In-orbit, automatic and periodic flat-field calculation of NewSat Mark IV imagery:

A high resolution microsatellite constellation

June 2023

Claudia Agliozzo

Software engineer,
Calibration - Validation

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Overview

- Mission Description
- Flat-field calibration
  - In-orbit calibration
  - Automatic validation
  - E2E workflow
- Results:
  - Consistency across the fleet
- Conclusions

The Ocean Race HQ, Alicante, Spain
Multispectral Imagery
May 17, 2022
Satellogic NewSat-15

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Mission Description

Ruwais Refinery, United Arab Emirates
Multispectral Imagery
July 11, 2022
Satellogic NewSat-23

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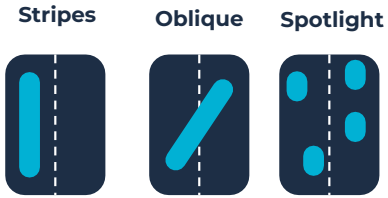
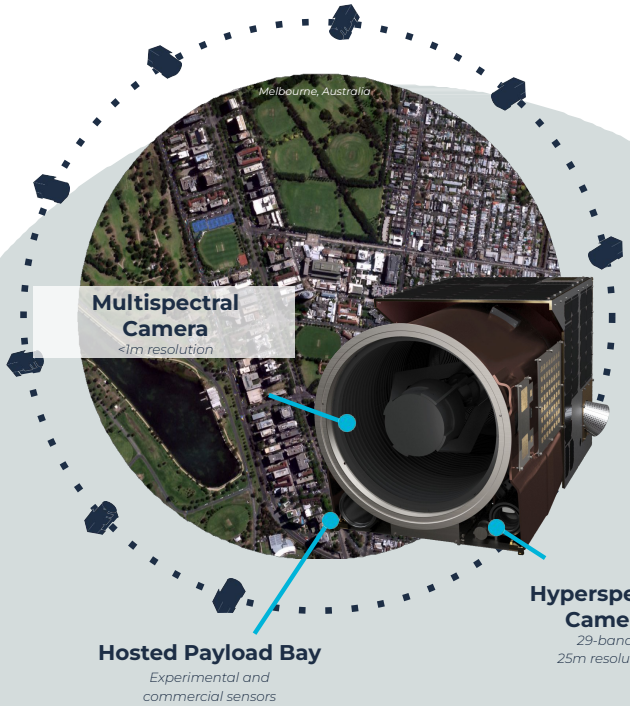
OUR SATELLITES (Mark IV)

- **Mission Goal:**
  - Scalable observation system
  - Remap the entire world at high resolution, high frequency and low cost
- **Fleet** of small, light and cost effective satellites that can be produced at scale
- **Newsat Mark IV** produced at scale
- **Newsat Mark V** under development
- **34 satellites** in orbit

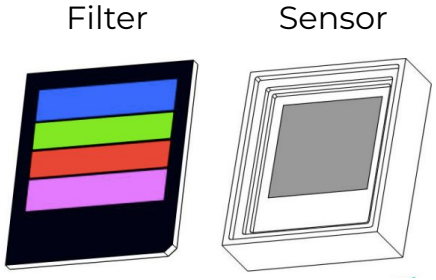
CAPTURE MODES





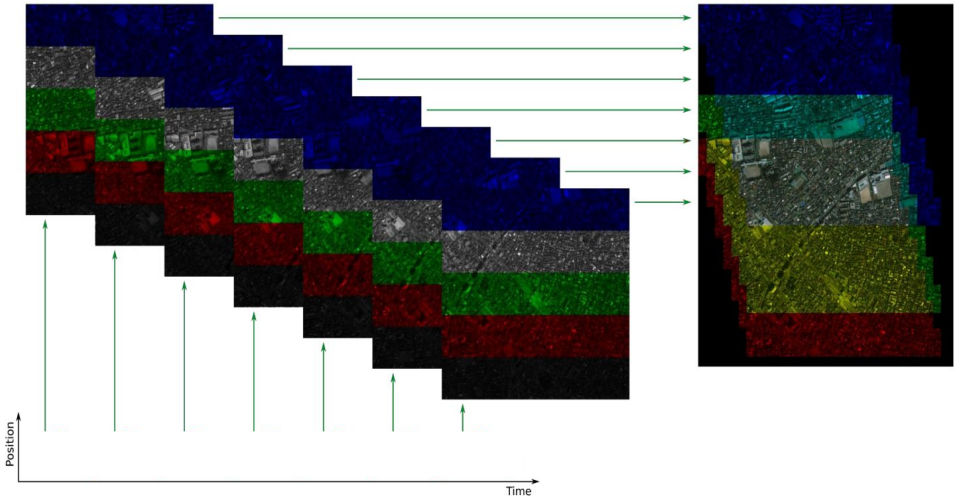
NewSat Design: MASS: **~40 kg** | LEO SSO: **~475 km** | LIFETIME: **3-4 YEARS**

OUR SATELLITES (Mark IV)



We have been iterating payload designs since 2015

Coming: Mark V - Slightly different design



PRODUCT	MULTISPECTRAL
Pixel resolution (GSD) at Nadir	0.99 m (native resolution) delivered as 1 m
Number of bands	4
Wavelengths	Blue: 450 - 510 nm Green: 510 - 580 nm Red: 590 - 690 nm NIR: 750 - 900 nm
Image swath	5 km
Image delivery bits / pixel	8 or 16 Bits
Mean SNR @ 800 DNs	95

Radiometric calibration

Koper, Slovenia
Multispectral Imagery
September 21, 2022
Satellogic NewSat-28

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RADIOMETRIC EQUATION FOR OUR L1 PRODUCT

$$L_{e,\Omega,\nu}(x,y) = \frac{\mathrm{DN}_{\mathrm{raw}}(x,y) - \mathrm{DN}_{\mathrm{dark}}(x,y)}{\mathrm{DN}_{\mathrm{flat}}(x,y)} \times \frac{G(\lambda)}{t_{\mathrm{exp}}} \quad [\mathrm{W\,sr^{-1}m^{-2}Hz^{-1}}]$$

