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# BENEFITS AND APPLICATIONS OF HYPERSPECTRAL IMAGERY FROM THE SPACE STATION

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# Presenters

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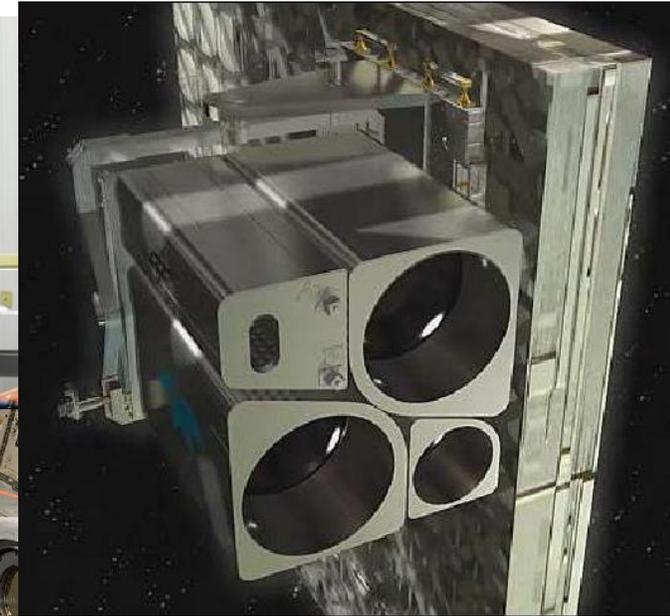
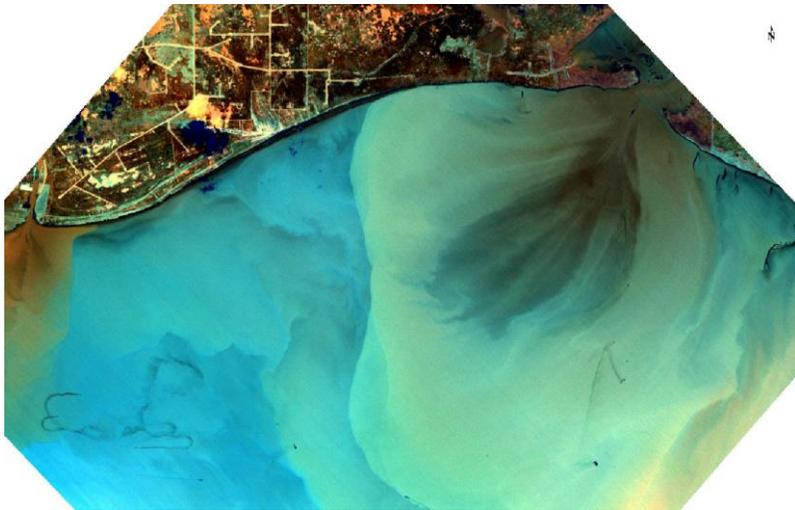


**Megan Gallagher**  
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# Agenda



- The value of hyperspectral imagery
- DESIS-30 specs, collecting on the ISS
- Case Studies with ENVI analytics
- DESIS Access
- Q & A





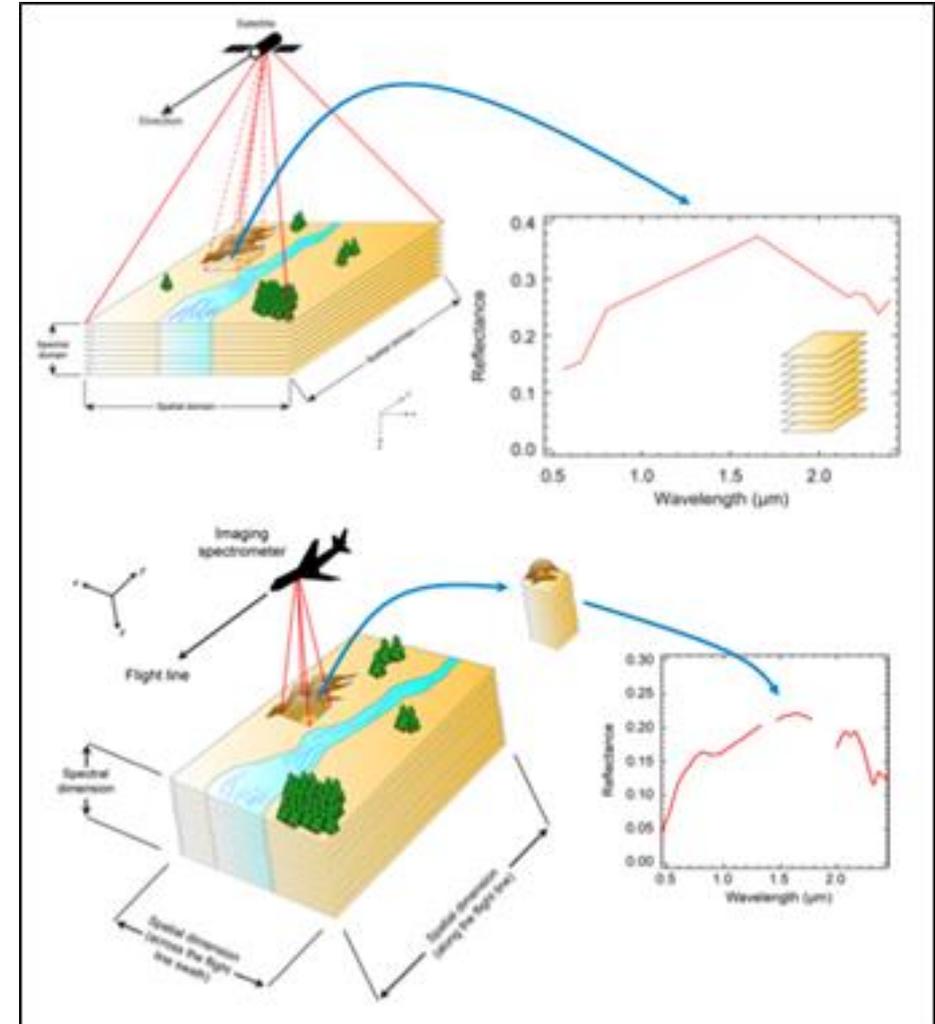
Have you used hyperspectral imagery before?

- Yes
- No

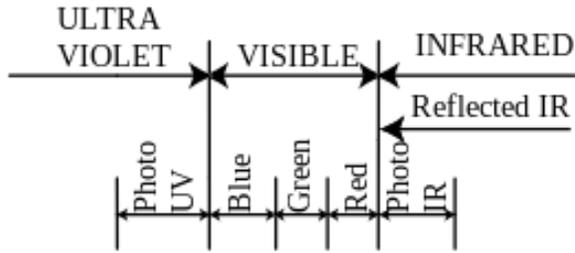
# Hyperspectral Background



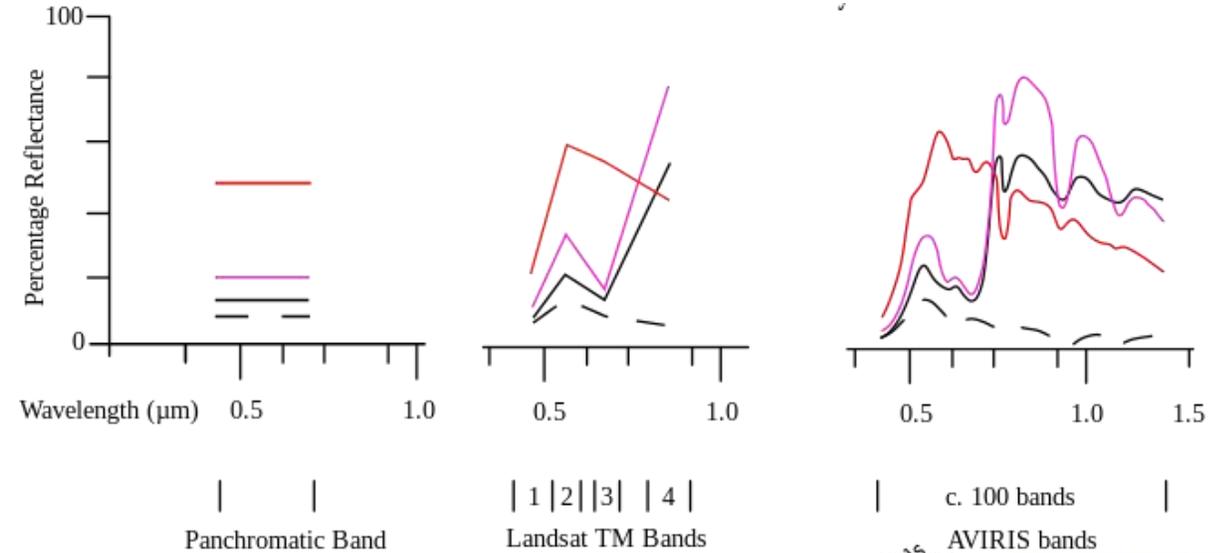
- Capability around for many years, but compute power struggled with large size of data
- That has been overcome and onboard processing is a reality
- Hyperspectral imagery (HSI) usually has at least 30 bands, as compared to multispectral
- Where as multispectral imagery, like a Landsat image, can give you a class like iron bearing minerals, HSI can give the exact type of mineral
- Think of it like a zoom button, multispectral is viewing a very blurred scene, where you can maybe pick out specific objects, with hyperspectral as the zoomed version, where you can much more easily discern what is in the image.



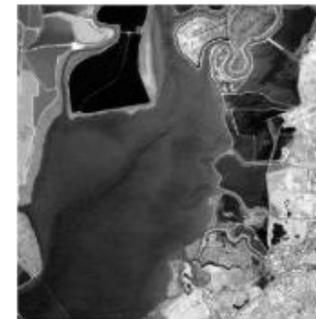
# Hyperspectral Overview



- Pinewood
- Grassland
- Red Sand Pit
- Silty Water



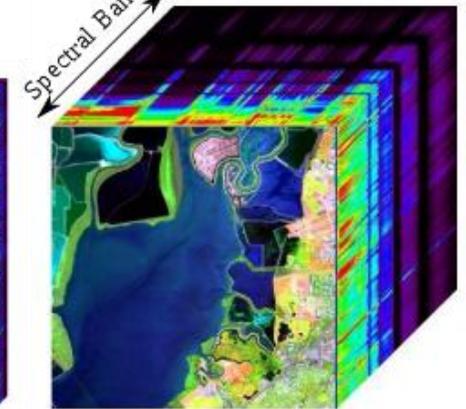
- A panchromatic band usually has higher resolution for less unique wavelength information
- Multispectral usually has lower resolution than pan, but more wavelength information
- Hyperspectral has a great amount of unique spectral information, and used to have lower resolution or much more expensive sensors



