The data archive of the spaceborne imaging spectrometer mission DESIS

U. Heiden, M. Bachmann, E. Carmona, D. Cerra, D. Dietrich, D. Marshall
R. Müller, M. Pato, P. Reinartz, R. de los Reyes, M. Tegler
Earth Observation Center
German Aerospace Center (DLR)
82234 Wessling, Germany

U. Knodt
Strategie und Vernetzungen
German Aerospace Center (DLR)
51147 Köln, Germany

David Krutz
Optical Sensor Systems
German Aerospace Center (DLR)
12489 Berlin, Germany
email address or ORCID

Heath Lester
Teledyne Brown Engineering (TBE)
Huntsville, AL 35805, USA

IGARSS 2024 - 2024 IEEE International Geoscience and Remote Sensing Symposium | 979-8-3503-6032-5/24/$31.00 ©2024 IEEE | DOI: 10.1109/IGARSS53475.2024.10640871

***Abstract*—On August 2024, the DLR Earth Sensing Imaging Spectrometer (DESIS) completed six years of operations onboard the International Space Station (ISS). In that time, DESIS has acquired data worldwide for both scientific and commercial users. The continuously growing data archive supports methodical and application developments for the monitoring of the Earth's surface. We present a short update of the mission status and then provide a deeper view into the DESIS data archive. DESIS is currently operating in nominal conditions, further expanding its multitemporal data archive, which holds great value for a wide range of applications and serves as a database for recent and upcoming hyperspectral Earth-observing missions. It enables long-term analysis of physical phenomena and land use changes by providing high-resolution data spanning an extended temporal range for the monitoring of a site of interest.**

***Index Terms*—DESIS, imaging spectroscopy, data archive, multitemporal analyses, synergies, spaceborne**

I. Introduction

The DESIS imaging spectrometer, which has been in operation for six years on the Multi-User System for Earth Sensing (MUSES) platform aboard the International Space Station (ISS), is a collaborative effort between Teledyne Brown Engineering (TBE) and the German Aerospace Center (DLR). TBE provided the MUSES platform, where DESIS is installed, and the infrastructure for operation, data tasking and commercial data distribution. DLR developed and built the instrument, along with the development of the associated software for data processing and delivery. Additionally, DLR is responsible for the scientific exploitation of the mission.

The MUSES platform represents a space-based Earth-imaging initiative that is both owned and operated by TBE. This comprehensive venture, encompassing design, construction, ownership, and operation, is positioned as a commercialization project affiliated with the NASA and the International Space Station (ISS). Strategically located on ExPRESS Logistics Carrier 4 (ELC 4), MUSES is uniquely configured to accommodate up to four instruments that can be robotically installed and removed. One of MUSES' distinctive capabilities lies in its provision of precision pointing for Earth-observing instruments. Equipped with an integrated two-axis gimbal, it facilitates a ±25° forward/backward view, a 45° backboard view, and a 5° starboard view, ensuring a versatile observational range. The system is inertially stabilized, further enhancing its observational accuracy, and incorporates target tracking mechanisms. MUSES serves as a centralized hub for all aspects of Earth observation (EO) mission planning, control, and data downlink. It boasts a robust data downlink capacity, capable of handling approximately 225 gigabytes per day.

Mission Instrument	ISS/MUSES DESIS
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, FWHM	2.55 nm, 3.50 nm
Radiometry	13 bits
Spatial (res., swath)	30 m, 30 km (@ 400 km)
SNR (signal-to-noise)	205 (no bin.)/406 (4 bin.) @ 550 nm
Instrument (mass)	93 kg
Capacity (km, storage)	2360 km per day, 225 GBit

Mission Instrument	ISS/MUSES DESIS
Target lifetime	2018-2023 (nominal) ...
Satellite (mass, dimension, usage)	455 t, 109.0×97.9×27.5 m^3 (multi-purpose)
Orbit (type, local time at equator, inclination, height, repeat cycle)	not Sun-synchronous, various, 51.6°, 320 km to 430 km, no repeat cycle
Coverage	55° N to 52° S

Fig. 1. Summary of the DESIS mission specification

The DESIS instrument (see Figure 1 for the specifications) is equipped with an onboard calibration unit (two LED banks with 9 different LEDs each) and a rotating pointing mirror (POI) and it allows the line of sight to change within ±15° in the forward/backward direction independently of the MUSES orientation [1]. The instrument was launched aboard the SpaceX-9 rocket in June 2018, integrated into MUSES in August 2018, and has been operational since October 2018. During the commissioning phase, the performance of DESIS was thoroughly evaluated and is monitored regularly [2]. Currently, the performance can be summarized as follows:

