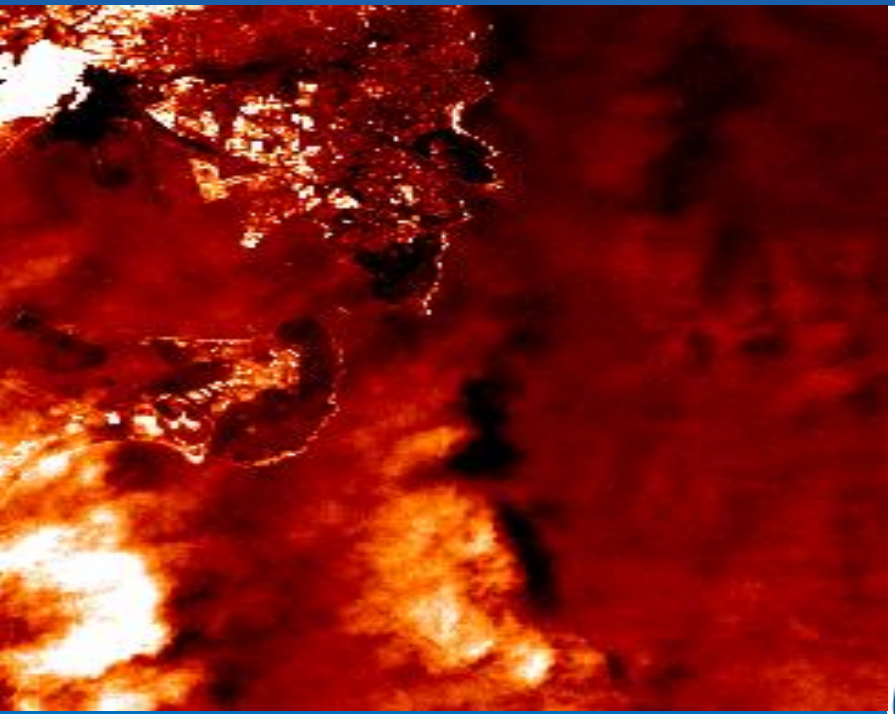
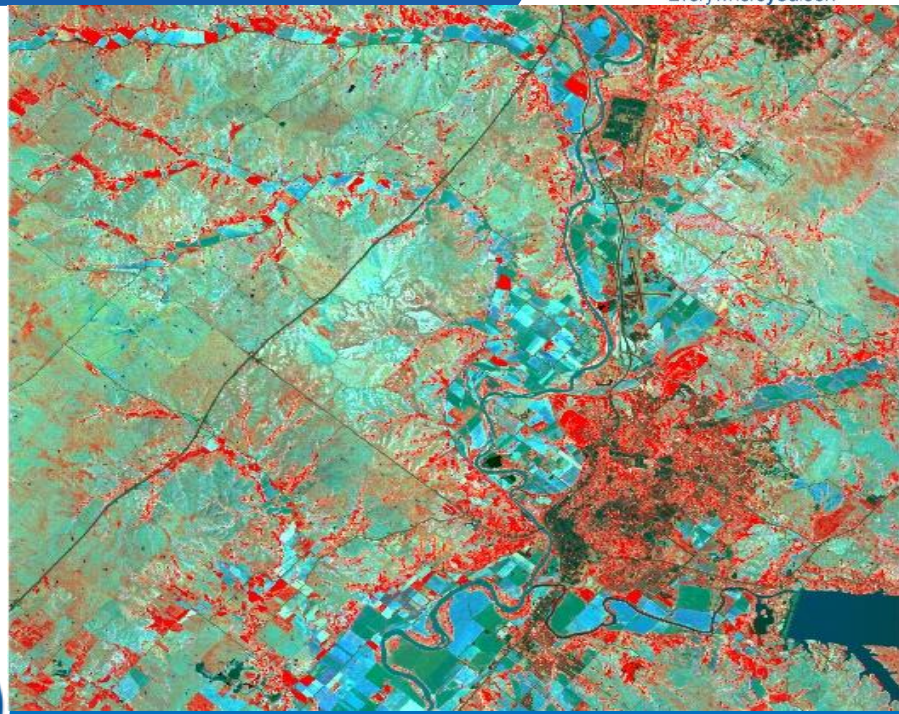




Introduction to TCloud and DESIS Data
March 4, 2021

Outline

1. Introduction of the DESIS Team
2. Brief Overview of MUSES and DESIS
3. TCloud Overview and Demonstration
4. Tasking Order Best Practices
5. DESIS Data Products
6. Review of Delivered Data
7. On-Orbit Performance
8. Brief Introduction to Data Processing
9. DESIS Data Access

DESIS Team

- **Jack Ickes**
  Teledyne Brown Engineering
  Senior Vice President, Geospatial Solutions
  Program Manager

- **Yvonne Ivey-Parker**
  Booz Allen Hamilton
  NASA Earth Science Data System Program
  POC for DESIS Data Access

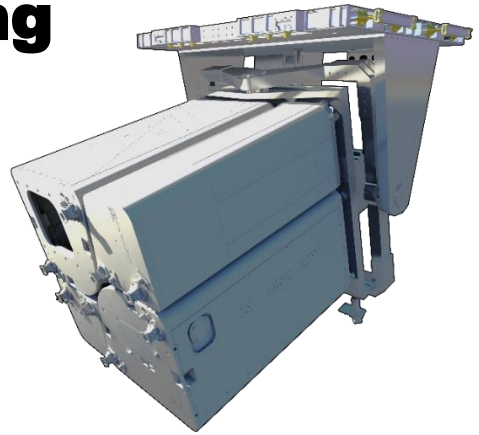
- **Kara Burch**
  Innovative Imaging and Research (I2R)
  Senior Scientist
  Technical POC for Image Quality & Instrument Performance

- **Heath Lester**
  Teledyne Brown Engineering
  Operations Manager
  Acquisition Coordinator

MUSES and DESIS Overview

TELEDYNE BROWN ENGINEERING Everywhereyoulook™

Multi-User System for Earth Sensing (MUSES)



- **Precision pointing platform, designed in cooperation with NASA, for low-cost earth observation from the International Space Station (ISS).**
- **Comprised of Platform (ISS external) and Server (ISS internal)**
- **Up to 4 robotically installed instruments.**
  - Payload can be removed and returned to earth for analysis or reuse.
- **Total data downlink ~225 GB/day.**
  - Onboard processing option.
- **< 12 Months: Contract to Launch.**
  - ~ 1/3 the cost of a free-flyer mission.

