DESIS on ISS

Announcement of Opportunity

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1. Purpose and structure of the document

This document describes the Call and procedure to conduct scientific research and education, as well as to develop, evaluate and demonstrate new applications using data of the DESIS mission.

Chapter 2 describes the objectives of the Announcement of Opportunity related to the utilization of DESIS data. Chapter 3 provides information on the AO procedure, including submission guidelines, proposal evaluation, how the proposal shall be implemented as a project, data costs and schedule. The data rights are provided as Annex in the user license agreement.

This document describes the specific conditions and procedures applicable to proposals related to the DESIS Announcement of Opportunity (AO).

2. DESIS mission overview

Introduction

Teledyne Brown Engineering (TBE) located in Huntsville, Alabama, USA, and the German Aerospace Center (DLR), Germany, operate a hyperspectral instrument integrated in the Multi-User-System for Earth Sensing (MUSES) platform installed on the International Space Station (ISS).

The MUSES platform was launched in June 2017 with SpaceX-11 and integrated to the ISS several days later. The launch of DESIS to ISS was on June, 29th 2018 by SpaceX-15. End of August, 2018, DESIS was unpacked and mounted on board the ISS. DESIS is the first instrument to utilise the MUSES external payload accommodation. The instrument DESIS is developed by DLR and delivered to TBE for integration into MUSES. TBE operates, commands and monitors DESIS with an own Ground Segment including processing, calibration, monitoring, validation and data dissemination.

DESIS has been designed, built and calibrated within 3 1/2 years at DLR. The commissioning and validation phase was finished in March 2019. Since this date, DESIS is working operationally and will continue at least until the end of 2023.

Generally, DESIS is a predominantly commercial mission. TBE has the exclusive right to license and transfer image data for commercial use. DLR has the right to task DESIS or request archived data for scientific purposes. For this purpose, TBE provides DLR a NOAA license that is applicable to image and auxiliary data of the MUSES Platform (e.g. inertial measurements, star tracker attitude measurements, orbit data, calibration and instrument housekeeping data relevant to the processing of the image data). DLR can task DESIS data at least 2,000 minutes per calendar year divided evenly over each month (i.e., approximately 167 minutes per month). Instrument data from the TBE archive (catalogue data) are available without quota, but have to be released by TBE.

MUSES on ISS

The MUSES platform provides accommodations for two large and two small hosted payloads. MUSES is attached at the ELC-4 (EXPRESS Logistics Carriers) starboard of the ISS (Figure 2-1). This is a space-based, Earth-pointing platform providing position sensing, data downlink, and other core services for each payload attitude control. DESIS has a mass of ~88 kg and is integrated in one of the large containers. Two gimbals allow a rotation of the whole MUSES platform around two axes resulting in ±25° forward / backward view, 45° backboard (port) view and 5° starboard view. Together with the POI of the DESIS instrument a ±40° along track viewing is possible. The platform is equipped with a star tracker (sampling rate 10 Hz) and a MIMU (Miniature Inertial Measurement Unit) (sampling rate 50 Hz) providing a 10 Hz attitude measurement after filtering. ISS GPS data provide position and velocity vectors and time tags (sampling rate 1 Hz) within the BAD (Broadcast Ancillary Data). The predicted viewing capability of MUSES, when operating at the ISS orbit inclination of 51.6°, will enable the DESIS instrument to scan the majority of the populated Earth.

