36th Annual Small Satellite Conference 2022

Low-Earth Orbit Multi-Spectral Imaging

NAPA-2 Turn-Key **Mission**: High-Resolution **Images** and **Data**

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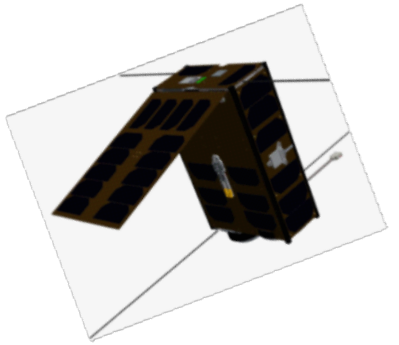
P.J. Bouwer, T. Prinsloo

The Mission



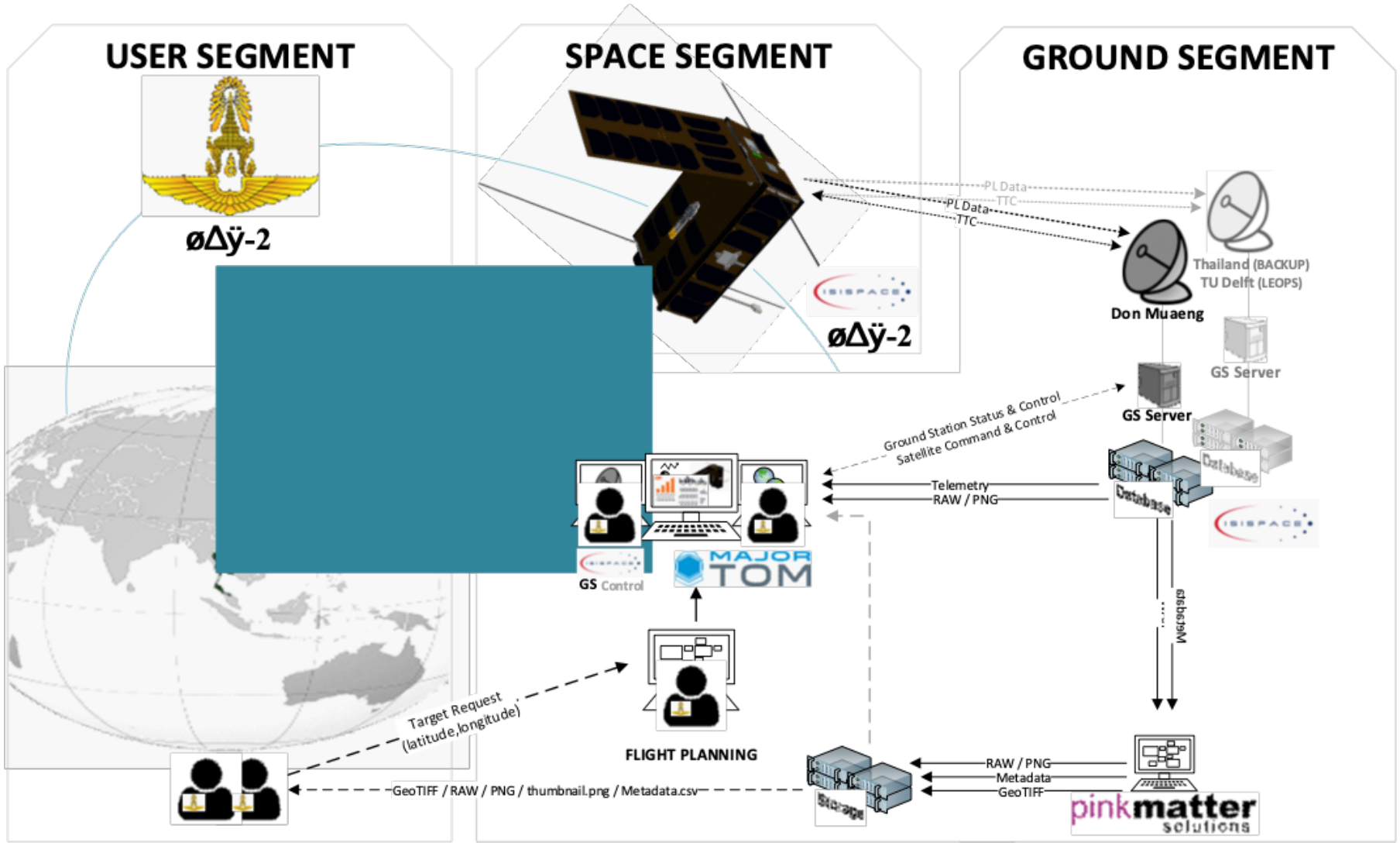
User Requirements

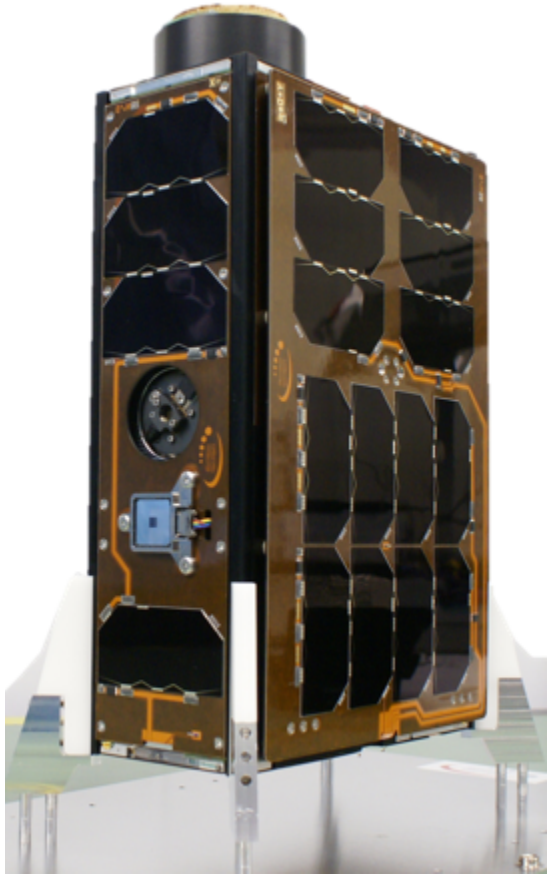
NAPA-2 - Royal Thai Airforce (RTAF)

- The satellite shall be able to **capture Thailand** and nearby area defined by latitude and longitude
- Ground targets shall be captured with a **GSD of <5m** at **500km** altitude
- The system shall support target capture **planning >24 hours before**
- All captured data shall be downlinked **within 24 hours** thereafter
- On ground **processing** of data shall be done up to **level L1B**