Characteristic	MUSES Performance Target
Field of Regard	Outboard Cross-Track: 5°
	Inboard Cross-Track: 45°
	Along-Track: +/- 25°
Thermal Control	Passive
Star Tracker	Sodern SED26
Inertial Measurement Unit	Honeywell Miniature Inertial Measurement Unit (MIMU)
Precision Time	Sourced from the ISS GPS, ≤ ± 250 µsec to MUSES instruments
Pointing Accuracy	≤ ± 60 arc seconds
Pointing Knowledge	≤ ± 30 arc seconds (~ 60 m on ground from 400 km altitude)
Location knowledge	Sourced from the ISS GPS, ± 50 meters, RMS
Orbit	51.6° Inclination, 400 km altitude ± 5% (nominal)
Data Processing	Linux Server on-board ISS with redundant 6 TB storage
Daily Downlink Capacity	225 GB

Earth Observation From the ISS – Why It Works/Challenges

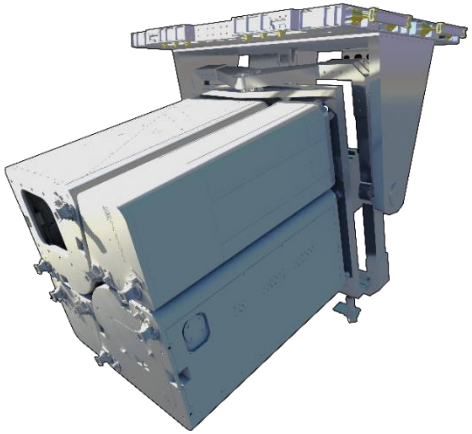
Benefits

- Coverage of ~90% of populated Earth.
- Coverage of tropics, frequent revisit times off-noon allow for reduced-cloud image acquisition.
- Orbit enables acquisitions at different times of day, useful for BRDF or diurnal dynamics.
- Upgrade, repair and exchange of instruments as technology and/or markets evolution.
- Traditional barriers to entry are minimized.

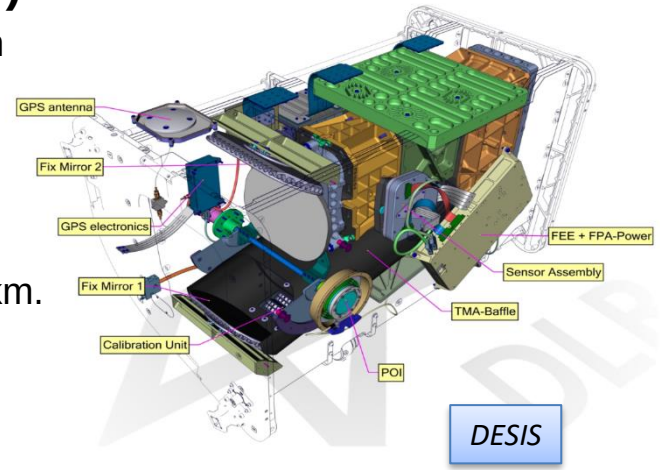
Challenges

- Above 55^{o} N and below 52^{o} S not covered in orbit.
- Revisit time has a beat frequency that depends on latitude.

DESIS Overview



- **Cooperative effort between the German Aerospace Center (DLR) and Teledyne Brown Engineering (TBE)**
  - MUSES first payload – Launched in June 2018.
  - Teledyne has commercial rights to imagery while DLR retains the rights for scientific use.
- **DLR Earth Sensing Imaging Spectrometer (DESIS)**
  - 235 bands with 2.55 nm sampling over the VNIR spectral region (400-1000 nm).
  - 30 m GSD @ ISS 400 km orbit.
  - Sensor pointing ±15° along track, enables BRDF and stereo acquisitions.
  - Push Broom Sensor: Maximum length of a single strip ~ 3000 km.
  - Each strip is broken into 1024 x 1024 pixel tiles, or 30 x 30 km.