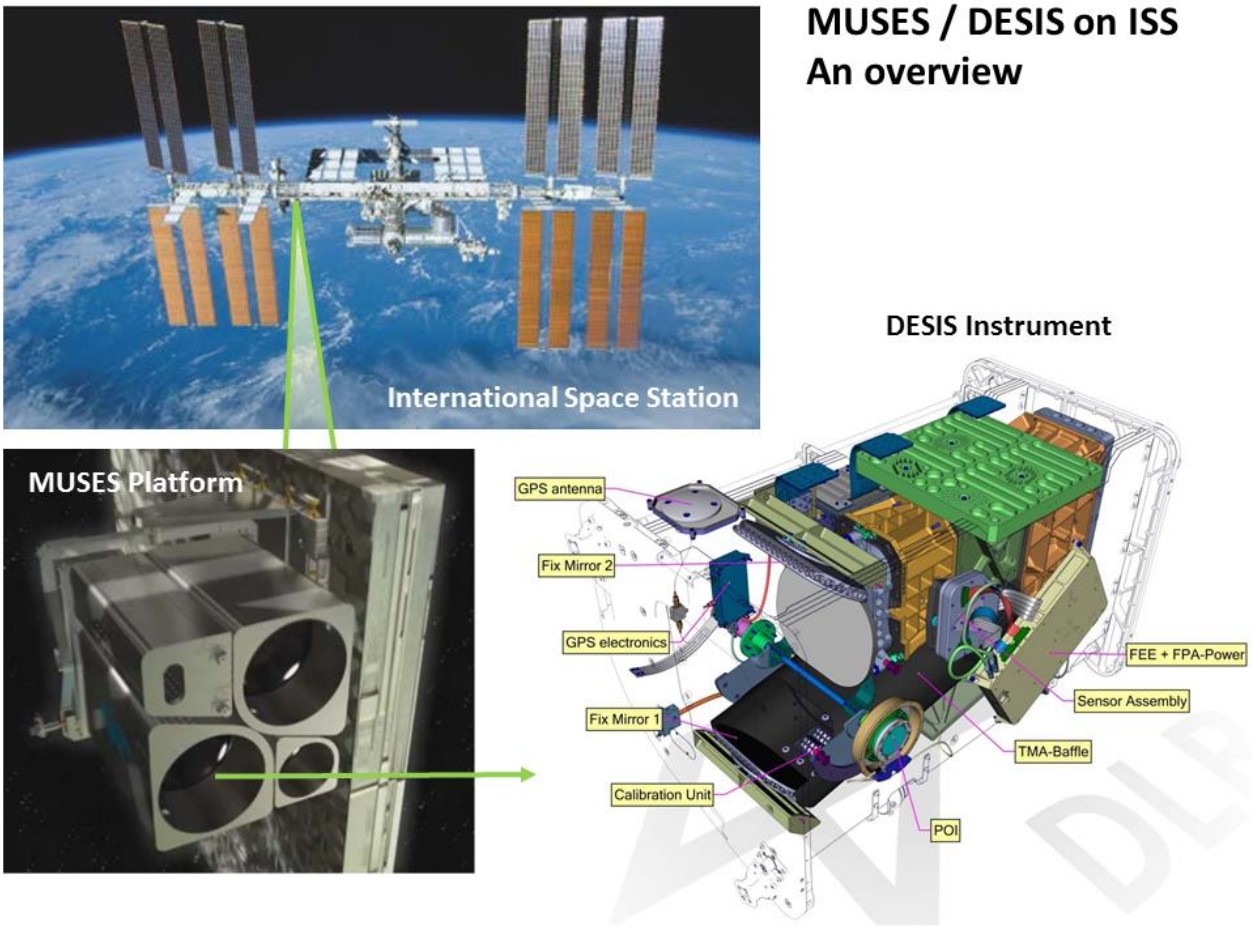

Figure 2-1 MUSES platform and DESIS instrument on ISS

Imaging spectrometer DESIS

The DESIS hyperspectral instrument is realized as a pushbroom imaging spectrometer spectrally sensitive over the VNIR range from 400 to 1000 nm with a spectral sampling distance of 3.33 nm employing a 2-dimensional back illuminated CMOS (Complementary Metal Oxide Semiconductor) detector array. The across direction of the array is used for the spatial resolution and the along direction for the spectral resolution (channels). The optical design is based on the Offner-type grating spectrometer widely used in hyperspectral imaging. The electronic shutter mechanism is realized as a rolling shutter, in which each channel collects light during the same period of time, but the time light collection starts and ends are slightly different for each channel. The Ground Sampling Distance (GSD) at nadir view depends on the flight altitude of the ISS and is about 30 m resulting in a swath width of about 30 km.

DESIS is equipped with a Pointing Unit (POI) consisting of two fixed and one rotating mirror in front of the entrance slit that allows, by rotating one mirror, a forward and backward viewing change up to ±15° w.r.t. the nominal (e.g. nadir) view. The POI can be operated in a static mode with 3° angle steps for the viewing direction and in a dynamic mode with up to 1.5° change in viewing direction per seconds. This allows - besides normal Earth data takes (Image Strip Mode) - acquiring stereo or Bidirectional Reflectance Distribution Function (BRDF) products (Image Stereo Mode). The POI can be also operated in calibration mode to minimize the external light fields and allowing on-board calibration measurements. The specifications of the MUSES platform and DESIS instrument are listed in Table 2-1.

