The ground segment includes:

- **The Flight Operations Segment (FOS)** – Responsible for all flight operations of the spacecraft including monitoring and control, execution of all platform activities and commanding of the payload schedules.
- **The Payload Data Ground Segment (PDGS)** – The PDGS is responsible for payload and downlink planning, data acquisition, processing, archiving and downstream distribution of the satellite data, while contributing to the overall monitoring of the payload and platform in coordination with the FOS.
- In ESA, the FOS is located in ESOC (Germany) and the PDGS in ESRIN (Italy).

Payload Data Ground Segment (PDGS)

The PDGS is constituted by:

- The **Ground Stations** that receive the source packets from the satellite. The data is sent to ground to two type of stations:
 1. Telemetry, Tracking and Control (TT&C) ground stations ☐ HKTM data. Uses the S-band.
 2. Mission Data Acquisition (MDA) ground stations ☐ payload data. Uses the X-band to download the data.
- **Mission Operations Facility** ☐ in charge of the satellite and mission operations and flight dynamics.
- **Instrument Processing Facilities (IPF)** ☐ Performs the Level-1 processing. The IPF is called the „operational”. There is an IPF per instrument on board of the Satellite. The PDGS manages the data from the several payloads and the processing in the different IPFs.
- **Level-2 Processing Facility (L2PF).**

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▪ Payload Data Ground Segment (PDGS)

The Payload Data Ground Segment (PDGS) is responsible for exploitation of instrument data: generation, archiving and dissemination of Level-1B and Level-2 products to the user community. The PDGS is operated from DLR, the German Aerospace Center, in Oberpfaffenhofen, Germany.

The main tasks performed by the PDGS are:

- The reception of the S/X-band acquisition timeline from the FOS and planning of the S/X-band downlink.
- The acquisition of the instrument measurement data and the recorded satellite housekeeping telemetry data from the S/X-band ground station and the ingestion of the data into the processing chain.
- The systematic and data driven provision of received S-band telemetry to the FOS.
- The systematic and data driven generation of Level-0, Level-1 and Level-2 science products in NRT and offline (see [Data Products](#) section).
- The on-request re-processing of science data if needed.
- The archiving of all products and associated auxiliary data.
- The provision of access to SENTINEL-5P products from the PDGS archive to SENTINEL-5P end users.
- The interface to external auxiliary data providers for the reception of data required to generate the SENTINEL-5P products.
- Interfacing to the multi mission Copernicus facilities to ensure coherency of user services between the Sentinel missions.

SENTINEL-5P/TROPOMI products are provided to the user through online access.

Figure 1 shows a schematic of the PDGS functionalities and its interfaces with the other facilities of the core ground segment.

Missions

Missions Home

[Sentinel-1](#)[Sentinel-2](#)[Sentinel-3](#)[Sentinel-4](#)[Sentinel-5](#)[Sentinel-5P](#)

Satellite Description

Ground Segment

Core Ground Segment

[Payload Data Ground Segment \(PDGS\)](#)[Flight Operations Segment \(FOS\)](#)

Instrumental Payload

Data Products

Mission Status

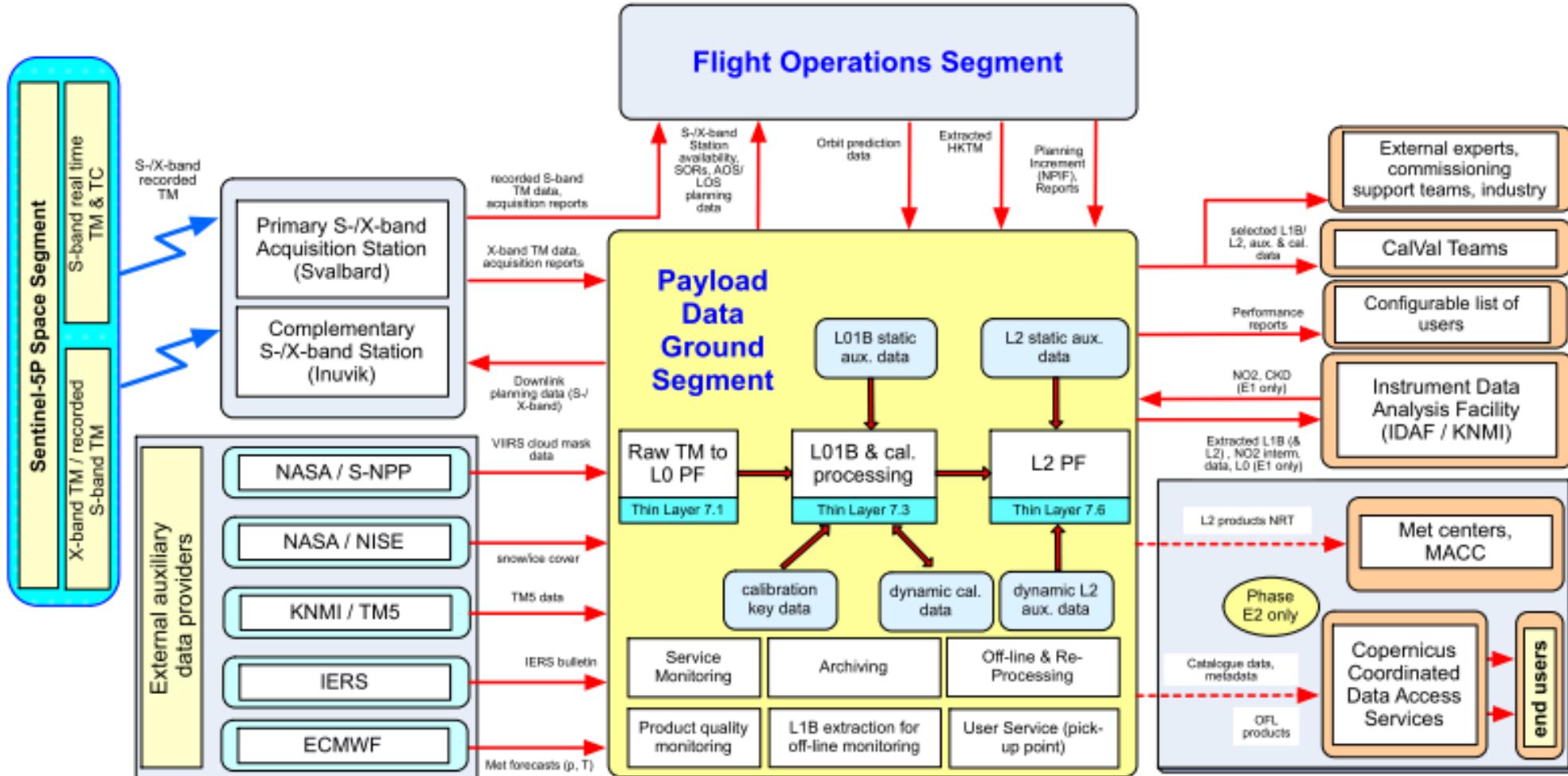
Commissioning/Ramp-up Phase

Collaborative Ground Segment

International cooperation

▪ Key Resources

[Copernicus Sentinel Data Access](#)





MTG GROUND SEGMENT

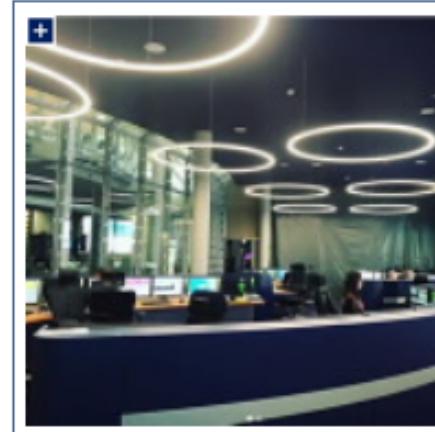
SATELLITES
CURRENT SATELLITES
FUTURE SATELLITES
METEOSAT THIRD GENERATION
MTG IMAGING SERVICE
MTG SOUNDING SERVICE
MTG DESIGN
MTG DATA
EVOLUTIONS TO EUMETCAST SERVICES FOR THE MTG ERA
MTG IN OPERATIONS
MTG GROUND SEGMENT
MTG RESOURCES
EUMETSAT POLAR SYSTEM -

The Meteosat Third Generation Ground Segment will acquire data from all the MTG satellites, and generate, archive and distribute the products.

It will also provide the capabilities to command and control the satellites and the ground segment itself.

The ground segment consists of:

- The Telemetry, Tracking and Control (TT&C) ground stations — the TT&C interface between the Space Segment and the ▶ **Mission Control Centre** (Figure 1).
- The Mission Data Acquisition (MDA) ground stations — the payload data interface between the Space Segment and the Mission Control Centre.
- The Mission Operations Facility (MOF) — provides functions for the preparation, planning and operation of the system, including satellite and mission operations and flight dynamics.
- The Instrument Level 1 Data Processing facilities (IDPF-I and IDPF-S) — these extract the measurements from the sensors. They also perform a series of functions for the generation of level 1b data and the processing of level 1c data.
- Level 2 Processing Facility (L2PF), for the extraction of centrally generated products.



On-board Data Processing

On-board payload data processing includes the **data acquisition, selection, compression or reduction** (depending on the specific scenario), as well as their **storage**.

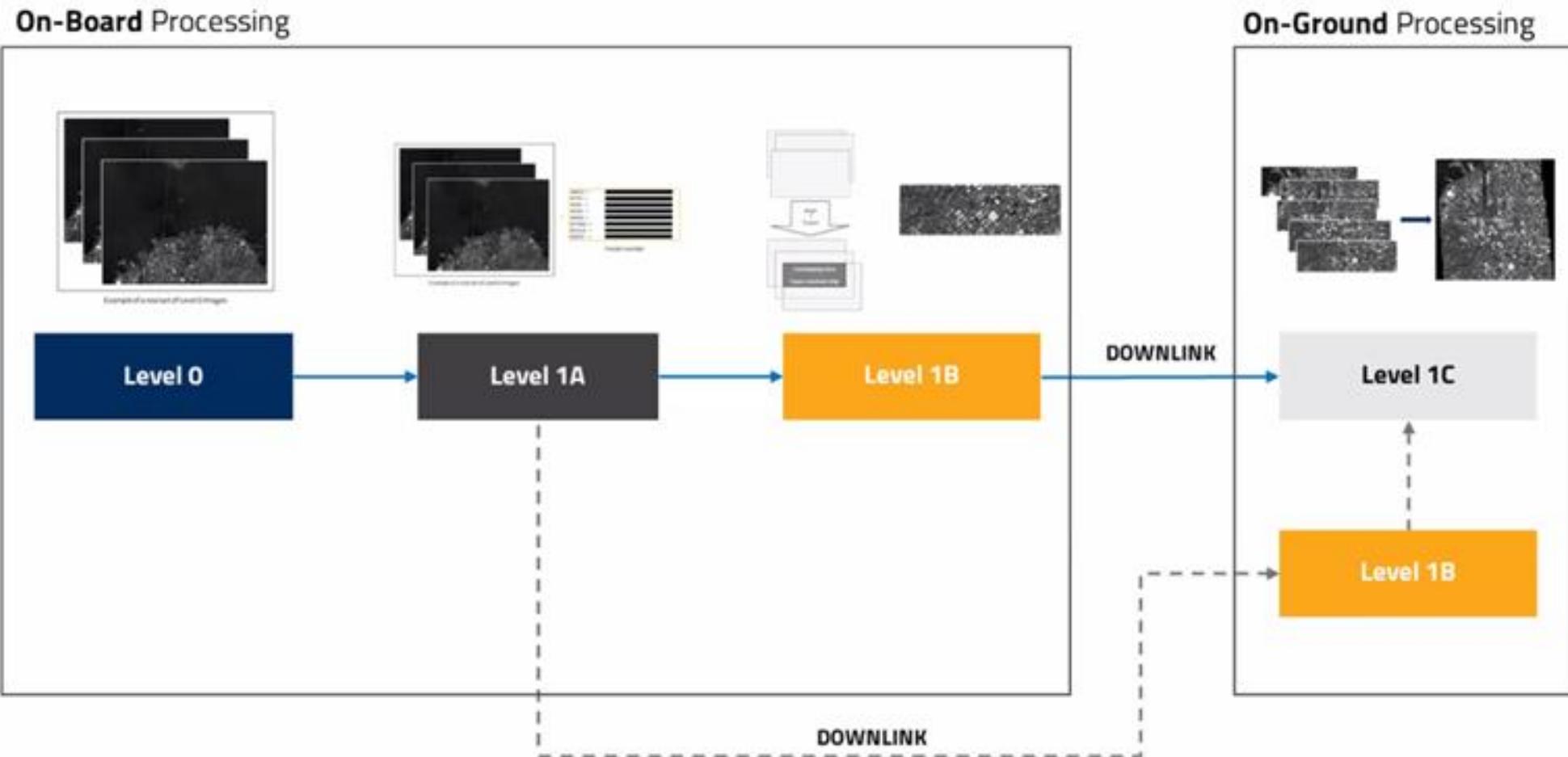
Data acquisition and selection involves gathering pertinent information and analysing it (for instance, removing cloudy images).