TELEDYNE BROWN ENGINEERING Everywhereyoulook™

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

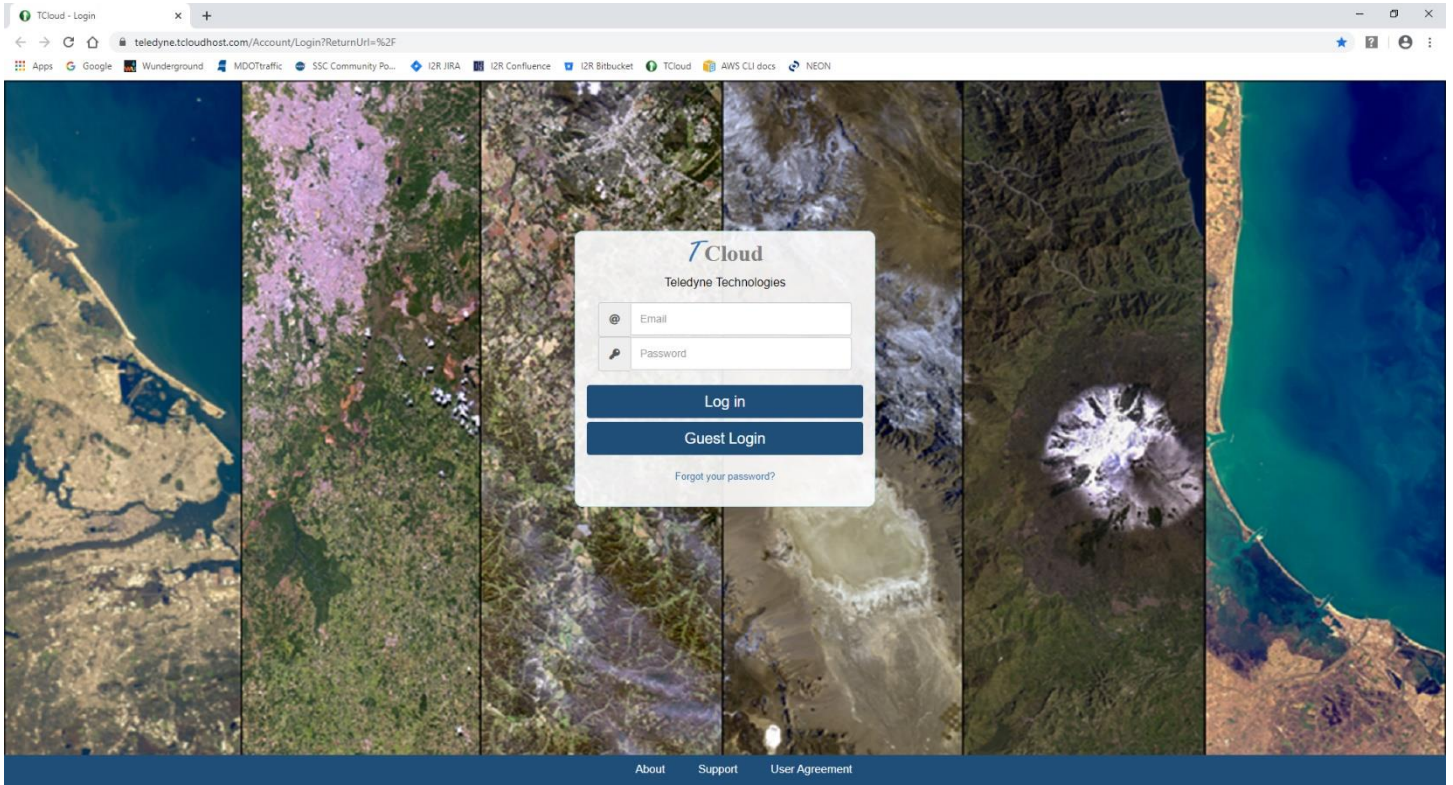
TCloud
Overview and Demonstration

TCloud Overview

- **TCloud is a Teledyne Brown Engineering – Geospatial Solutions cloud-based data management and distribution system for geospatial imagery.**
  - Front end – user interface
  - Back end – data processing
- **Allows approved users to submit DESIS sensor tasking requests and/or order archived DESIS data and retrieve the requested data.**
- **Allows for post-processing of the data in multiple ways.**

TCloud Demonstration

TCloud Website: https:\\teledyne.tcloudhost.com



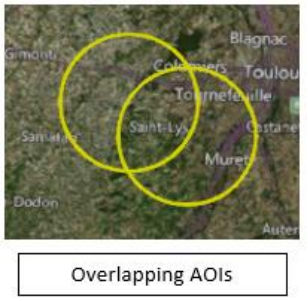
Tasking Order Best Practices

Tasking Order Best Practices

- **Tasking Order Timeframe**
  - Use the longest acceptable collection timeframe for orders.
    - Overpass opportunities are cyclical in nature based on the ISS orbit and can vary based on location/time of year.
    - Additionally, cloud cover for certain areas makes collection within a short timeframe more challenging.
    - Longer collection windows allow for the greatest possibility to successfully complete the order.
    - Short duration windows are still possible if the tasking submission shows ‘feasible’, but this does not account for unacceptable cloud cover or ISS dynamic events that can occur on occasion that impact collections.

Tasking Order Best Practices

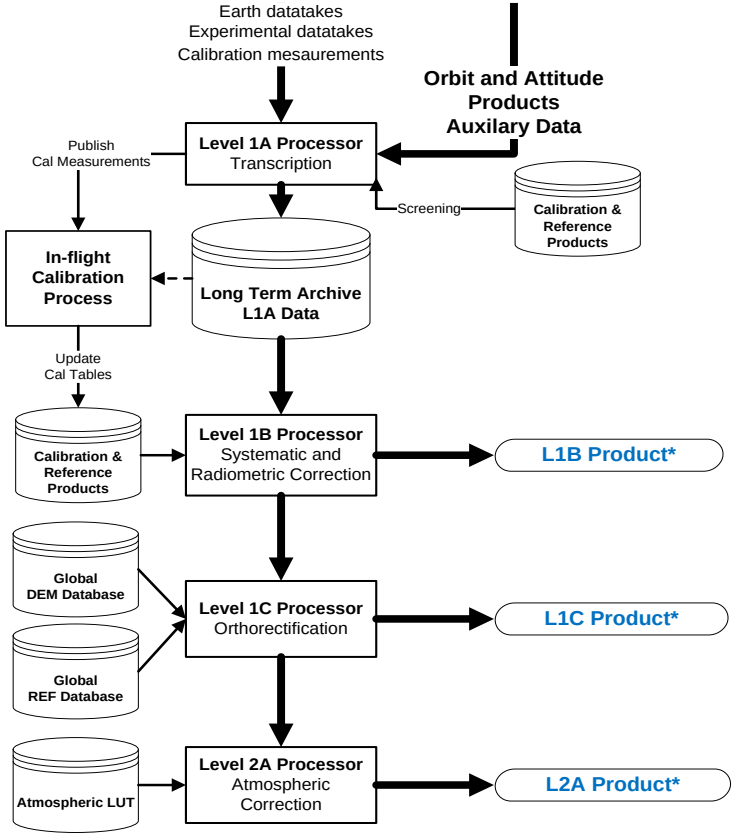
- **Area Of Interest (AOI) Size/Location**
  - If smaller Area Of Interests (AOIs) are relatively close together or even overlap sometimes it is best to submit as one order.
  - Good rule of thumb – If AOI borders are within 30 km (one tile width) of each other consider one order.
  - Dependent on user's preference for potential extra data which in the rule of thumb above would not be significant.



