Jet Propulsion Laboratory
California Institute of Technology

SIMULATING SBG WITH ECOSTRESS AND EMIT

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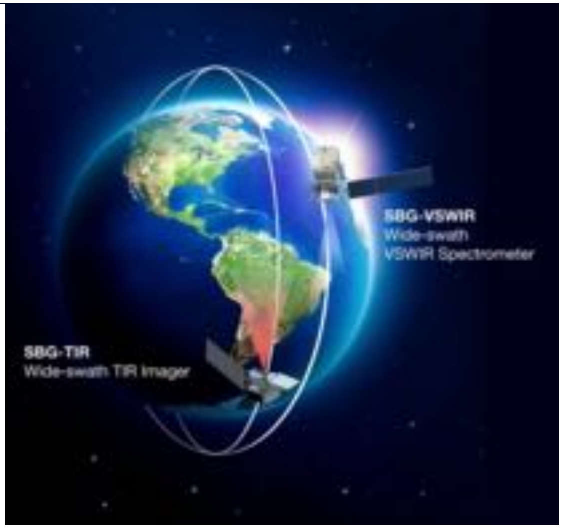
with contributions from the SBG, ECOSTRESS and EMIT teams

Outline

- Description of SBG
- Description of ECOSTRESS Instrument
- Description of EMIT Instrument
- Comparison of SBG-TIR with TRISHNA and LSTM
- Comparison of SBG-VSWIR with CHIME and PRISMA
- ECOSTRESS and EMIT Products and Processing
- ECOSTRESS and EMIT for SBG Simulation in Geological Studies

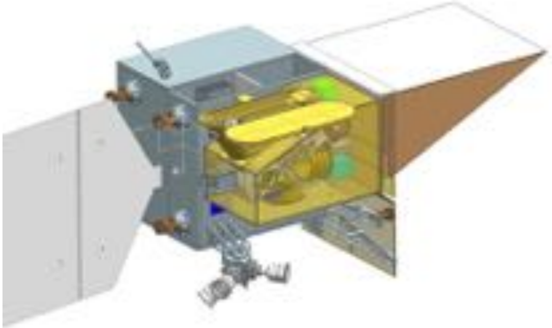
SBG Architecture Description: Two Primary Platforms

- Two vehicles in SSO
  - TIR 665 km, 12:30 equatorial crossing time descending node
  - VSWIR 632 km, 10:45 local time
- VSWIR on a NASA spacecraft with launch vehicle contributed or NASA
- TIR on ASI-spacecraft with ASI-provided launch (VEGA-C) and VNIR camera



- NASA VSWIR
  - FoV: 25.5°
  - Spatial Res: 30 m
  - Swath: 185 km
  - Spectral Res: 10 nm
  - Range: 0.38 – 2.5 µm
  - Bands: 220
- NASA TIR
  - Spatial Res: 60 m
  - Swath: 935 km
  - Range: 1.6 – 12 µm
  - Bands: 8
- ASI VNIR
  - Spatial Res: 30 m
  - Range: 665, 834 nm centers
  - Bands: 2

VSWIR-1 on NASA Bus



TIR on ASI Bus

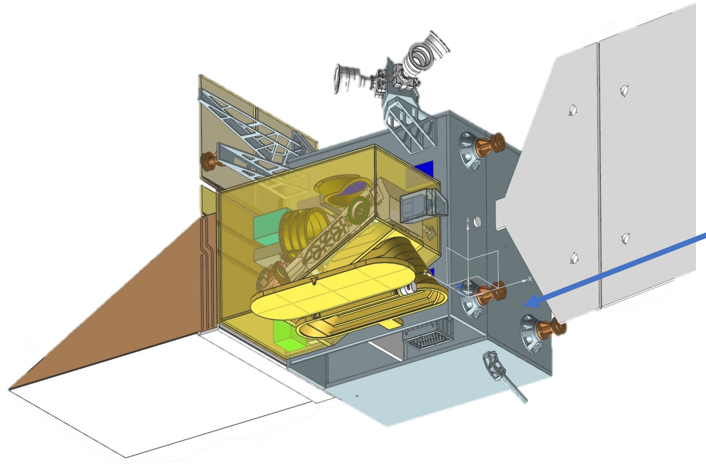
- Science valuation
  - Two-Platform solution allows orbits to utilize optimum observing time coordinate with international efforts
    - VSWIR orbit can be coordinated with CHIME for reduced revisit
    - TIR orbit can be coordinated with CNES-ISRO TRISHNA and ESA-LSTM for daily revisit
  - ASI contributed VNIR provides full coincidence with NASA TIR and improved performance

