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

Martin Bachmann[2], Kevin Alonso[1], Emiliano Carmona[1], Daniele Cerra[1], Daniele Dietrich[2], Uta Heiden[2], Uwe Knodt[3], David Krutz[4], David Marshall[2] , Rupert Müller[1], Raquel de los Reyes[1], Mirco Tegler[5]

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

(1) DLR German Aerospace Center, Remote sensing Technology Institute, Oberpfaffenhofen
(2) DLR German Aerospace Center, German Remote Sensing Data Center, Oberpfaffenhofen
(3) DLR German Aerospace Center, DLR Headquaters, Cologne
(4) DLR German Aerospace Center, Institute of Optical Sensors, Berlin-Adlershof
(5) DLR German Aerospace Center, German Remote Sensing Data Center, Neuztrelitz
(6) I2R Innovative Imaging and Research Corp
(7) Teledyne Brown Engineering

SBG Cal/Val Workshop, 23.07.2020

DLR

Content of the presentation

- Mission and instrument
- Product examples
- Calibration and Validation
- Application examples

Teledyne

DESIS, MUSES and ISS

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

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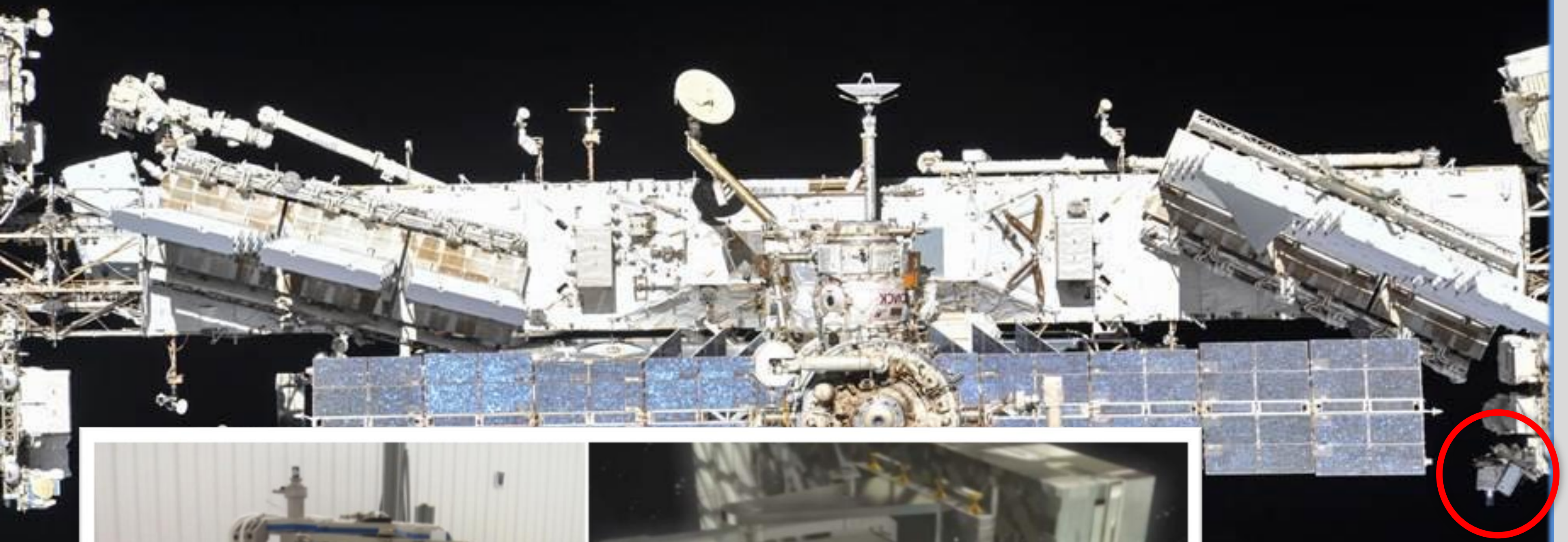
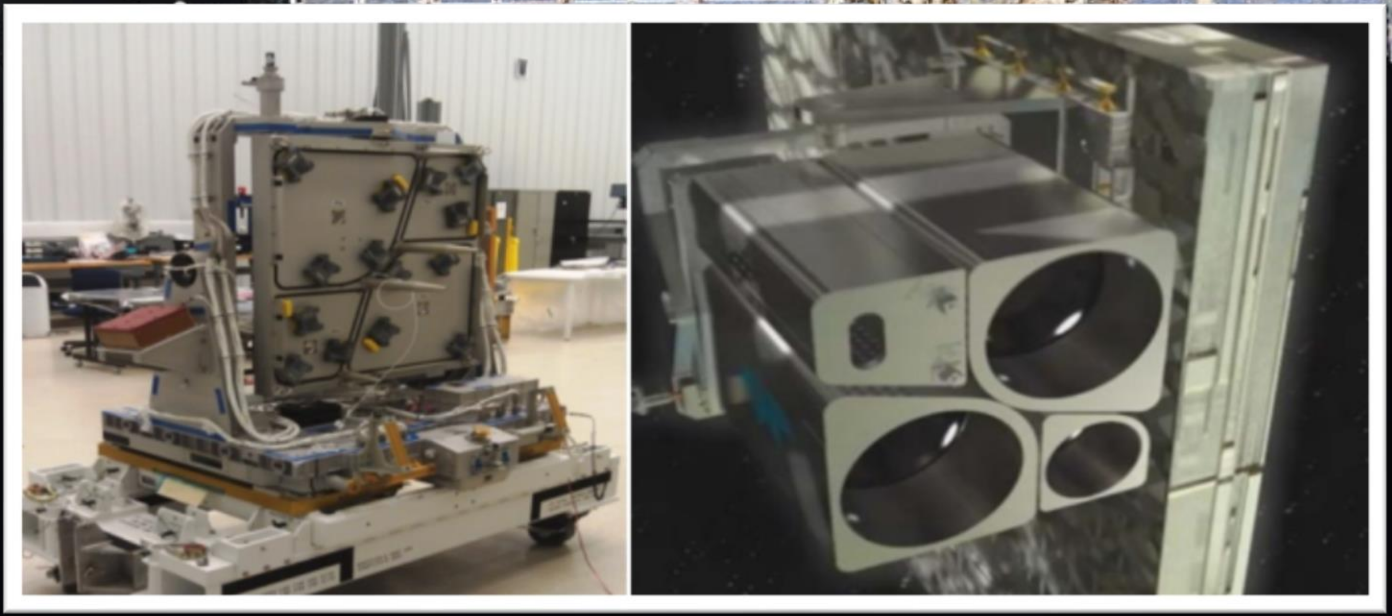
DESIS, MUSES and ISS





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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 µsec)
- **2 Gimbals** ±25° for/back; 45° backboard; 5° starboard
- **Downlink** 225 Gbit / day Ku band

DESIS, MUSES and ISS

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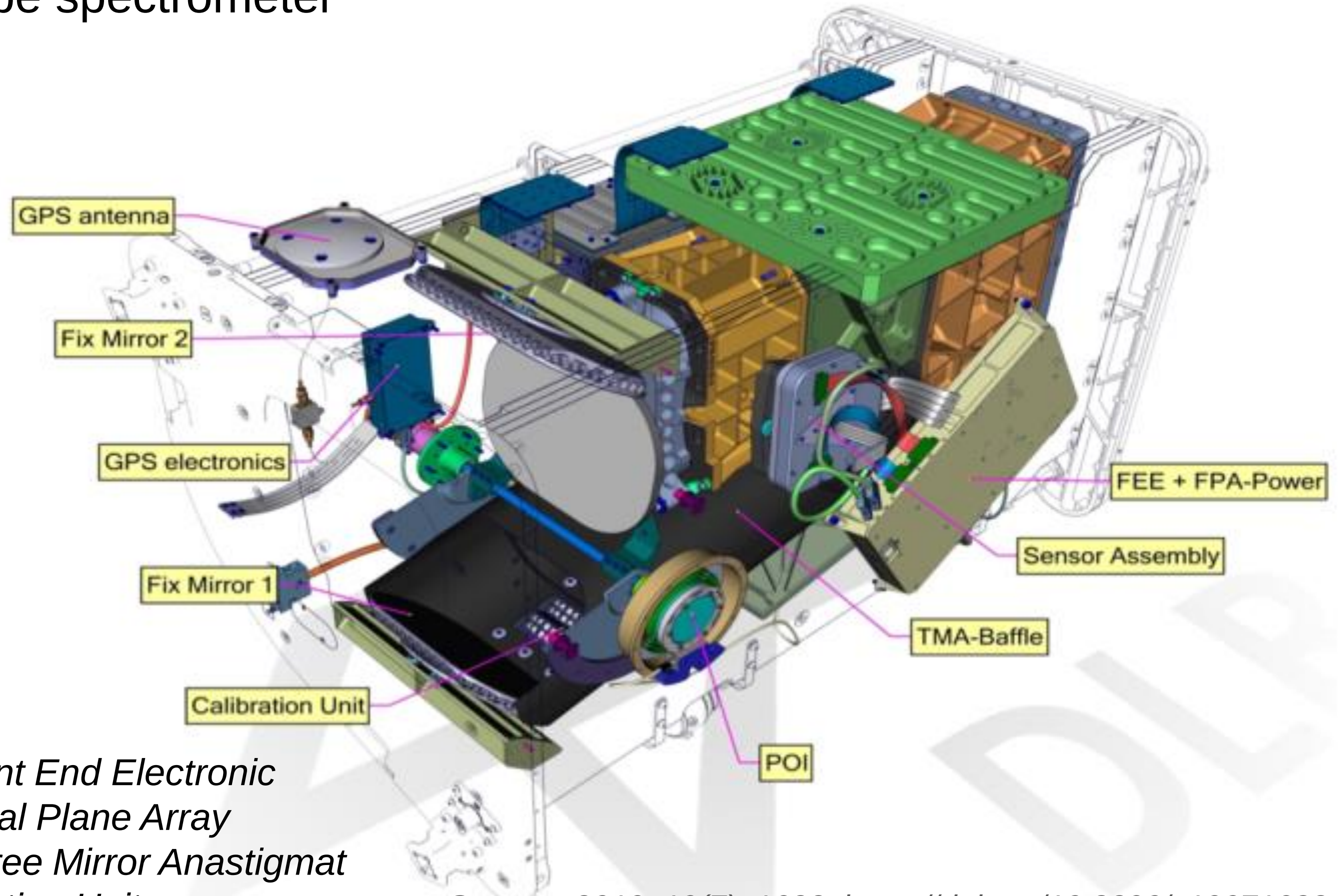
DESIS, the hyperspectral sensor developped by DLR, which is currently the first payload of MUSES.

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



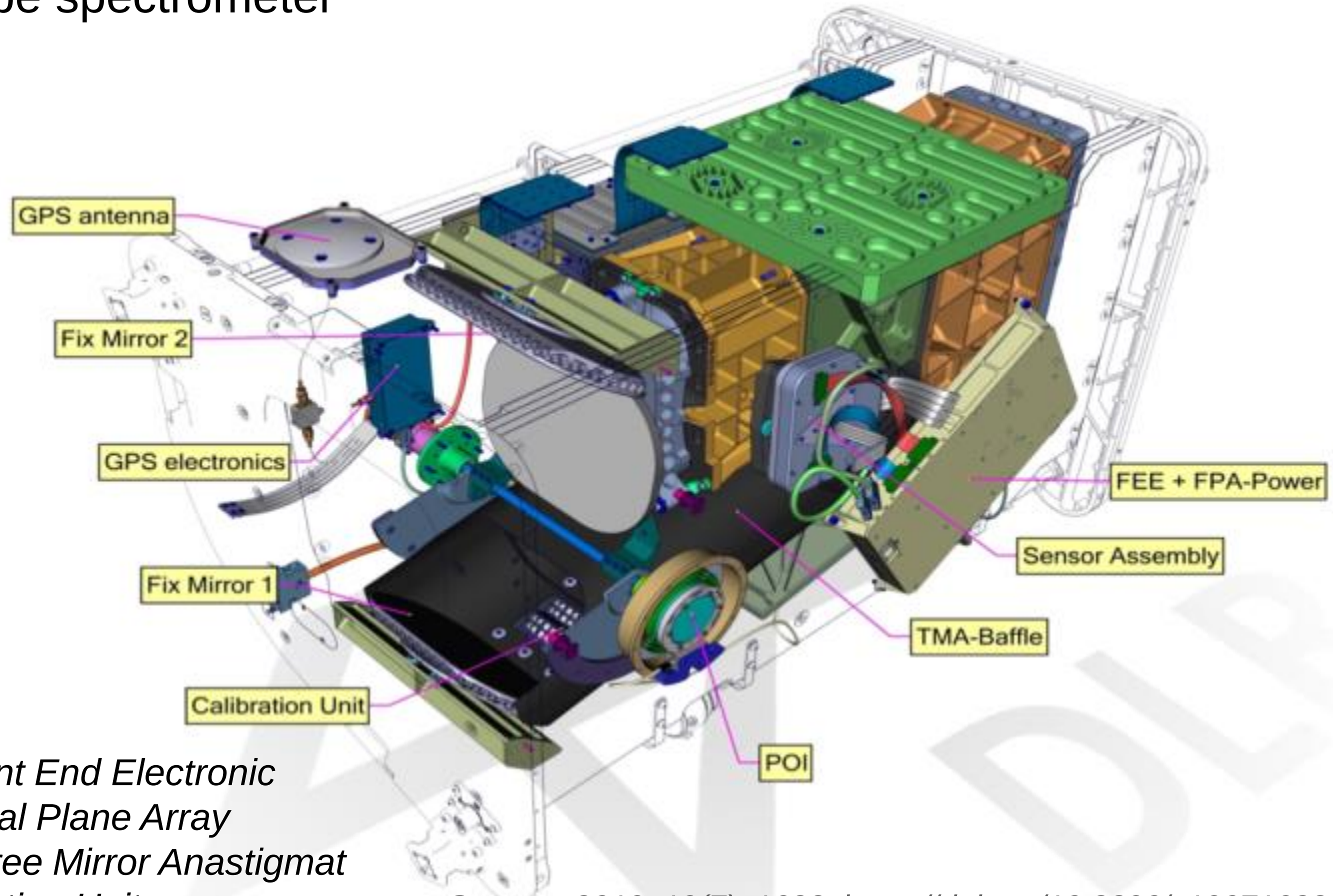
FEE: *Front End Electronic*
FPA: *Focal Plane Array*
TMA: *Three Mirror Anastigmat*
POI: *Pointing Unit*

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

- 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 ±15°
    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

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 Sampling (res., 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*
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Sensors 2019, 19(7), 1622; https://doi.org/10.3390/s19071622