DESIS
Data 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

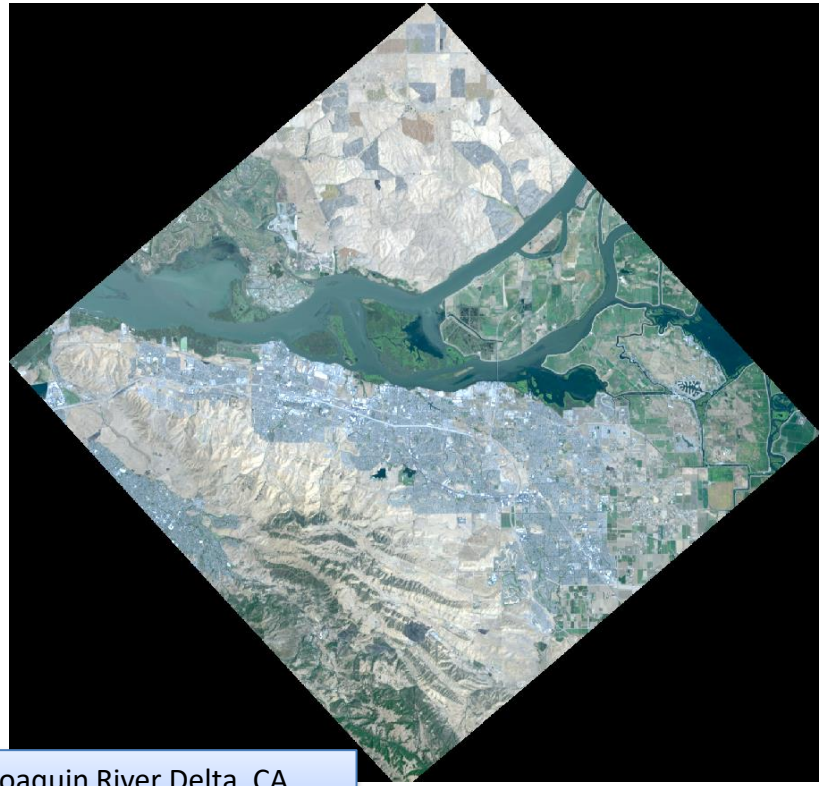
L1B Radiance

- **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.**

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

L1C Orthorectified Radiance

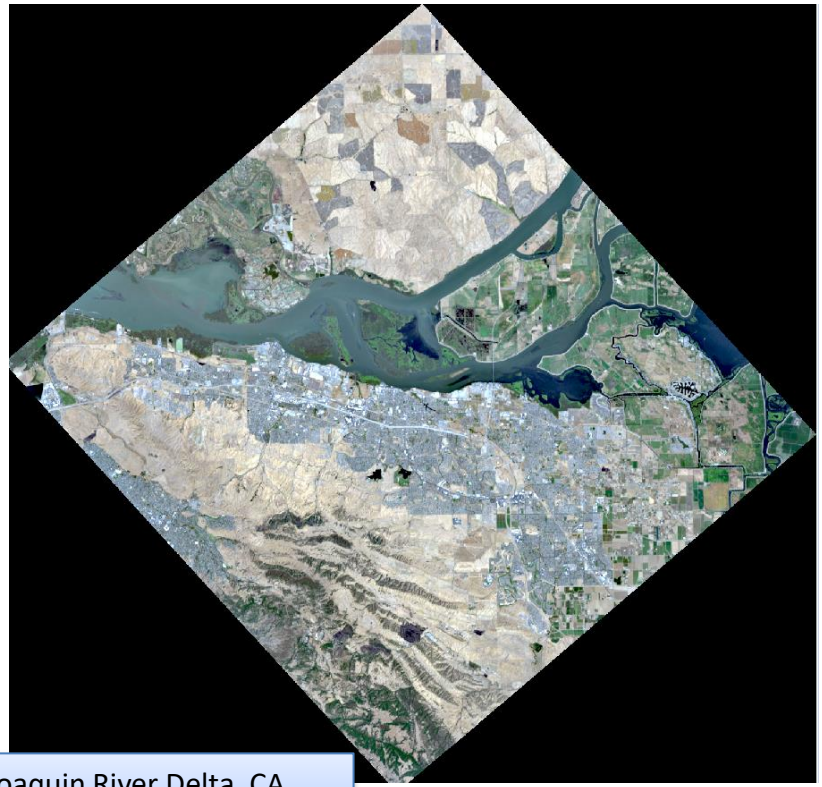
- **Orthorectified TOA Radiance product (L1C)**
  - Sensor distortion removed.
  - On-the-fly image matching using high geometric accuracy reference images to extract ground control points (GCP).
  - When image matching not possible, correction consists of on-board position/attitude, and estimated boresight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



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.**



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

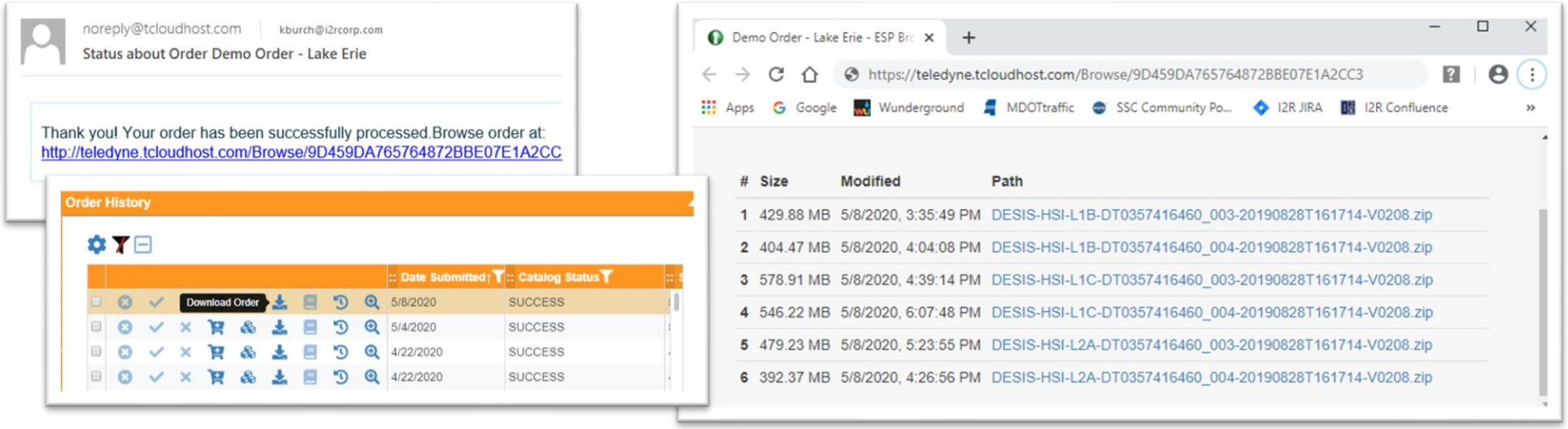
Additional Product Options

- **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.
- **Orthorectified L1C and L2A 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.