Data compression involves changing the method of recording information to minimize redundancy and, effectively, the volume of the data set.

When it comes to **data storing**, currently, the biggest problem is posed by huge amounts of the generated raw data unable to reach Earth quickly due to their size. Consequently, they need to be stored for a long time on board of the satellite, which has limited storage capabilities.

It is crucial to speed up the data analysis if you want to use the downlink throughput most efficiently. One of the most effective solutions are currently **field-programmable gate arrays (FPGAs)**, which, combined with **artificial intelligence**, work much more efficiently, resulting in faster data analysis than before.

On-board Data Processing



END-TO-END SIMULATORS



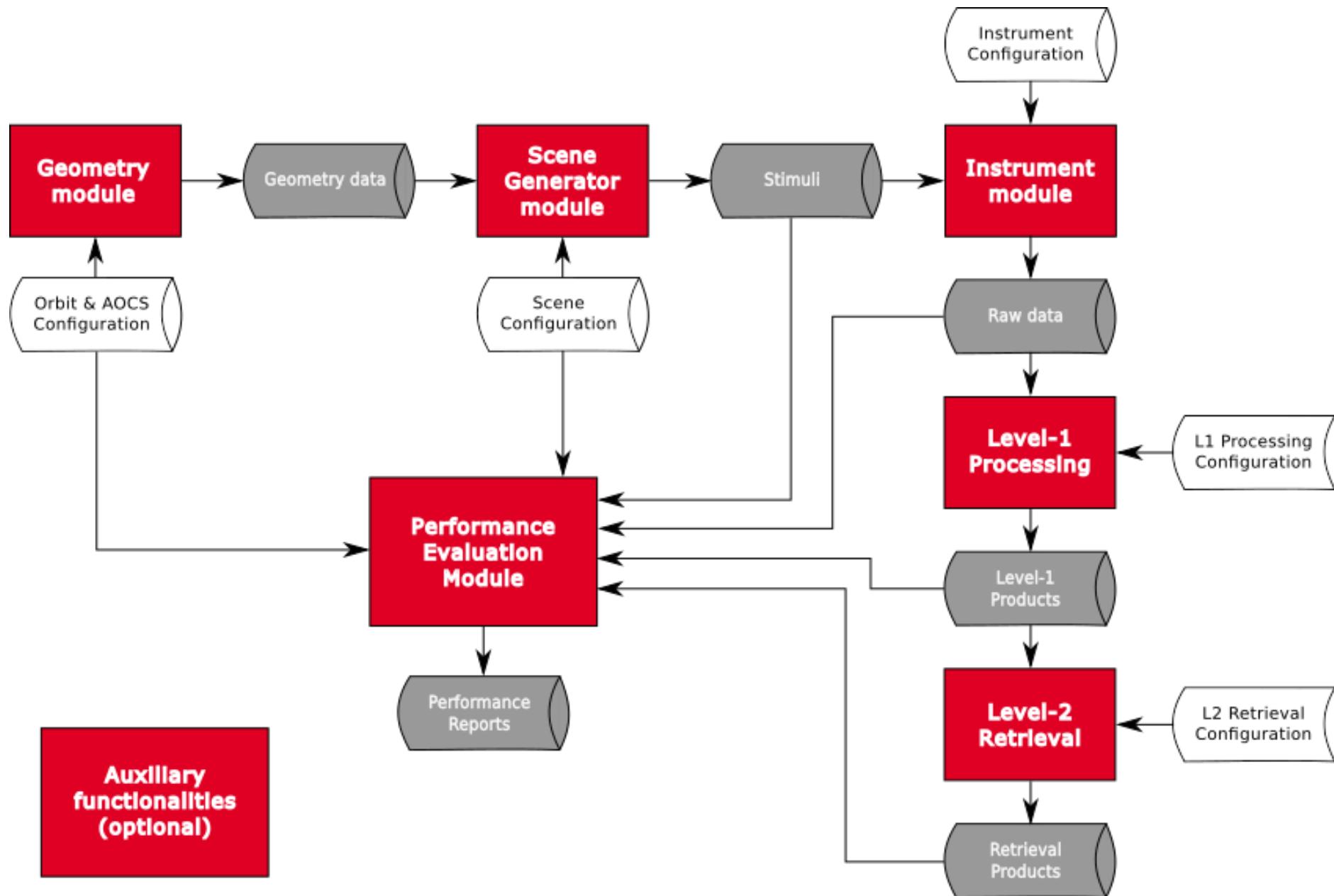
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End-to-End Simulators (E2ES)

- Before we spend several hundred million euros on building a satellite & payload, we want to make sure that a) it works & b) we can process the data to obtain whatever we are looking for ☺ This is why we develop E2ES starting in phase A.
- An End-to-End Simulator is a tool for the engineering and scientific team.
- The **engineering team**, responsible of the instrument, needs the E2ES to:
 - Validate the **instrument performances** – if the instrument responds in the expected way to the input stimuli.
 - Validate the **calibration** strategy. The calibration strategy is essential for the processing. There is typically a calibration programme which includes on-ground calibration campaigns, airborne campaigns and sometimes a proto-flight model of the satellite (e.g. GIOVE-A for the Galileo constellation).
 - **Support** the development of the **operational** processor by providing datasets and for cross-validation.

End-to-End Simulators (E2ES)

- The **scientific team**, responsible of the mission outputs, needs the E2ES to:
 - Validate the retrieval algorithms.
 - Works with the instrument team for the compromise between accuracy and processing time. Right now, that's the core problem in most missions – scientists want maximum accuracy, but the processing times makes it unfeasible, so a certain degradation or simplification of the L1 and L2 algorithms need to be done. An example is the straylight correction in FLEX (on-going...).
- It is composed of the **Instrument Data Simulator (IDS)** and the **Ground Processor Prototype (GPP)**.



Instrument Data Simulator (IDS)

The IDS is in charge of simulating the **space** segment. It simulates the scene, the payload acquisition, and the on-board processing and packetisation. The main three modules are:

1. **Geometry Module** – in charge of simulating the SC orbit and attitude, as well as the generation of the observation geometry of each instrument.
2. **Scene Generator Module** – in charge of simulating the scene to be observed (terrain, ocean or atmosphere) and all environmental effects (radiative transfer models, atmosphere simulation, illumination conditions...) to be considered for the correct generation of the stimuli to be entered to the instrument model.
3. **Instrument Module** – in charge of simulating the sensor behaviour, having different outputs depending on the type of instrument.
4. There can be a 4th module called the **On-board Data Generation Module**, in charge of simulating the on-board processing and packetisation.

Ground Processor Prototype (GPP)

The GPP is in charge of simulating the **ground** segment. It simulates the L0, L1 processing and L2 retrieval. The main two modules are:

- 1. Level-1 Processing Module** – in charge of the generation of level-1 products, from level-1a to level-1c.
- 2. Level-2 Retrieval Module** – in charge of performing the retrieval of the geophysical parameters that are objective of the mission/instrument. Depending on the mission and on its definition of the products, this module would generate level-2 data or products at higher level of processing.
3. Level-3 processing and above are not usually part of the E2ES, as they obtain derivative products.

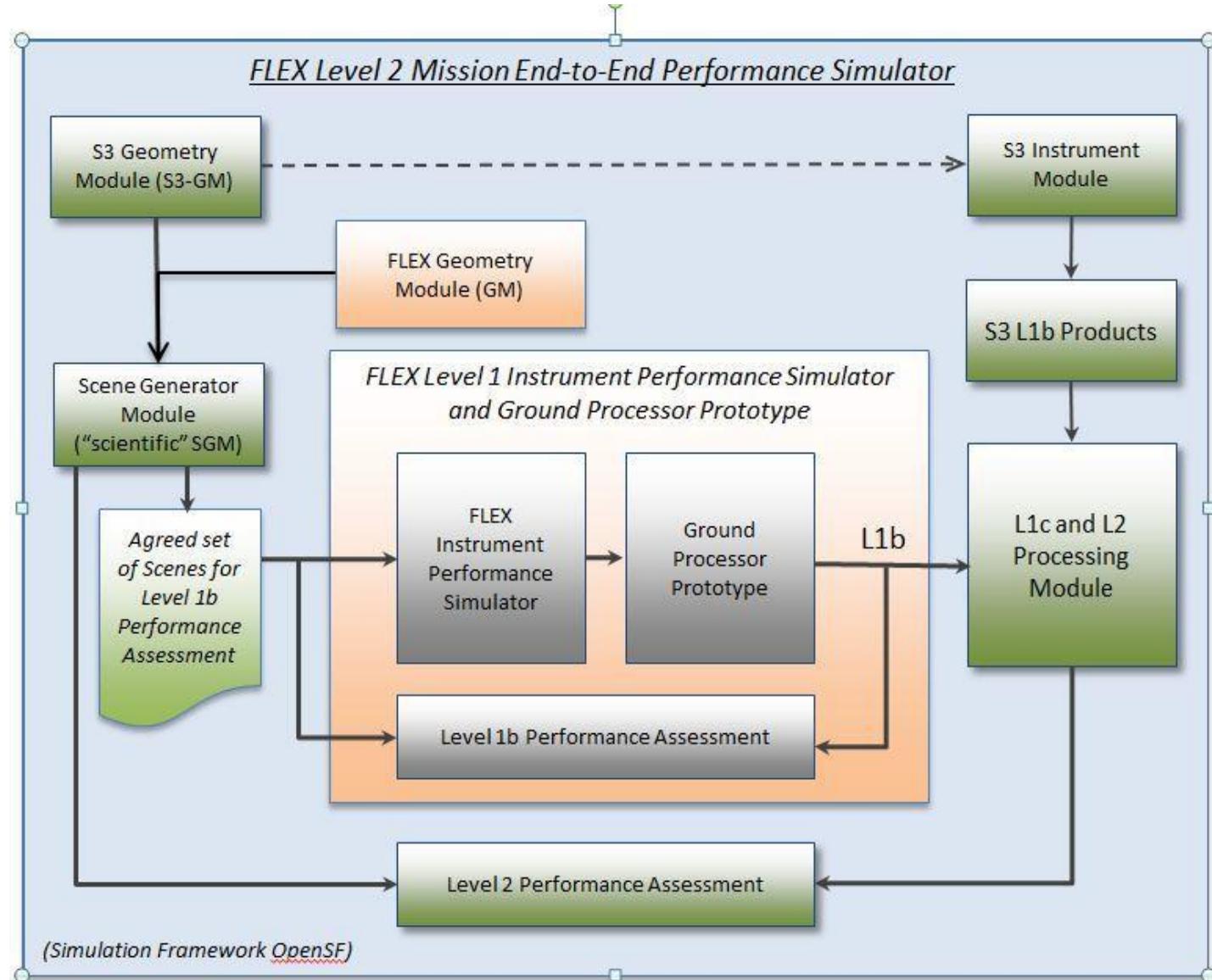
Performance Assessment Module (PAM)

- The PAM is used to verify and validate the instrument and mission requirements.
- Instrument requirements → These requirements are on the payload performance. They specify how well the instrument shall function.
- **Instrument performances** are obtained by comparing :
 - the input of the instrument module, the physical truth. For example, the input radiance that reaches the camera, which is „the truth”;
 - and the outputs of the Level-1 processing, the physical variable retrieved after calibration.

