

First Results of the DESIS Imaging Spectrometer on board the International Space Station

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Thanks to: Kara Bruch⁽⁶⁾, Birgit Gerasch⁽¹⁾, Burghardt Günther⁽⁴⁾, Heath Lester⁽⁷⁾, Jack Ickes⁽⁷⁾, Harald Krawczyk⁽¹⁾, David Krutz⁽⁴⁾, Ben Murphy⁽⁷⁾, Mary Pagnutti⁽⁶⁾, Robert Ryan⁽⁶⁾, Thomas Säuberlich⁽⁴⁾, Ilse Sebastian⁽⁴⁾, Ingo Walter⁽⁴⁾

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(4) DLR German Aerospace Center, Institute of Optical Sensors, Berlin-Adlershof

(5) DLR German Aerospace Center, German Remote Sensing Data Center, Neuztrellitz

(6) I2R Innovative Imaging and Research Corp

(7) Teledyne Brown Engineering



Knowledge for Tomorrow



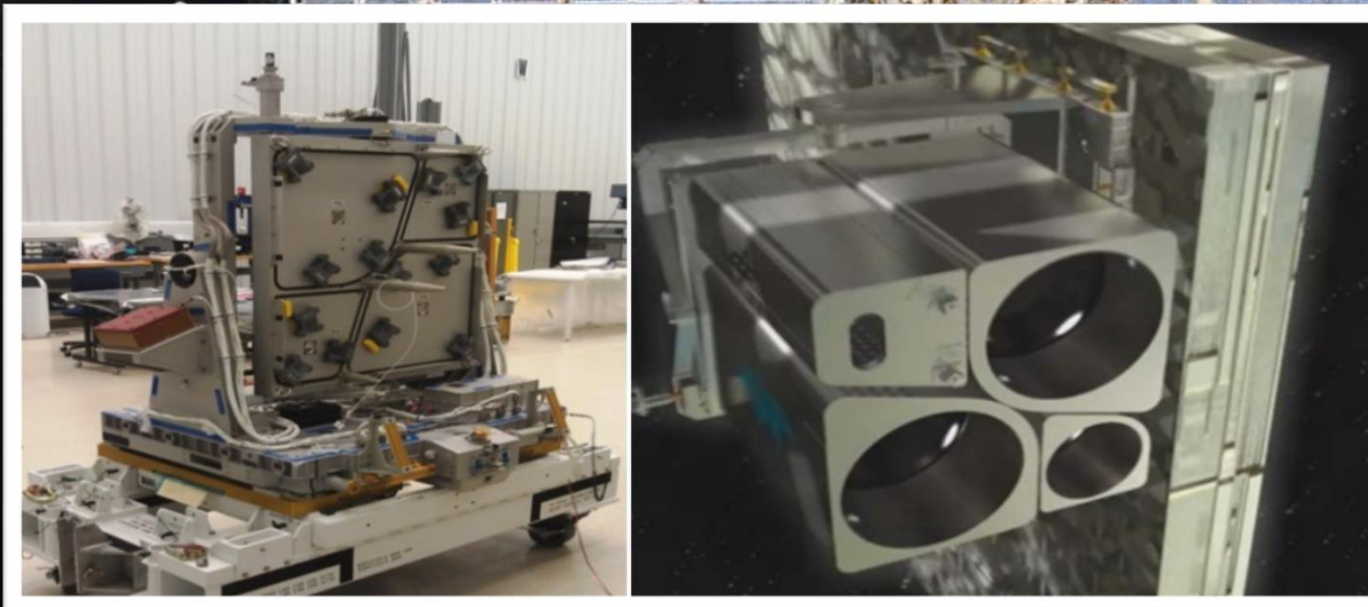


DEGIS, MUSES and ISS



Teledyne Brown Engineering (USA) and DLR have partnered to build and operate the DLR Earth Sensing Imaging Spectrometer (**DEGIS**) from the Teledyne-owned Multi-User System for Earth Sensing (**MUSES**) Platform on the ISS

DESI, MUSES and ISS



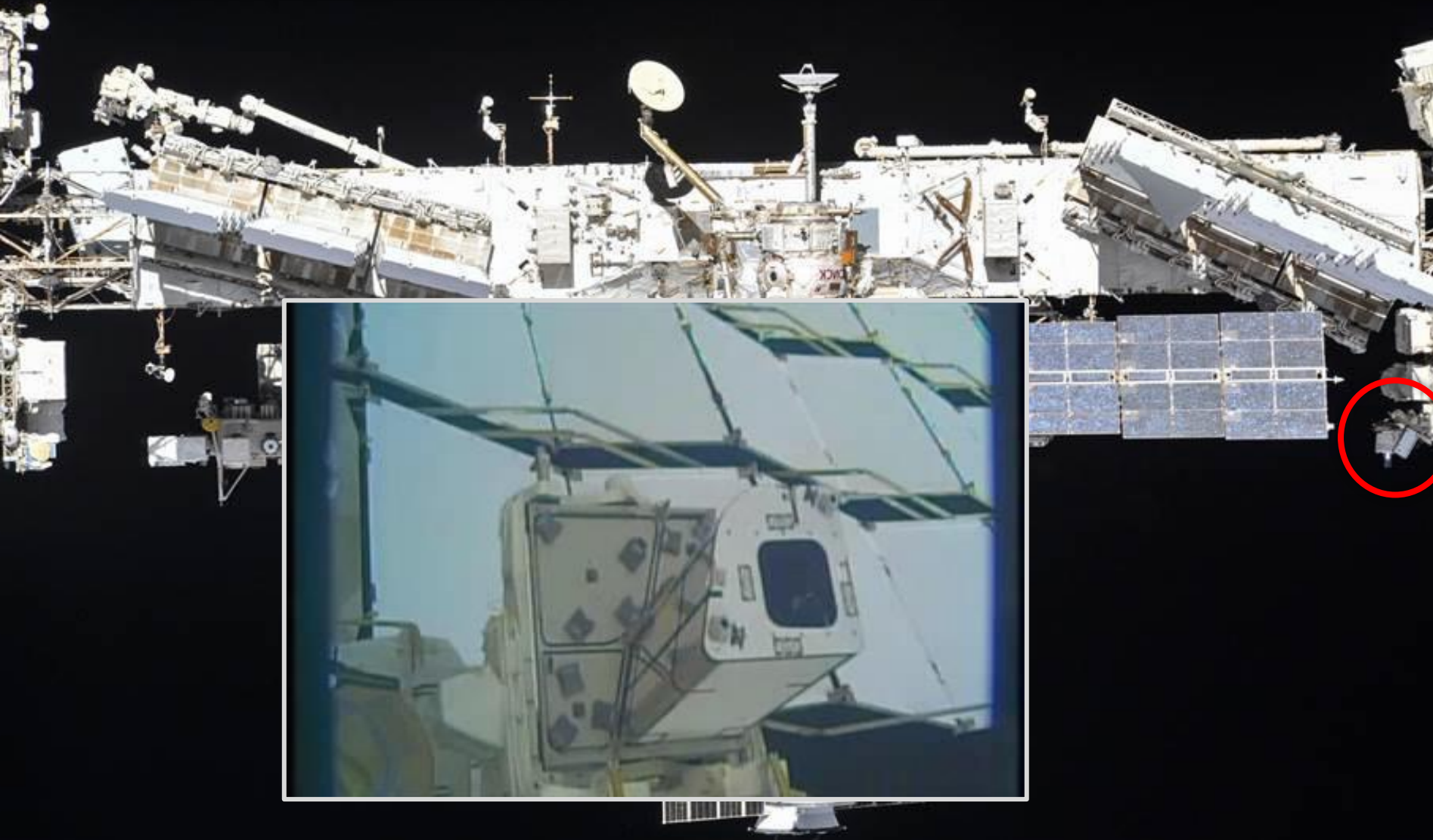
Teledyne Brown Engineering (USA) and DLR have partnered to build and operate the DLR Earth Sensing Imaging Spectrometer (**DESI**) from the Teledyne-owned Multi-User System for Earth Sensing (**MUSES**) Platform on the ISS

MUSES provides accommodations for two large and two small hosted payloads and provides **core services** for the instruments like

- **Position** via GPS (1 Hz)
- **Attitude** via Startracker + MIMU (10 Hz)
- **Master time** (acc. <150 μ sec)
- **2 Gimbals** $\pm 25^\circ$ for/back; 45° backboard; 5° starboard
- **Downlink** 225 Gbit / day Ku band



DEGIS, MUSES and ISS



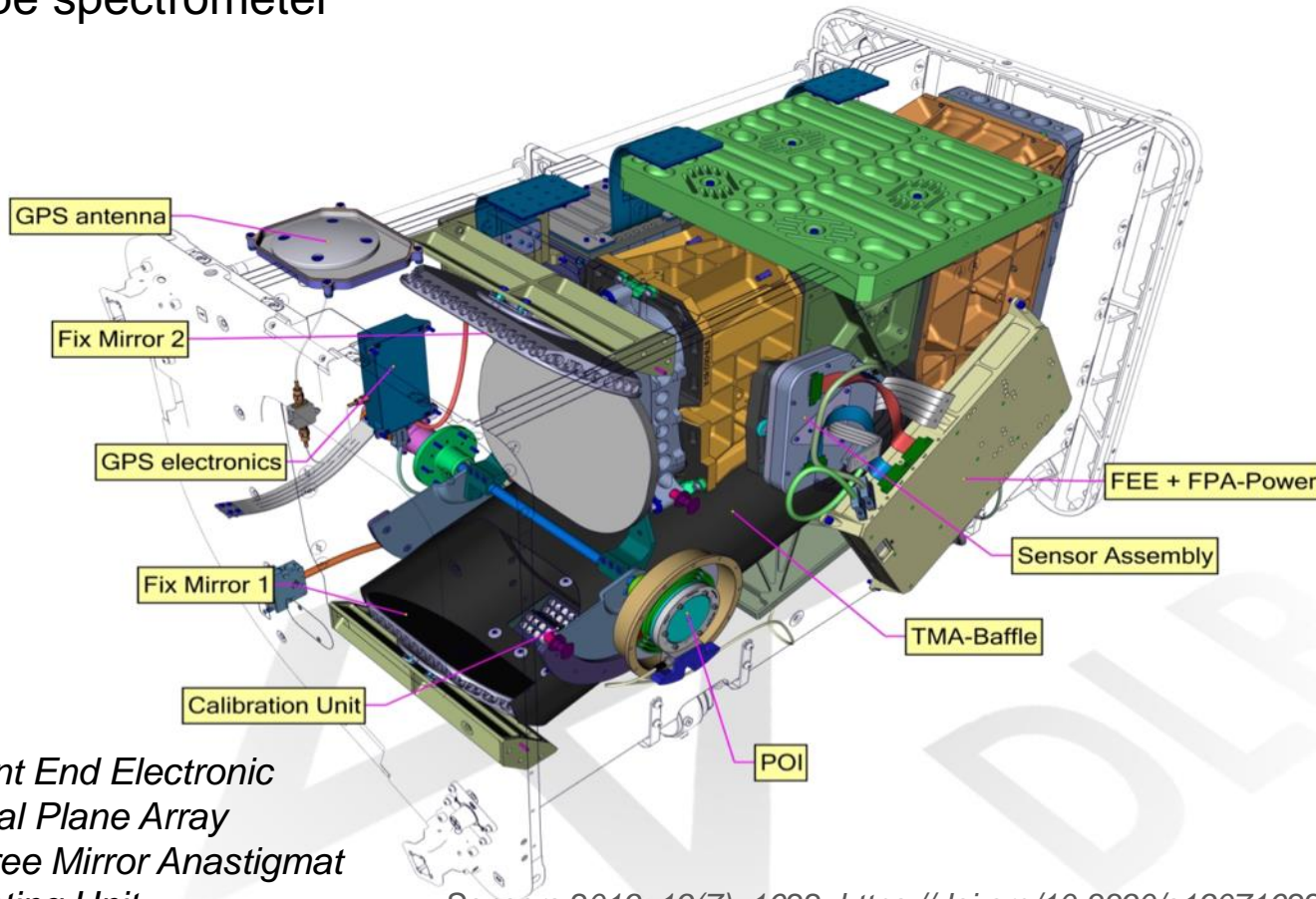
Teledyne Brown Engineering (USA) and DLR have partnered to build and operate the DLR Earth Sensing Imaging Spectrometer (**DEGIS**) from the Teledyne-owned Multi-User System for Earth Sensing (**MUSES**) Platform on the ISS

DEGIS, the hyperspectral sensor developed by DLR, which is currently the first payload of MUSES.

DLR also established the Ground Segment and licensed the SW processors to Teledyne running in an Amazon Cloud

DESIS Instrument

- Hyperspectral instrument consisting of a Three-Mirror-Anastigmat (TMA) telescope combined with an Offner-type spectrometer



- Equipped with:
 - **Calibration Unit:** 2 banks with 9 LED types. Allows for Radiometric & Spectral calibration/monitoring
 - **Pointing Unit:** Changes the instrument line of sight in the along-track direction between $\pm 15^\circ$
Allows for *BRDF observation mode* and *Forward Motion Compensation (FMC) mode*
 - **GPS receiver:** working as a time calibration unit for latency calibration and jitter measurement

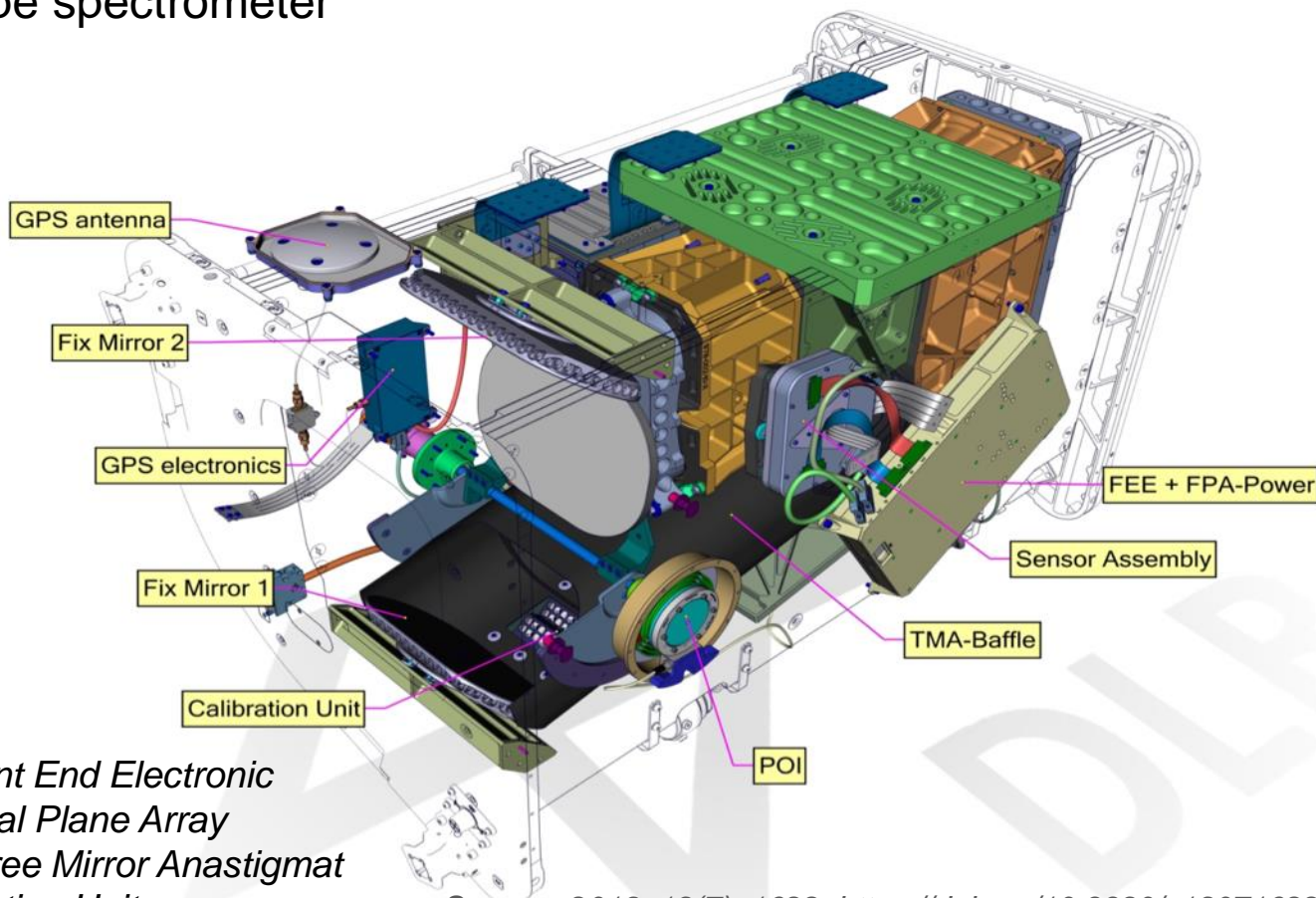
FEE: Front End Electronic
FPA: Focal Plane Array
TMA: Three Mirror Anastigmat
POI: Pointing Unit

Sensors 2019, 19(7), 1622; <https://doi.org/10.3390/s19071622>



DESIS Instrument

- Hyperspectral instrument consisting of a Three-Mirror-Anastigmat (TMA) telescope combined with an Offner-type spectrometer



Mission Instrument	MUSES/DESIS
Target lifetime	2018-2023
Off-nadir tilting (across-track, along-track)	-45° (backboard) to +5° (starboard), -40° to +40° (by MUSES and DESIS)
Spectral range	400 nm to 1000 nm
Spectral acc., bands	2.55 nm, 0.5 nm, 235 bands, 118 (bin 2), 79 (bin 3), 60 (bin 4)
Software Binning (sampling distance, number bands)	Binning 2 (5.1 nm, 118 bands) Binning 3 (7.6 nm, 79 bands) Binning 4 (10.1 nm, 60 bands)
Radiometry (res., acc.)	13 bits, ~10%
Spatial (res., swath)	30 m, 30 km (@ 400 km)
SNR (signal-to-noise)	195 (w/o bin.) / 386 (4 bin.) @ 550 nm
Instrument (mass)	93 kg
Capacity (km, storage)	2360 km per day, 225 GBit

FEE: Front End Electronic
FPA: Focal Plane Array
TMA: Three Mirror Anastigmat
POI: Pointing Unit

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DESIS Chronology



2014 / 2015
MUSES / DESIS
mission
starts



7. June 2017
MUSES installation on ISS



29. June 2018
DESIS launch from
Cape Canaveral to ISS
via SpaceX Dragon



27. - 28. August 2018
Unpacking of DESIS and
installation in MUSES



Orbit and Products

- Not Sun-synchronous orbit at ~400 km altitude, 51.6° inclination, covers 75% of Earth and 95% of populated Earth (between 55° N and 52° S). Orbit period 93 minutes. Revisit time 3 to 5 days (average)

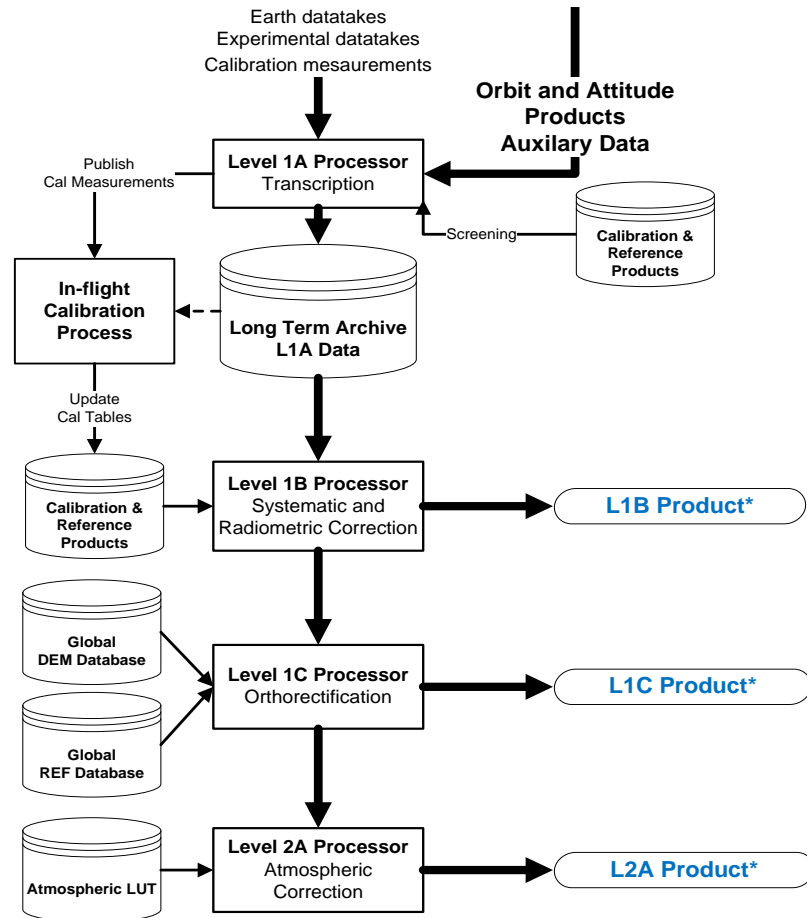


DESIS L1A product catalogue (<https://repositorio.dlr.de/handle/document/3604>)



Data Processing

Which products are getting the user



Products:

- **Level 0 (L0)**
 - Raw data (Datatakes up 100 tiles 30x30 km², trajectory files, DC)
- **Level 1A (L1A)**
 - Tiled images, browse image, metadata, quality flags <= archived
- **Level 1B (L1B)***
 - Top of Atmosphere (TOA) radiance ($W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$)
 - Systematic and radiometric correction (rolling shutter, smile, suspicious pixels,....)
 - All metadata attached for further processing
- **Level 1C (L1C)***
 - Level 1B data ortho-rectified, re-sampled to a specified grid
 - Global DEM (SRTM, 1arcsec), sensor model refinement using global reference image (Landsat-8 PAN with acc. 18m CE90)
- **Level 2A (L2A)***
 - Ground surface reflectance (i.e. after atmospheric corrections)
 - With and w/o terrain correction

Processors at the Ground Segments

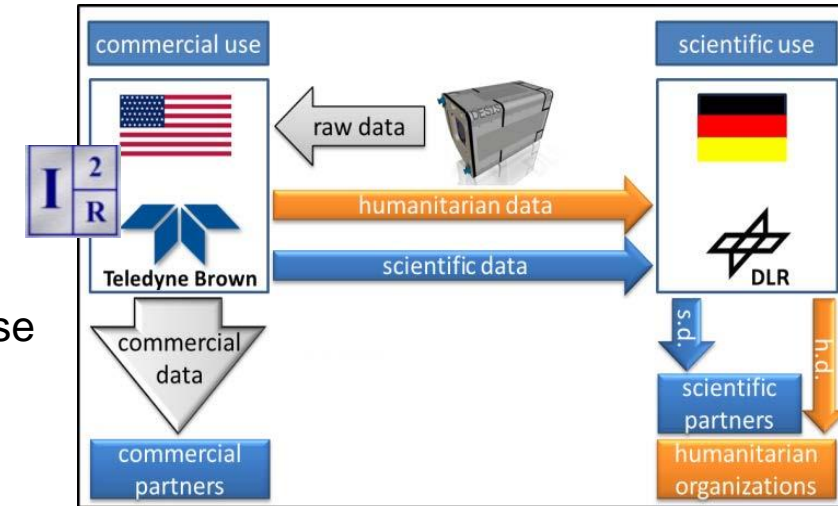
- Fully automated
- Run 'on-request' over archived data
- Two instances: one at Teledyne (Amazon Cloud), one at DLR. Same processing

*Delivery product



Data Policy

- DESIS is operated by Teledyne (TBE), data are distributed under NOAA License and:
 - TBE has the exclusive right to license or transfer image data for commercial use
 - For scientific and humanitarian purposes, DLR has the right to:
 - Task 2000 minutes/year
 - Request archived data