DESIS
Data Delivery

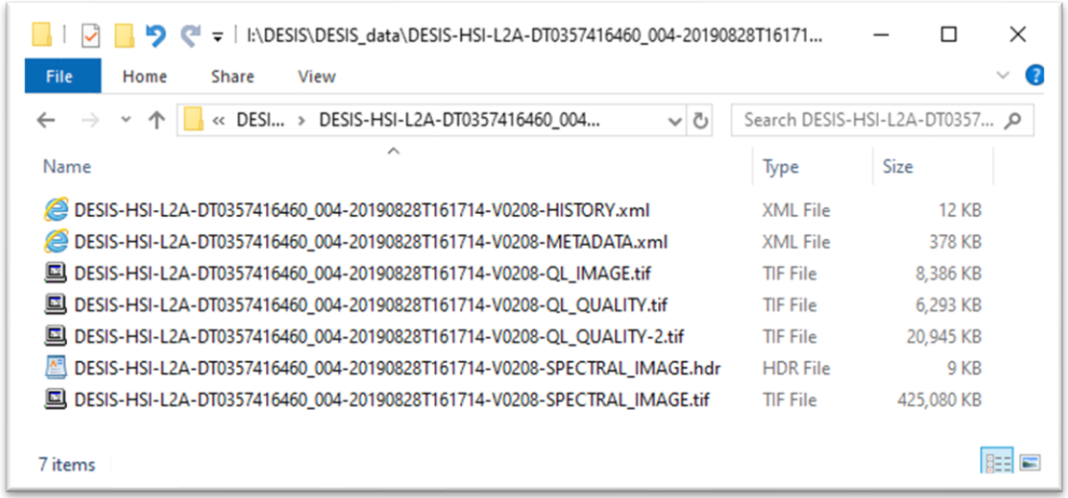
Order Download

- **DESIS data ordered from TCloud is delivered either via user download from the TCloud repository or to an AWS S3 bucket**
  - Each requested product/tile is provided as a separate zip file
  - Users are sent an email when ordered data is available for download
  - Users may also download directly from their order history



DESIS Delivered Files

- **Each delivered zip file contains:**
  - QuickLook Image
  - Metadata File
  - Quality Image
  - Ancillary Files
  - Hyperspectral Image
- **Expected zip file data volumes:**
  - Full spectral resolution data
    - 400 – 600 MB
  - Binned x 4 (10.2 nm)
    - 100 – 200 MB



File Naming Convention

DESIS-HSI-L<XX>-DT<nnnnnnnnnn>_<fff>-<yyyymmdd>T<hhmmss>-V<vvvv>-<file type>.<ext>

Where, <XX> is the product level (1B, 1C or 2A)
<nnnnnnnnnn> is a unique identifier from the planning system
<fff> is the tile number of the image strip
<yyyymmdd> is the date in year, month, day format
<hhmmss> is the time in UTC (hour, minute, second)
<vvvv> is the image processor version number
<file type> is the type of file (SPECTRAL_IMAGE, QL_QUALITY, QL_IMAGE, or METADATA)
<ext> is the file extension (tif, xml, or hdr)

QuickLook Image

- **Each delivered tile includes a QuickLook image tif file (*QL_Image.tif)**
  - 3-band (~500 nm, 650 nm and 850nm) 8-bit image
- **Viewable using standard and image processing software**
  - Windows Photo Viewer
  - ENVI
  - Imagine
  - MATLAB

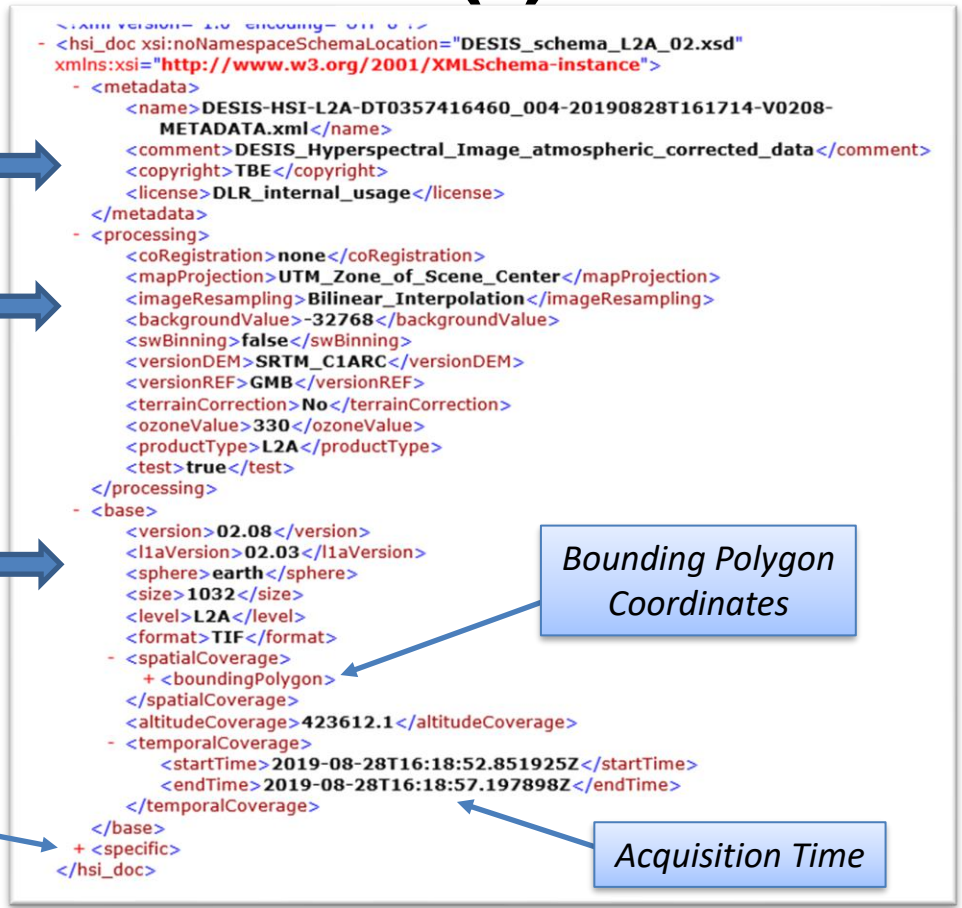
Lake Erie/Toledo OH, August 28, 2019
L2A Surface Reflectance QuickLook Image