Single band



Multispectral

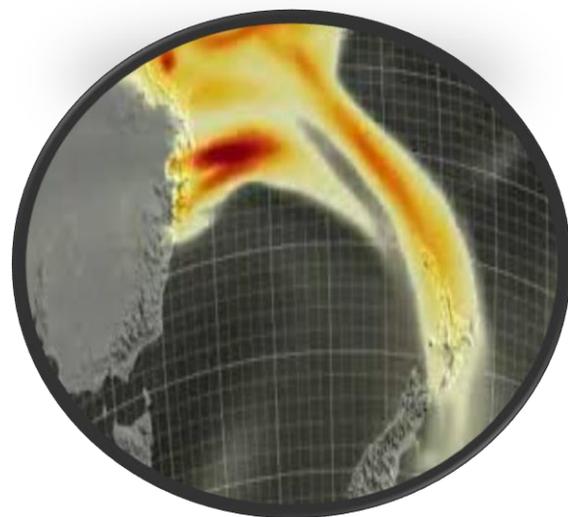
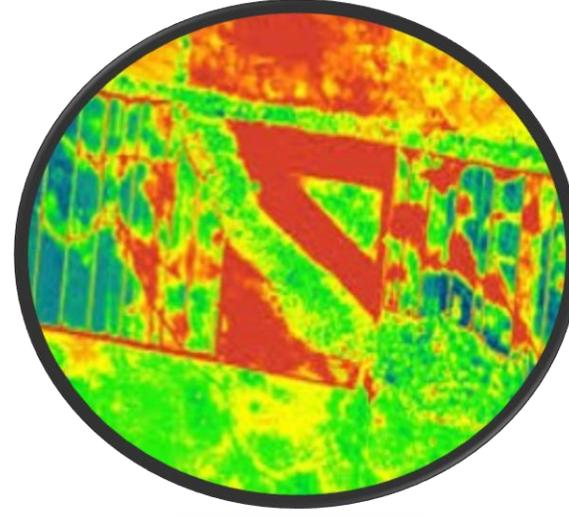
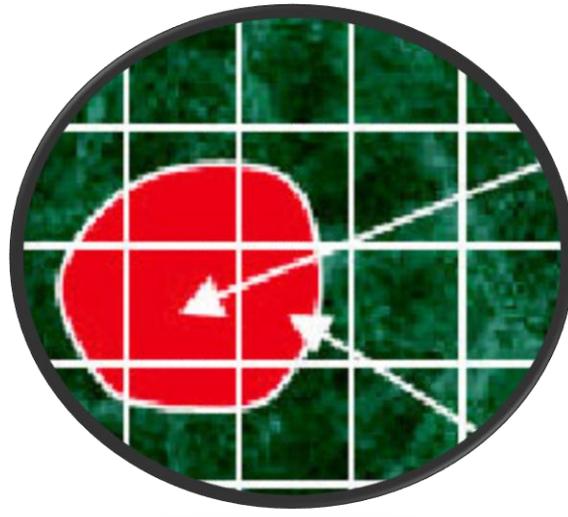


Hyperspectral



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 Author: <http://commons.wikimedia.org/wiki/User:Arbeck>

# Why Hyperspectral?

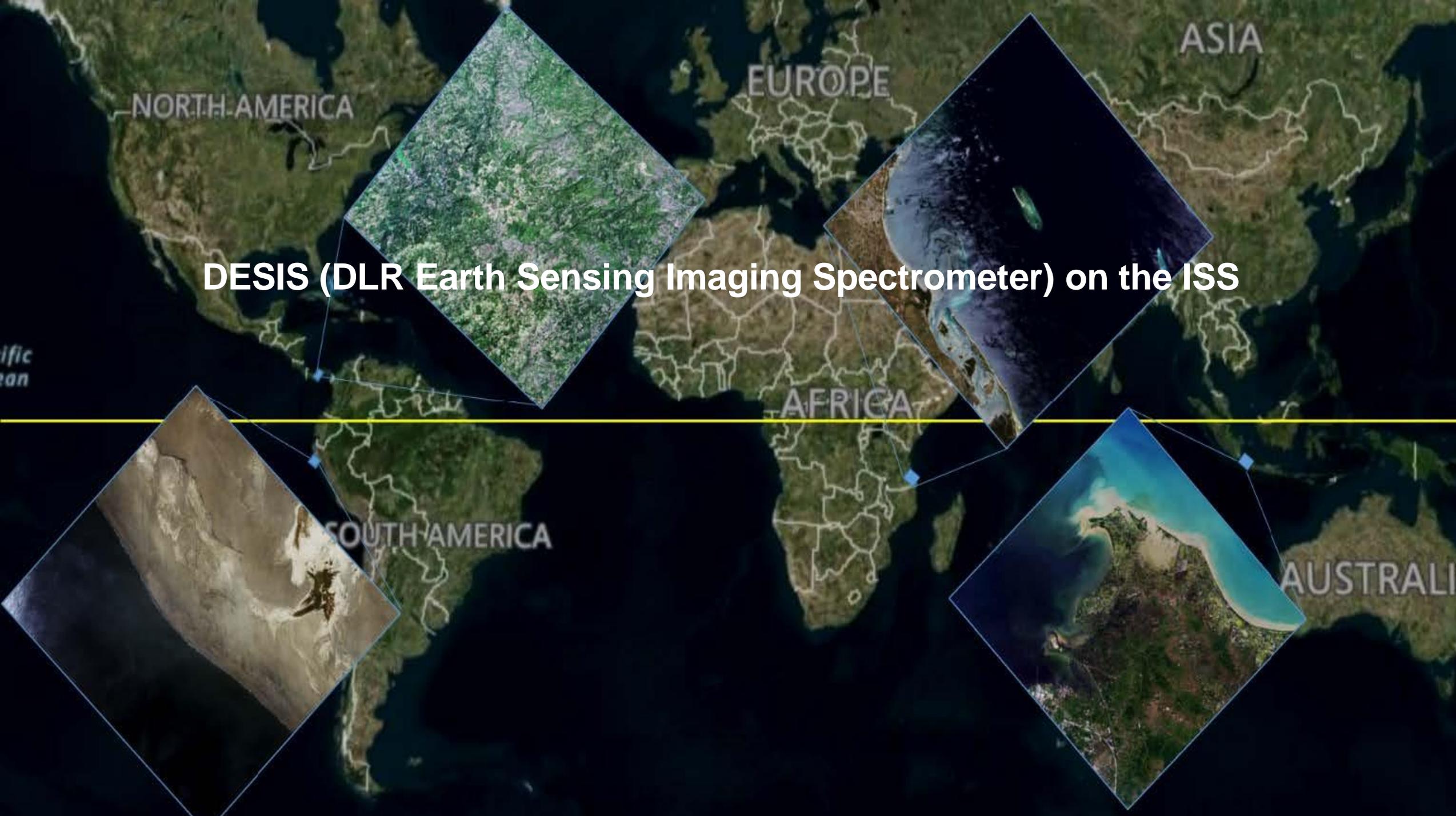




What are the main use cases you have used hyperspectral before, or what would you be interested in using it for?

*Select all that apply*

- Marine Monitoring
- Object Detection
- Land Use/Land Cover
- Rare Earth Elements
- Other



ASIA

EUROPE

NORTH-AMERICA

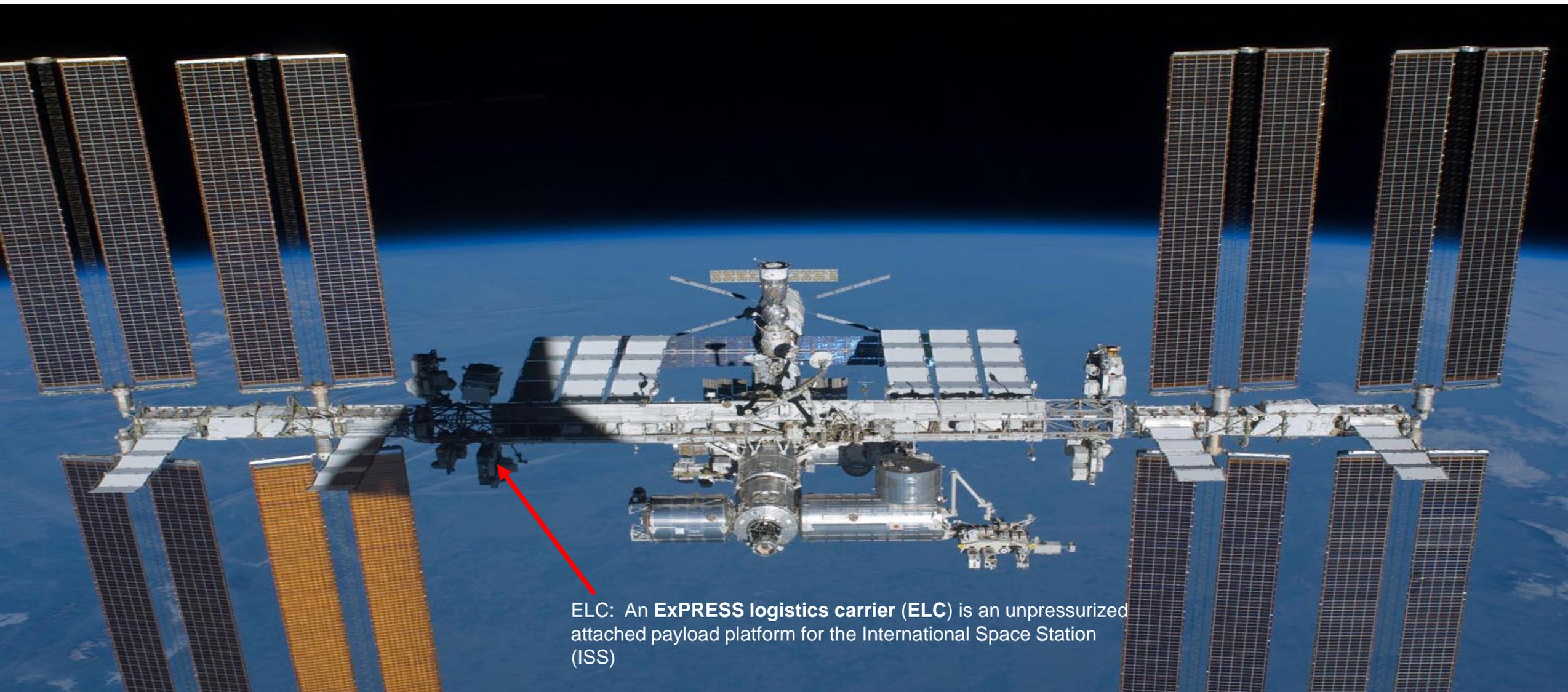
**DEGIS (DLR Earth Sensing Imaging Spectrometer) on the ISS**

AFRICA

SOUTH-AMERICA

AUSTRALIA

# MUSES/DESIS Location on the ISS Express Logistics Carrier 4 (ELC-4)



ELC: An **ExPRESS logistics carrier (ELC)** is an unpressurized attached payload platform for the International Space Station (ISS)

# Multi-User System for Earth Sensing (MUSES)



- DESIS is installed on MUSES (Teledyne developed)
- Precise pointing and Earth surface target tracking
- Up to 4 robotically installed instruments
- Total data downlink ~225 GB/day
- Onboard processing option
- Instruments launched in “soft stowage”, ISS National Lab covers transport cost, Teledyne manages integration, safety, testing, downlink, ops, etc.
- 6-12 months from agreement to installation
- Currently exploring SWIR, other payloads