Parameter	**Value**
Target lifetime	2018-2023
Orbit type (local time at equator, inclination, altitude, period, repeat cycle)	not sun-synchronous (various, 51.6°, 400 ± 5 km, 93 min, no repeat cycle)
Coverage	55° N to 52° S ~ 90% of populated Earth
Revisit frequency	3 to 5 days (strongly depends on frequency of orbit manoeuvres – see also section orbit characteristics)
Tilt (across-track, along-track)	-45° to +5°, -40° to +40° by MUSES and DESIS
Spectral coverage	402 nm to 1000 nm
Number of spectral channels	235 (no binning) 118 (binning 2) 79 (binning 3) 60 (binning 4)
Spectral Sampling: resolution, accuracy	2.55 nm (w/o binning); ~10.2 nm (binning 4)
Full Width Half Maximum (FWHM)	~3.5 nm (w/o binning); ~7.0 nm (binning 4)
Radiometric resolution	12 bits + 1 bit gain
Geometry (rolling shutter mode) resolution & pixel, accuracy	30 m & 1024 (@400 km), (acc. ~20 m with GCPs, 300 – 500 m w/o GCP)
Radiometric accuracy	+/-10% (based on on-ground calibration and with support of inflight radiometric calibration)
Radiometric linearity	99%
MTF @ Nyquist	30%-40% based on on-ground calibration / static MTF without smearing effects / wavelength depending
Signal-to-Noise ratio (albedo 0.3 @ 550 nm)	195 (w/o binning), 386 (4 binning) (based on laboratory calibration)
Dark/Read noise (electrons)	30-60e- (global shutter) 15-30e- (rolling shutter)
Quantum scale equivalent (e-/DN)	0.04 e-/DN
Max frame rate	235Hz (@235 spectral lines, rolling shutter) 117Hz (@235 spectral lines, global shutter)

Capacity (km, storage, transmission)	2360 km per day, 225 GBit, Ku-band

Table 2-1: Selective DESIS / MUSES Key Parameters

Besides a pre-flight spectral, radiometric and geometric calibration and characterisation of the instrument in laboratory, the instrument contains an on-board calibration unit comprising different monochromatic and white light LEDs between 400 and 1000 nm. The calibration unit is located close to the POI mirror in front of the DESIS instrument, and allows the illumination of the full spectrometer FoV with color and white light. The calibration unit is characterised in laboratory and temperature controlled in orbit within 1 K.

Specifics of the ISS Orbit

For the design of scientific experiments using DESIS data it is important to understand the specifics of the ISS orbit. The ISS orbit is using a non-sun-synchronous orbit resulting in observation and illumination conditions that are not reproducible. ISS moves on an orbit with an inclination of 51.6° from west to east approximately 400km above the Earth surface. ISS covers areas from 55° N to 52° S. Based on the tilting capabilities of the platform and the instrument, DESIS data can view from -45° (backboard) to +5° (starboard) and between -40° to +40° (along track). The tilting specification allows the observation of up to 90 % of the populated land masses.

In principle, ISS orbital tracks are repeated every 3 – 5 days. However, the times of overpasses vary widely resulting in different illumination conditions during the acquisition. Further, the prediction of the orbit is very difficult and only possible approximately few days in advance. This is because the ISS position is strongly affected by effects such as sun activity, debris manoeuvres and other orbit manoeuvres. It results in different heights of the ISS above the Earth and can vary in very extreme cases up to ~100 km difference. Figure 2-2 shows the mean semi-major orbital axis for the year 2016.

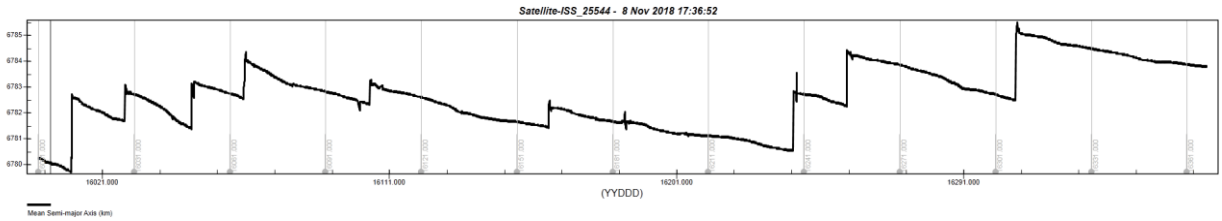

Figure 2-2 Mean semi-major orbital axis in 2016

Huemmrich et al. (2017) have analysed the possibilities of the HICO instrument onboard of the ISS for Ecosystem Carbon Flux analyses. They found out that the ISS orbit provides longer periods (up to weeks) without any daytime acquisition possibilities and periods providing multiple observations at different times of the day within a period of a few days.