Don Mueang, Bangkok, RTAF Headquarters

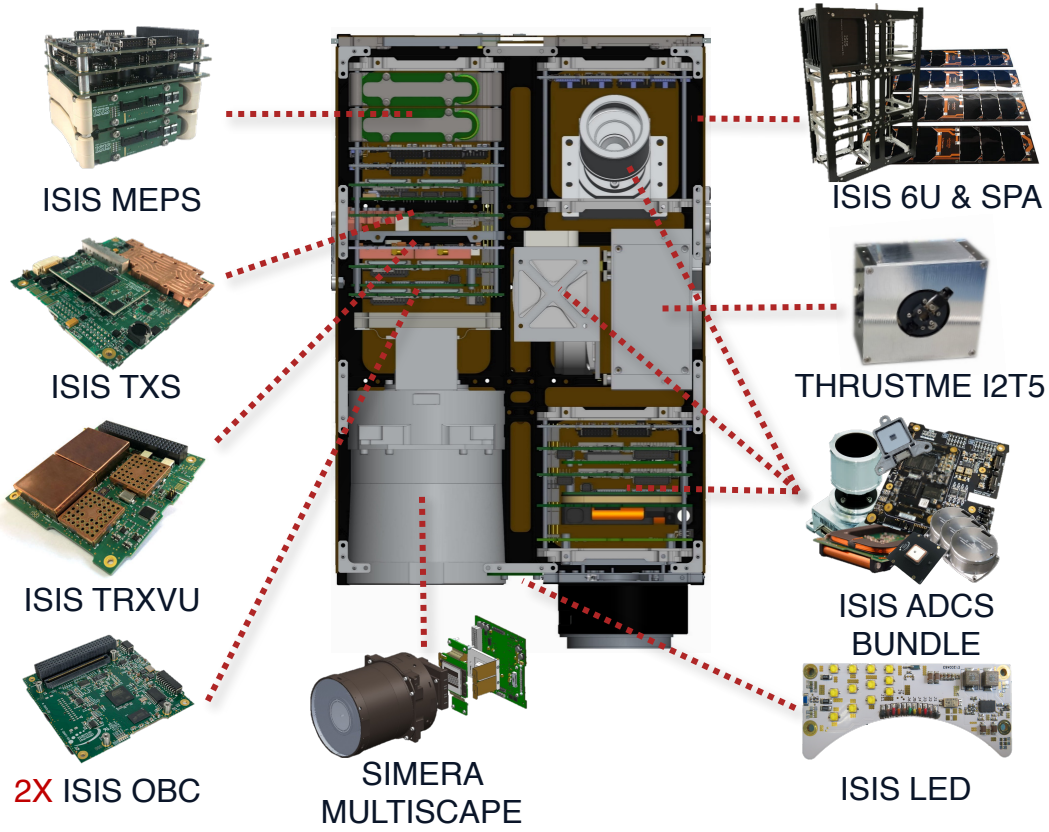
The System

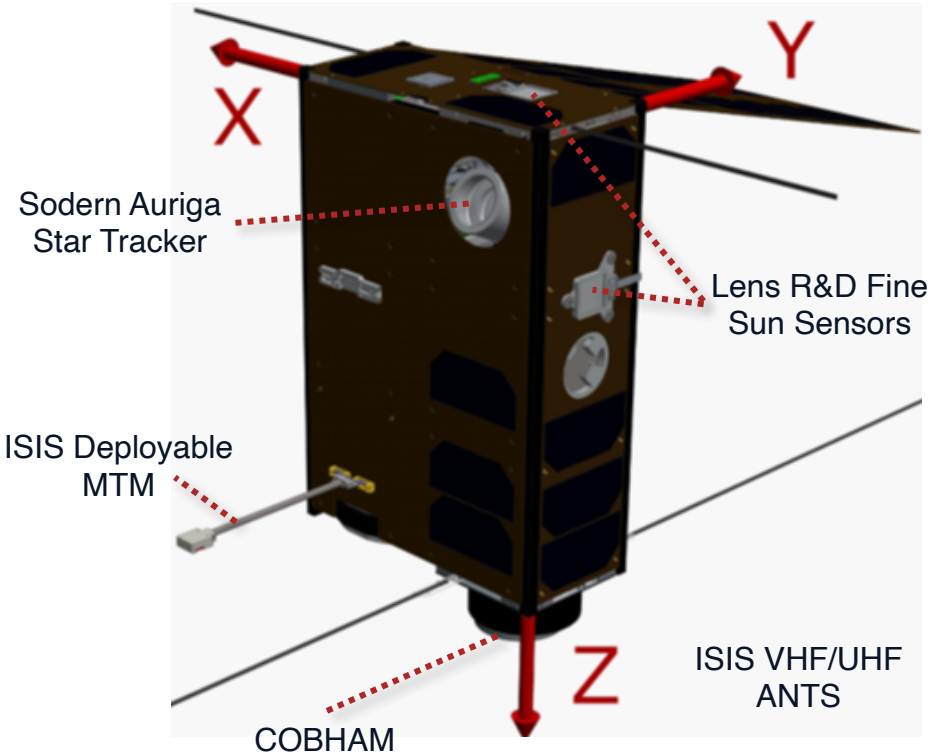

USER SEGMENT
SPACE SEGMENT
GROUND SEGMENT
øΔÿ-2
øΔÿ-2
PL Data
TTC
PL Data
TTC
Thailand (BACKUP)
TU Delft (LEOPS)
Don Muaeng
GS Server
GS Server
Ground Station Status & Control
Satellite Command & Control
Telemetry
RAW / PNG
Database
Database
GS Control
MAJOR TOM
FLIGHT PLANNING
Target Request
(latitude,longitude)
GeoTIFF / RAW / PNG / thumbnail.png / Metadata.csv
RAW / PNG
Metadata
GeoTIFF
Storage
pinkmatter solutions



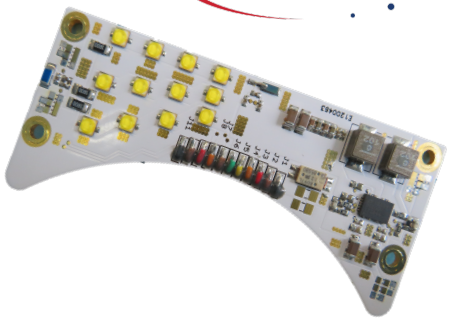
The Satellite

NAPA-2 SATELLITE





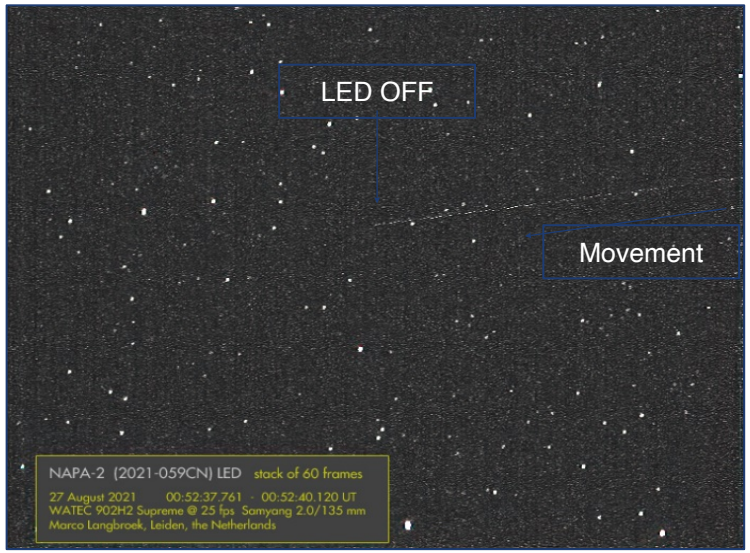
The Payloads

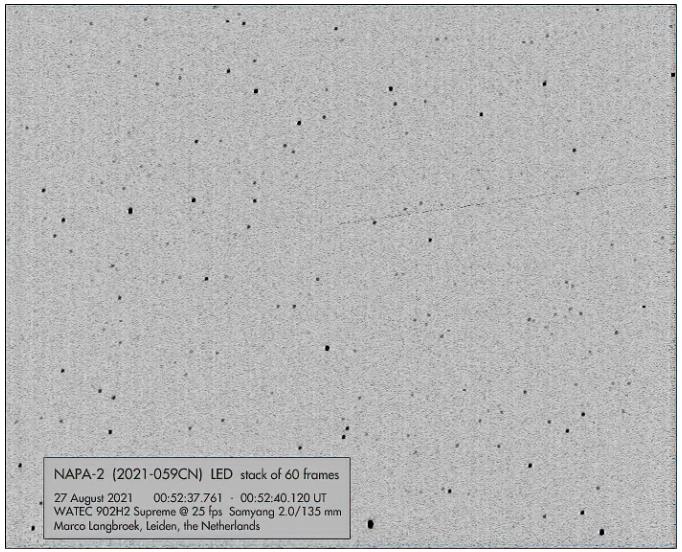


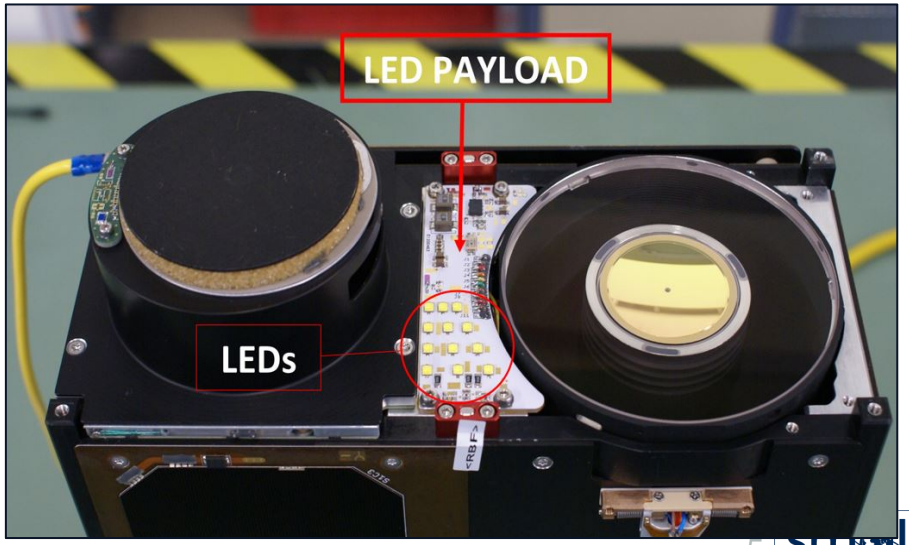
ISISPACE LED Board

LED-based satellite tracking

- Demonstrator for on-ground satellite tracking and telescope calibration
- Design includes 12 white OSLON LEDs, 150° FoV, ~370 candela
- Power consumption of <10W
- Custom implemented thermal and power FDIR
- Measured Vmag of +9.5







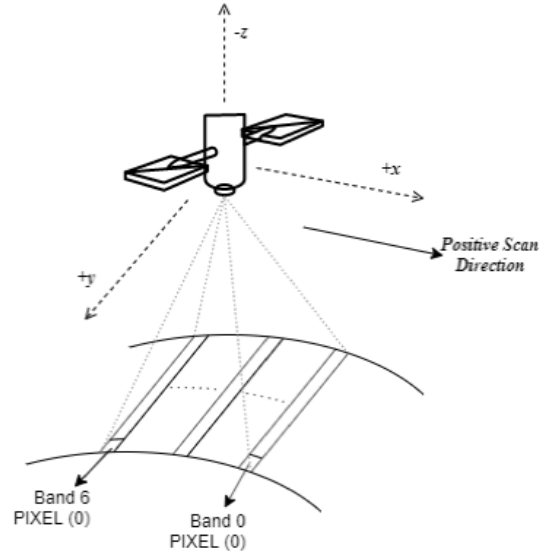
Marco Langbroek, https://sattrackcam.blogspot.com/2021/08/first-positive-observations-of-led.html

