INNOVATIVE
IMAGING & RESEARCH

The DLR Earth Sensing Imaging Spectrometer (DESIS) Instrument On-Orbit Performance and Data Access Through TCloud

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Pecora 21, Baltimore, MD
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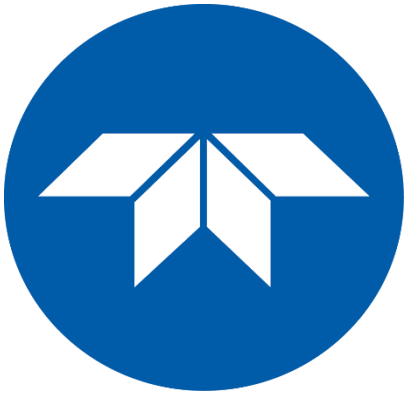
- GeoCue Group



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- Product Overview
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  - Radiometric Accuracy
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- Data Access and Ordering
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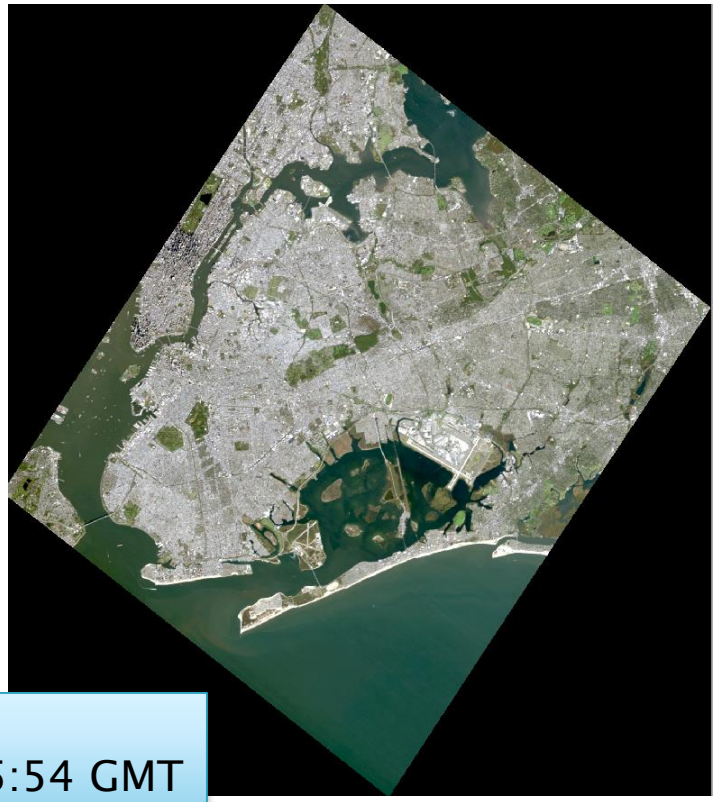
- Summary