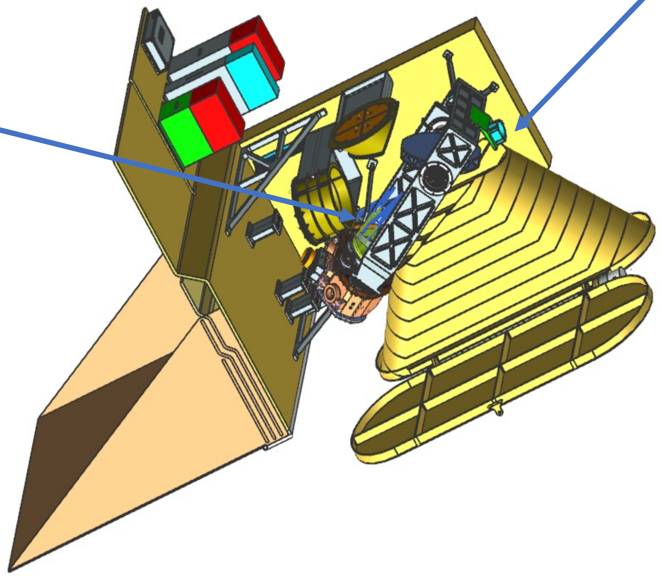
- Earliest Launch Readiness Dates:
  - TIR: 2027
  - VSWIR: 2028

SBG TIR Key Instrument Parameters

Key Parameters	SBG-TIR
Number of satellites	1
Combined revisit (days)	≤ 3 (different obs. angles)
Nominal Altitude (km)	665
Orbit cycle (days)	3
GSD (nadir/edge of scan) (m)	TIR: ≤60 /93, VNIR: ≤30 /52*
FOV (degrees)	± 34.4
Swath (km)	935
Coverage	Land and Coastal
Day/Night	Day + Night
LTDN	12:30
LWIR bands (8-12 µm)	6
VNIR/SWIR/MWIR	2/0/2
Accuracy (K)	0.5
NeDT (K)	<0.2
Data latency (hours)	<24

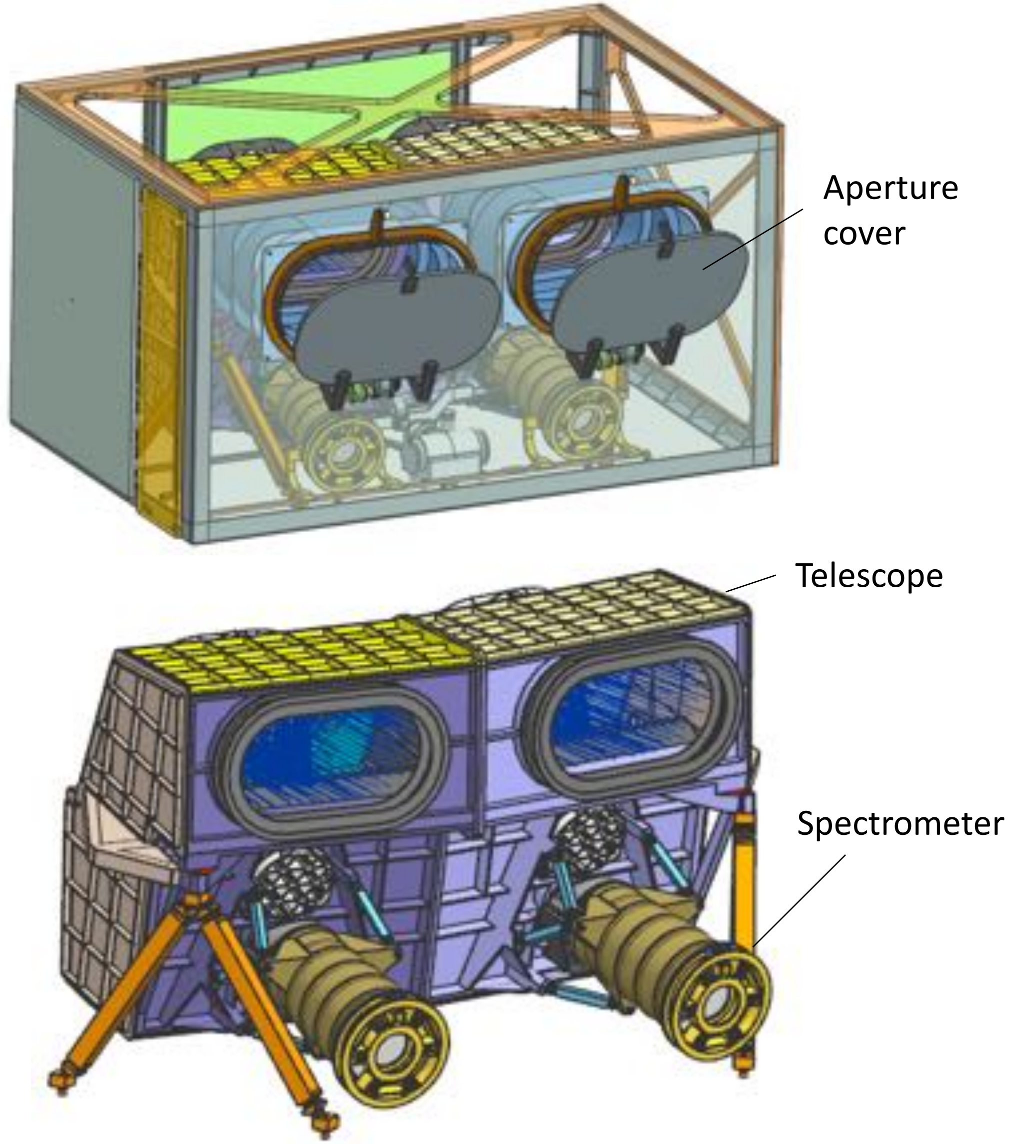
* Based on angle will be less when combine with mask