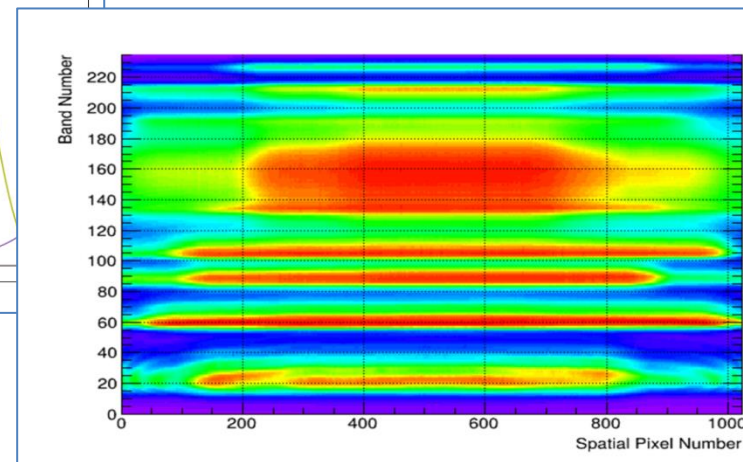
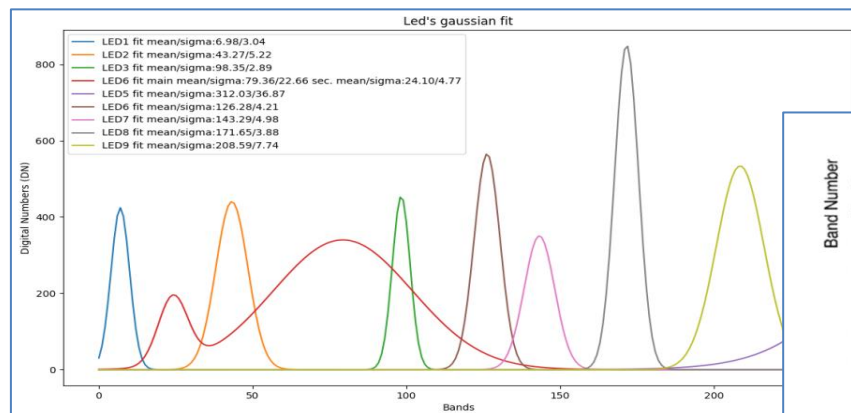


- For scientific purposes only DLR can share DESIS 10.2 nm data with other scientific organizations within projects (data are free for the partners). Scientific use includes:
 - basic and application oriented research
 - projects by national and international educational or research institutions or by governmental institutions
 - development and demonstration of future applications for scientific and/or operational use and
 - preparation and execution of government-funded education, research and development programs
- Distribution of 2.55, 5.1 nm spectral sampled data is subjected to NOAA approval
 - Currently these data are restricted to US governmental agencies and DLR (through waiver)
 - DLR Scientific partners willing to use 2.55 and 5.1 nm data would require a waiver from NOAA

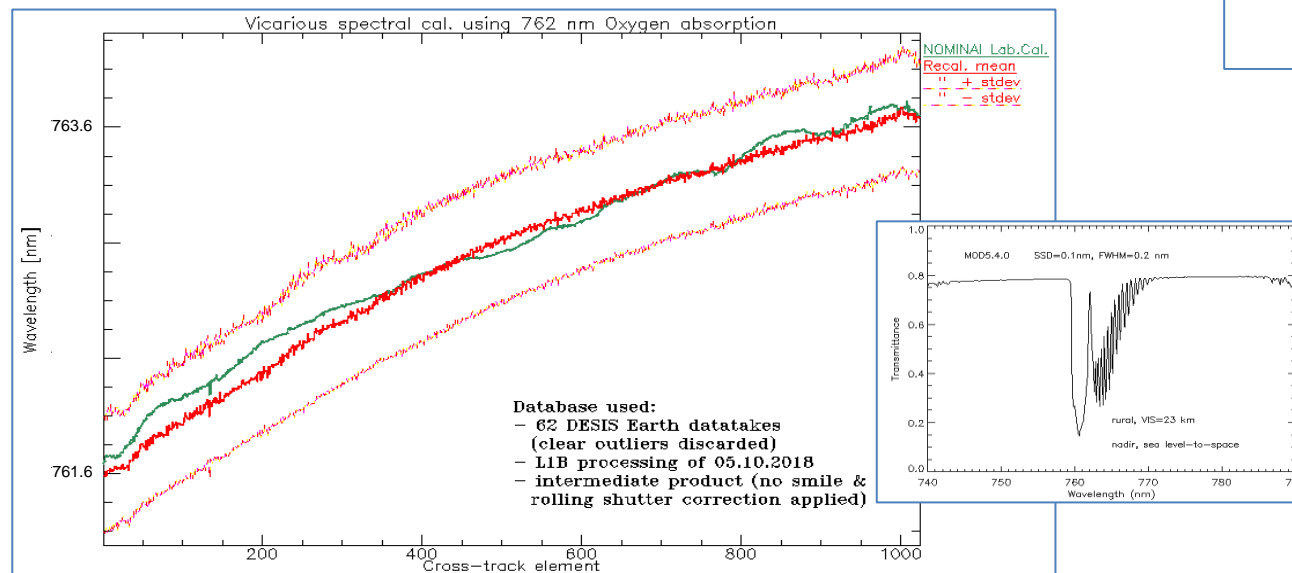


Instrument stability

- Using on-board calibration sources (LEDs)
 - ✓ • Pre- and post-launch characteristics
 - Incl. temperature stability & other HK / telemetry data
- Using atmospheric absorption features

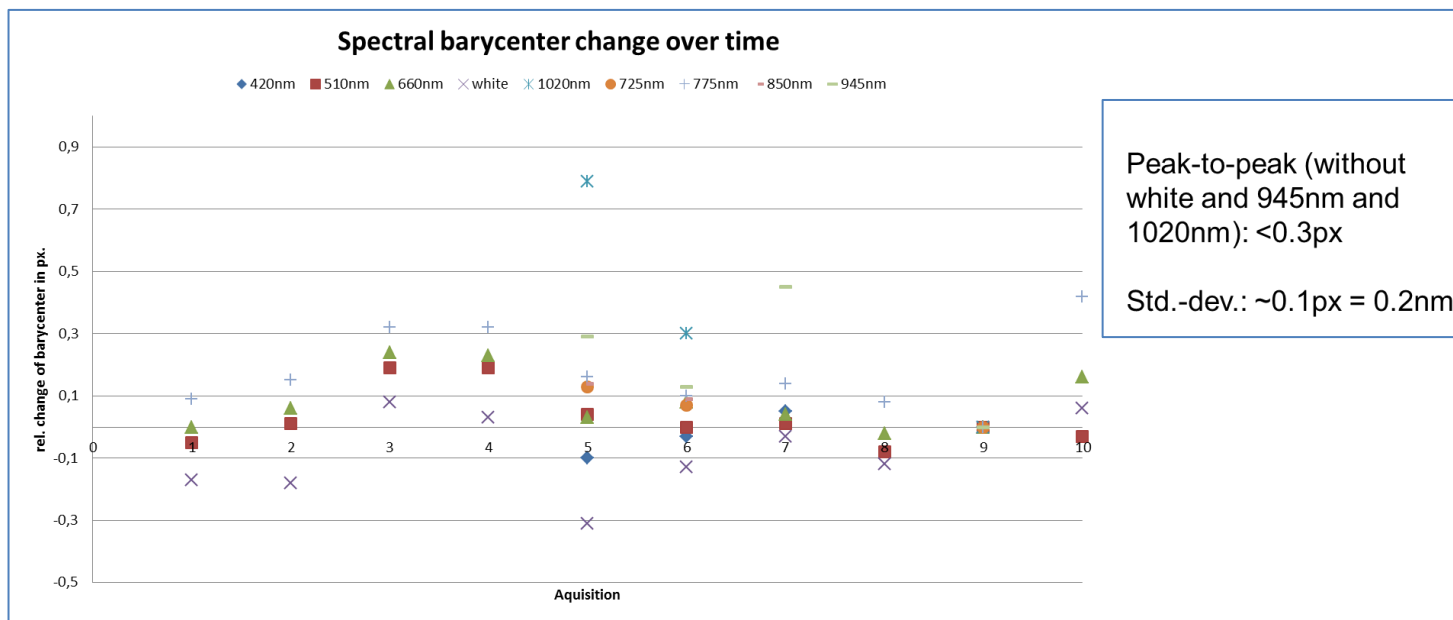
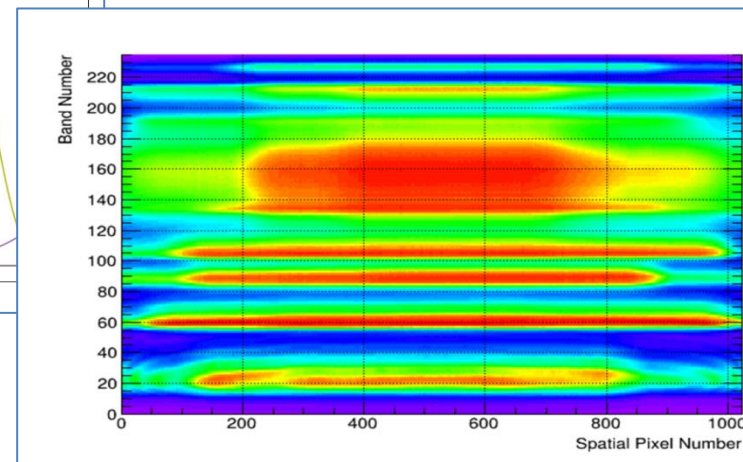
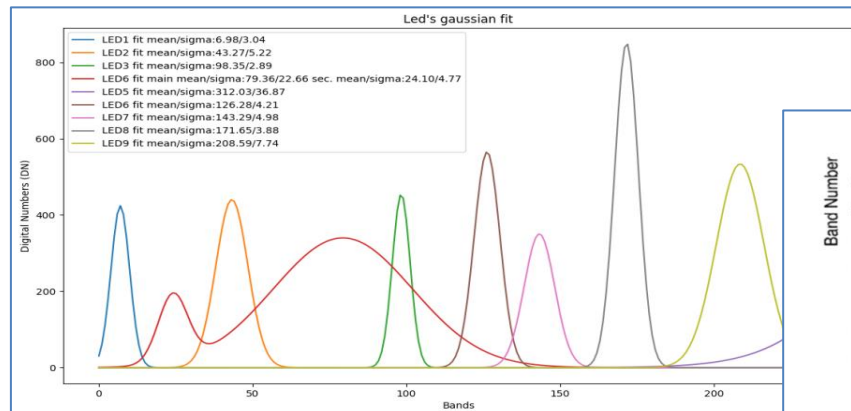


Smile pre- & Post-launch comparison

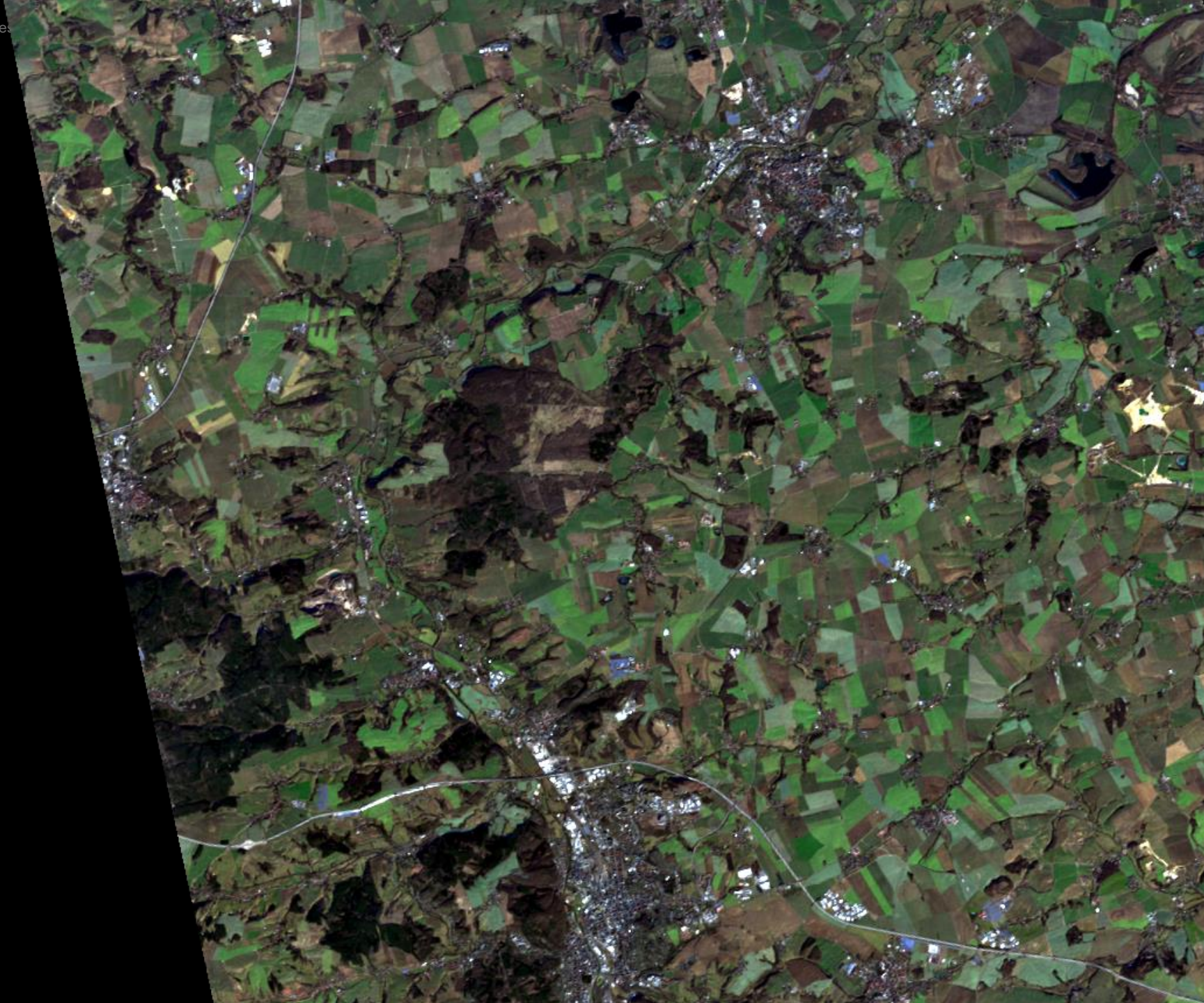


Instrument stability

- Using on-board calibration sources (LEDs)
 - ✓ • Pre- and post-launch characteristics
 - Incl. temperature stability & other HK / telemetry data
- Spectral stability over time:



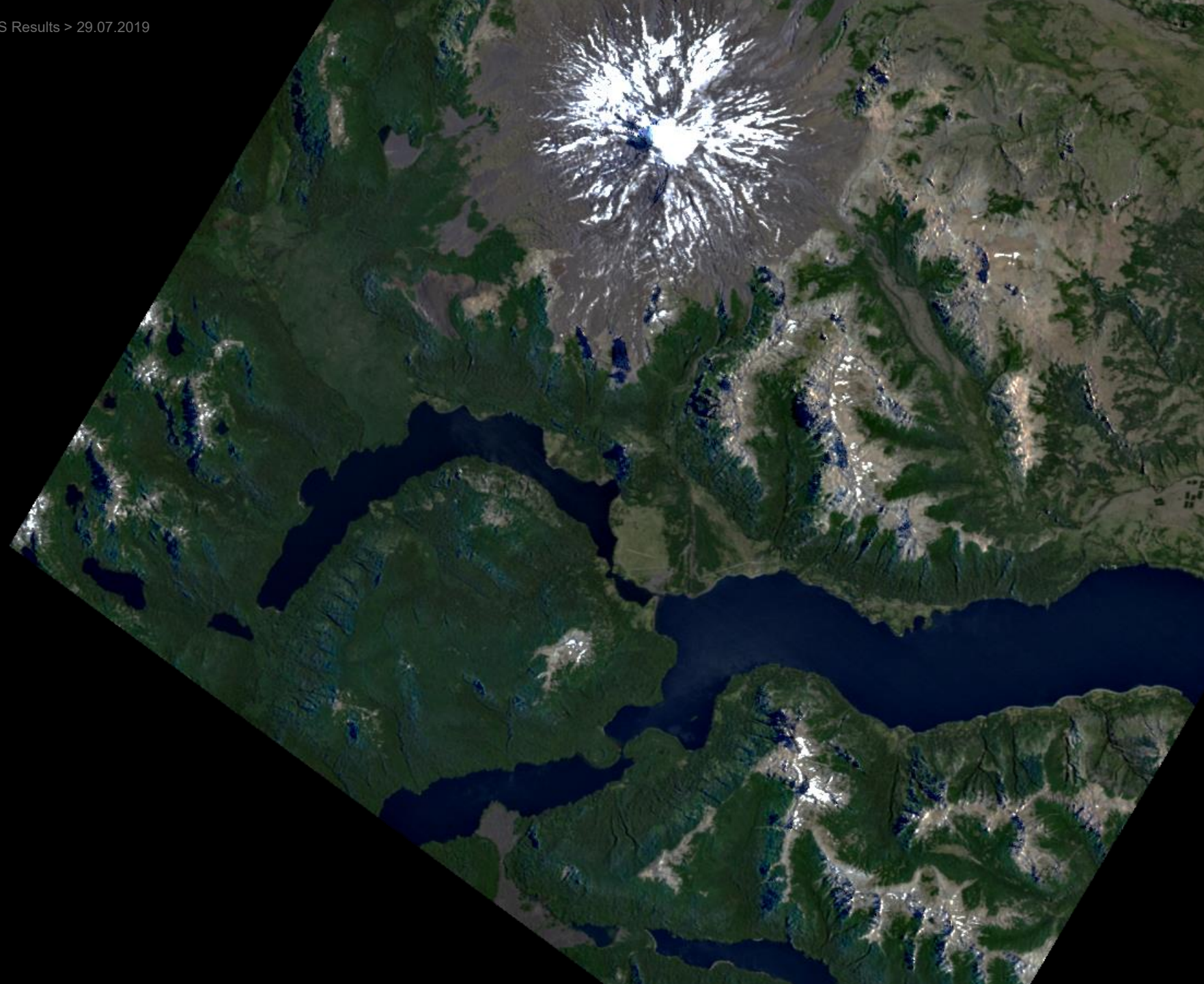
DESIS Scenes



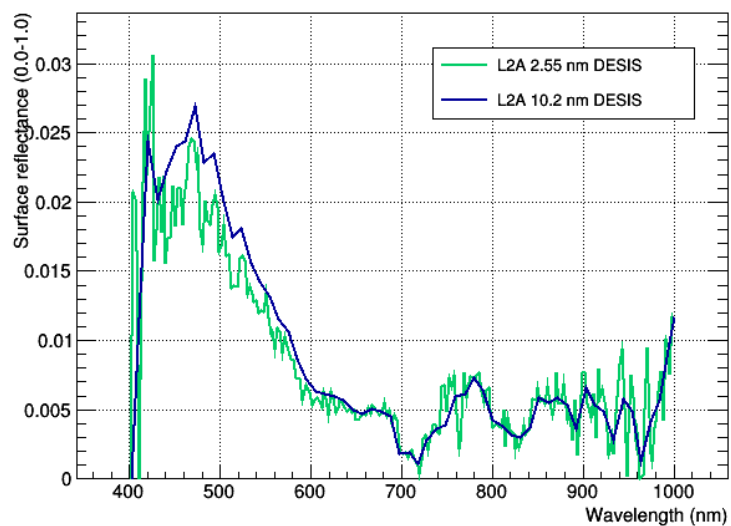
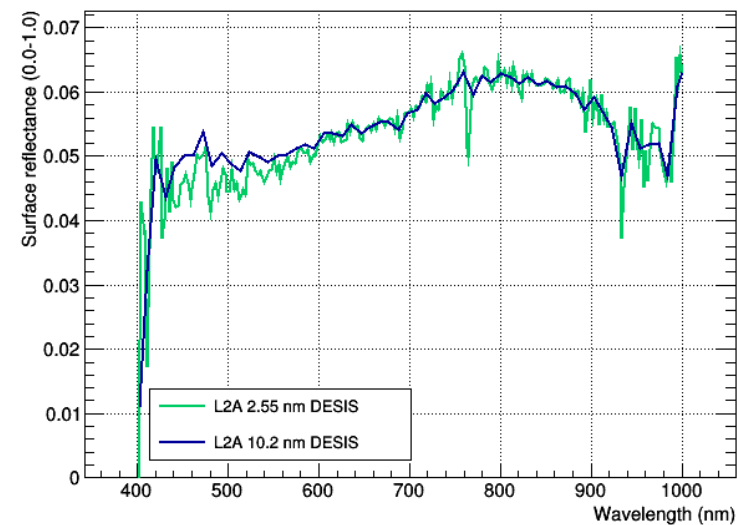
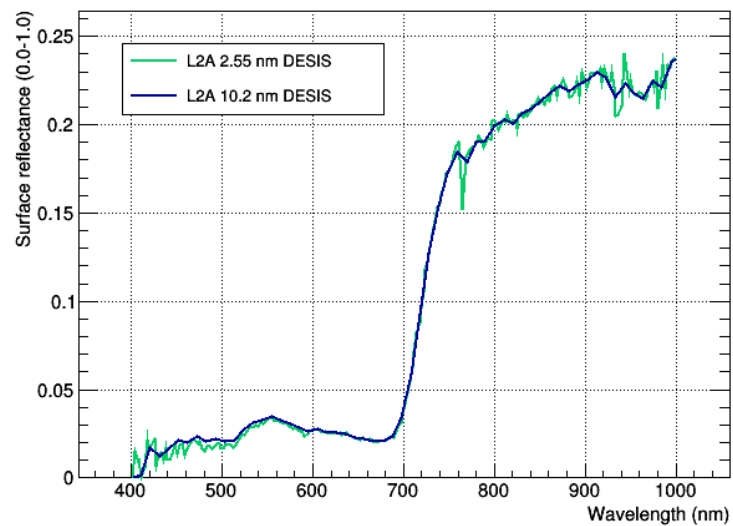
DESIIS Scenes



DESIS Scenes



DESIS Scenes



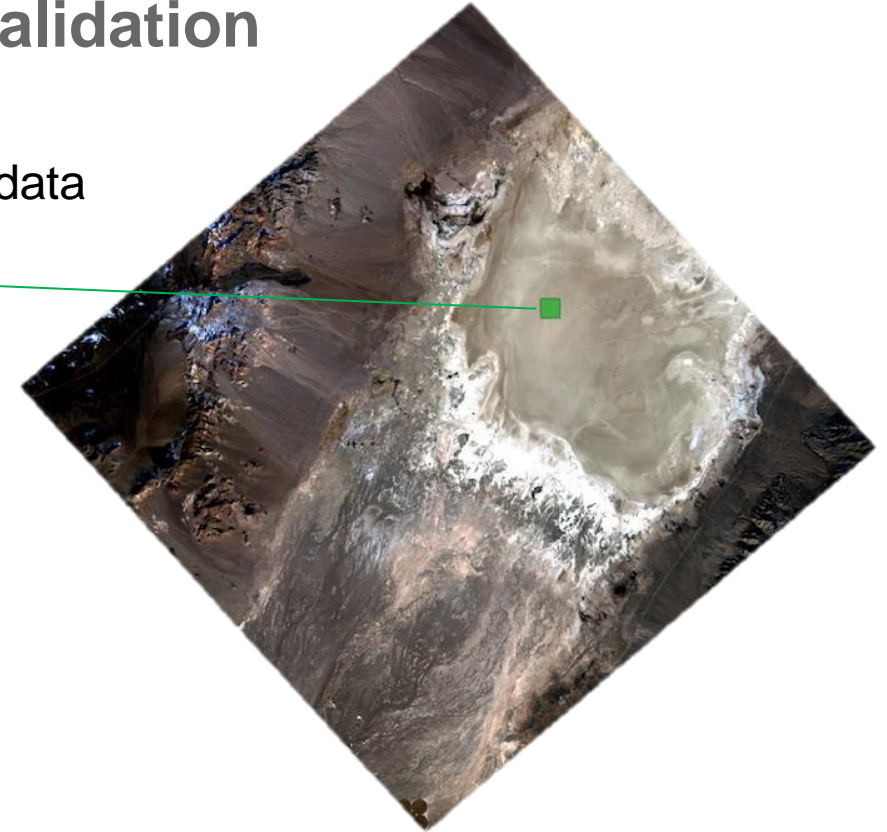
Radiometrically corrected data: TOA reflectance validation