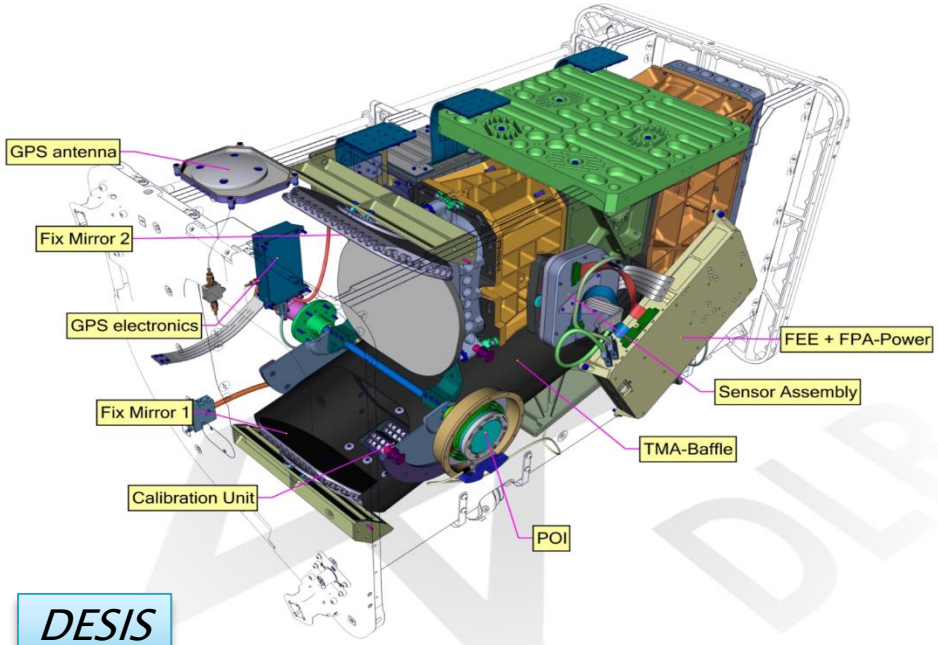


New York, NY
October 30, 2018 @ 15:54 GMT

DESIS Overview

DESIS Overview

- The DLR Earth Sensing Imaging Spectrometer (DESIS) instrument is a spaceborne hyperspectral imager
  - 235 bands with 2.55 nm sampling over the VNIR region
  - 30 m GSD @ 400 km orbit
- Teledyne and DLR partnered to build and operate the first payload for the Multi-User System for Earth Sensing (MUSES) platform on the ISS
  - Teledyne has commercial rights to imagery while DLR retains the rights for scientific use
- I2R providing image quality validation



DESIS

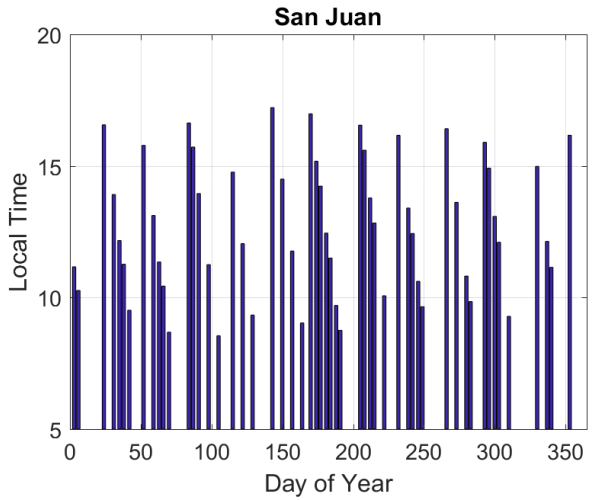
MUSES

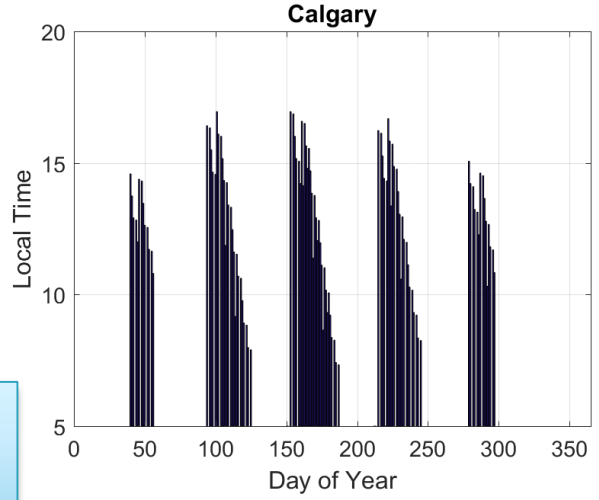
- The Multi-User System for Earth Sensing (MUSES) is a remote sensing platform designed, built, and operated by TBE for integration of facility class payloads on the International Space Station (ISS)
  - Up to 4 attached instruments
  - Payloads installed and removed robotically
- MUSES provides position and attitude, master time and data downlink for the DESIS sensor
  - Also enables cross-track pointing from 5° (outboard) to 45° (inboard)
- DESIS launched June 29, 2018
- Integrated into MUSES on August 27, 2018

DESIS installed on MUSES

ISS Orbit

- The ISS orbit is ~ 400 km altitude, non sun-synchronous
  - 51.6° inclination
  - Acquisition coverage limited to 55° N to 52° S
- Orbit enables acquisitions at different times of day, useful for studying BRDF or diurnal dynamics
- Acquisitions are often grouped, depending on latitude





Predicted DESIS acquisition opportunities for San Juan (~ 20° N) compared to Calgary (~ 50° N)

Data Acquisition

- DESIS is a pushbroom sensor with a 1024 pixel x 235 band focal plane
- Acquires data in a continuous strip
  - Maximum length of a single strip ~ 3000 km
  - Each strip is broken into 1024 x 1024 pixel tiles, equivalent to 30 x 30 km
- Sensor pointing ±15° along track, enables BRDF and stereo acquisitions
  - Combined with MUSES ±25°, gives ±40° along track pointing