SBG VSWIR Key Instrument Parameters

Key Parameters	SBG-VSWIR
Number of satellites	1
Combined revisit (days)	≤ 16
Nominal Altitude (km)	~620
GSD (nadir) (m)	30-35
FOV (degrees)	± 8.1
Swath (km)	180
Coverage	Land and Coastal
Day/Night	Day
LTDN	~11am
Spectral range (nm)	380 - 2500
Spectral sampling (nm)	10
Signal to Noise, VNIR*	400
Signal to Noise, SWIR*	250
Data latency (hours)	<24



* Typical value, reference observation with equatorial illumination and 25% surface reflectance

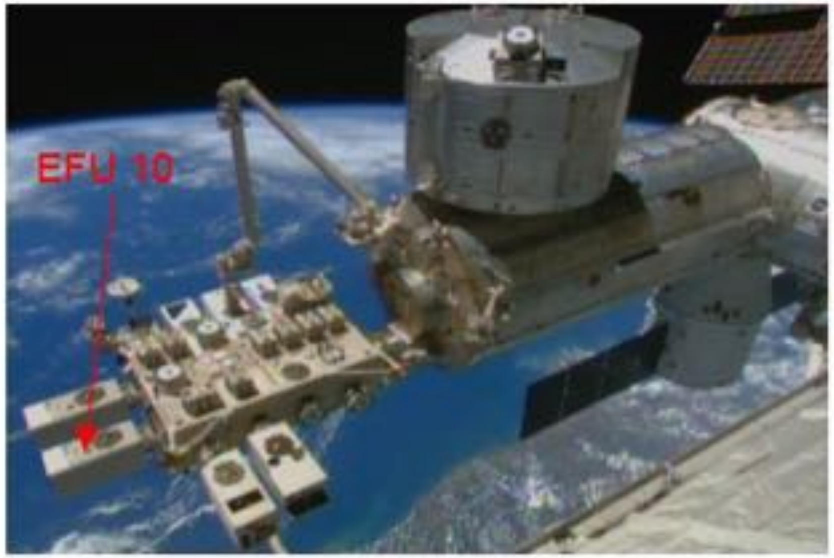
ECOSTRESS Project Overview

Salient Features

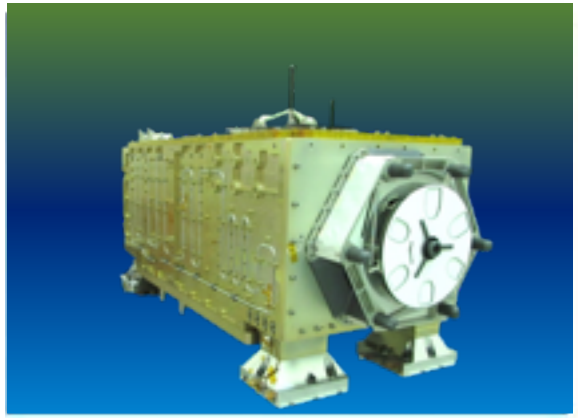
- *Category: 3, Risk Class: D*
- *8–12.5 µm radiometer with a 400km swath, 69 x 38 m resolution*
- *Measure brightness temperatures of Earth in 5 spectral bands*
- *Launched on SpX-15 on June 29, 2018*
- *Deployed on the ISS on JEM-EFU 10*
- *Baseline Operations: 1 year after 30 days on-orbit checkout*
- *Prime Mission Completed August 19, 2019*
- *In 2019 Phase E extended until September 2023*
- *In 2023 Phase E extended until 2029*