In Figure 3, all possible acquisition for Berlin, Germany, are shown for the DOY on x-axis and the off-nadir angle on Y-axis with the following restrictions:

- Considers the MUSES/DESIS tilting capabilities of -45° (backboard) to +5° (starboard)
- Daytime overpasses only with a maximum solar zenith angle of 70°
- Observations 90° orthogonal to the ground track
- Off-Nadir viewing angle < 30°

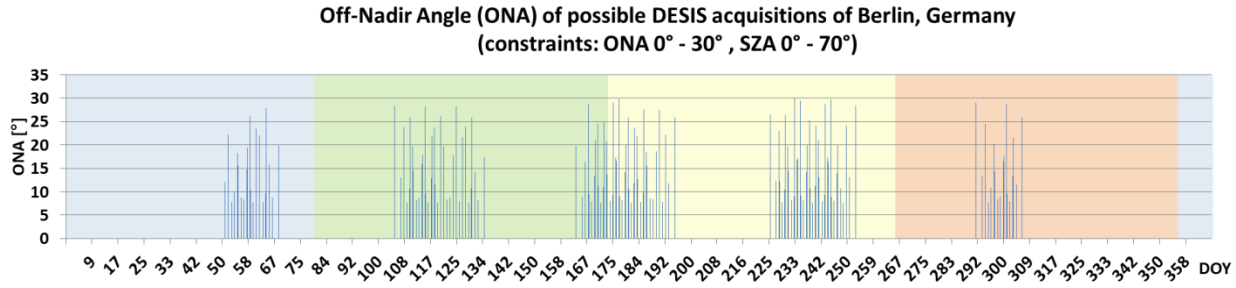

Figure 2-3 Theoretical DESIS acquisition of Berlin, Germany, based on the orbital axis of the ISS in 2016. Colours mark the seasons (by calendar) of the year from winter (blue), spring (green), summer (yellow) and autumn (orange).

For the year 2016, theoretically 170 DESIS acquisition would have been possible given the above listed constraints. The distribution of the acquisitions show a periodical grouping with weeks with nearly daily tasking opportunities followed by weeks with no tasking options. Further, the off-nadir angle (ONA; Figure 2-3) and the acquisition time of day (Figure 2-4) vary widely. The complex viewing and illumination conditions of each task need to be considered especially for multitemporal and comparative data analyses.

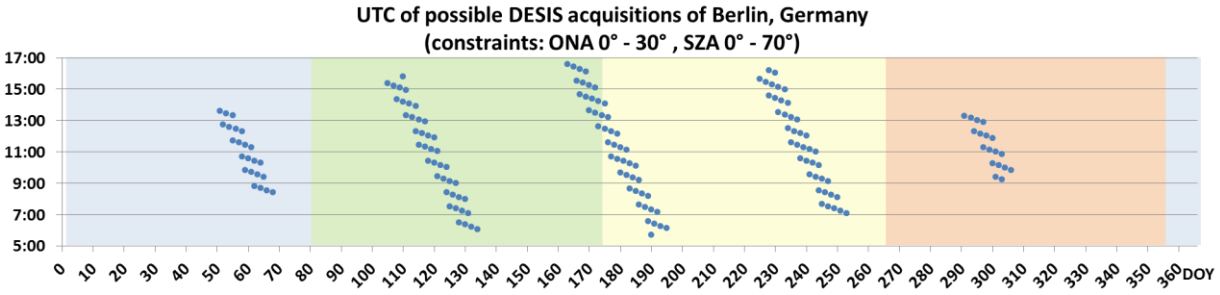

Figure 2-4 Theoretical DESIS acquisition of Berlin, Germany, based on the orbital axis of the ISS in 2016. Colours mark the seasons (by calendar) of the year from winter (blue), spring (green), summer (yellow) and autumn (orange).