DESIS Chronology

2014 / 2015
MUSES / DESIS mission starts

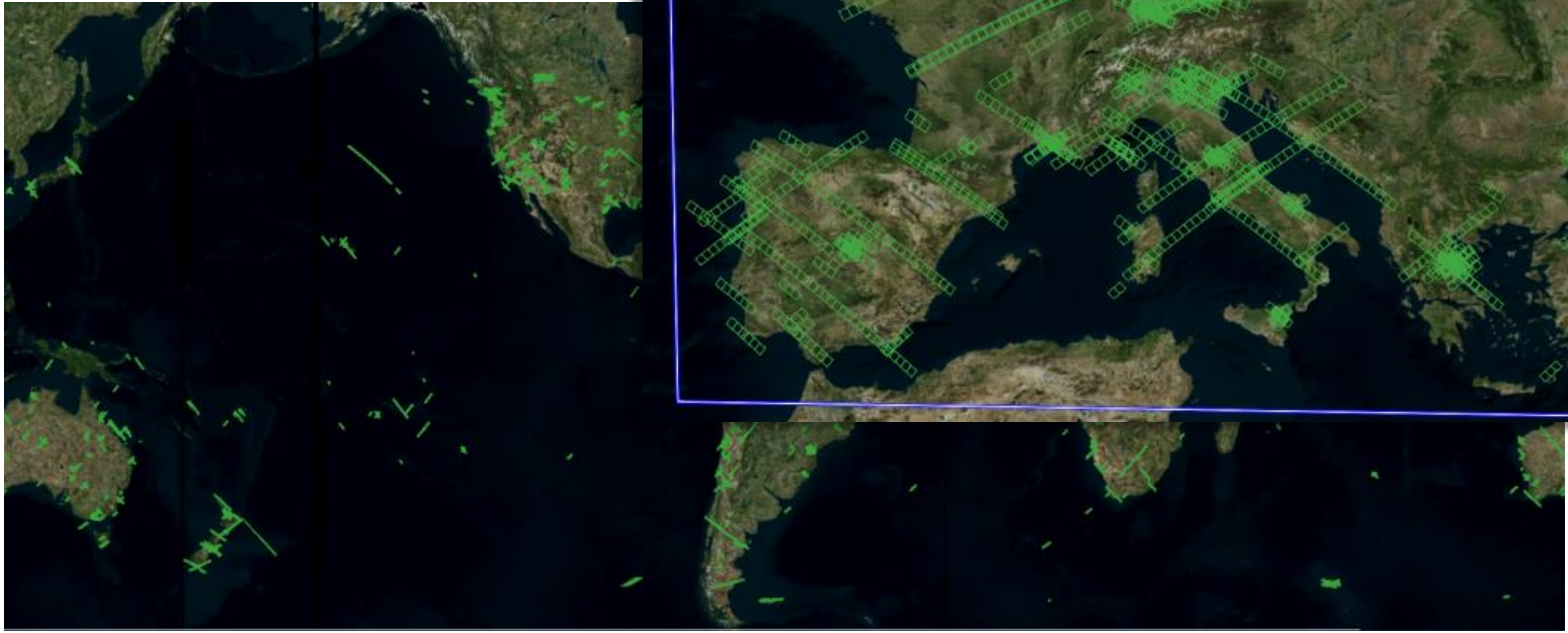
7. June 2017
MUSES installation on ISS

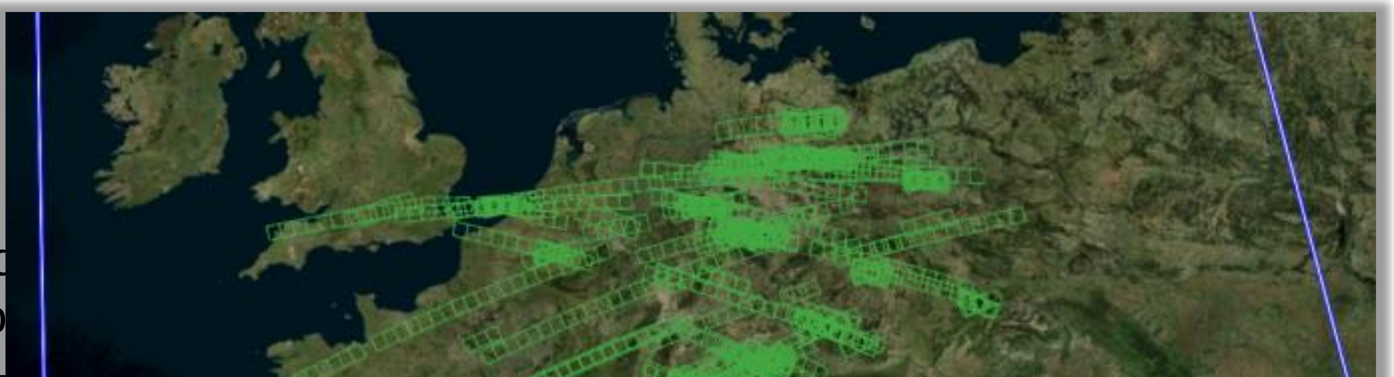
29. June 2018
DESIS launch from Cape Canaveral to ISS via SpaceX Dragon

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

Orbit and Products

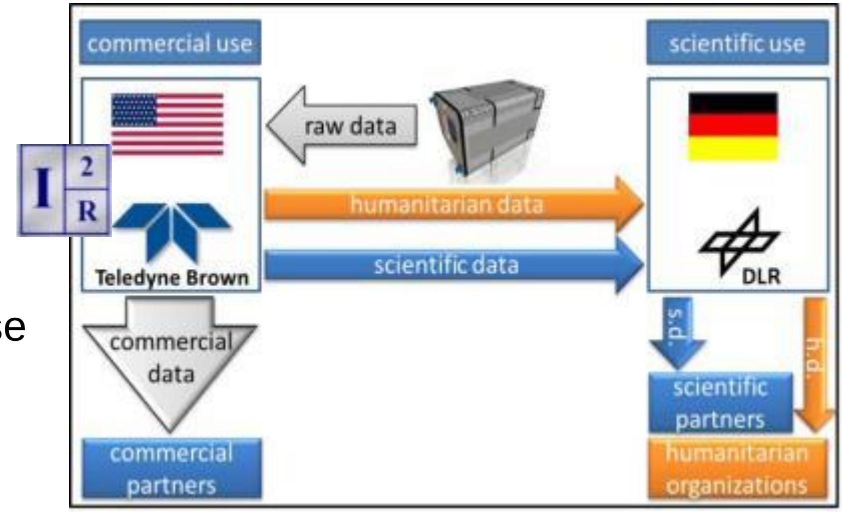
- Not Sun-synchronous orbit at ~400 km altituc
  Earth (between 55° N and 52° S). Orbit perio





DESIS L1A product catalogue (https://teledyne.tcloudhost.com) Previsat Software V3.6.4

Data Policy

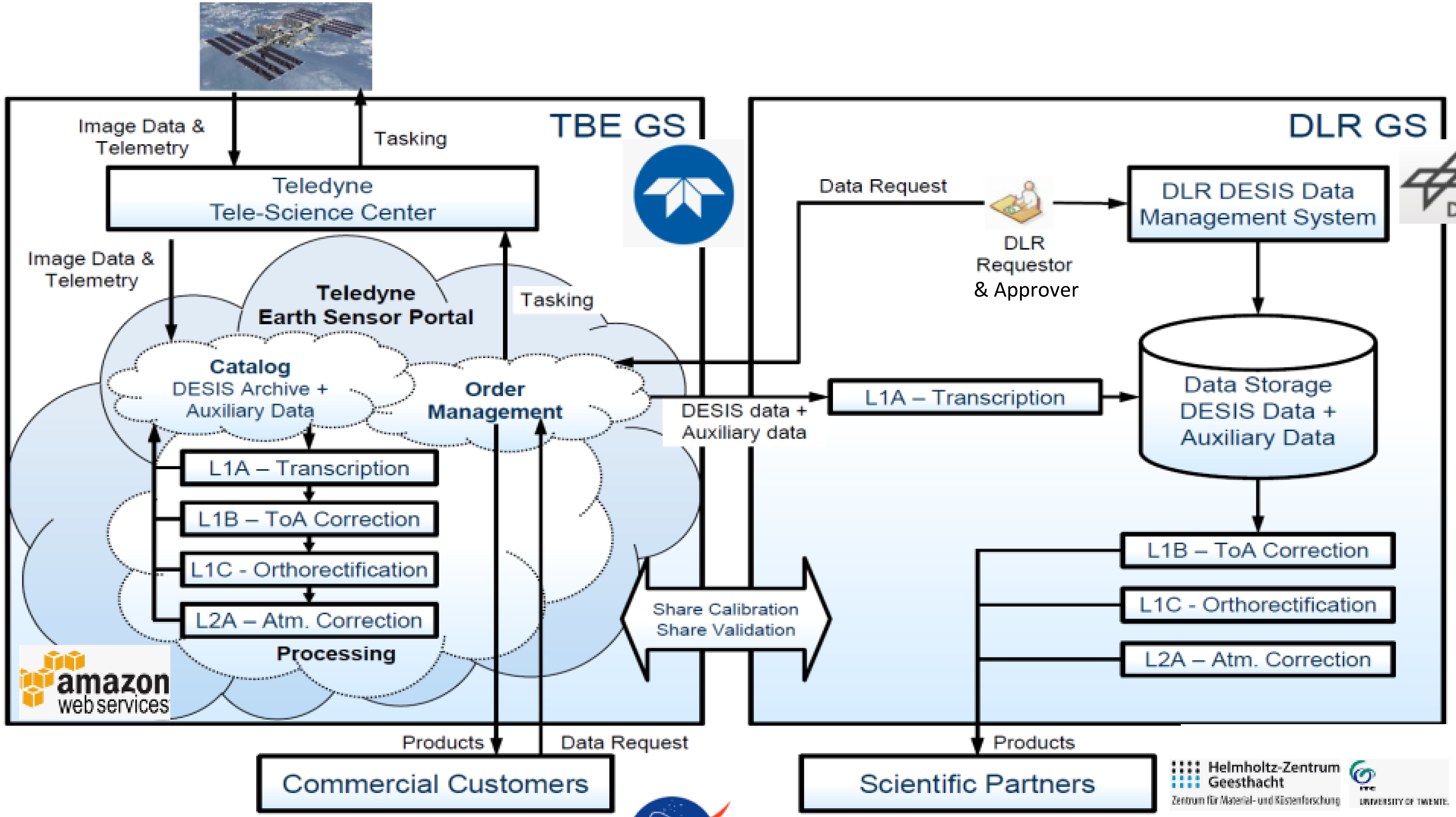


- DESIS is operated by Teledyne (TBE), data are distributed under NOAA License and:
  - TBE has the exclusive right to license or transfer image data for commercial use
  - For scientific and humanitarian purposes, DLR has the right to:
    - Task 2000 minutes/year
    - Request archived data

- 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

DESIS Mission Overview – Two Ground Segments



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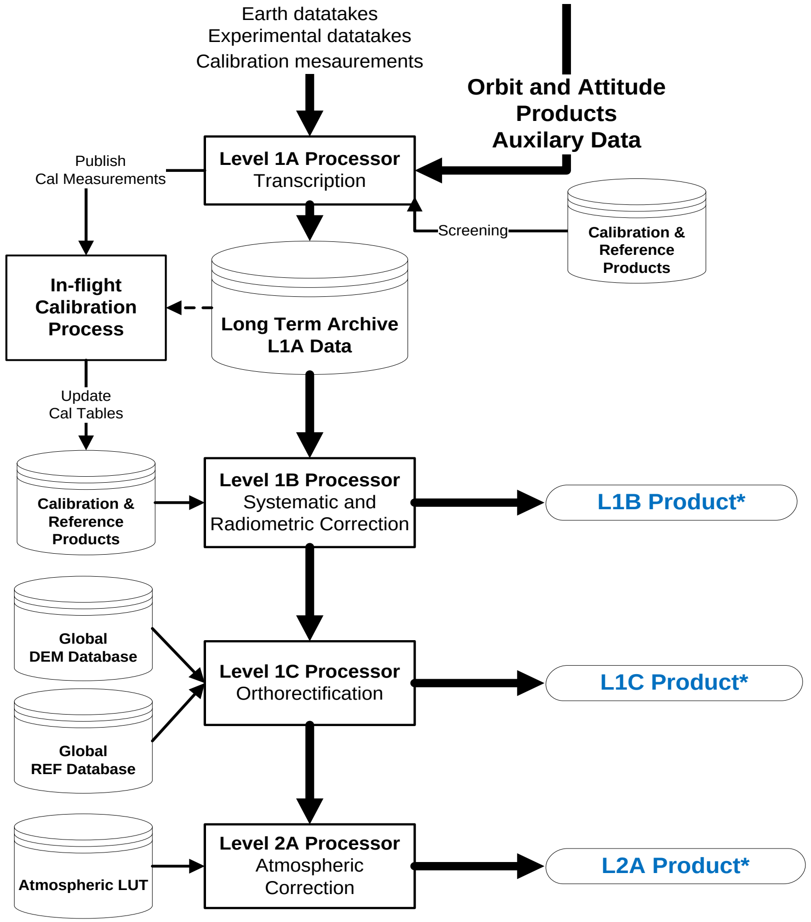
Data Processing
Which products are getting the user



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

Product Example L1B

- Corrections applied:
  - Dark Current
  - Absolute Radiometric
  - Rolling Shutter
  - Smile correction
  - Relative radiometric (de-striping)

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Product Example L1B

- Corrections applied:
  - Dark Current
  - Absolute Radiometric
  - Rolling Shutter
  - Smile correction
  - Relative radiometric (de-striping)

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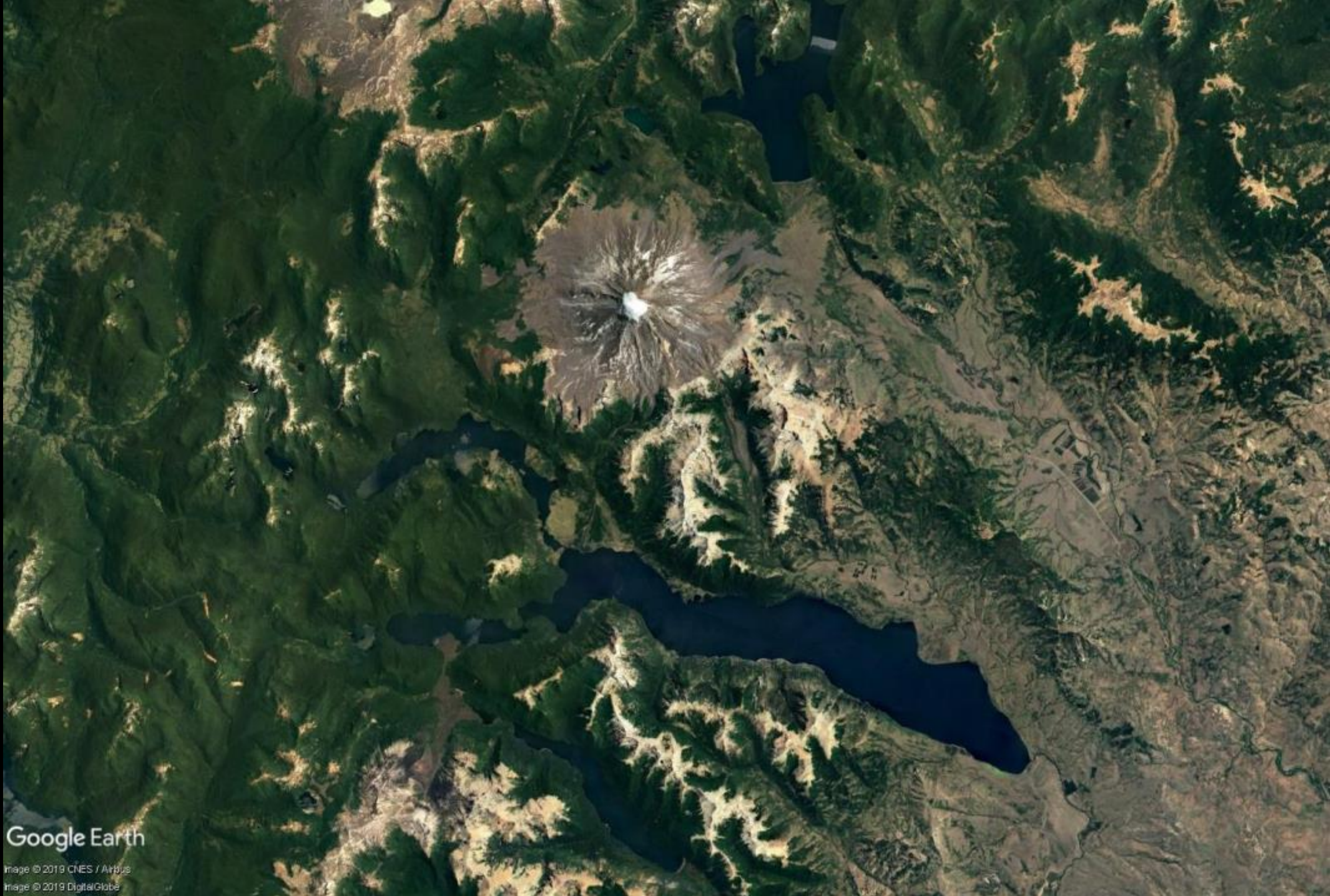
Product Example L1C