Original Science Goals

- *ECOSTRESS will measure the temperature of plants and use that information to better understand how much water plants need and how they respond to stress via high spatiotemporal resolution thermal infrared measurements of evapotranspiration from the International Space Station (ISS).*
- *ECOSTRESS will:*
    - *Identify critical thresholds of water use and water stress in critical plant biomes*
    - *Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the diurnal cycle*
    - *Measure agricultural water consumptive use over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy*



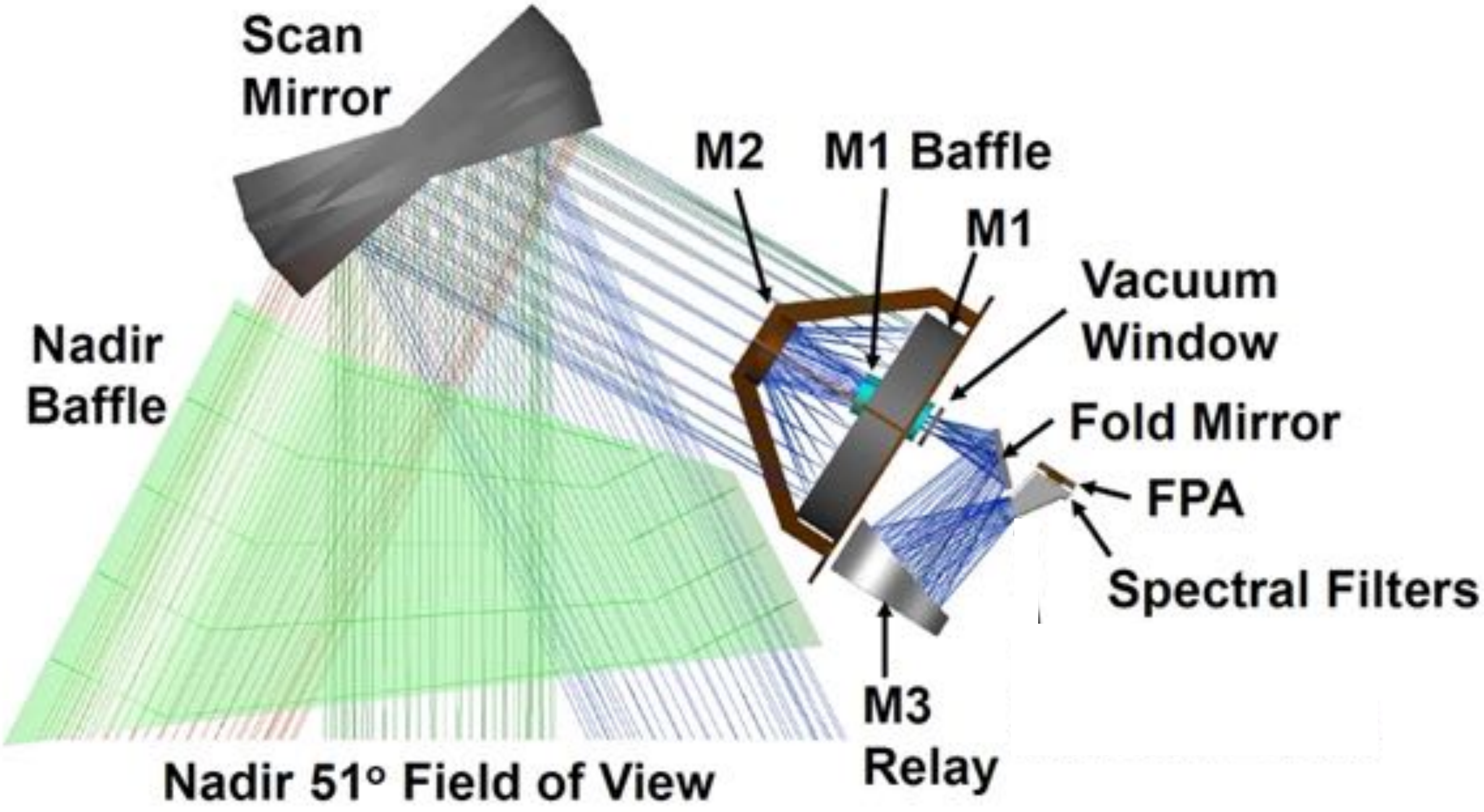
ISS JEM-EF



ECOSTRESS

Falcon-9

ECOSTRESS Instrument and Properties



ECOSTRESS Imaging Radiometer Elements

- **Three mirror Korsch Telescope + Scanner + built-in vacuum enclosure**
  - All aluminum and gold coated
  - Scan (double sided planar)
  - M1 (asphere)
  - M2 (y-decentered, ashpere)
  - M3 (y-decentered, asphere)
  - Flat fold mirror (planar)