Measured in orbit

- Pixel-wise calibration
- Spatial variation

Measured in the lab, fine tuned in orbit

- Global calibration
- Spectral variation

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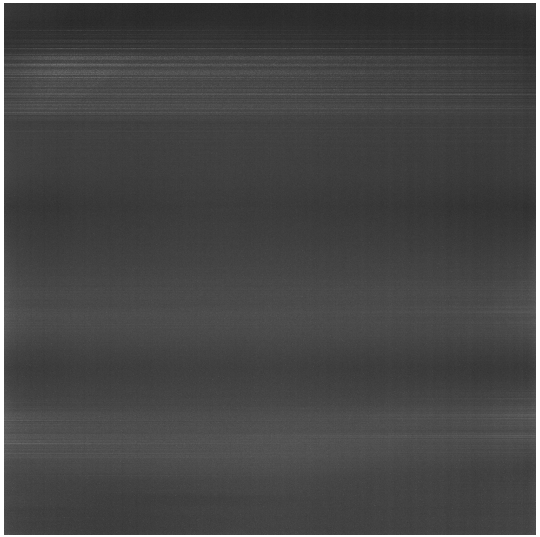
Non uniformity correction:
In-orbit flat-field calibration

Ashburton, New Zealand
Multispectral Imagery
June 22, 2022
Satellogic NewSat-21

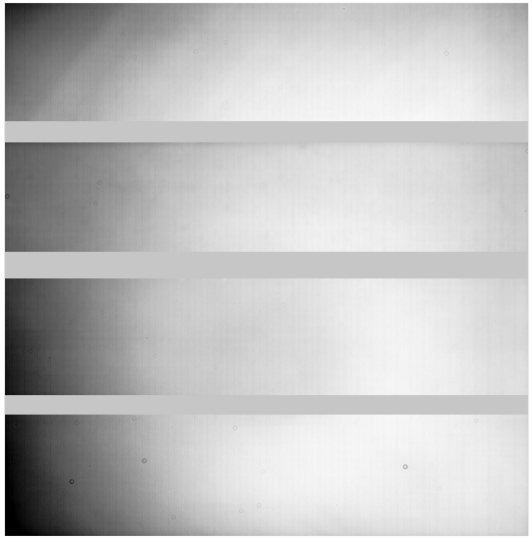
NON-UNIFORMITY CORRECTIONS

Dark calibration (*)



Captures of oceans at night

Flat-field calibration (*)



Average of at least 6000 random frames (production imagery)

Why calibrate them in orbit?

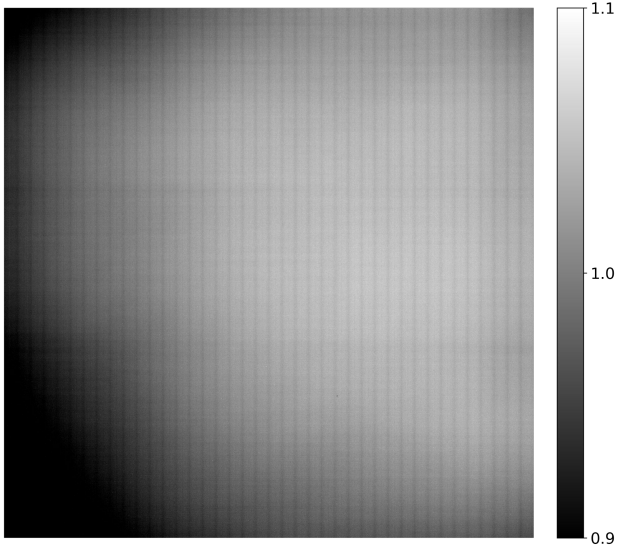
- Optical + thermal conditions as in production imagery
- Assess if something changed during launch
- Periodic recalibration

In orbit calibrations without the need of moving parts

(*) Grey levels stretched for visualization purposes

PAYLOAD NON-UNIFORMITY

Sensor pixel and electronic system response non-uniformity (*)



(*) Grey levels stretched for visualization purposes

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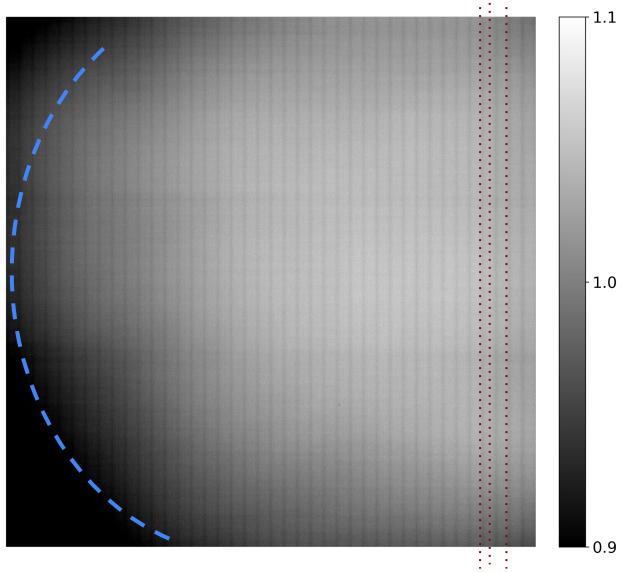