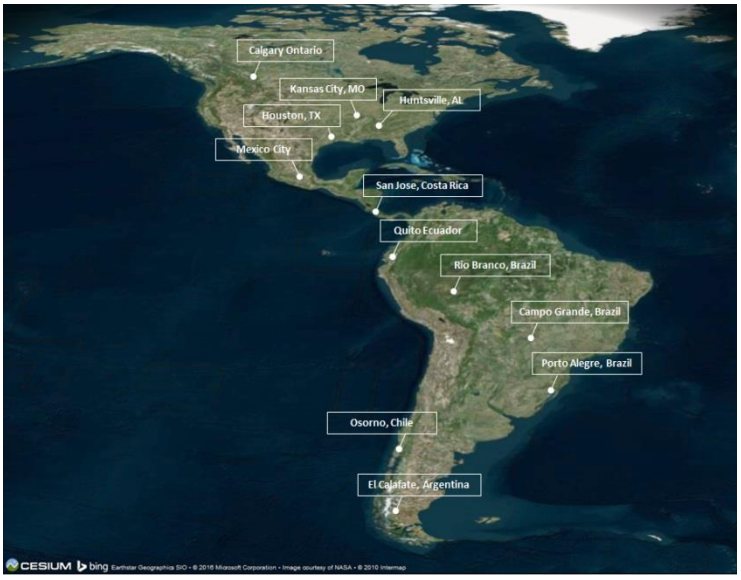

Figure 2-5 MUSES Imaging Opportunity Analysis – Selected Locations

TBE have analysed theoretical imaging opportunities for various places across latitude (Figure 2-5) and by considering sun elevation > 30° and and Off-Nadir angle of <25°. The orbit analysis confirms the results of Huemmrich et al. (2017) that the distribution of tasking opportunities is dependent on latitude (Figure 2-6). Grouping of tasking possibilities increase with latitude while tasking opportunities closer to the equator get more dispersed.

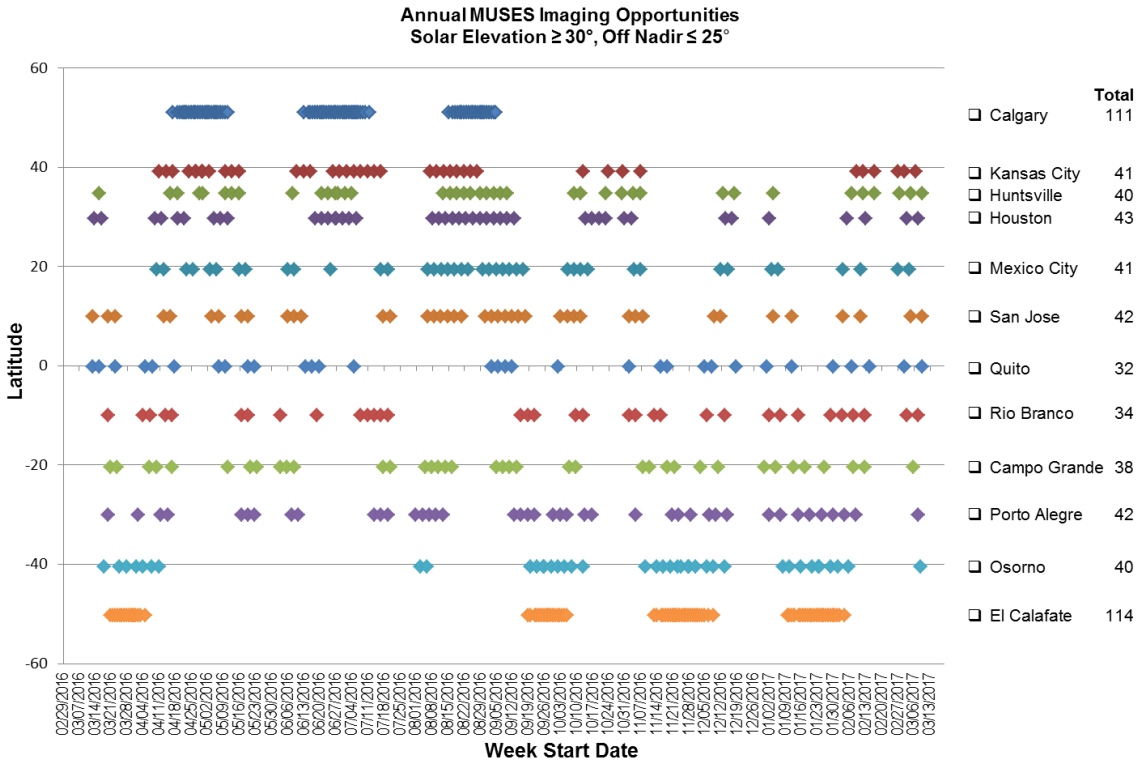

Figure 2-6 MUSES Imaging Opportunities for Solar Elevations ≥ 30°

Acquisition Modes

Acquisition modes are a well-defined sequence of activities on the DESIS instrument. Depending on the measurement aim, different nominal operation modes are defined. All operation modes will generate one data take. The following modes are available for science users:

Image Strip Mode - The Image Strip Mode is the standard measurement for earth observation. The acquisition parameters include observation direction (by DESIS POI and by MUSES rotation).