Metadata File

- **Metadata includes information about the sensor, acquisition and processing in xml format (*METADATA.xml)**
  - Image corner coordinates, acquisition times and sun and sensor geometry at the time of acquisition are provided
  - Center wavelengths, spectral band information, and scale factors (gains and offsets) are provided for each band
  - Information relating to the image orthorectification is also included for L1C and higher products
- **Text file viewable using web browser (e.g. Internet Explorer) or text editor (e.g. WordPad or Notepad)**
- **Metadata fields described in Section 5.1 of DESIS Product Specifications: https://tbe.com/__documents/PDFs/DESIS_Specifications.pdf**

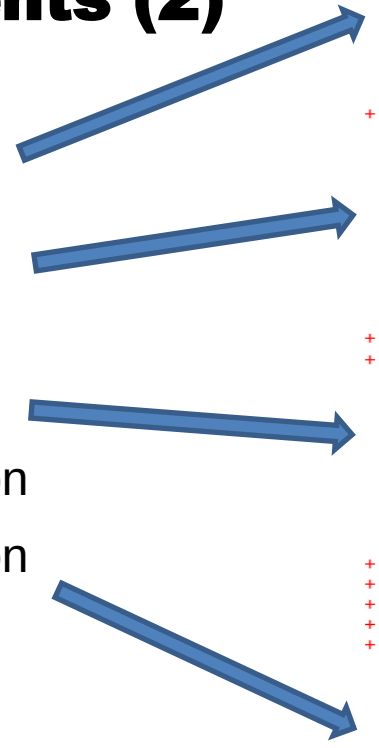
Metadata File Contents (1)

- **Metadata file contents**
  - File information
  - Processing parameters (product type, resampling, map projection)
  - Base parameters (location, time, processing level)



Metadata File Contents (2)

- **Specific Parameters**
  - Sensor information
  - Orbit and processing information
  - Product dependent processing information
  - Acquisition information (sun and sensor geometry)



```
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    <datatakeID>0357416460</datatakeID>
    <imageID>0357416460004</imageID>
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  + <waterVapour>
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    <qualitySZA>normal</qualitySZA>
  + <qualityIndicator>
</specific>
```

Spectral Band Information (next slide)

Metadata File Contents (3)

- **Band Characteristics provided for each spectral band**
  - Center wavelength (nm)
  - Band FWHM (nm)
  - Band spectral response and corresponding wavelengths
  - Gain and Offset
    - For conversion to radiance or reflectance
  - % dead or suspicious pixels

```
- <band>
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    <wavelengthWidthOfBand>3.6</wavelengthWidthOfBand>
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    <suspiciousPixel>0.0</suspiciousPixel>
  </band>
- <band>
    <bandNumber>11</bandNumber>
```
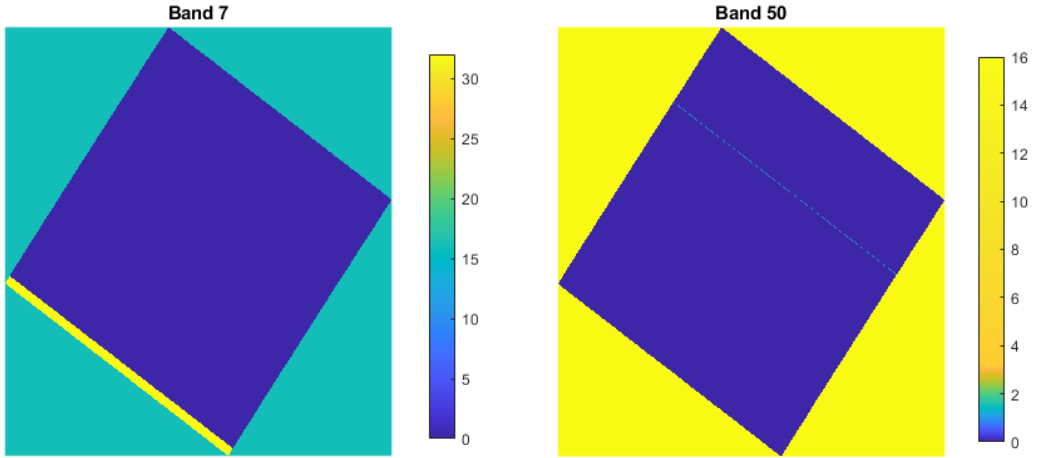

Quality File

- **Quality file provides location of defect or suspect pixels, and identifies the quality issue (*QL_QUALITY.tif)**
  - 8-bit tif with same number of bands as hyperspectral image
  - Each bit provides a flag for possible image quality issues
    - Pixel with quality issue (and surrounding pixels) have appropriate bit set to 1

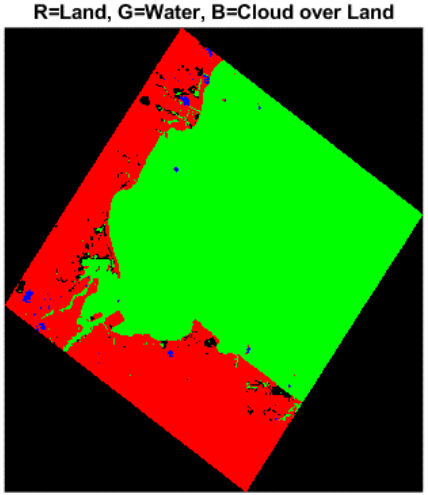
Bit Value	Quality Flag
7	Not Used
6	Unreliable Calibration
5	Manufacturing Defect
4	No Data
3	Low Radiance Value
2	High Radiance Value
1	Suspicious
0	Dead