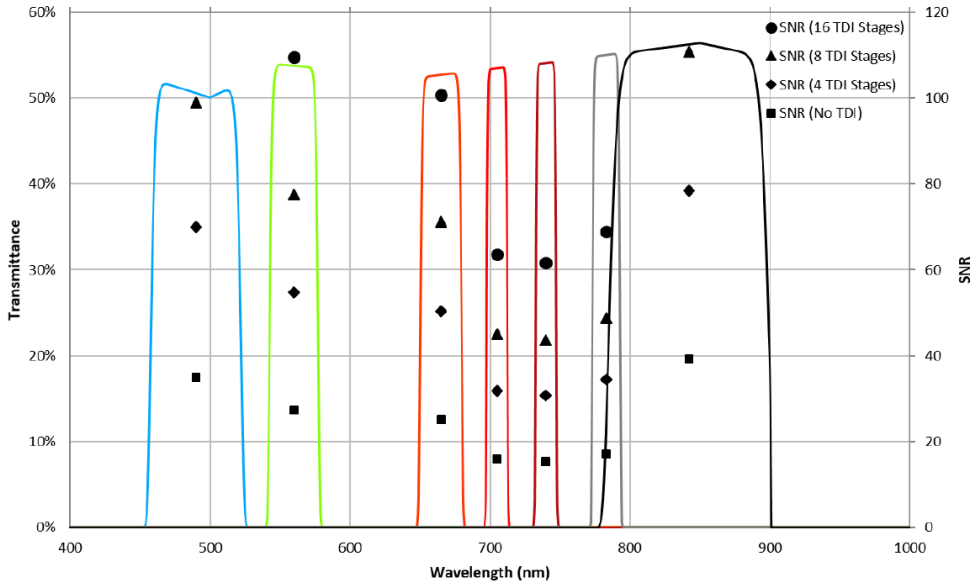
The Payloads

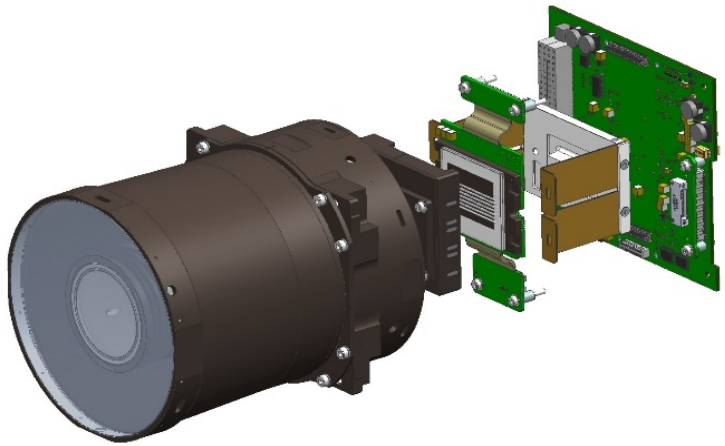
SIMERA Sense MultiScape CIS 100

7-Band high-resolution multispectral imager

- Visual (RGB) and Near IR spectral bands covering the 450 – 900nm range
- 5-meter Ground Sampling Distance (GSD) @500km altitude (swath 19km)
- Up to 16 configurable TDI stages @500km altitude
- CubeSat compatible volume of 1.5U







Band Use Cases
1-3 (RGB):
Object detection
Change monitoring
Reconnaissance
2-7 (RGVNIR):
Vegetation detection (NVDI)
Natural disaster monitoring

SIMERA SENSE

The Operational Concept

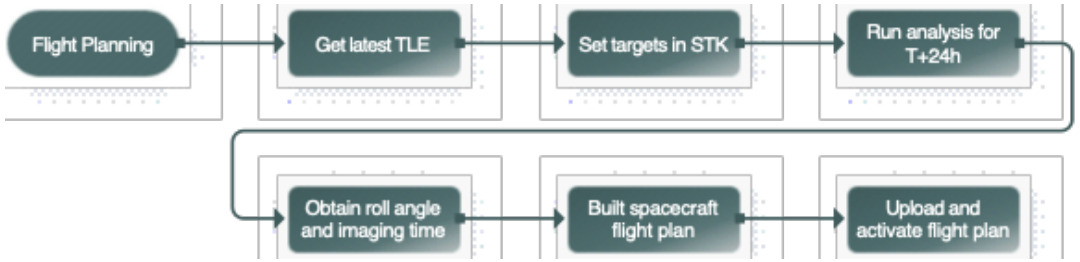
Imaging Concept of Operations

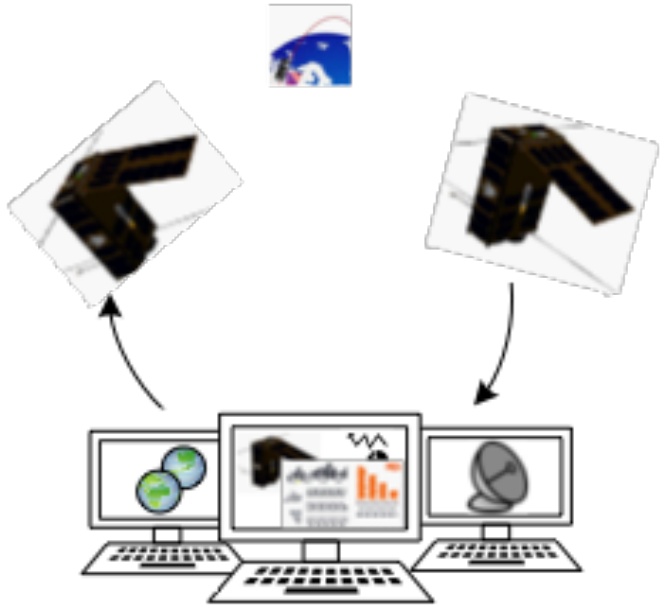
Three-staged approach

1. Flight Planning
   a) Obtain target requirements
   b) Compute camera and platform settings
   c) Develop satellite flight plan

2. Image Acquisition
   a) Upload and activate flight plan
   b) Ready platform and take image
   c) Transfer data

3. Data Retrieval
   a) Verify image acquisition execution
   b) Download thumbnail and inspect
   c) Download full data set





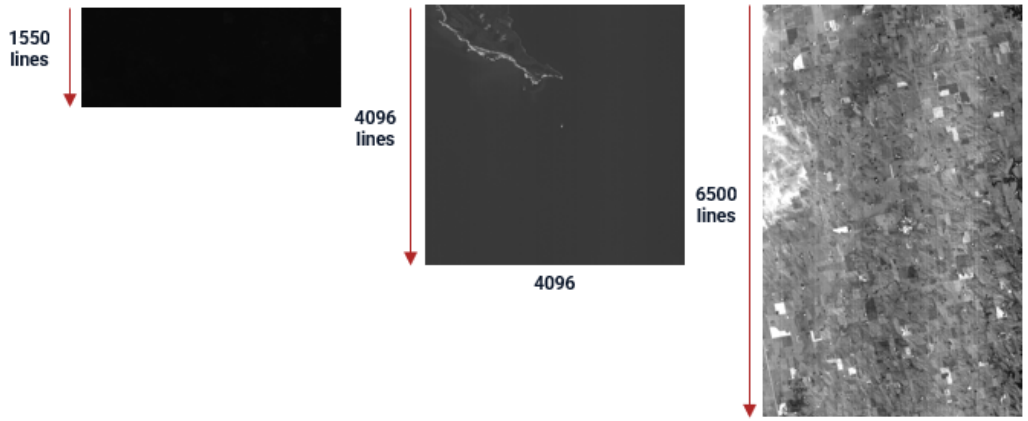
The Operational Concept

Flight Planning Challenges

Time accuracy

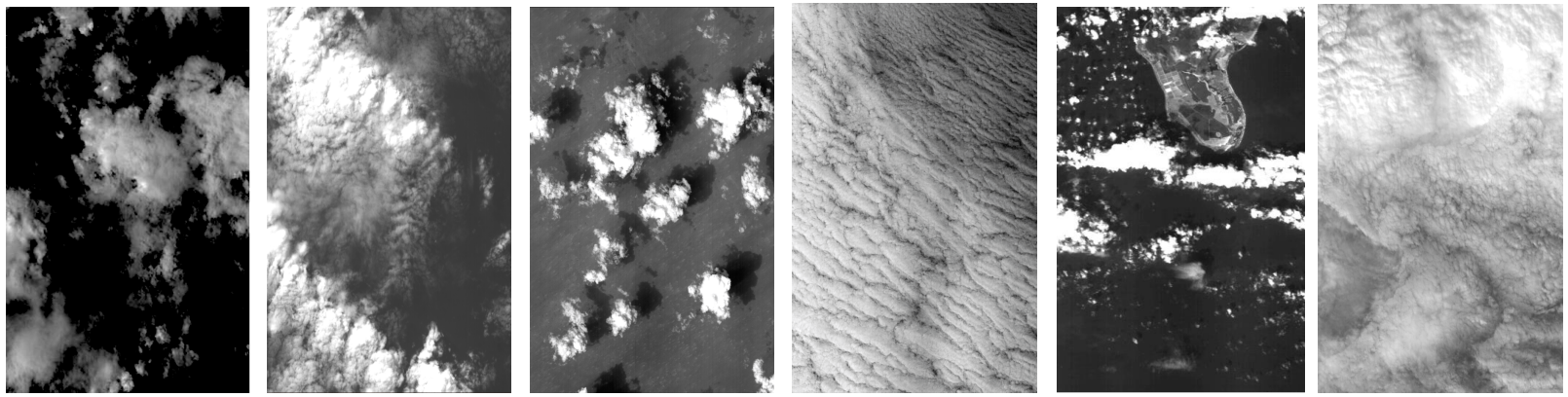
- Two-Line Element age
- Accuracy of command scheduler and command execution (PPS)
- Target in center of image

1s delay in-flight means ~7km delay in ground



Weather forecast

Check the weather forecast for the planned image acquisitions!