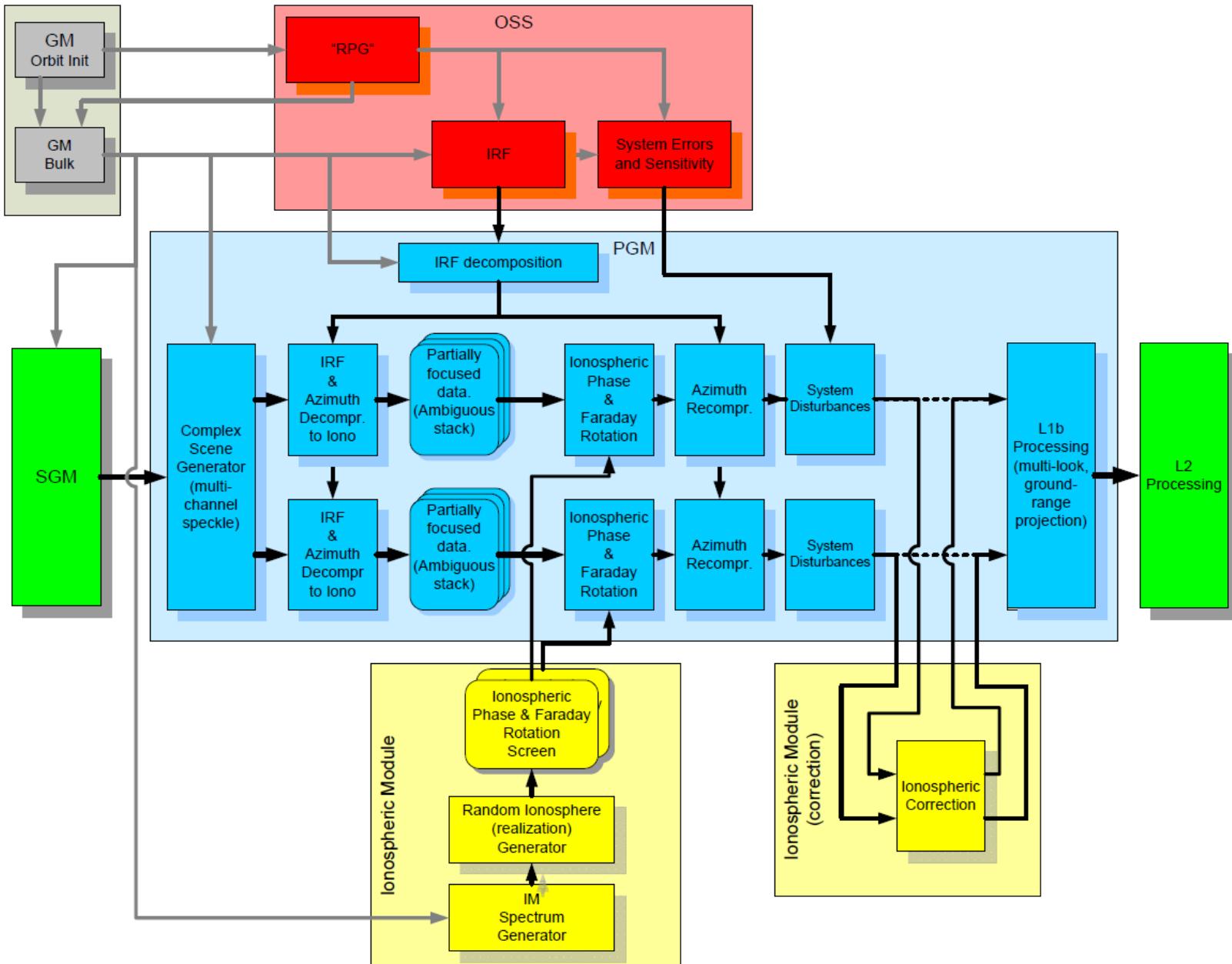
Performance Assessment Module (PAM)

- Mission requirements → These requirements are on the final output of the Level-2 retrieval algorithms, the „science”. They specify what accuracy the outputs shall have.
- **Mission performances** are obtained by comparing:
 - The scene from the Scene Generation Module (the input geophysical variables that feed the forward model).
 - The output of the Level-2 retrieval algorithms.

① FLEX E2ES



① BIOMASS E2ES
 OSS = Observing System Simulator
 PGM = Product Generation Module
 IRF = Impulse Response Function (chirp)



OPERATIONAL PROCESSORS



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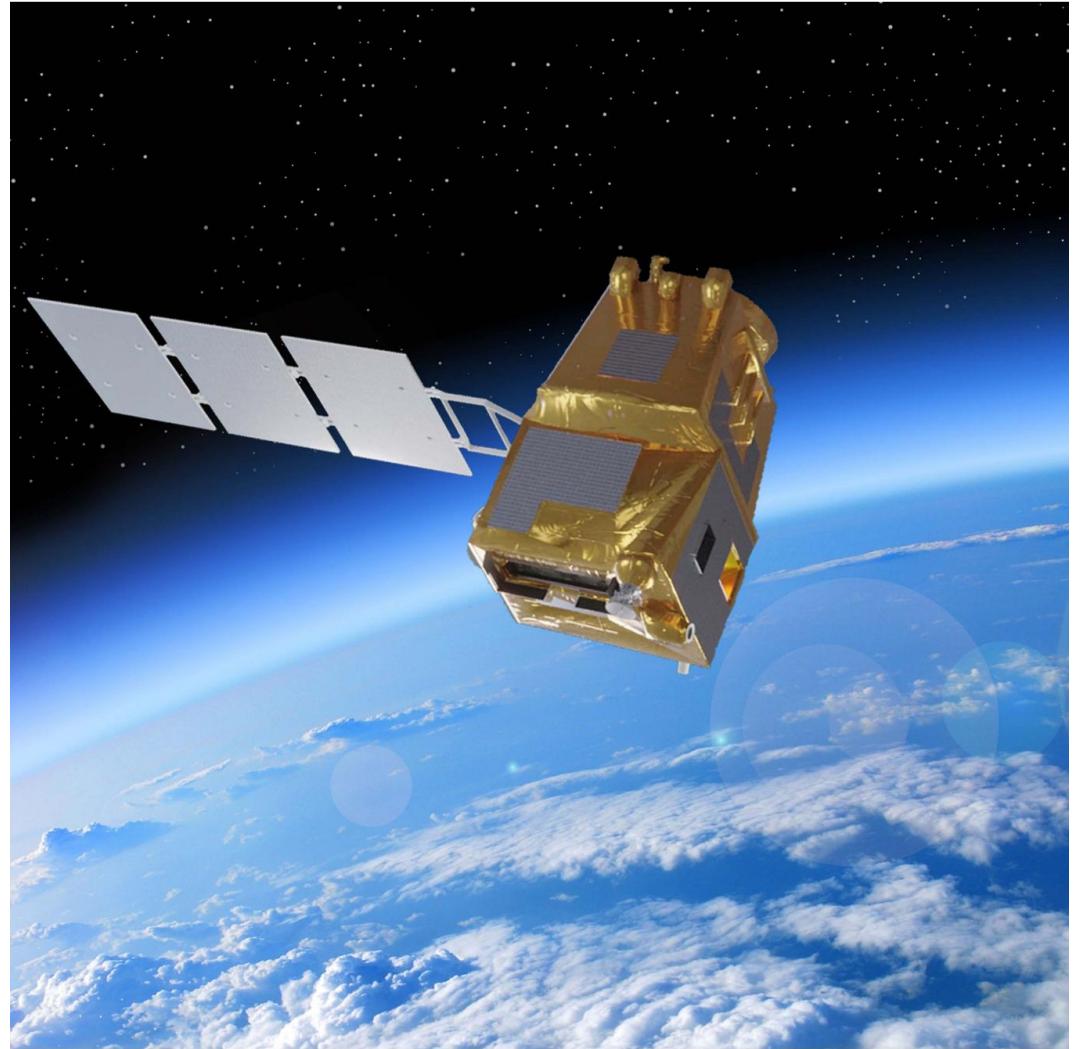
Operational Processors

- The «operational processors» are the actual processors used in the exploitation of the payload data.
- The processing time requirements are very stringent (for near-real time data requests). They also have to manage a continuous data flow of input packets (RAW or L0 packets) provided by the PDGS that come from the Satellite.
- The «operational processors» is basically the chain of elements and tasks used to generate a products.
- The task of operational software processors within the ground segment of an earth observation mission is to generate **fast and continuously predefined products** from the incoming raw data, and work largely without interactive intervention.

Operational Processors

- Operational processors are used to generate data in near-real-time (NRT) and in an off-line mode to produce the highest possible precision.
- For test and development purposes prototype versions evolve at each development level, supporting interactive control and —if required— detailed investigation of single processing steps.
- In the course of a mission, processors and baseline algorithms are continuously updated because of subsequent improvements in instrument calibration and ability to extract predefined and new geophysical parameters from the data. It is not unusual to reprocess the entire data volume of a mission from time to time, using updated state-of-the-art algorithms.

SUMMARY

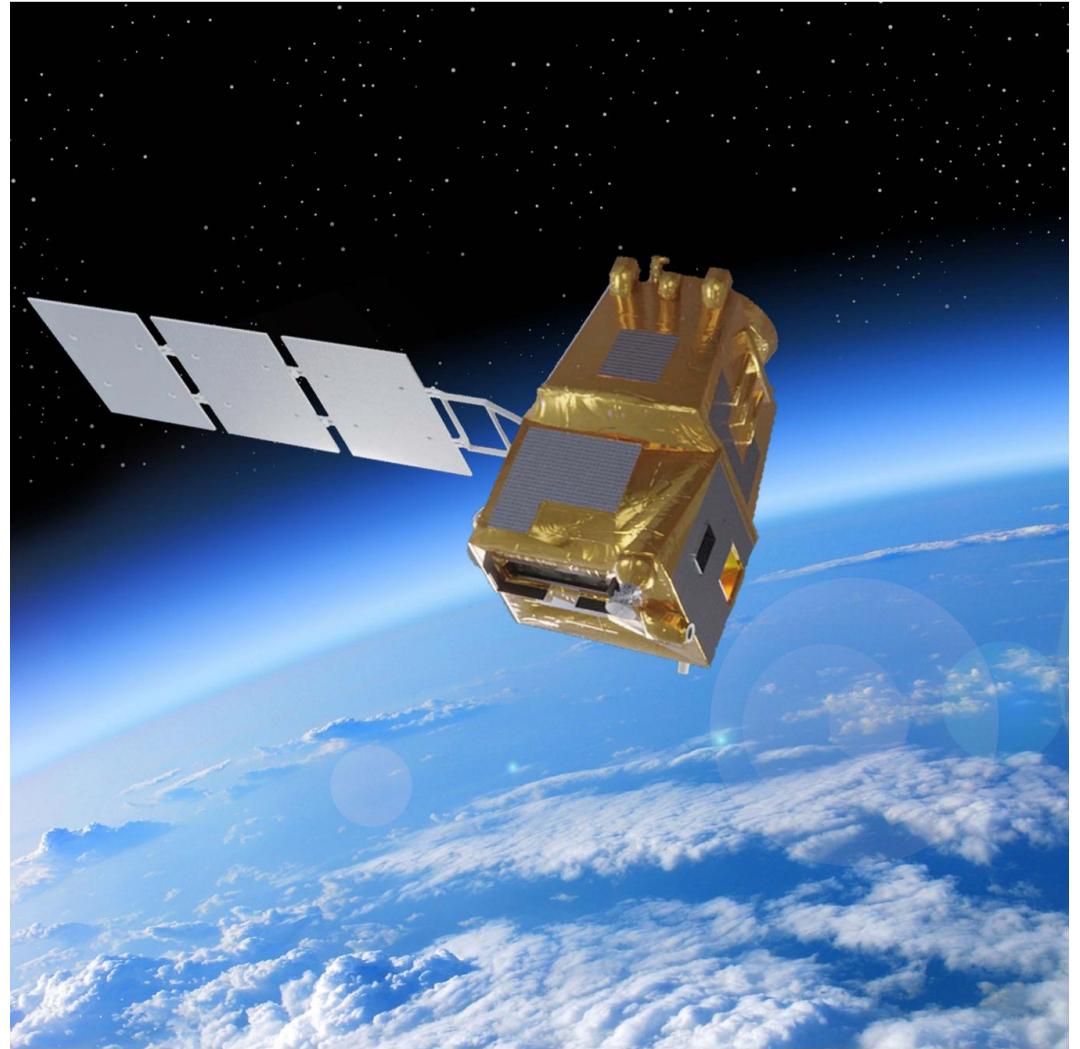


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Take-away points of this topic