- Absolute radiometric calibration proved to be exceptionally accurate, with deviations well within $\sim$ 5 percent at the Top-of-Atmosphere (TOA) radiance and TOA reflectance levels, as validated against RadCalNet, Sentinel-2, and Landsat-8.
- Spectral calibration, following smile correction, exhibited high precision, typically better than $\sim$ 0.5 nm, and consistently within 1/3 of a spectral pixel. The instrument's geometric accuracy, in relation to reference points, demonstrated a linear root mean square error (RMSE) of approximately 20 m ($<$ 1 pixel) when ground control points (GCPs) could be derived from image-to-image matching. In cases where GCPs were unavailable, the RMSE ranged from 300 to 500 m [3]
- Signal-to-noise ratio (SNR) measurements exceeded 200 at five bands (443 nm, 482 nm, 562 nm, 655 nm, 865 nm) and were in agreement with ground-based measurements. The modulation transfer function (MTF) at Nyquist frequency (across track) was observed to be approximately 0.3-0.4.
- Furthermore, the DESIS instrument demonstrated excellent agreement in terms of Bottom-of-Atmosphere (BOA) reflectance, with uncertainties within $\sim$ 5 percent of the reference RadCalnet surface reflectance and significant agreement within uncertainties with other sensors processed with DESIS L2A processor PACO [4] [5].

II. DESIS Data Access

DESIS data is made accessible for scientific purposes, being freely available and open for exploration with commercial opportunities available through TBE. The data is stored in the Level-1A (L1A) format within the DESIS data archive at DLR's Earth Observation (EOWEB) GeoPortal and the Earth Sensor Portal (TCloud) at TBE. The DESIS mission operates on an on-demand basis, allowing users to request specific tasking and data processing tailored to their parameters [6].

Multiple processing levels are made available to users. The Level-1B (L1B) data is defined as radiometric and sensor-specific corrected information, providing TOA. All metadata necessary for further processing are attached to this data, facilitating a comprehensive scientific investigation [2]. Level-1C (L1C) data takes a step further by ortho-rectifying and resampling the L1B data to a specified grid. This process utilizes the global Shuttle Radar Topography Mission (SRTM) 1 arcsec Digital Elevation Model (DEM) for terrain correction, and global Landsat ETM+ references to refine the sensor model [2], [3]. At Level-2A (L2A), the L1C data undergoes atmospheric correction, yielding Bottom-of-Atmosphere reflectance. This correction employs the global SRTM 1 arcsec DEM for topographic correction and generates various masks, including those for water, land, clouds, cloud shadows over land, haze over land, haze over water, Aerosol Optical Thickness (AOT), and water vapor [2], [4], [7].

The DESIS products are provided in GeoTiff format with XML metadata, ensuring compatibility and ease of use. Integration with analysis tools is facilitated through the compatibility of DESIS data with the EnMAP-Box and an open-source Python plug-in for Quantum Geographic Information System (QGIS). Additionally, the ENVI software suite supports DESIS data, taking into account radiance gains and offsets, along with all relevant metadata for a comprehensive analytical approach.

III. DESIS Data Archive

As of October 2023, the TCloud data archive encompasses a substantial repository, hosting more than 270,000 scenes. This marks a 30% increase from its status at the beginning of the same year. The archive is still steadily growing. Figure 2 illustrated the status of acquisitions in October 2023, presenting a heatmap delineating the global distribution of available scenes.

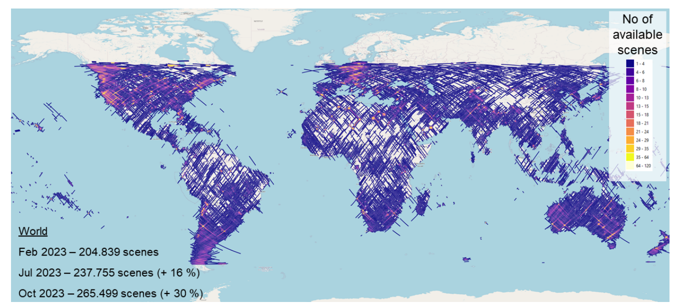

Fig. 2. Heatmap of the coverage of all available DESIS data scenes (status 10/2023)

Evidently, certain regions exhibit sparse coverage, including parts of the Sahara, the Amazon rainforest, and the desert areas in Asia. In contrast, others undergo multiple recordings, some reaching frequencies of up to 120 times. Noteworthy among these areas are vicarious calibration and validation sites such as the RadCalNet sites La Crau (France), Railroad Valley (USA) and Gobabeb (Namibia). Similarly, sites in Australia, such as the vicarious calibration and validation site Pinnacles (Australia) contribute to the diverse coverage.