The Operational Concept

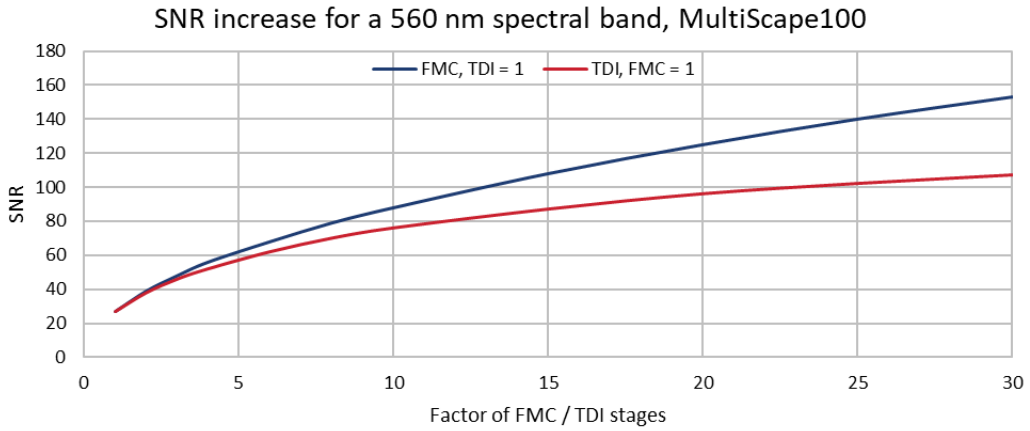
Image Acquisitions

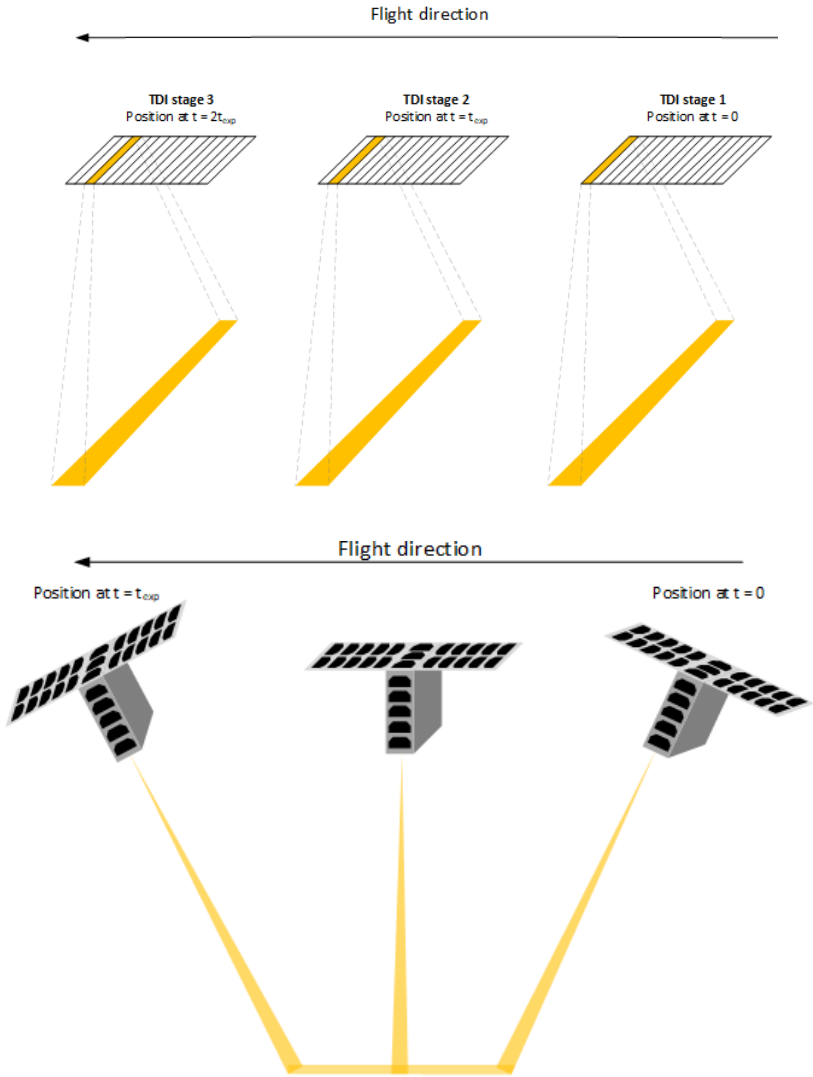
Calibration: Fly-over

- Nadir pointing [0,0,0] or with a pre-determined roll angle
- Varying the TDI-levels (1,2,4,8,16) pending target (pixel smear)
- Fixed line period/integration time based on NAPA-2's orbital altitude

Performance: Forward Motion Compensation

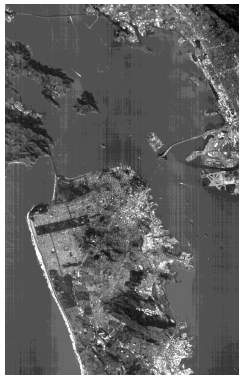
- Reduces effective ground speed velocity; increased integration time
- Can also be used as 'fly-over' (FMC1) **eliminating along-track time errors**
- Significantly impacts ADCS requirement(s) related to stability (pixel smear)





The Data

Thumbnail and RAW



~500KB

~40MB

Thumbnail usage

- Visual inspection and optimize downlink bandwidth usage

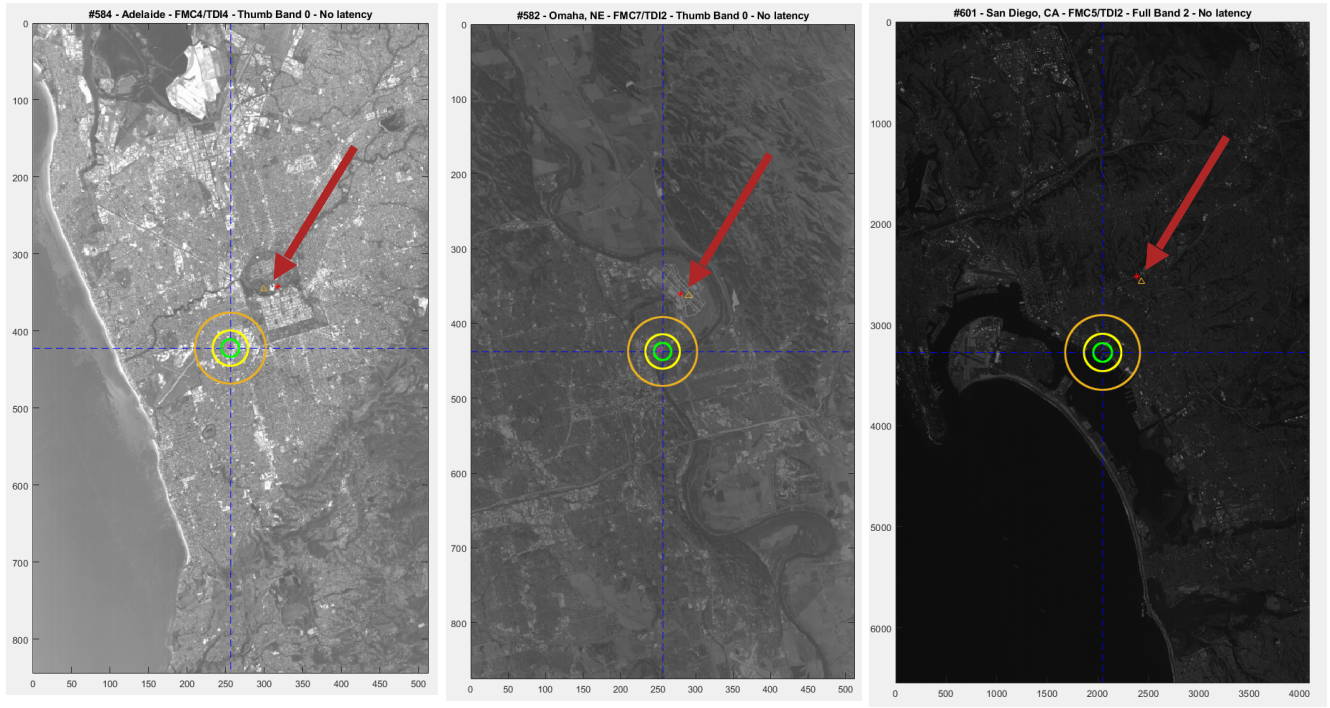
RAW data usage

- Determine ADCS/Platform performance
- Input for image processing

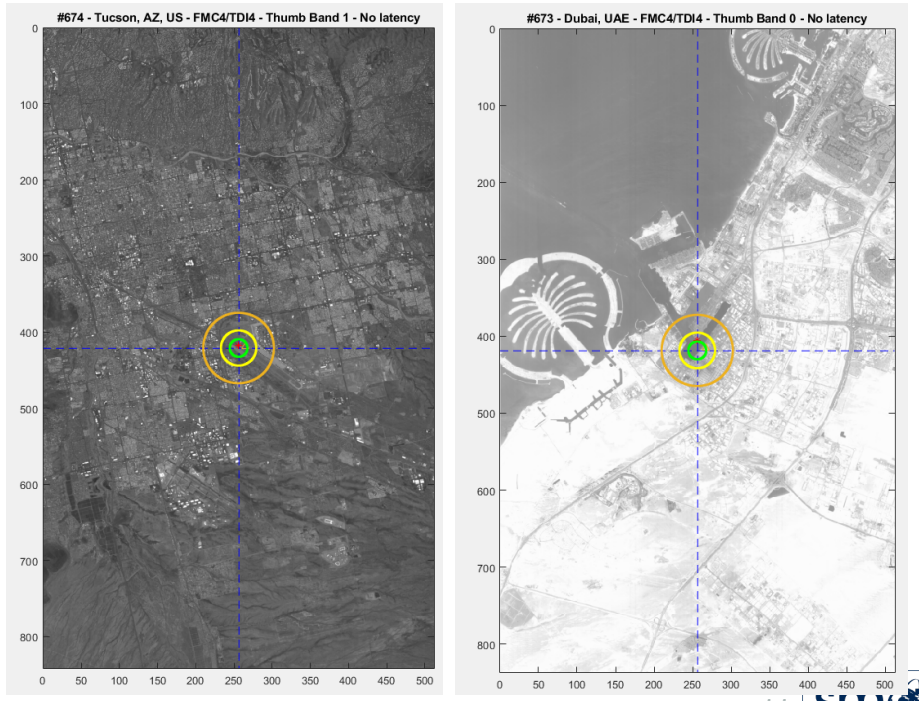
The Performance

Pointing Accuracy and Knowledge

- Initial images and metadata showed both overall pointing **accuracy** and **knowledge** to be >0.2°
- After acquiring **many** images, a consistent bias was observed in reported ADCS roll and pitch angles
  - Henceforth, the bias was considered during image acquisition planning to improve the pointing **accuracy**
  - ADCS configuration (STR mounting angles) updated to improve pointing **knowledge** (metadata)