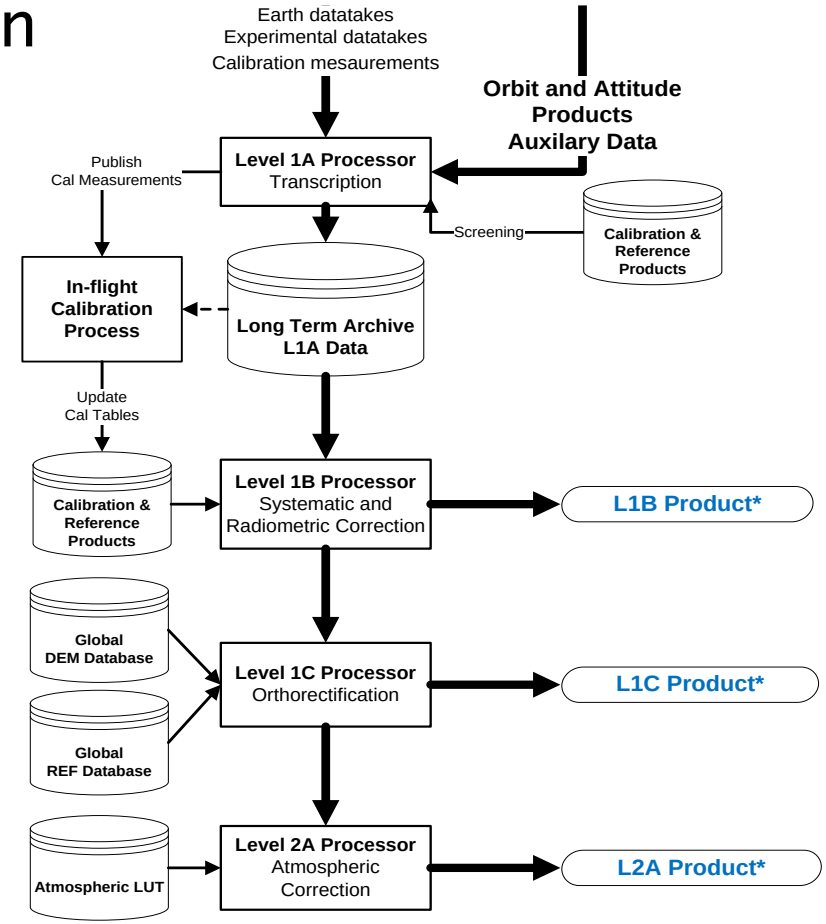
DESIS Specifications

Parameter	DESIS Specification (Commissioning Phase)
Orbit	not Sun-synchronous, 51.6°, 400 ± 5 km, 93 min, no repeat cycle
Coverage	55° N to 52° S
Tilt (across-track, along-track)	-45° to +5°, -40° to +40° by MUSES and DESIS
Sensor Pointing	±15° along-track to enable BRDF or Stereo acquisitions
Spectral coverage	402 nm to 1000 nm (Part of FPA defective at low wavelengths)
Number of spectral channels	235 (no binning); 118 (binning 2); 79 (binning 3); 60 (binning 4)
Spectral Sampling resolution	2.55 nm (w/o binning); ~10.2 nm (binning 4)
Full Width Half Maximum (FWHM)	~3.5 nm (w/o binning); ~10.5 nm (binning 4)
Radiometric resolution	12 bits + 1 bit gain
Radiometric Accuracy	±10% (based on on-ground calibration and with support of inflight radiometric calibration; Expect ±5%)
Radiometric Linearity	99%
Swath	30 km
Spatial resolution, pixels	30 m, 1024 pixels (@400 km)
Geometric accuracy	~20 m with GCPs ~300 m - 400 m w/o GCPs (i.e. water only collects)
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)
Solar zenith angle restrictions (for L2A level processing)	> 55° produces reduced quality L2A product > 65° produces low quality L2A product > 70° not processible to L2A

DESIS Products

Product Overview

- DESIS L1A raw data stored in archive
  - Not an available product
- Several levels of processing available for end-users
  - L1B Radiance
  - L1C Orthorectified Radiance
  - L2A Surface Reflectance
- Processing applied on-the-fly in the online archive when data is ordered



*Delivery product

L1B Radiance

- Top-of-Atmosphere (TOA) Radiance product (L1B)
  - Radiometric corrections applied: non-linearity, dark current, and radiometric conversion
  - Sensor corrections applied: defect pixel, rolling shutter, spectral smile and striping
- Quality information included identifies suspect pixel values