- What is calibration, processing, geolocation, a DEM and ISPs.
- Data extraction.
 - Conversion from Digital numbers, to physical units.
 - Correction for the sensor imperfections (radiometric & spectral calibration); geometrical calibration, cloud screening, atmospheric correction, topographic & solar correction ☐ L1B products;
 - Orthorectification, co-registration ☐ L1C products
 - Retrieval ☐ L2 products;
 - Interpretation, classification, analysis ☐ L3 products.
- Levels of Earth Observation data processing: L0, L1A, L1B, L1C, L2, L3.
- Components of the Ground Segment. Components of the PDGS.
- End-to-end simulators. What they are, what are they used for. What is the IDS, GPP and PAM.
- What is an operational processor. What is the difference with the GPP.

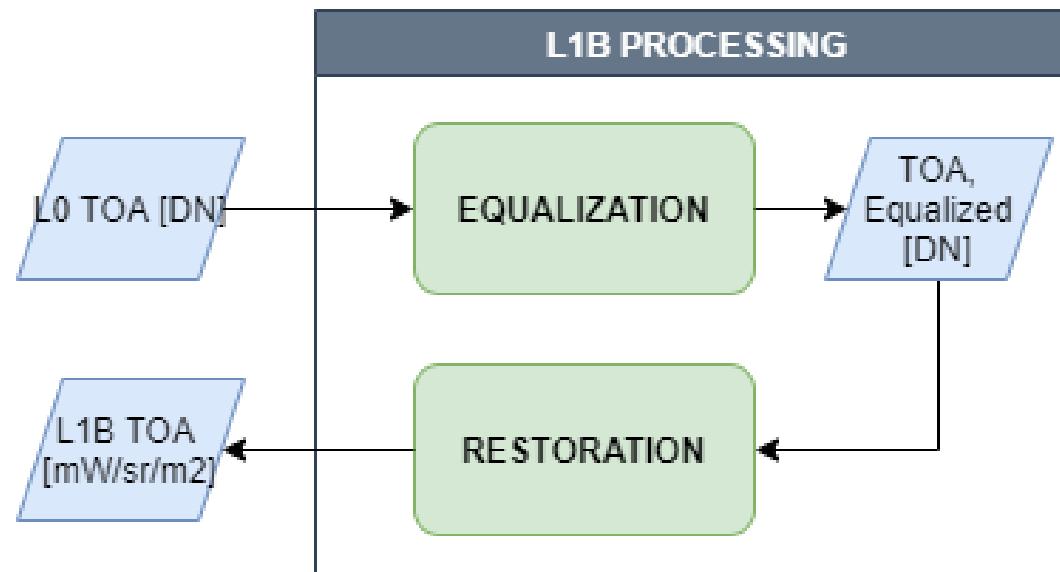
WS1: APPLY CORRECTION ON L1 DATA



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L1B calibration

- The goal of this exercise is to apply a basic first-order calibration (gain, offset)
- And compare with the ideal, and the uncalibrated data.



L1B calibration

8.1. EODP-ALG-L1B-1000: Radiometric Correction.

The Level-1B processing chain is quite simple conceptually. The input to the Level-1 processing chain are the Level-0 packets, which are the time-ordered (with several quality checks) satellite RAW packets. This is reconstructed to form an image in Digital Numbers. The EODP simulator starts at this point, with an input image in DN. In the Level-1 processing the input Digital Numbers need to be converted to radiances by multiplying by the Gain [mW/m²/nm/sr/DN]. This is the "absolute radiometric gain application", § 8.1.3. In the previous section, the Instrument Model, the physics of the system was presented as well as the non-ideal response. In the Level-1B processing, this non-ideal response is partially reverted through the application of the calibration coefficients. The geometric and radiometric calibration is presented in § 8.2 and § 8.3. The application of the coefficients is the "radiometric correction" or equalization, § 8.1.1.

Other activities in the Level-1 processing are the compensation of bad/dead pixels ("cosmetic filling"), the straylight correction and denoising & deconvolution. Both the straylight correction and the deconvolution require the deconvolution of the image with kernels which are the inverse of the effect, so the inverse of the straylight pollution, and the inverse of the Point Spread Function.

8.1.1. EODP-ALG-L1B-1010: Radiometric Correction (equalization)

The radiometric corrections can be reduced to an equalization of the response of the pixels that are responsible for capturing the image such that, overall, a flat response is obtained when observing a homogenous landscape.

The correction is based on a bilinear model which allows correction for offset (Dark Signal), gain (PRNU) and non-linearity, with 2 parameters per pixel, an offset and a gain.

From § 7, there are two effects that affect the readout value (not taking into account defective pixels):

L1B calibration

- The Dark Signal. This is an additive factor which varies from pixel to pixel, and is constant in time. When the satellite acquires a black image (no input illumination), the read-out value shall be the Dark Signal (this is the philosophy used for its calibration).
- The PRNU, which is the modulation of the response inherent to each pixel. For an input "flat", homogeneous scene (e.g. a desert), the response of each pixel will vary slightly. This response is a function of the radiance. The simplest model is to assume it is linear, so $TOA_{measured} = TOA_{real} \cdot (1 + k \cdot PRNU)$.

The following plot shows the measured signal with respect the real signal.

$$TOA_{measured} = TOA_{real} \cdot (1 + k \cdot PRNU) + DS$$

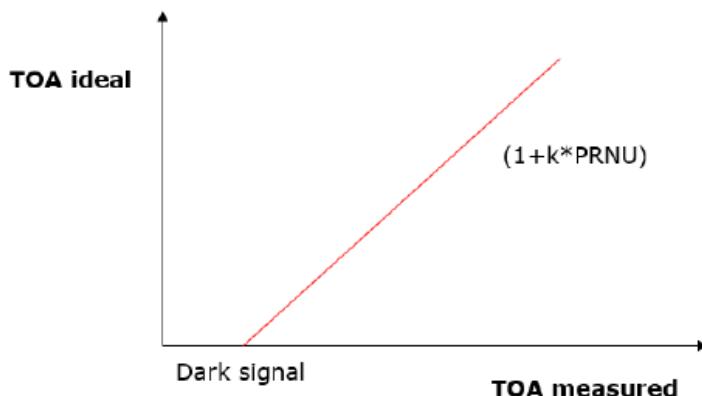


Figure 8-2: Equalization model

The goal of the equalization is to retrieve the "real" input signal. This is done this way:

$$TOA_{real} = (TOA_{measured} - DS) / (1 + k \cdot PRNU)$$

The DS and $(1+PRNU)$ is measured and stored in the Instrument Characterisation Database and are applied to the measured signal.

$$TOA_{real} = (TOA_{measured} - eqadd) / eqmult$$

Where eq_add and eq_mult are two factors provided by the Instrument manufacturer, per pixel.