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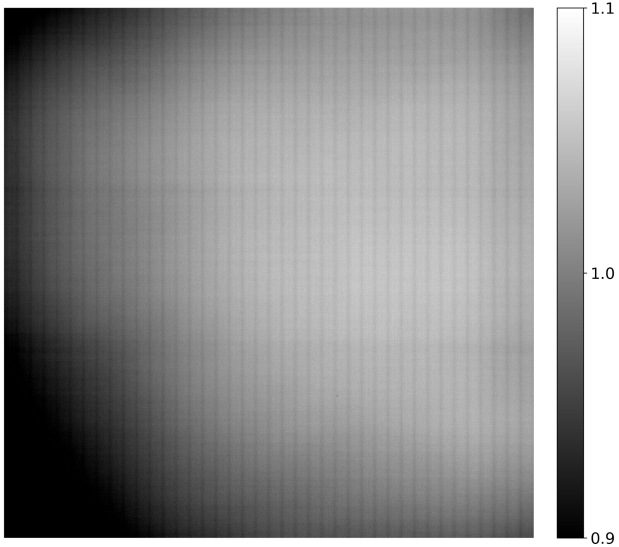
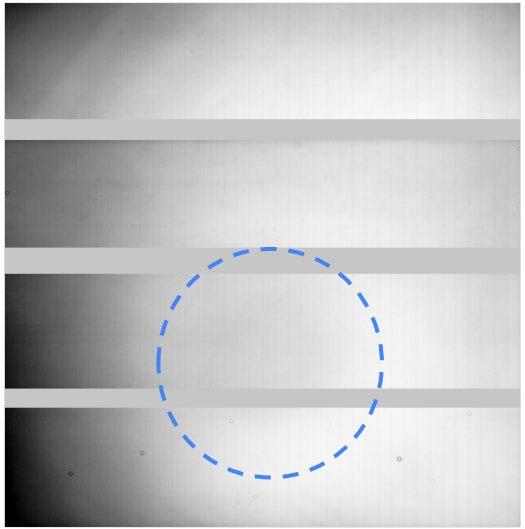


Optical system response non uniformity, dust particles (*)



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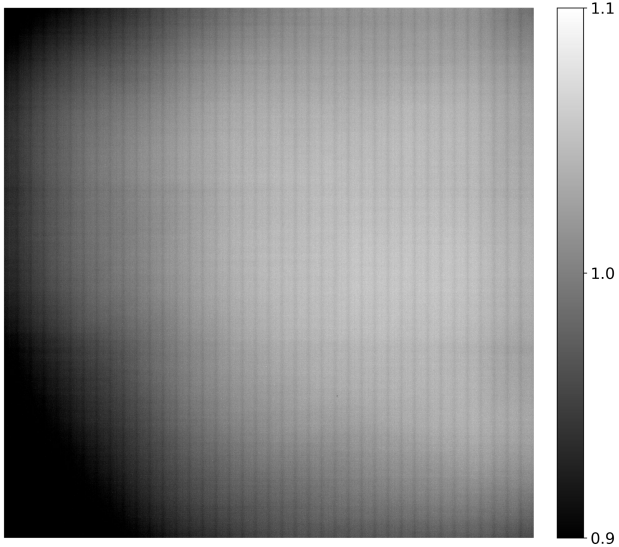

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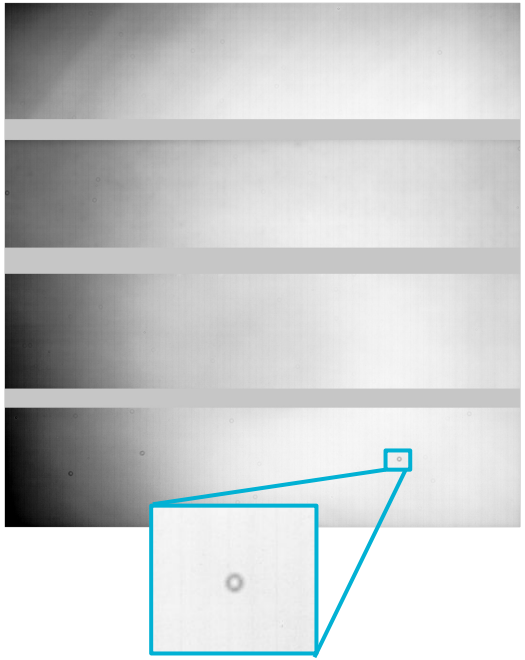

(*) Grey levels stretched for visualization purposes

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Flat-field calculation

Port of Rotterdam, The Netherlands
Multispectral Imagery
August 23, 2022
Satellogic NewSat-27

FLAT-FIELD CALCULATION (Per satellite)

Averaging input scenes from production imagery (*)

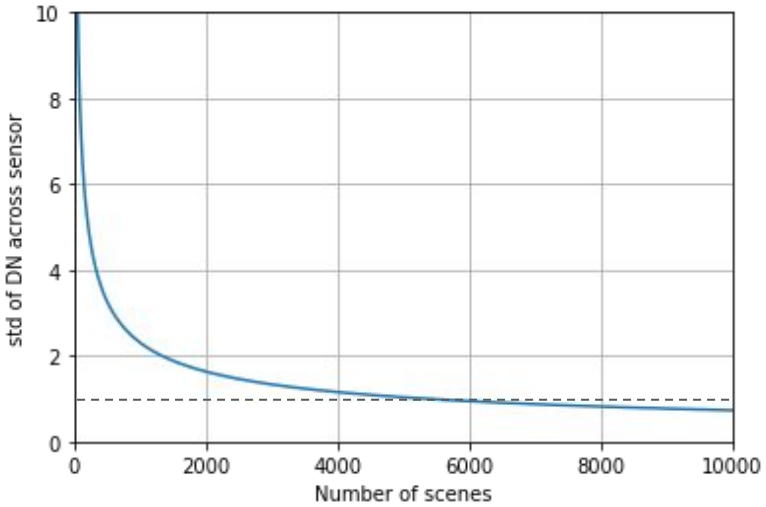
- From the past 7–10 days
- From random locations on Earth (any spectral signature)
- Pre-validated (e.g. excluded saturated frames)
- Minimum 6000 valid frames

Goal
$\sigma_{xy} = 1\ \%$

(*) Similar approach using statistics gathered from acquired image dataset also in Brunn et al. 2010, ISPRS proceedings (RapidEye)