L1B Radiance Image

San Joaquin River Delta, CA
August 14, 2019 @ 17:50 GMT

L1C Orthorectified Radiance

- Orthorectified TOA Radiance product (L1C)
  - Sensor distortion removed
  - On-the-fly image matching using high geometric accuracy reference images to extract ground control points (GCP)
  - When image matching not possible, correction consists of on-board position/attitude, and estimated boresight angles
- Quality information included identifies suspect pixel values

L1C Radiance Image

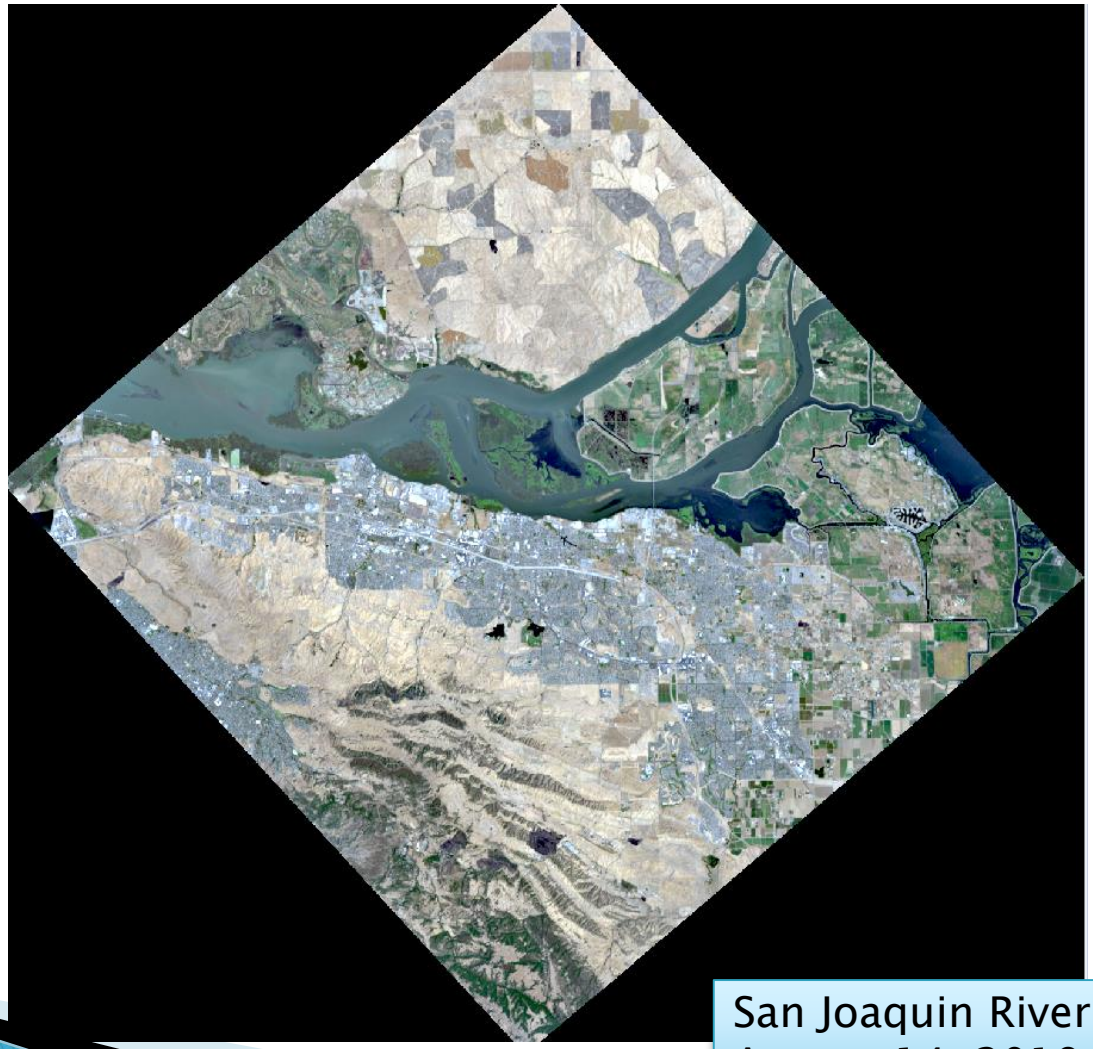
San Joaquin River Delta, CA
August 14, 2019 @ 17:50 GMT

L2A Surface Reflectance

- Atmospherically-corrected Surface Reflectance product (L2A)
  - TOA radiance corrected for atmospheric molecular absorption, scattering, and aerosol effects
    - Radiative transfer look-up-tables generated using MODTRAN
  - Data corrected using either rugged terrain or flat terrain algorithms
- Quality information also includes pixel classification, aerosol optical thickness and water vapor