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Product Example L1C

Product Example L2A

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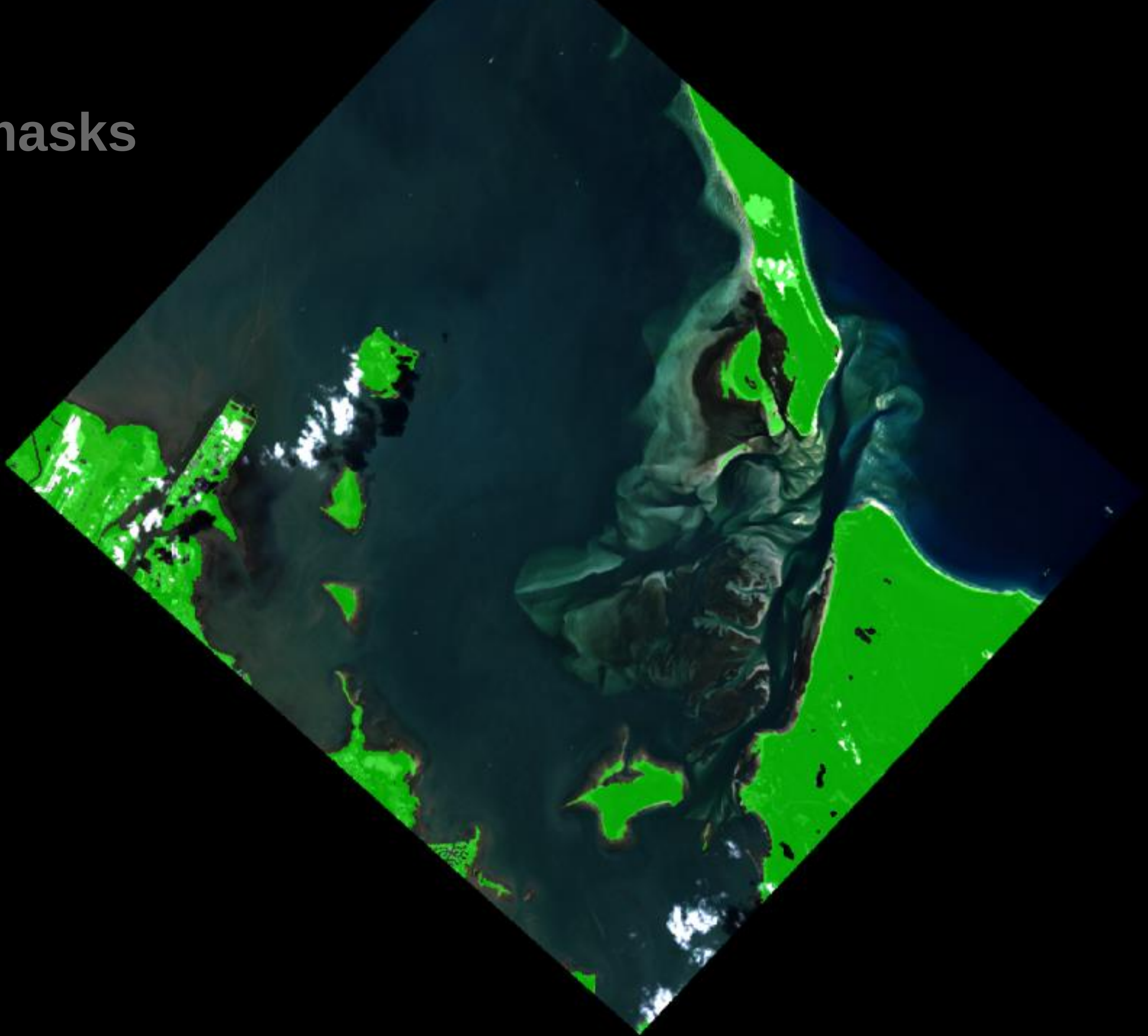
Product Example L2A masks