Mathematical justification

- $\sigma_{xy} = \sigma_s / \sqrt{N}$
- Assumption: for each scene, intensity *I* sample of a uniform distribution (pessimistic)



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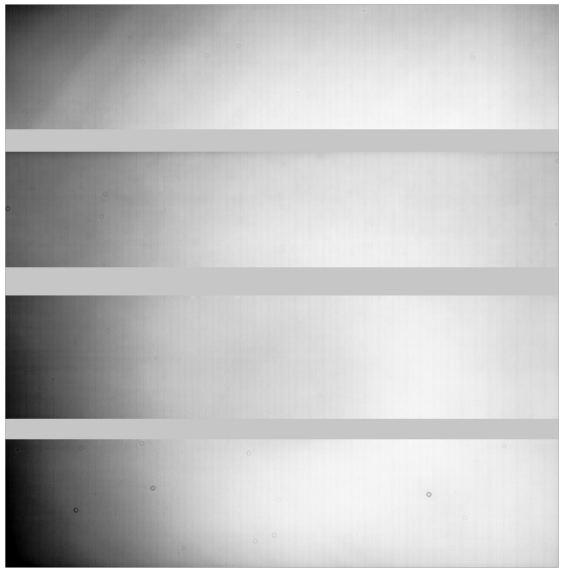
Resulting flat-field frame



Grey levels stretched for visualization purposes

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Flat-field pipeline trigger

Goal: automatic, programmatically, to catch any possible variation

We implemented an automatic validation of the flat-field frame to facilitate the operations and guarantee high quality flat-field frame.

(*) Similar approach using statistics gathered from acquired image dataset also in Brunn et al. 2010, ISPRS proceedings (RapidEye)

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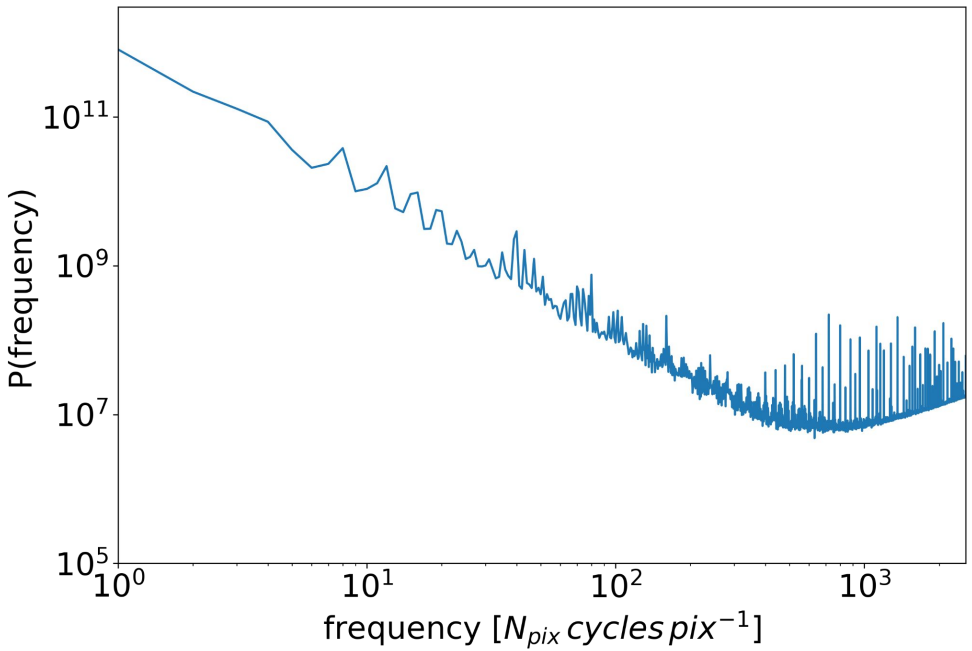
Automatic Validation

Gemasolar, Seville, Spain
Multispectral Imagery
March 1, 2022
Satellogic NewSat-20

Isolating possible noise due to input images

- Apply Fourier domain filter to suppress payload artifacts at high and low frequencies, and vertical and horizontal lines at any frequency

Power spectrum



Isolating possible noise due to input images

- Apply Fourier domain filter to suppress payload artifacts at high and low frequencies, and vertical and horizontal lines at any frequency
  - Vignetting-like
  - Optical system non uniformity