Other areas of interest which are monitored by scientific and commercial users include mining areas in Northern Canada and the Middle East, as well as National Parks such as the Terraba Sierpe wetland area in Costa Rica and Kruger National Park in South Africa. Certain regions show a comprehensive coverage, notably Europe, due to the regular acquisition for the upcoming hyperspectral Sentinel mission CHIME of the European Space Agency (ESA) since 2020. Substantial and repeated coverage is also evident in Southern America and Australia.

Each scene in the archive is accompanied by a data quality rating, with 90.7% of the data deemed acceptable, while the remainder are labeled as questionable. Users have the flexibility to define permissible cloud coverage, and commercial cloud

Sensor	DESIS	EMIT
Spatial resolution [m]	30	60
Spectral sampling [nm]	2.55	7.40
Swath width [km]	30	75
Spectral coverage [nm]	400 - 1000	380 - 2500

TABLE I
SELECTIVE SENSOR SPECIFICATIONS OF THE TWO IMAGING SPECTROMETERS EMIT AND DESIS

cover forecasts serve as a pivotal tasking parameter. Having these constraints in mind, more than 67% of scenes exhibit cloud coverage of less than 25%.

IV. Synergies with other Missions

For many years, there have been ongoing discussions about the harmonization of imaging spectroscopy data derived from different spaceborne missions. A decisive step is the establishment of common metadata standards, exemplified by the Analysis Ready Data (ARD) Framework initiated by the Committee on Earth Observation Satellites (CEOS [8]). This framework is intended to support time series analysis and improve the interoperability of the data.

However, several critical questions persist. The feasibility of employing different imaging spectroscopy sensors to generate a unified data L3+ product remains a focal point. The radiometric and spectral differences inherent in various sensors requires a comprehensive understanding of their effects on the L3+ product. Fundamental investigations revolve around the existence of conceptual frameworks, tools or data developed for the interoperability of space-based IS sensor data. Key terms, including cross-calibration and data harmonization, require further clarification.

The ISS serves as a host for multiple imaging spectrometers, among them NASA's EMIT instrument. EMIT covers the entire reflective wavelength range from 380 nm to 2500 nm with a spatial pixel resolution of approximately 60 m and a spectral sampling of 7.4 nm (see Table I). As of October 2023, the acquisition of more than 10000 data pairs for EMIT and DESIS within a 60-minute time window has been realized globally, with over 1250 data pairs specifically for Australia. This dataset is continually expanding, driven by EMIT's ongoing mapping acquisitions and DESIS user-controlled acquisitions. These data pairs are valuable resources for training and testing biochemically and biophysically models aiming to estimate the sensoral differences to monitor Earth system processes. Figure 3 provides an exemplary illustration of the geometric match between DESIS and EMIT, a prerequisite for further data analysis.

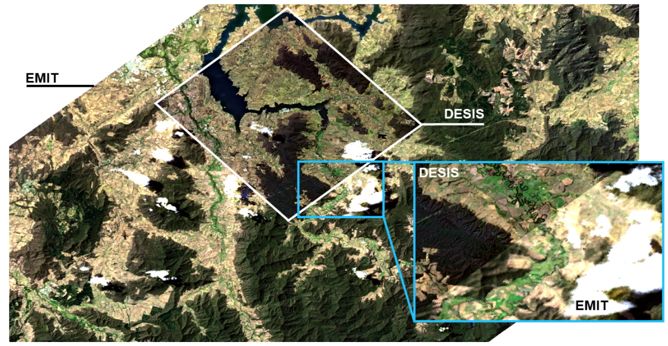

Fig. 3. Synergies with other imaging spectroscopy missions onboard the ISS: The Albury forest in Australia recorded by EMIT and DESIS on the 16th of March 2023 (4:50 GMT).