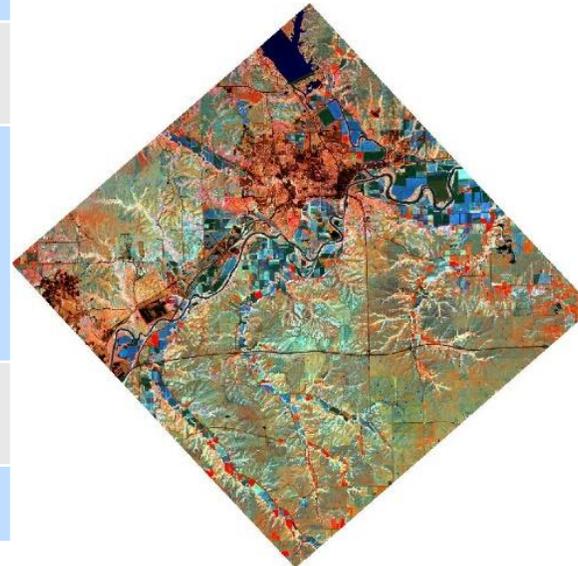
Characteristic	MUSES Performance Target
Field of Regard	Outboard Cross-Track: 5°
	Inboard Cross-Track: 45°
	Along-Track: +/- 25°
Thermal Control	Passive
Star Tracker	Sodern SED26
Inertial Measurement Unit	Honeywell Miniature Inertial Measurement Unit (MIMU)
Precision Time	Sourced from the ISS GPS, $\leq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



# DESI Spec



Characteristic	DESI-30 Features
Ground Sampling Distance	30 m @ 400 km altitude
Ground Swath	30 km @ 400 km altitude
Spectral Range	400 nm – 1000 nm
Spectral Bins	Measured: 235 @ 2.55 nm Programmable binning on-orbit
Quantization	12 bits + 1 gain bit
Signal to Noise Ratio @ 550 nm	205:1 sampled at 2.55 nm 406:1 binned to 10.2 nm
On-board calibration	Dark Field for DSNU LED Array for PRNU
Independent Pointing	Pointing Unit $\pm 15^\circ$ Along Track
Independent Time and Location	On-board GPS



# Earth Observation From the ISS – Why It Works/Challenges



## Benefits

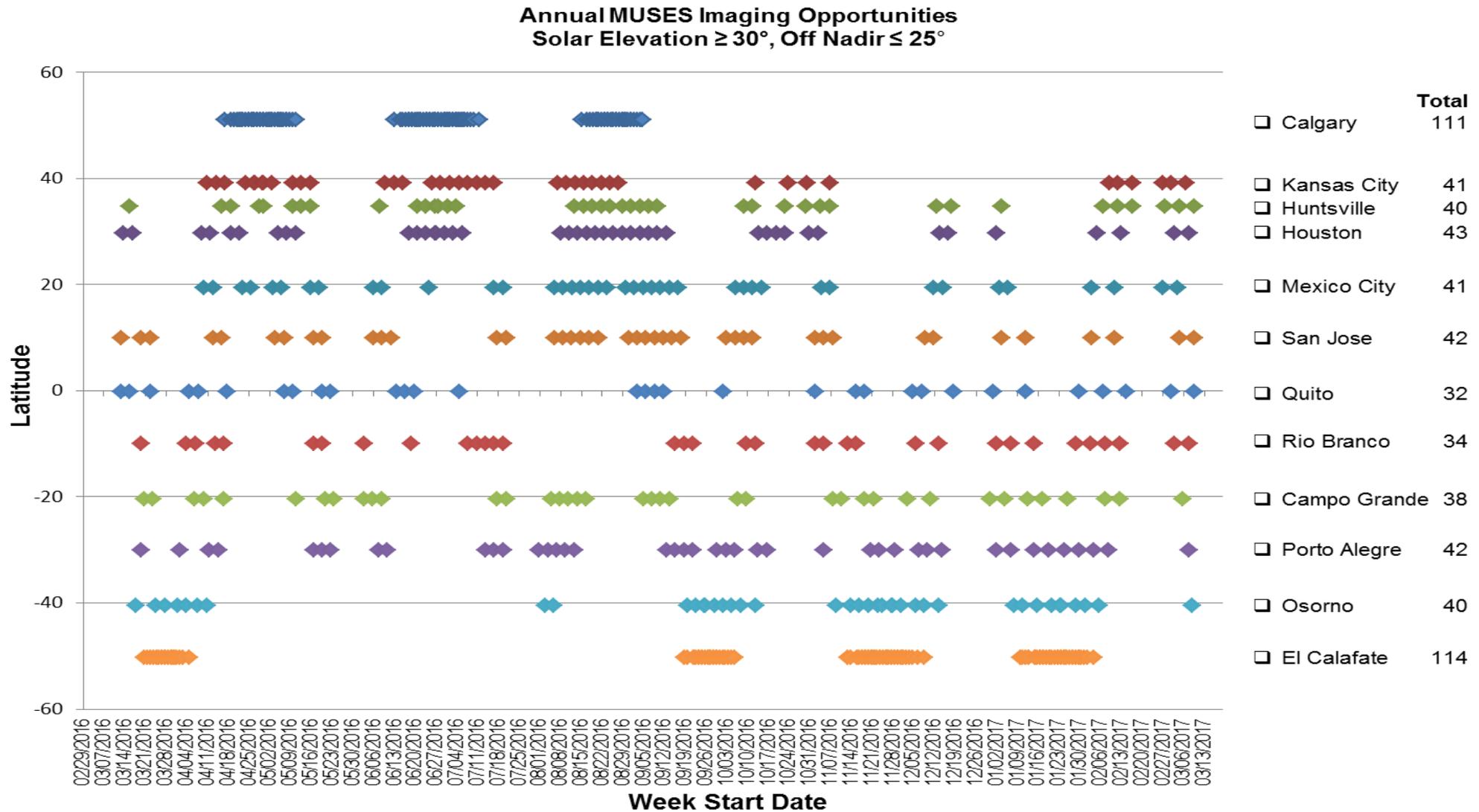
- Coverage of ~90% of populated Earth
- Coverage of 100% of tropics, frequent revisit
- Upgrade, repair and exchange of instruments as technology and/or markets evolution. Traditional barriers to entry are minimized

## Challenges

- Maneuvers, resupplies, spacecraft location can cause missed collects (field coordination)
- 55 degrees N and below 51 degrees S not covered in orbit



# MUSES Imaging Opportunities from the ISS



An aerial hyperspectral image of a landscape. The image is color-coded by spectral data, showing a river on the right side, agricultural fields in the center, and a forested area on the left. The colors range from blue and purple to green and yellow. The text 'Case Studies' is overlaid in the center in a large, white, sans-serif font.

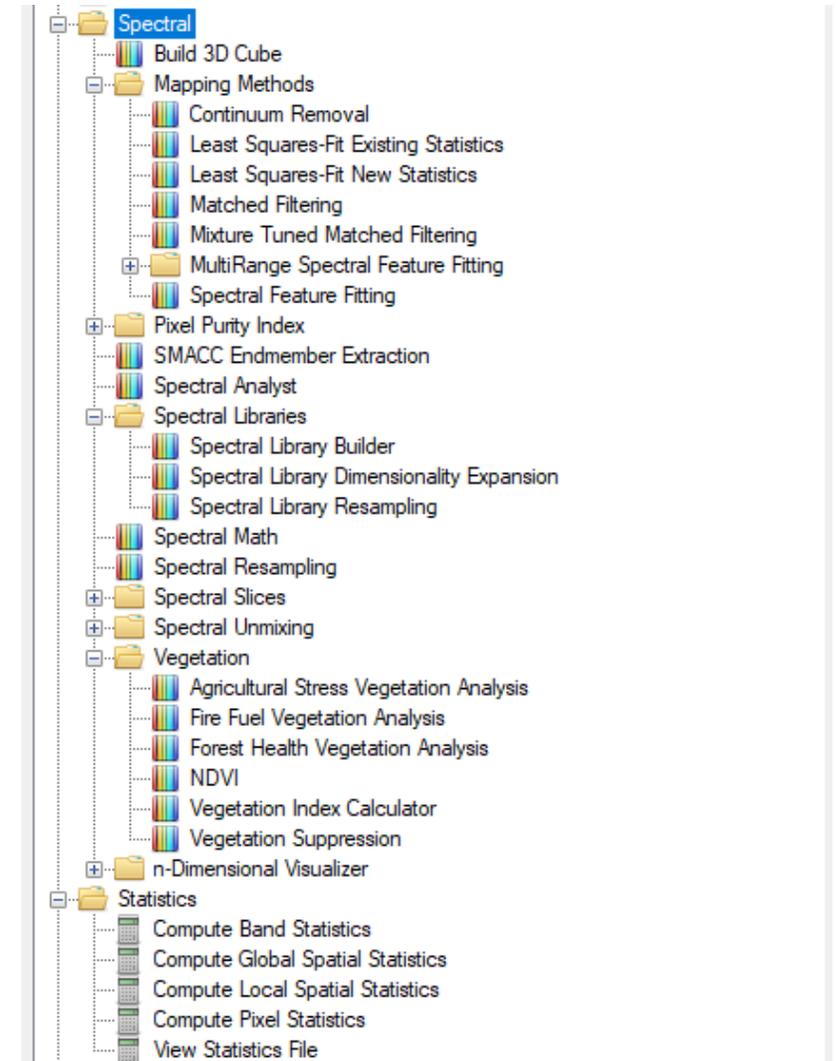
# Case Studies

ENVI Hyperspectral Analytics

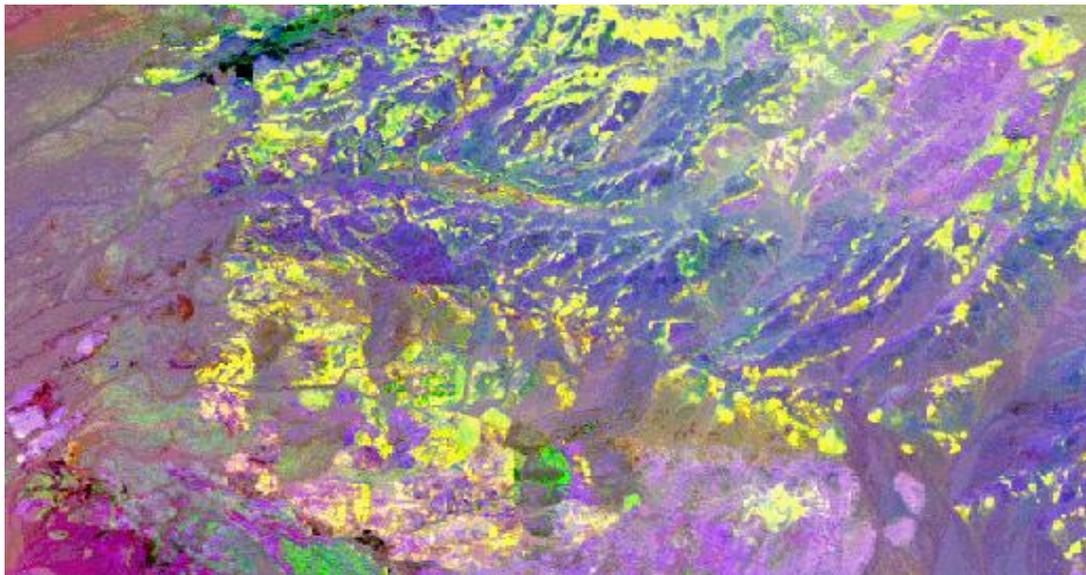
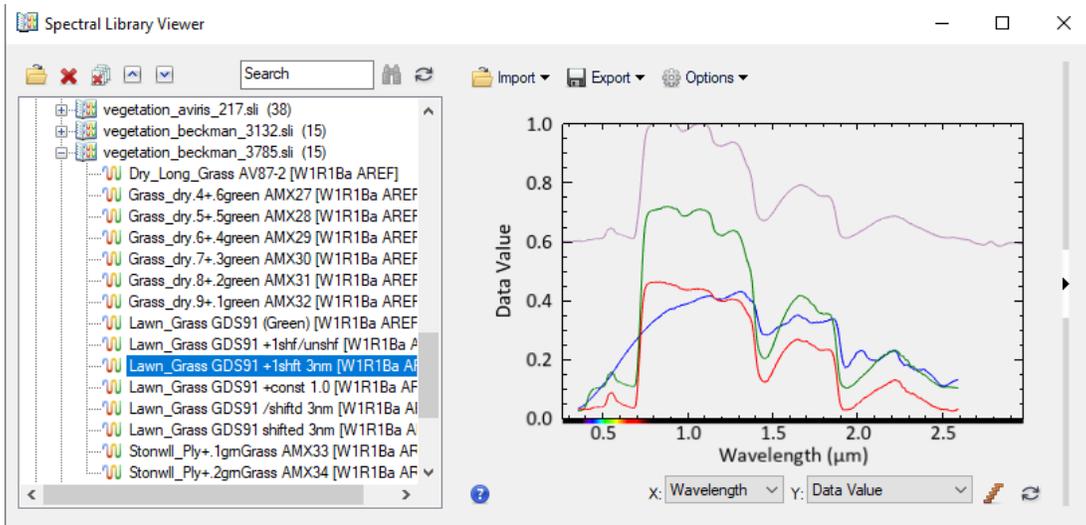
# ENVI and Hyperspectral