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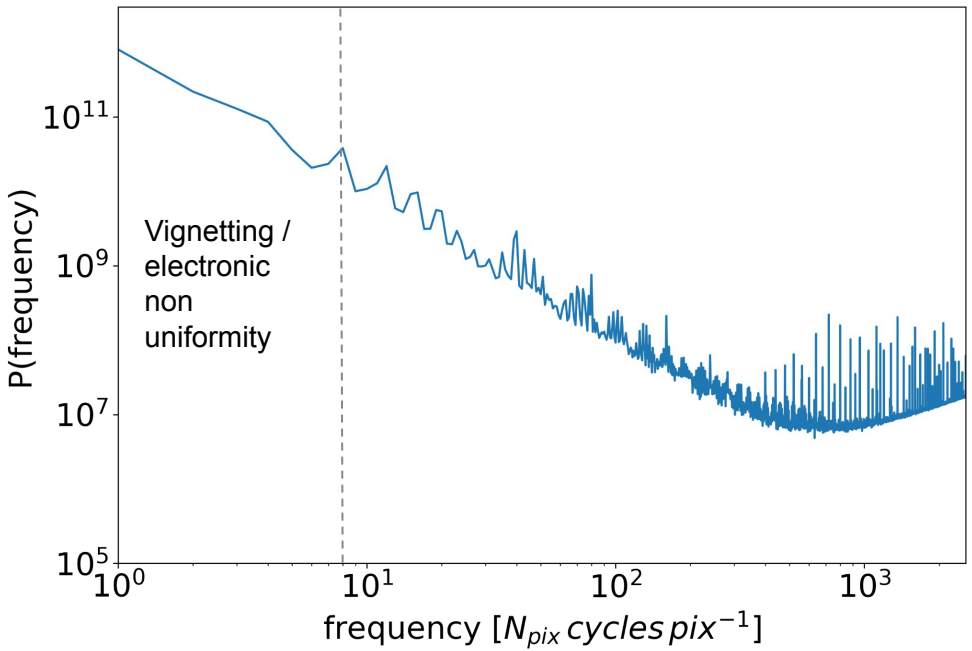
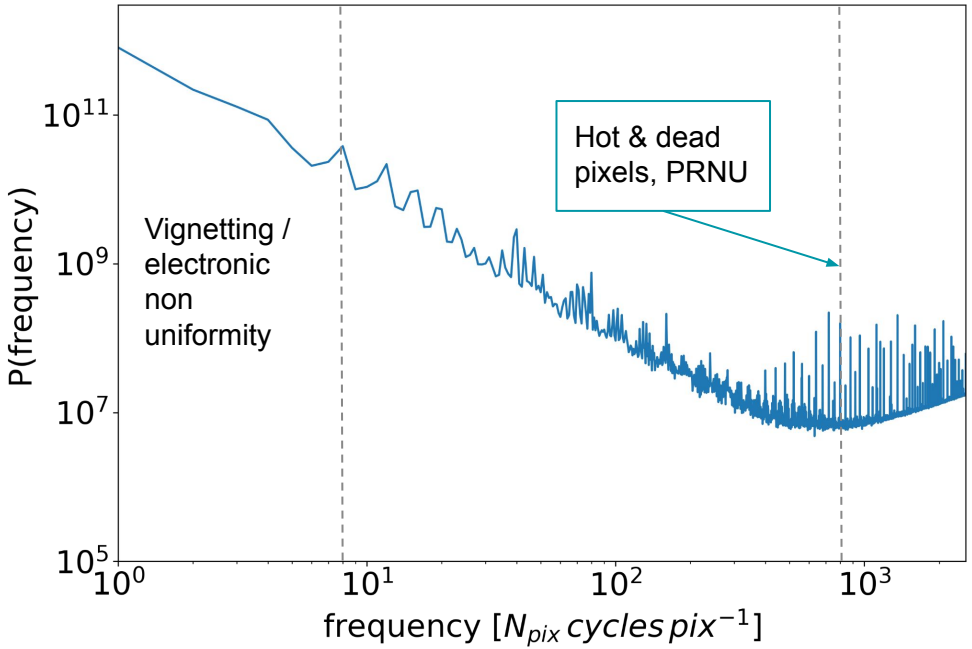


THRESHOLD-BASED VALIDATION

Isolating possible noise due to input images

- Apply Fourier domain filter to suppress payload artifacts at high and low frequencies, and vertical and horizontal lines at any frequency
  - Vignetting-like
  - Optical system non uniformity
  - Hot and dead pixels
  - PRNU

Power spectrum



Isolating possible noise due to input images

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At the intermediate frequencies we find other payload artifacts, such as dust particles.

Here is where we expect to find structures due to input images. These are the spatial frequencies were we perform our threshold-based validation of our flat-field frames.

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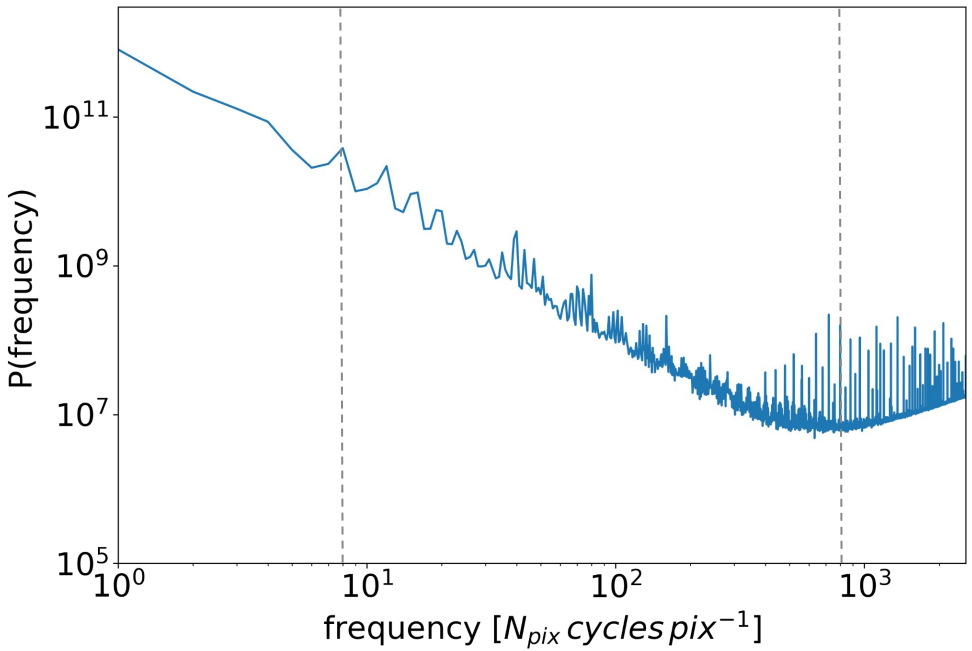