- Compare TOA reflectances with RadCalNet sites using simultaneous data

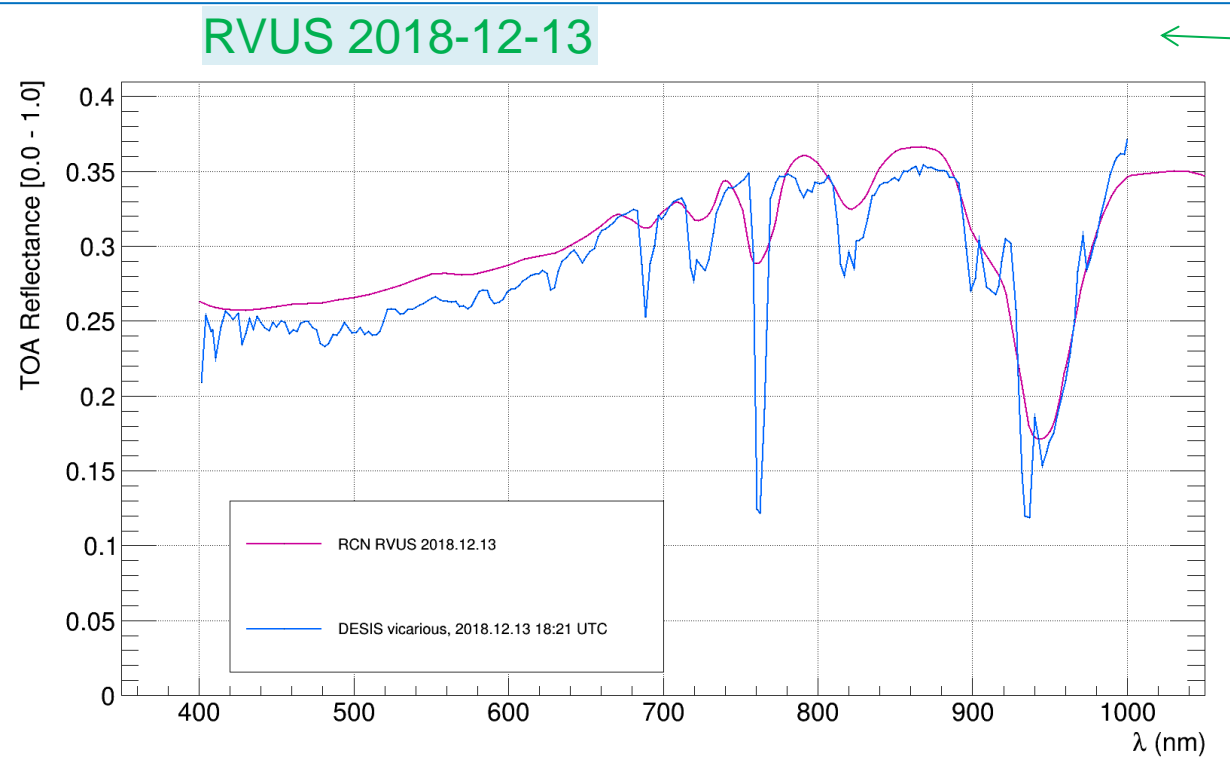


Radiometrically corrected data: TOA reflectance validation

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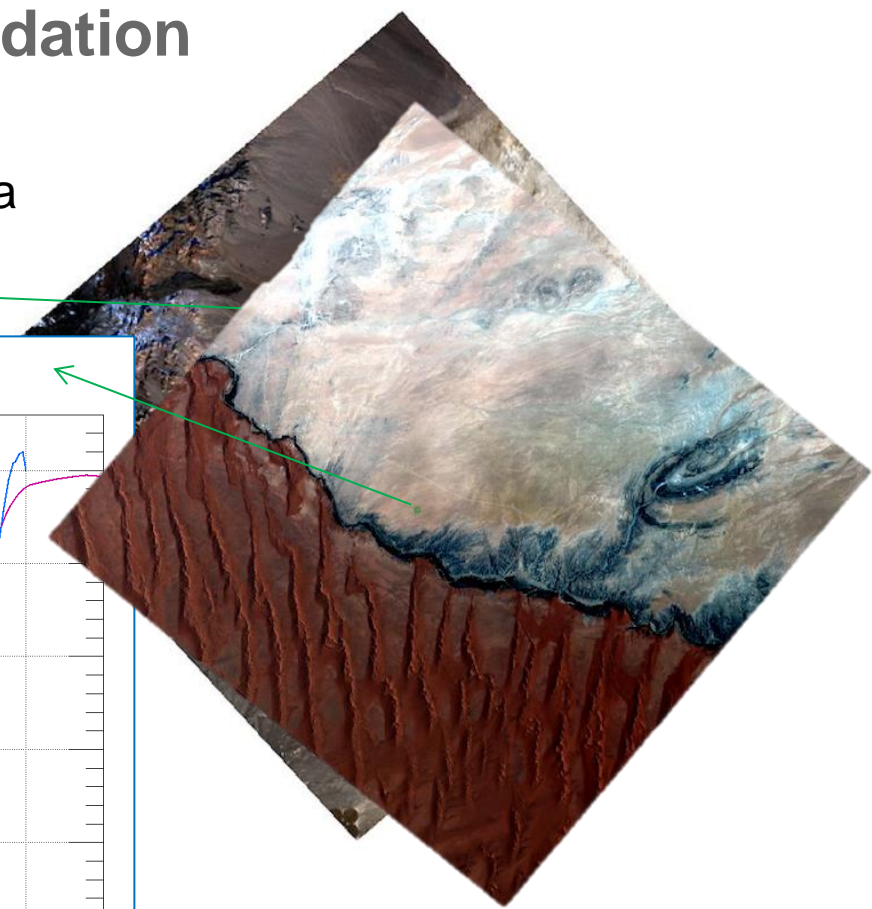
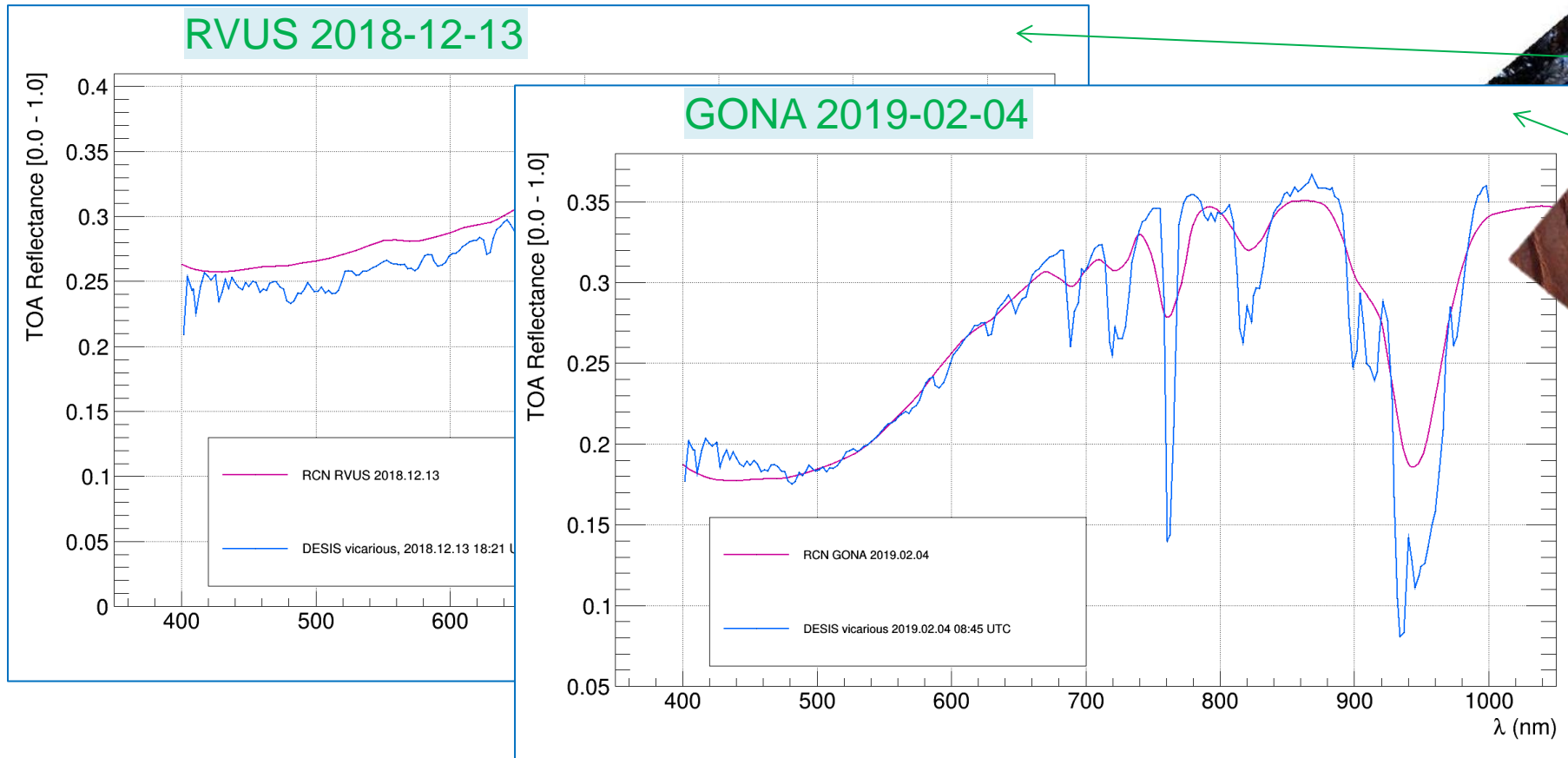


RVUS 2018-12-13



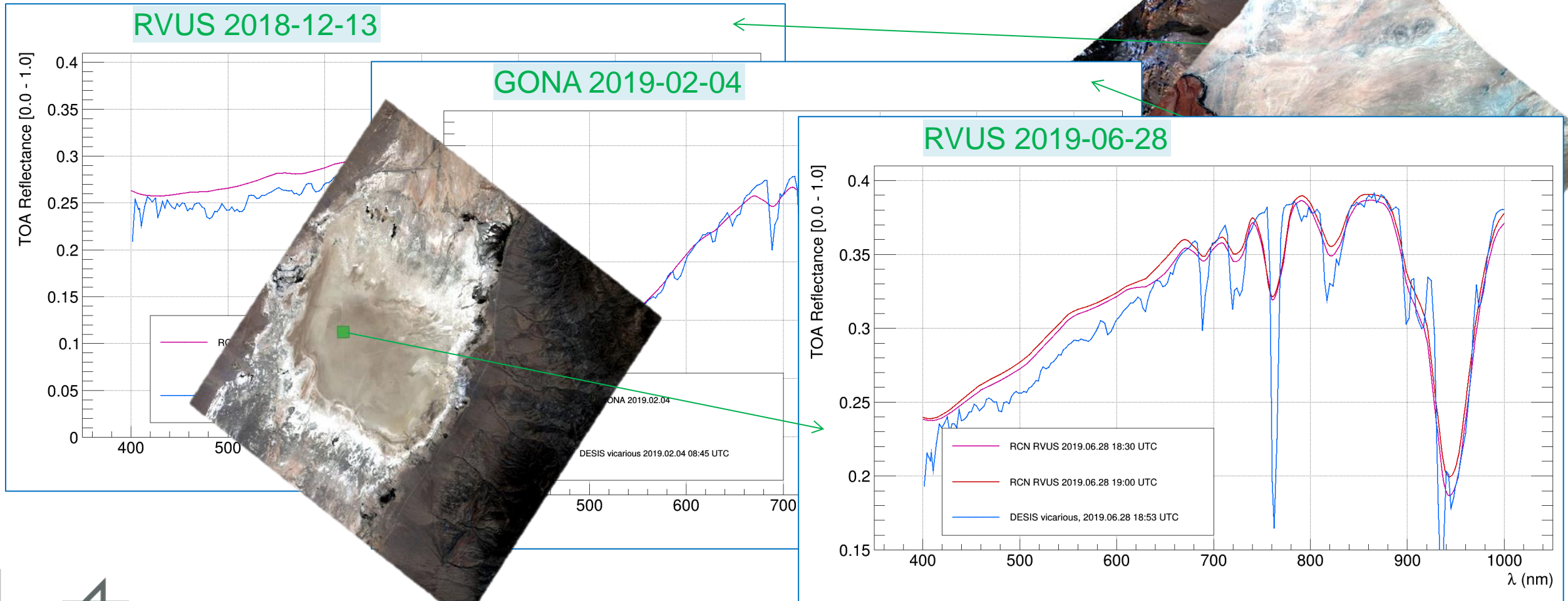
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Radiometrically corrected data: TOA reflectance validation

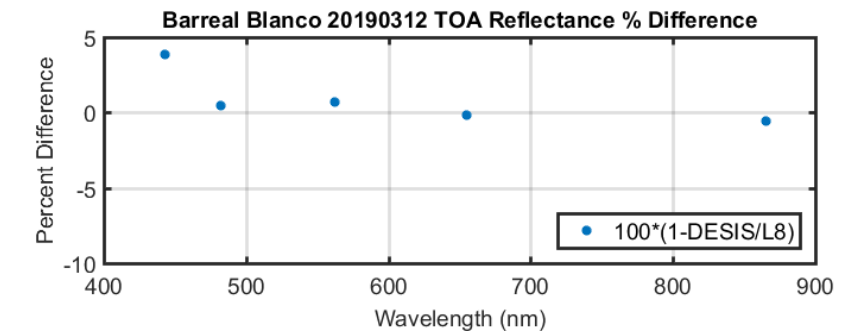
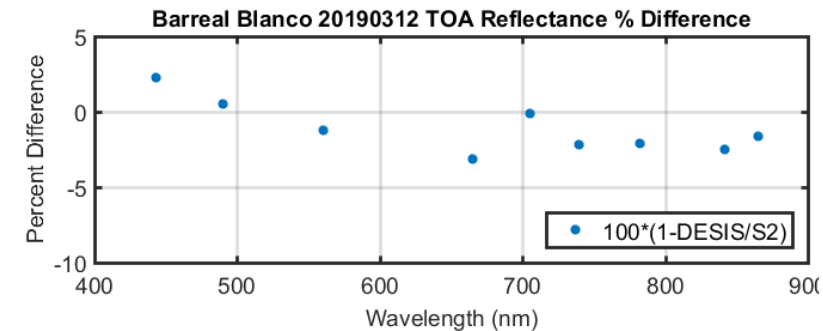
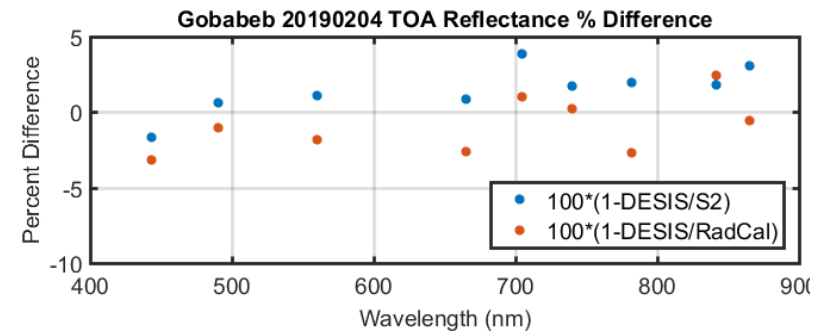
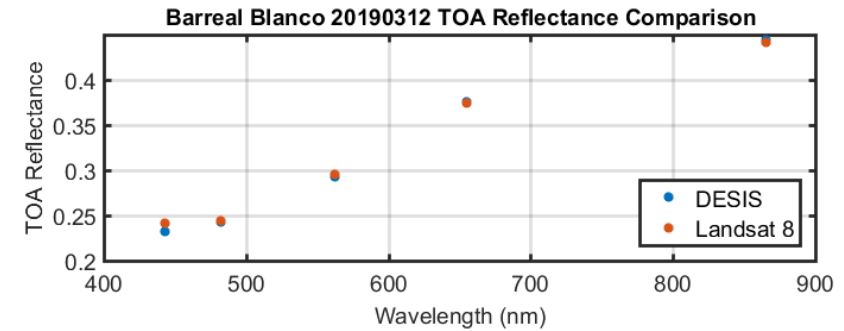
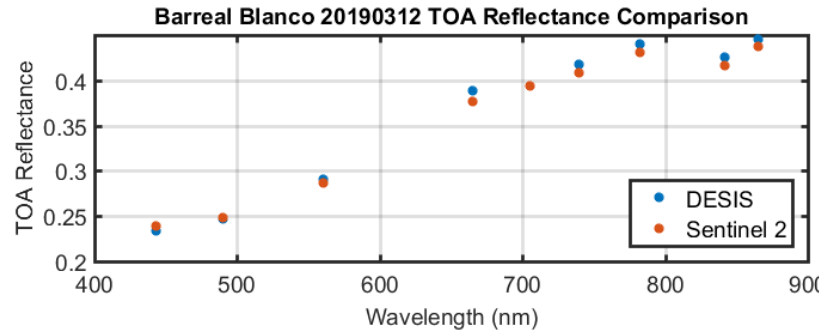
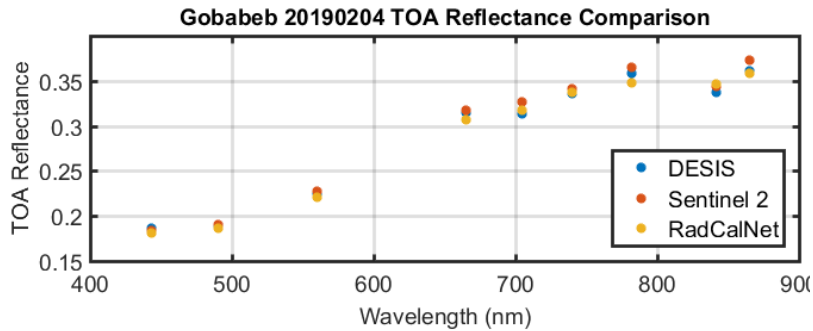
- Compare TOA reflectances with RadCalNet sites using simultaneous data





Radiometrically corrected data: TOA reflectances validation

- DESIS / RadCalNet / Sentinel / Landsat comparisons by I2R Corp:



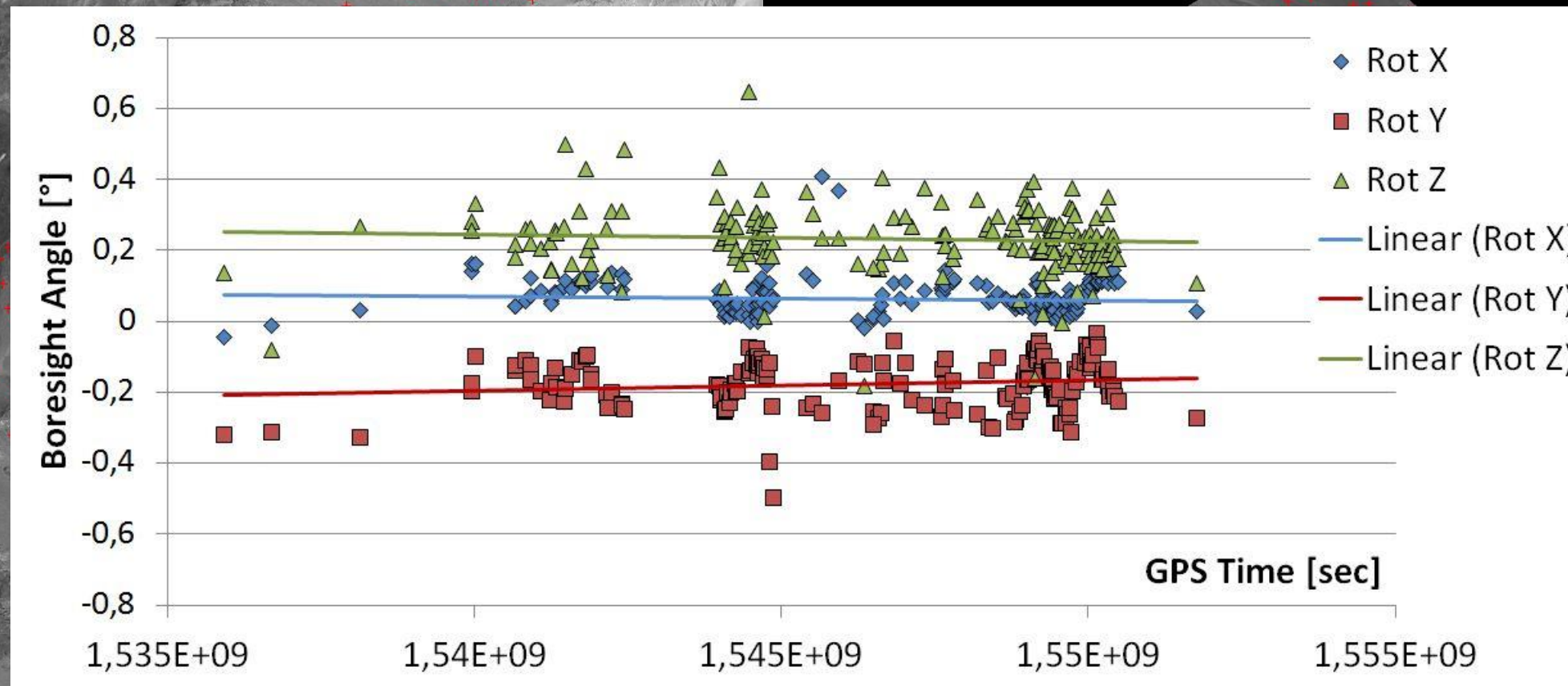
Kara Burch, Mary Pagnutti, Robert Ryan, I2R Corp
Analysis by K. Burch



Geometrically corrected data: Calibration & Validation

Reference Image
(Landsat 8 Pan, ~18 m CE90)

DESIS Image
(after coarse rectification)



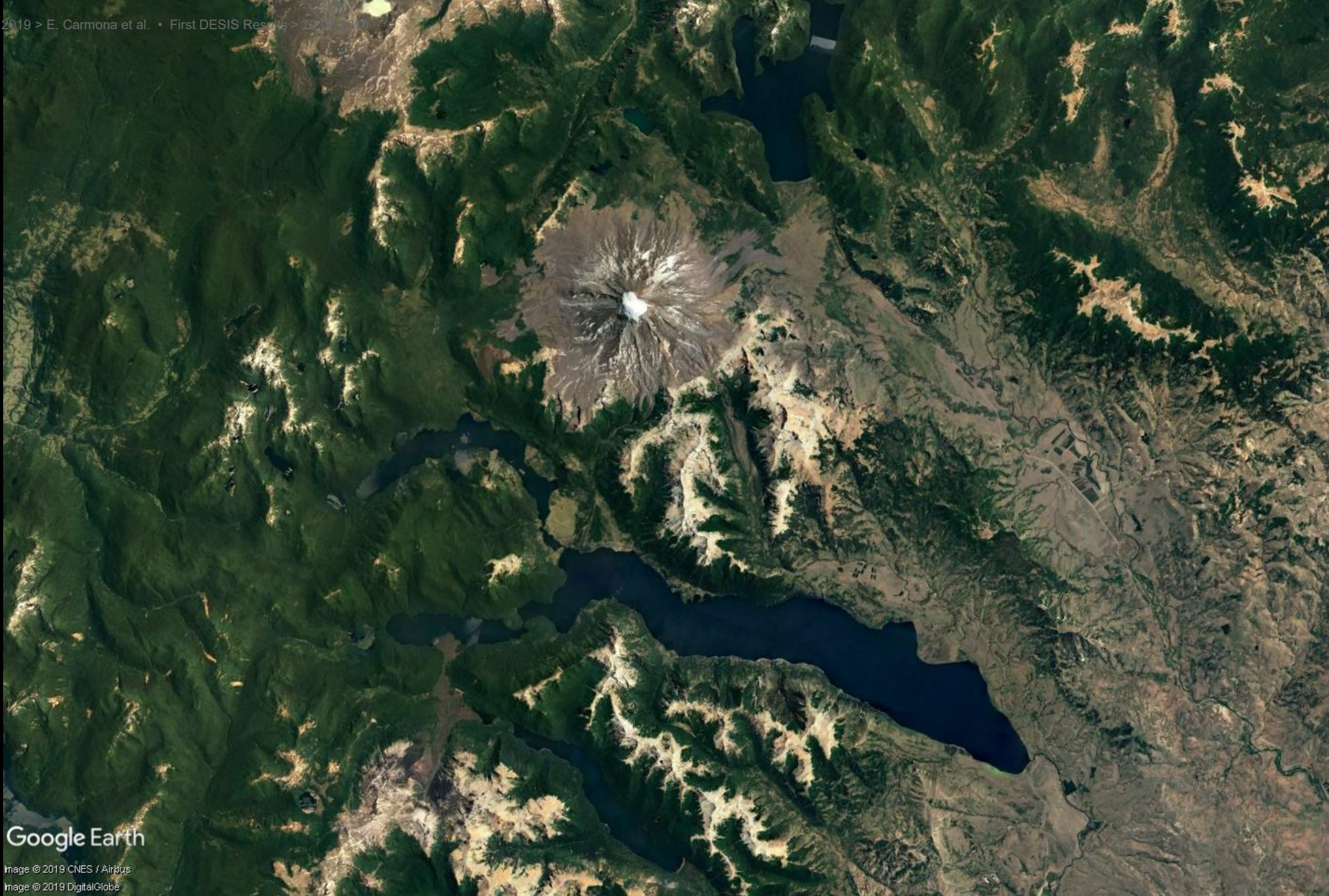
• BRISK (Binary Robust Invariant Scalable Keypoints)

Selected GCP to improve LLSQ (Local Least Squares) (on the fly and for boresight calibration)

Others are used for Quality Assessment • SIFT (Scale-Invariant Feature Transform)

Railroad Valley, USA
13-12-2018
18:23:11 UTC
38.4467°N
115.7512°W
Sun: 64.14°, 160.58°
Incident Angle: 0.8°

