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

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Content of the presentation

• Mission and instrument

• Product examples

• Calibration and Validation

• Application examples
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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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
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.

DESIS, 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 ±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

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

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**DESIS Instrument**

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### Mission Instrument

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

**FEE:** Front End Electronic  
**FPA:** Focal Plane Array  
**TMA:** Three Mirror Anastigmat  
**POI:** Pointing Unit
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 (between 55° N and 52° S). Orbit period 93 minutes. Revisit time 3 to 5 days (average).
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
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·m⁻²·sr⁻¹·μm⁻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)
Product Example L1B

- Corrections applied:
  - Dark Current
  - Absolute Radiometric
  - Rolling Shutter
  - Smile correction
  - Relative radiometric (de-striping)
Product Example
L1C
Geometric accuracy within 1 pixel (image-to-image matching), RMS ~20m
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
Product Example L3
Suspended Matter in Water
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

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 datakes, L1B processing, no smile correction applied
- Shift confirmed for Oxygen absorption region (762 nm) & other wavelengths (483, 524 & 819 nm)

Fit for 2 datakes with different ΔT

- Earth datakes 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
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

Geometric accuracy within 1 pixel (image-to-image matching), RMS ~ 20m
Geometric Calibration & Accuracy

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

DESIS Image (after coarse rectification)

Accuracy w.r.t. Reference

19 scenes
- #GCP: average 282 per scene
- #Control Points: average 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)
- LLSQ (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
Application examples

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

![RGB: 440 nm, 550 nm, 650 nm](image)

<table>
<thead>
<tr>
<th>Sierpe, Costa Rica 2019-03-04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total suspended matter concentration</td>
</tr>
<tr>
<td>Colored Dissolved Organic Matter CDOM Absorption at 440 nm</td>
</tr>
<tr>
<td>Phytoplankton concentration</td>
</tr>
</tbody>
</table>

- 0 [g m⁻³] 5 [g m⁻³]
- 0 [m⁻¹] 1 [m⁻¹]
- 0 [mg m⁻³] 10 [mg m⁻³]
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

Better Target Detection

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!

DEISIS Website

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