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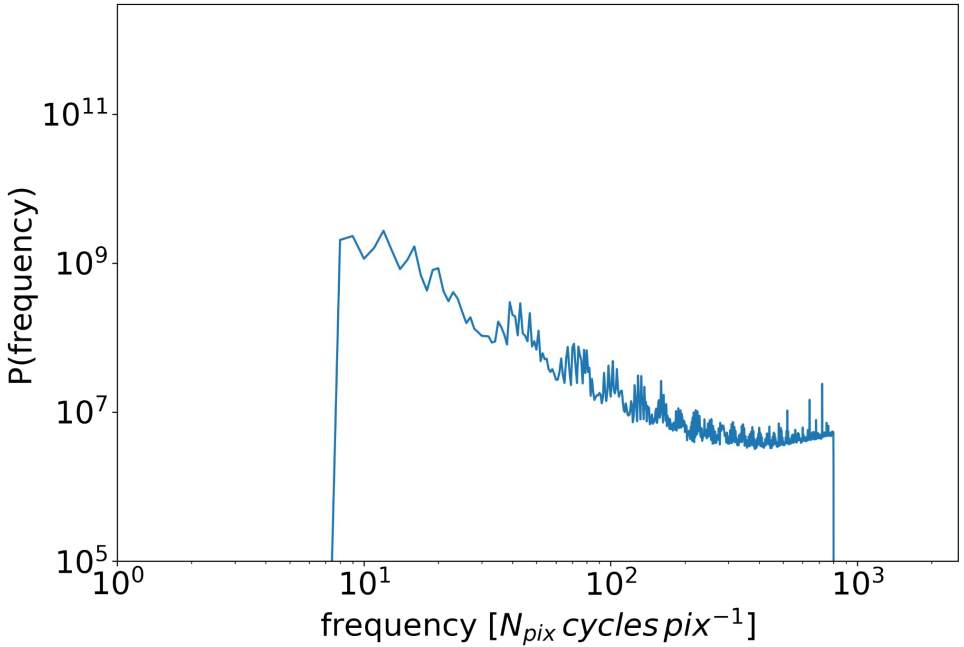
Power spectrum (residuals)



THRESHOLD-BASED VALIDATION

Statistical analysis of flat-field residuals

- Analyse residuals (noise at intermediate frequencies, possibly due to image content)
- Get statistics in each band

Thresholds

- Goal: desired noise level of up to 1% of DN_{max} (equivalent to up to ~0.4% in normalized flat-field frame)
- Variations 30% larger than ~0.4% are automatically rejected (down to 0.5%)
- Everything between 0.4% and 0.5% is to be inspected visually

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Comparison with previous flat-field frame

If the coefficient of variation > 1%, visual inspection to investigate the origin of change.

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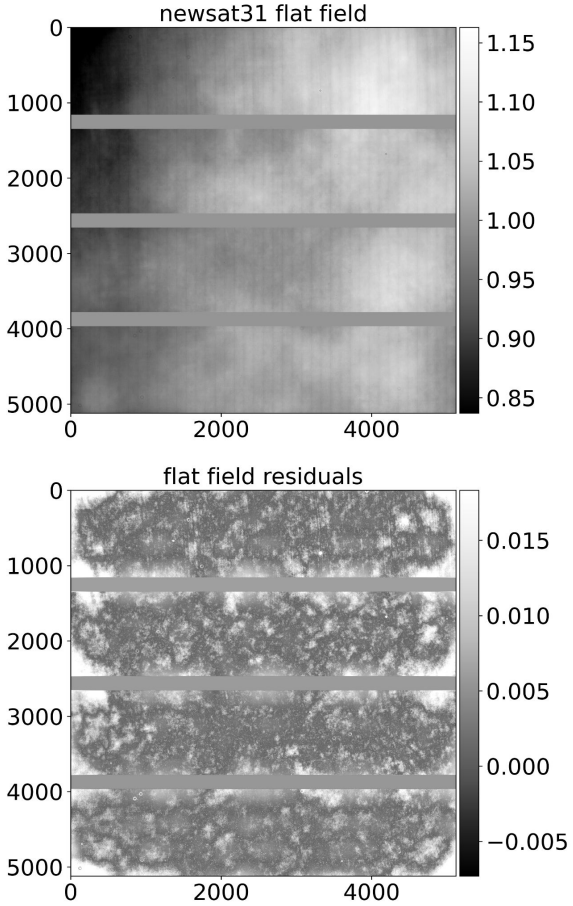
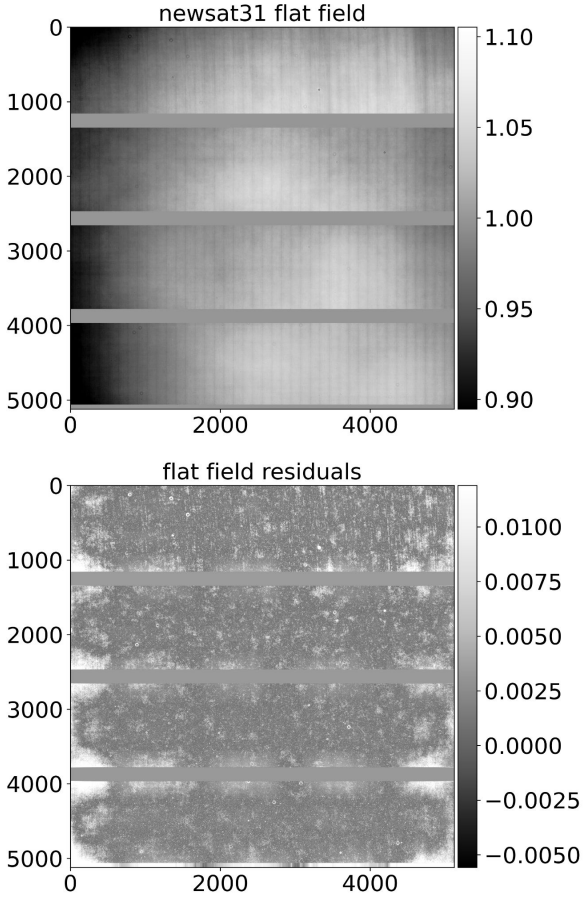
AN EXAMPLE OF BAD AND GOOD FLAT-FIELD FRAMES

Bad



Good



Grey levels stretched for visualization purposes

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E2E Flat-field calibration workflow