- ENVI was developed originally for working with hyperspectral imagery because it is so fast at processing large data
- ENVI has curated a large number of tools specific to hyperspectral imagery as well as all the pre-processing tools such as:
  - Radiometric calibration
  - Atmospheric correction
  - Careful pixel care—preserve the original signal so spectra aren't muddled



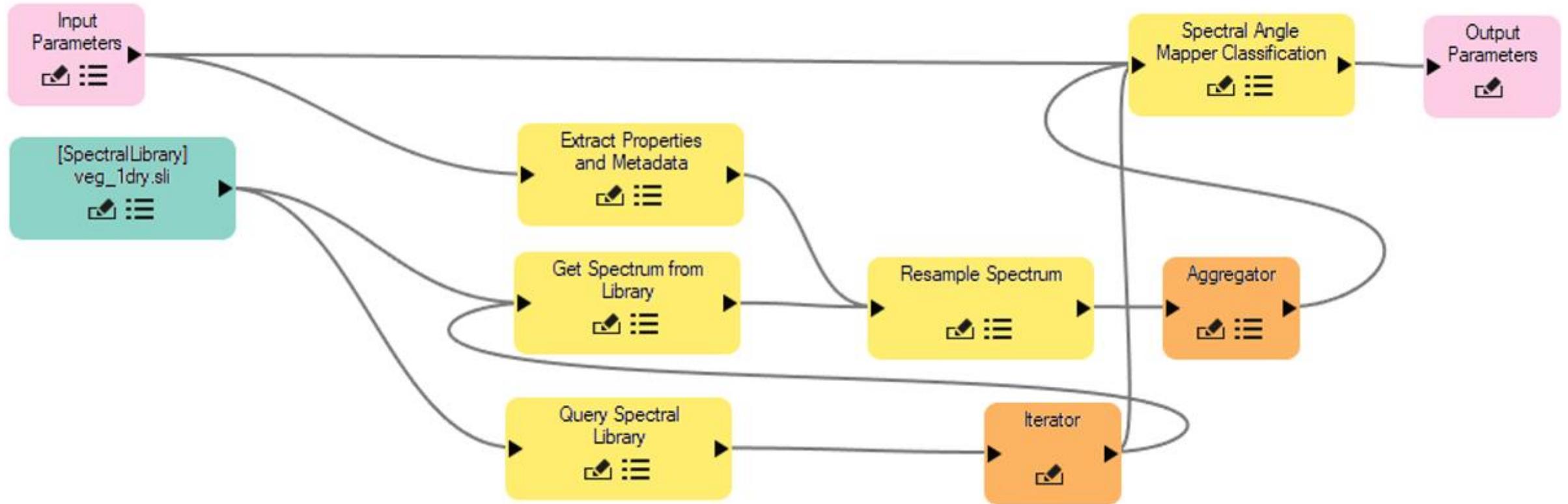
# ENVI and Hyperspectral



A large, dense cloud of text listing numerous vegetation indices and spectral indices, including:

- WorldView Non-Homogeneous Feature Difference
- Modified Chlorophyll Absorption Ratio Index - Improved
- Red Green Ratio Index
- Anthocyanin Reflectance Index 1
- WorldView Improved Vegetative Index
- Renormalized Difference Vegetation Index
- Visible Atmospherically Resistant Index
- Infrared Percentage Vegetation Index
- Normalized Difference Snow Index
- Normalized Difference Nitrogen Index
- Vogelmann Red Edge Vegetation Index
- WorldView New Iron Index
- Global Environmental Monitoring Index
- WorldView Chlorophyll Index 2
- Leaf Area Index 1
- Leaf Area Index 2
- WorldView Soil Index
- WorldView Water Index
- Clay Minerals
- Modified Simple Ratio
- Modified Triangular Vegetation Index - Improved
- Soil Adjusted Vegetation Index
- Difference Vegetation Index
- Non-Linear Index
- Cellulose Absorption Index
- Normalized Burn Ratio
- Water Band Index
- Simple Ratio
- Red Edge Position Index
- Modified Soil Adjusted Vegetation Index
- Wide Dynamic Range Vegetation Index
- Green Difference Vegetation Index
- Iron Oxide
- Lignin Cellulose Absorption Index
- Normalized Difference Lignin Index
- Moisture Stress Index
- Modified Non-Linear Index
- Burn Area Index
- Sum Green Index
- WorldView Built-Up Index
- Carotenoid Reflectance Index 2
- Normalized Difference Water Index
- Green Soil Adjusted Vegetation Index
- Modified Red Edge Normalized Difference Vegetation Index
- Normalized Burn Ratio Thermal 1
- Green Optimized Soil Adjusted Vegetation Index
- Normalized Difference Vegetation Index
- Transformed Difference Vegetation Index
- Normalized Difference Infrared Index
- Structure Insensitive Pigment Index
- Normalized Difference Vegetation Index
- Green Ratio Vegetation Index
- Optimized Soil Adjusted Vegetation Index
- Triangular Vegetation Index
- Vegetation Resistant Index
- Carotenoid Reflectance Index 1
- Normalized Difference Mud Index
- Modified Chlorophyll Absorption Ratio Index
- Modified Red Edge Simple Ratio
- Red Edge Normalized Difference Vegetation Index

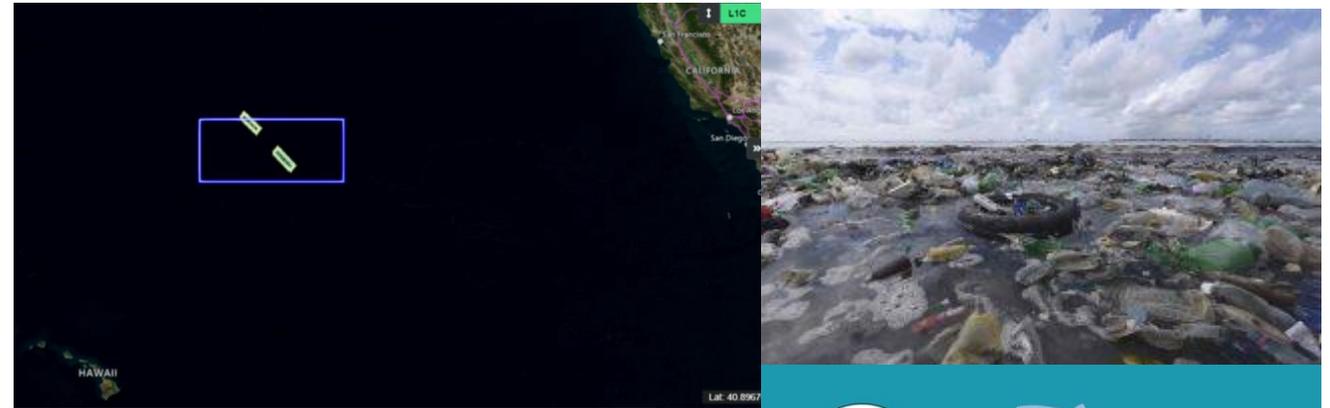
# Automated Workflows with ENVI Modeler



# Marine Debris



- Marine Debris is a major environmental and transportation hazard
- Significant impact to marine food chain and ecological collapse
- DESIS can image these remote gyres, shorelines and sources for debris/plastics flowing into oceans
- Some gyre locations known, find dense debris areas for clean up and transit avoidance
- Different types of debris appear at different times of year. The more we can learn about this global crisis, the more we can mitigate impacts
- Started this kind of work after the Fukushima Earthquake



<https://theoceancleanup.com/great-pacific-garbage-patch/>

# Detecting Marine Debris

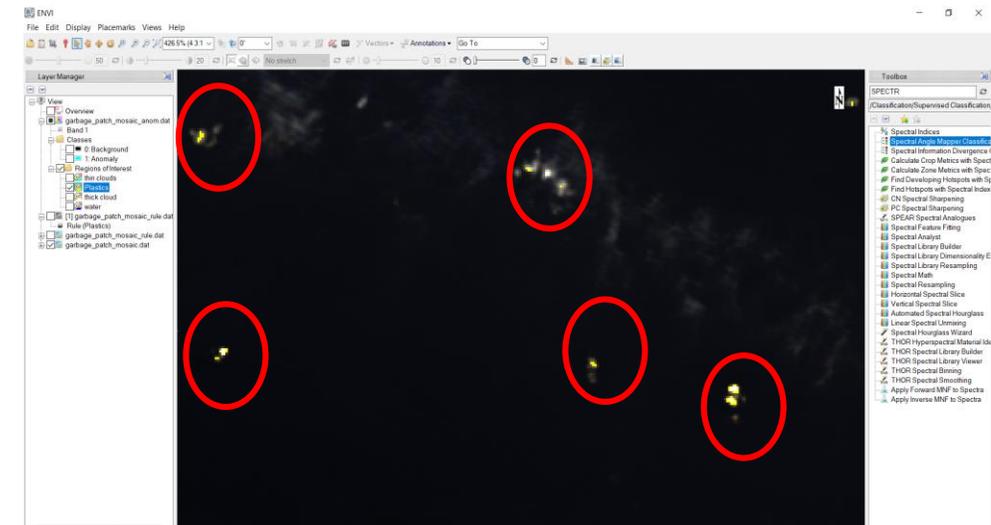
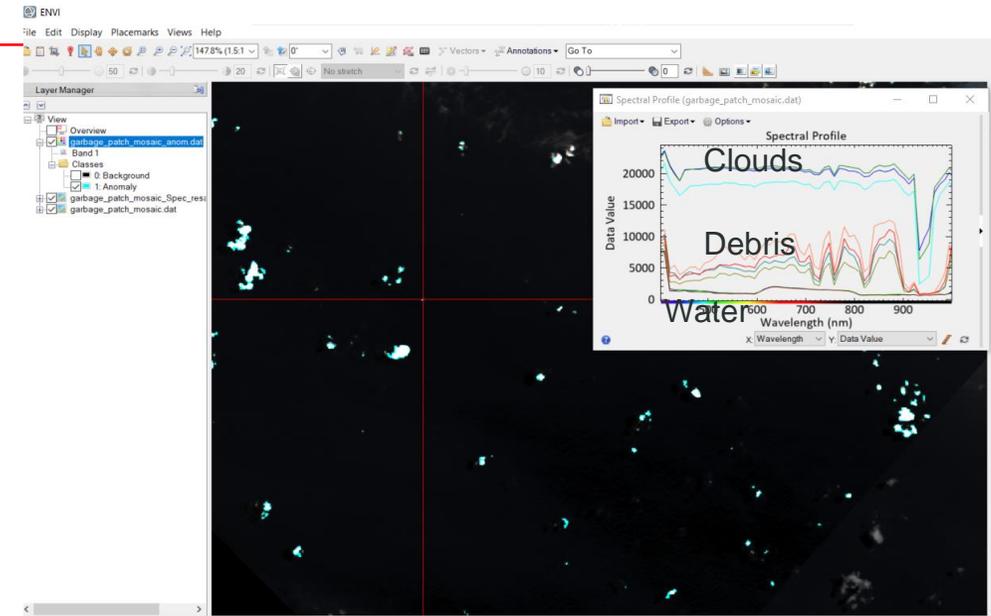