Product Example L1C

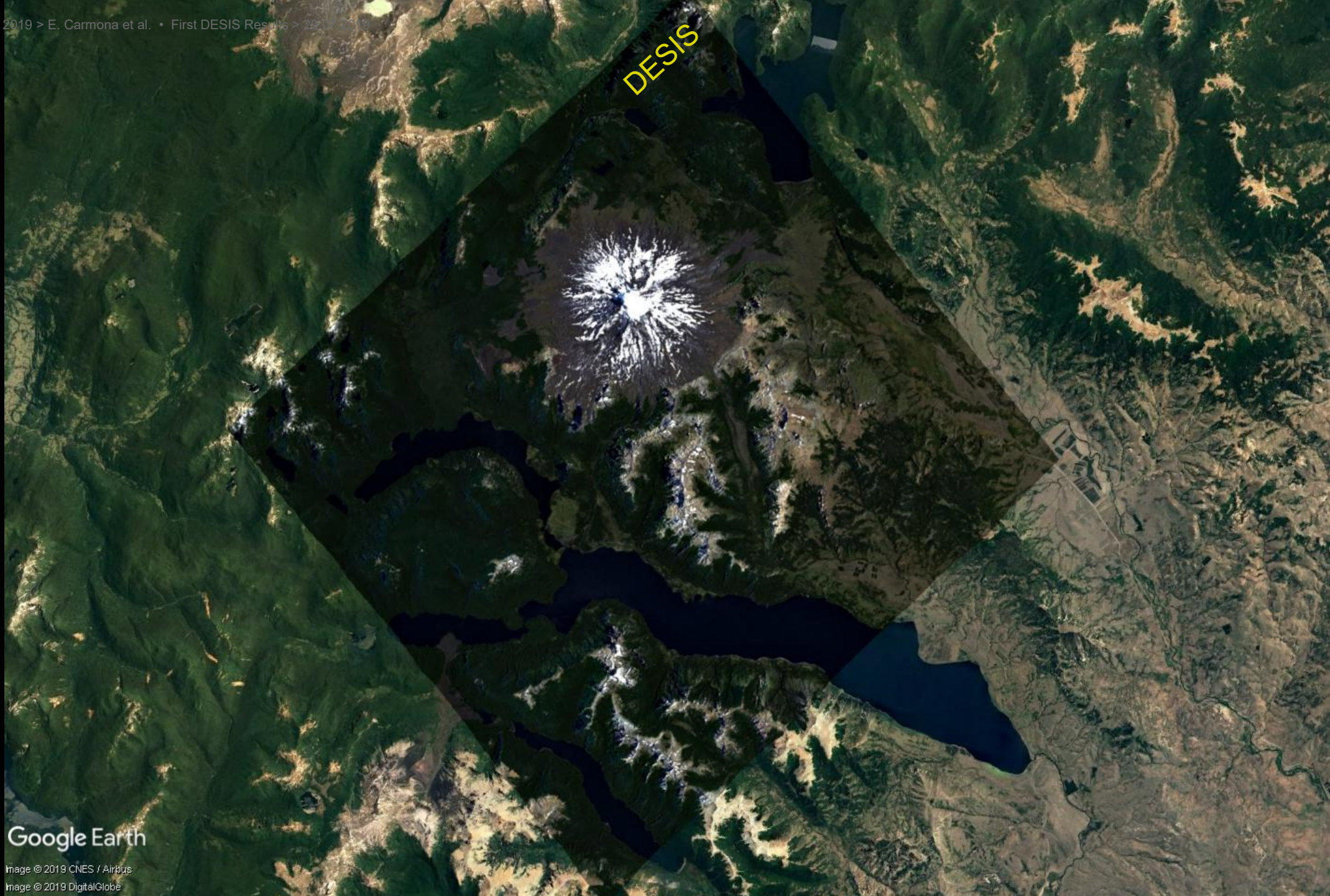


Google Earth

Image © 2019 CNES / Airbus

Image © 2019 DigitalGlobe

Product Example L1C



Google Earth

Image © 2019 CNES / Airbus
Image © 2019 DigitalGlobe

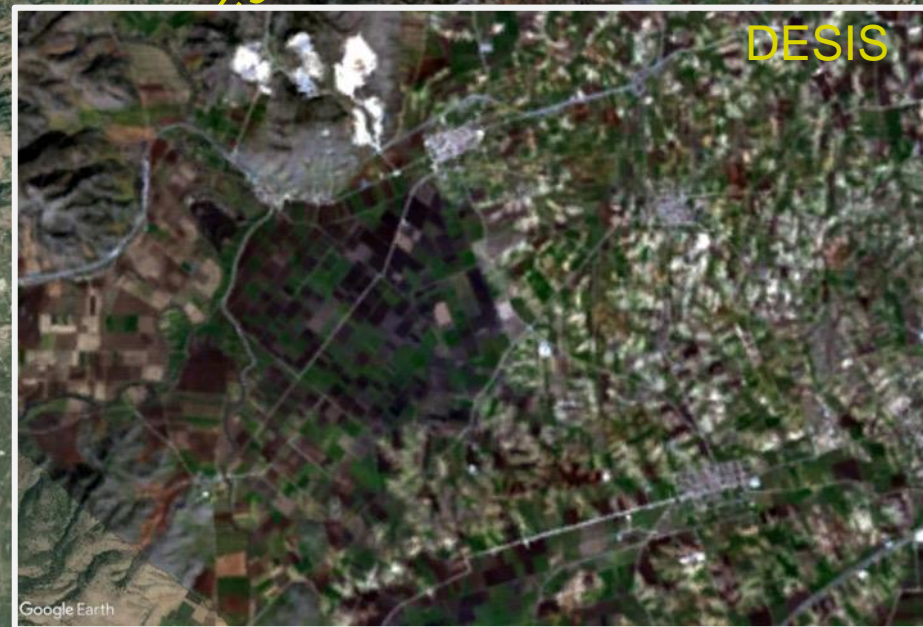
Product Example L1C



Product Example L1C



Product Example L1C



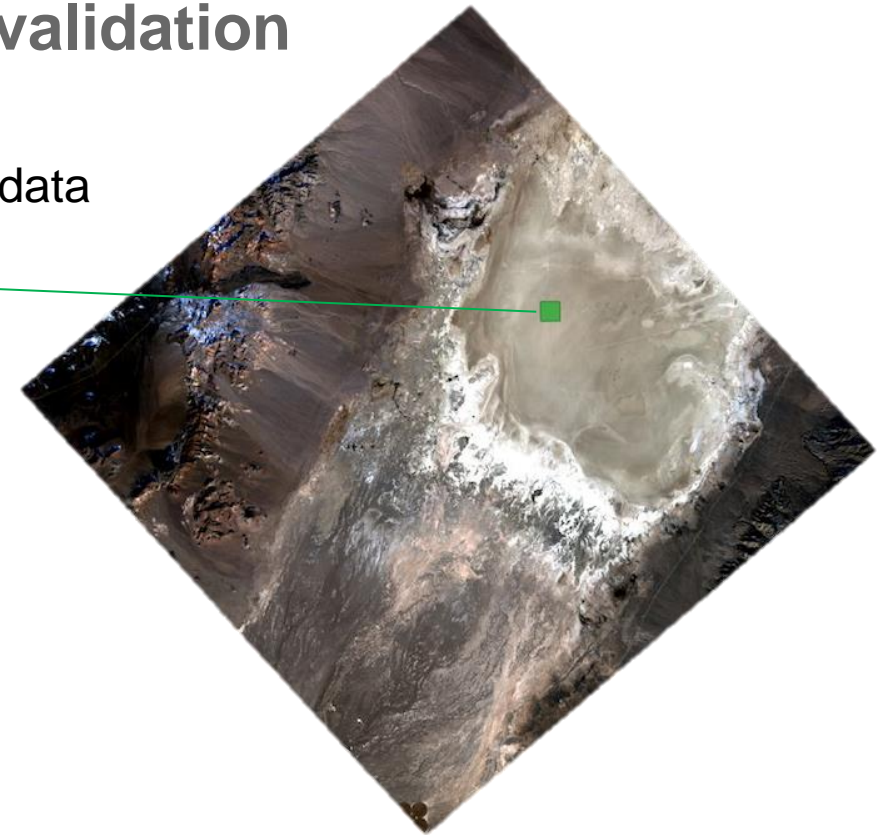
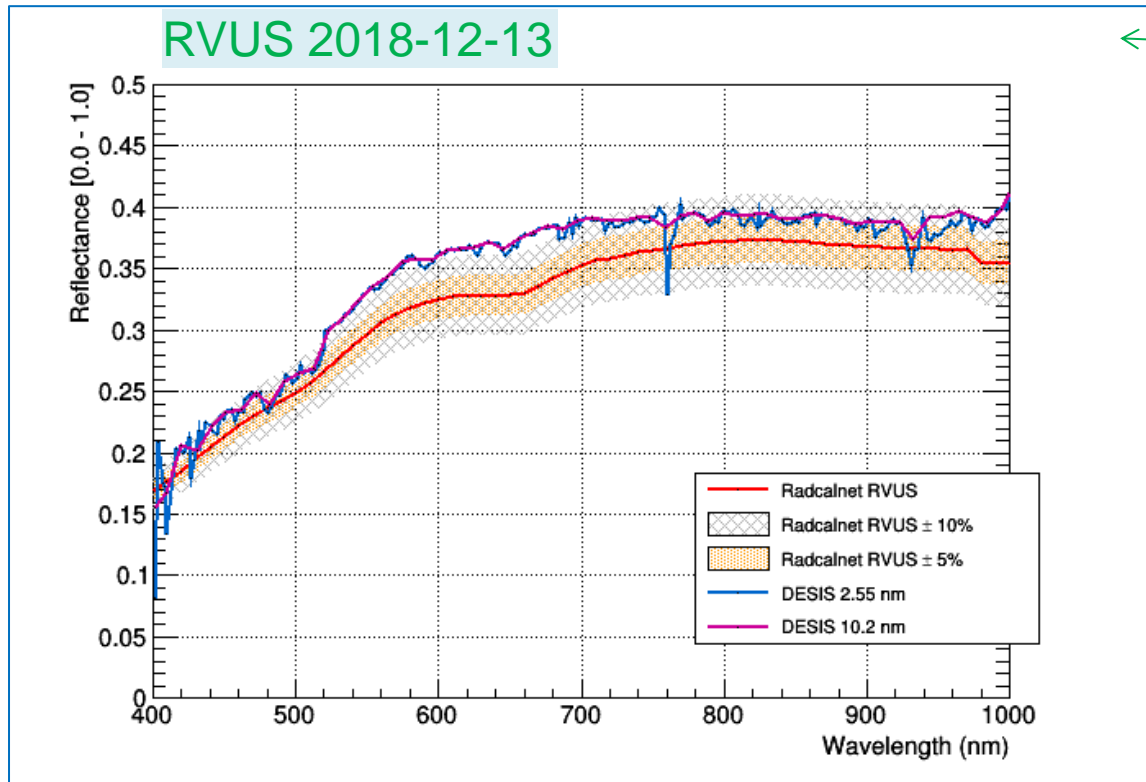
Atmospherically corrected data: BOA reflectance validation

- Compare BOA reflectances with RadCalNet sites using simultaneous data



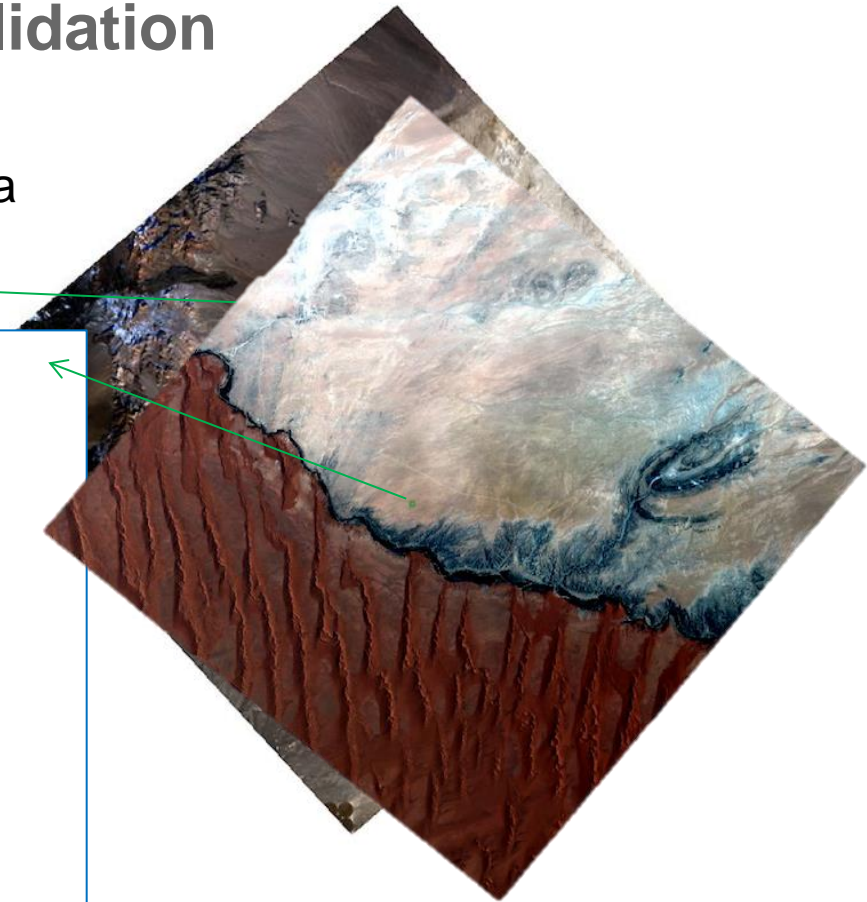
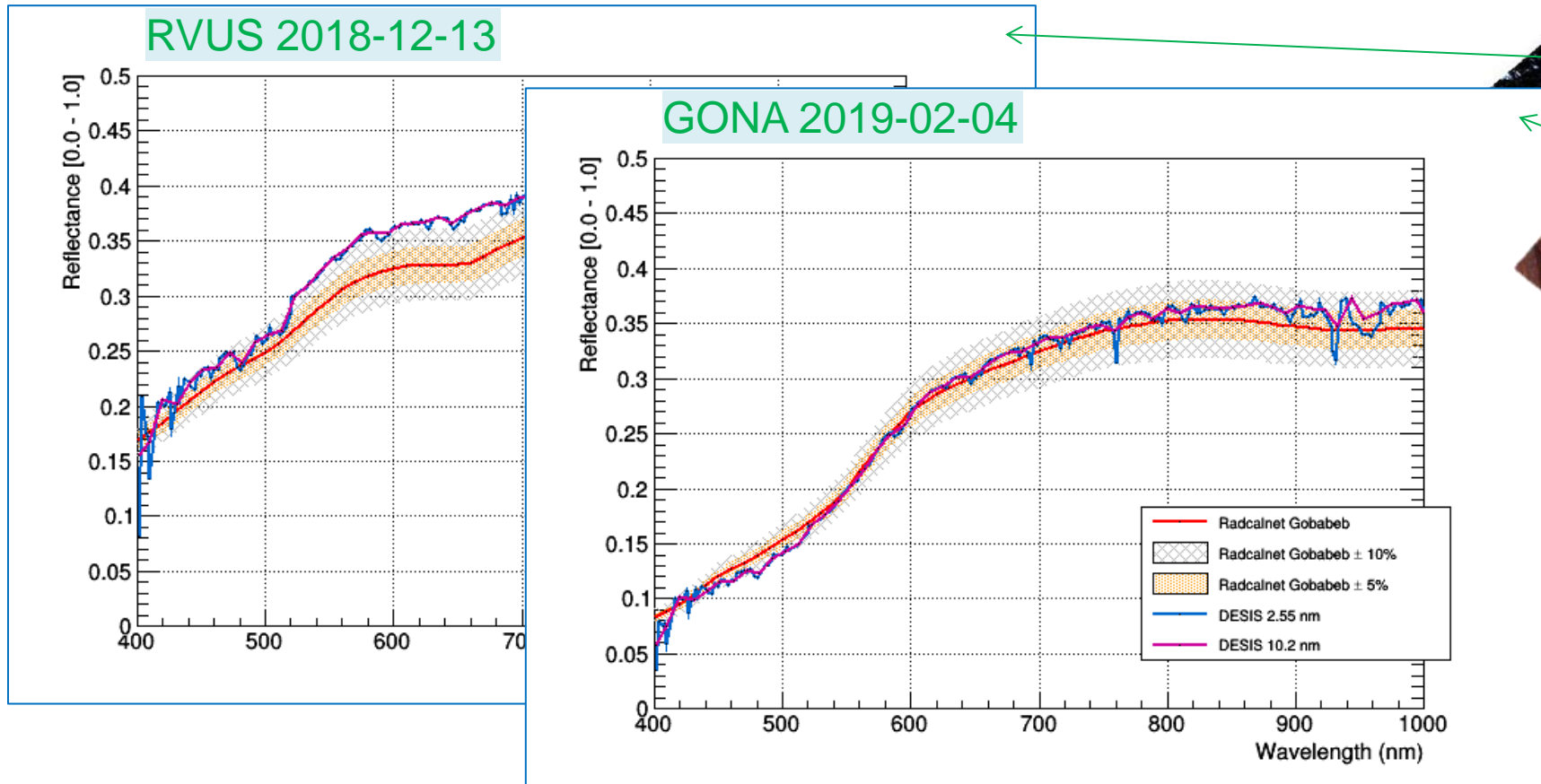
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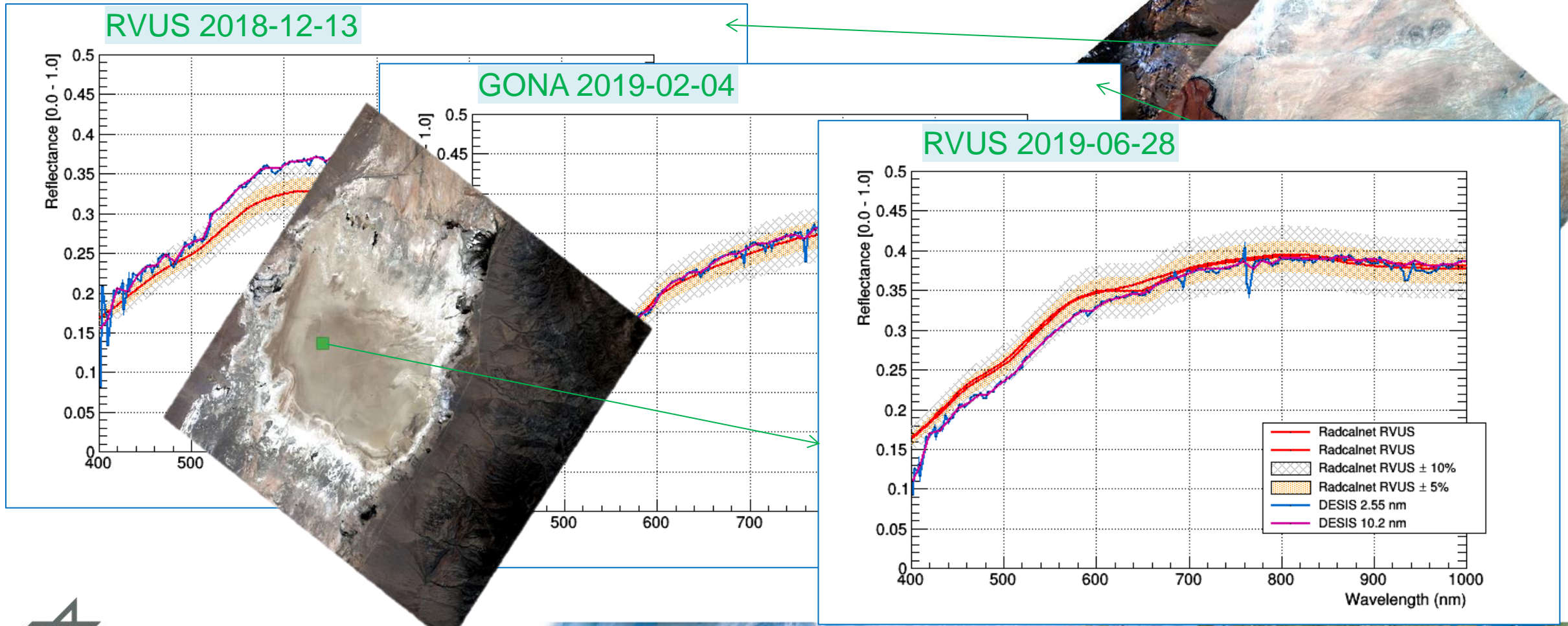
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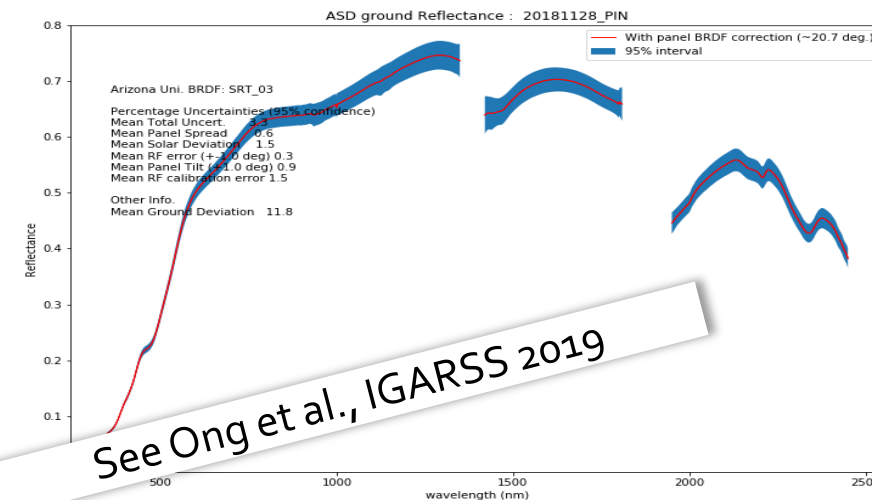
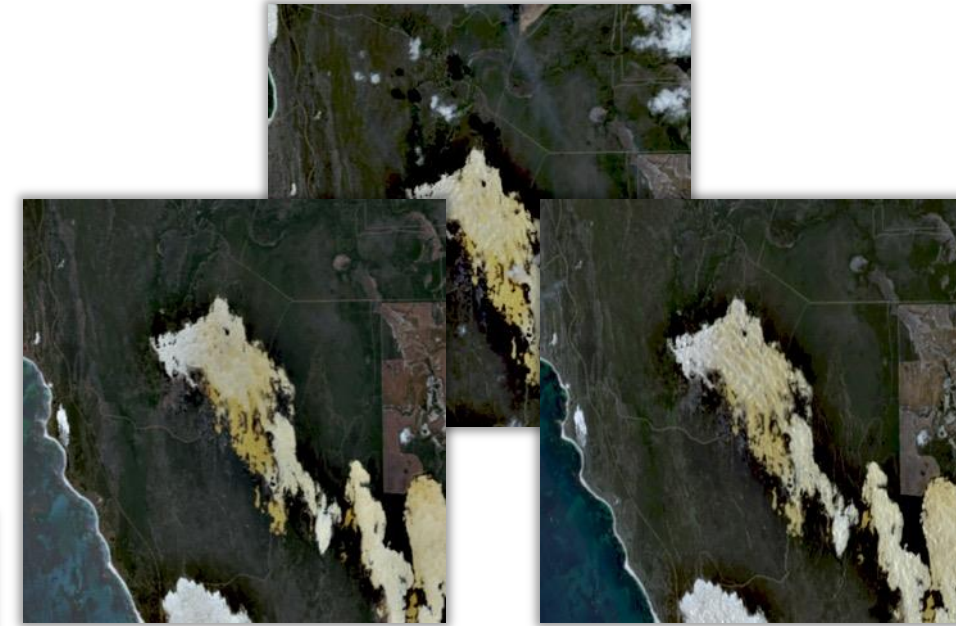
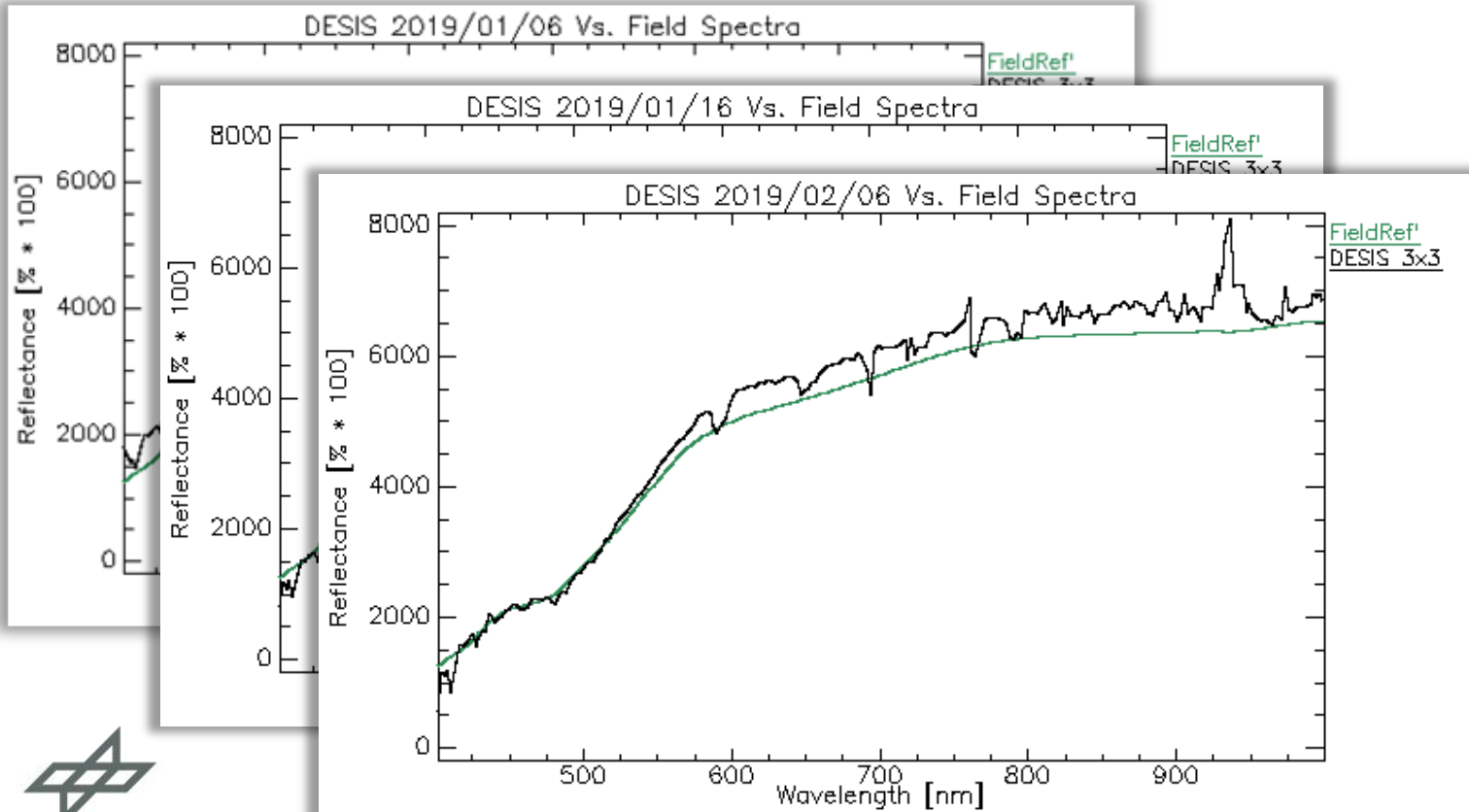
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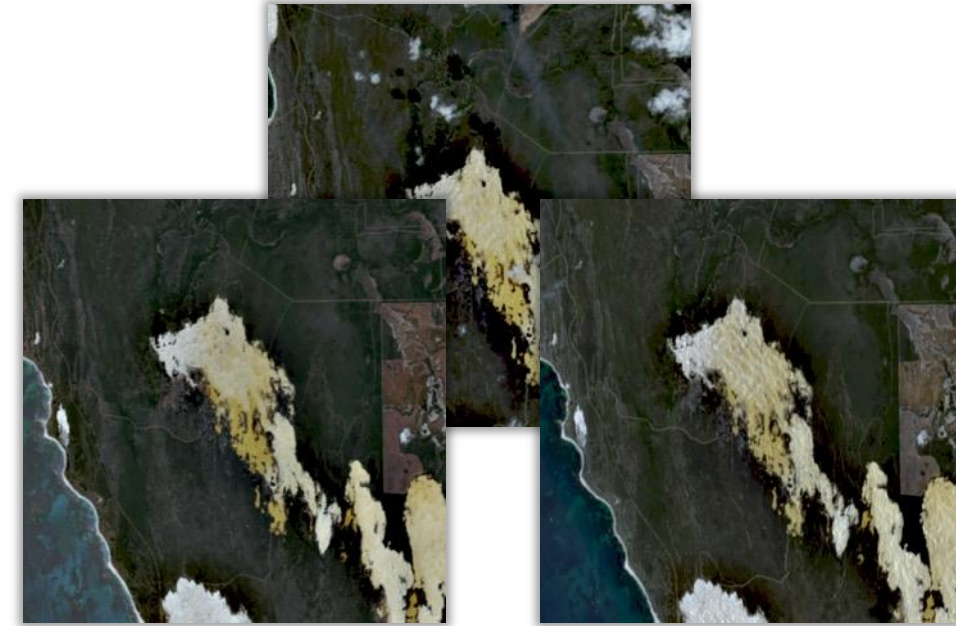
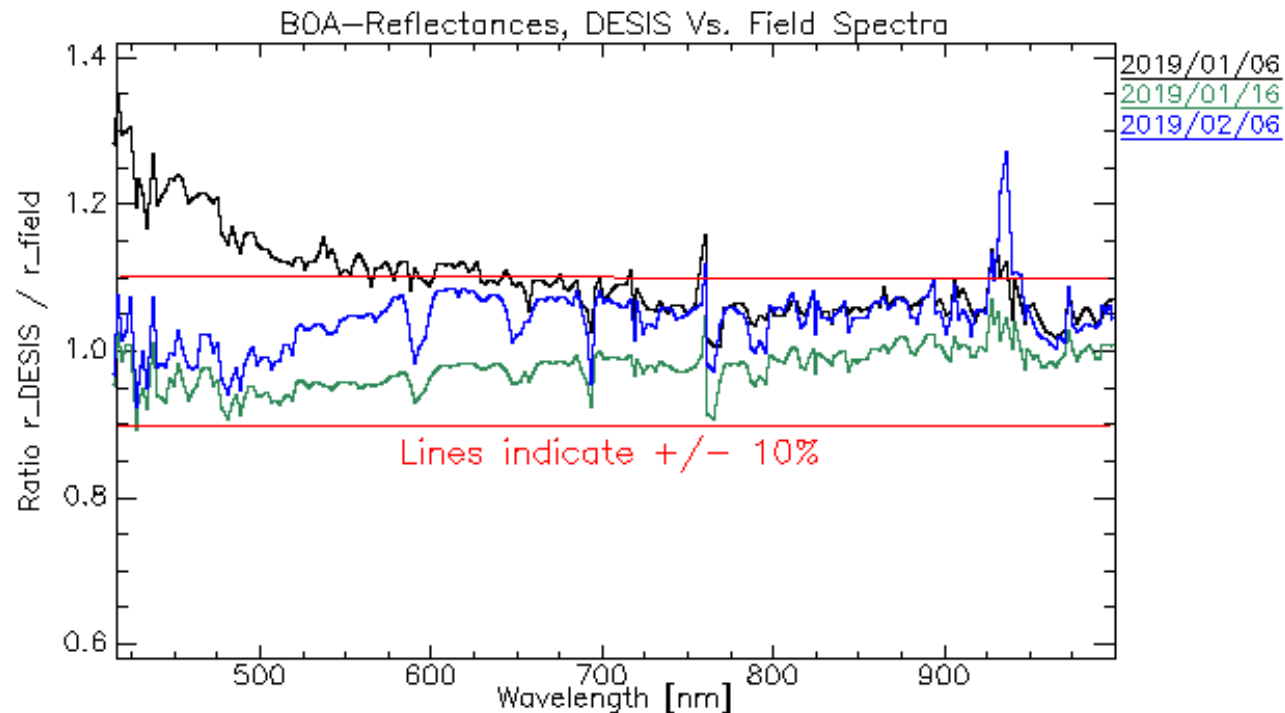
- Comparison on BOA-reflectance level with ground measurements at Pinnacles site
- Caveat: larger time difference between field data and DESIS data !