L1B calibration

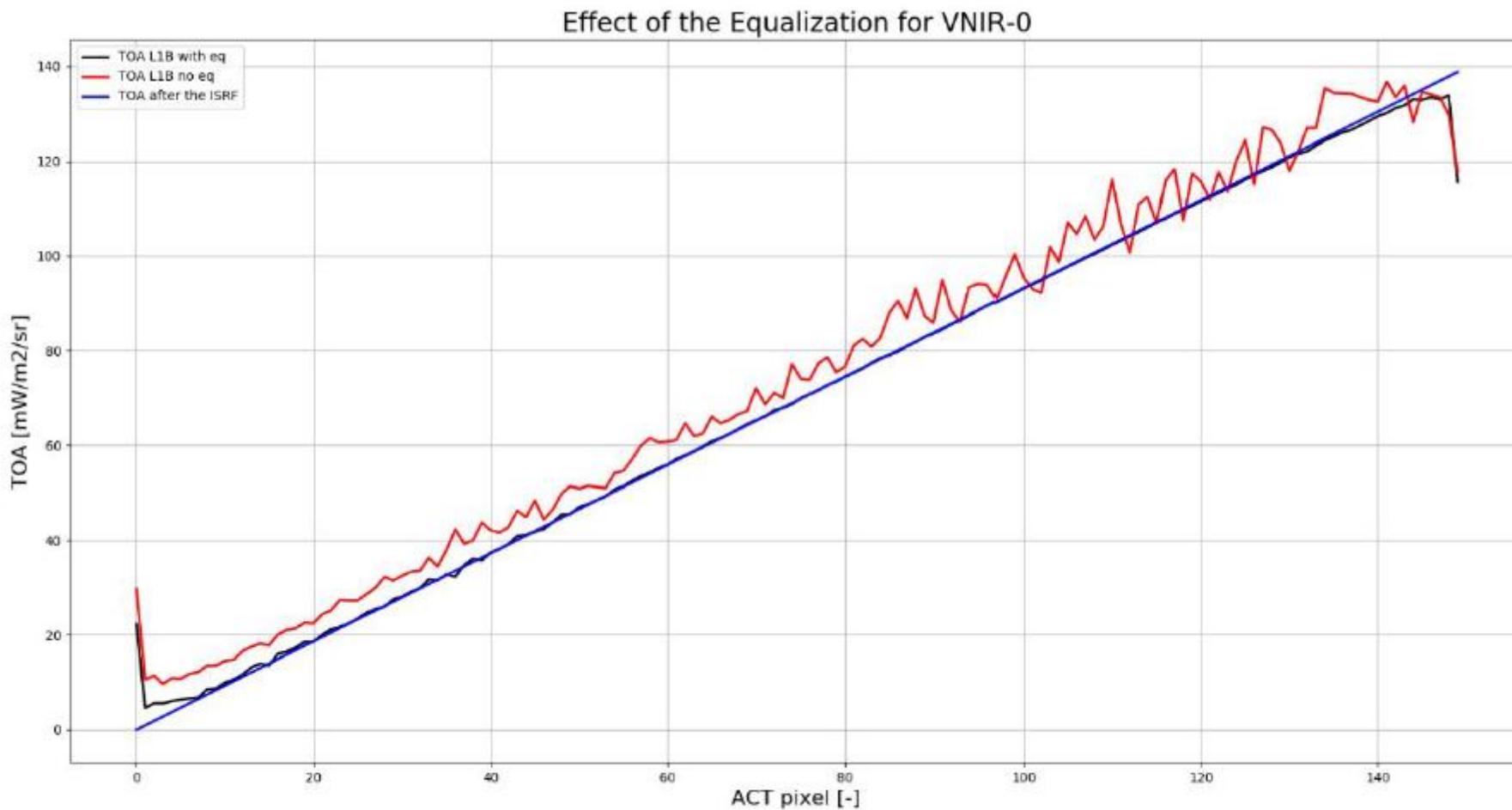
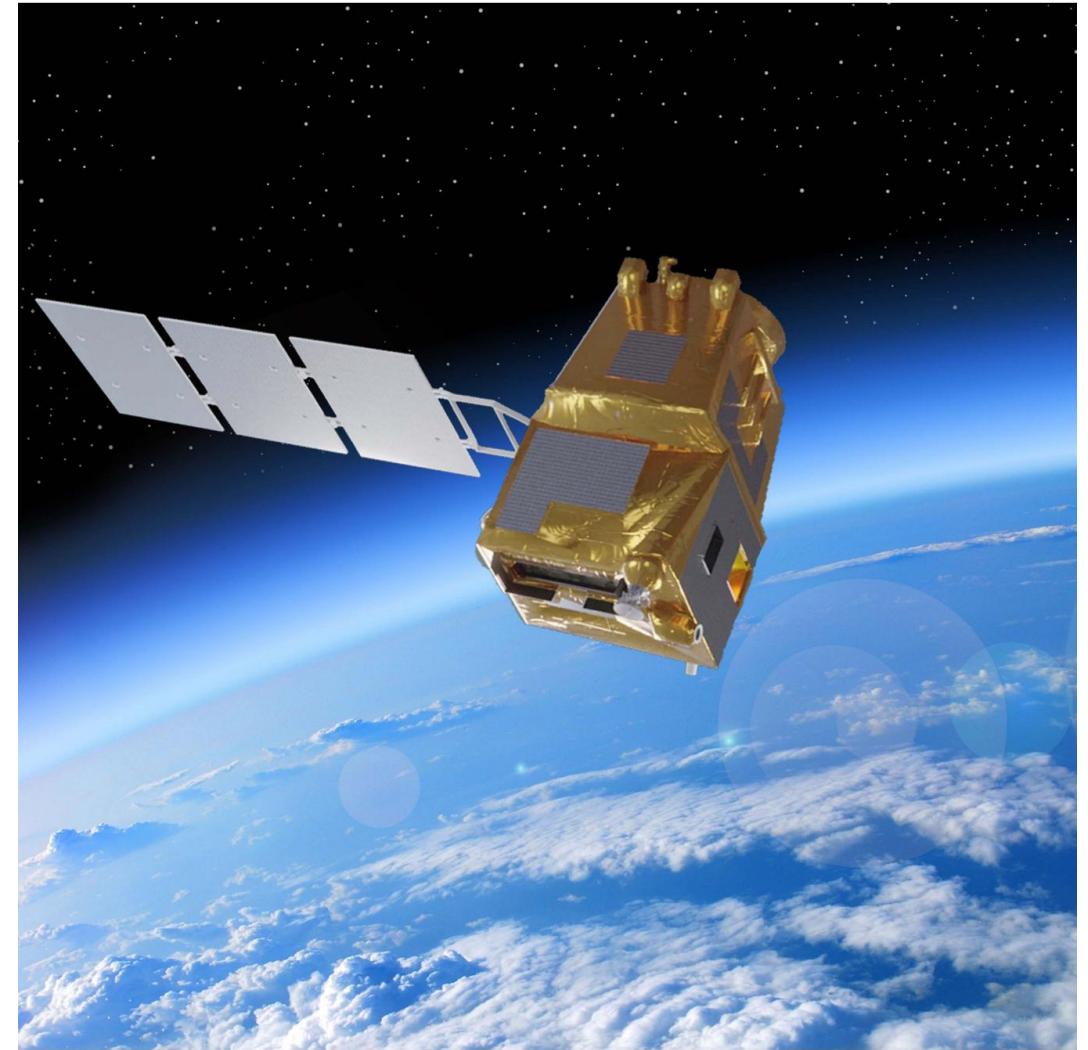


Figure 8-3: Equalization model

WS2: BROWSE LANDSAT DATA



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Exploiting information from different bands

Workshop goals:

- 1. Choose your favourite disaster disaster e.g. 15-20 June 2022 in Zamora (Sierra de la Culebra).**

<https://www.lavanguardia.com/natural/20220620/8352286/incendio-forestal-zamora-entra-lista-peores-fuegos-siglo-espana.html>

- 2. Download data from USGS Landsat 8&9 in Thermal Infrared and Visual bands**

- 3. Open data in QGIS and compare before and after the disaster, in visual and thermal imagery.**

- 4. Analysis: What differences do you see?**

LANDSAT 8 & 9 Bands

<https://www.usgs.gov/faqs/what-are-band-designations-landsat-satellites>

Landsat 8 and Landsat 9 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images consist of nine spectral bands, and two thermal bands. The approximate scene size is 170 km north-south by 183 km east-west (106 mi by 114 mi).

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Coastal aerosol	0.43-0.45	30
Band 2 - Blue	0.45-0.51	30
Band 3 - Green	0.53-0.59	30
Band 4 - Red	0.64-0.67	30
Band 5 - Near Infrared (NIR)	0.85-0.88	30
Band 6 - Shortwave Infrared (SWIR) 1	1.57-1.65	30
Band 7 - Shortwave Infrared (SWIR) 2	2.11-2.29	30
Band 8 - Panchromatic	0.50-0.68	15
Band 9 - Cirrus	1.36-1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.6-11.19	100 (resampled to 30)*
Band 11 - Thermal Infrared (TIRS) 2	11.50-12.51	100 (resampled to 30)*

Sierra de la Culebra (Zamora)

Sierra de la Culebra

4.6 ★★★★★ (122) ⓘ
Mountain range

Overview Reviews About

Directions Save Nearby Send to phone Share

Known for its large wolf population, this forest range features sweeping views of lakes & mountains.

49522, Zamora Your Maps activity Add a label

Updates from customers

Donde están los animalistas no somos los de campo ponemos
4 months ago



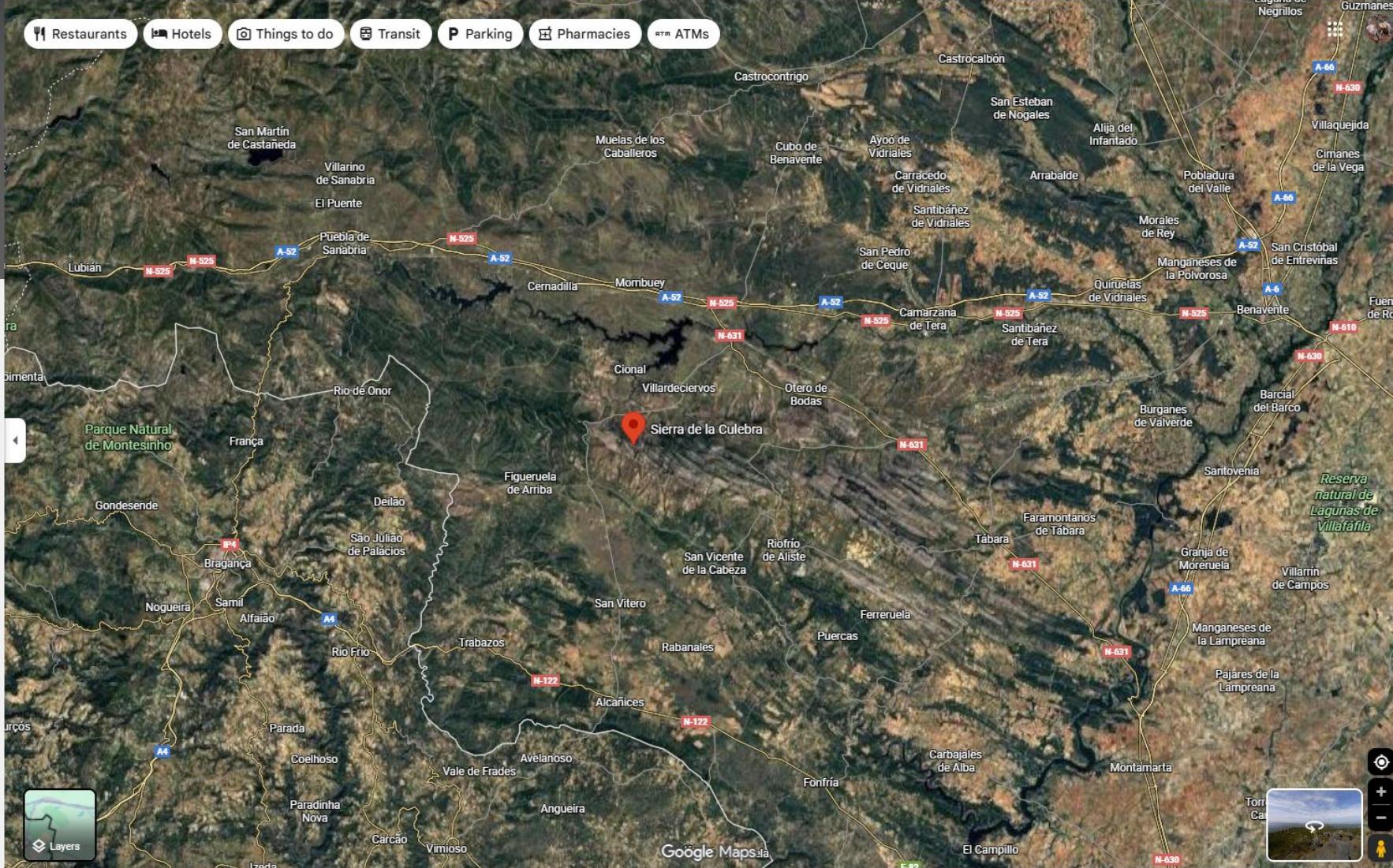
Photos & videos

Restaurants Hotels Things to do Transit Parking Pharmacies ATMs

Sierra de la Culebra

Parque Natural de Montesinho Reserva natural de Lágunas de Villafáfila

Google Maps



Download data from USGS

<https://earthexplorer.usgs.gov/>

1. Select only Landsat 8 & 9

2. Define a small circle around the area of interest.

It will return any image intersecting this circle so don't make it too big.

3. Select the Month of the disaster to filter out other acquisitions

2. Select Your Data Set(s)

Check the boxes for the data set(s) you want to search. When done selecting data set(s), click the *Additional Criteria* or *Results* buttons below. Click the plus sign next to the category name to show a list of data sets.

Use Data Set Prefilter ([What's This?](#))

Data Set Search:

+ EO-1

+ Global Fiducials

+ HCMM

+ ISERV

+ Land Cover

- Landsat 

+ Landsat Collection 2 Level-3 Science Products

+ Landsat C2 U.S. Analysis Ready Data (ARD)

+ Landsat Collection 2 Level-2

- Landsat Collection 2 Level-1 

   Landsat 8-9 OLI/TIRS C2 L1

   Landsat 7 ETM+ C2 L1

   Landsat 4-5 TM C2 L1

   Landsat 1-5 MSS C2 L1

+ Landsat C2 Atmospheric Auxiliary Data 

+ Landsat Collection 2 DEM

+ Landsat Legacy

+ LCMAP

+ Radar

+ UAS

+ Vegetation Monitoring

+ ISRO Resourcesat

Download data from USGS

<https://earthexplorer.usgs.gov/>

Search Criteria Data Sets Additional Criteria Results

Search Criteria Summary (Show) Clear Search Criteria

1. Enter Search Criteria

To narrow your search area: type in an address or place name, enter coordinates or click the map to define your search area (for advanced map tools, view the [help documentation](#)), and/or choose a date range.

Geocoder GeoJSON/KML/Shapfile Upload

Select a Geocoding Method Feature (GNIS)

Search Limits: The search result limit is 100 records; select a Country, Feature Class, and/or Feature Type to reduce your chances of exceeding this limit.