FPA assembly

- Butcher block filter array (holds up to 6 filters)
- Detector (HgCdTe)
  - 256 x 16 x 8 format
  - 40 μm pixel size

Key ECOSTRESS Properties

F-number	F/2.1
Cross-track FOV	51°
IFOV (cross-track x along-track)	190 x 173 μrads
Focal length	420 mm
Entrance pupil aperture	200 mm
Spectral range	8.1 to 12.4 μm
Spectral sampling	5 bands

Two full aperture onboard blackbodies used for calibration
69 x 76 m ground sampling (resampled)
384 km swath width (400km ISS altitude)

EMIT Project Overview

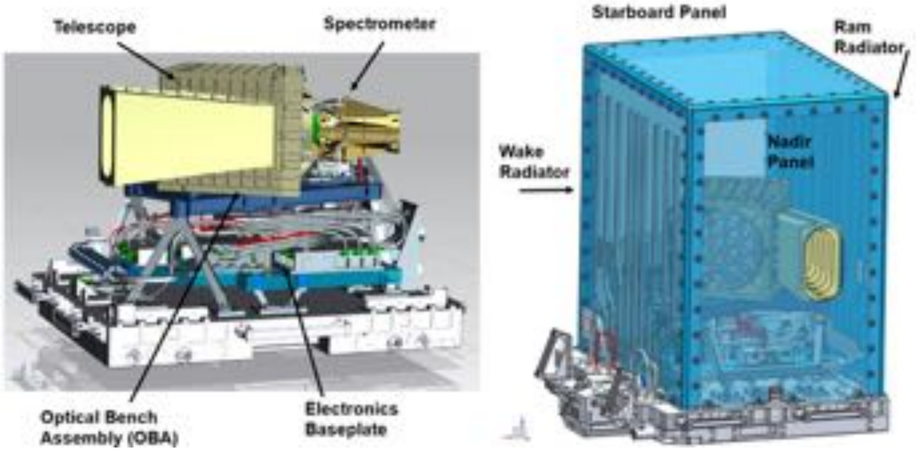
Salient Features

- *Risk Class: C*
- *380-2500 nm imaging spectrometer with 10 nm spectral sampling*
- *75km swath, 60 m sampling*
- *98% spectral uniformity*
- *Launched on SpX-25 on July 15, 2022*
- *Deployed on the ISS on ELC FRAM*
- *Baseline Operations: 1 year after 30 days on-orbit checkout*
- *Prime Mission in progress*
- *Extension possible*