See Ong et al., IGARSS 2019

Atmospherically corrected data: BOA reflectance validation

- Comparison on BOA-reflectance level with ground measurements at Pinnacles site
- Caveat: larger time difference between field data and DESIS data !



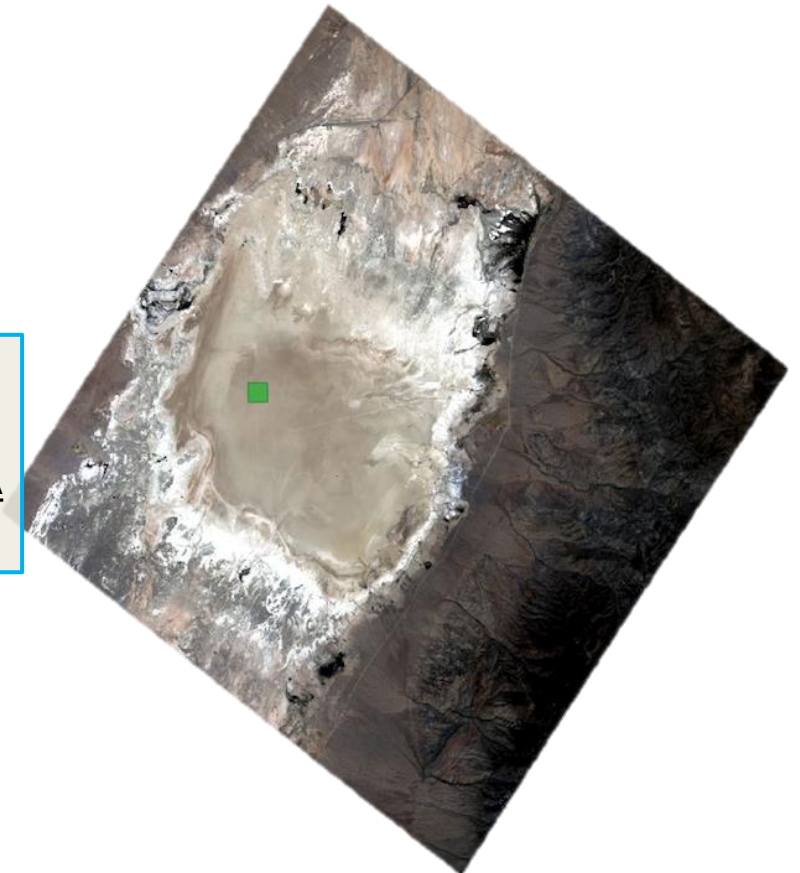
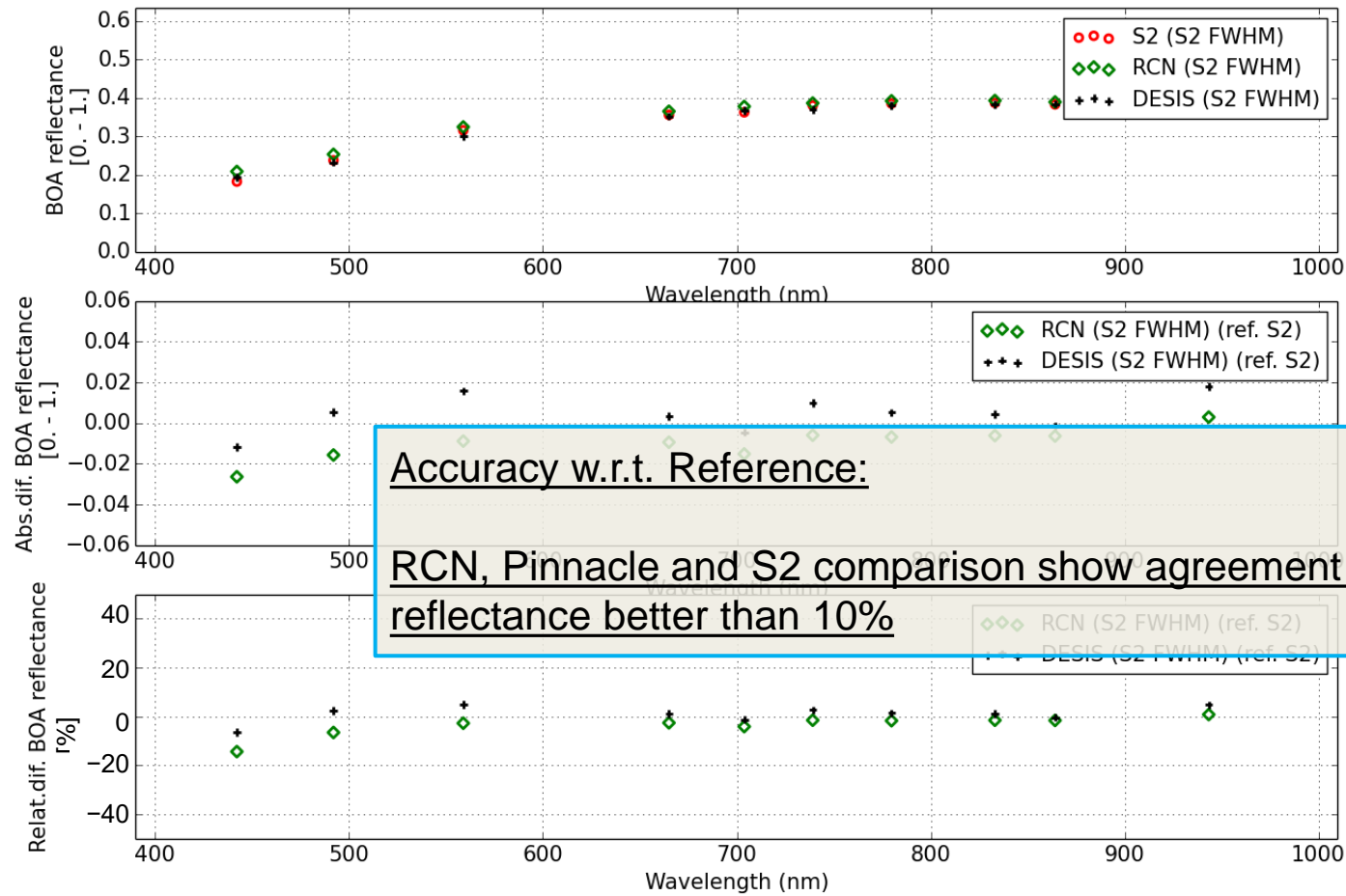
Radiometric properties on Pinnacles site:

- consistent over time intervals (also for longer time intervals)
- consistent over binning modes