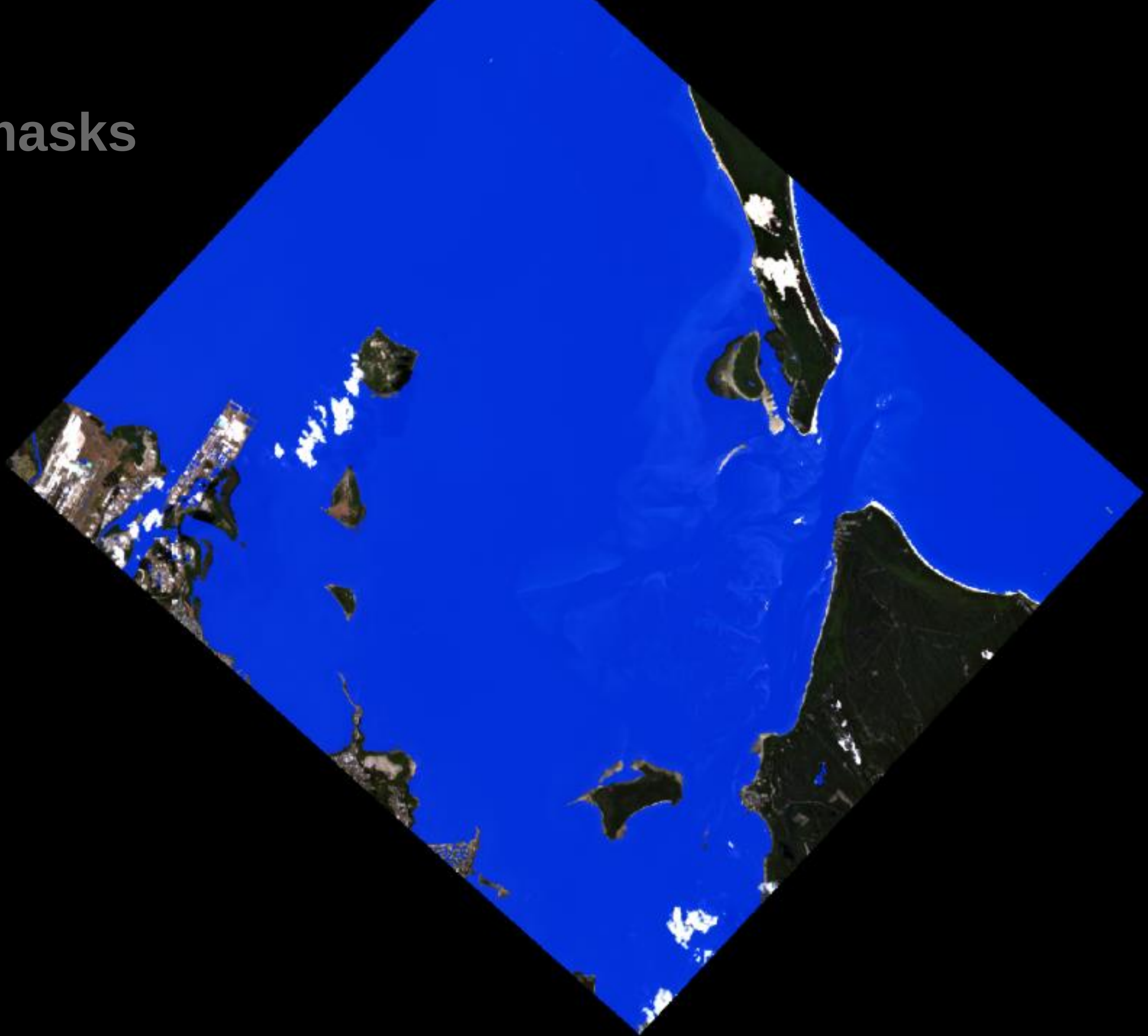
Land Mask



Product Example L2A masks

Land Mask

Water Mask

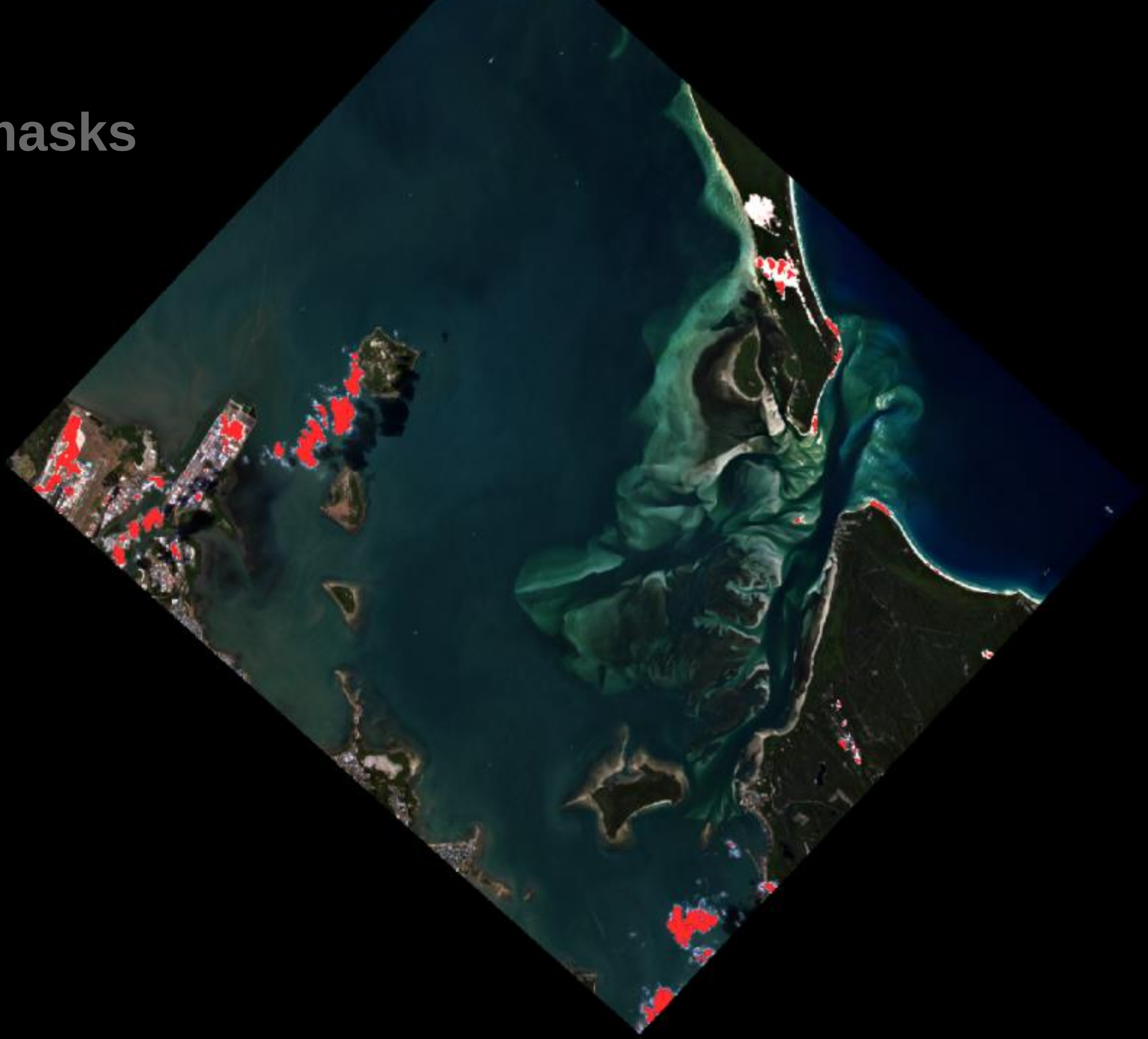


Product Example L2A masks

Land Mask

Water Mask

Cloud Mask



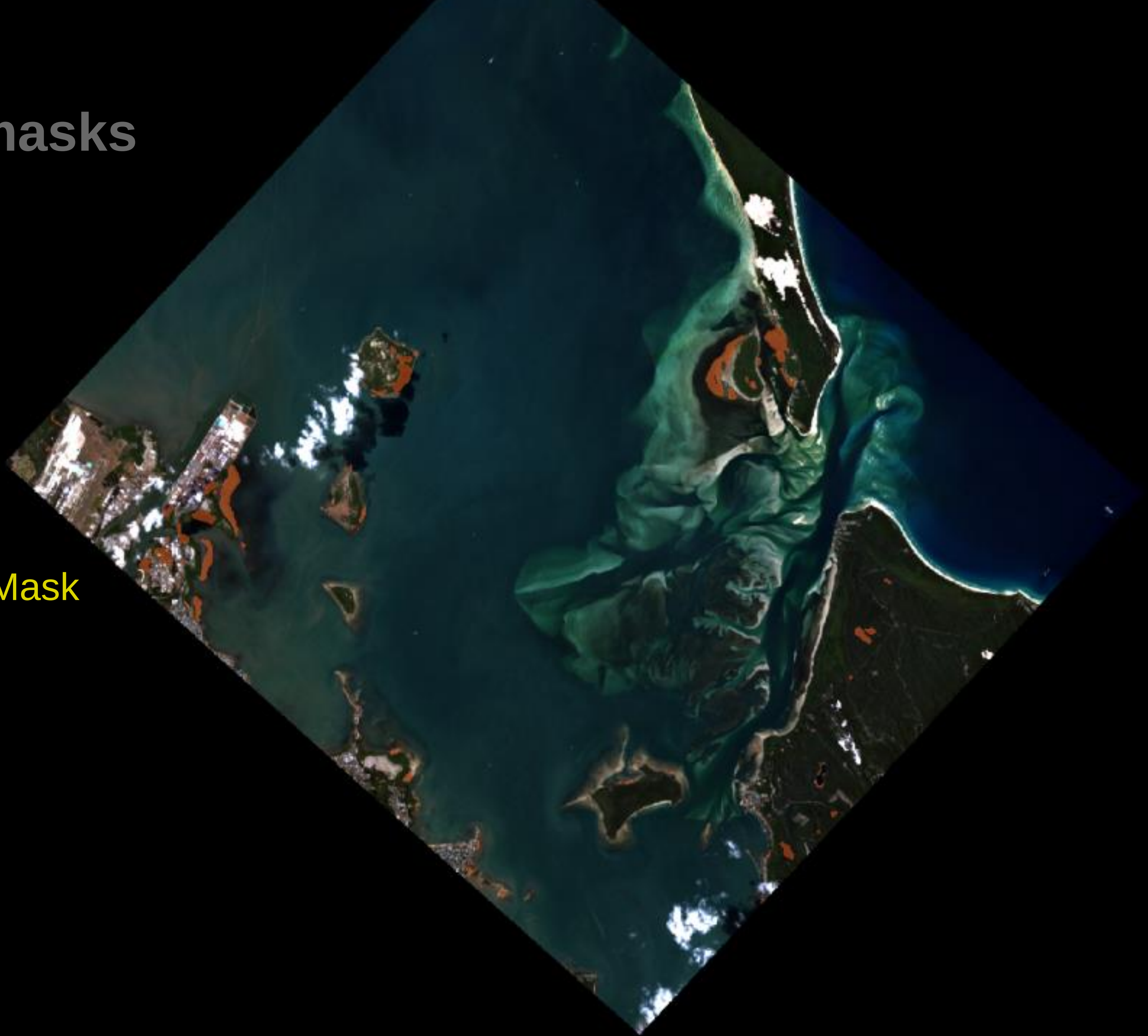
Product Example L2A masks

Land Mask

Water Mask

Cloud Mask

Cloud Shadow over land Mask



Product Example L2A masks

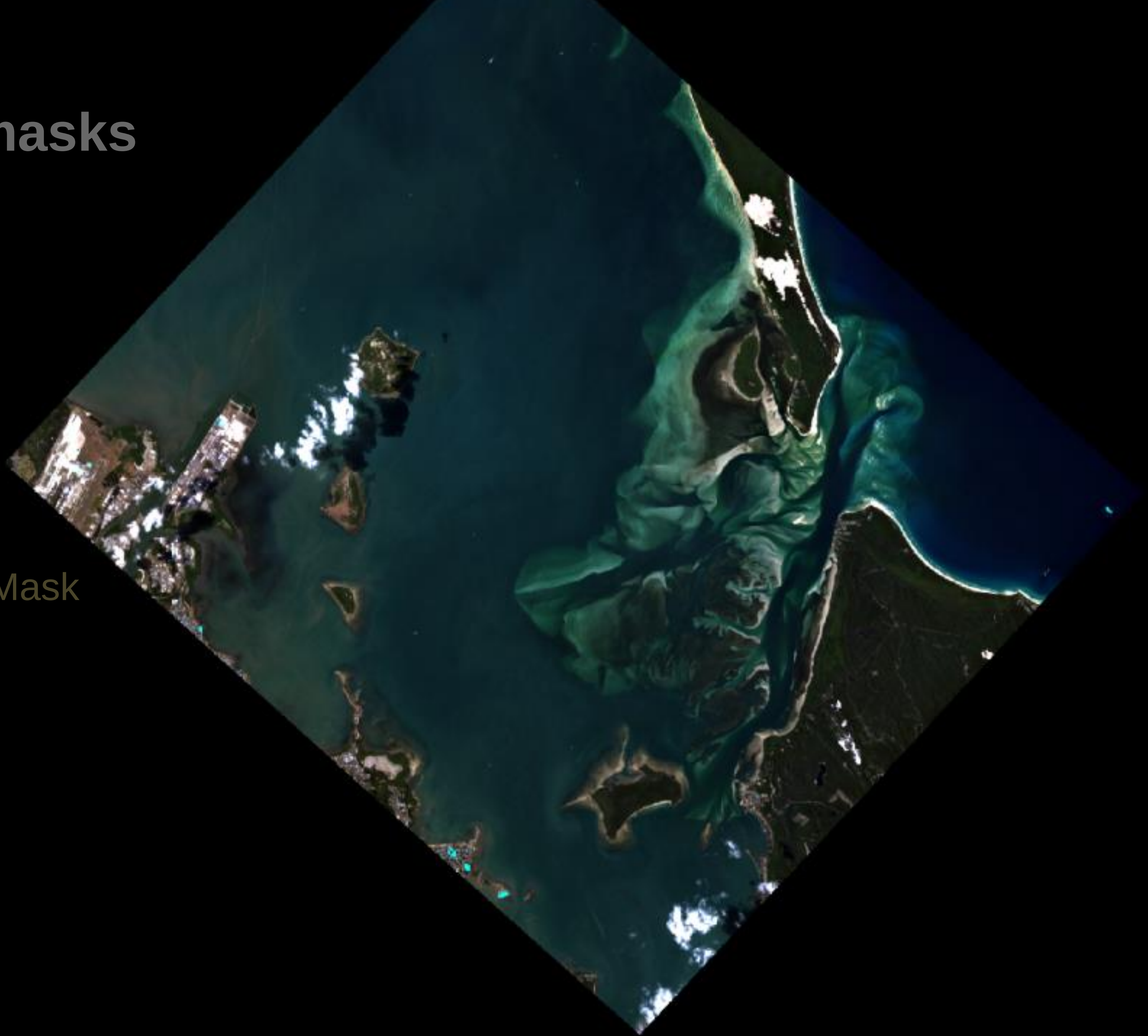
Land Mask

Water Mask

Cloud Mask

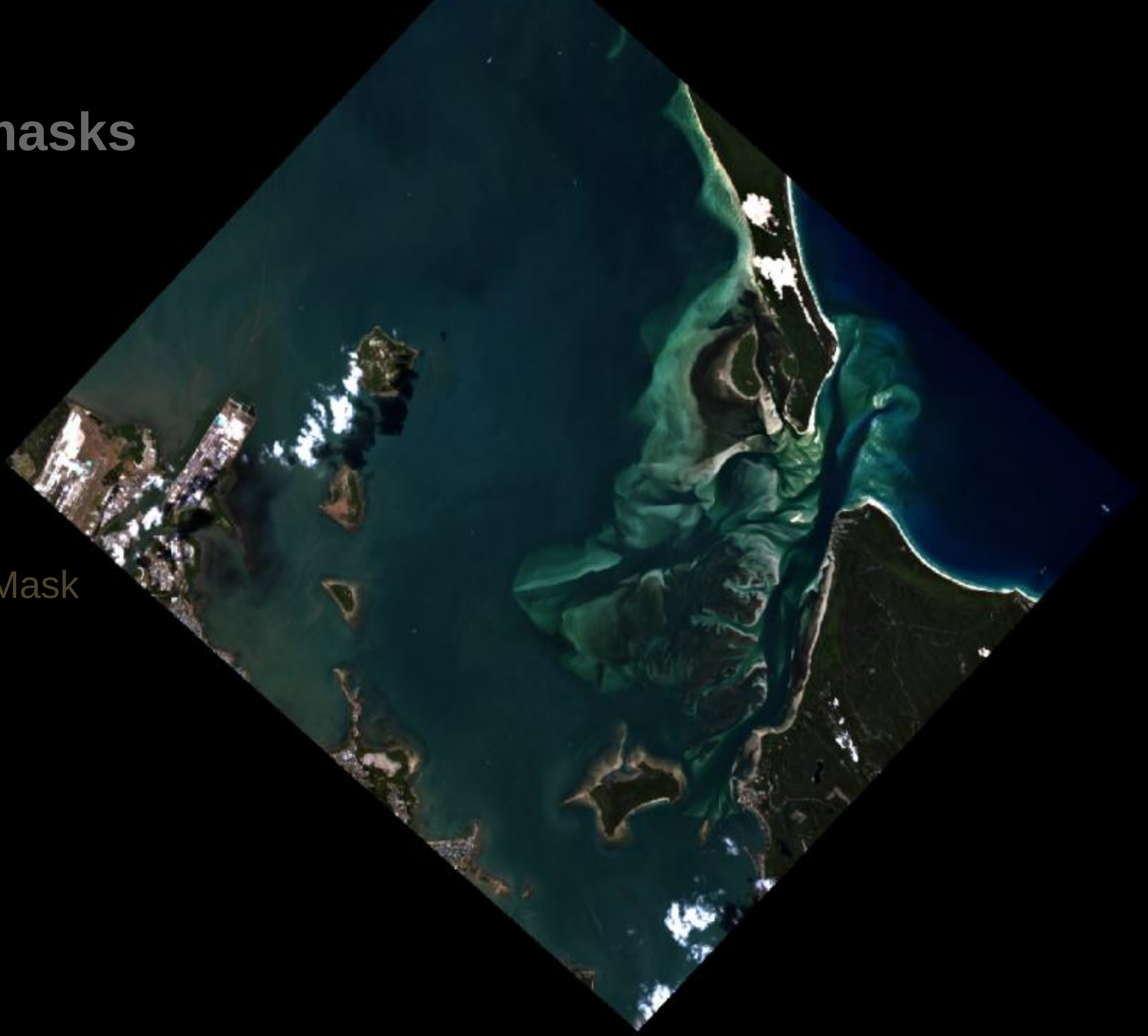
Cloud Shadow over land Mask

Haze over land Mask



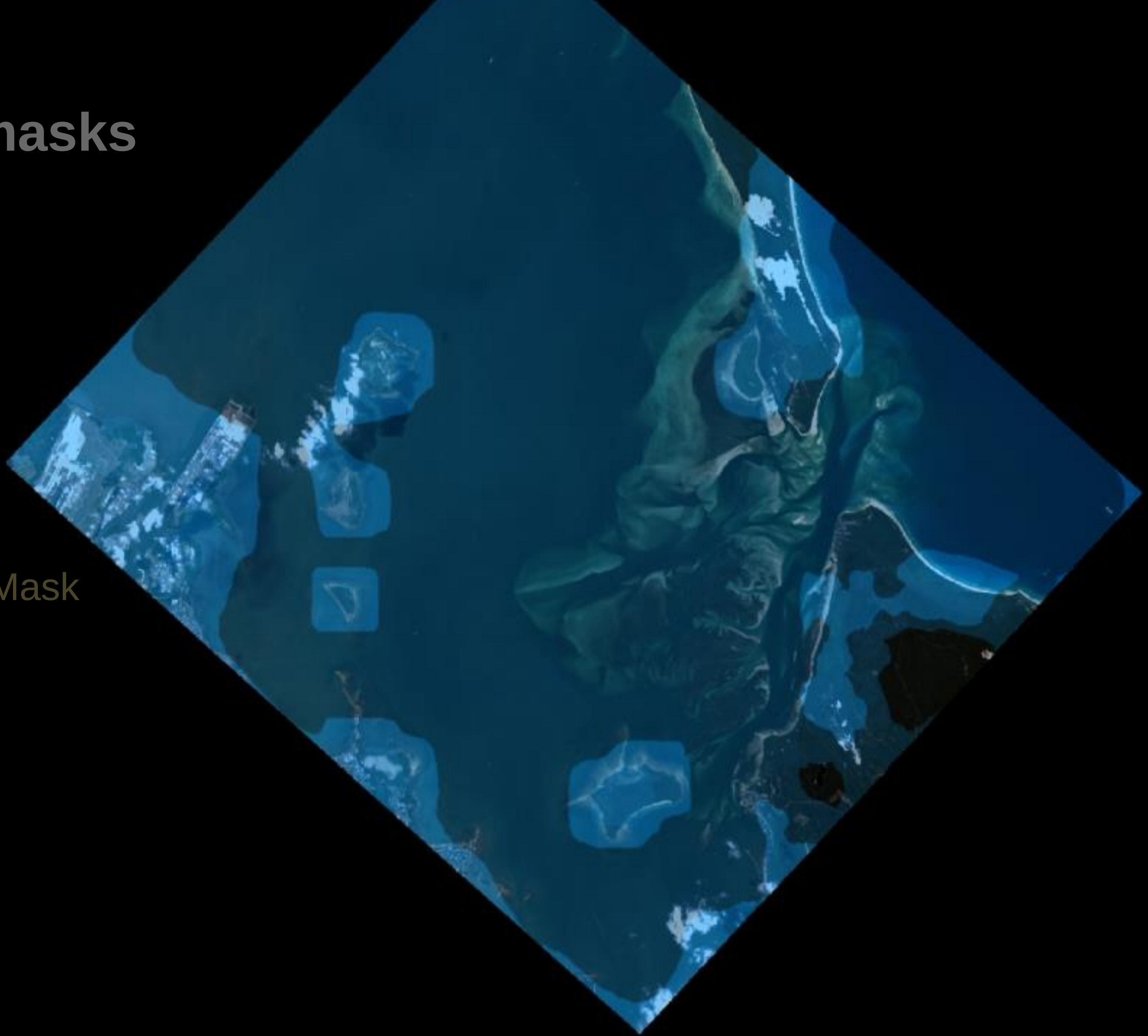
Product Example L2A masks

- Land Mask
- Water Mask
- Cloud Mask
- Cloud Shadow over land Mask
- Haze over land Mask
- Haze over water Mask