## ENVI Process

- Prepared DESIS imagery
  - Radiometric calibration
- Seamless Mosaic
- RX Anomaly Detection to search a large area
- Viewed anomalous spectral profiles
- Create new spectral signature library and ROIs
- SAM to separate anomalies (cloud fringe) from real plastics

## In the Future

- Fully automate workflow for monitoring
- Automate process for other searches
- On-Board processing to downlink locations



# Oil Slicks and Seeps



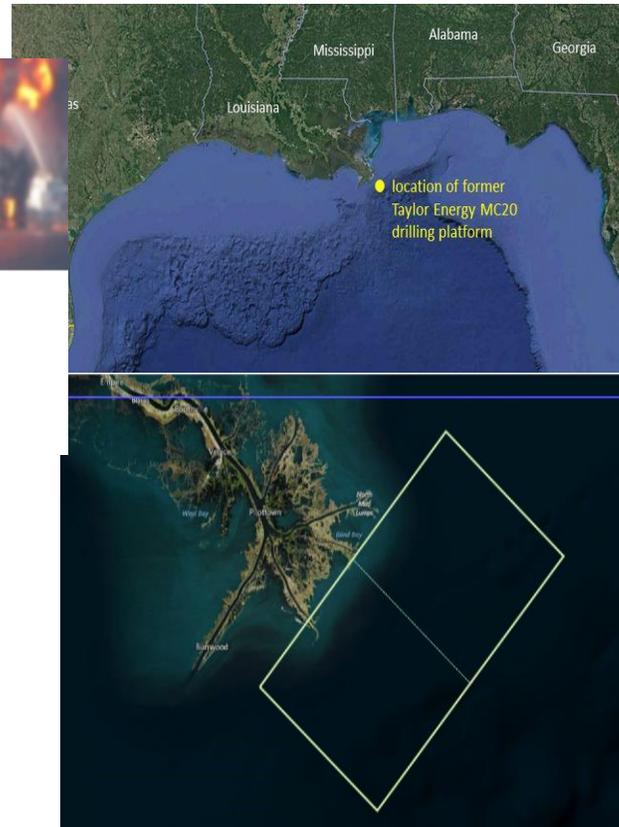
- Mississippi Canyon Seep, <https://coastalscience.noaa.gov/news/mc20report/>
- Oil Seeps and spills observable with hyperspectral data and more detailed level, such as oil type and thickness

**Taylor Energy Platform "Saratoga"**  
Gulf of Mexico off Mississippi River Delta | 2013-Jul-14

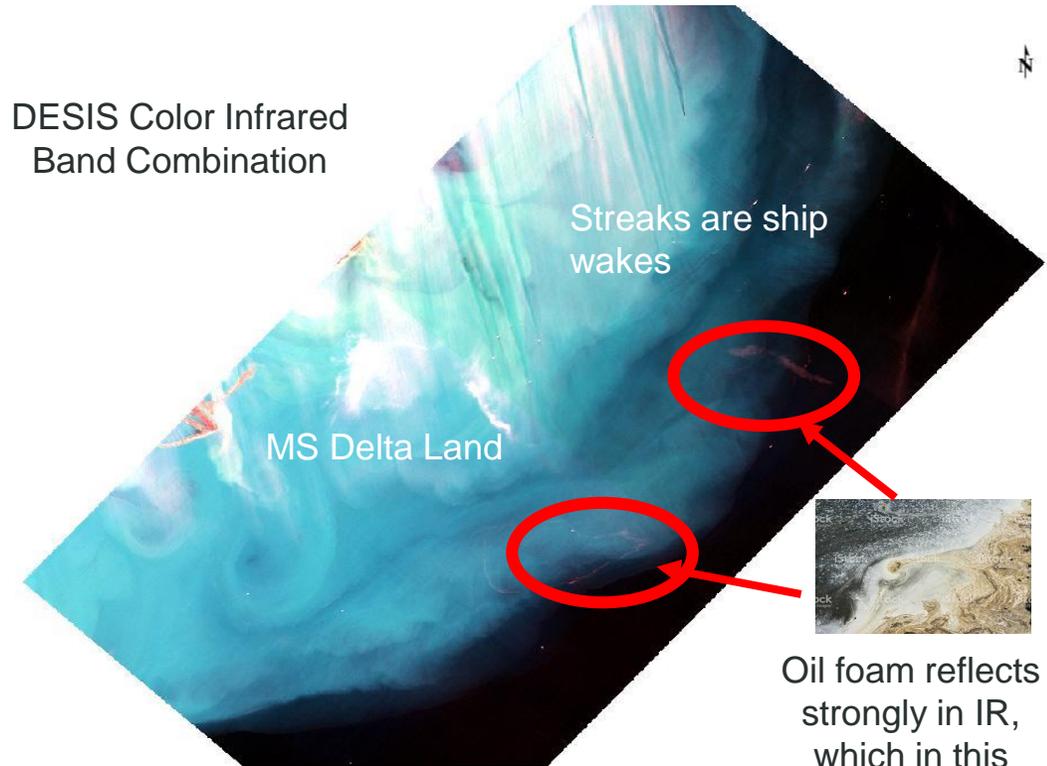
Initial Notification: On 14 July 2013, the USCG Sector New Orleans contacted the NOAA SSC requesting trajectory support for a reported crude oil discharge from the Platform "Saratoga" that was destroyed during Hurricane Ivan in 2004. A bloom of varying colors was reported in lease block Mississippi Canyon 20A. The NRC report number is 1053820.

Incident Details	
Primary Threat:	Oil
Products Of Concern:	South LA Sweet Crude
Latitude (Approximate):	28° 56.16' North
Longitude (Approximate):	88° 58.13' West

Public Information and Incident-Related Links	
<small>On 14 July 2013, the USCG Sector New Orleans contacted the NOAA SSC requesting trajectory support for a reported crude oil discharge from the Platform "Saratoga" that was destroyed during Hurricane Ivan in 2004. A bloom of varying colors was reported in lease block Mississippi Canyon 20A. The NRC report number is 1053820.</small>	

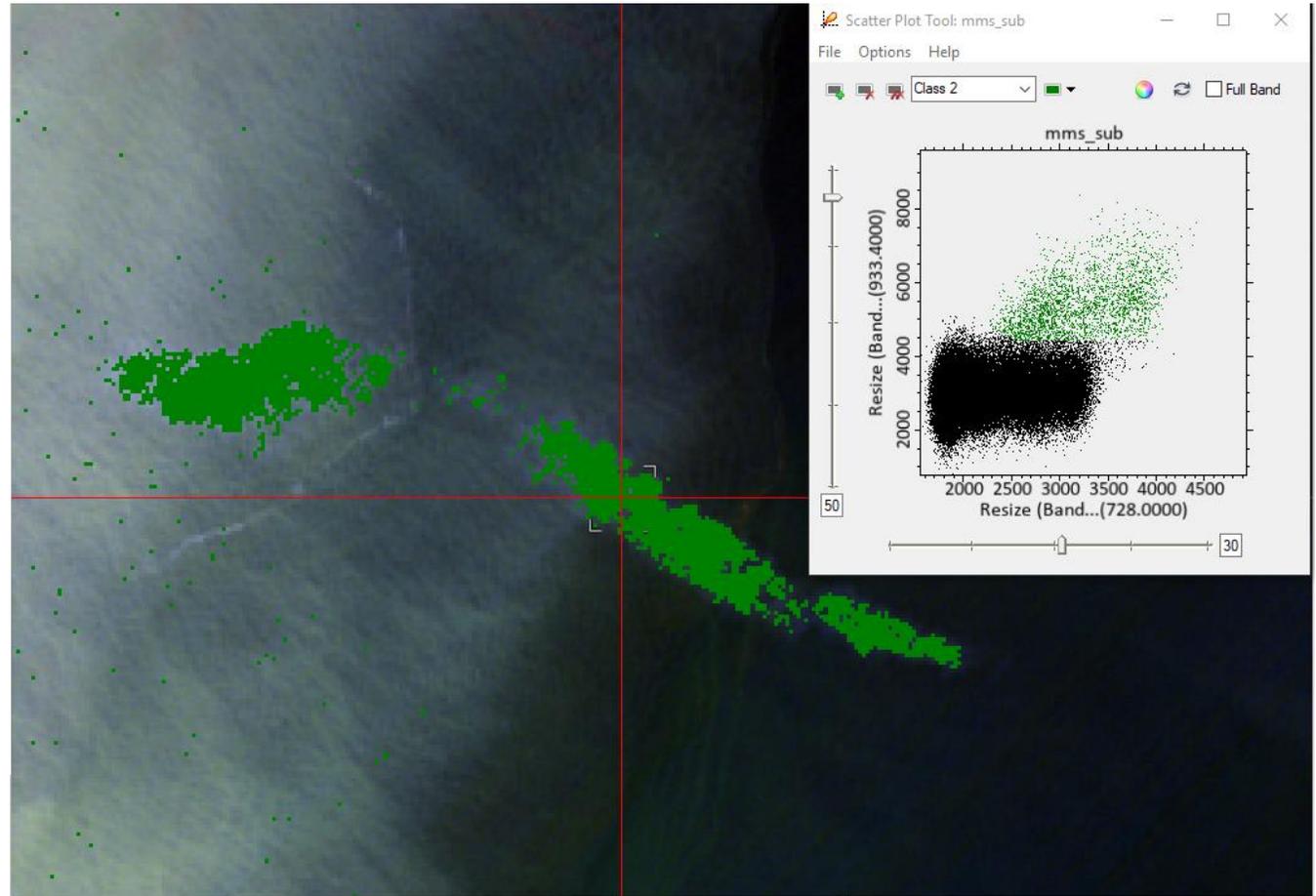
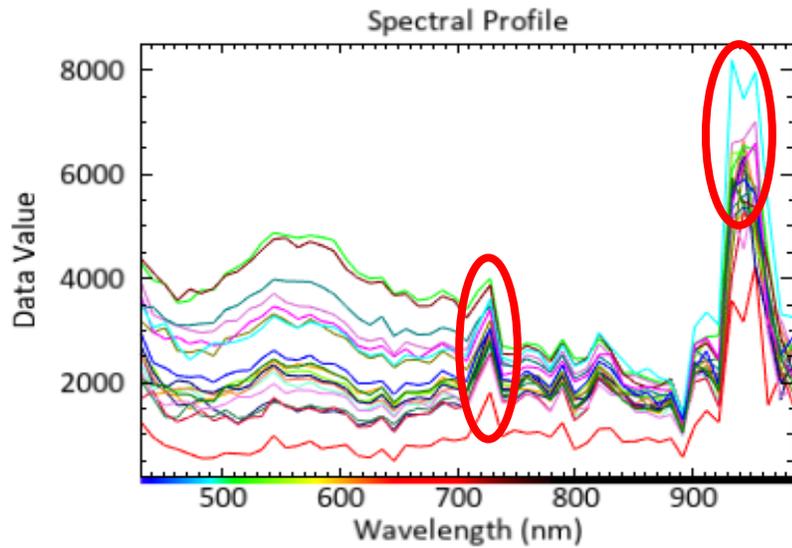