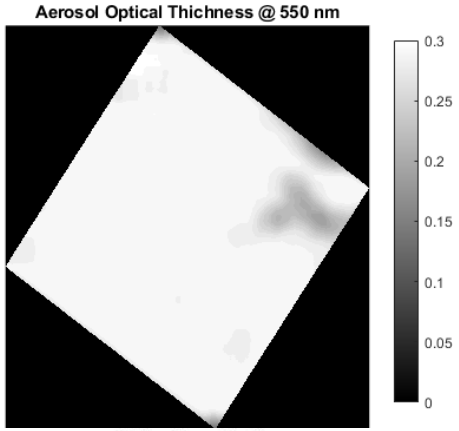


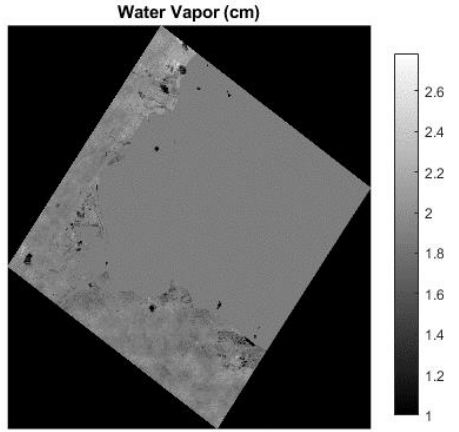
L2A Quality-2 File

- **L2A surface reflectance products are delivered with an additional quality file in a 10-band 8-bit tif (*QL_QUALITY-2.tif)**
  - Per pixel classification with 8 mask layers (0=false, 1=true)
  - Aerosol optical depth at 550 nm (layer 9, scaled by 100)
  - Water vapor in cm (layer 10, scaled by 42)

Layer	Pixel Classification
1	Shadow
2	Clear Land
3	Snow
4	Haze over land
5	Haze over water
6	Cloud over land
7	Cloud over water
8	Water





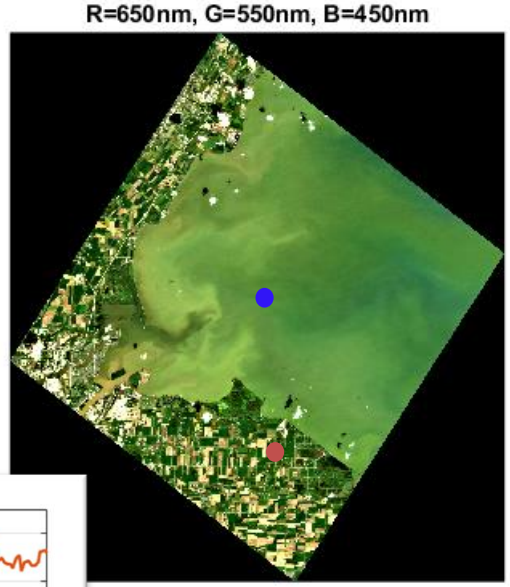


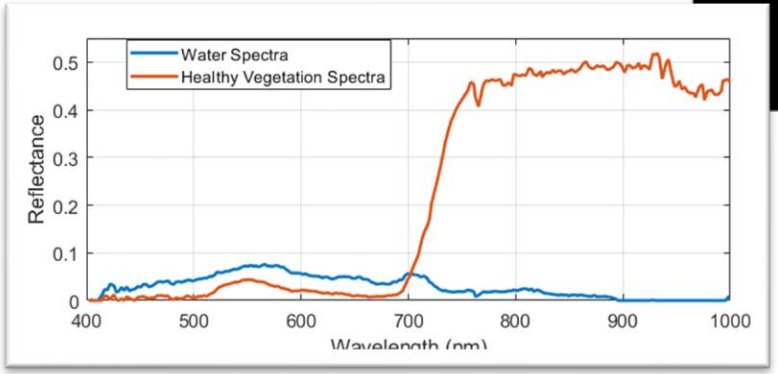
Ancillary Files

- **ENVI format header file (*.hdr)**
  - Includes projection information for rectified image display
  - Includes per band center wavelengths and scale factors required to convert data to radiance or reflectance
- **Product history file (*HISTORY.xml)**
  - Contains information about the executed processing steps and the algorithms and files used to produce the data product

Hyperspectral Image

- **Spectral image file contains the hyperspectral data (*SPECTRAL_IMAGE.tif)**
  - 16-bit tif with a separate image layer per hyperspectral band
  - Scaled DN
- **Requires image processing software or specialized reader to view**
  - ENVI
  - Imagine
  - MATLAB/Python





DESIS
On-Orbit Performance, Calibration and Validation

On-Orbit Performance

- **On-Orbit performance is continually being evaluated by I2R and DLR.**
  - Radiometric, geometric and spatial
- **Detailed description of original validation (2019):**

Alonso, K., Bachmann, M., Burch, K., Carmona, E., Cerra, D., de los Reyes, R., Dietrich, D., Heiden, U., Hölderlin, A., Ickes, J., Knodt, U., Krutz, D., Lester, H., Müller, R., Pagnutti, M., Reinartz, P., Richter, R., Ryan, R., Sebastian, I., Tegler, M., **Data Products, Quality and Validation of the DLR Earth Sensing Imaging Spectrometer (DESIS)**. Sensors 2019, 19, 4471.

- **Updated validation results (2020)**

Heiden, U., Alonso, K., Bachmann, M., Burch, K., Carmona, E., Cerra, D., de los Reyes, R., Dietrich, D., Knodt, U., Krutz, D., Mueller, R., Pagnutti, M., Richter, R., Ryan, R., Sebastian, I., Tegler, M., **Data Validation of the DLR Earth Sensing Imaging Spectrometer DESIS.** IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium, Waikoloa, HI, USA, 2020, pp. 3274-3277, doi: 10.1109/IGARSS39084.2020.9323367.