BRDF Mode - The Image Stereo Mode can be used to generate image data from the same area on ground under different angles. It collects up to 3 image tiles at different angles (15° forward, nadir, 15° backward).

Data products and data processing

Two types of data products can be distinguished. The internal L1A products are stored in the long-term archive of the DLR and are accessible for internal use only. The L1B, L1C and L2A products can be generated and delivered to DESIS science users according to their request. A short overview of the complete processing chain of the raw DESIS data developed by DLR is given in Figure 2-7.

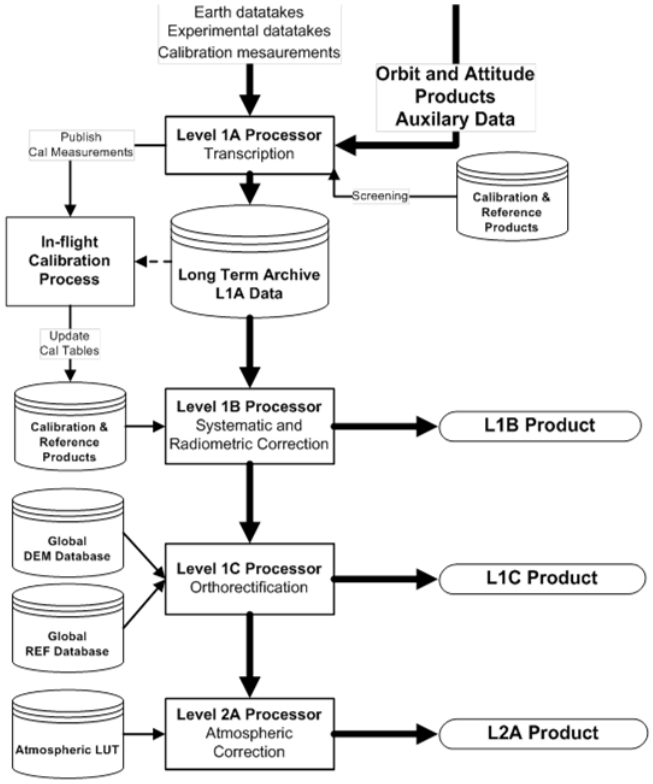

Figure 2-7 MUSES Imaging Opportunities for Solar Elevations ≥ 30°

The fully automated processor works on tiled data (1024 x 1024 pixels) covering ~ 900 km^2. It runs on users request and considers processing parameters defined by the users.

The DESIS products are described in Table 2-2 (all products with a * can be delivered to science users via a proposal).

Data level (Abbreviation)	**Description**
Level 0 (L0)	Raw data
Level 1A (L1A)	L0 data with correction and calibration computed and appended
Level 1B (L1B)*	Top of Atmosphere (TOA) radiance [mW/(cm^2 sr um)] Corrected for smile and rolling shutter
Level 1C (L1C)*	Level 1B data ortho-rectified, resampled to a specified grid • *UTM_Zone_of_Scene_Center* • *UTM_Zone_of_Scene_Center(-1)* • *UTM_Zone_of_Scene_Center(+1)* • *Geographic* With interpolation user option • *Nearest_Neighbour*

	• *Bilinear_Interpolation* • *Cubic_Convolution* Note: Global DEM database used for terrain correction Note: Sensor model refinement using global reference image (Landsat-8 PAN with 14 m GSD)
Level 2A (L2A)*	Surface reflectance (i.e. after atmospheric corrections for land) with Ozone Column user option given in Dobson Units and terrain correction Yes/No.

Table 2-2: DESIS data products and availability

Binning

Spectral binning means the summation of adjacent spectral bands (taking into account the spectral response functions). Standard binning is performed in the L1B processor and is denoted as software (SW) Binning.

(Note: Four spectral binnings can be selected with no-binning results in 235 spectral bands at ~2.55 nm spectral resolution (FWHM), 2x binning with 118 spectral bands (~5.10 nm FWHM), 3x binning with 79 spectral bands (~7.65 nm FWHM) and 4x binning with 60 spectral bands (~10.20 nm FWHM)). As the spectral resolution is band-dependent, the given spectral resolutions are average values, and the precise values are provided in the metadata.