DESI Color Infrared Band Combination



Oil foam reflects strongly in IR, which in this image shows up as red

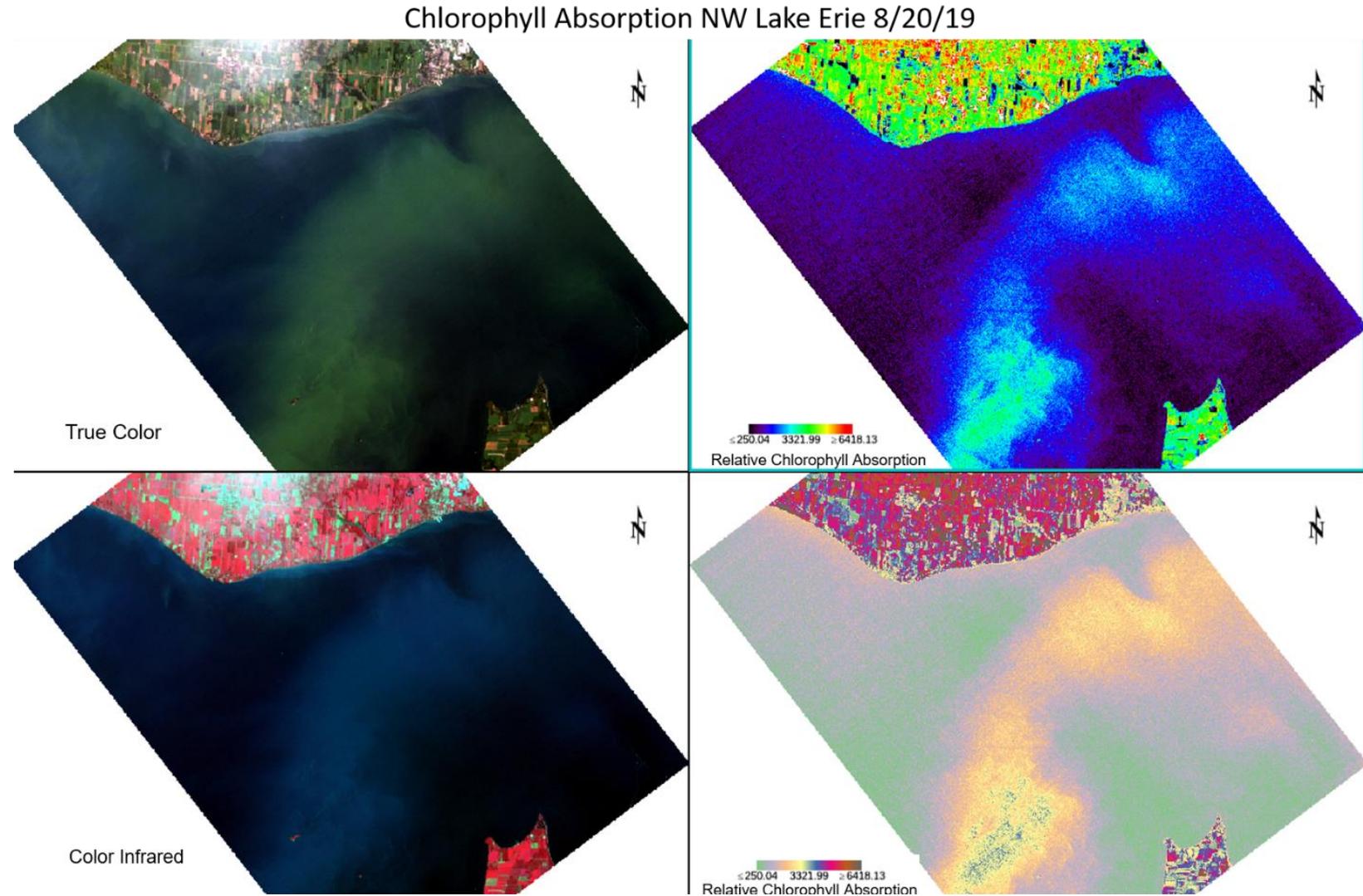
# Spectral Properties to Map Oil Extents



# Water Quality



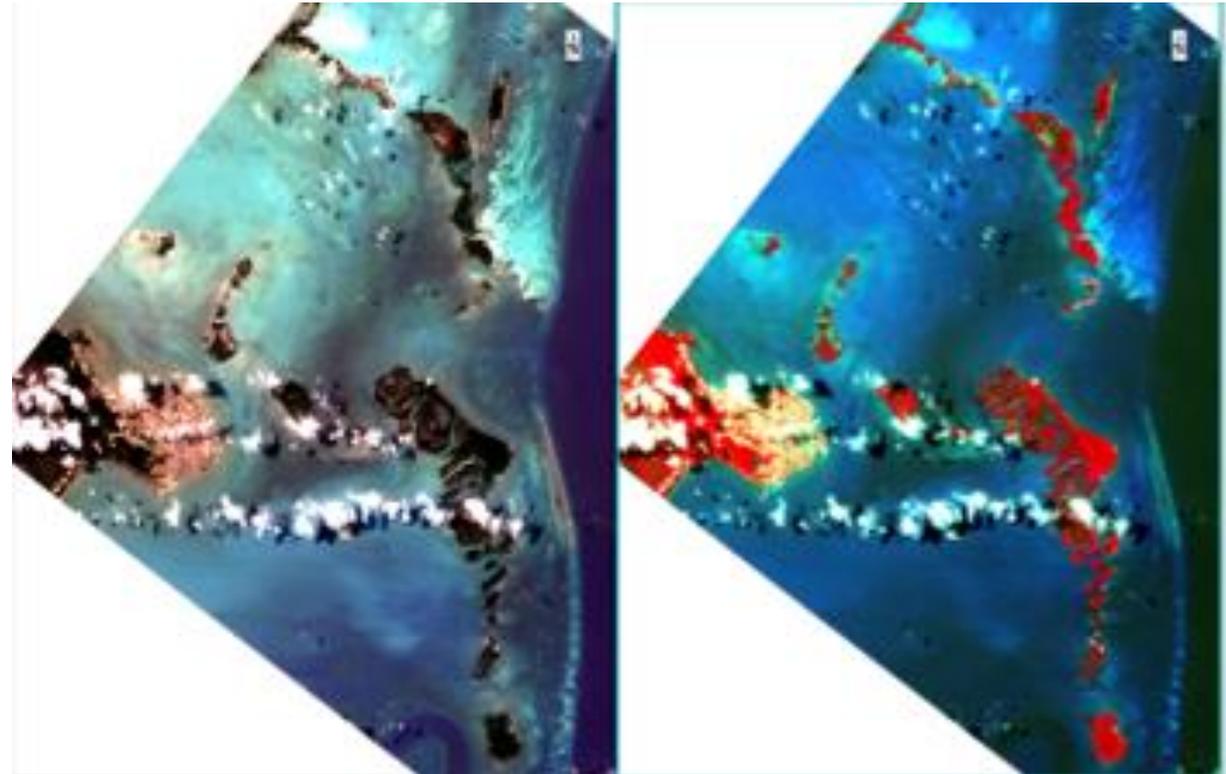
- ENVI provides 60+ spectral indices for detecting different materials, water quality is just one
- Inputs are straight forward so product creation can be automated with ENVI workflows
- Those workflows can also be run in the cloud or inside of ArcGIS





- In dry times, vegetation can behave differently which can reveal the presence of ancient structures
- Ongoing research using DESIS data
- More frequent equatorial repeats mean more chances for clear imagery and comparison
- Collections in coordination with field efforts with ASD spectra collection
  - Because of ISS activities, can't always time correctly, work with Amanda and Teledyne Operations