US Features World Features

Feature Name (use % as wildcard)

State All

Feature Type All

Show Clear

Polygon Circle Predefined Area

Circular polygons are created using a center point defined by decimal latitude and longitude values and a radius.

Center Latitude: 41.4861 Center Longitude: -5.7458

Radius: 20 Kilometers

Apply Clear Circle

Date Range Cloud Cover Result Options

Search from: mm/dd/yyyy to: mm/dd/yyyy

Search months: June

Map of Spain showing a search area centered around Madrid. A red circle highlights the search area, and three blue location pins mark specific points within it. The map includes place names like Lugo, Leon, Burgos, Valladolid, Salamanca, Segovia, Madrid, and various rivers and roads. A legend in the top right corner shows coordinates (41° 20' 53" N, 010° 20' 56" W) and includes zoom controls (+, -, Options).

The provided maps are not for purchase or for download; they are to be used as a guide for reference and search purposes only; layers not owned or managed by the USGS may not reflect new naming conventions.

Download data from USGS

<https://earthexplorer.usgs.gov/>

The query will result in many acquisitions from the descending pass (daylight) and some ascending (nighttime).

Search Criteria Data Sets Additional Criteria Results

Search Criteria Summary (Show)

Clear Search Criteria

4. Search Results

If you selected more than one data set to search, use the dropdown to see the search results for each specific data set.

Note: You must be logged in to download and order scenes

Hide Browse/Footprint Controls

Show All Footprints From Current Page
 Show All Browse From Current Page

Compare Browse: Map Overlay ▾ All Scenes ▾ Compare

Browse Overlay Opacity: 36%

Default Browse Overlay Option (Visualization Only)
Reflective Color - Bands 6, 5, 4

Alternate Browse Overlay Option (Visualization Only)
Thermal Browse - Band 10

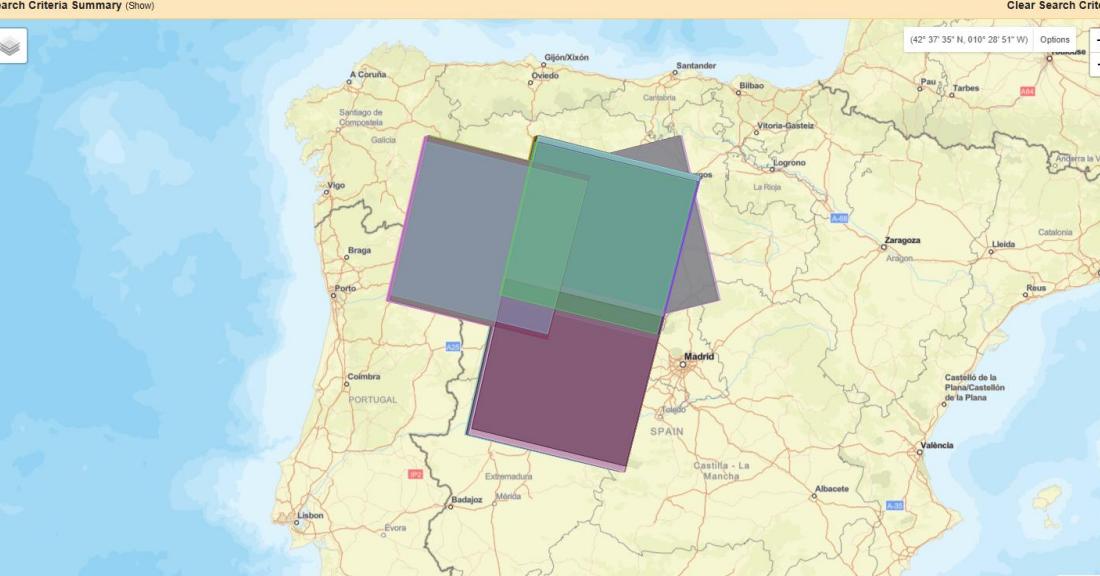
Show Result Controls

Data Set Click here to export your results ▾

Landsat 8-9 OLI/TIRS C2 L1

ID: LC08_L1TP_203031_20220622_20220705_02_T1
Date Acquired: 2022/06/22
Path: 203
Row: 031

ID: LC08_L1TP_202031_20220615_20220627_02_T1
Date Acquired: 2022/06/15
Path: 202
Row: 031



4. Search Results

If you selected more than one data set to search, use the dropdown to see the search results for each specific data set.

Note: You must be logged in to download and order scenes

Show Browse/Footprint Controls

Show Result Controls

Data Set

Click here to export your results ▾

Landsat 8-9 OLI/TIRS C2 L1

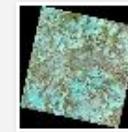
ID:

LC08_L1TP_203031_20220622_20220705_02_T1

Date Acquired: 2022/06/22

Path: 203

Row: 031



ID:

LC08_L1TP_202031_20220615_20220627_02_T1

Date Acquired: 2022/06/15

Path: 202

Row: 031



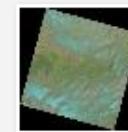
ID:

LC08_L1TP_202032_20220615_20220627_02_T1

Date Acquired: 2022/06/15

Path: 202

Row: 032



ID:

LC09_L1TP_203031_20220614_20230412_02_T1

Date Acquired: 2022/06/14

Path: 203

Row: 031



Download data from USGS

4. Select images before and after the disaster, for example here on the 14th and 22 of June.

With the footprint icon, check the map overlay and check they cover the same area and your area of interest.

4. Search Results

If you selected more than one data set to search, use the dropdown to see the search results for each specific data set.

Show Browse/Footprint Controls

Show Result Controls

Data Set Click here to export your results »

Landsat 8-9 OLI/TIRS C2 L1

Path:	Row:	Date Acquired:	ID:
203	031	2022/06/15	LC08_L1TP_202031_20220615_20220627_02_T1
202	031	2022/06/15	LC08_L1TP_202032_20220615_20220627_02_T1
203	031	2022/06/14	LC09_L1TP_203031_20220614_20220612_02_T1

Path: 203 Row: 031

ID: LC08_L1TP_202031_20220615_20220627_02_T1 Date Acquired: 2022/06/15 Path: 202 Row: 031

ID: LC08_L1TP_202032_20220615_20220627_02_T1 Date Acquired: 2022/06/15 Path: 202 Row: 032

ID: LC09_L1TP_203031_20220614_20220612_02_T1 Date Acquired: 2022/06/14 Path: 203 Row: 031

Click here to export your results »

A map of the Iberian Peninsula showing a green polygon overlay representing the footprint of a selected Landsat image. The map includes place names like A Coruña, Santiago de Compostela, Vigo, Braga, Porto, Coimbra, Lisbon, Badajoz, Mérida, and Valladolid. Red arrows point from the 'Footprint Controls' icons in the search results table to the footprint on the map.

Download data from USGS

5. Download color and thermal data

The image shows a two-panel interface for downloading USGS data. On the left, a 'Search Results' page is displayed for the 'Landsat 8-9 OLI/TIRS C2 L1' dataset. It lists four items, each with a thumbnail, ID, date acquired, path, row, and a set of download icons. The first item's details are shown: ID LC08_L1TP_203031_20220622_20220705_02_T1, Date Acquired 2022/06/22, Path 203, Row 031. On the right, a map of a region in Castilla and Leon, Spain, is shown with a red circular footprint indicating the download area. A 'Download Options' overlay is open over the map, listing various file types and their sizes. The options include:

- All Level-1 Files (20 files) - Add All Files to Bulk (button), Download All Files Now (button), Select Files (button)
- Product Options ▾ Landsat Collection 2 Level-1 Product Bundle
- Download Full Resolution Browse (Reflective Color) GeoTIFF (14.00 MiB)
- Download Full-Resolution Browse (Thermal) GeoTIFF (14.00 MiB)
- Download Full-Resolution Browse (Quality) GeoTIFF (14.00 MiB)
- Download Full Resolution Browse (Reflective Color) JPEG (6.00 MiB)
- Download Full-Resolution Browse (Thermal) JPEG (6.00 MiB)
- Download Full-Resolution Browse (Quality) JPEG (6.00 MiB)

Geographical features labeled on the map include Benavente, Ralencia, Almendra Reservoir, CL-517, CL-612, ZA-324, and N-610.

Download data from USGS

**5. Download
B2, B3, B4
(RGB data),
B10, B11
(thermal), and
quality data.**

Product Download Options for LC09_L1TP_203031_20220614_20230412_02_T1

Landsat Collection 2 Level-1 Product Bundle



1.20 GiB

Landsat Collection 2 Level-1 Product Bundle



The following items are available for individual download

(Item Name Filter)



90.52 MiB

LC09_L1TP_203031_20220614_20230412_02_T1_B7.TIF
Landsat Collection 2 Level-1 Band File - B7.TIF



341.47 MiB

LC09_L1TP_203031_20220614_20230412_02_T1_B8.TIF
Landsat Collection 2 Level-1 Band File - B8.TIF



73.01 MiB

LC09_L1TP_203031_20220614_20230412_02_T1_B9.TIF
Landsat Collection 2 Level-1 Band File - B9.TIF



88.36 MiB

LC09_L1TP_203031_20220614_20230412_02_T1_B10.TIF
Landsat Collection 2 Level-1 Band File - B10.TIF



87.24 MiB

LC09_L1TP_203031_20220614_20230412_02_T1_B11.TIF
Landsat Collection 2 Level-1 Band File - B11.TIF

LC09_L1TP_203031_20220614_20230412_02_T1_MTL.txt

Add All to Bulk

Close

Analysis

What to do. Individual assignment. Send slides with the following:

1. Choose disaster, area and date.

Send description of the disaster (e.g. Newspaper summary). Screenshot in google maps of area.

In QGIS:

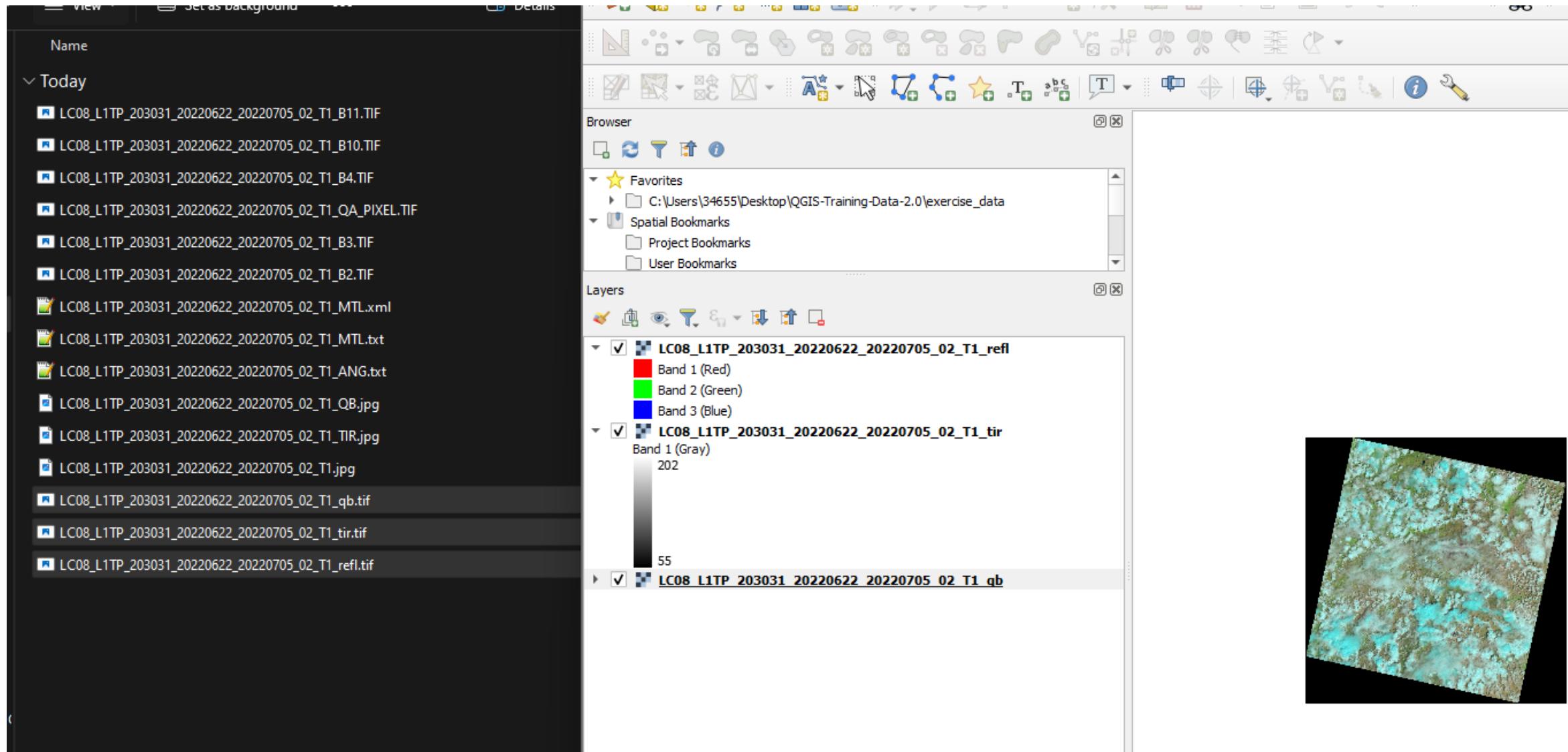
2. For the prior and then the after-disaster dates: compare the RGB data versus thermal.