V. Conclusions and Outlook

The DESIS imaging spectrometer deployed aboard the ISS is a unique instrument that provides the highest spectral sampling and resolution currently available in orbit. This state-of-the-art technology has been in operation for six years and yields the potential to improve our understanding of the Earth's surface processes through the collection of high-quality spectral data. DESIS has been operating since 2018 resulting in the largest archive of imaging spectrometer data that is freely available for scientific purposes.

A distinctive feature of the mission is its free and open data policy for scientific users, which enables scientists and researchers worldwide to harness the potential of this extensive dataset for scientific investigation. With a primary focus on site repetition, the mission has enabled multi-temporal acquisitions from multiple sites and has established itself as an excellent laboratory for the testing and development of operational algorithms and processors. More recently, the mission has extended its coverage to large areas such as entire continents and visited them multiple times. This strategic approach enables the exploration of dynamic changes of land surfaces in the hyperspectral range and provides insights into temporal changes and ecosystem dynamics.

One further aspect is the potential synergy between DESIS and other hyperspectral sensors as well as multispectral Earth observation systems. Despite the enormous possibilities, this remains still largely unexplored. The prospect of denser timelines and the creation of novel information products opens up opportunities for groundbreaking research.

References

[1] D. Krutz, R. Müller, U. Knodt, B. Günther, I. Walter, I. Sebastian, T. Säuberlich, R. Reulke, E. Carmona, A. Eckardt, H. Venus, C. Fischer, B. Zender, S. Arloth, M. Lieder, M. Neidhardt, U. Grote, F. Schrandt, S. Gelmi, and A. Wojtkowiak, "The instrument design of the dlr earth sensing imaging spectrometer (desis)," *Sensors*, vol. 19, no. 7, 2019. [Online]. Available: https://www.mdpi.com/1424-8220/19/7/1622

[2] K. Alonso, M. Bachmann, K. Burch, E. Carmona, D. Cerra, R. de los Reyes, D. Dietrich, U. Heiden, A. Hölderlin, J. Ickes, U. Knodt, D. Krutz, H. Lester, R. Müller, M. Pagnutti, P. Reinartz, R. Richter, R. Ryan, I. Sebastian, and M. Tegler, "Data products, quality and validation of the dlr earth sensing imaging spectrometer (desis)," *Sensors*, vol. 19, no. 20, 2019. [Online]. Available: https://www.mdpi.com/1424-8220/19/20/4471

[3] R. Müller, T. Krauss, M. Schneider, and P. Reinartz, "Automated georeferencing of optical satellite data with integrated sensor model improvement," *Photogrammetric Engineering Remote Sensing*, vol. 78, no. 1, 2012.

[4] R. de los Reyes, M. Langheinrich, P. Schwind, R. Richter, B. Pflug, M. Bachmann, R. Müller, E. Carmona, V. Zekoll, and P. Reinartz, "Paco: Python-based atmospheric correction," *Sensors*, vol. 20, no. 5, 2020. [Online]. Available: https://www.mdpi.com/1424-8220/20/5/1428

[5] R. de los Reyes, M. Langheinrich, K. Alonso, M. Bachmann, E. Carmona, B. Gerasch, S. Holzwarth, D. Marshall, R. Müller, M. Pato, M. Schneider, and P. Schwind, "Inter-comparison of

paco boa surface reflectance between multi- and hyperspectral sensors: Enmap overpasses with desis, sentinel-2, landsat and cal-val sites," https://www.dropbox.com/s/l5od0tylspjntqg/LVPE2023_DESIS_EnMAP_S2_L2A_delosReyes_v3.pdf?dl=0.

[6] J. Avbelj, H. Krawczyk, R. Müller, A. Makarau, M. Bachmann, V. Ziel, R. de los Reyes, B. Gerasch, K. Alonso Gonzalez, and E. Carmona, "DESIS-PAV - ATBD L1A, L1B, L1C, L2A processors," https://www.dlr.de/eoc/PortalData/60/Resources/dokumente/DESIS/DESIS_Products/PAV-DLR-TN-004.pdf.

[7] R. Richter, "A spatially adaptive fast atmospheric correction algorithm," *International Journal of Remote Sensing*, vol. 17, no. 6, pp. 1201–1214, 1996. [Online]. Available: https://doi.org/10.1080/01431169608949077

[8] "CEOS analysis ready data," https://ceos.org/ard/, accessed: 2024-01-10.