Product Coming Soon

L2A Reflectance Image



San Joaquin River Delta, CA
August 14, 2019 @ 17:50 GMT

Additional Product Options

- Spectral binning is available for all product levels
  - Four binning levels – x1 (no binning), x2, x3 and x4 – provide data at 2.55 nm, 5.1 nm, 7.65 nm, and 10.2 nm spectral resolutions, respectively
    - Currently, < 10 nm spectral resolution data available only to US government agencies and DLR for German government use only
- Orthorectified L1C Radiance additional processing options
  - Map Projection may be UTM or Geographic
  - Resampling may be Nearest-Neighbor, Bilinear, or Cubic Convolution
- Atmospherically-corrected L2A reflectance additional processing options
  - Terrain Correction either rugged or flat
  - Ozone Column value

On-Orbit Performance

On-orbit Performance

- On-orbit performance is being evaluated by I2R and DLR
  - Radiometric, spatial and geometric
- DESIS is actively acquiring a set of land and water acquisition targets were identified in support of:
  - Calibration
  - Atmospheric Correction
  - Validation
  - Underflights and Coincident Satellites
- Over 100 target sites were identified for acquisition and are available in the online archive

Radiometric Accuracy

- Vicarious calibration of DESIS was performed to determine the radiometric accuracy of the instrument
  - Used spectrally smooth scenes, including CEOS pseudo-invariant calibration sites (PICS), and RadCalNet sites
- Radiometric performance of DESIS was evaluated using several methods
  - Comparison to ground truth
  - Cross-calibration with other satellite sensors
  - Assessment of Signal-to-Noise Ratio (SNR)

Ground Truth Comparison

- DESIS was compared to ground truth values acquired by RadCalNet
  - CEOS Radiometric Calibration Network currently consists of 4 sites
  - Provides quality screened 10-nm resolution surface reflectance and scaled TOA reflectance, as well as atmospheric measurements, on a half-hourly basis
- RadCalNet TOA reflectance acquired closest in time to DESIS acquisition of a site was converted to TOA Radiance