Screenshot data and describe what you see.

3. Compare the RGB data for both dates, what has changed?

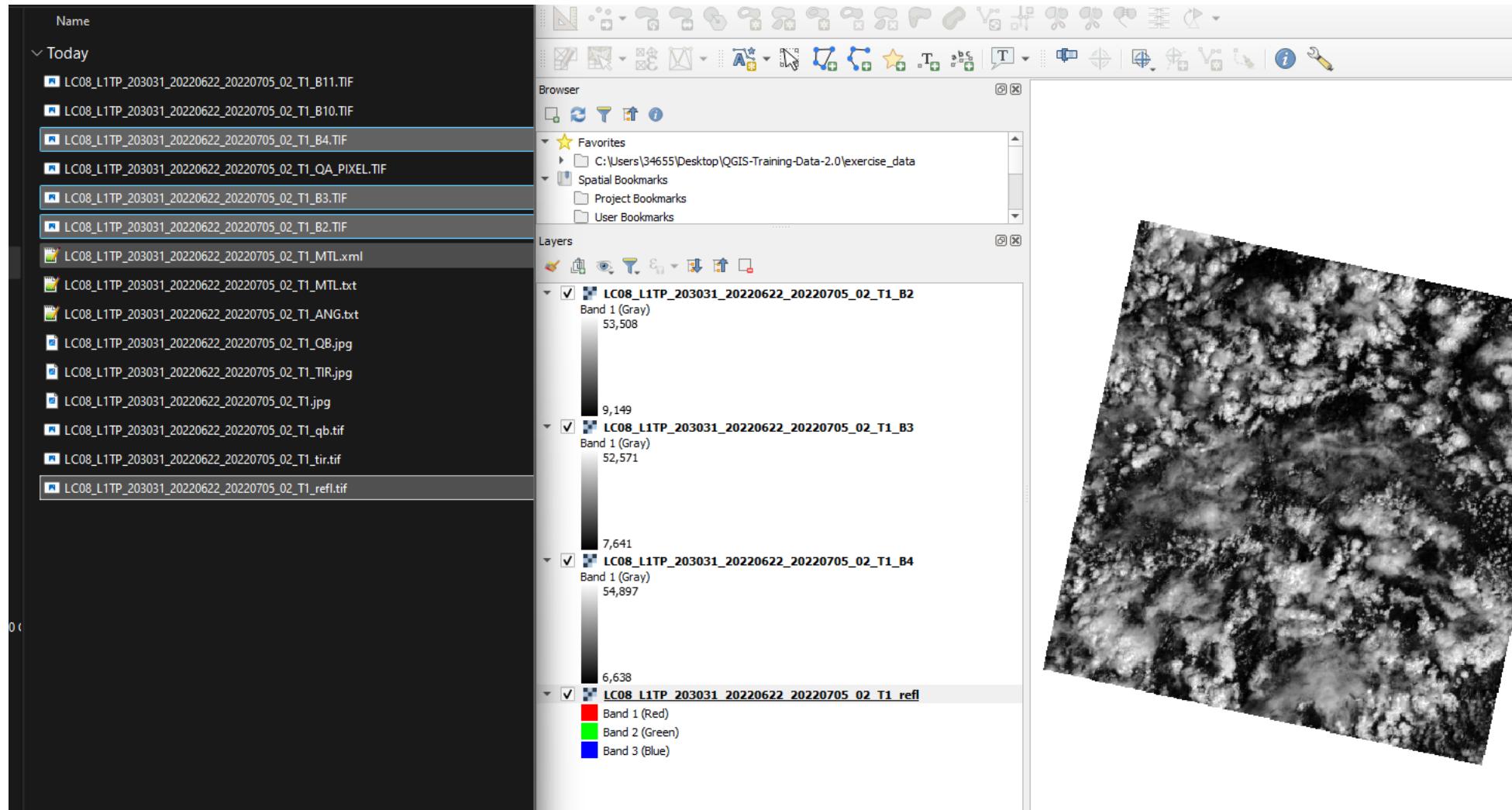
4. Compare the thermal data for both dates, what do we see, and what are the differences w.r.t. RGB data

Example 22-06-2022



Compare RGB bands

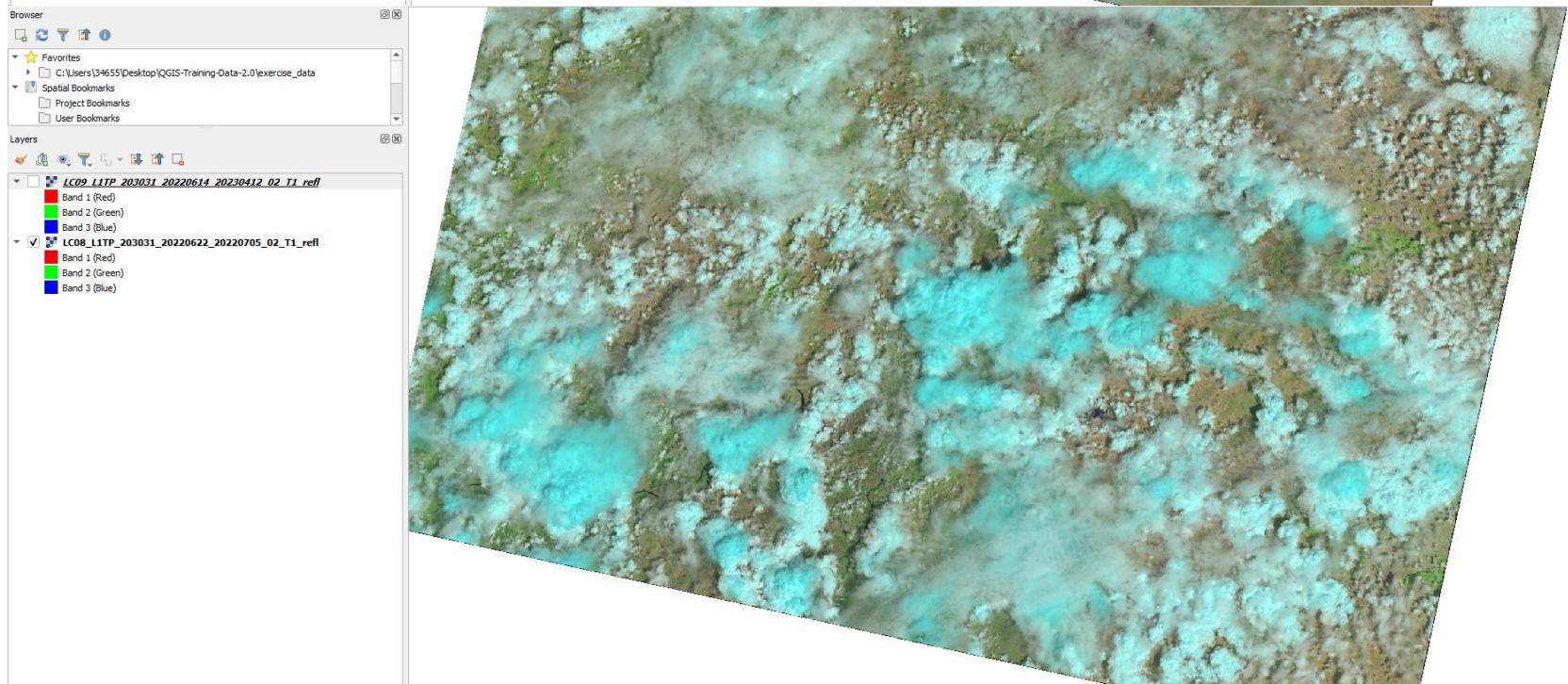
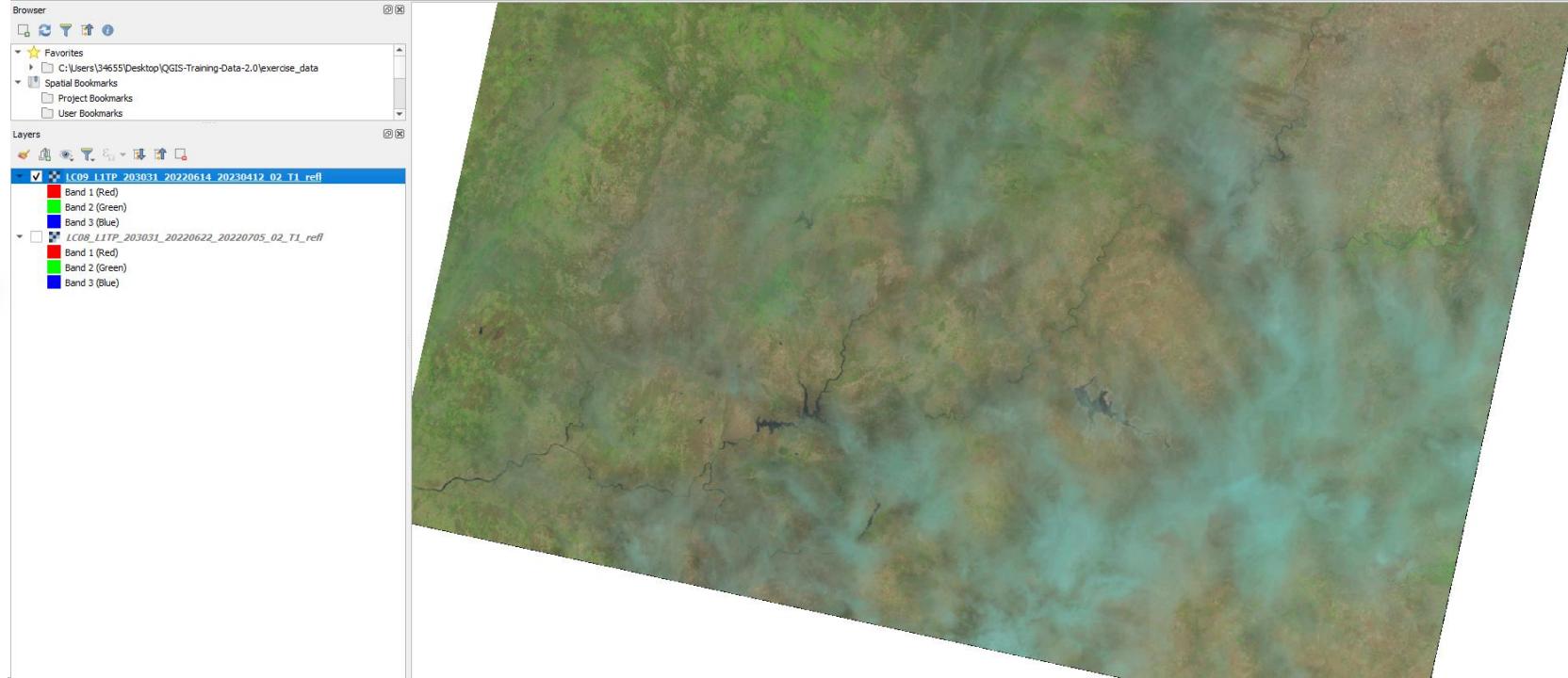
The refl product has RGB data, compare with the B2, B3 and B4 data.