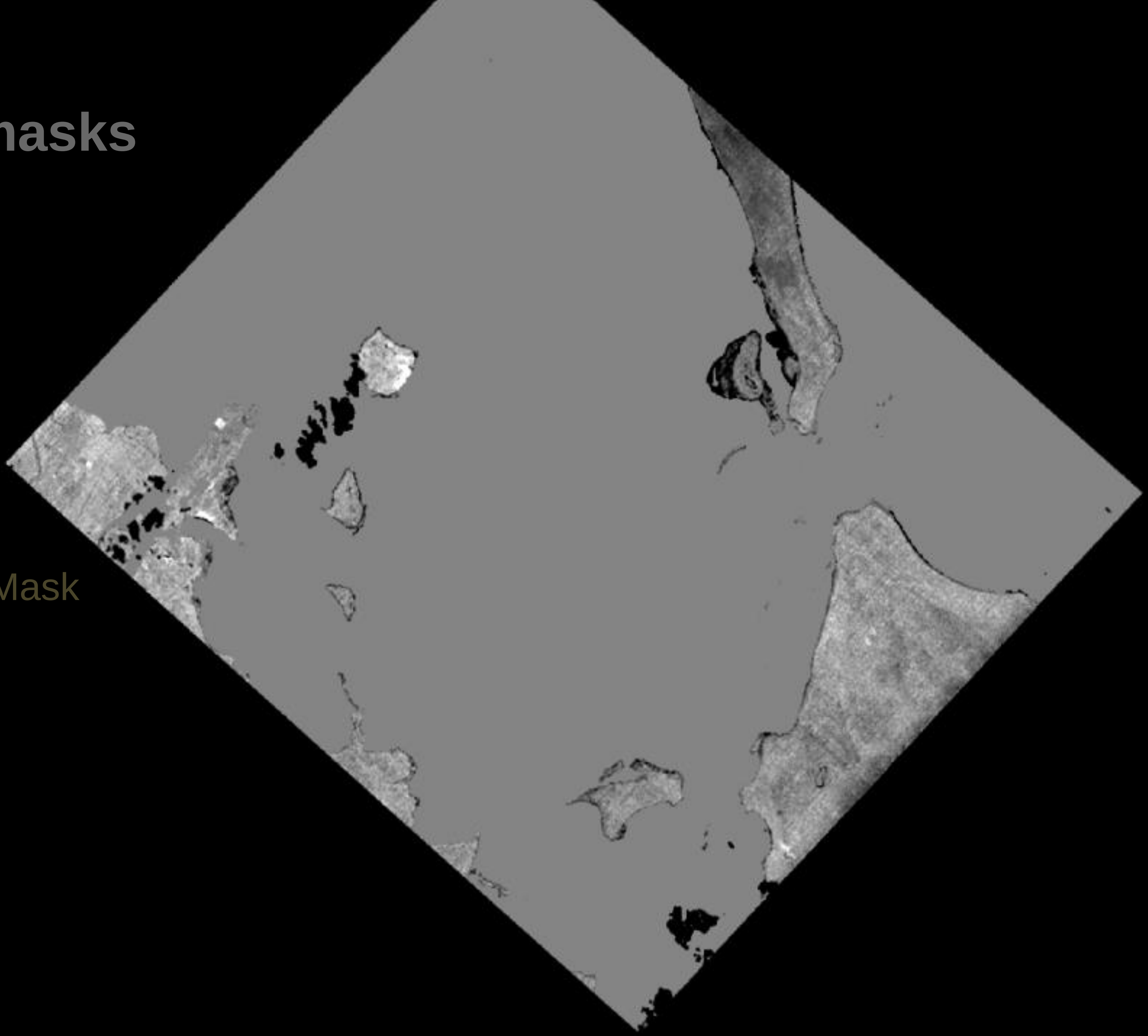
Product Example L2A masks

- 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



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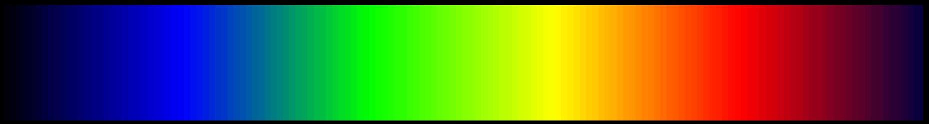
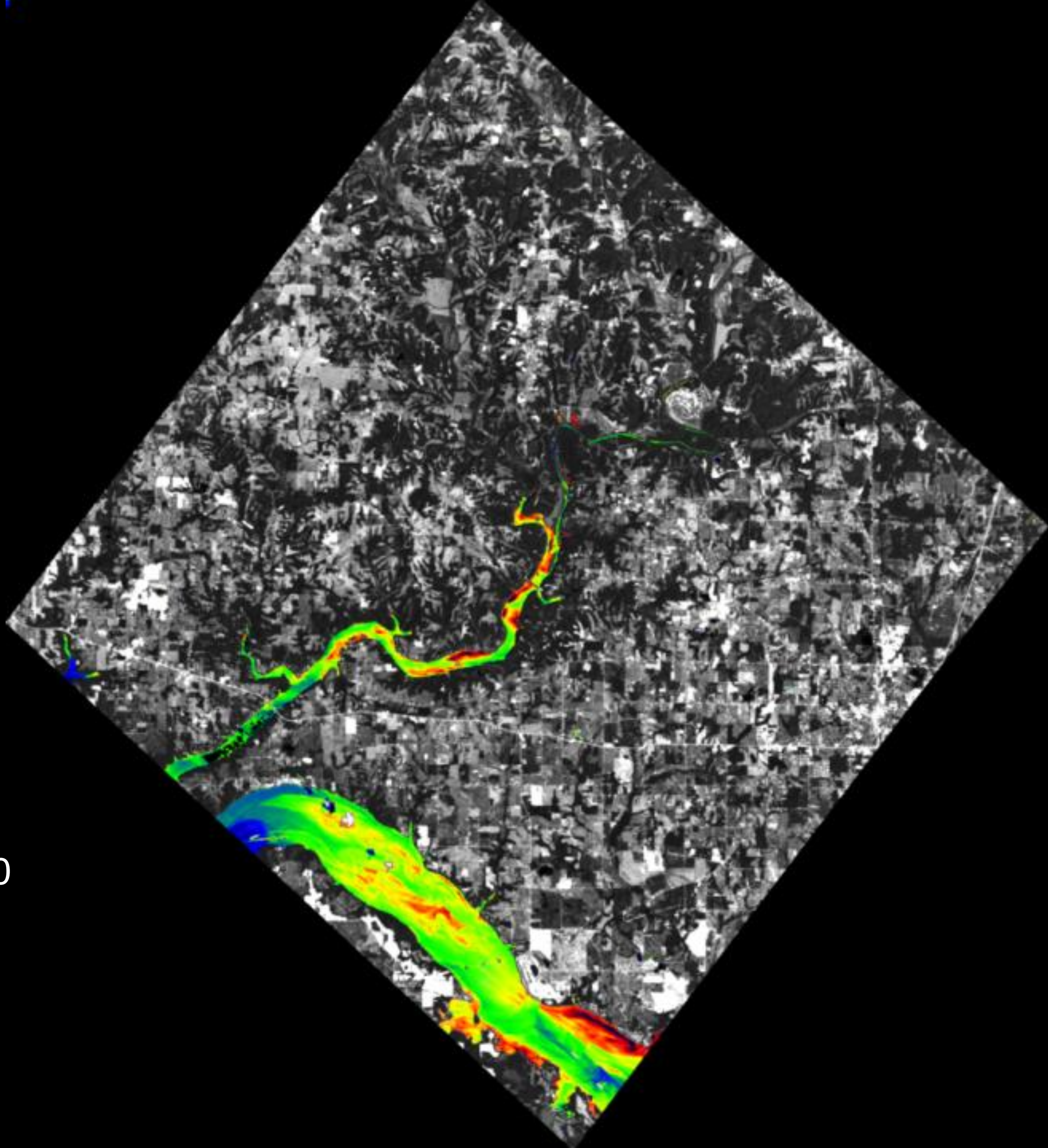
Product Example L3
Suspended Matter in Water

0  10

mg / l



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DESIS Cal/Val Concept

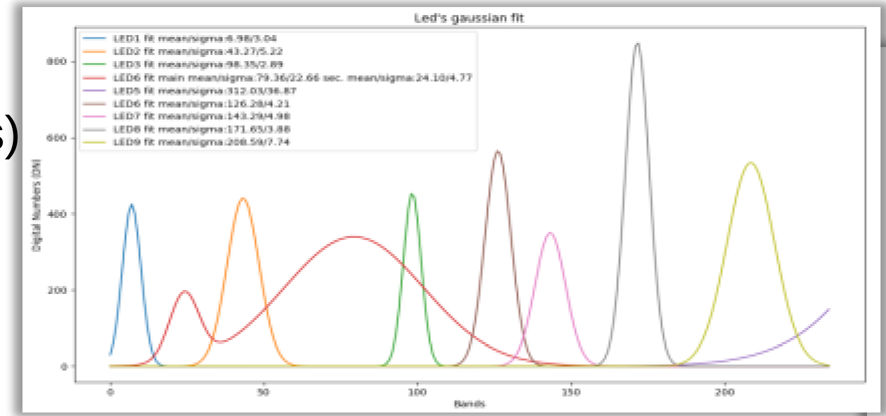
- Lab. calibration by DLR
    - Characterization of LEDs & detector

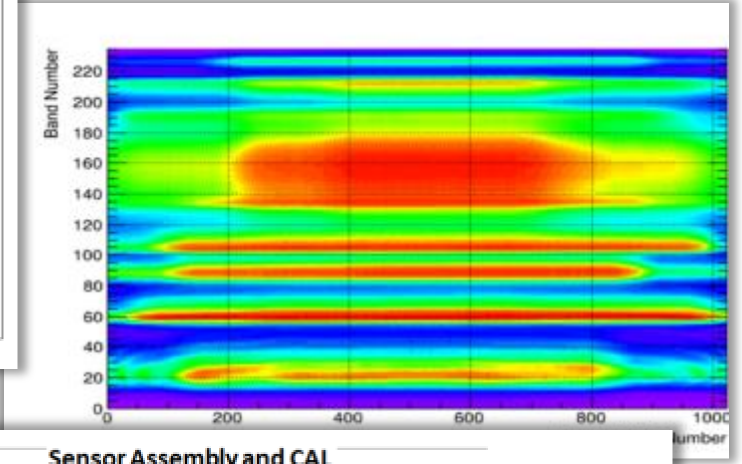
- During commissioning phase (DLR & I2R)
    - Instrument in-orbit characterization using on-board LEDs + telemetry
    - Update of defective / unstable pixel mask (only 0.3%)
    - Fine-adjustment of spectral and radiometric calibration using vicarious approaches
        - Absolute radiometry: RadCalNet, cross-CalVal using S2 and L8
        - Relative radiometry: CEOS PICS
        - Validation: Aeronet sites, Pinnacles (CSIRO), S2 & L8, airborne sensors
    - Fine-adjustment of processors & instrument modes
        - standard gain settings, SW instead of HW binning,

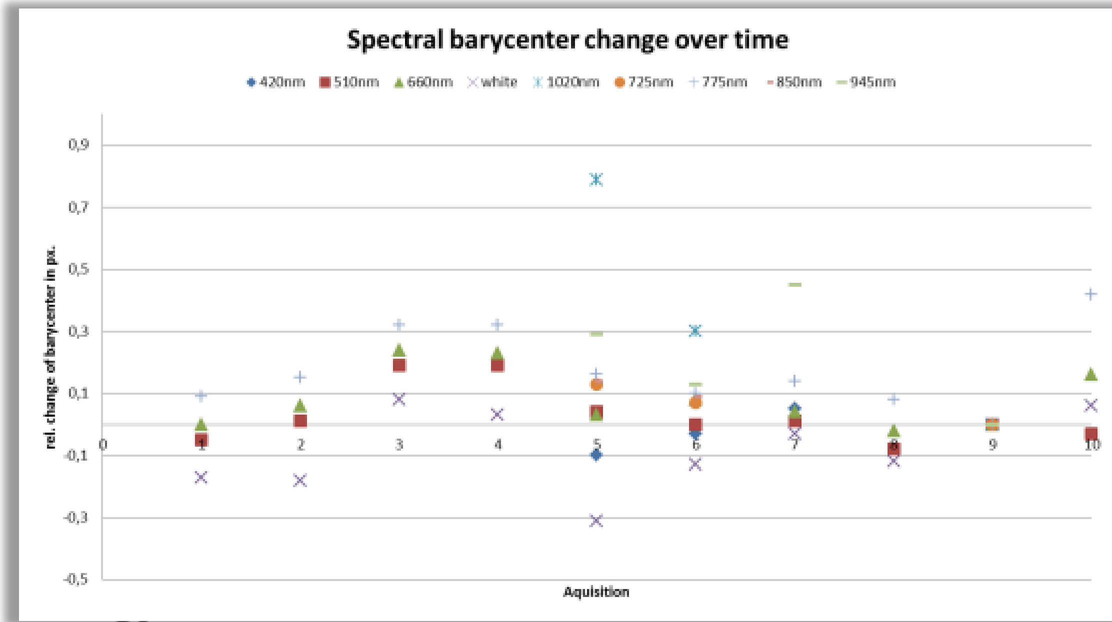
- Operational phase
    - Minor update of radiometric calibration table
    - Continuous validation activities by DLR & I2R

Commissioning Phase Activities – In-Orbit Spectral Characterization

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







Peak-to-peak (without white and 945nm and 1020nm): <0.3px

Std.-dev.: ~0.1px = 0.2nm

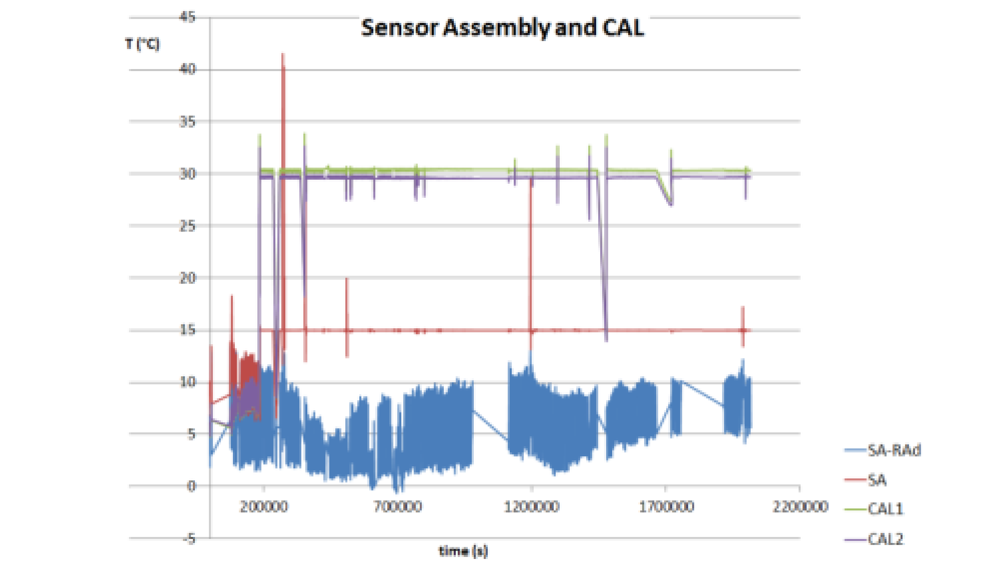
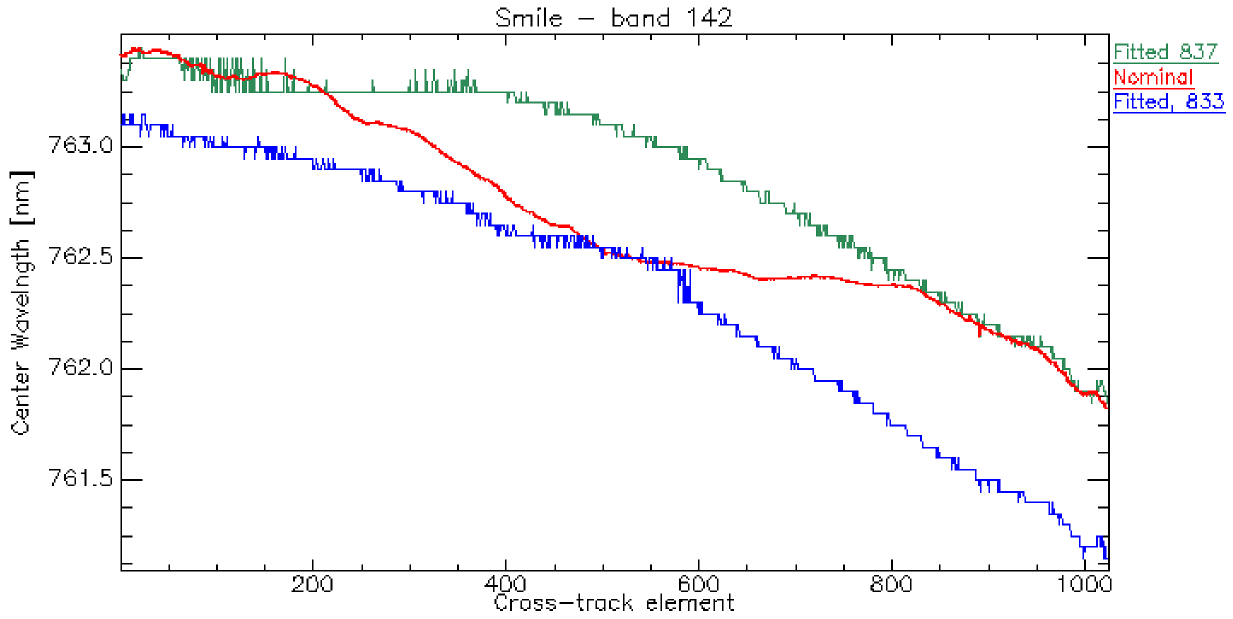