Pointing accuracy > 0.2°, knowledge > 0.2°

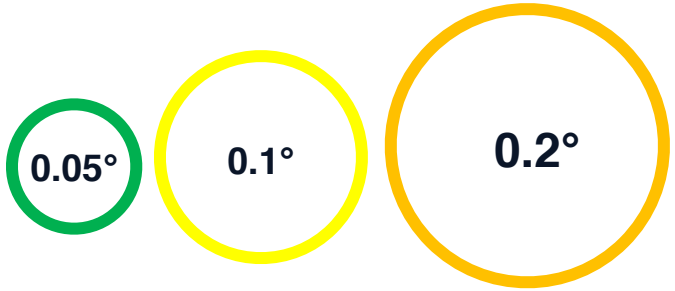


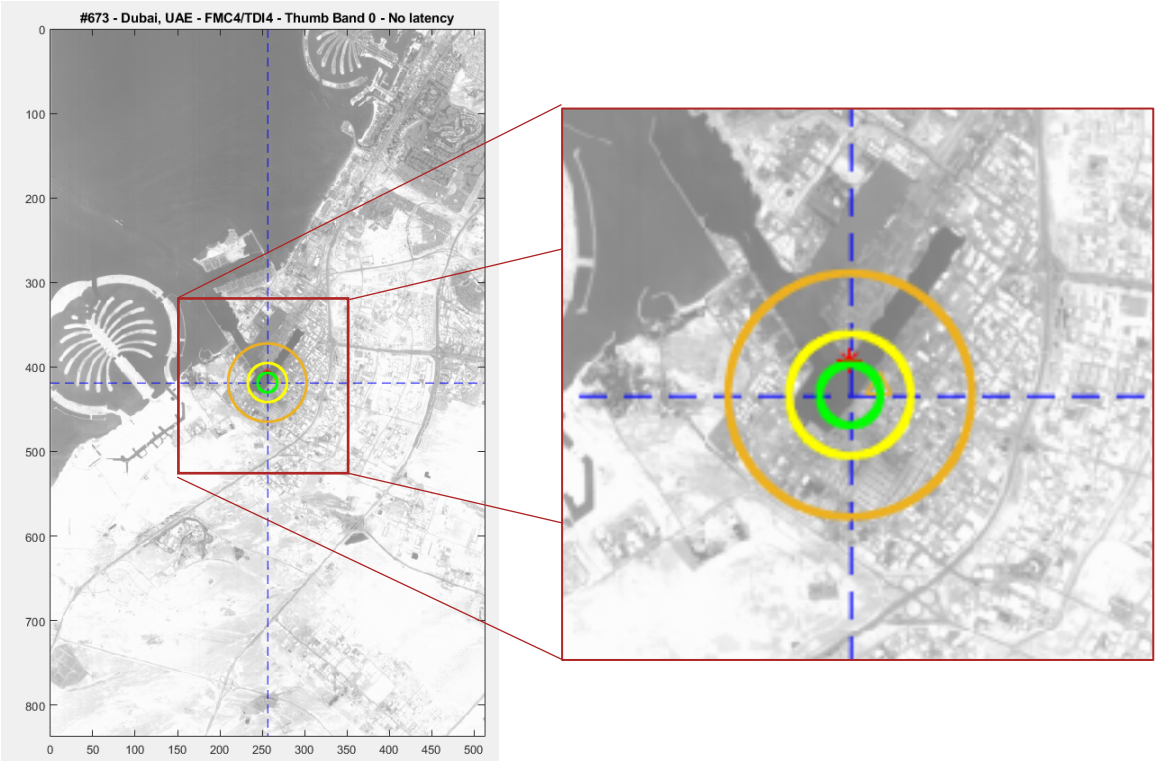
Pointing accuracy < 0.1°, knowledge < 0.1°

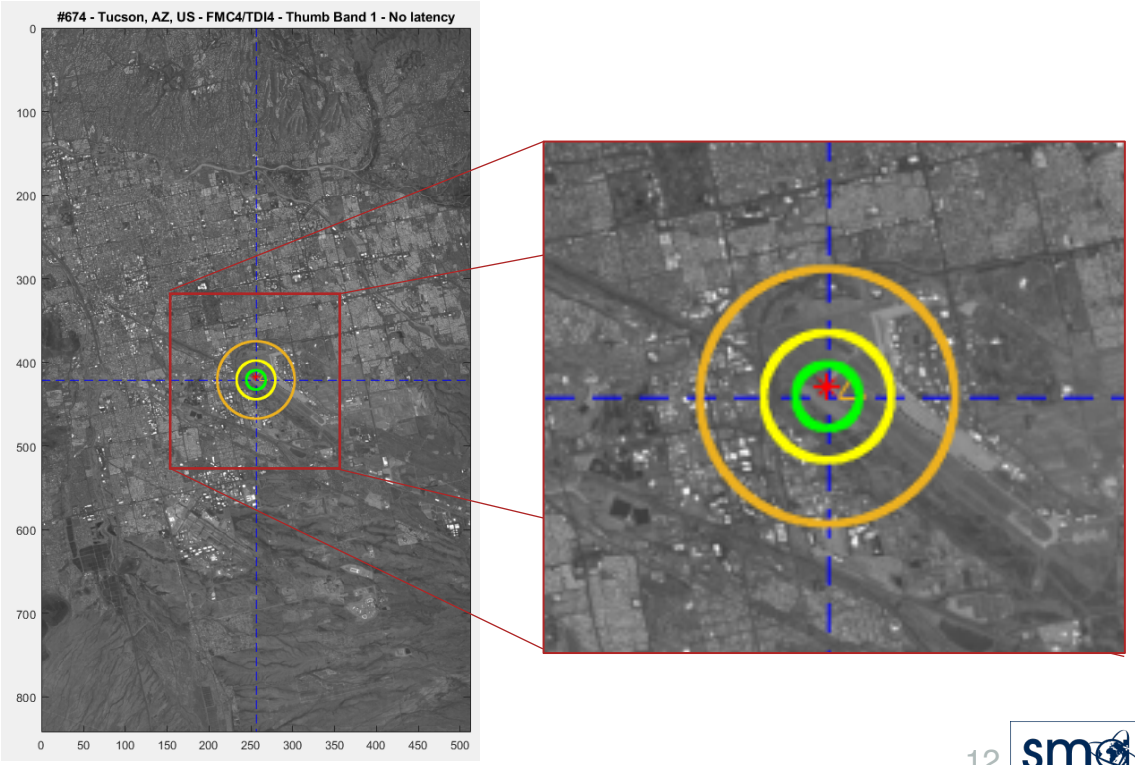
The Performance

Pointing Accuracy and Knowledge

- Red Star: Targeted point at a certain time-stamp
- Orange Triangle: AOCS attitude estimate on that time-stamp





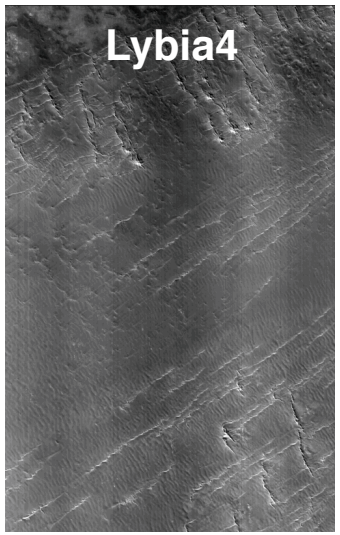


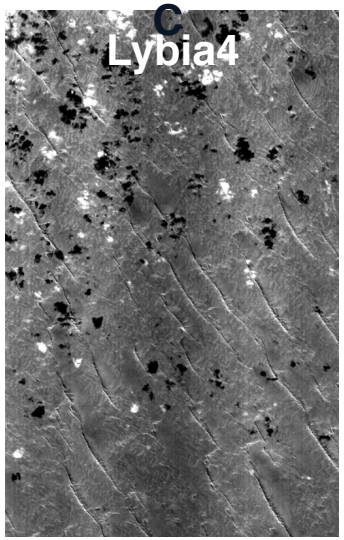
The Processing

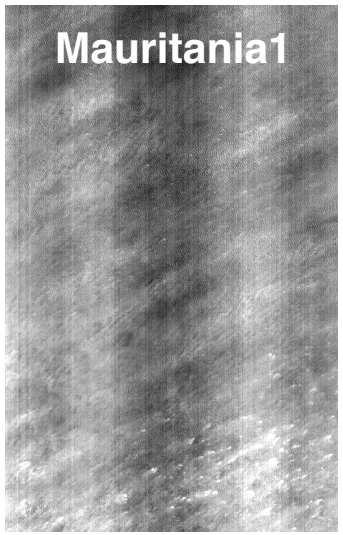
Geometric and Radiometric Calibration Inputs