Base Aerea Torrejon
Madrid, Spain
Multispectral Imagery
June 30, 2022
Satellogic NewSat-13

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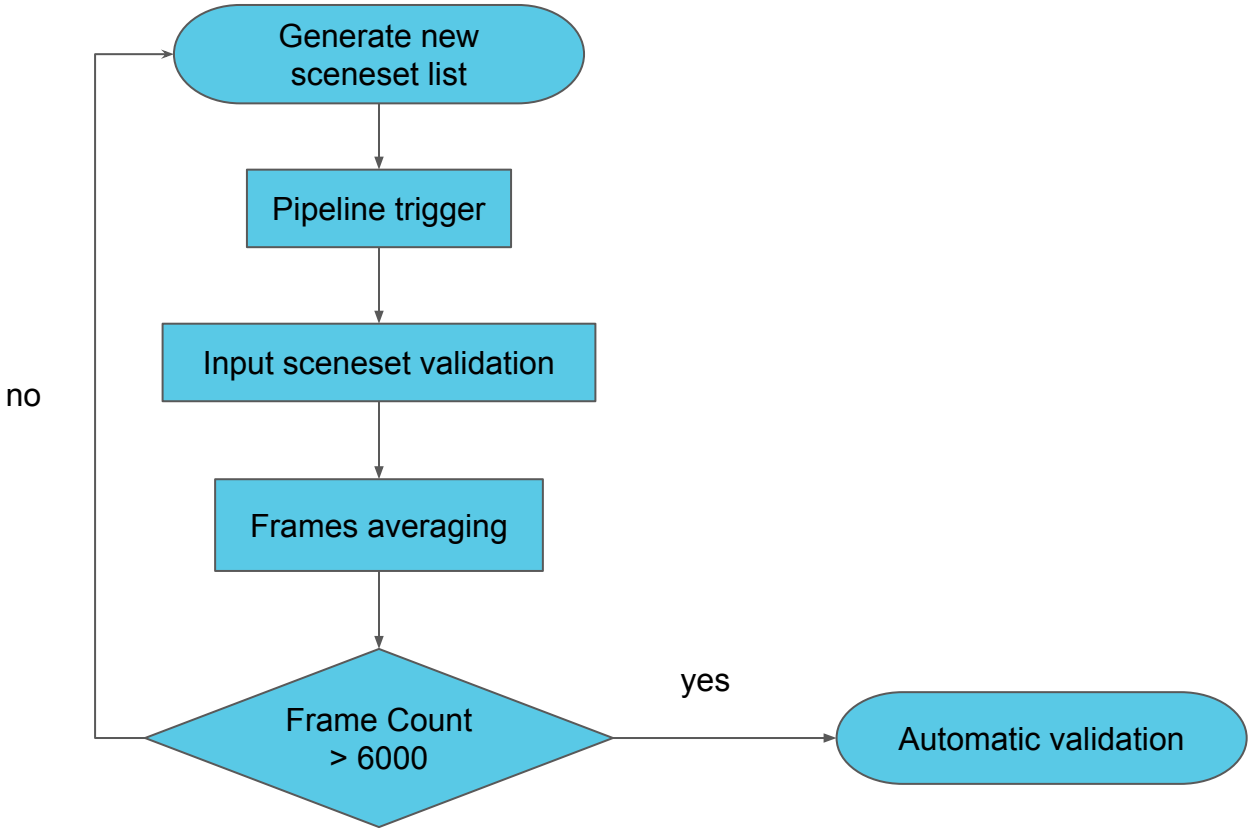
CALCULATION WORKFLOW



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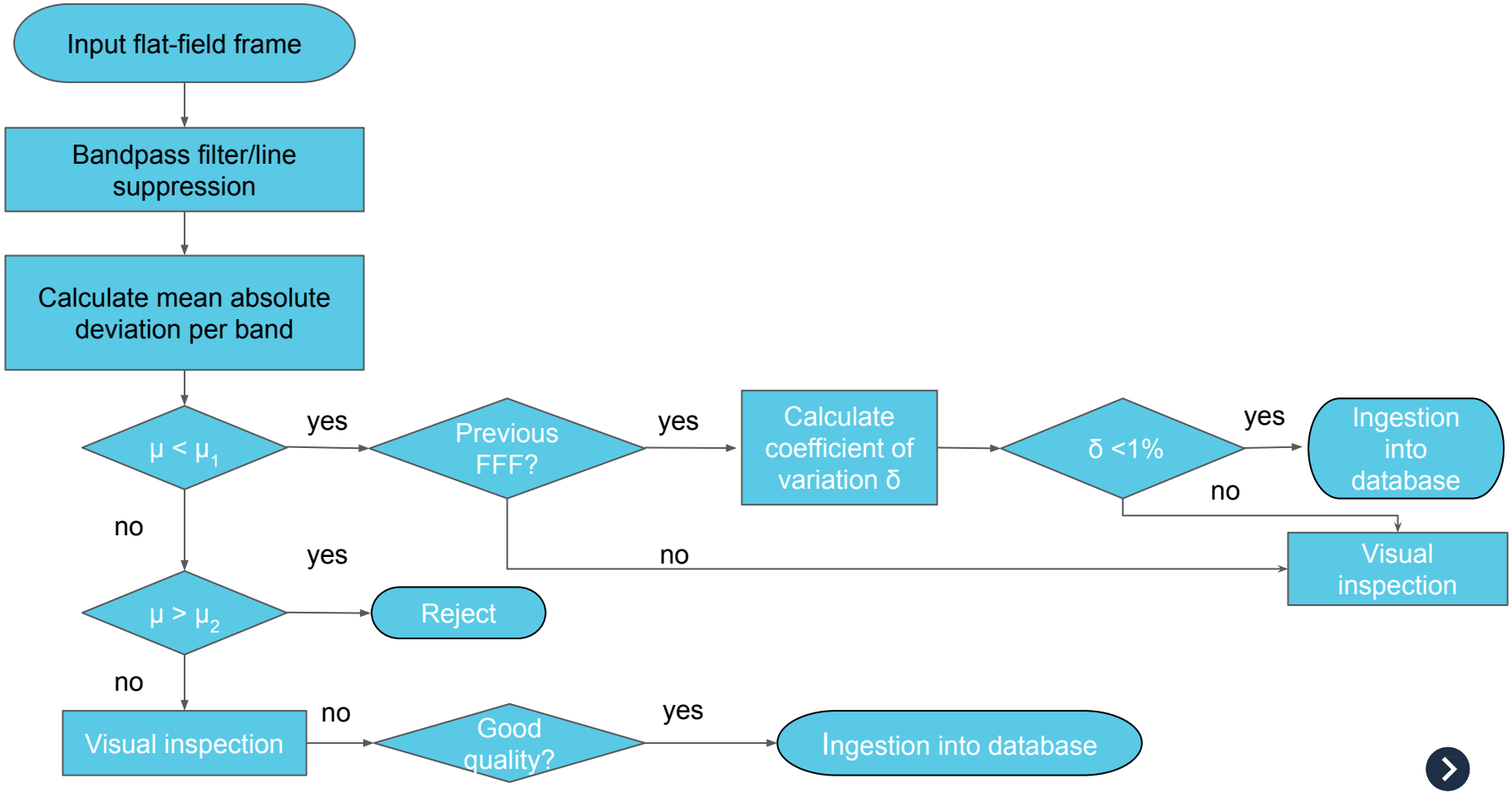
VALIDATION WORKFLOW