Figure 11: Real DESIS temperatures from the sensors on the SA and the CAL

Vicarious Spectral Characterization - Atmospheric Absorption Features

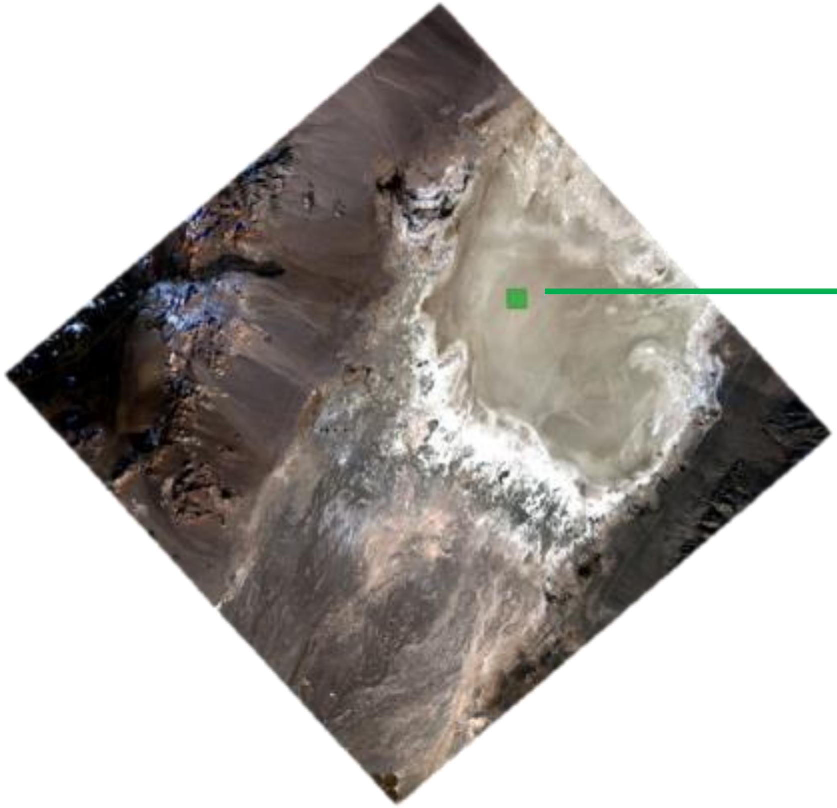
- Performed on regular DESIS Earth datatakes, L1B processing, no smile correction applied
- Shift confirmed for Oxygen absorption region (762 nm) & other wavelengths (483, 524 & 819 nm)



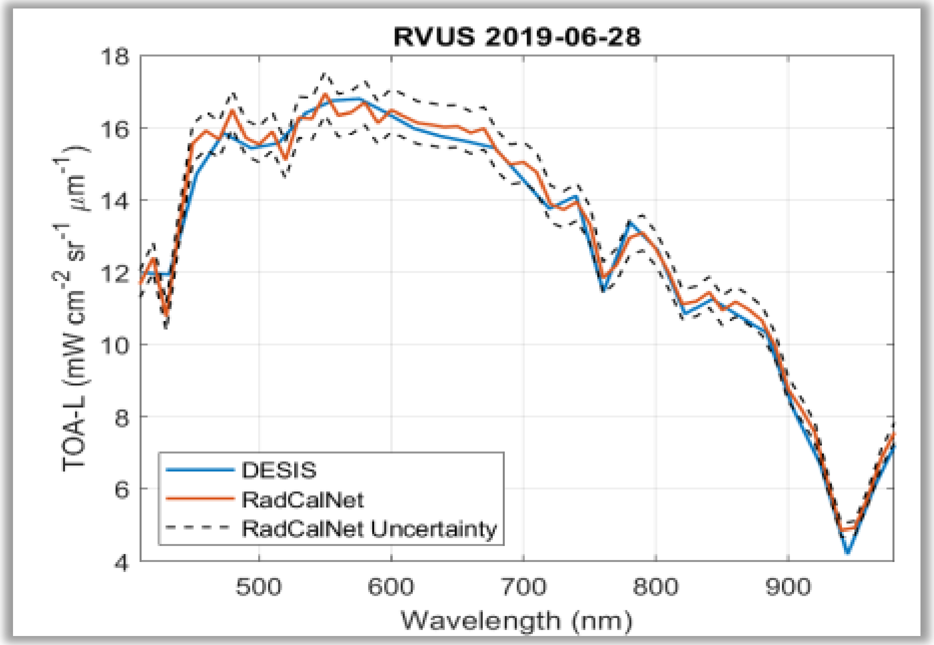
Fit for 2 datatakes with different ΔT

- Earth datatakes without smile correction are used
- Fitting step size: 0.05 nm

Ongoing validation & re-calibration activities @ DLR and I2R

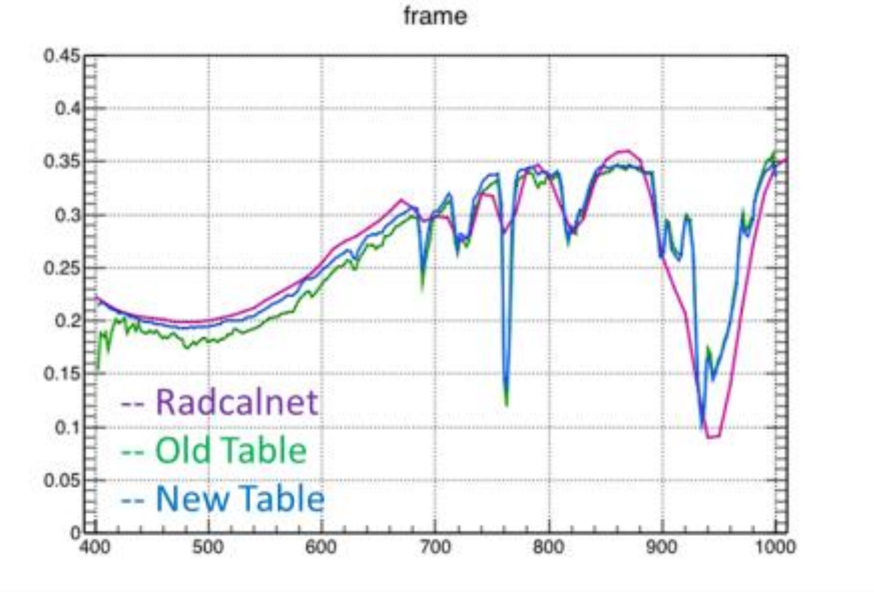


Comparison DESIS & RadCalNet

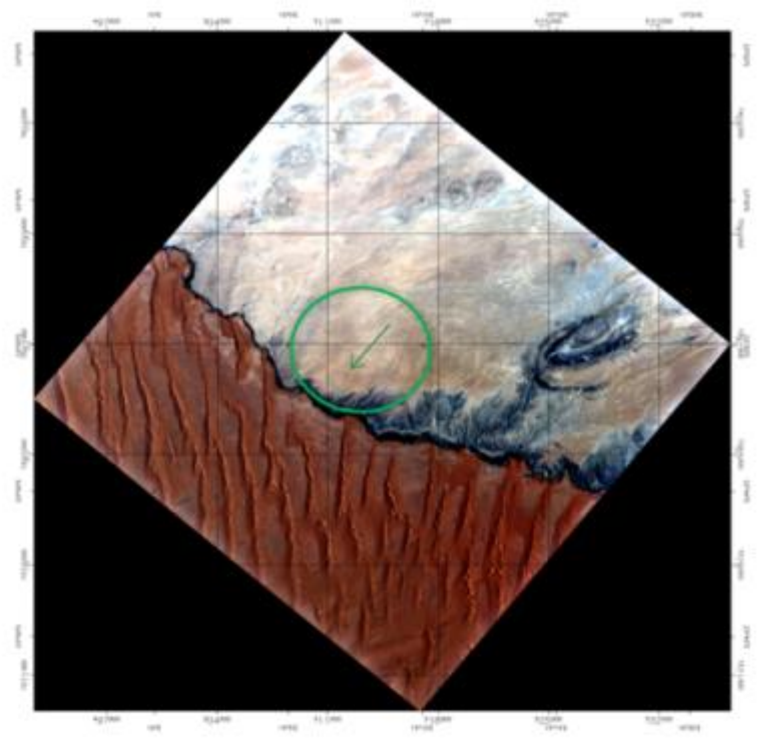


Ongoing validation & re-calibration activities @ DLR and I2R

TOA-Ref within 10% (typically <5%) relative to RadCalNet



Scene 821-2

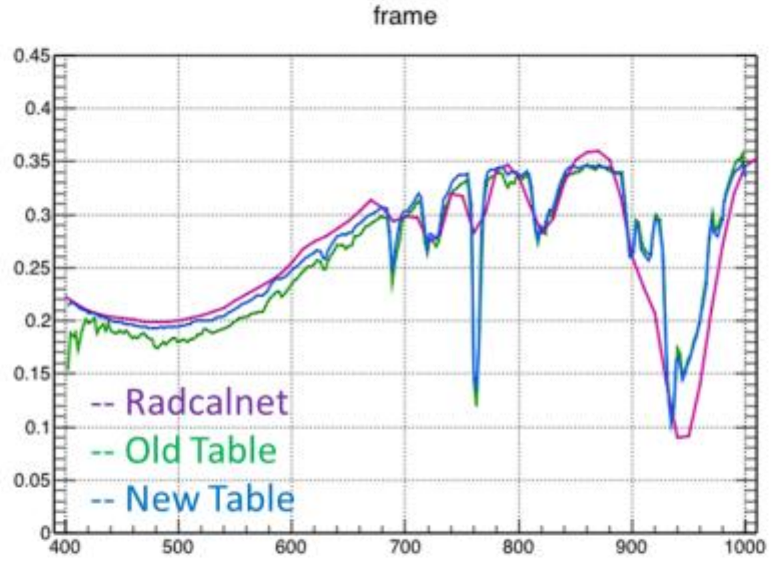


Gobabeb

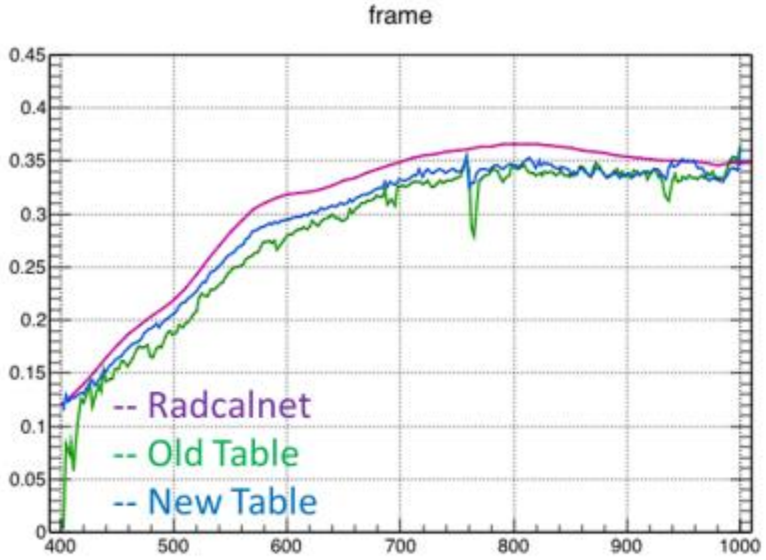
Ongoing validation & re-calibration activities @ DLR and I2R

TOA-Ref within 10% (typically <5%) relative to RadCalNet

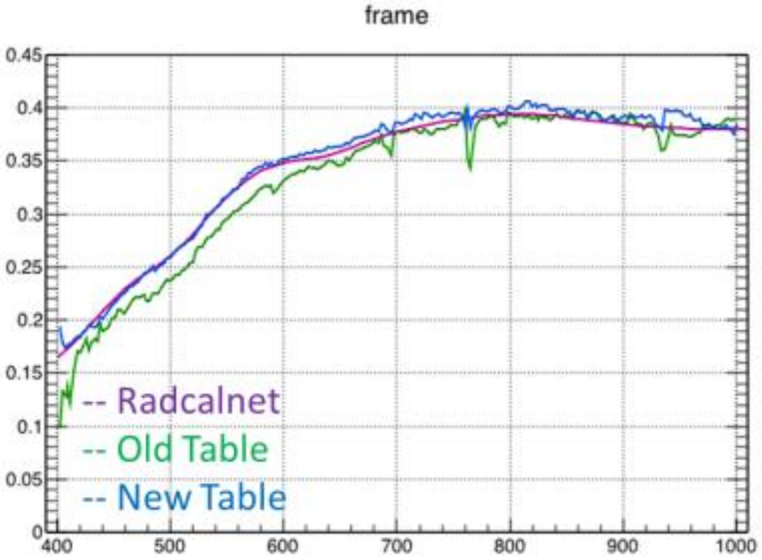
BOA-Ref within 10% relative to RadCalNet