- Iterative calibration process between ISISPACE and Pinkmatter Solutions
  - Different TDI settings: 1, 2, 4, 8, 16
  - Integration time fixed: f(altitude)
  - Constant satellite angle (nadir)
- Radiometric sites and Geometric sites targeted
  - **Radiometric:** Desert or snow-covered areas, high solar elevation
  - **Geometric:** Rectangular or clear architectural features (agriculture, urban areas)

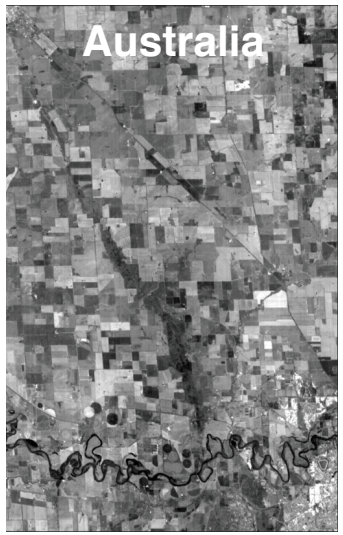
RADIOMETRIC







GEOMETRIC



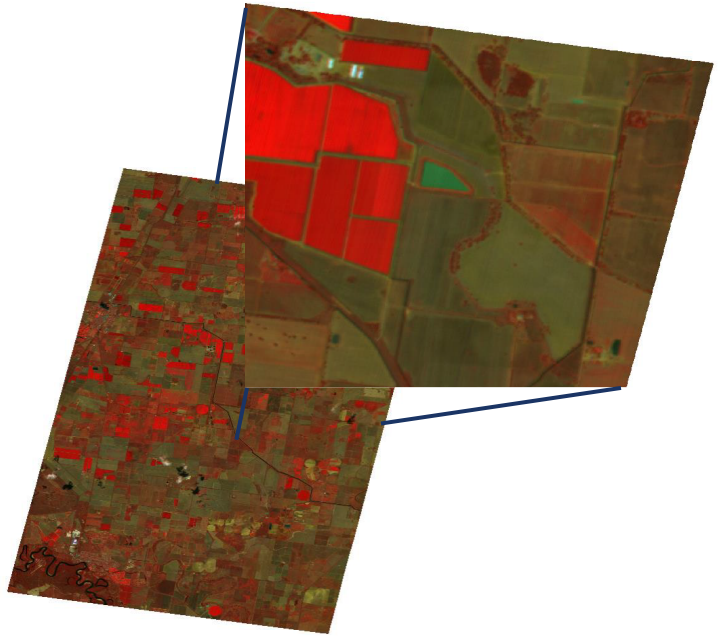
The Processing

Pinkmatter Solutions FarEarth

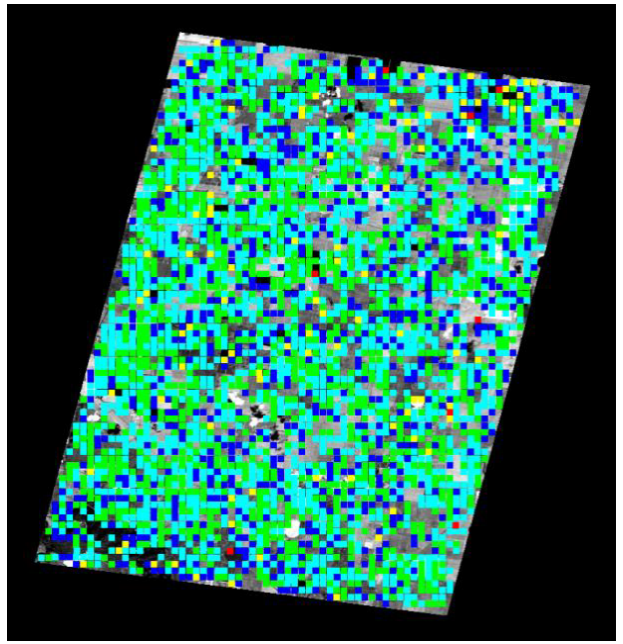
- Radiometric correction through **pre-flight calibration parameters** and **radiometric parameter file (RPF)**
- Geometric correction through **orthorectification**, **band alignment**, **viewing angle generation**
- Level 1B product data: GeoTIFF for each band, browse files .png, and metadata

RPF input

Band alignment



Geometric accuracy



Green: disparity between 0 and 0.5 pixels
Teal: disparity between 0.5 and 1.0 pixels
Blue: disparity between 1.0 and 2.0 pixels
Yellow: disparity between 2.0 and 5.0 pixels
Red: disparity larger than 5.0 pixels

The Processing

Achieved performance (so far)

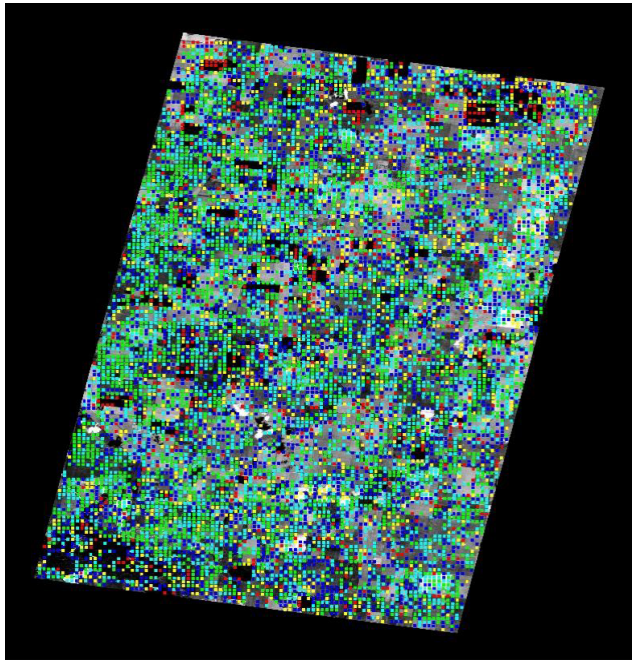
Geometric

- Band aligned scenes within 1 pixel (outliers expected on edge of the scene)
- Absolute geometric accuracy compared to Sentinel 2 is ~1-2 pixels

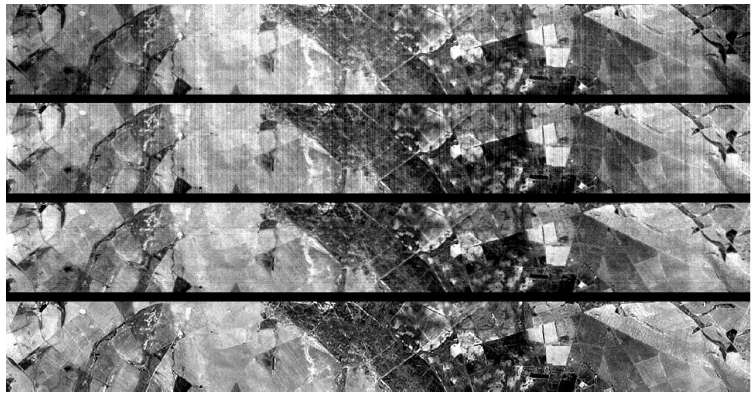
Radiometric

- Top Of Atmosphere (TOA) reflectance values (error & st.dev) compared to Sentinel-2 **<5%**

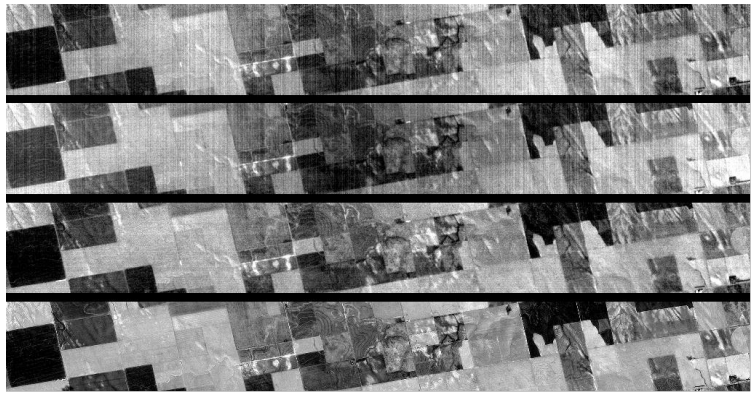
Ground Sampling Distance in the range of 5-8m



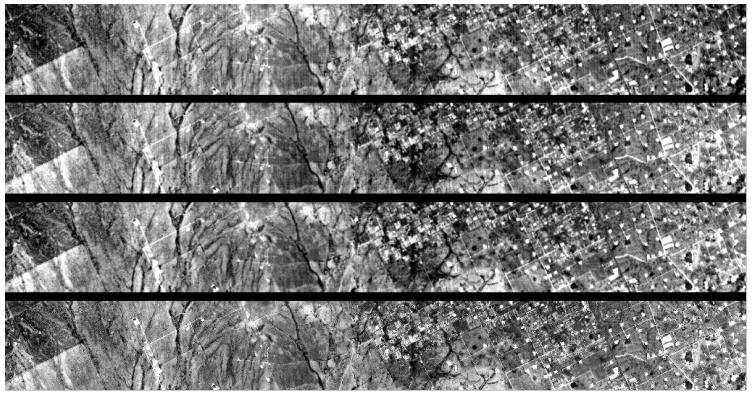
Disparity between NAPA-2 Band 3 (red) and Sentinel-2 L1C Band 4 (red)