DESI Imagery of Belize City

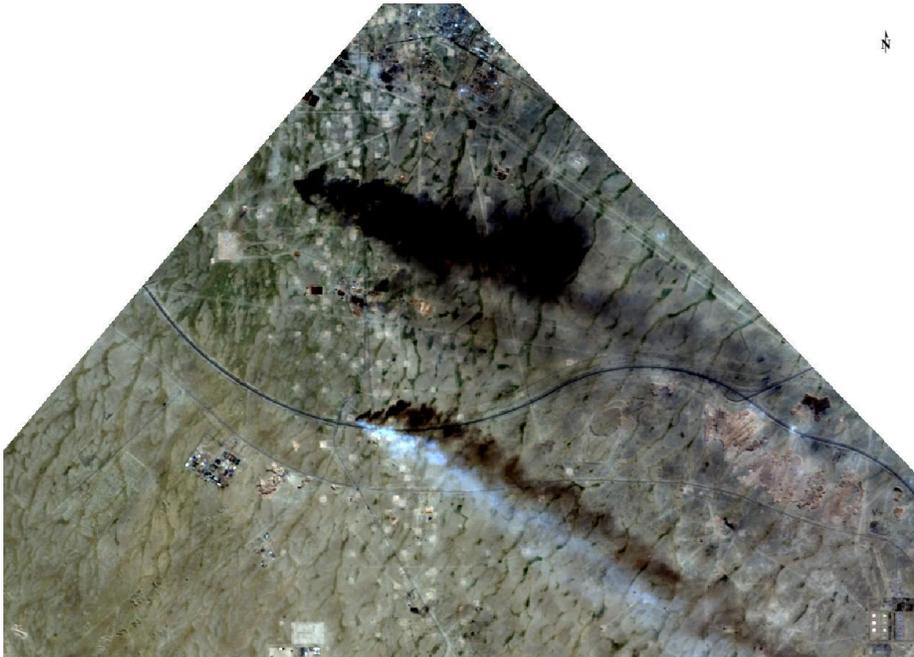


# Oil and Gas

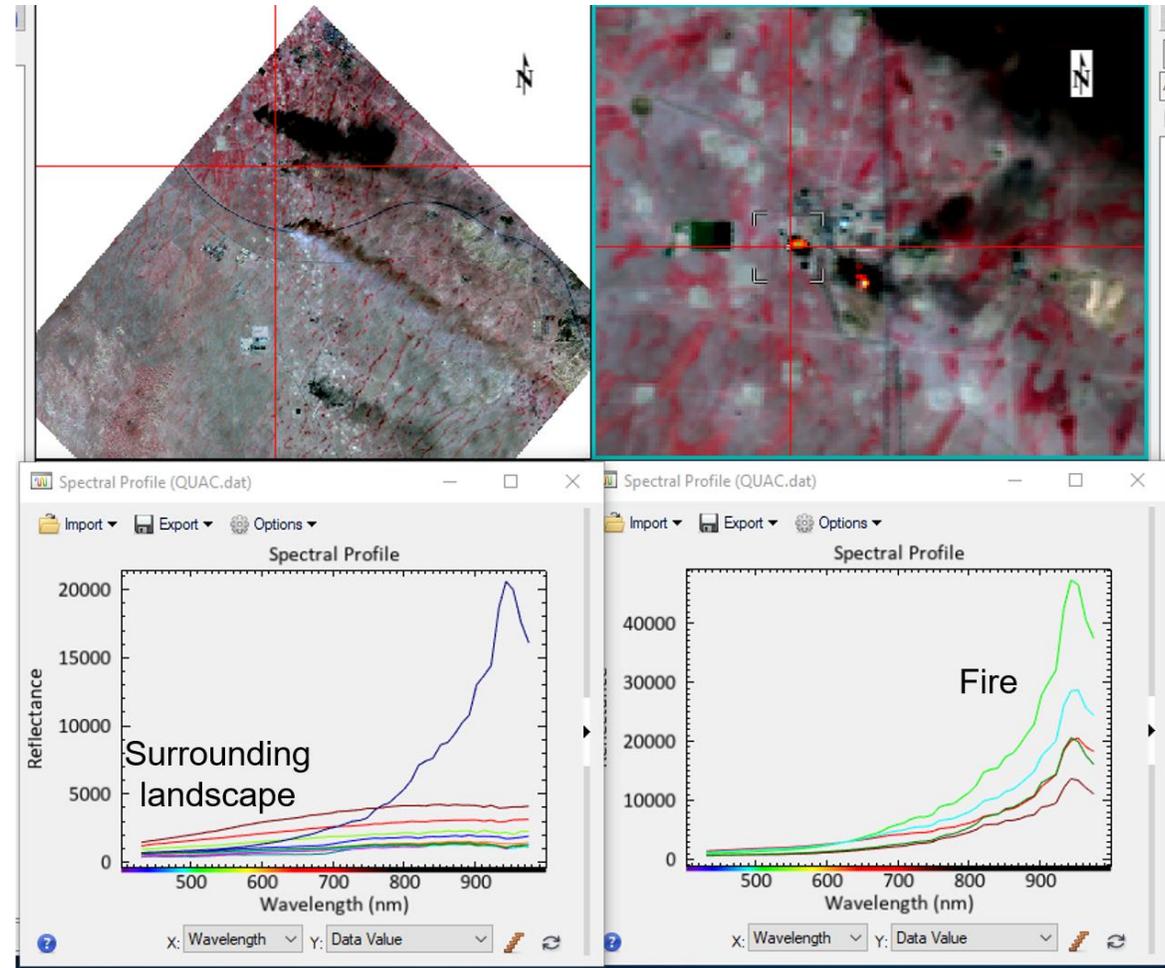


- Observe oil and gas flaring
- Dynamic range large enough to detect fire through plumes

DESIS True Color, no flame visible



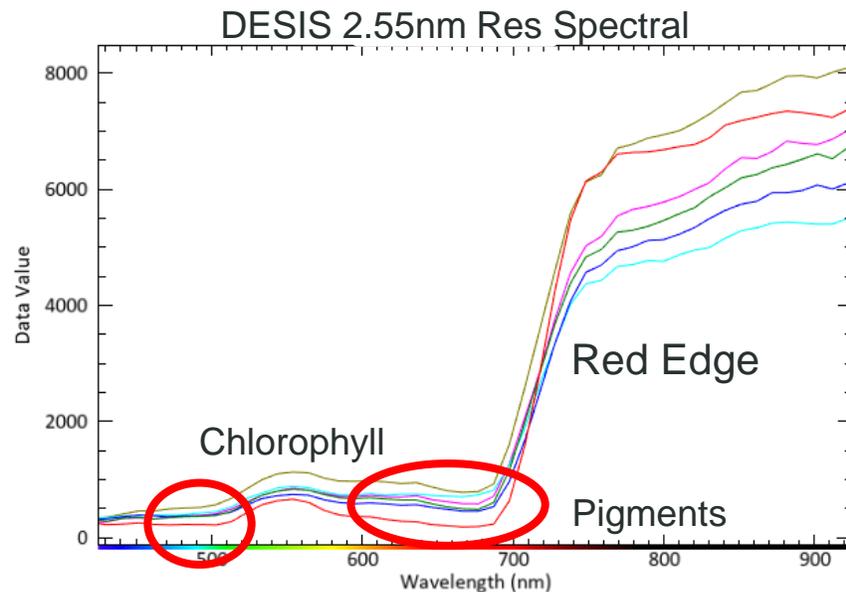
CIR Composite of Oil Wells Near Bagra, Iraq



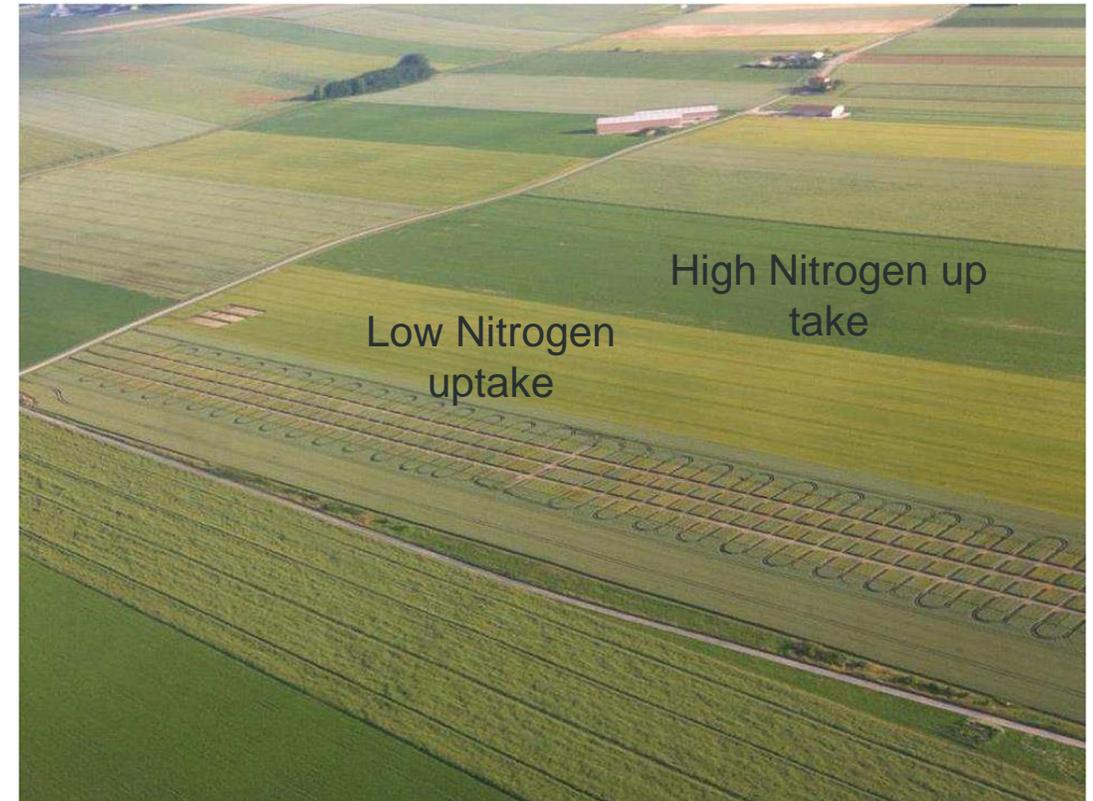
# Vegetation and Food Security



- 30m resolution effective for regional area analysis and trend analysis
- Hyperspectral data sensitive to vegetation pigments that can indicate stress
- Stress over time can create food insecurity and lead to geopolitical instability
- Agriculture companies can use the subtle pigment changes to study the efficacy of treatments



Different Wheat Phenotype Nitrogen absorption

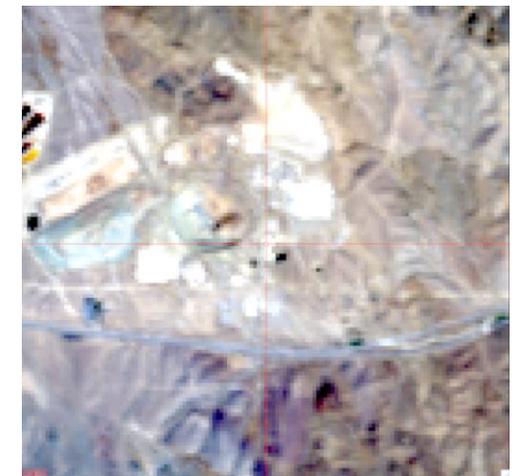
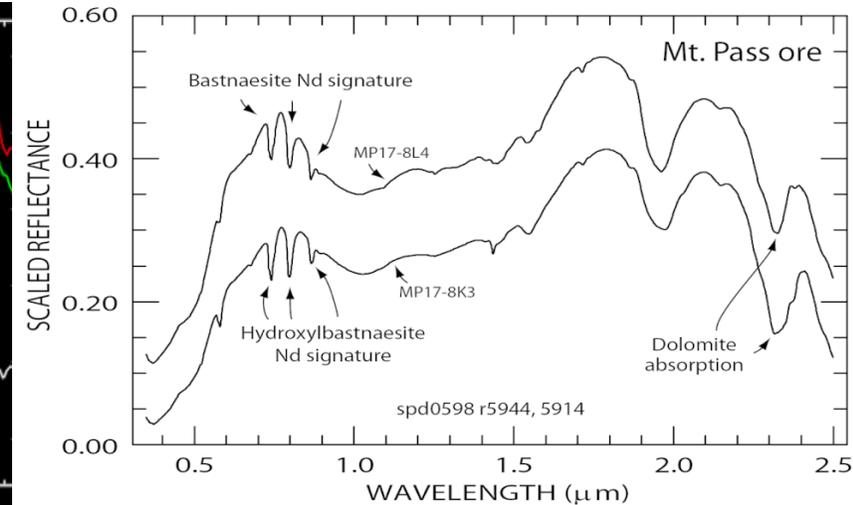
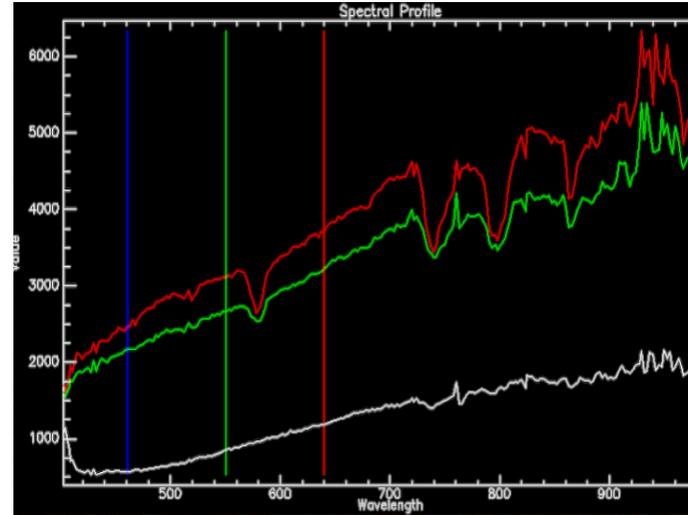