Scene 821-2

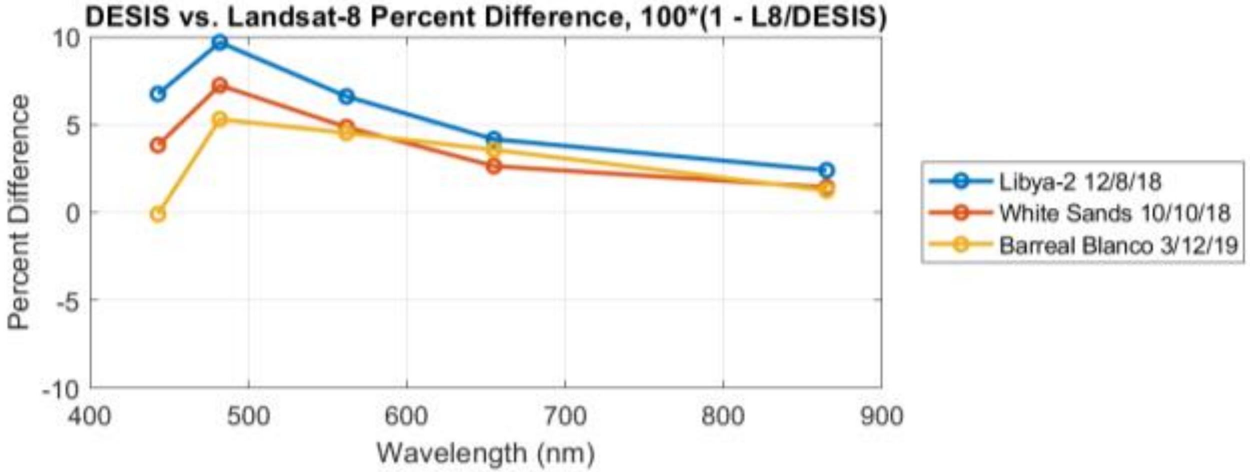


Scene 816-2

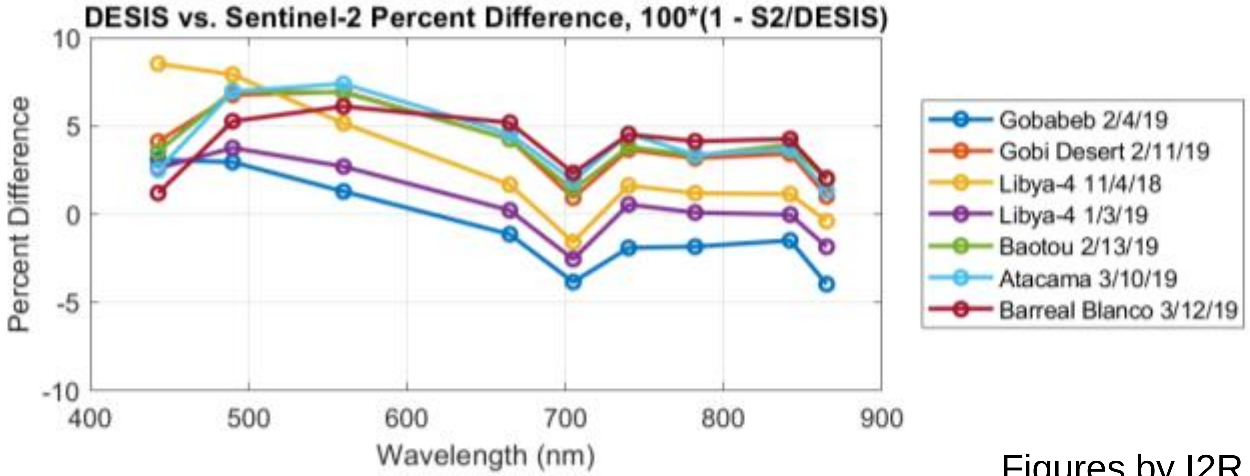


Scene 817-3

Ongoing validation & re-calibration activities @ DLR and I2R

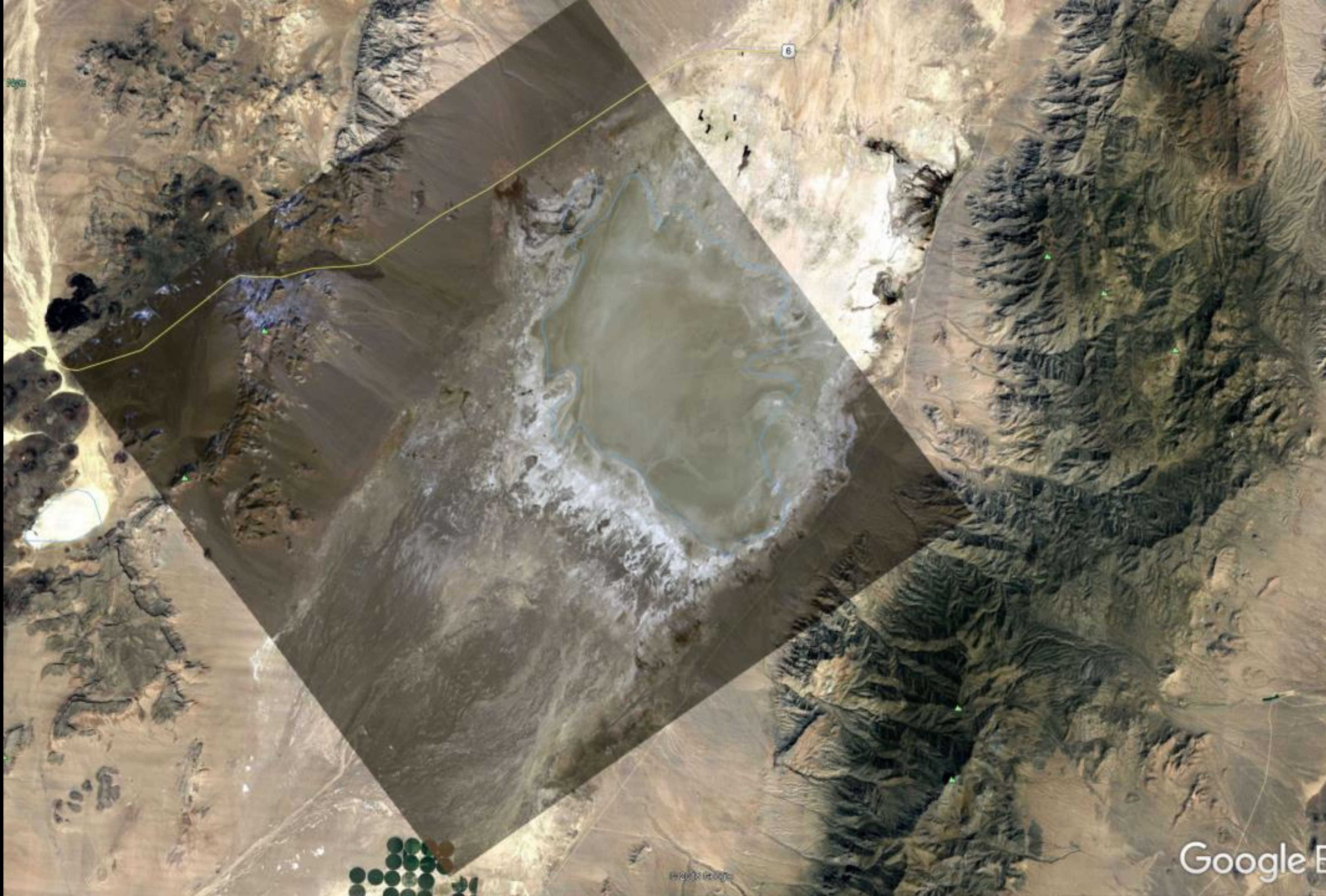


TOA-Ref within 10% relative to L8 & S2 for PICS



Figures by I2R

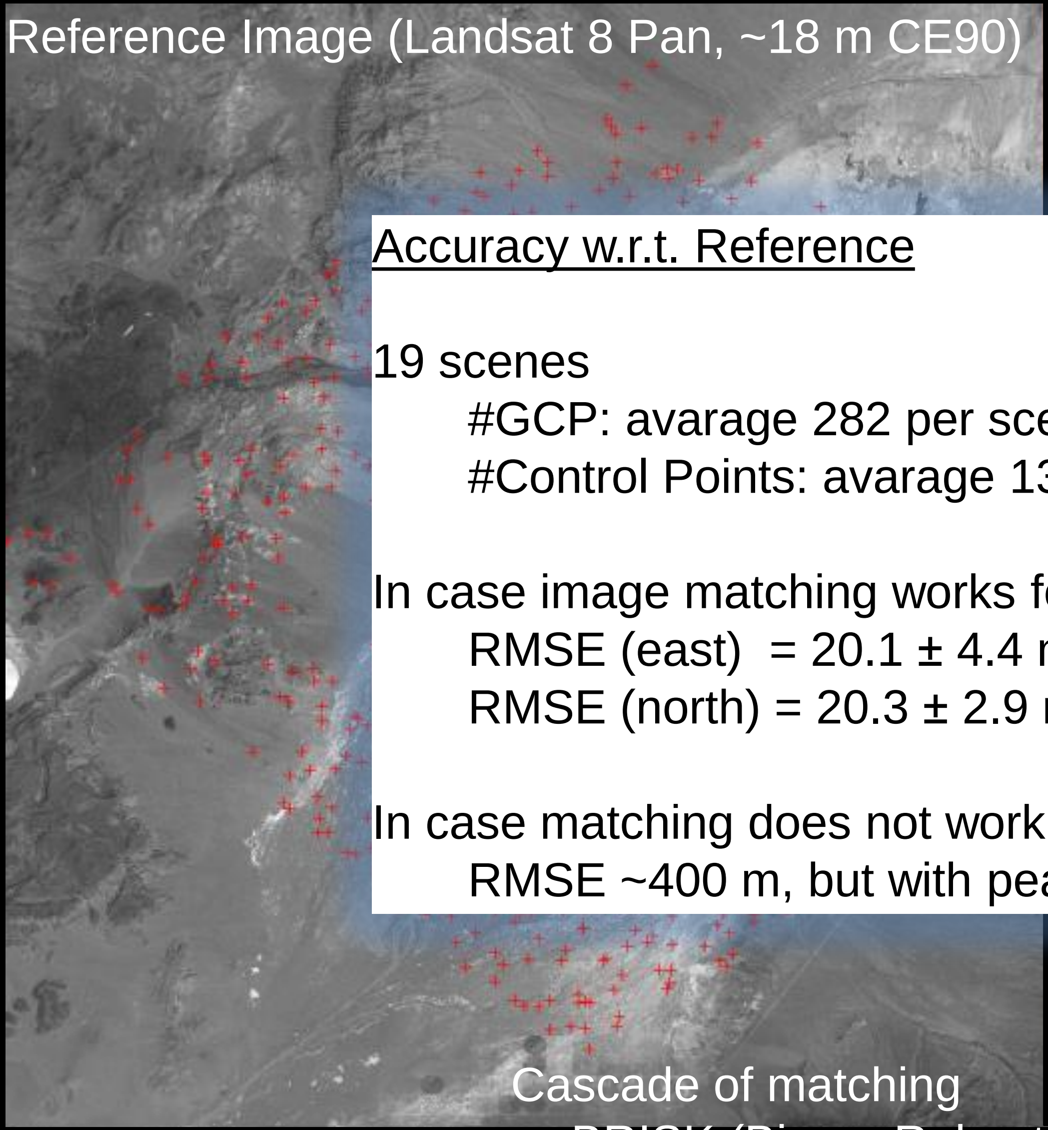
Product Example L1C



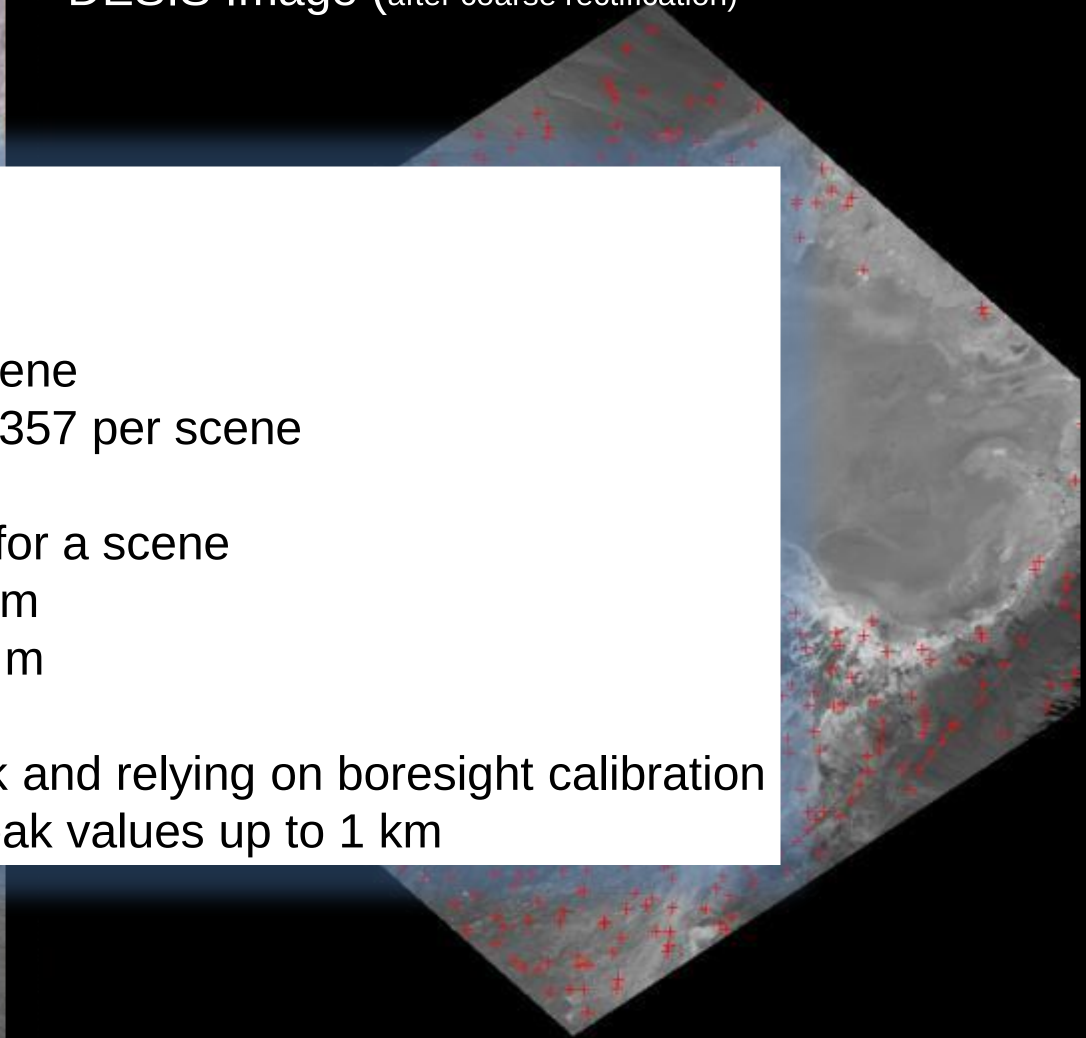
DLR

Geometric Calibration & Accuracy

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



DESIS Image (after coarse rectification)



Accuracy w.r.t. Reference

19 scenes
- #GCP: avarage 282 per scene
- #Control Points: avarage 1357 per scene

In case image matching works for a scene
- RMSE (east) = 20.1 ± 4.4 m
- RMSE (north) = 20.3 ± 2.9 m

In case matching does not work and relying on boresight calibration
- RMSE ~400 m, but with peak values up to 1 km

Cascade of matching
- BRISK (Binary Robust Invariant Scalable Keypoints)
- ELSQ (Local Least Squares)
- SIFT (Scale-Invariant Feature Transform)

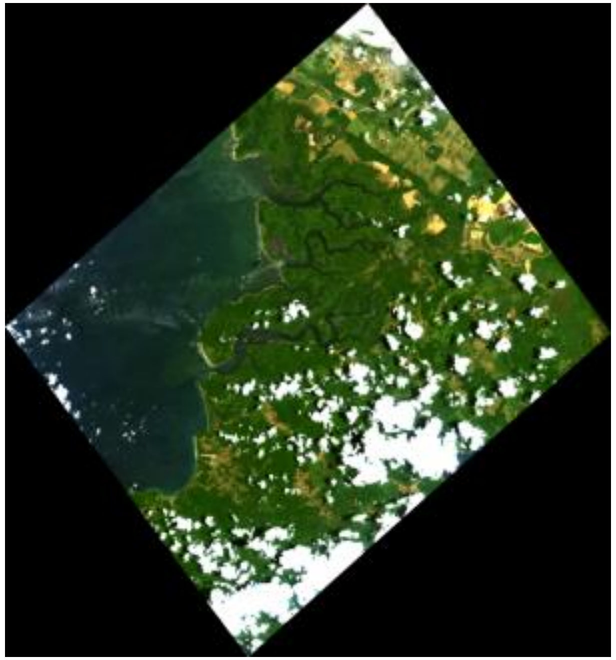
Selected GCP to improve DESIS sensor model (on-the-fly and for boresight calibration)
Others are used for Quality Assessment

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°

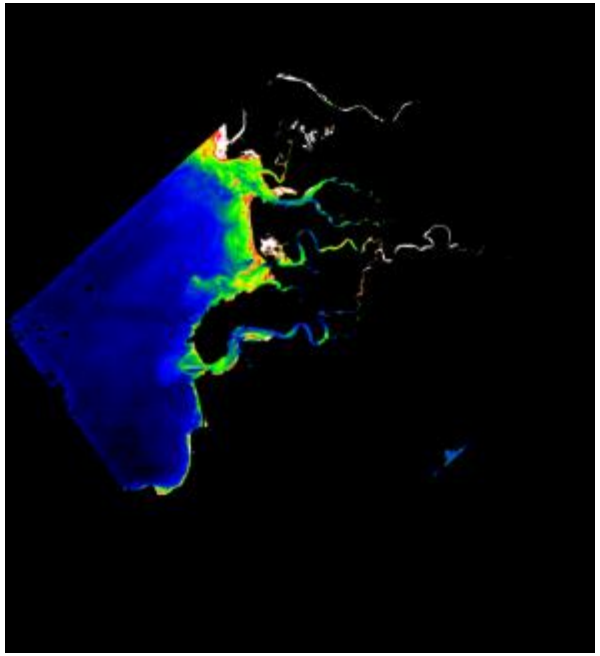
Nicole Pinnel & Peter Gege DLR EOC

Application examples

- Hyperspectral imagery for water quality studies related to agricultural activities within the National Wetland Térraba Sierpe, Costa Rica