Atmospherically corrected data: BOA reflectance validation

- Compare TOA reflectances with Sentinel 2

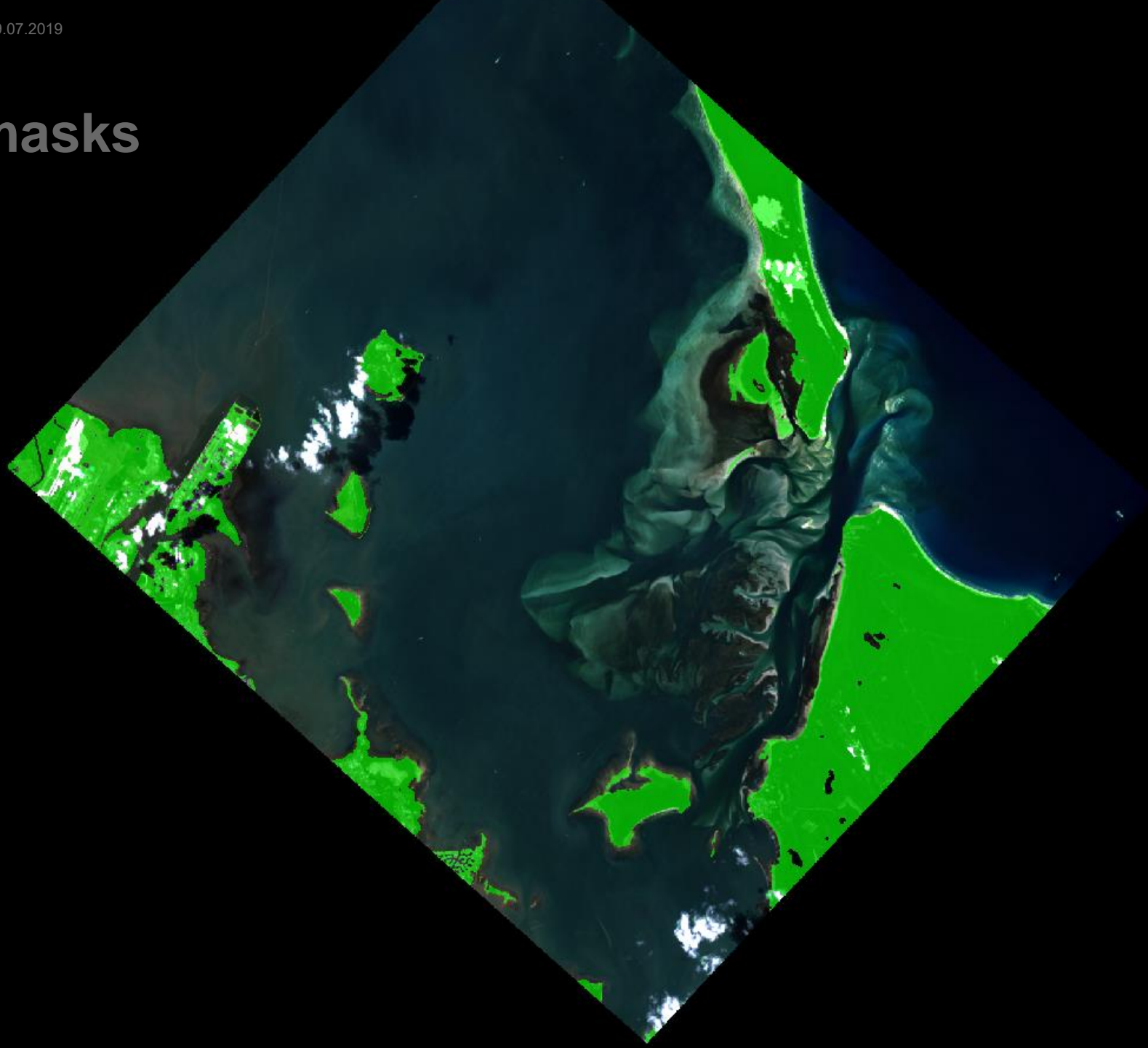


Product Example L2A



Product Example L2A masks

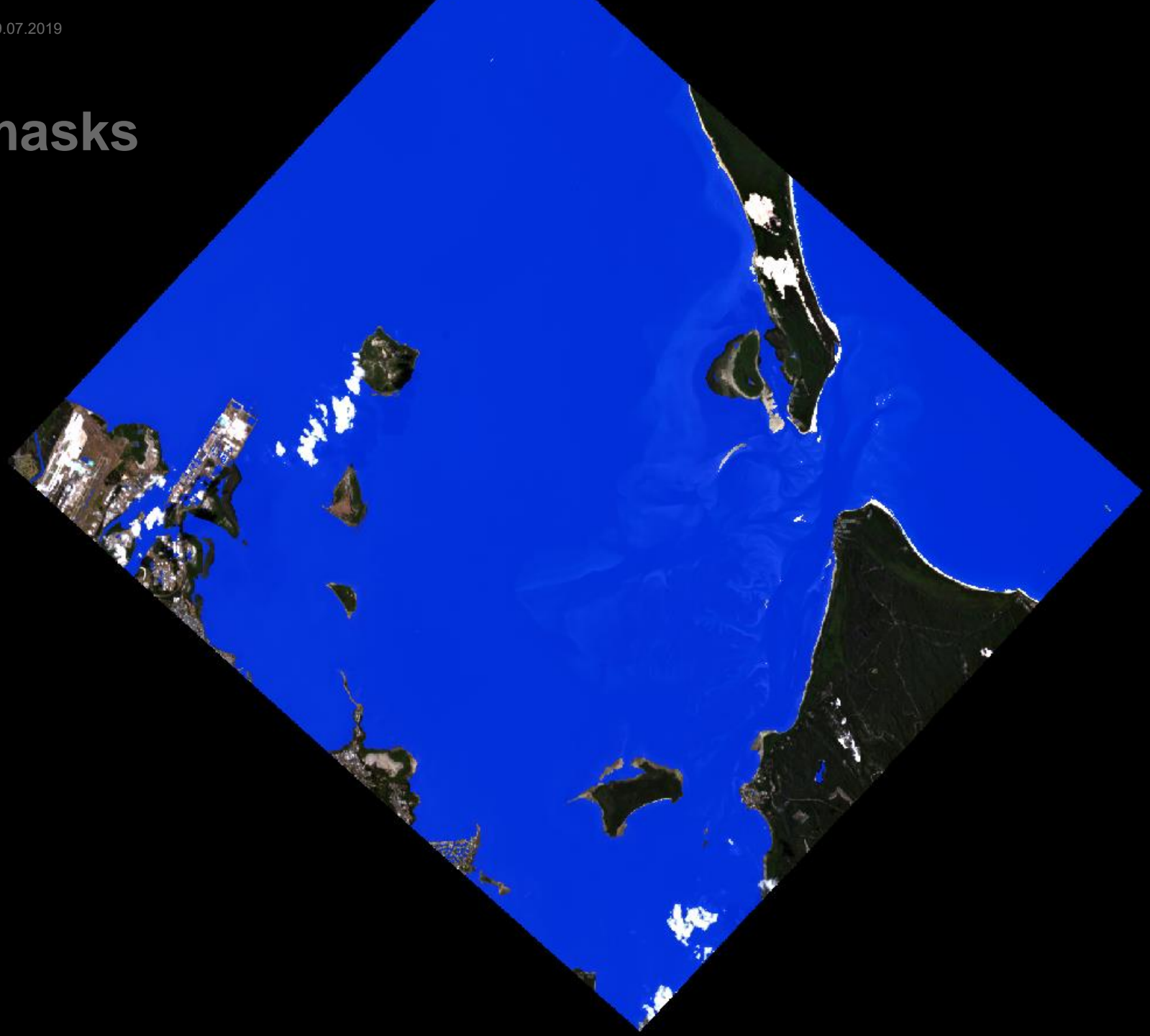
Land Mask



Product Example L2A masks

Land Mask

Water Mask



Product Example L2A masks

Land Mask

Water Mask

Cloud Mask



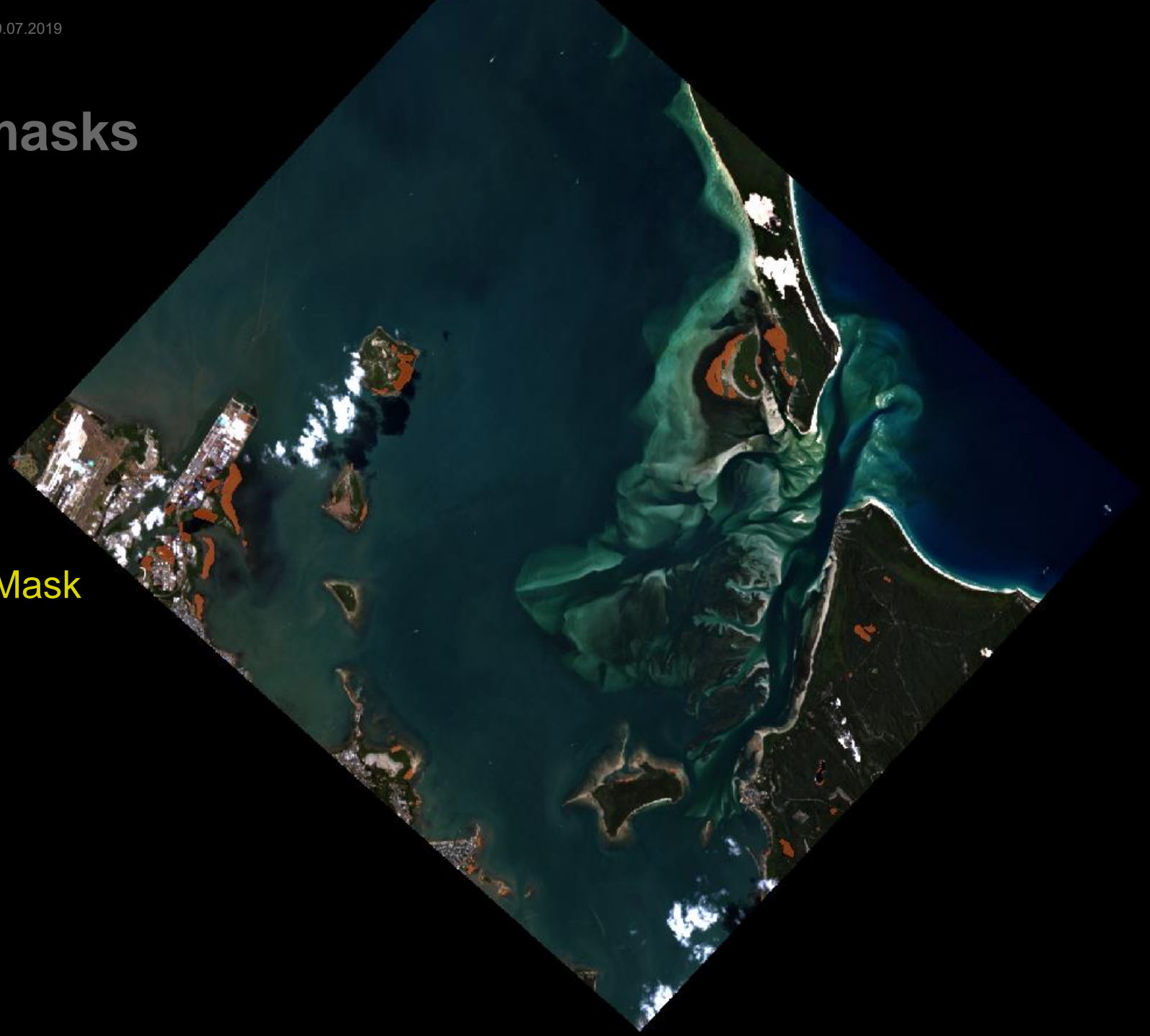
Product Example L2A masks

Land Mask

Water Mask

Cloud Mask

Cloud Shadow over land Mask



Product Example L2A masks

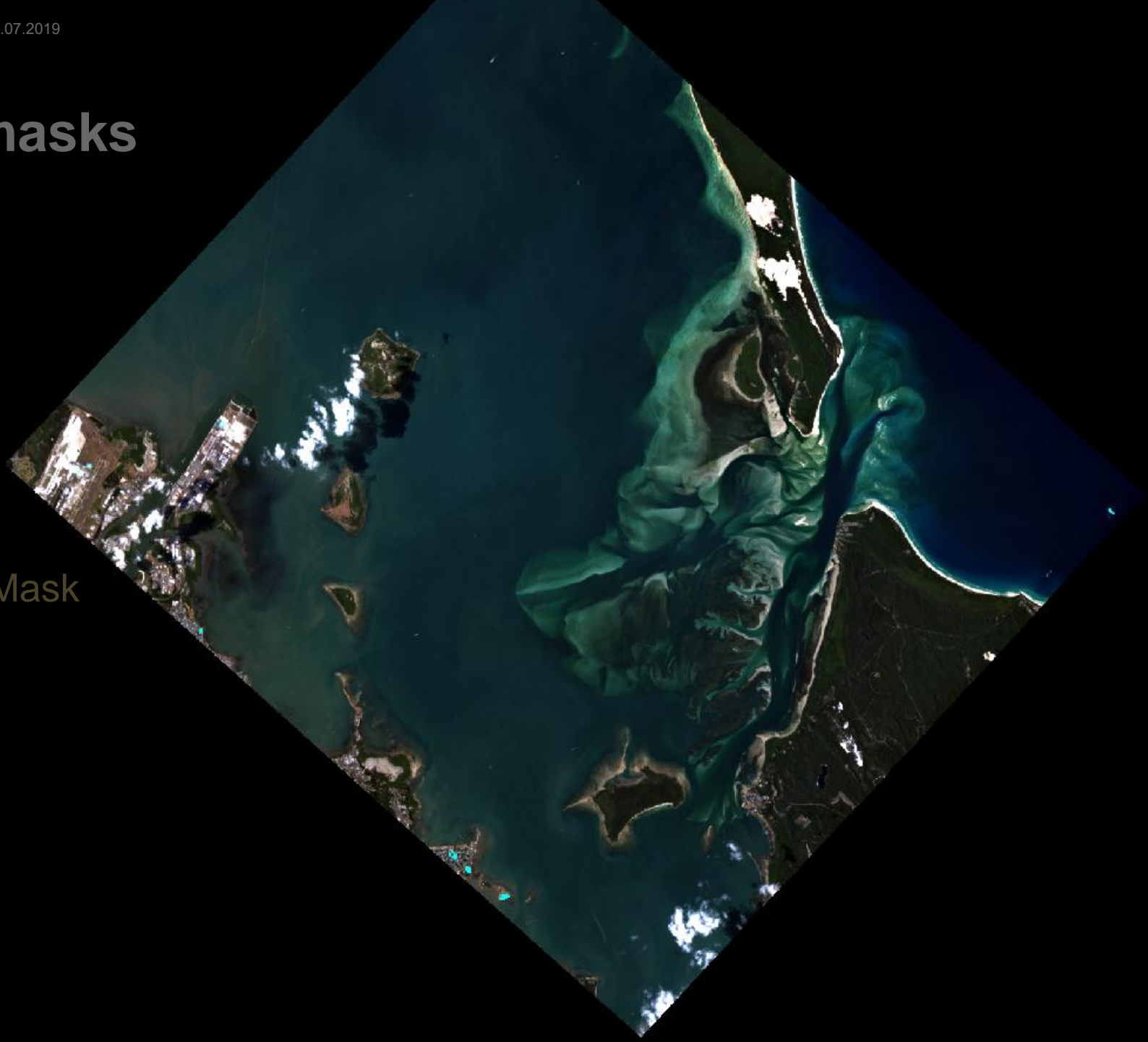
Land Mask

Water Mask

Cloud Mask

Cloud Shadow over land Mask

Haze over land Mask



Product Example L2A masks

Land Mask

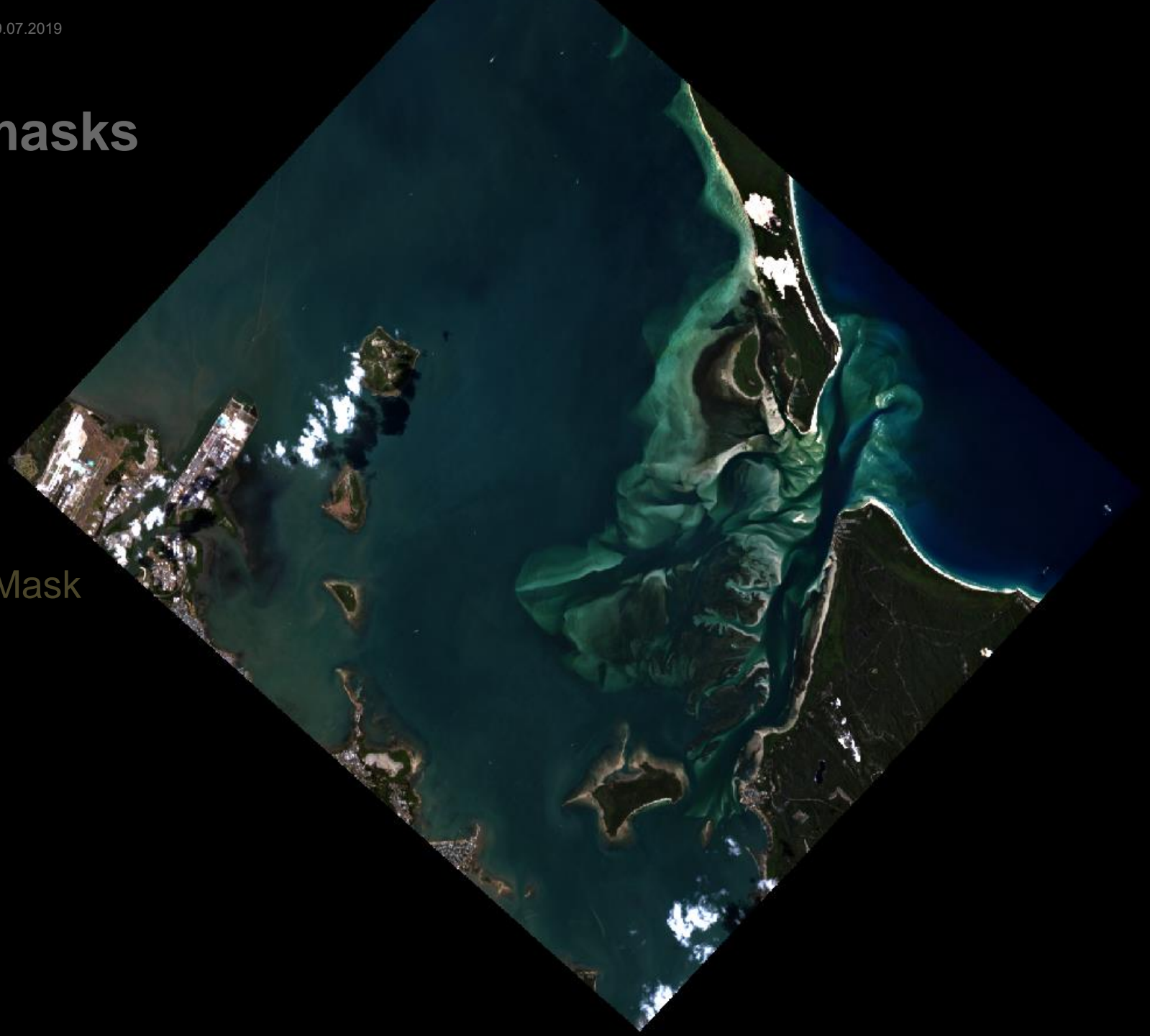
Water Mask

Cloud Mask

Cloud Shadow over land Mask

Haze over land Mask

Haze over water Mask



Product Example L2A masks

Land Mask

Water Mask

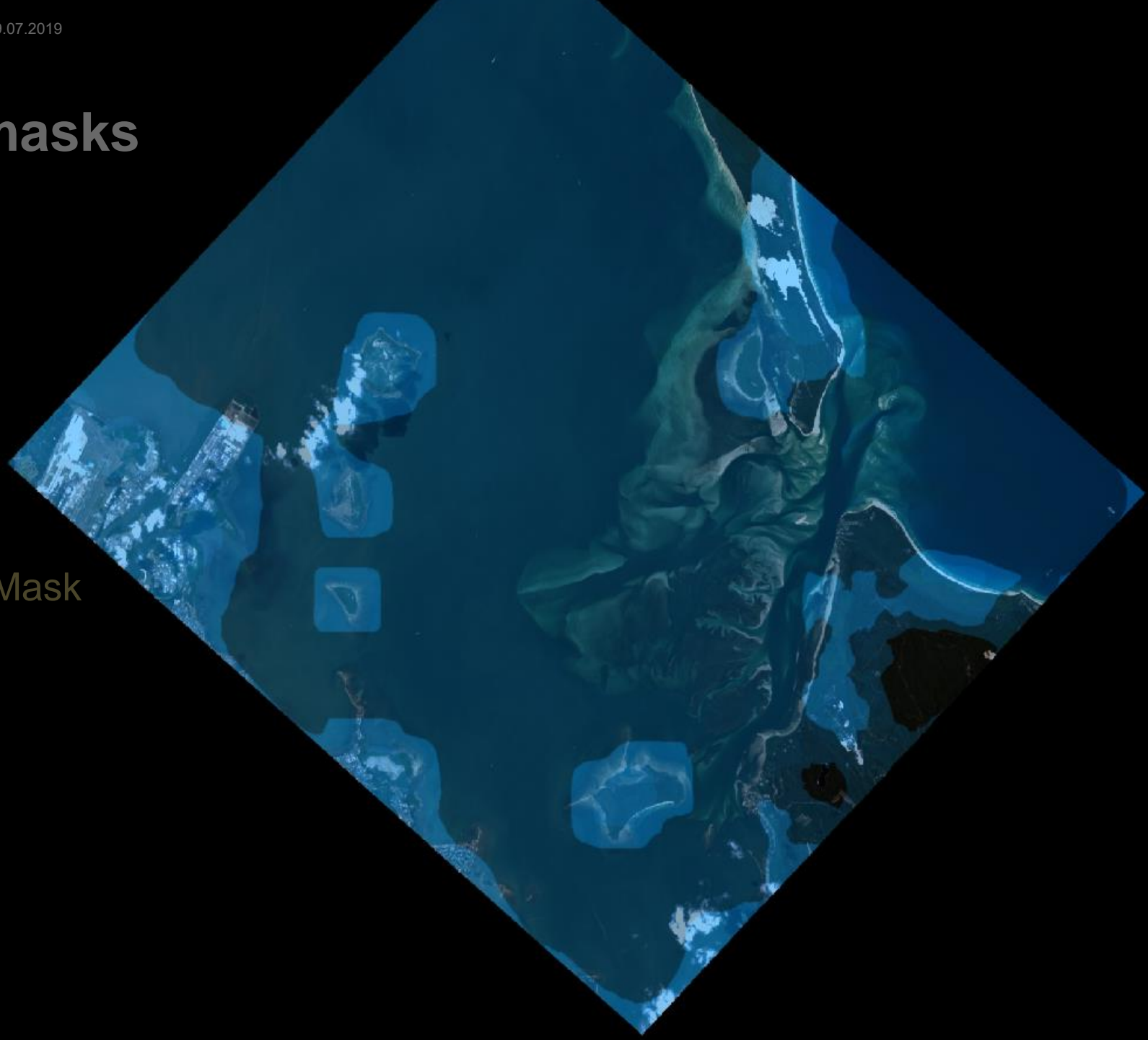
Cloud Mask

Cloud Shadow over land Mask

Haze over land Mask

Haze over water Mask

AOT Map



Product Example L2A masks

Land Mask

Water Mask

Cloud Mask

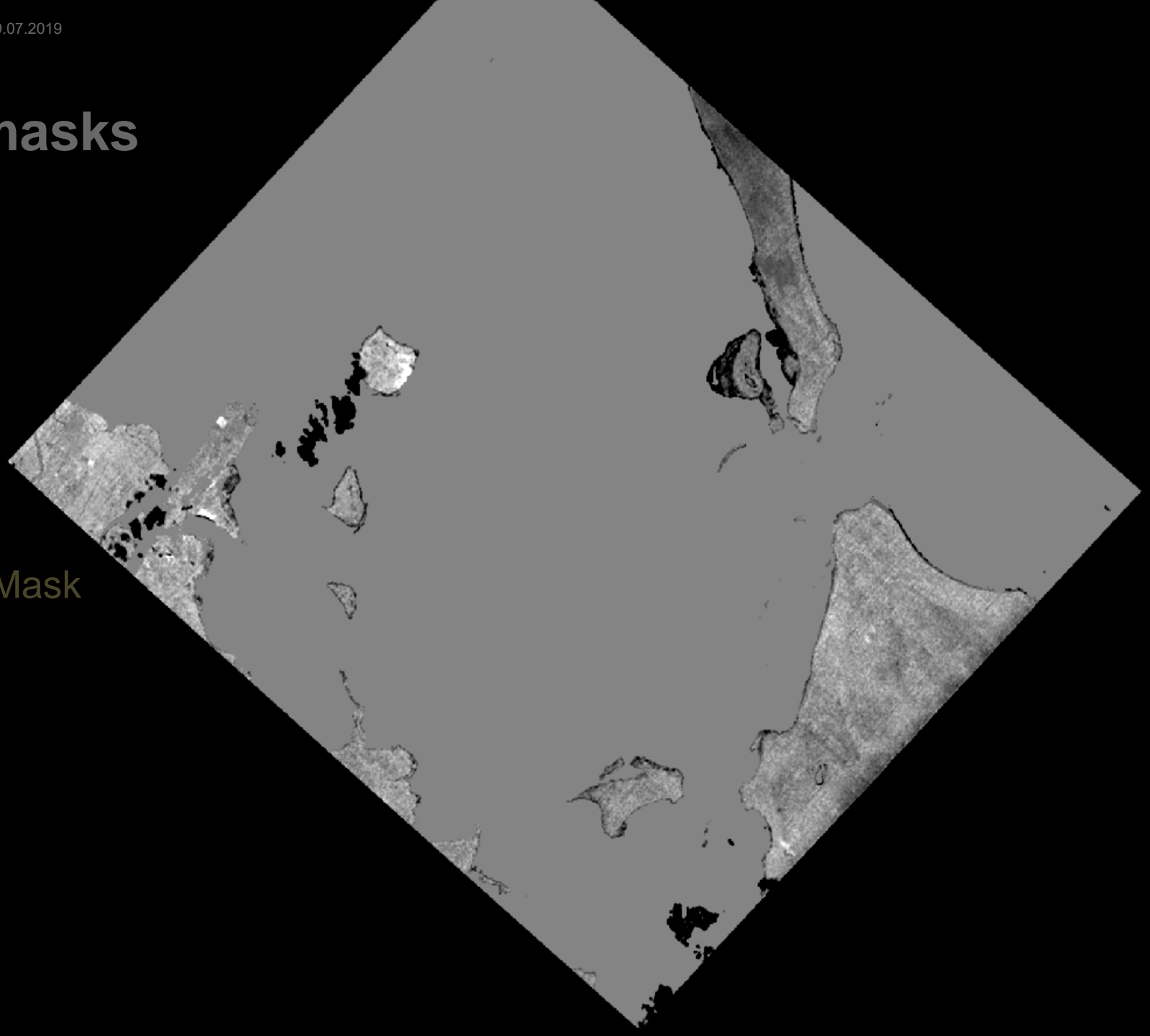
Cloud Shadow over land Mask

Haze over land Mask

Haze over water Mask

AOT Map Mask

WV Map Mask



Summary

- DESIS in-orbit functional tests successful. Instrument is operating stably and correctly
- Processing chain up and running. Products include L1B, L1C up to L2A
 - Including smile & rolling shutter correction
 - Relative radiometric correction (de-stripping)
- Radiometric within $< \sim 5\%$ for TOA reflectance based on RadCalNet, S2, L8 comparisons
- Geometric accuracy within 1 pixel (image-to-image matching), RMS ~ 20 m
- BOA reflectance within $< \sim 10\%$ based on RadCalNet, Pinnacles, S2 comparisons
- DESIS Orders can be placed now
 - TBE ordering and catalogue (<https://teledyne.tcloudhost.com>)
 - For access through DLR see instructions in web (<https://www.dlr.de/eoc/desktopdefault.aspx/tabid-13614/>)
- Outlook: looking forward to cross-calibration with Hisui and Prisma



Thank you



Knowledge for Tomorrow



EXTRA



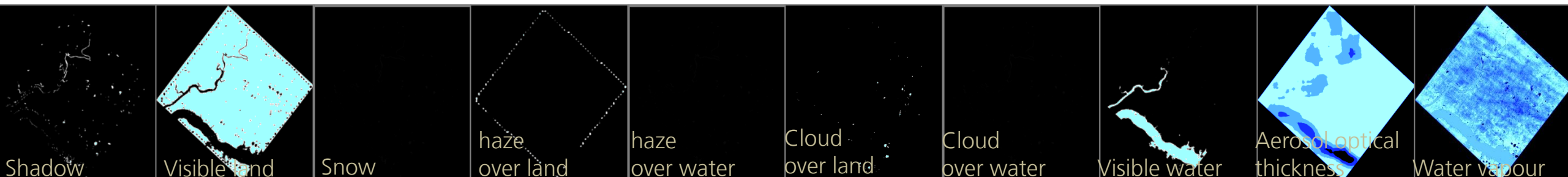
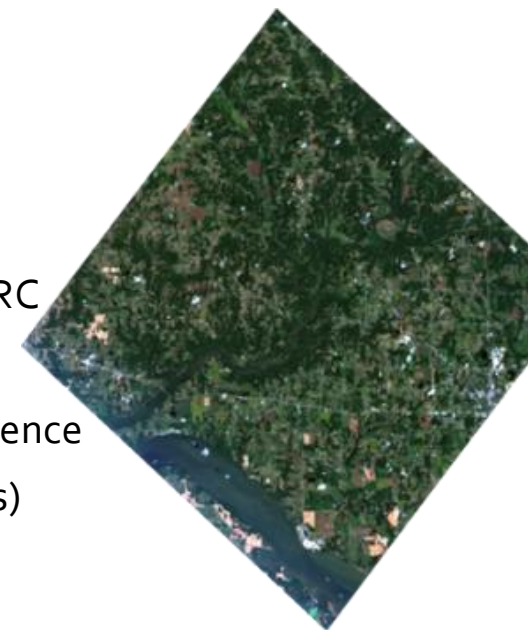
Knowledge for Tomorrow



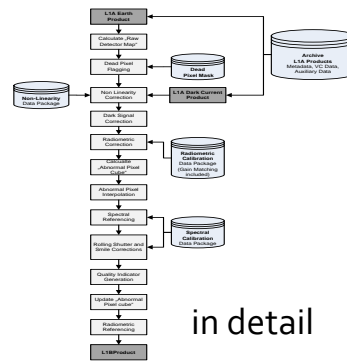
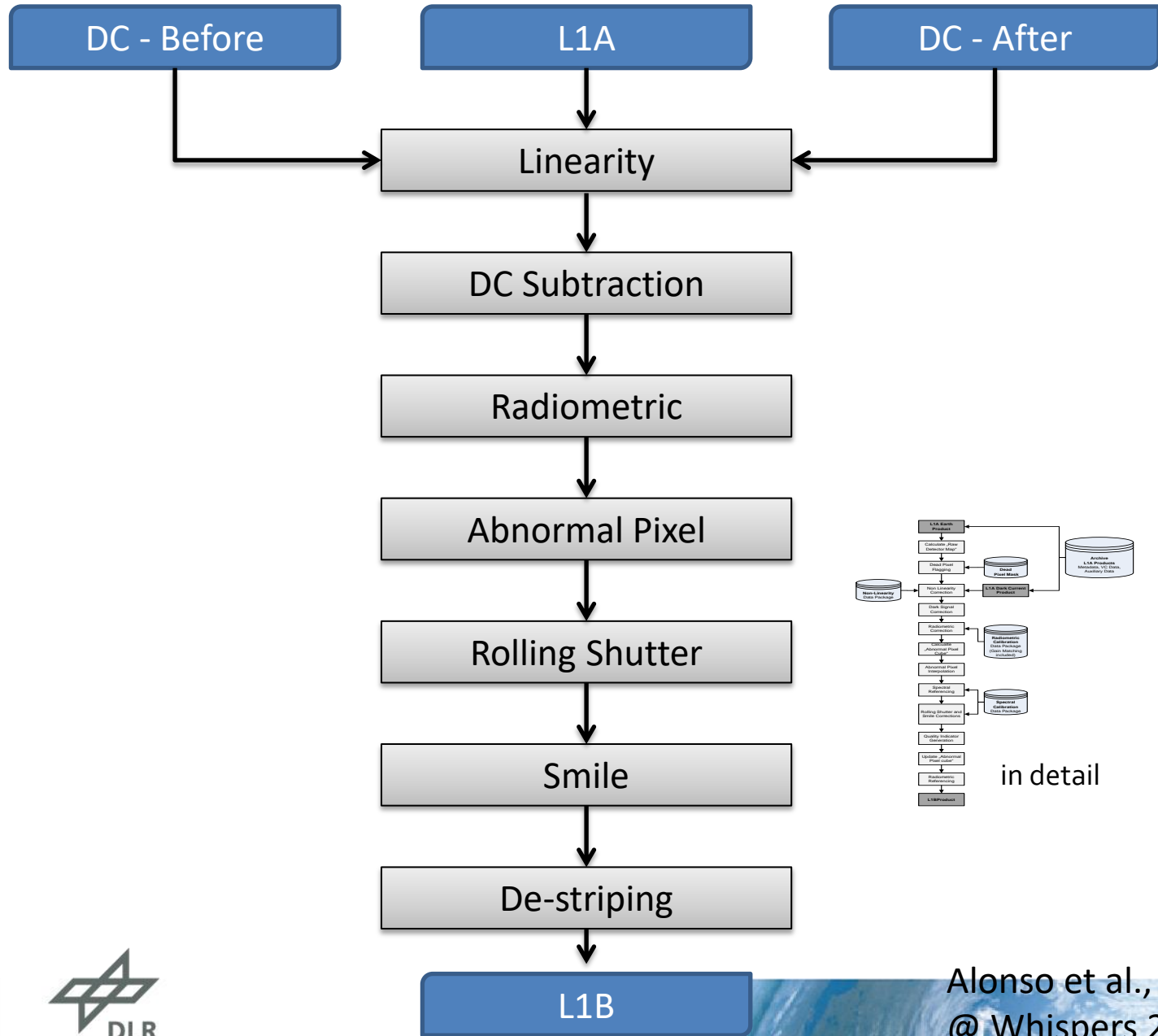
Quality Layers and Metadata

Quality Layer (Geotiff)	L1A	L1B	L1C	L2A
Dead pixels		X	X	X
Suspicious pixels		X	X	X
Too high radiance level		X	X	X
Too low radiance level		X	X	X
Shadow				X
Land				X
Water				X
Haze over land				X
Haze over water				X
Cloud over land				X
Cloud over water				X
Aerosol optical thickness				X
Perceptible water vapour				X
Detector Map (Digital Number)	X			
Detector Map (Radiance Level)	X			