Cape Town, Band 4 (Red-edge)



Kansas, Band 1 (Blue)



Permian Basin, US, Band 2 (Green)

Raw

Pre-flight parameters

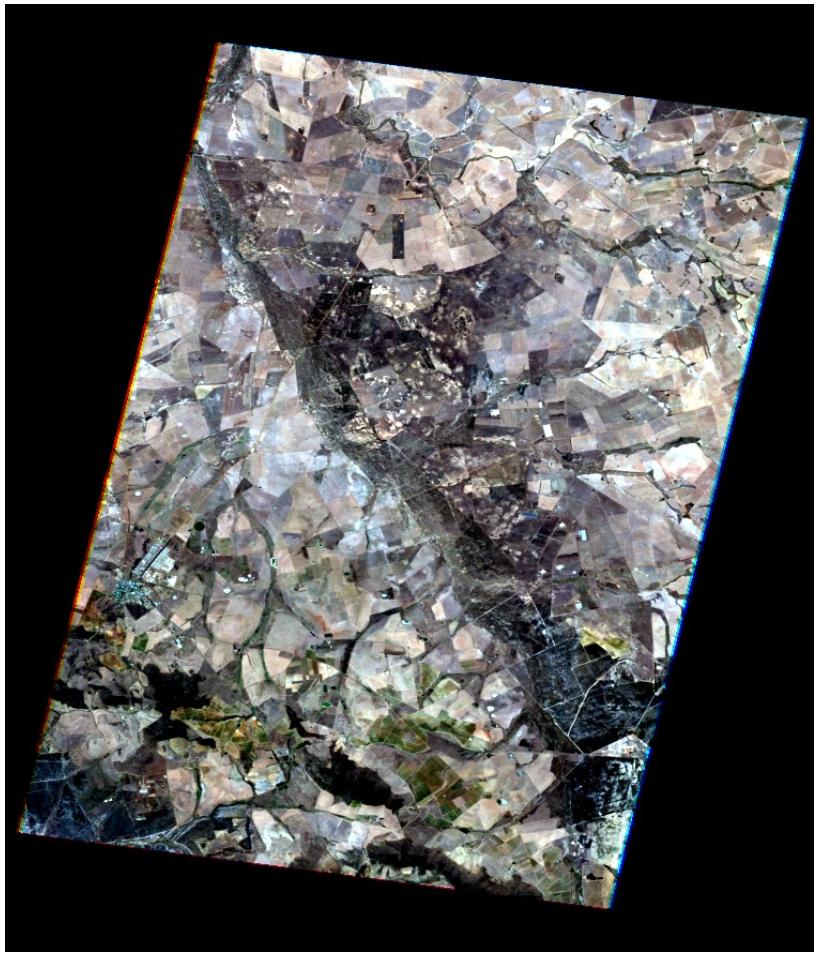
In-orbit calibration parameters

Sentinel-2 reference image

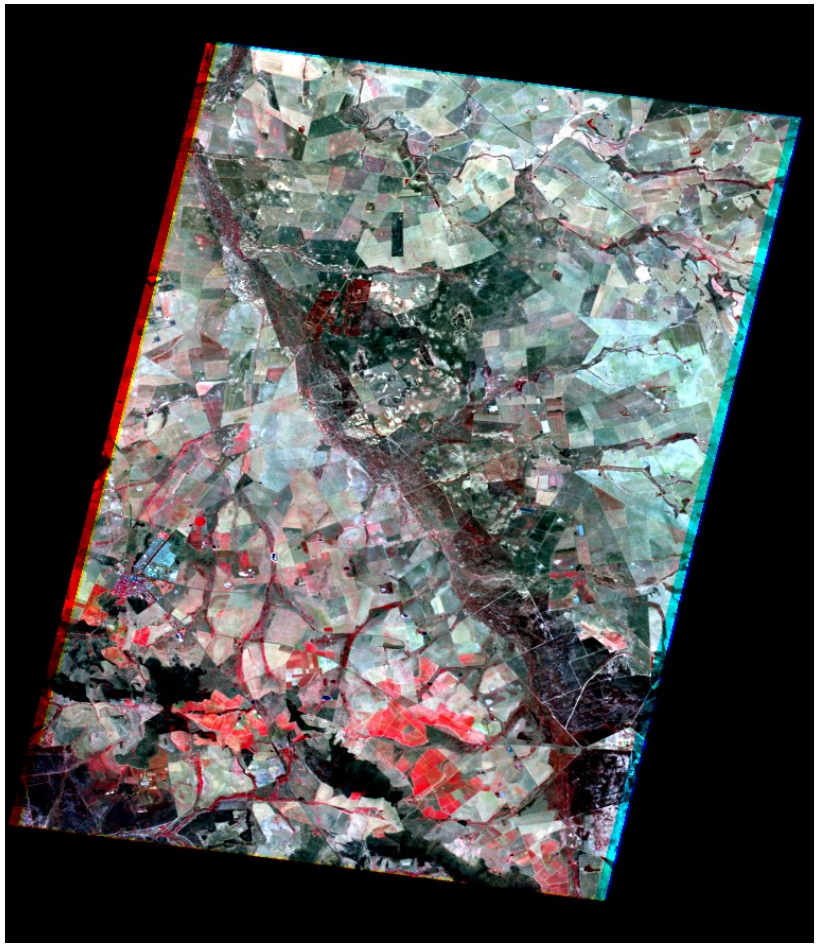
The Product

South Africa (north of Cape Town)

RAW (enhanced)



RGB – L1B



NRG – L1B

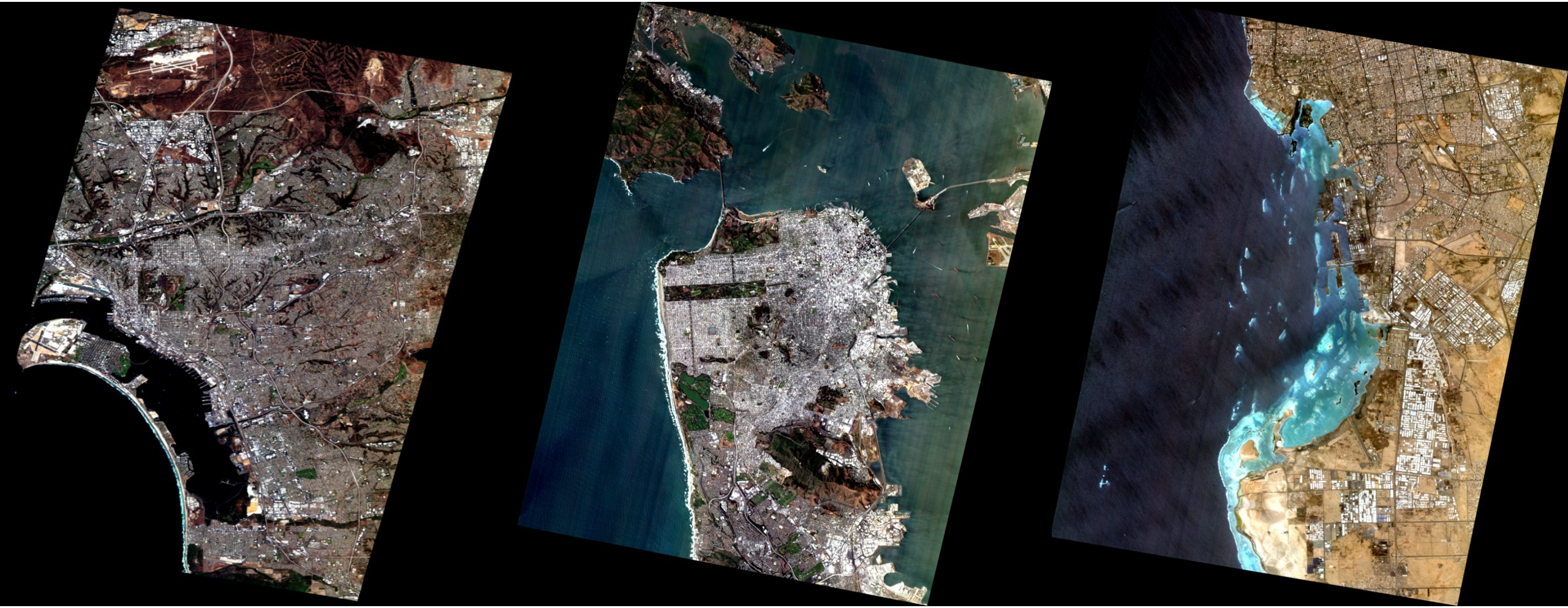
The Product

Cities (RGB – L1B)

