DESIS: Overview and Calibration

Emiliano Carmona for the DESIS Ground Segment Team

Kevin Alonso\(^{(1)}\), Martin Bachmann\(^{(2)}\), Emiliano Carmona\(^{(1)}\), Daniele Cerra\(^{(1)}\), Raquel de los Reyes\(^{(1)}\), Uta Heiden\(^{(1)}\), David Marshall\(^{(1)}\), Rupert Müller\(^{(1)}\), Peter Reinartz\(^{(1)}\)

\(^{(1)}\) DLR German Aerospace Center, Remote sensing Technology Institute, Oberpfaffenhofen, Germany
\(^{(2)}\) DLR German Aerospace Center, German Remote Sensing Data Center, Oberpfaffenhofen, Germany
Teledyne Brown Engineering (TBE, 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.

MUSES provides accommodations for two large and two small hosted payloads and provides core services for the instruments.
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DESIS, the hyperspectral sensor developed by DLR, is the first payload of MUSES.

DLR also established the Ground Segment and licensed the SW processors to Teledyne running in an Amazon Cloud.
DESIS – Timeline and Results

2014 / 2015

7. June 2017
MUSES / DESIS Start Mission

29. June 2018
MUSES installation on ISS

27.-28.08 2018
DESIS launch from Cape Canaveral to ISS via SpaceX Dragon

23. October 2019
Installation of DESIS in MUSES

29.09 – 01.10.2021
@ IAC Washington
Start operational Phase

1st DESIS User Workshop (online)

Design, Implementation, Test
Commissioning
Operations

Since 2018 ~130.400 scenes processed and archived

~23.000 scenes in USA
~8.600 scenes in Europe

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DESIS Data Products

L1A Raw Data
(prepared for selection & ordering & processing)

L1B Top-Of-Atmosphere (TOA) Radiance

L1C Geocoded & Orthorectified

L2A Bottom-of-Atmosphere (BOA) Reflectance

Analysis Ready Data

Land Mask
Water Mask
Cloud Mask
Cloud Shadow over land
Haze over land
Haze over water
AOT Map
WV Map
Data Tasking and Access to Data Archive for Scientific* purposes

Tasking new DESIS data

A proposal is requested to understand the basic research question and the amount of data that will be ordered

Order archived data

Can be ordered without restrictions

Proposal Process

1. Proposal evaluation

2. **TBE TCloud portal**: Task L1A data

3. Get notification from Tcloud

4. Order your data via **DLR EOWEB Portal**

5. Download data (L1B, L1C, L2A) via EOWEB Portal

*For Non-scientific activities contact Teledyne Brown Engineering for data access
DESIS Image Impressions (see official DESIS website)

- New York, USA
- South-Eastern Australia
- Venice, Italy
- Five Lakes Area, Germany, Bavaria
- Railroad Valley, Nevada, USA
- Palo Alto, USA
- Mount Everest, Nepal
- Lake Frome, Australia
**DESIS Instrument**

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

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**Mission Instrument**

<table>
<thead>
<tr>
<th>Mission Instrument</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</td>
<td>2.55 nm, 0.5 nm, 235 bands. Binning: 118, 79, 60 bands</td>
</tr>
<tr>
<td>Spectral response</td>
<td>Gaussian shape, 3.5 nm FWHM</td>
</tr>
<tr>
<td>Software Binning</td>
<td>Binning 2 (5.1 nm, 118 bands)</td>
</tr>
<tr>
<td></td>
<td>Binning 3 (7.6 nm, 79 bands)</td>
</tr>
<tr>
<td></td>
<td>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>

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**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 Calibration Concept

• Based on laboratory pre-launch calibration with updates over time for:

  • **Central wavelengths**: from on-board calibration unit + vicarious calibration

  • **Radiometric parameters**: from vicarious calibration

  • **Geometric parameters** (Boresight angles, POI offset): from vicarious calibration
On Board Calibration Unit

- LED Bank with 9 different LED types (7 used for spectral calibration)
- Data from sensor can be fitted for different LED type

Fit parameters
Normalization = 0.996495
Spectral_shift = -1.25566 (nm)
Vertical_shift = -0.0680321
Spectral Calibration Unit Results

- Mostly obtained from on-board Spectral Calibration. Very precise measurement of LEDs profile provides accurate values.
- Observed simultaneous jumps of 0.5 nm in all LEDs and all pixels across-track. Correlated with different temperature gradients inside DESIS sensor. Two populations: low-temperature gradient (LTG) and high-temperature gradient (HTG).
Spectral Calibration Unit Results

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- Observed simultaneous jumps of 0.5 nm in all LEDs and all pixels across-track. Correlated with different temperature gradients inside DESIS sensor. Two populations: low-temperature gradient (LTG) and high-temperature gradient (HTG).
- Small gradient with time (0.2 nm/year) until September 2019 (Firmware update).
- For any of the two populations, RMS 0.10 nm. Most measurements within 0.10 nm, but small fraction of measurements can deviate as much as 0.3 – 0.4 nm.
- A correction of the 0.5 nm jumps between populations implemented inside smile resampling.
**Other Calibration Unit Results**

- First bands show a fast degradation reaching 50% of initial performance 1000 days after reference point. The decrease is very close to linear.