3. Description of the call

3.1 Announcement objectives

The main objective of the “DESIS Data Announcement of Opportunity” is to evaluate the scientific capabilities of the DESIS data. It comprises basic and application-oriented research, including development and demonstration of future applications to increase knowledge in science and excludes commercial use. Scientific use of the DESIS data is not restricted to any specific topic but it can include:

- Basic and application oriented research,
- Preparation and execution of government-funded education, research and development programs,
- Development and demonstration of future applications for scientific and/or operational use,
- Support of the DESIS mission (e.g. calibration, monitoring and validation) and
- Exploring synergies with other operating and upcoming Earth observing sensors onboard ISS such as ECOSTRESS, GEDI, OCO-3 and EMIT (all NASA), the hyperspectral HISUI (METI) and future sensor systems integrated into MUSES platform.

This general “DESIS Data Announcement of Opportunity” will be open until the DESIS mission ends. The general constraints of the call and the data ordering procedure are described in the following.

3.2 General constraints

This AO is addressed to users that are interested to use DESIS for scientific purposes only. For any commercial use of the data, please contact TBE directly. DLR may use and distribute or otherwise make available to Third Parties DESIS Image Data for scientific use under the following assumptions (user shall keep themselves updated about changes of license conditions and is referred to the DESIS website):

- For scientific purposes, DLR can share DESIS data with partners and institutions without any restrictions (e.g. nationality) and without any approval by Teledyne Brown Engineering

Based on contractual requirements with TBE, DLR can allow scientific users to task DESIS at least 2.000 minutes per calendar year, divided evenly over each month (i.e., approximately 166 minutes per month). It means that the DESIS instrument is not applicable to map larger areas. Due to this major constraint, DESIS data tasking requires a short proposal that needs to be submitted to DLR DESIS Science Coordination (for details, be referred to section 6). Based on the user proposal, it will be evaluated, if:

- requested amount of data is suits the purpose of the research question,
- it is considered that DESIS is not a mapping mission due to the restriction to 2000 min data takes per year.

However, DLR can’t guarantee exclusive rights of requested and tasked data based on the above mentioned proposals because every registered DESIS science user can access all archived DESIS products in the data archives of DLR (EOWEB GeoPortal). Further, everybody can access data archived at TBE.

4. AO procedure

There are two possibilities to get access to DESIS data: 1) the user can task new data (section 4.1) and 2) the user can select DESIS data from the existing data archive (section 5). For 1), a proposal describing the basic research question is requested. Archived data – option 2) - can be ordered without restrictions.

4.1 New data tasks

Information about the DESIS mission, calibration and validation results, available products, sample data, metadata description, open data AOs as well as needed information and template documents to task DESIS are available via the DESIS website (https://www.dlr.de/eoc/desktopdefault.aspx/tabid-13614/). To task new DESIS data, the following steps have to be done:

a. Prepare a proposal

The proposal must be submitted electronically to DESIS Science Coordination (SC) via email only: desis-scientific@dlr.de. Each submitted proposal will then go through a scientific and technical evaluation. One proposal should be related to one project. The Principal Investigators (PI) may submit several proposals. For each proposal, a maximum quota of 50 acquisitions is allowed. Exceptions shall be discussed with SC directly.

The Principal Investigators may form a consortium that will utilise the DESIS data jointly. For each proposal one PI has to be identified who will act as the interface to the SC of the DESIS mission at DLR. The PI will be informed about the evaluation results by the SC. The number of Co-Is as well as the number of products requested must be reasonable.

The use of DESIS data is regulated via the DLR data license agreement, which must be signed by the PI and all Co-Is. It is understood that proposals require a certain degree of flexibility in terms of data acquisition parameter. Therefore, it will be possible to slightly adjust the data requirements and the test sites after the acceptance of the proposal as long as the proposal's character remains unchanged. Any change requires the agreement by DLR's SC.

The proposal should clearly describe the intended research, it should justify the requested amount of data and it shall emphasize the scientific benefit of the research. In particular the following information should be provided (please use the template provided at the DESIS website):

- General information about the PI and the person authorised to sign the license agreement;
- Proposal Title
- Application domain
- Proposal Type (the AO ID that the proposal shall be assigned to is: General DESIS AO)
- List of all Co-Is and the team organization;
- An executive summary of the research
- Objectives of the research
- General information about the envisaged methodology
- Information about the area of interest

The title, the PI, a list of the Co-Is and the executive summary of accepted proposals might be made available to the public on a dedicated web page. It is assumed that every person listed as Co-I or in the list of authorized people will get access to the DESIS products and that the list is complete. The PI is responsible for keeping both lists up to date during the lifetime of the project.

b. Evaluation of the proposal

Each proposal will be scientifically and technically evaluated by a DLR internal science team. The reviewers will judge the scientific benefit, the data requirements and whether the scientific use criteria are met. The PI shall be informed about the evaluation result within 2 months after submission.