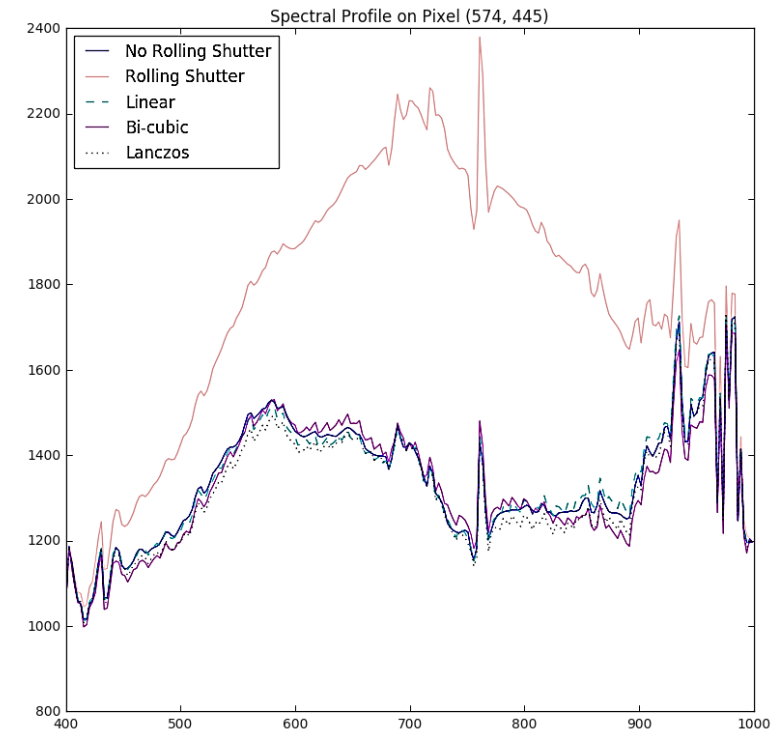
- Dead Pixels
 - generated through calibration
- Suspicious pixels
 - Generated by comparison between measured radiances and calibration
- Data Screening
 - Temperatures, Voltages, Currents, CRC
- Geometric accuracy
 - Subset of matching points with reference
- Bad columns/lines (based on detector maps)
 - Generated by statistical tests
- Smile Indication
 - Based on Absorption Bands (like O₂ at 760 nm)



L1B Workflow – from Digital Numbers to Top-of-Atmosphere Radiances

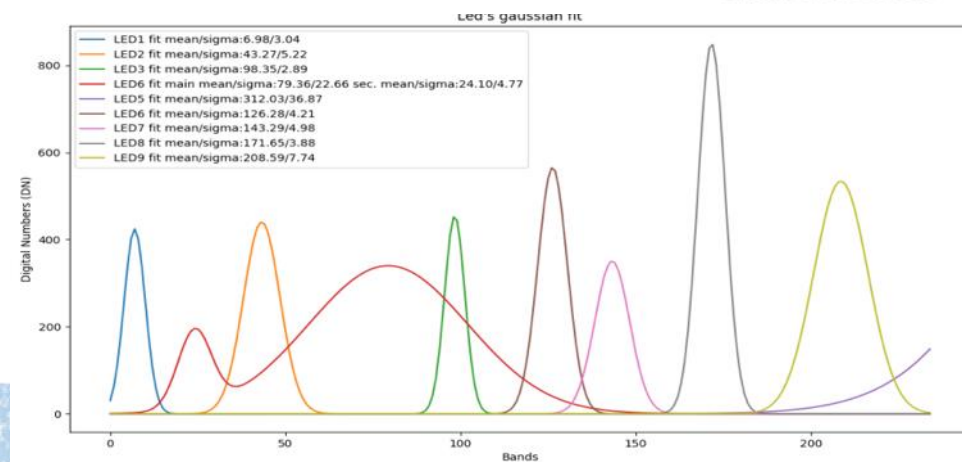
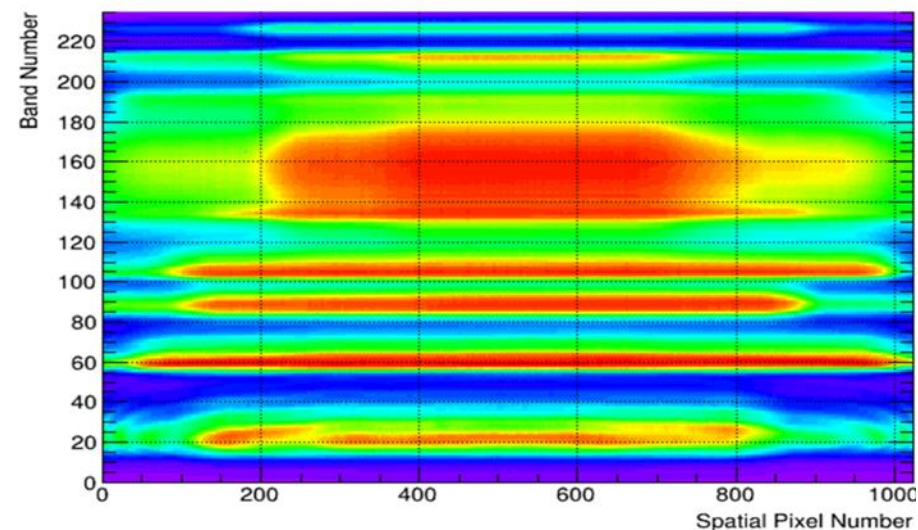
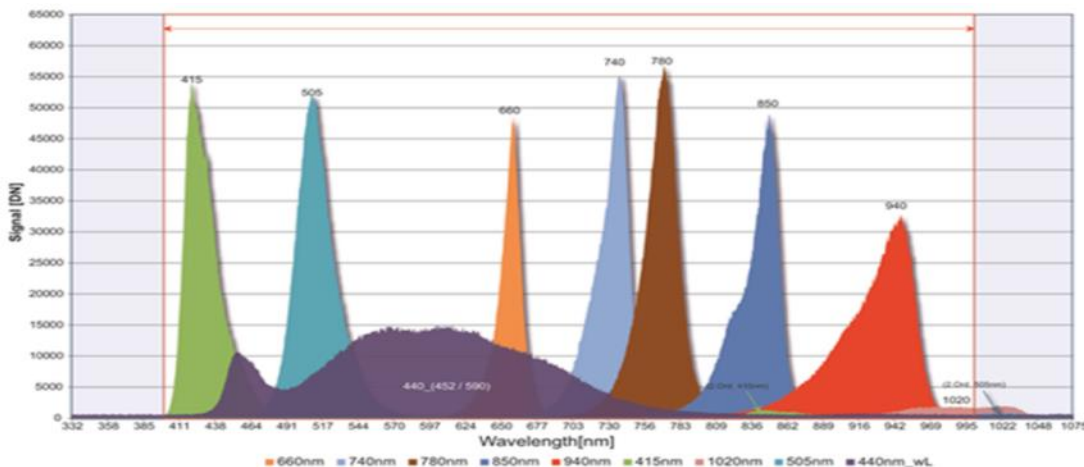


Rolling Shutter Correction Reconstruction of spectral signatures



Calibration Unit

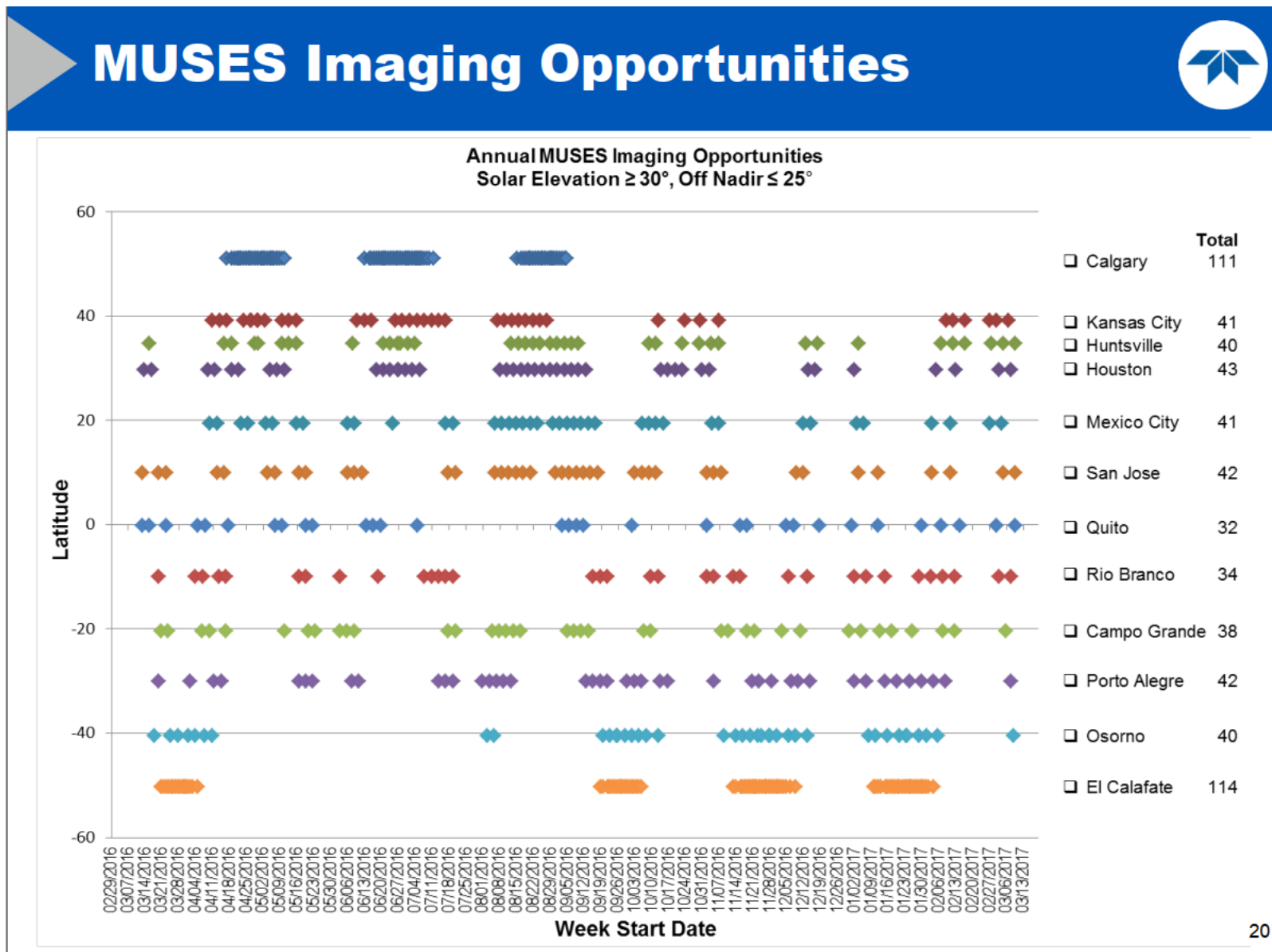
- For in-flight calibration of DESIS
 - Absolute (PRNU: Photo Response Non Uniformity)
 - Spectral
- Two identical LED banks with 9 lamps each
- Stable in peak and spectral bandwidth after Proton radiation (30 MeV). Burn-in time ~1000 hours.



Krawczyk et al., RADIOMETRIC AND SPECTRAL ONBOARD CALIBRATION CONCEPTS OF HYPER SPECTRAL SENSORS - SPECIFICS OF ENMAP AND DESIS @ WHISPERS 2018

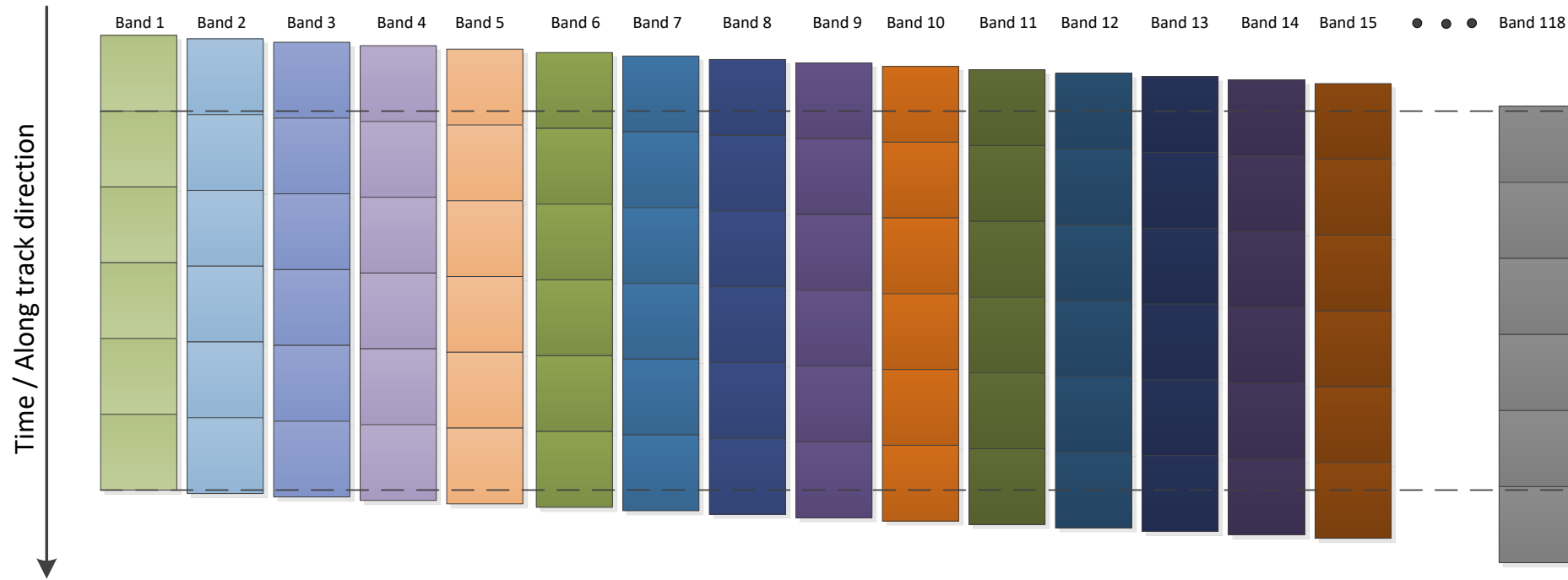


MUSES:
Total data downlink ~225 GB/day



DESIS Data Processing

Rolling Shutter



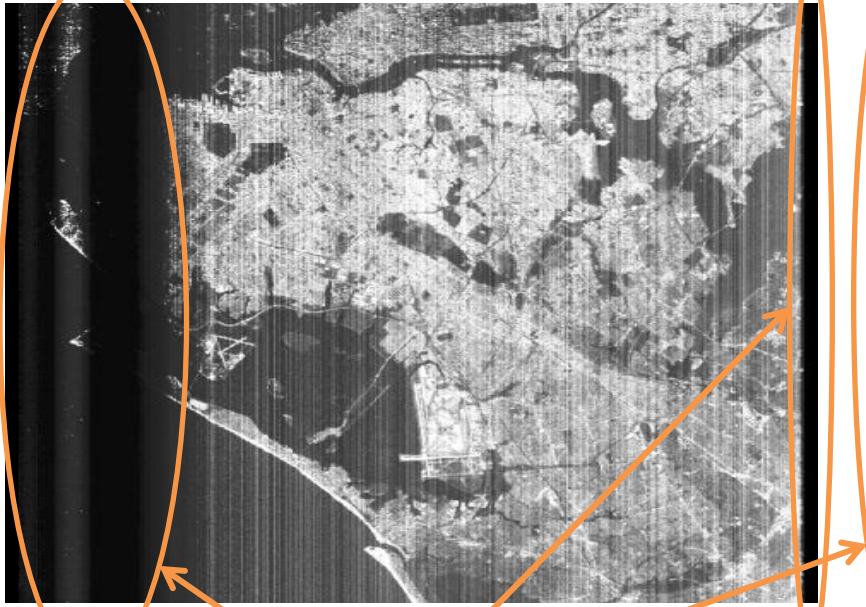
- DESIS will be the first multiband spaceborne sensor featuring a rolling shutter
- Each consecutive band is observed at a slightly delayed position on ground

- Need to re-sample data to have all wavelength registered values at the same position on ground
- Correction integrated in processor

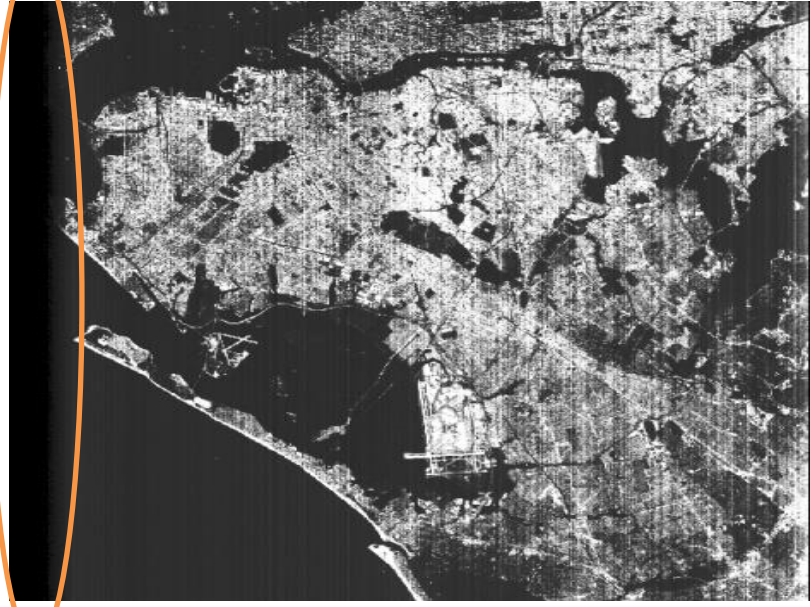


Striping – not solvable

Band 1 (2.55 nm)



Band 4 (2.55 nm)



Band 22 (2.55 nm)

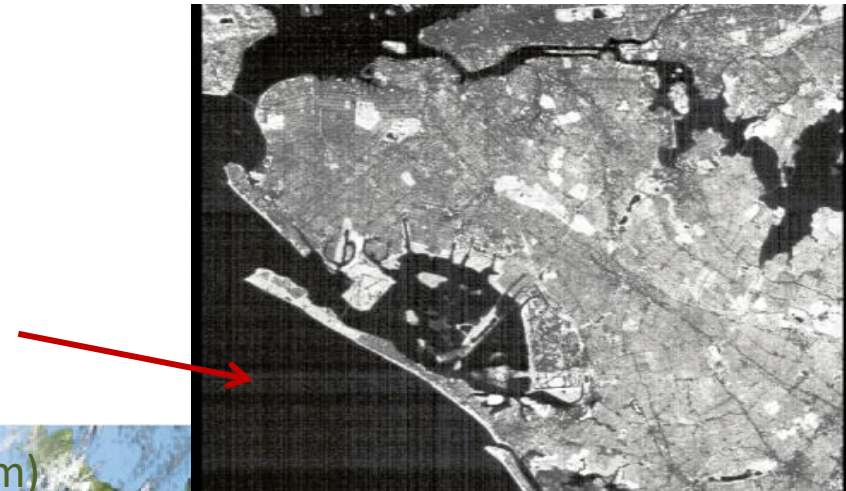


Manufacturing defects

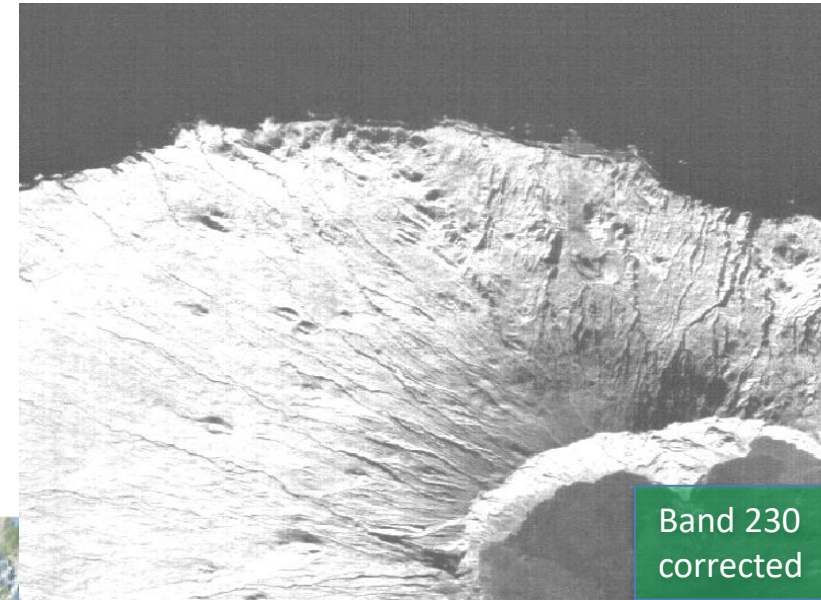
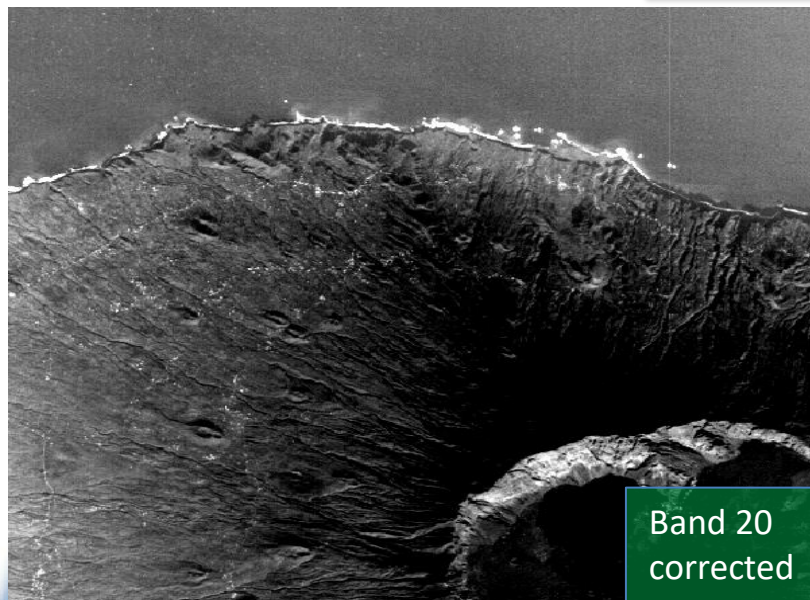
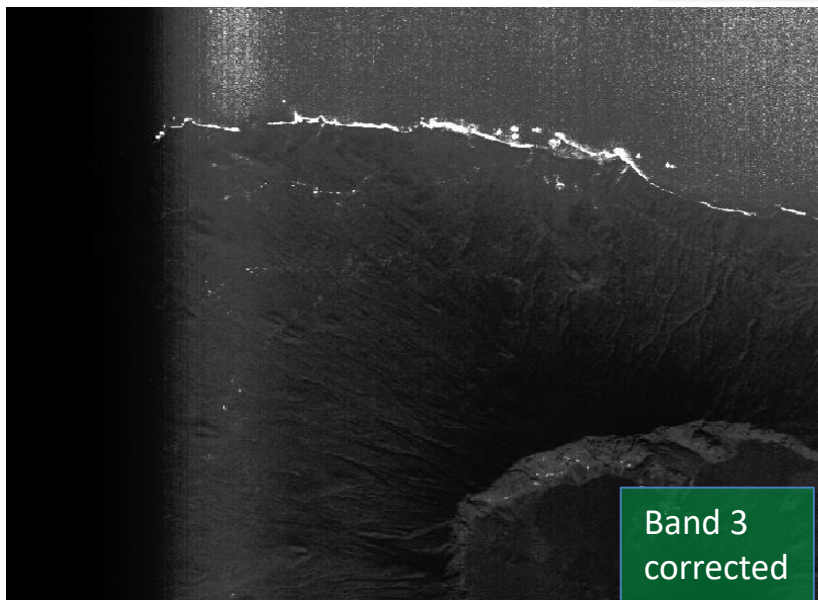
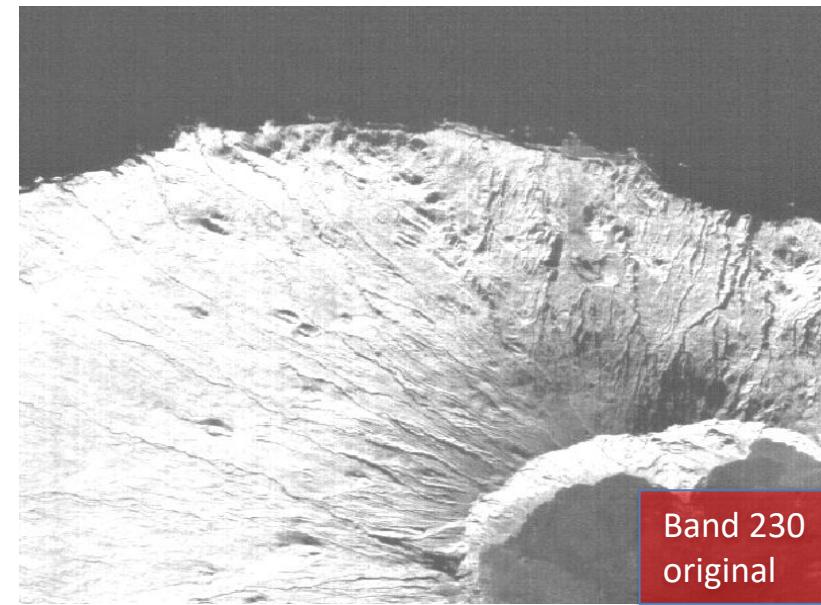
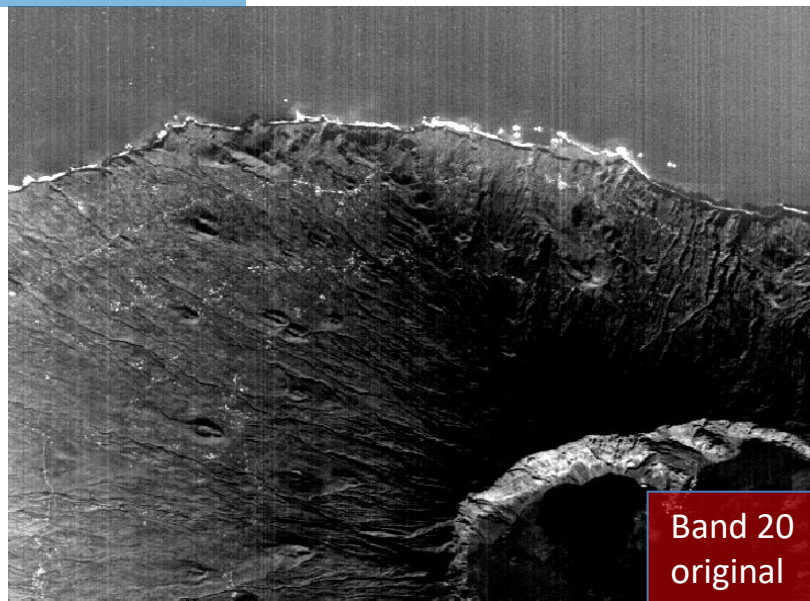
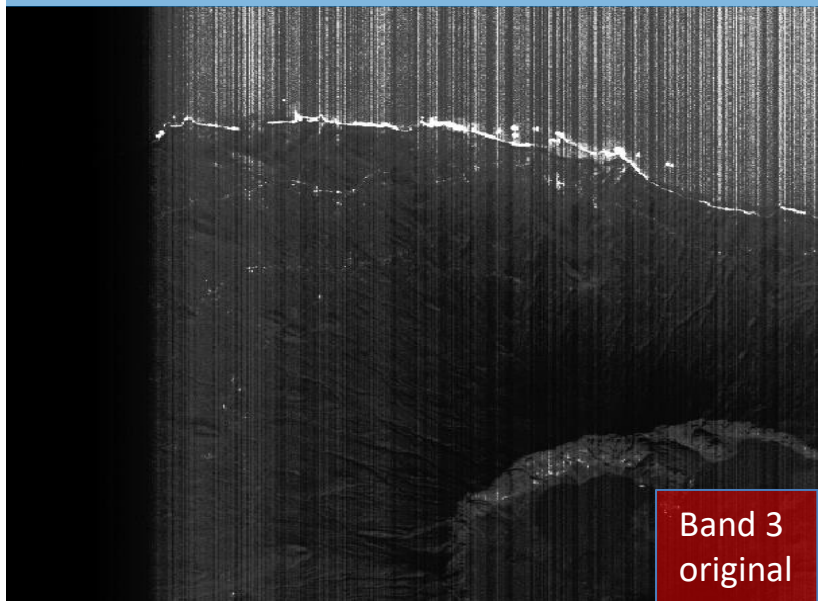
Different Striping