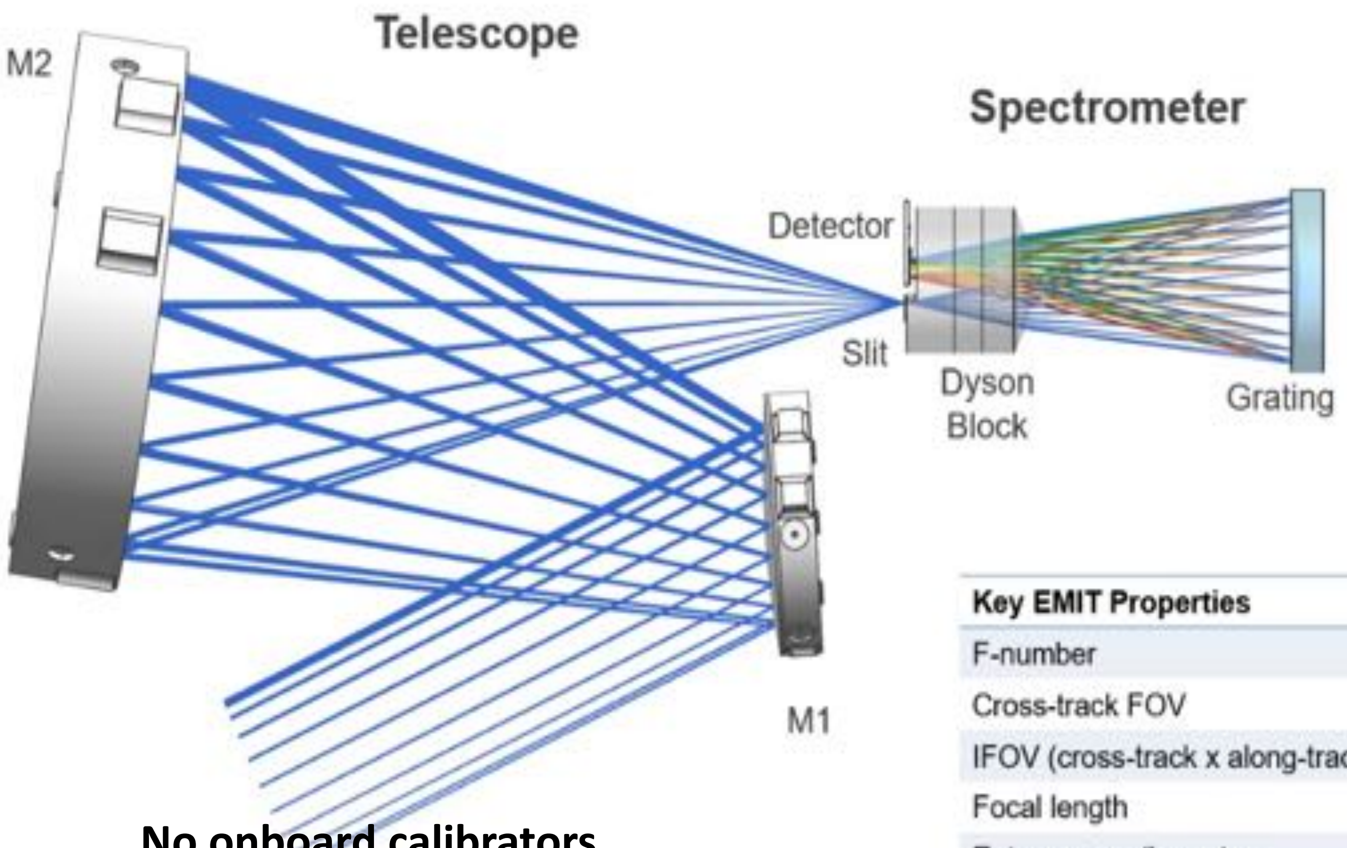
Original Science Goals

1. Constrain the sign and magnitude of dust-related RF at regional and global scales.
EMIT achieves this objective by acquiring, validating and delivering updates of surface mineralogy used to initialize Earth System Models.

2. Predict the increase or decrease of available dust sources under future climate scenarios.
EMIT achieves this objective by initializing Earth System Model forecast models with the mineralogy of soils exposed within at-risk lands bordering arid dust source regions.



EMIT Instrument and Properties



EMIT Imaging Spectrometer Elements

- **Two-mirror Telescope**
  - M1 (y-decentered, asphere)
  - M2 (y-decentered, asphere)
- **Dyson spectrometer**
  - Dyson block: CaF2 lens with step
  - Slit (30 µm width, 37.2 mm length)
  - Diffraction grating (structured blaze)
- **FPA Assembly**
  - Order sorting filter (three zone)
  - Detector (HgMgTe)
    - 1280 x 480 pixel format
    - 30 µm pixel size

Key EMIT Properties	
F-number	F/1.8
Cross-track FOV	11°
IFOV (cross-track x along-track)	155 x 171 µrad
Focal length	193.5 mm
Entrance pupil aperture	110 mm
Spectral Range	380 – 2500 nm
Spectral Sampling	7.4 nm

No onboard calibrators
60 m ground sampling
75 km swath width

Comparison of LSTM, TRISHNA and SBG-TIR

	LSTM	TRISHNA	SBG-TIR
Number of satellites	2	1	1
Combined revisit (days)	2 (same obs. angles)	≤ 3 (different obs. angles)	≤ 3 (same obs. angles)
Nominal Altitude (km)	649	761	665
Orbit cycle (days)	4 (for each sat.)	8	3
GSD (nadir/edge of scan) (m)	37/50	57/60	TIR: ≤60 /93, VNIR: ≤30 /52*
FOV (degrees)	± 28	± 34	± 34.4
Swath (km)	700	1000	935
Coverage	Land and Coastal	Land and Coastal	Land and Coastal
Day/Night	Day + Night	Day + Night	Day + Night
LTDN	12:30	13:00	12:30
LWIR bands (8-12 µm)	5	4	6
VNIR/SWIR/MWIR	4/2/0	5/2/0	2/0/2
Accuracy (K)	0.5	0.5	0.5
NeDT (K)	<0.15	<0.2	<0.2
Data latency (hours)	6-12	12 (demo)	<24