San Diego

San Francisco

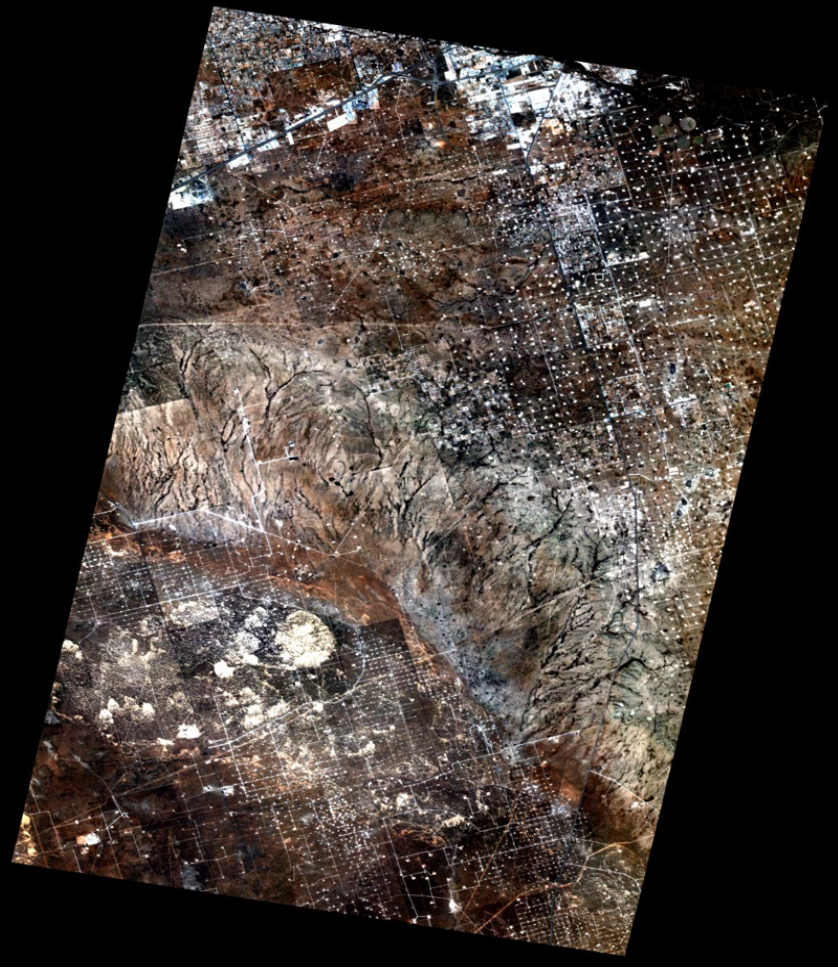
Jeddah



The Product

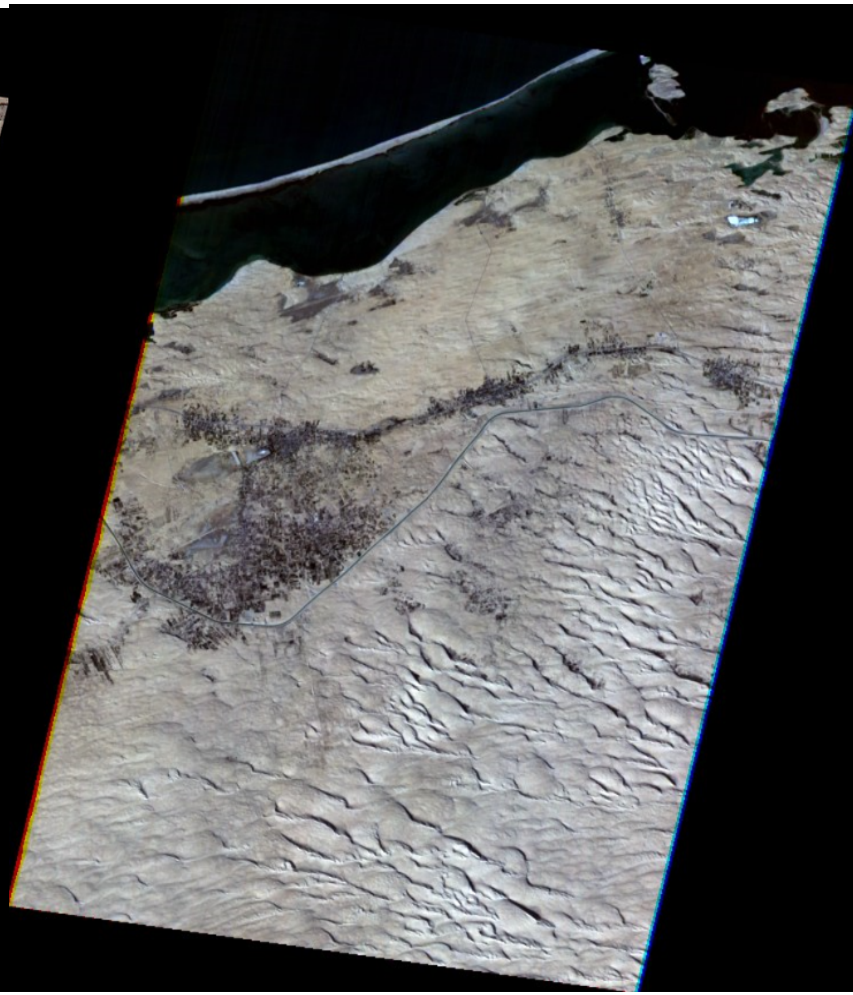
Landscape (RGB – L1B)

Permian Basin



Australia

Egypte coastline



The Product

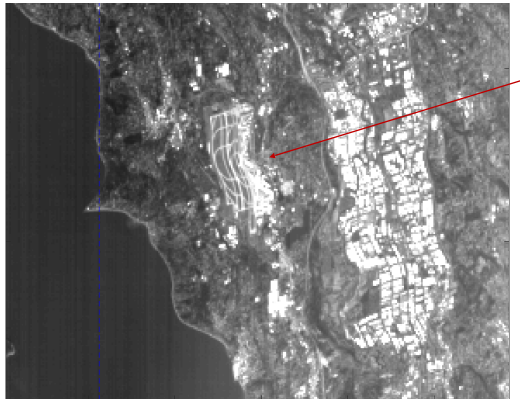
Zoom-in (RGB – L1B)

Dubai, UAE

The Product

Not so successful attempts…

Satellite instabilities



Airport not safe for landing!

Operational errors…

Behind every successful acquisition there are multiple failed acquisitions.
Taking multi-spectral images from space is challenging!

The Product

Dealing with the not-so-successful attempts

FMC factors of up to 50x were executed but instability occurs caused by reaction wheels

- Zero-wheel crossings
- Wheel speeds in unfavorable frequency range(s)

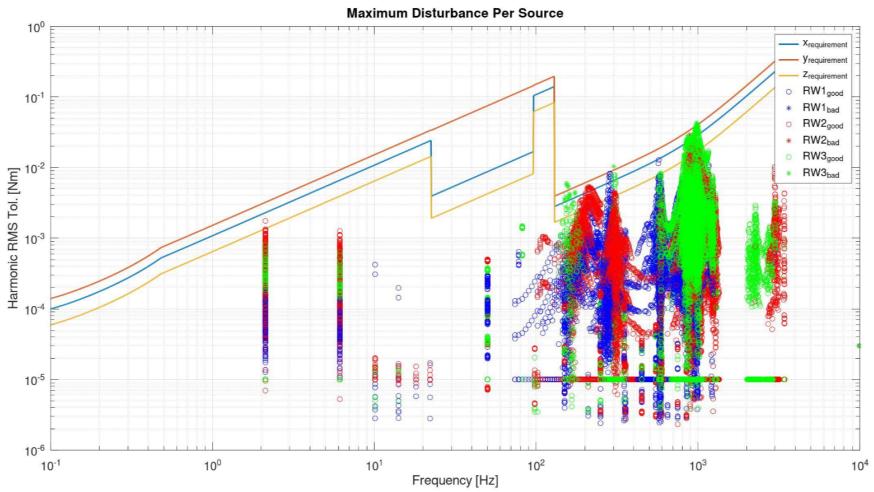
Assessment of micro-vibrations

- Ongoing cooperation with ESA to identify the cause of the instabilities
- Identify the effect of micro-vibrations on optical quality

Initial lesson/implementation for future missions: Fly **four** reaction wheels

Allow (some) flexibility in choosing reaction wheel speeds (set a bias) to avoid:

- Critical frequency ranges
- Zero-wheel crossings



The Future

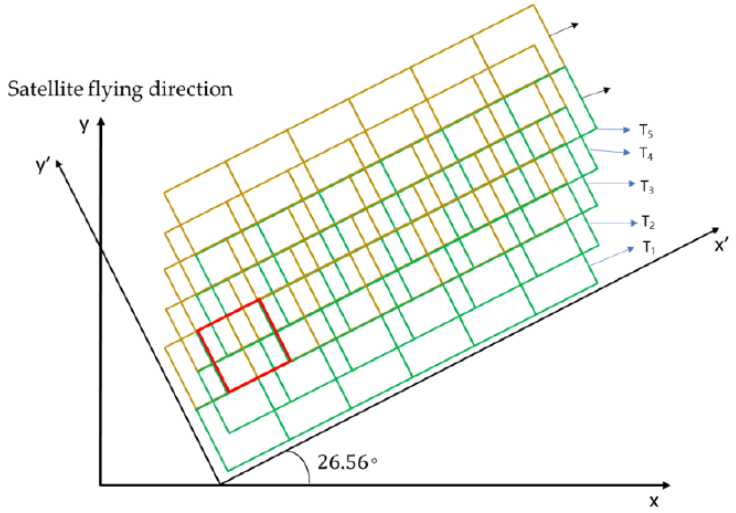
Processing Improvements and Imaging

Improve on-ground processing

- Improve radiometric calibration files (more data)
- Employ on-ground processing techniques to increase resolution (GSD)

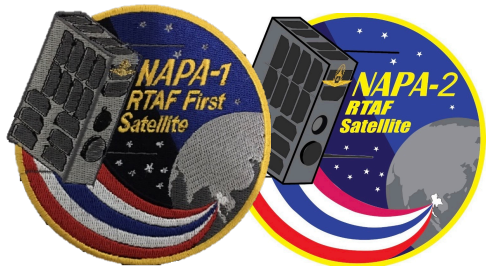
Employ super-resolution technique

- Improve spatial resolution by flying at a fixed yaw rotation and increasing the sensor frame rate - potential factor 2 increase in resolution
- First results are promising yet not constant



Potential successful super-resolution images obtained

Thank you



Hugo Brouwer & NAPA-2 OPS Team

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Booth #007

ISISPACE