Compare visual data before and after the disaster

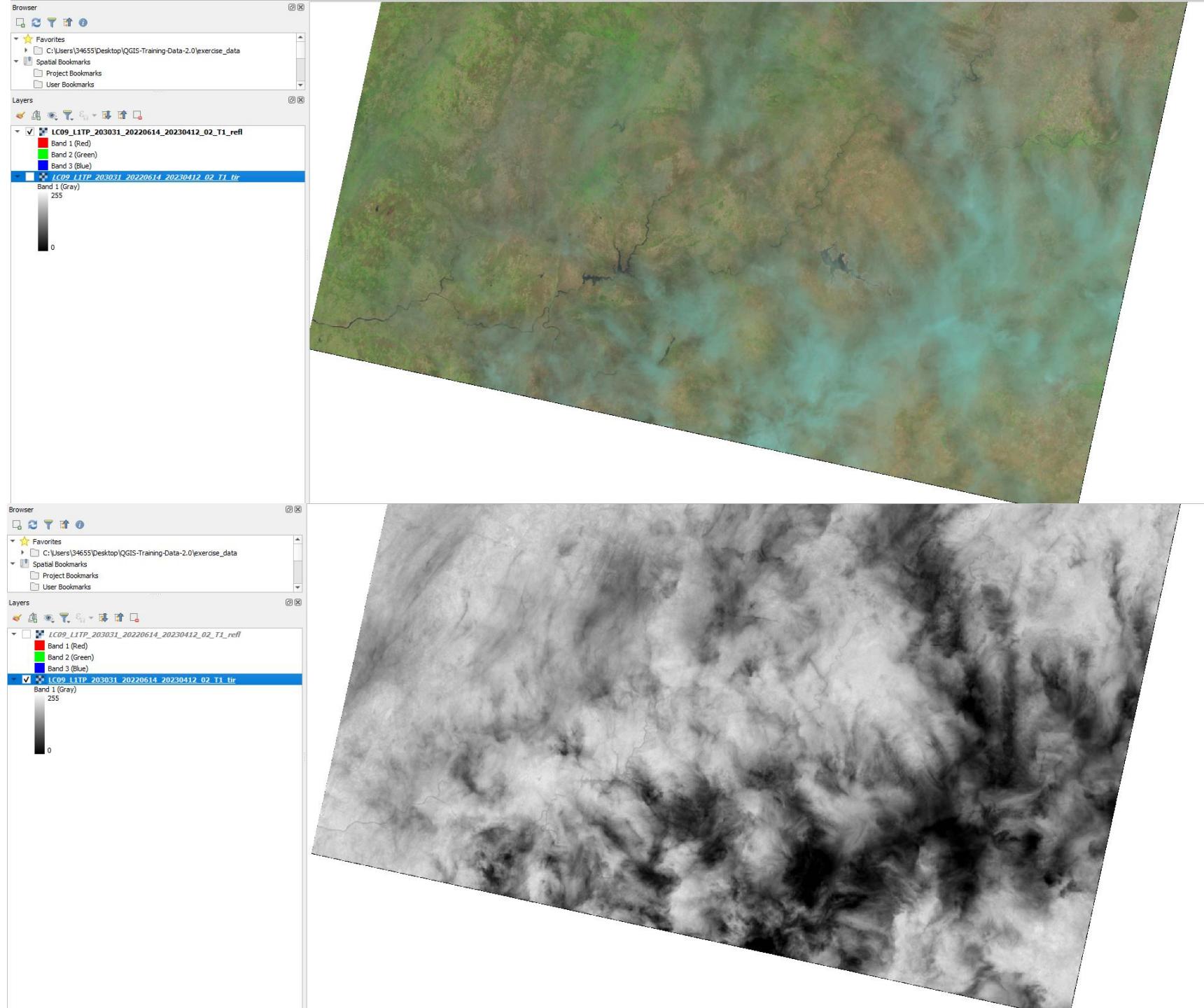
Open the refl product for both dates. Notice that you will only see the top layer. You need to toggle/untoggle.

Notice the clouds of smoke



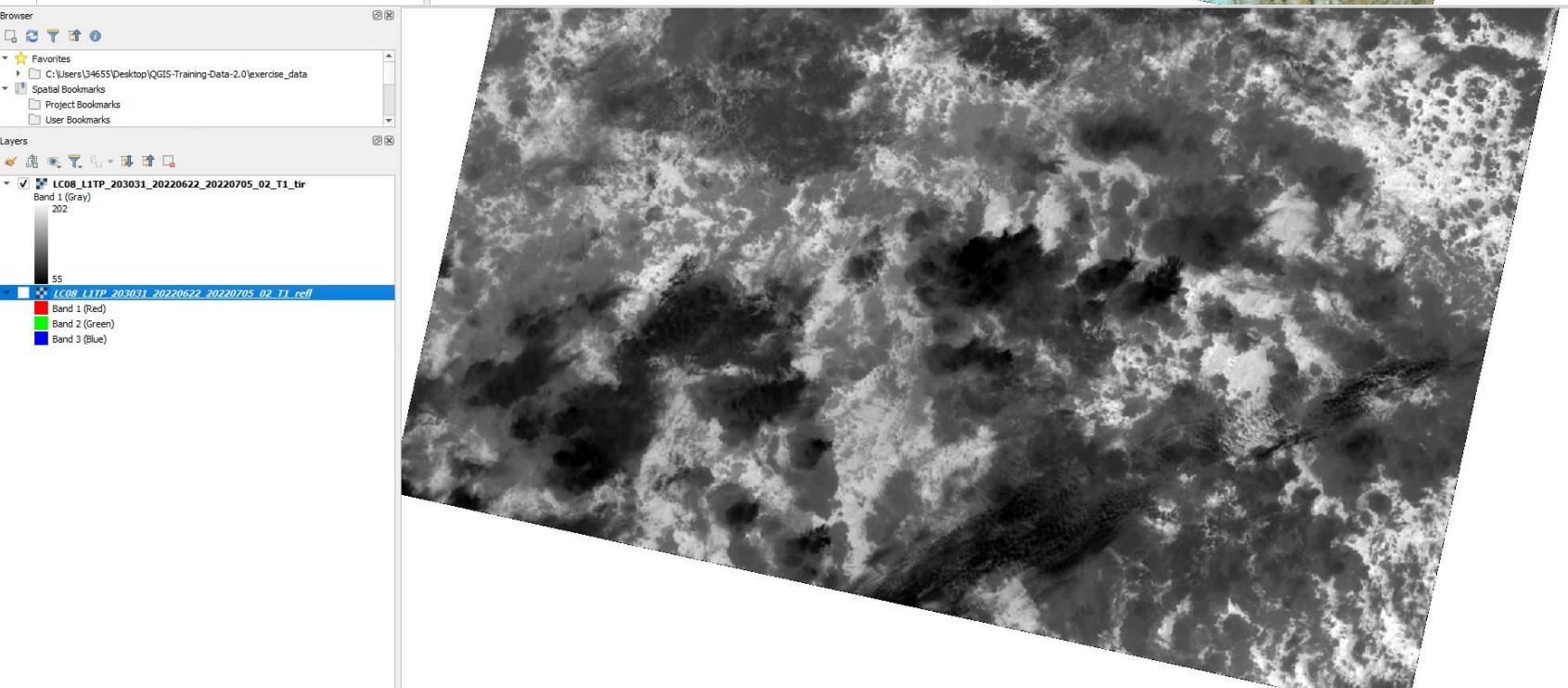
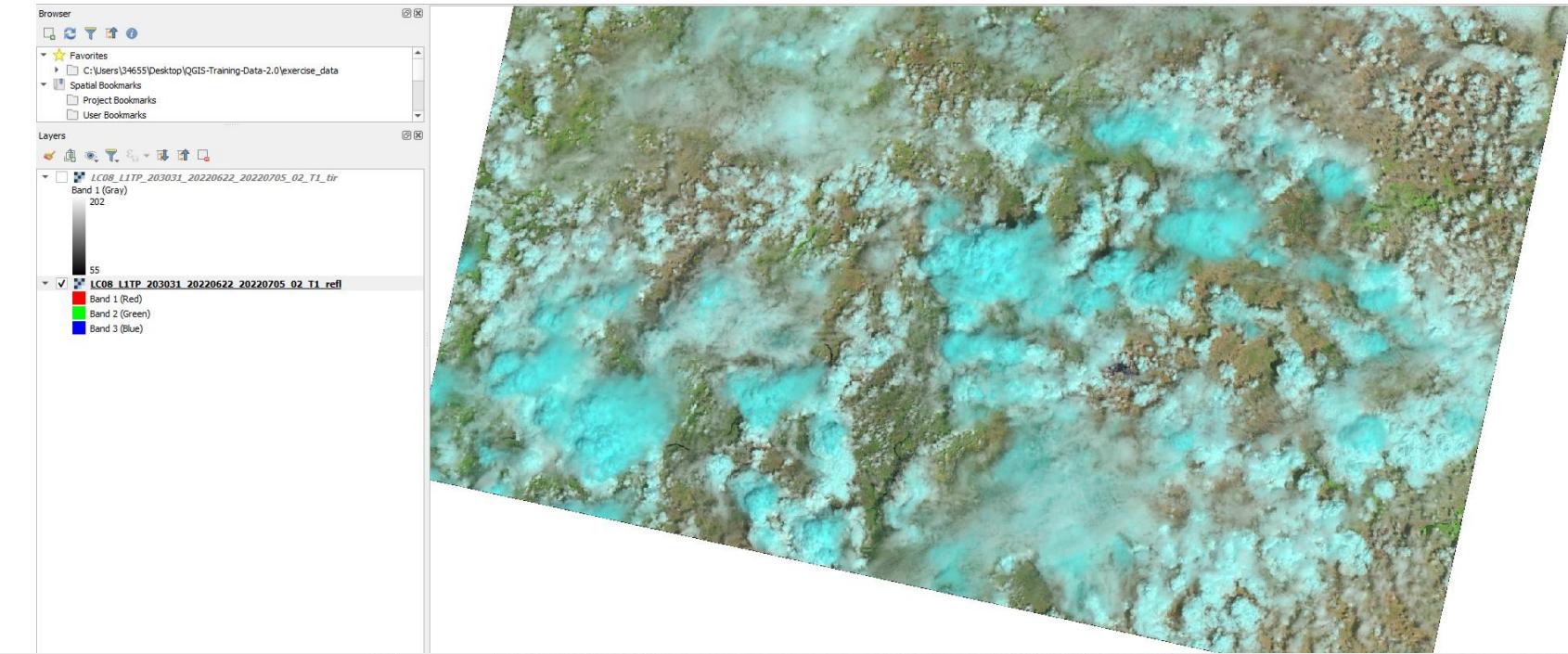
Compare visual with thermal data

BEFORE the fire



Compare visual with thermal data

AFTER the fire



MASTER X