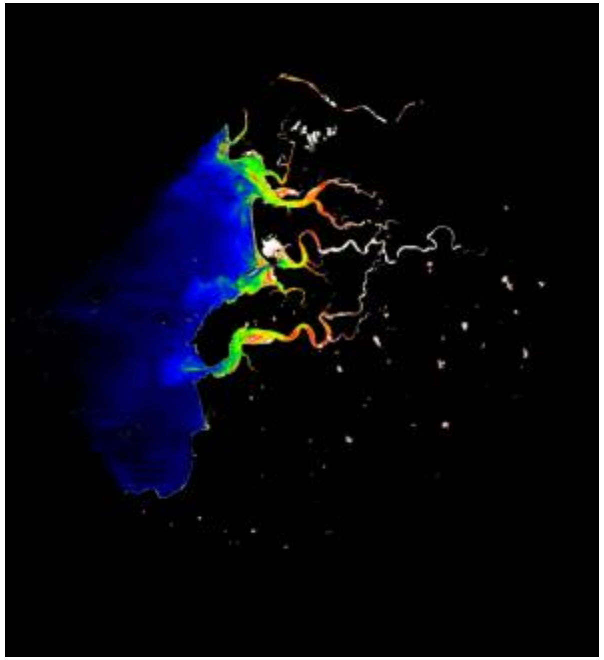
Sierpe, Costa Rica 2019-03-04
RGB: 440 nm, 550 nm, 650 nm



0 – 5

[g m^{-3}]

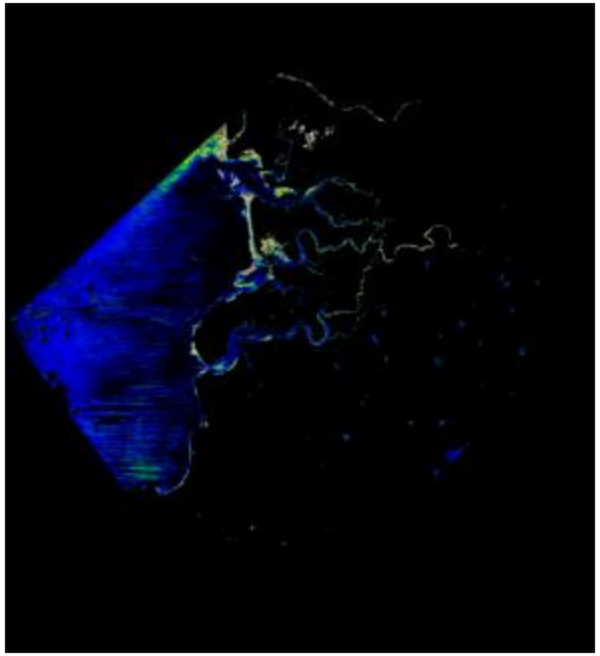
Total suspended matter concentration



0 – 1

[m^{-1}]

Colored Dissolved Organic Matter CDOM Absorption at 440 nm



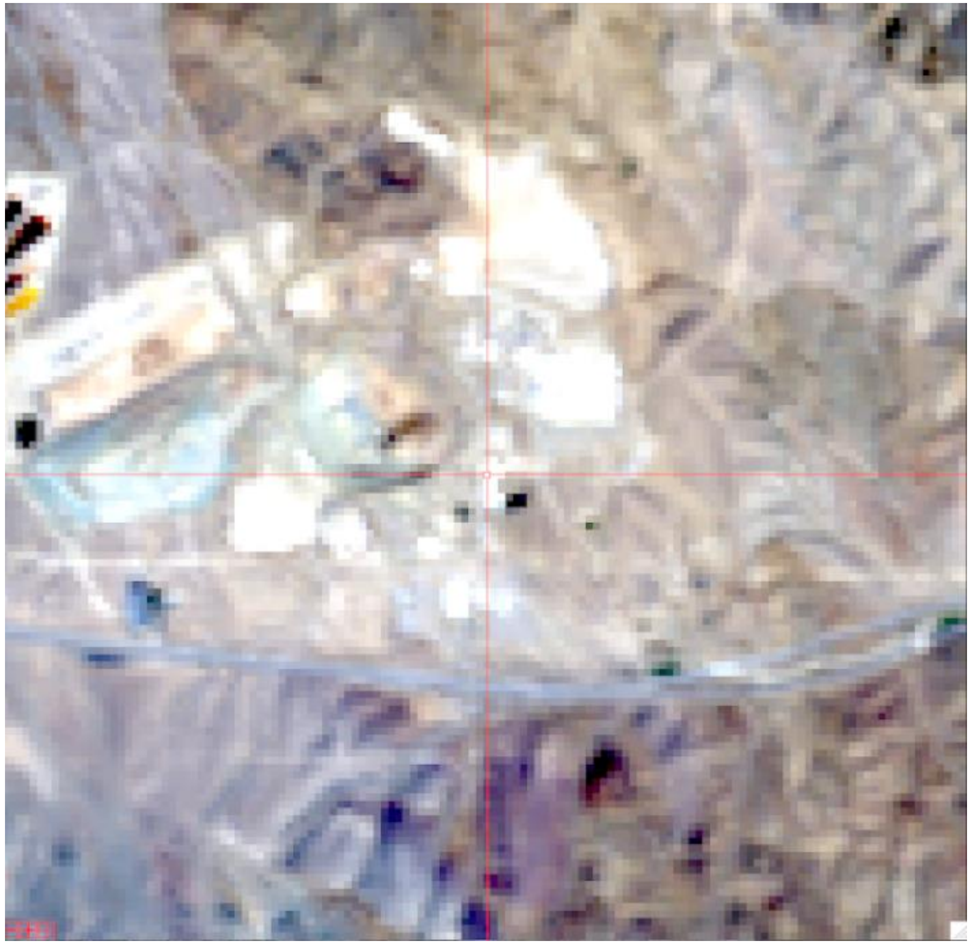
0 – 10

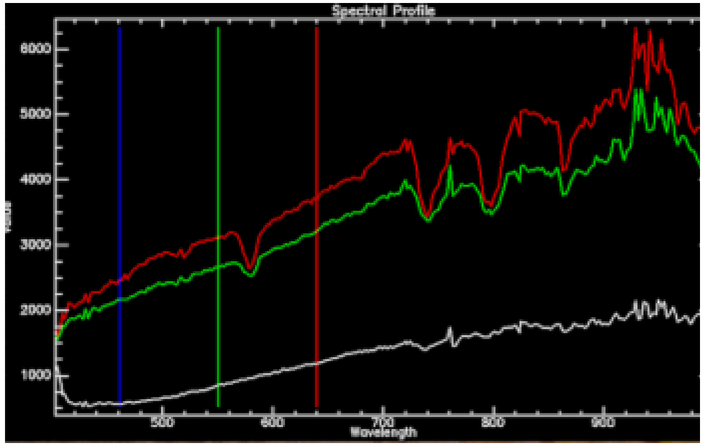
[mg m^{-3}]

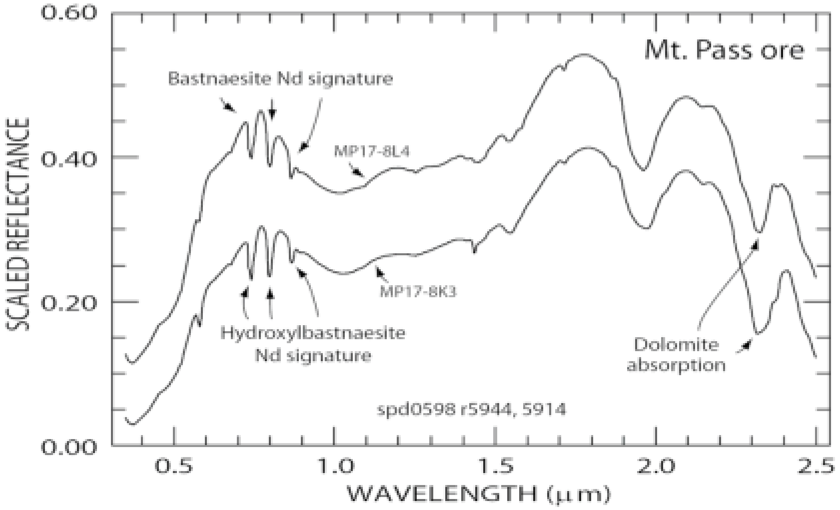
Phytoplankton concentration

Application examples

- Rare Earth Elements (REE) @ Mt. Pass mine (USA / California)







Gregg Swayze from USGS Spec Lab

"So this may be the first demonstration of REE detection from space but may also have high enough resolution and SNR to allow differentiation of individual REE minerals"

Element: Neodymium (Nd); Class: Lanthanoide

Usage: Magnets, Laser, Glas,…

Application examples

- Data Fusion: Enhance Ground Sampling Distance (GSD) of DESIS using Sentinel 2

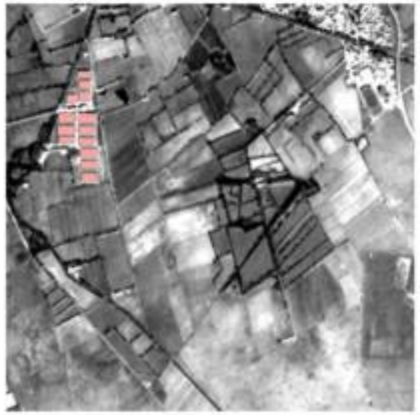
DESIS, 30 m GSD

Sentinel 2, 10 m GSD

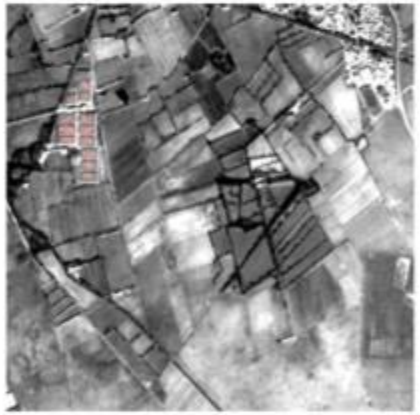
Fusion results, 10 m GSD

<u>Better Target Detection</u>

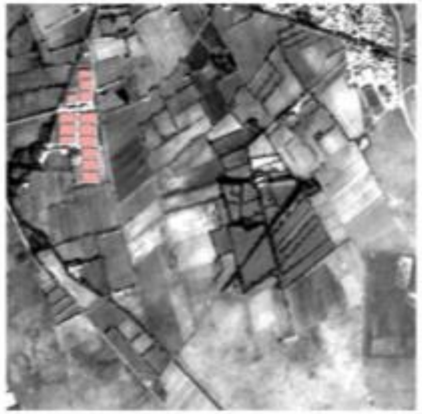
Solar panels by spectral similarity



Solar panels locations



Detection Sentinel 2



Detection (fused product)

Summary

- DESIS in-orbit functional tests successful. Instrument operating on a stable and correct manner
- Processing chain up and running. Products include L1B, L1C up to L2A
  - Including smile & rolling shutter correction
  - Relative radiometric correction (de-striping)
- Radiometric within ~10% (typically within 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 <~10% based on RadCalNet, Pinnacles, S2 comparisons
- DESIS can be used as base for higher level products.
- Outlook: looking forward to cross-calibration with Hisui and Prisma

Thank you for your attention !

DESIS Website

https://www.dlr.de/eoc/desktopdefault.aspx/tabid-13614/

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Article

The Instrument Design of the DLR Earth Sensing Imaging Spectrometer (DESIS)

David Krutz [1,*], Rupert Müller [2], Uwe Knodt [3], Burghardt Günther [1], In…
Ilse Sebastian [1], Thomas Säuberlich [1], Ralf Reulke [1], Emiliano Carmona …
Holger Venus [1], Christian Fischer [1], Bernd Zender [1], Simone Arloth [1], Mat…
Michael Neidhardt [1], Ute Grote [1], Friedrich Schrandt [1], Samuele Gelmi [1] a…
Andreas Wojtkowiak [1]

1 Institute of Optical Sensor Systems, DLR, Rutherfordstraße 2, 12489 Berlin, Ger…
burghardt.guenther@dlr.de (B.G.); ingo.walter@dlr.de (I.W.); ilse.sebastian@dlr.…
thomas.saeuberlich@dlr.de (T.S.); ralf.reulke@dlr.de (R.R.); andreas.eckardt@dlr.…
holger.venus@dlr.de (H.V.); c.fischer@dlr.de (C.F.); bernd.zender@dlr.de (B.Z.); s…
matthias.lieder@dlr.de (M.L.); michael.neidhardt@dlr.de (M.N.); ute.grote@dlr.d…
friedrich.schrandt@dlr.de (F.S.); samuele.gelmi@dlr.de (S.G.); andreas.wojtkowi…
2 Remote Sensing Technology Institute, DLR, Oberpfaffenhofen, 82234 Weßling, G…
rupert.mueller@dlr.de (R.M.); emiliano.carmona@dlr.de (E.C.)
3 Department of Strategic Services, DLR, Linder, Höhe, 51147 Köln, Germany; uw…
* Correspondence: david.krutz@dlr.de

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sensors MDPI

Article

Data Products, Quality and Validation of the DLR Earth Sensing Imaging Spectrometer (DESIS)

Kevin Alonso [1], Martin Bachmann [2], Kara Burch [3], Emiliano Carmona [1], Daniele Cerra [1], Raquel de los Reyes [1], Daniele Dietrich [2], Uta Heiden [2], Andreas Hölderlin [4], Jack Ickes [5], Uwe Knodt [6], David Krutz [7], Heath Lester [5], Rupert Müller [1,*], Mary Pagnutti [3], Peter Reinartz [1], Rudolf Richter [1], Robert Ryan [3], Ilse Sebastian [7] and Mirco Tegler [2]

1 Remote Sensing Technology Institute, DLR, Oberpfaffenhofen, 82234 Weßling, Germany; Kevin.AlonsoGonzalez@dlr.de (K.A.); Emiliano.Carmona@dlr.de (E.C.); Daniele.Cerra@dlr.de (D.C.); Raquel.delosReyes@dlr.de (R.d.l.R.); Peter.Reinartz@dlr.de (P.R.); Rudolf.Richter@dlr.de (R.R.)
2 German Remote Sensing Data Center, DLR, Oberpfaffenhofen, 82234 Weßling, Germany; Martin.Bachmann@dlr.de (M.B.); Daniele.Dietrich@dlr.de (D.D.); Uta.Heiden@dlr.de (U.H.); Mirco.Tegler@dlr.de (M.T.)
3 Innovative Imaging and Research, Corp. (I2R), Building 1103, Suite 140C, Stennis Space Center, Hancock County, MS 39529, USA; kburch@i2rcorp.com (K.B.); mpagnutti@i2rcorp.com (M.P.); rryan@i2rcorp.com (R.R.)
4 Technology Marketing, DLR, Linder Höhe, 51147 Köln, Germany; Andreas.Hoelderlin@dlr.de
5 Teledyne Brown Engineering (TBE), 300 Sparkman Drive, Huntsville, AL 35805, USA; jack.ickes@Teledyne.com (J.I.); Heath.Lester@Teledyne.com (H.L.)
6 Strategic services, DLR, Linder Höhe, 51147 Köln, Germany; Uwe.Knodt@dlr.de
7 Institute of Optical Sensor Systems, DLR, Rutherfordstraße 2, 12489 Berlin, Germany; David.Krutz@dlr.de (D.K.); Ilse.Sebastian@dlr.de (I.S.)
* Correspondence: rupert.mueller@dlr.de

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check for updates

DLR