E2E FLAT-FIELD CALIBRATION WORKFLOW

Flat-field pipeline trigger

Currently: manual, periodically (1 or 2 per month)

Goal: automatic

Validation of flat-field frame

Automatic

Currently:

- Sometimes may require visual inspection

Goal:

- No visual inspection required

Ingestion in production

Currently:
semi-automatic, requires operator to ingest into database

Goal: automatic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Results
Riyadh, Saudi Arabia
Multispectral Imagery
October 26, 2022
Satellogic NewSat-20

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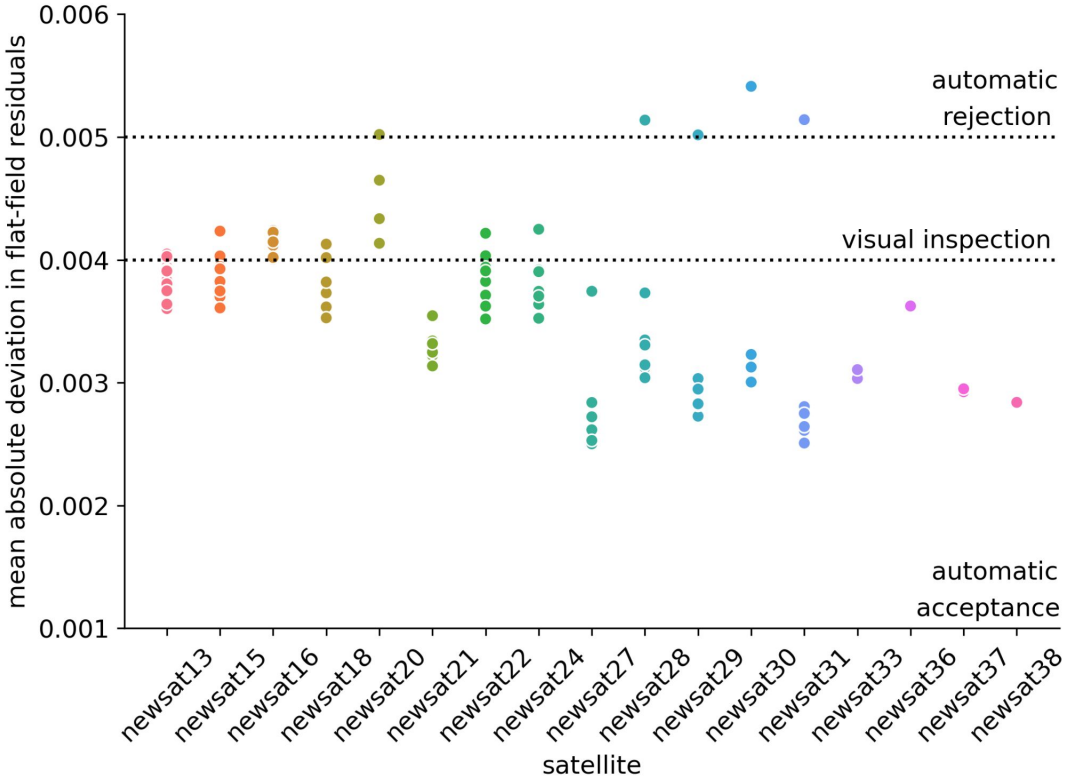
CONSISTENCY ACROSS THE FLEET



Monitoring of metrics will permit to fine tune the metrics per satellite

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Newsat 9
Date: 2023-03-23
Time: 08:51:50
Off-nadir: 14.99

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Newsat 31
Date: 2023-03-20
Time: 12:01:02
Off-nadir: 5.19

Time diff: 4hs
Off-nadir diff: 10°

Changes in shadows

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Conclusions

- Pixel-wise calibration:
  - Defined a procedure to recalibrate periodically the flat-field for the entire fleet, minimizing the operational effort
  - Accuracy goal of 1% achievable with production imagery acquired in 7–10 days
- E2E flat-field in-orbit calibration of the fleet:
  - Will be fully automated

THANK YOU!

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Special thanks to an amazing team!
Agustina Pose, Agustin Martina, Kati Takats, Tomas Link,
Luis Di Martino, Florian Pignol, Francesco Franzoni

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The Port of Algiers, Algeria
Multispectral Imagery
August 14, 2022
Satellogic NewSat-31