- Good approximation for this decrease with a gaussian fit:

  \[
  \text{Decrease 1000 days} = \frac{A}{\sigma} \exp\left(-\frac{(x - \mu)^2}{2\sigma^2}\right)
  \]

  - Where x is wavelength and A, \(\mu\), \(\sigma\) are 3 parameters fitted from the calibration data

- Small discrepancies in first 2 bands and across-track
Vicarious Calibration Concept

- Two main goals:
  1. **consistent relative response in spatial and spectral direction:**
     - Flat response on homogenous input
     - Smooth pixel to pixel transitions
     - Consistent behavior across-track
  2. **Correct absolute radiance scale**

- Use a sequence of configurable steps to achieve both goals:

  Original sequence of steps followed on first ground-to-space calibration. Newer calibration updates require simpler sequences
Vicarious calibration Input data

RadCalNet Scenes
- Gobabeb ("GONA")
- La Crau ("LCFR")
- Railroad Valley ("RVUS")
- Gobabeb ("GONA")

Uniform Scenes
Uniform Scenes Processing Steps

- **Rad./Spc. Correction (before smile corr.)**

- **Striping correction:**

- **Flatfielding spatial:**

- **Flatfielding spectral:**

- **L2A spectral smooting:**
Absolute radiometric scale

- Use TOA Reflectance from RCN sites for estimation of absolute calibration

- Compare DESIS measurement against:
  - RCN measurement (10 nm)
  - DESIS team TOA calculation from RCN BOA

- Compute deviations of DESIS w.r.t. both references:
Absolute radiometric scale

• Use selected “calibration” scenes from RCN and perform a fit to mean value (2 times in steps sequence) in order to obtain a per-band factor
• Use Average from 2 TOA reference data: RadCalNet provided (10 nm), DESIS calculated (DESIS resolution)
Vicarious calibration Periods

- Input scenes not evenly distributed in time
- Particularly challenging to have abundant good quality Radcalnet (RCN) scenes
- Calibration updates arrive several months after data acquisition
Results from 3 calibration periods: Calibration RCN Data Results

• Absolute calibration adjusted with RCN data for 3 different periods

• Absolute calibration uses only part of RCN scenes (19)
  • good atmospheric conditions
  • below 50 degrees Sun Zenith Angle

• These summary plots show 19 RCN scenes used for calibration
Results from 3 calibration periods: All RCN Data Results

- Absolute calibration adjusted with RCN data for 3 different periods

- Absolute calibration uses only part of RCN scenes (19)
  - good atmospheric conditions
  - below 50 degrees Sun Zenith Angle

- These summary plots show all RCN scenes (30 scenes)
Latest Vicarious calibration data

- New calibration periods continue using baseline vicarious calibration used in DESIS
- Data in period #4 calibrated with calibration in period #4 (preliminary):
  - Similar results as seen in other periods
  - After calibration bias is corrected, but RMS below 500 nm is significant larger than above 500 nm
Latest Vicarious calibration data

- New calibration periods continue using baseline vicarious calibration used in DESIS
- Data in **period #5** calibrated with calibration in **period #5** (preliminary):
  - As indicated by LED calibration data, no sign of degradation below 500 nm on Period 5 (starts 01.07.2022)
  - LED calibration data seem to reproduce well the trends, but not the actual intensity of the effect
  - Not accurate enough for model, but probably accurate about change of behavior in July 2021
Comparison between CAL Unit and Vicarious Calibration

- Model derived from CAL unit data does not match well the data obtain in Vicarious calibration

- Main similarity with LED data:
  - CAL data reproduces the fast decrease in performance below 500 nm
  - End of degradation <500 nm after July 2021

- Main differences are:
  - CAL data shows a maximum decrease down to 40% from the initial values, Vic. data maximum decrease is 60%
  - CAL data does not reproduce decrease of ~2% between periods (3.4%/year) above 500 nm
  - CAL decrease below 500 nm is constant until July 2021, but vicarious results show different intensities for different periods
Comparison with Radiometric update from Vicarious Calibration

- Unfortunately model does not seem to match well the data obtained in Vicarious calibration.
- The plot shows relative change of detector performance obtained from the Vicarious calibration.
- Main similarity with LED data:
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  - CAL data does not reproduce a decrease of ~2% between periods (3.4%/year) above 500 nm.
  - CAL decrease below 500 nm is constant until July 2021, but Vicarious results show different intensities for different periods.
- Baseline for radiometric calibration is difficult to match RCN data with radiometric results from CAL unit (difficulties known since start of mission).
- Good news that DESIS shall be more stable since July 2021 below 500 nm.
- Results in agreement with independent study by:
  - S2, L8 crosschecks performed by TBE/I2R.
L1C Processing (and Calibration)

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

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

DESIS Image
(after coarse rectification)

Cascade of matching
- BRISK (Binary Robust Invariant Scalable Keypoints)
- LLSQ (Local Least Squares)
- SIFT (Scale-Invariant Feature Transform)
**L1C Processing (and Calibration)**

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

**Accuracy w.r.t. Reference**
177 scenes
- #GCP: average 210 per scene
- #Control Points: average 969 per scene

In case image matching works for a scene
- RMSE (east) = 21.0 ± 5.9 m
- RMSE (north) = 21.4 ± 6.0 m

In case of no-matching values rely on boresight calibration:
- RMSE ~289 m (across); ~496 m (along), but with peak values up to 1 km

Boresight angles are stable over time:

Check parameters “orthoRMSE_x” or “orthoRMSE_y”. When value is -1 it means that no matching could be achieved.
Thank you!

More DESIS information at:

- Sensors 2019, 19(7), 1622; https://doi.org/10.3390/s19071622
- Sensors 2019, 19(20), 4471; https://doi.org/10.3390/s19204471
- IGARS 2021, Vicarious Calibration of the DESIS Imaging Spectrometer
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• Main differences are:
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