David Gouache, SPIE Newsroom 2016

# Rare Earth Elements



- Most geologic features found in Shortwave Infrared
- REE absorptions are “due to crystal-field transitions involving deep-lying electrons”  
<https://www.usgs.gov/media/images/reflectance-spectra-rare-earth-oxides>
- China is primary source of REEs
- Costs and international politics are changing REE sourcing
- USGS scientist confirm ability to delineate 2 versions of REEs present in 2.55 nm data (bastnaesite from hydroxylbastnaesite)
- The different kinds of REE’s separated OH group



Credit:   
USGS  
science for a changing world

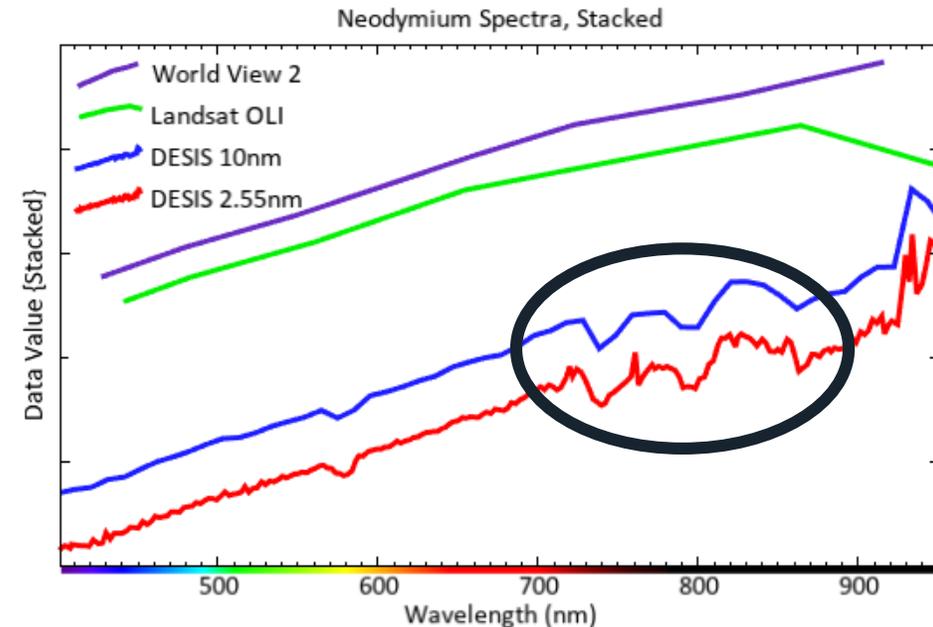
# The Value of Hyperspectral for REE



- Using ENVI's Resampling tools we can see that the absorption features that define REEs disappear
- **Gregg Swayze from USGS SpecLab**

**“So this may be the first demonstration of REE detection from space but may also have high enough resolution and SNR to allow differentiation of individual REE minerals.”**

- Because of DESIS' quality, this application is a reality

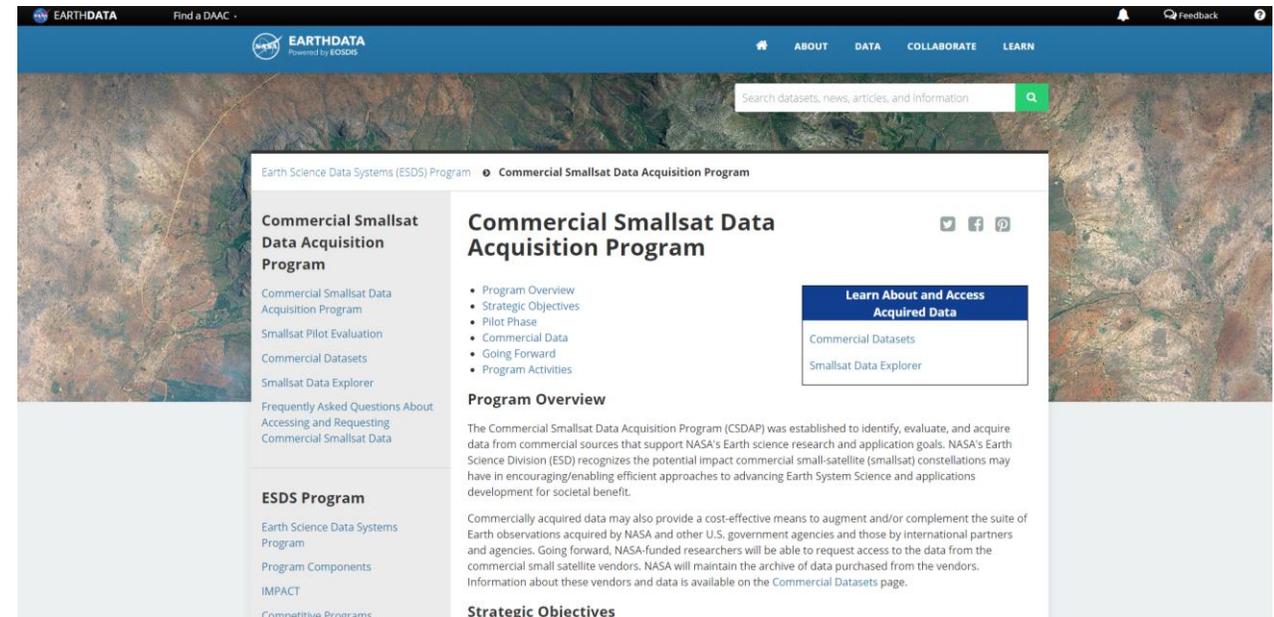
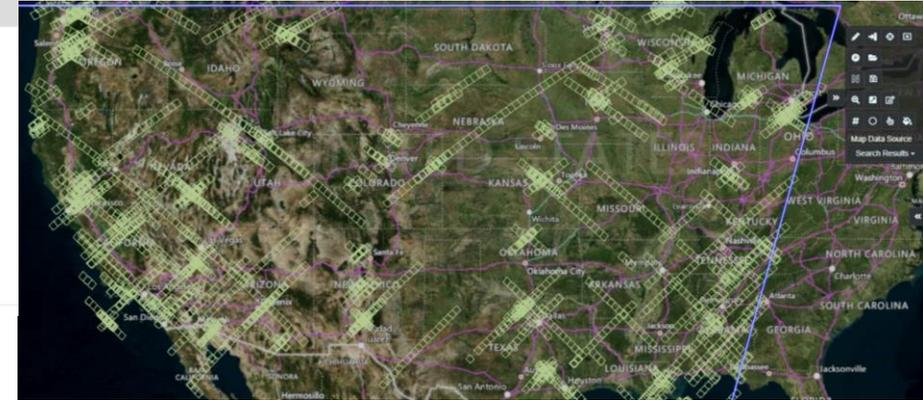
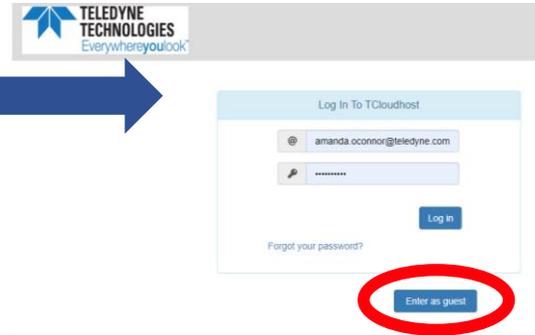


# Data Access



- Catalog can be browsed here:  
[Teledyne.tcloudhost.com](https://Teledyne.tcloudhost.com)
- Catalog data freely available to US federal **Research Scientists** VIA NASA contract.  
[Yvonne Ivey](#) is the POC for catalog access
- DESIS will eventually be available here:  
<https://earthdata.nasa.gov/esds/small-satellite-data-buy-program>
- Academic and NGO small data needs (Several Scenes), contact the DLR  
[https://www.dlr.de/eoc/desktopdefault.aspx/tabid-13629/23675\\_read-54295/](https://www.dlr.de/eoc/desktopdefault.aspx/tabid-13629/23675_read-54295/)
- Commercial, Academic/NGO site access, technical questions, [Amanda O'Connor](#)

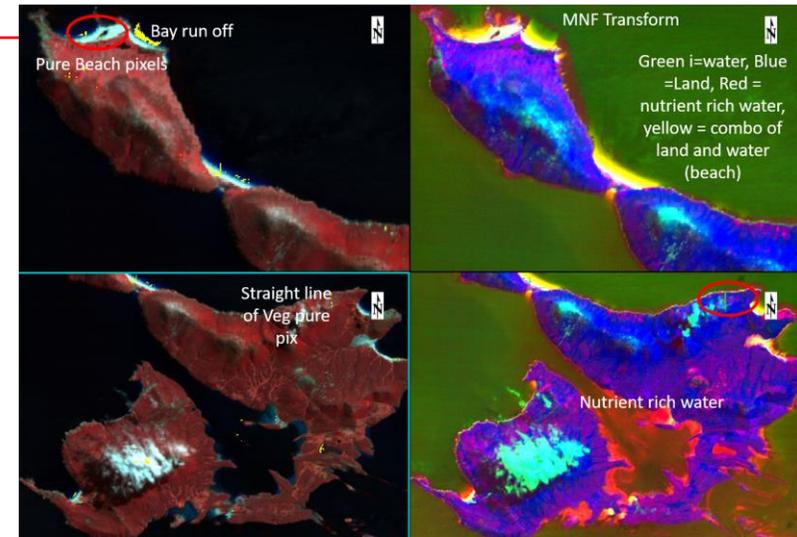
Fine print: 2.55nm resolution only available to US Gov and DLR. Larger commercial or site access may be eligible for a NOAA waiver on a case by case basis



# Every pixel can tell a story.....



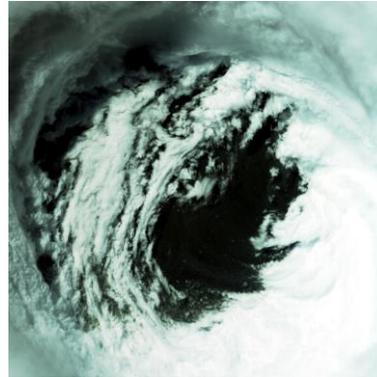
- The questions yet to be asked of hyperspectral are infinite and more and more sensors are coming on line
- Find your rockhopper penguin colony and understand how it changes
- For those interested, Teledyne Brown Engineering will make a DESIS sample image available. Please send Amanda your contact information
  - Name, Address, Country, email, organization
- DESIS Cal/Val information  
[https://tbe.com/\\_documents/PDFs/sensors-19-04471-v2.pdf](https://tbe.com/_documents/PDFs/sensors-19-04471-v2.pdf)
- If you are interested in Exploring ENVI, please reach out to your Account Manager to determine Temporary License Availability



# Questions?



**Amanda O'Connor**  
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L3Harris Geospatial  
Email: [Megan.Gallagher@L3Harris.com](mailto:Megan.Gallagher@L3Harris.com)

*[NASA ROSES](#) call for Research Opportunities in Space and Earth Sciences, DESIS may be used as a proposal component*