$$L_{TOA} = \frac{\rho_{TOA}\, E_0 \cos(SZA)}{\pi\, d^2}$$

Where, L_{TOA} = TOA radiance

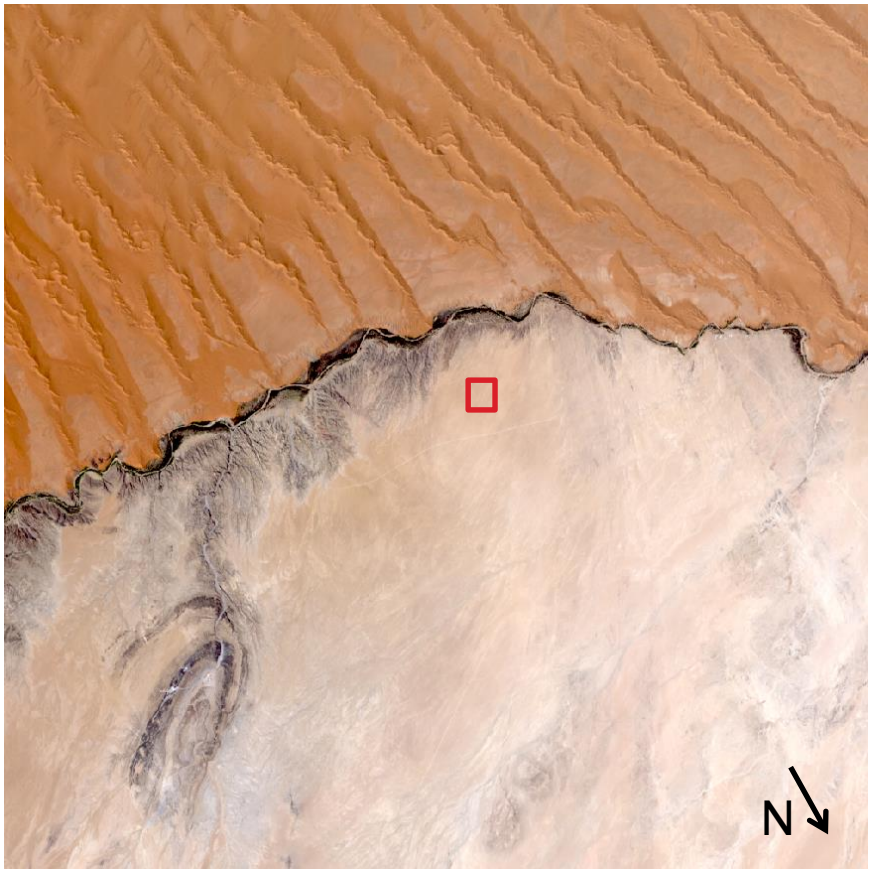
ρ_{TOA} = TOA reflectance

E_0 = Thuillier solar irradiance

SZA = Solar zenith angle

d = Earth-Sun distance in astronomical units

RadCalNet Sites Used



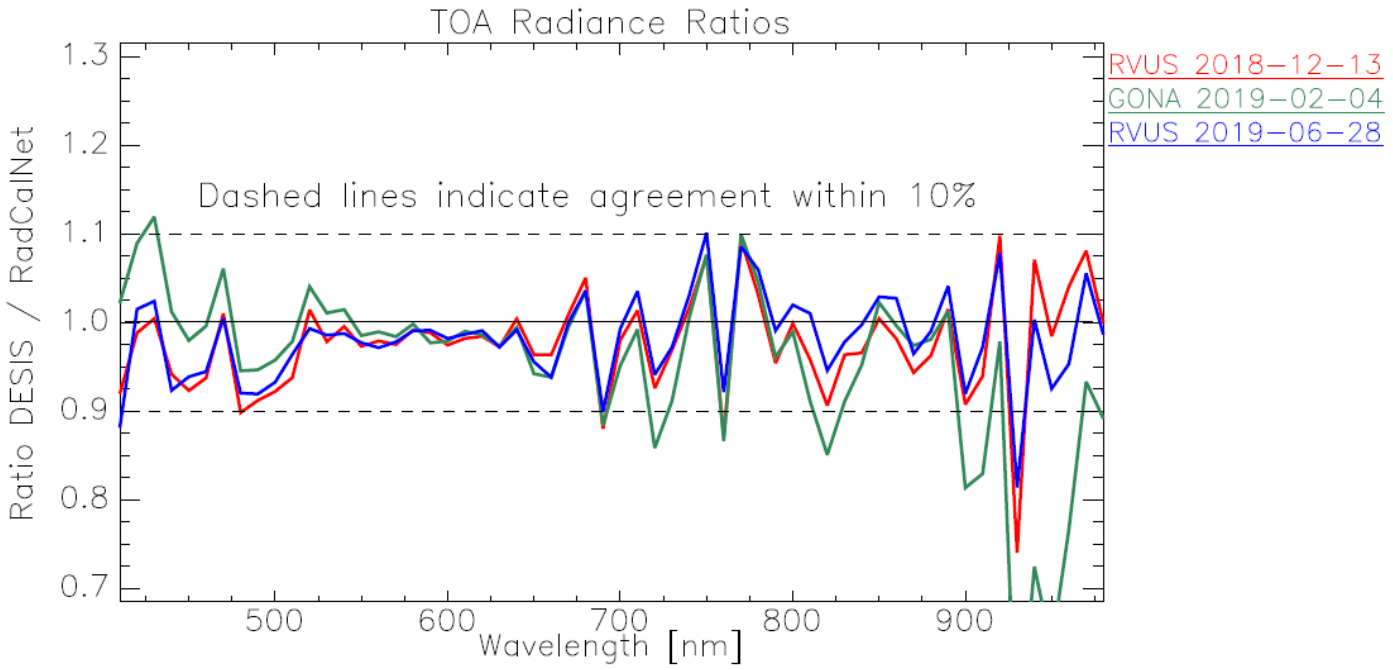
Gobabeb, Namibia
February 4, 2019 @ 8:45 GMT

Railroad Valley, NV
June 28, 2019 @ 18:53 GMT

= approximate area used in analysis

Ground Truth Comparison Results

- DESIS data was compared to three RadCalNet data sets
  - Railroad Valley 12/13/18 and 6/28/19
  - Gobabeb Namibia 2/4/19
- DESIS agrees with RadCalNet within 10%, except for atmospheric absorption features