* Based on angle for SBG, for other instruments based on combination of angle and mask

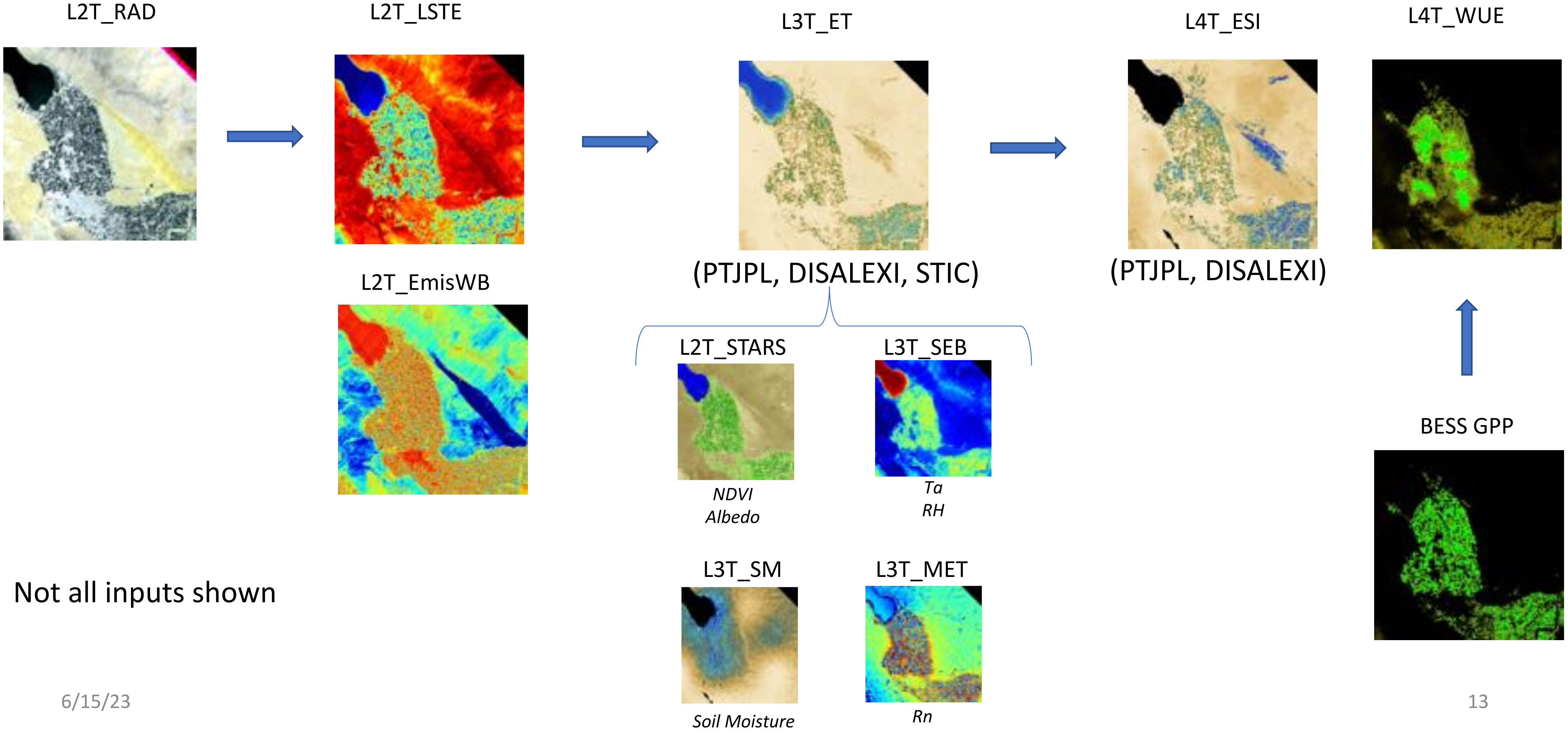
Comparison of SBG-VSWIR, CHIME and PRISMA-NG

	SBG-VSWIR	CHIME	PRISMA-NG
Number of satellites	1	2	2
Combined revisit (days)	≤ 16	10-12.5	3-6 days (pointing capability ± 40°)
Nominal Altitude (km)	~620	632	
GSD (nadir) (m)	30-35	30	hyperspctral instrument: STRIPMAP ≤ 30 m SPOTLIGHT≤ 10 m Pancromatic STRIPMAP ≤ 5 m SPOTLIGHT≤ 2.5 m
FOV (degrees)	± 8.1	± 5.8	
Swath (km)	180	~130	STRIPMAP ≥30 km up to 90 km (mosaic multiple images) SPOTLIGHT ≥30 km up to 60 km (mosaic multiple images)
Coverage	Land and Coastal	Land	Land
Day/Night	Day	Day	Day
LTDN	~11am	10:30-11:30 am	10:30
Spectral range (nm)	380 - 2500	400-2500	400-2500
Spectral sampling (nm)	10	<10	<10
Signal to Noise, VNIR*	400		>200
Signal to Noise, SWIR*	250		>100