In case of a positive answer, the PI gets a Proposal ID and a predefined EOWEB GeoPortal user name that is needed to get a specific DESIS EOWEB Account (see section 4.1c). All other EOWEB Accounts are not valid to access DESIS data. Additionally, the PI will be registered at the TBE Tasking Tool by SC and will be requested by email to activate the account and to provide a password for login.

In case of a negative answer, the PI will be informed by SC and no further actions from DLR will be done. To get DESIS data, the PI is requested to revise/renew his proposal.

c. Register at the EOWEB GeoPortal for access to DESIS data

The PI is requested to register at the EOWEB GeoPortal by using the predefined DESIS user name and to provide the contact details. This is the **only** entry for PI to access the DESIS data for scientific purposes.

d. Enter TBE Tasking Tool and define your L1A data request

The TBE tasking tool allows the PI to task L1A data only. For data access, processing to higher data levels and for data delivery, the PI needs to enter the EOWEB GeoPortal (see section 4.1e) with the specific DESIS EOWEB Account. First, the user shall get informed about the functionalities of the TBE Tasking Tool at the respective website help and tutorials. Make sure that the data request matches with the information given in the proposal (e.g. Proposal ID!). Each data tasking request requires the confirmation of the SC. Only tasking request with a valid Proposal ID can be confirmed by SC. If information in the proposal deviates from the PIs data request, SC and TBE have the right to cancel the tasking request. TBE informs the PI about the successful data tasking and send the L1A data to the archives of DLR. To access data, to request processing to higher data levels and for data delivery, the PI needs to enter EOWEB GeoPortal using the specific DESIS EOWEB Account.

e. Ordering - Download your data from the EOWEB GeoPortal

Tasked DESIS data will be automatically transferred to the EOWEB GeoPortal archives in L1A format. If the PI wants to get DESIS data processed to higher data levels (L1B, L1C, L2A), the PI can select from several EOWEB GeoPortal order options (e.g. processing parameters) depending on the requested data product level and the rights of the PI. The generally available order options are listed in Table 4-1.

Data Level	Available Order Options
L1B	• No further processing options available except the binning factor between 1 - 4

L1C	• Definition of the map projection (UTM zone)
	• Resampling method:
	  ○ Bilinear Interpolation
	  ○ Nearest Neighbour
	  ○ Cubic Convolution
	• Binning of factor 1 - 4

L2A	• Definition of the map projection (UTM zone)

	• Resampling method:
	  ○ Bilinear Interpolation
	  ○ Nearest Neighbour
	  ○ Cubic Convolution
	• Binning of factor 1 - 4
	• Definition of ozone column value between 200 – 500 (default is 330)
	• Terrain correction:
	  ○ Yes (default)
	  ○ No

Table 4-1: EOWEB GeoPortal Order Options for DESIS L1A Products. Visibility of options depend on the rights of the PI.

If the data have been processed, the PI gets an email notification from DLR with the link to a ftp server directing to the data package for download. The PI is now able to access the tasked and processed DESIS data via the EOWEB GeoPortal.

4.2 Security Regulations

The provision of DESIS data is governed by regulations from NOAA. These regulations might affect the location of the test site, the acquisition time and the persons involved. DLR will be obliged to verify the sensitivity of data requests.

4.3 Role of the Principle Investigator (PI)

The Principle Investigator (PI) shall act as an interface between the proposal consortium and DLR. The PI will be responsible for:

- ensuring the consideration of the security regulations,
- ensuring the validity of the “Scientific Use” criteria for all investigators (including the Co-Is),
- reporting of any changes that might affect the security regulations or the status “Scientific Use” to DLR,
- distributing the DESIS data amongst all persons that shall have access to the DESIS data.

The PI’s activities are considered to cover the total time period of the project approved by DLR based on proposals.

4.4 Cost of the data

DESIS data will be delivered electronically and is free of charge.

5. Access to archived data

Only EOWEB GeoPortal user with a valid DESIS user account are able to browse, order and download DESIS data.

- L1B, L1C, L2A – science user
- L1A, L1B, L1C, L2A – mission internal user

There is no further proposal required for DESIS data in the EOWEB GeoPortal archive.

6. Points of contact

Questions related the proposal submission, evaluation, scientific use etc. should be addressed to the DESIS Science Coordinator:

Email: desis-scientific@dlr.de

Questions related to ordering and order status as well as the provision of product descriptions etc. should be sent to the Orderdesk of DLR-DFD:

Email: dfd-orderdesk@dlr.de