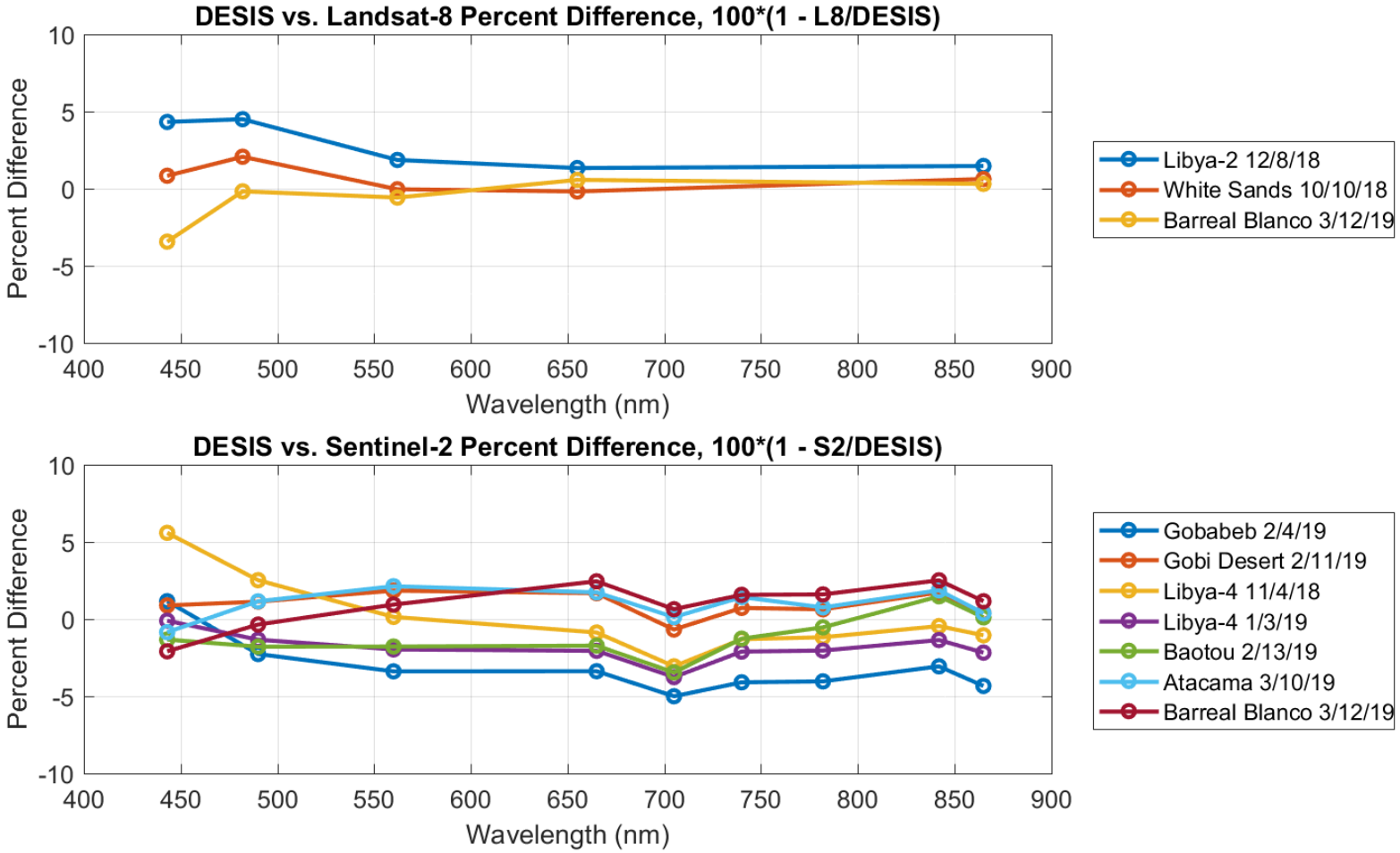
Cross-Calibration

- DESIS compared to other well-calibrated sensors for independent verification of radiometric accuracy
  - Landsat-8 OLI and Sentinel-2 MSI (A & B)
- Near coincident data sets, acquired within one hour and with low view zenith angles over high reflectance pseudo-invariant sites were used
  - 3 Landsat-8 acquisitions and 7 Sentinel-2 acquisitions
- DESIS L1B 2.55 nm radiance used for comparison
  - Data converted to TOA reflectance

$$\rho_{TOA} = \frac{\pi \, L_{TOA} \, d^2}{E_0 \cos(SZA)}$$

- DESIS hyperspectral data band integrated to match multispectral sensor resolution