Most likely caused by Noise in DC, most noticeable in last ~30 bands (2.55 nm). Notice also horizontal striping of same magnitude. Cosmetics solution could be used, but not real solution

Band 212 (2.55 nm)



L1B radiance range stretched to highlight stripping



Product Example L1C

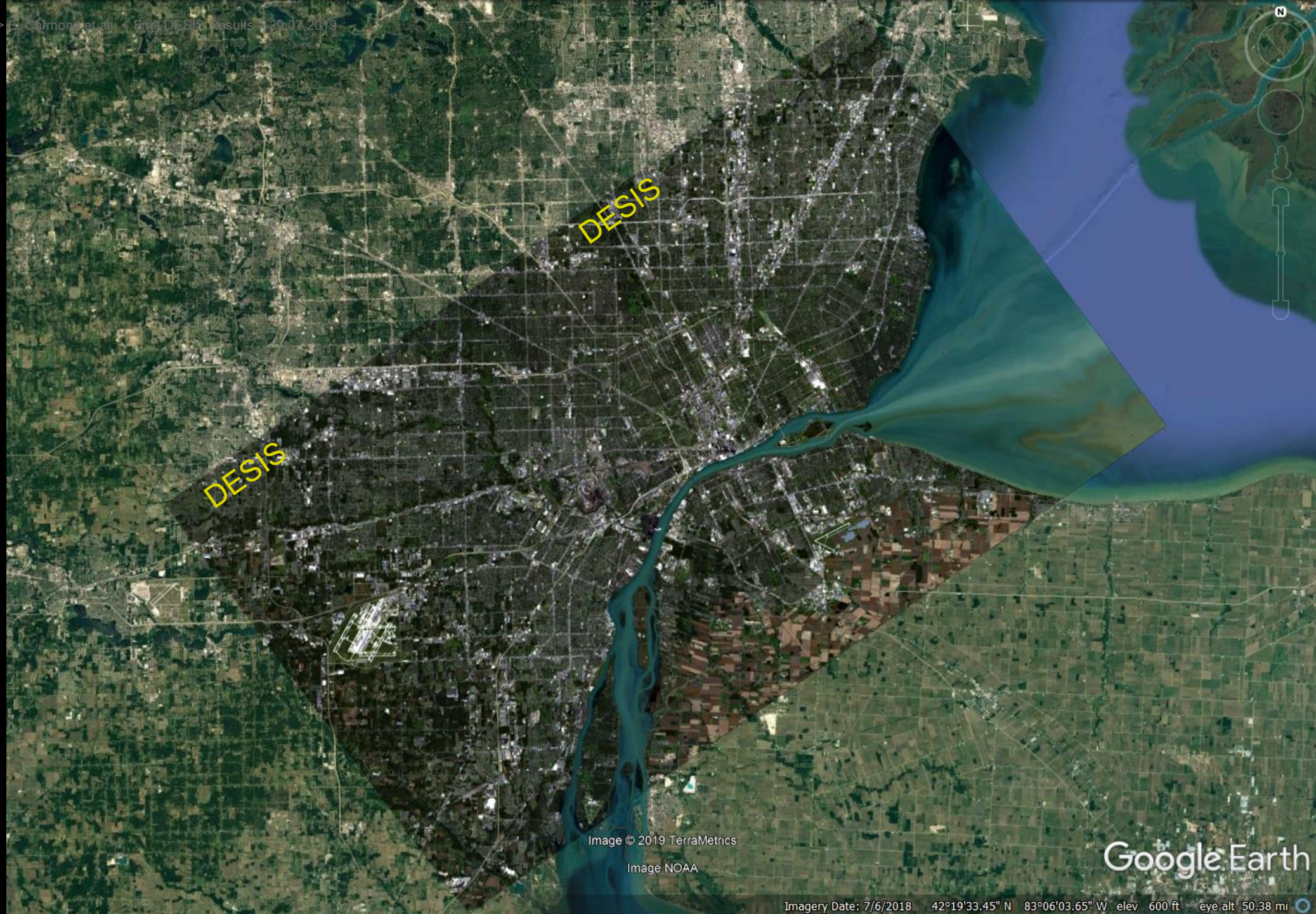


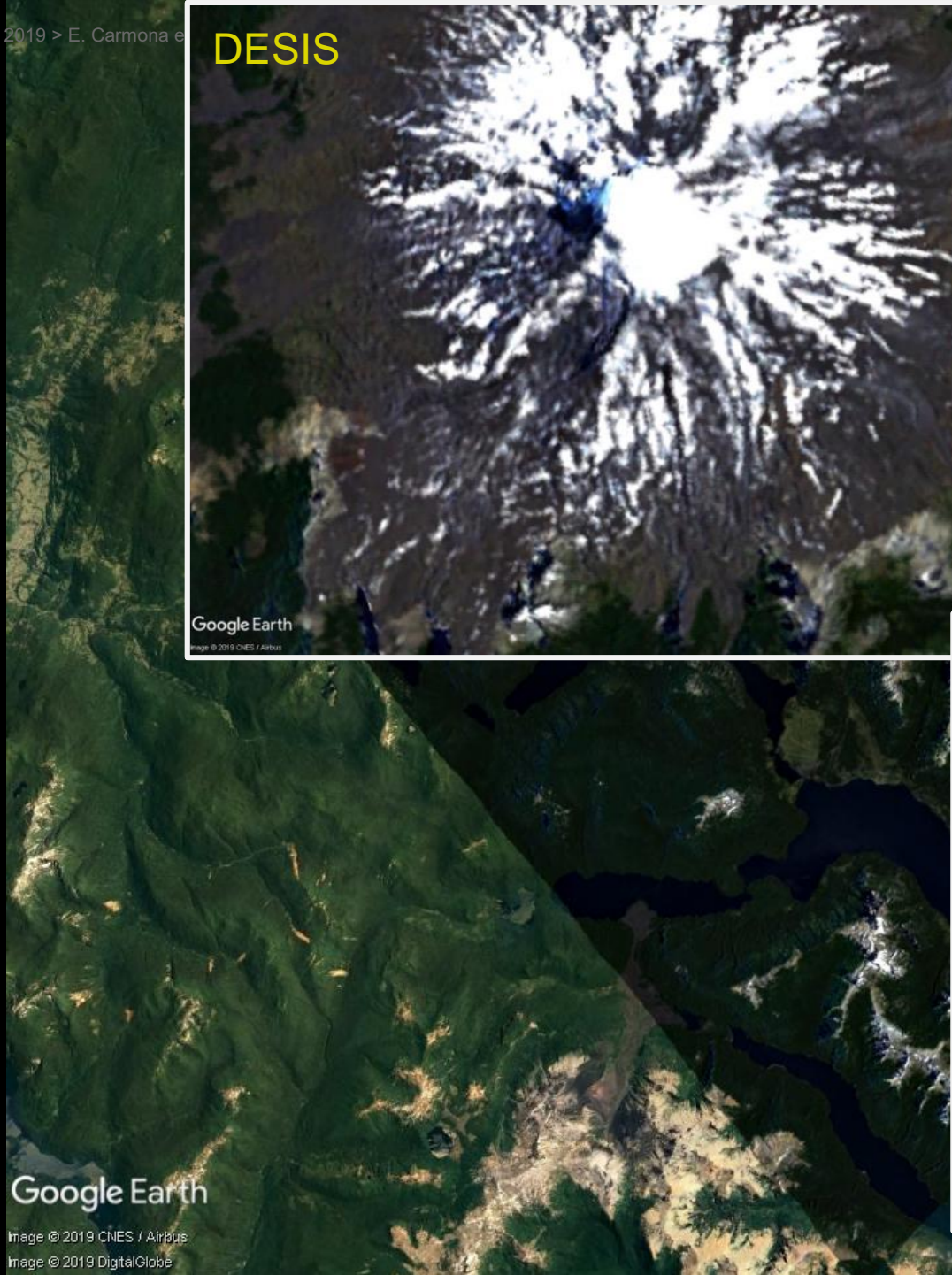
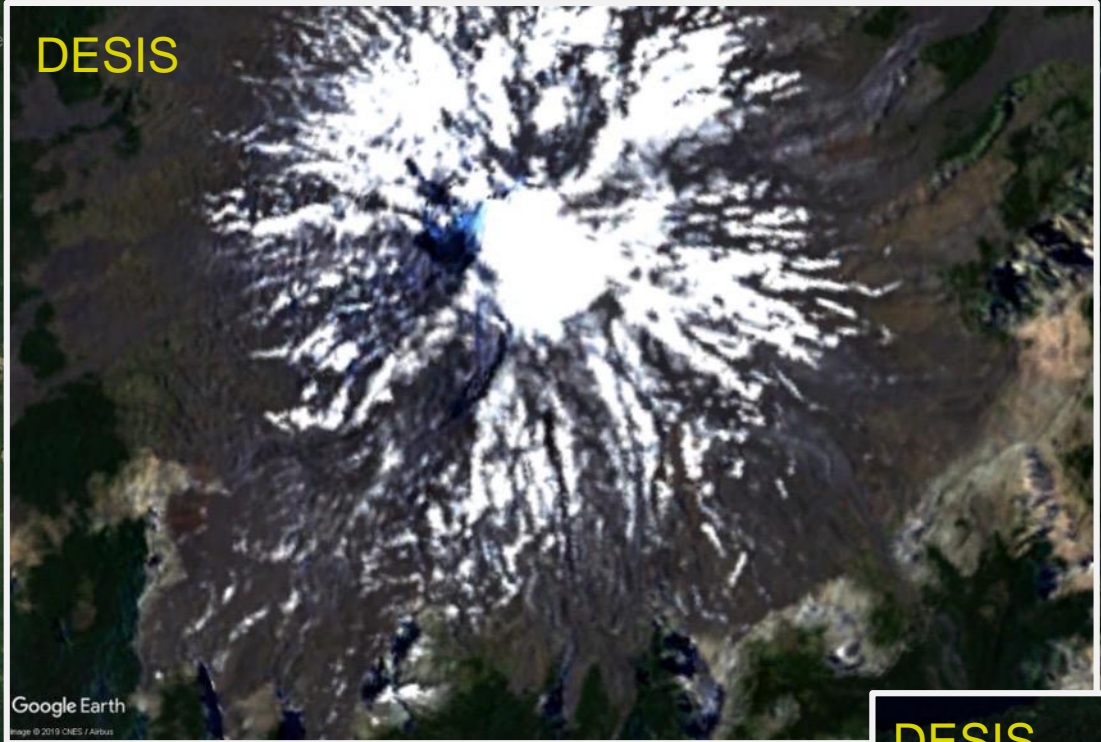
Image © 2019 TerraMetrics
Image NOAA

Google Earth

Product Example L1C



Product Example L1C

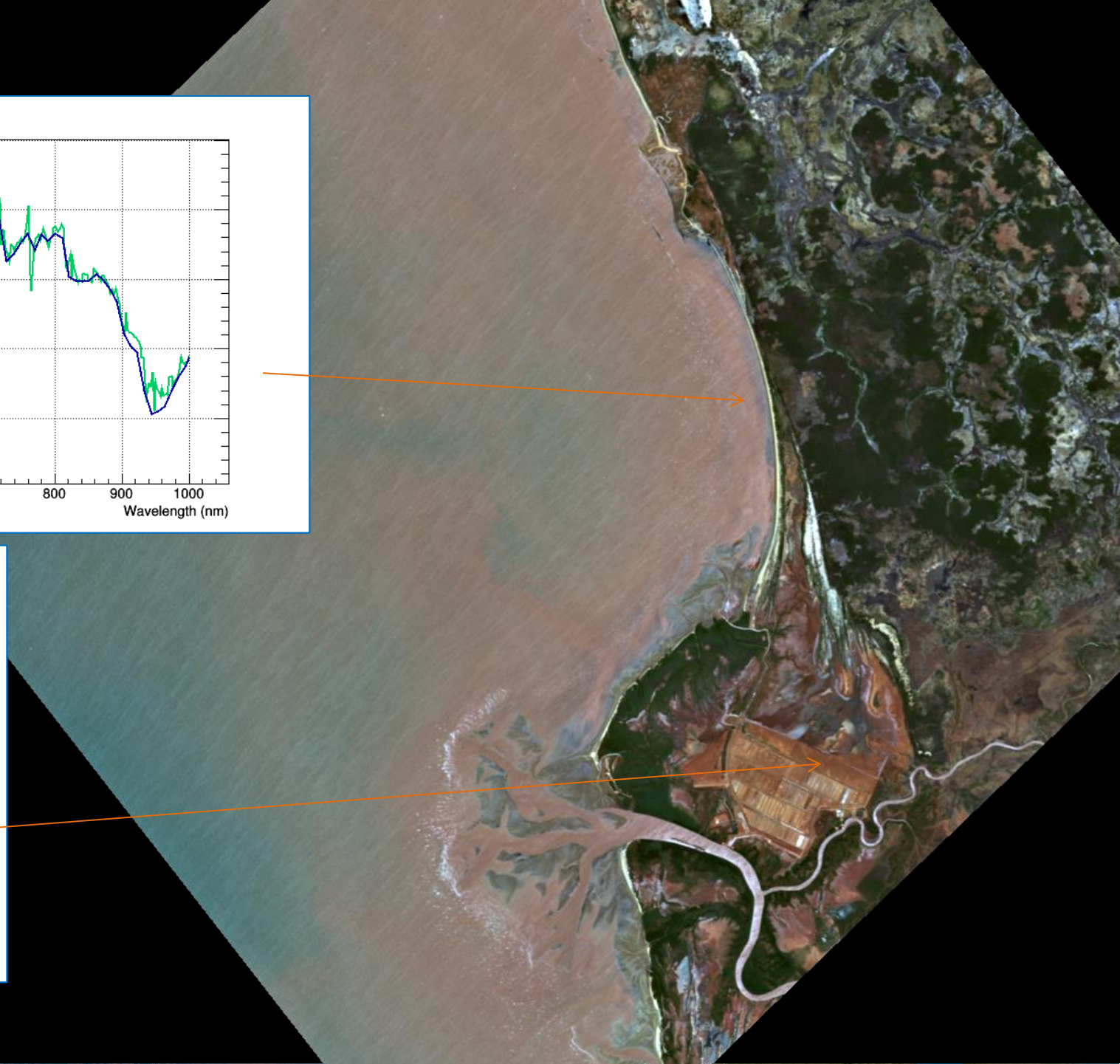
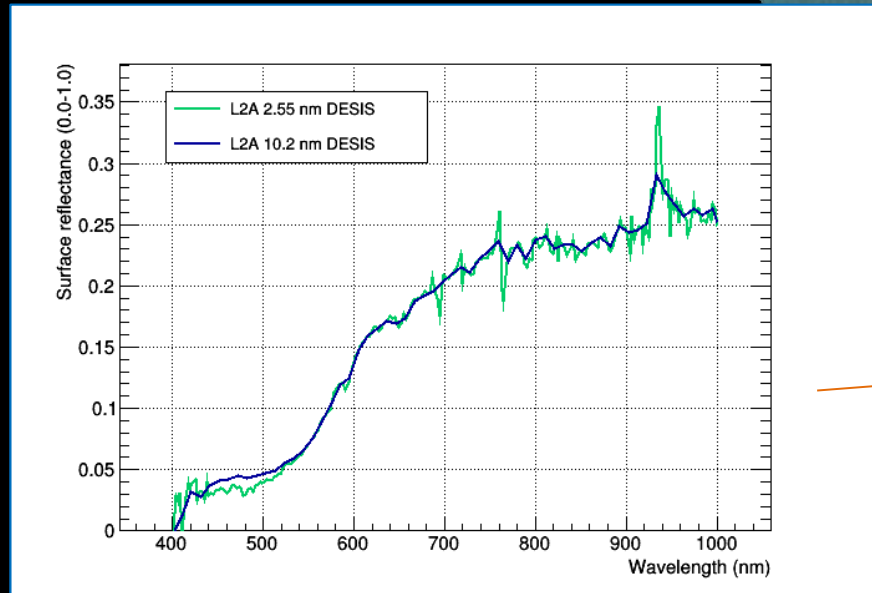
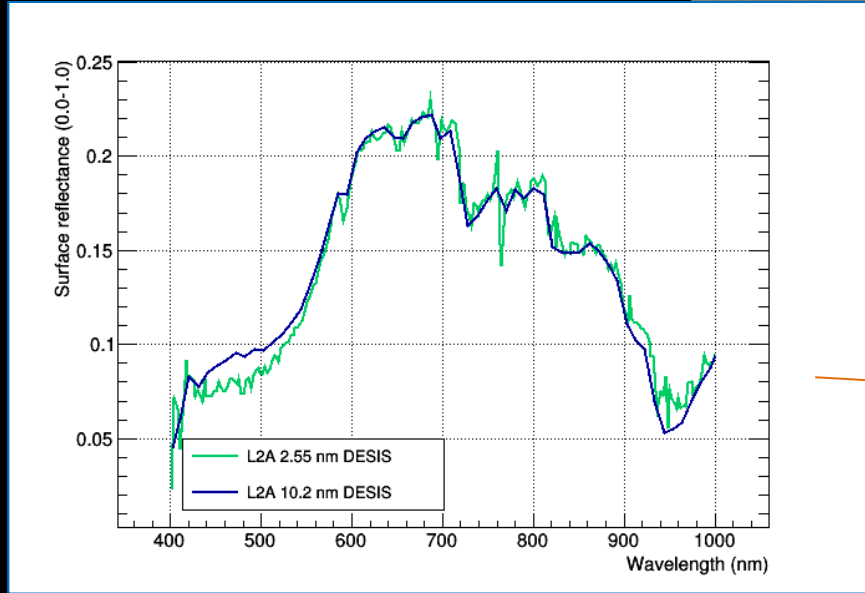


Google Earth

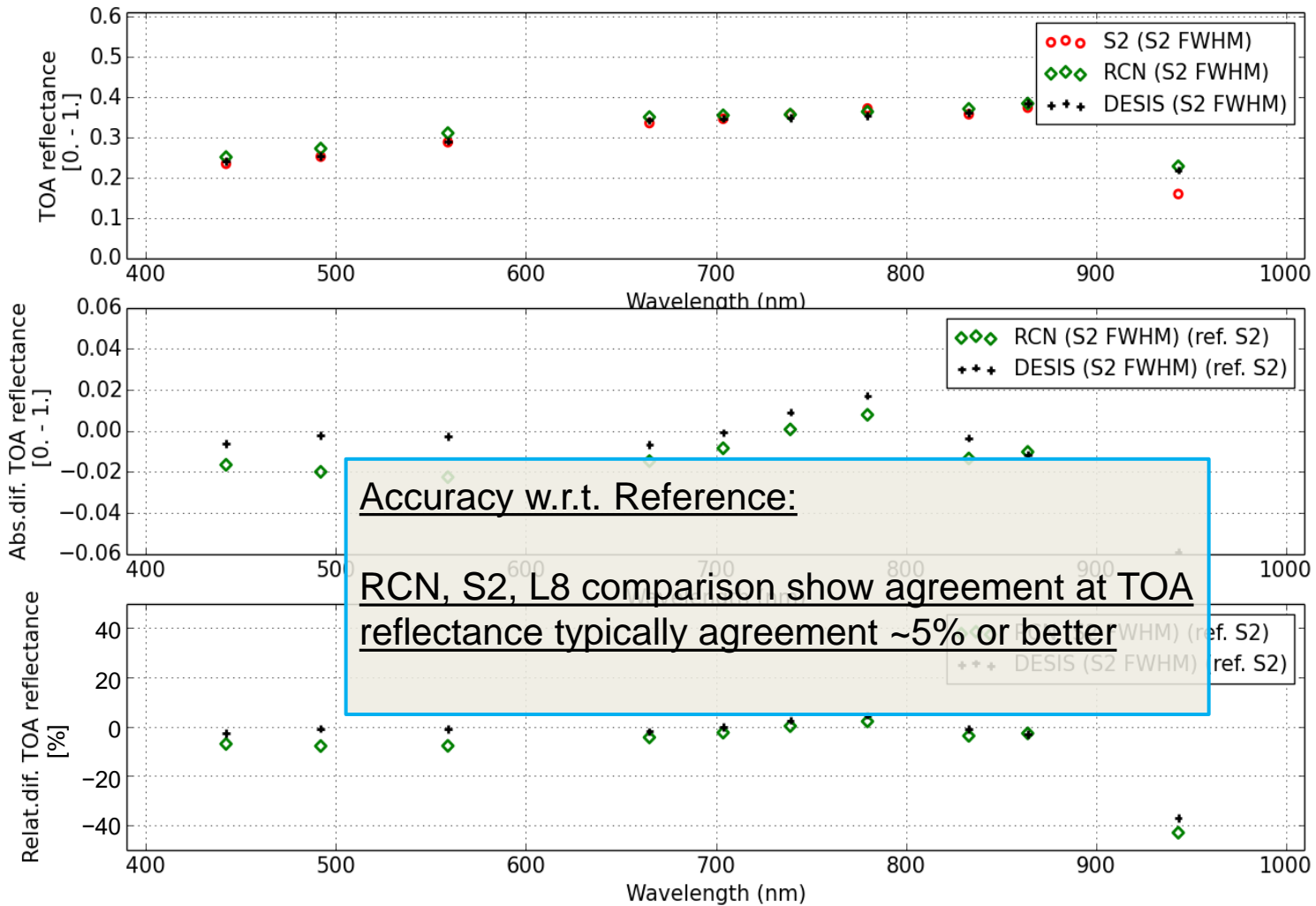
Image © 2019 CNES / Airbus

Image © 2019 DigitalGlobe

DESIS Scenes



Radiometrically corected data: TOA reflectance validation



- Compare TOA reflectances with Sentinel (2019-06-28, Railroad Valley)