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.
- **DLR updated the DESIS radiometric calibration tables in May 2020 (processor v2.10) based on ongoing validation efforts.**
- **DLR is currently developing an acquisition-date dependent calibration update which will be released soon**

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

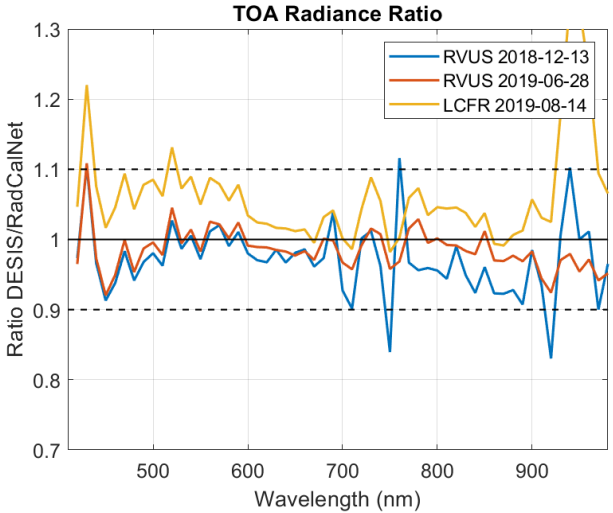
E_0 = Thuillier solar irradiance

SZA = Solar zenith angle

d = Earth-Sun distance in astronomical units

Ground Truth Comparison Results

- **DESIS data was compared to three RadCalNet data sets.**
  - Railroad Valley 12/13/18 and 6/28/19
  - La Crau, France 8/14/19
- **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.**

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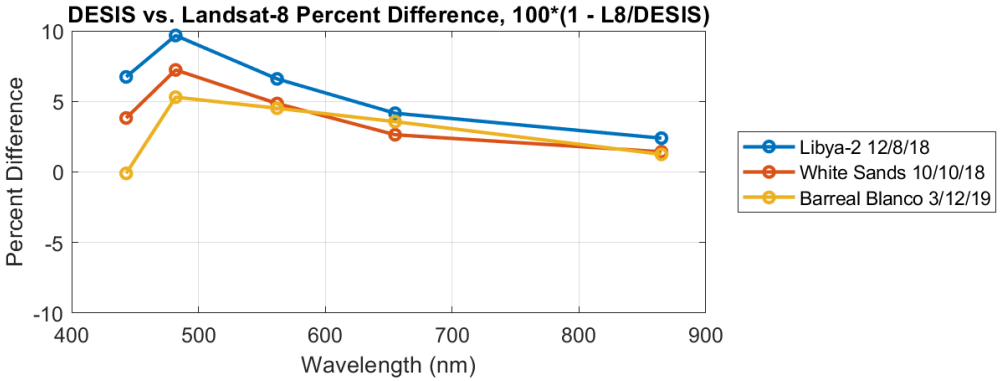
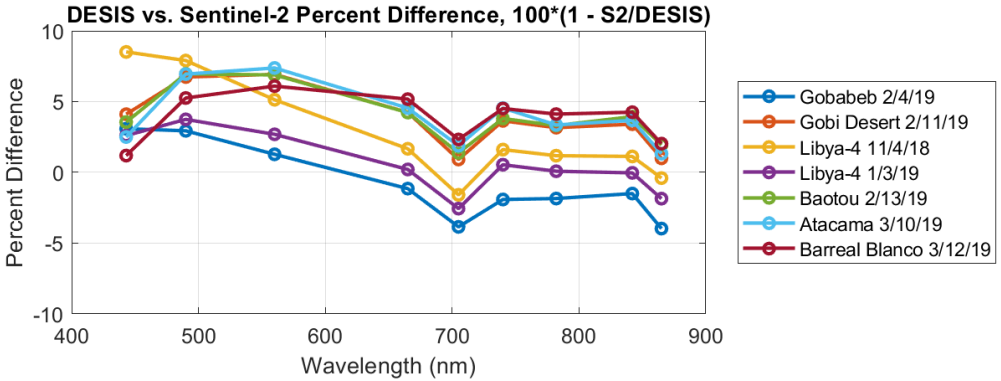
Cross-Calibration Results





Geometric Accuracy and Spatial Resolution

- **177 scenes used to assess geolocational 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.
- **Spatial resolution of the DESIS L1B 10.2 nm spectrally binned data was estimated.**
  - Modulation Transfer Function (MTF) and Edge Slope measured
  - Limited targets available for assessment due to the ISS orbit
  - Initial results show the cross track MTF@Nyquist exceeds 0.3.

DESIS
Data Processing Introduction

Image Processing Software

- **Specialized software is required to import, visualize and generate products from scientific image data.**
  - Software enables full exploitation of geometric and spectral properties of remotely sensed data.
- **Software specifically designed for image processing**
  - ENVI (L3 Harris) developed for hyperspectral imagery analysis
  - ERDAS Imagine
- **Programming software with significant image processing capability**
  - MATLAB (MathWorks)
  - Python (open source)

Converting to Radiance/Reflectance

- **Hyperspectral imagery provided in int16 scaled DN format.**
  - Gains and offsets provided in the .xml metadata for each spectral band convert the data to radiance (L1B, L1C) or reflectance (L2A).
    - Radiance units mW cm^{-2} sr^{-1} μm^{-1}
- **The .hdr file included with each DESIS image also contains the gains and offsets and can be used to convert the data in ENVI.**
  - Use the Apply Gains and Offsets function in the Toolboxes.

$$L_{i,j,B} = G_B * DN_{i,j,B} + O_B$$

Where, $L_{i,j,B}$ = Radiance (or reflectance) for pixel i,j per band, B
G_B = Gain per band, B
$DN_{i,j,B}$ = DN for pixel i,j per band, B
O_B = Offset per band, B

DESIS
Data Access and Resources

How to Access DESIS Data

- DESIS data is open for all NASA and US Government funded researchers with no allocation. If you're interested in accessing or tasking please fill out the form at the link here. This will provide the CSDA Data Management team with the information necessary to process your request.

- Note that there are designated fields required to be provided in order to submit the form.

- Once you confirm, you should have received an email from Teledyne Explorer to create an account in their Earth Sensor Portal.

- If you have any questions, please reach to Yvonne Ivey-Parker <yvonne.ivey@nasa.gov> or check out our Commercial Small Satellite Acquisition Program website for updates.

Resources

- **TCloud may be accessed at https://teledyne.tcloudhost.com**
- **Additional information about DESIS imagery, files and processing algorithms can be found at https://tbe.com/geospatial/desis**
- **Contacts information**
  - TCloud access: Yvonne Ivey-Parker at Yvonne.Ivey@nasa.gov
  - TCloud operation or data ordering questions: Heath Lester at Heath.Lester@Teledyne.com
  - DESIS technical or calibration questions: Kara Burch at kburch@i2rcorp.com

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