Cross-Calibration Results



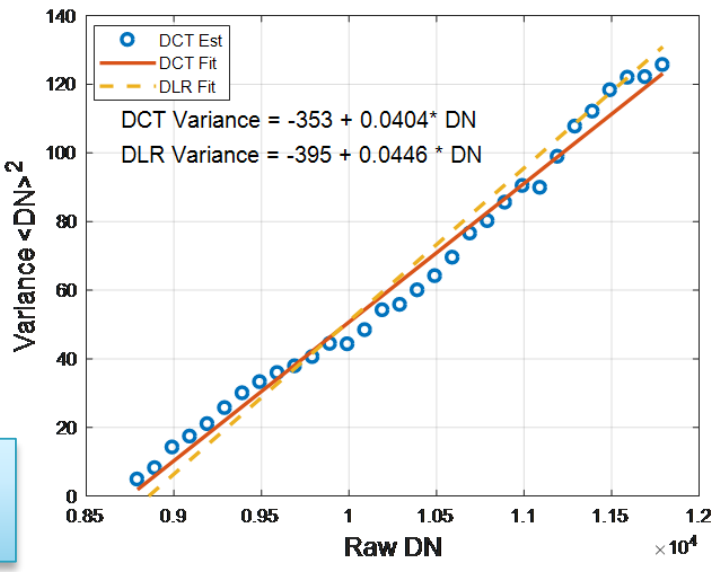
Cross-Calibration Summary

- For similar Landsat-8 and Sentinel-2 bands, percent differences from DESIS for both sensors were combined
- The mean differences between DESIS and the comparison sensors were all $< 1\%$
  - Very little bias in the radiometric accuracy with largest variation in the lower wavelengths

Statistic	Coastal Aerosol (~443 nm)	Blue (~482 nm)	Green (~562 nm)	Red (~655 nm)	NIR (~865 nm)
Mean Percent Difference	0.50	0.54	-0.08	-0.04	-0.31
Standard Deviation	2.77	2.13	1.86	1.92	1.76

Signal-to-Noise Ratio

- The laboratory-generated Photon Transfer Curve was reproduced using in-flight L1A 2.55 nm data
- Future work will validate predicted SNR as a function of radiance
  - Preliminary results: SNR > 200 for green spectral region, 30% albedo, 45 solar elevation angle, mid-latitude summer, 23 km rural aerosol



Photon Transfer Curve Comparison

Spatial Resolution

- Spatial resolution of the DESIS L1B 10.2 nm spectrally binned data was estimated
  - Modulation Transfer Function (MTF)
  - Edge Slope (ES)
- Because of ISS orbit, cardinal oriented targets cannot be used to estimate along-track and cross-track parameters
  - A set of large agricultural fields was identified that create near ideal cross-track edge responses
  - DESIS has been tasked to acquire additional imagery over this and other similar areas
- Initial results show the cross track MTF@Nyquist exceeds 0.3
  - Future work will evaluate along-track spatial resolution, which will likely be slightly lower than the cross-track direction

Geometric Accuracy

- 177 scenes used to assess geolocational accuracy
  - ~ 210 GCP points per scene were used to correct imagery
  - ~ 968 control points per scene were used to assess accuracy
- With image matching technique, linear RMSE was less than 1 pixel
  - 21.0 ± 5.9 m Easting RMSE
  - 21.4 ± 6.0 m Northing RMSE
- Without image matching, errors were found to be 298 m across track and 496 m along track RMSE

Data Access

Data Access

- DESIS L1A raw data is stored in the TCloud online archive (https://teledyne.tcloudhost.com/)
  - The archive is available for searching, but an account is required to order data
  - Catalog searches, product selection, and additional product options are all performed in TCloud
  - Tasks for new acquisitions are also submitted through TCloud
  - Ordered data is delivered via FTP link, or to an Amazon Web Services (AWS) bucket
- NASA-affiliated researchers may acquire DESIS data through the NASA data purchase
  - Contact: yvonne.ivey@nasa.gov
- Non-NASA researchers should contact: Amanda.O'Connor@Teledyne.com

DESIS Acquisition Map

DESIS acquisitions over North and Central America and the Pacific Ocean, as of September 16, 2019

Current Sensor Status

- DESIS has been acquiring data since October 2018
  - 2058 DESIS scans acquired
  - 11,170 DESIS tiles acquired
  - **>10 million km²** available in the catalog for ordering
- DESIS achieved full operational capability as of August 2019

Summary

- DESIS is the highest spectral resolution spaceborne imager, with high SNR, useful for applications including:
  - Coastal and inland water studies
  - Cryosphere characterization
  - Vegetation assessments
  - Soil sciences and raw materials
- Full resolution and binned TOA radiance data currently available
  - Surface reflectance coming soon
- Visit https://teledyne.tcloudhost.com/ to review the catalog of DESIS acquisitions