ECOSTRESS Data Processing Flow

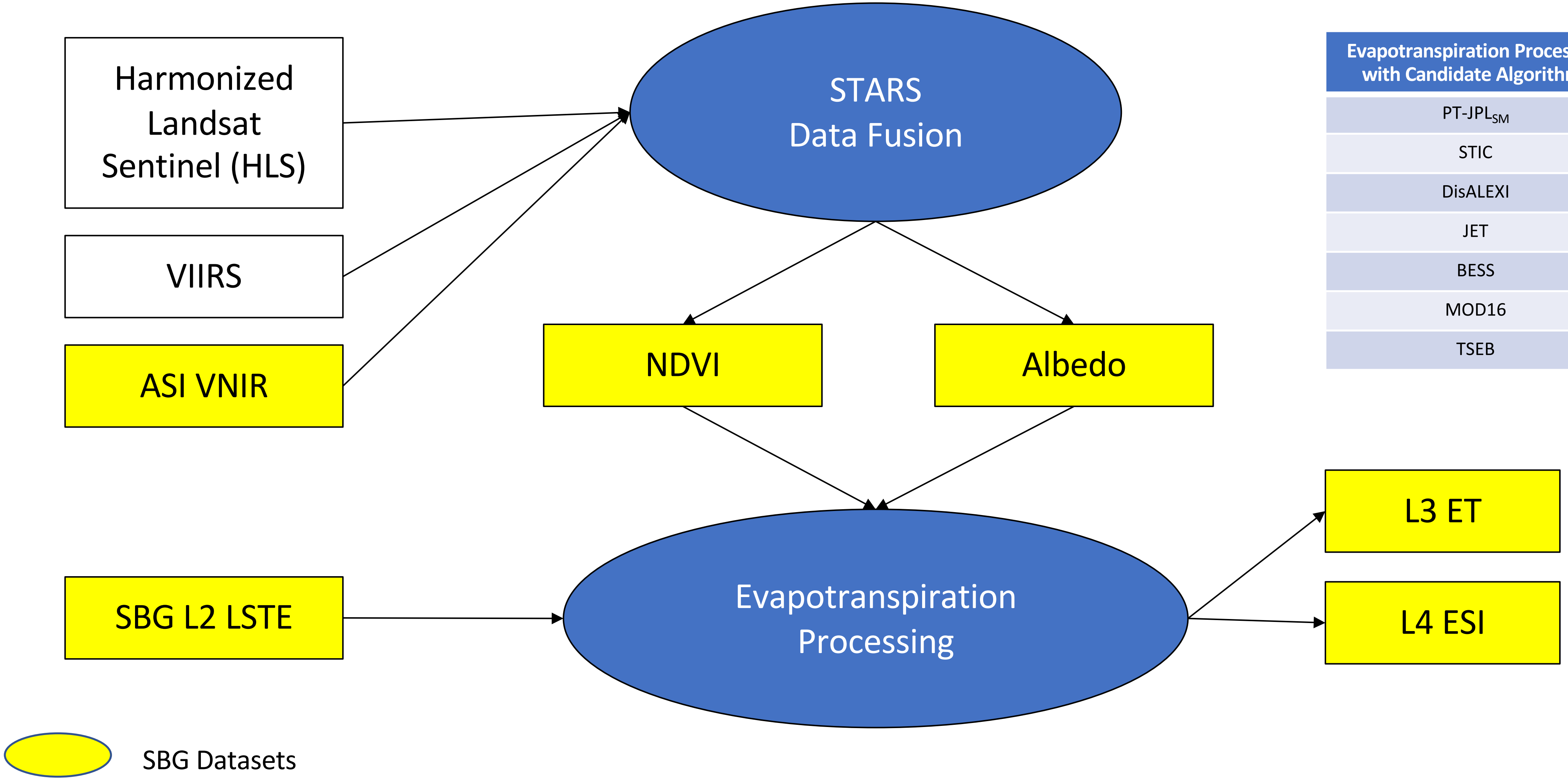
ECOSTRESS Data Analysis

Uncertainties included for all products



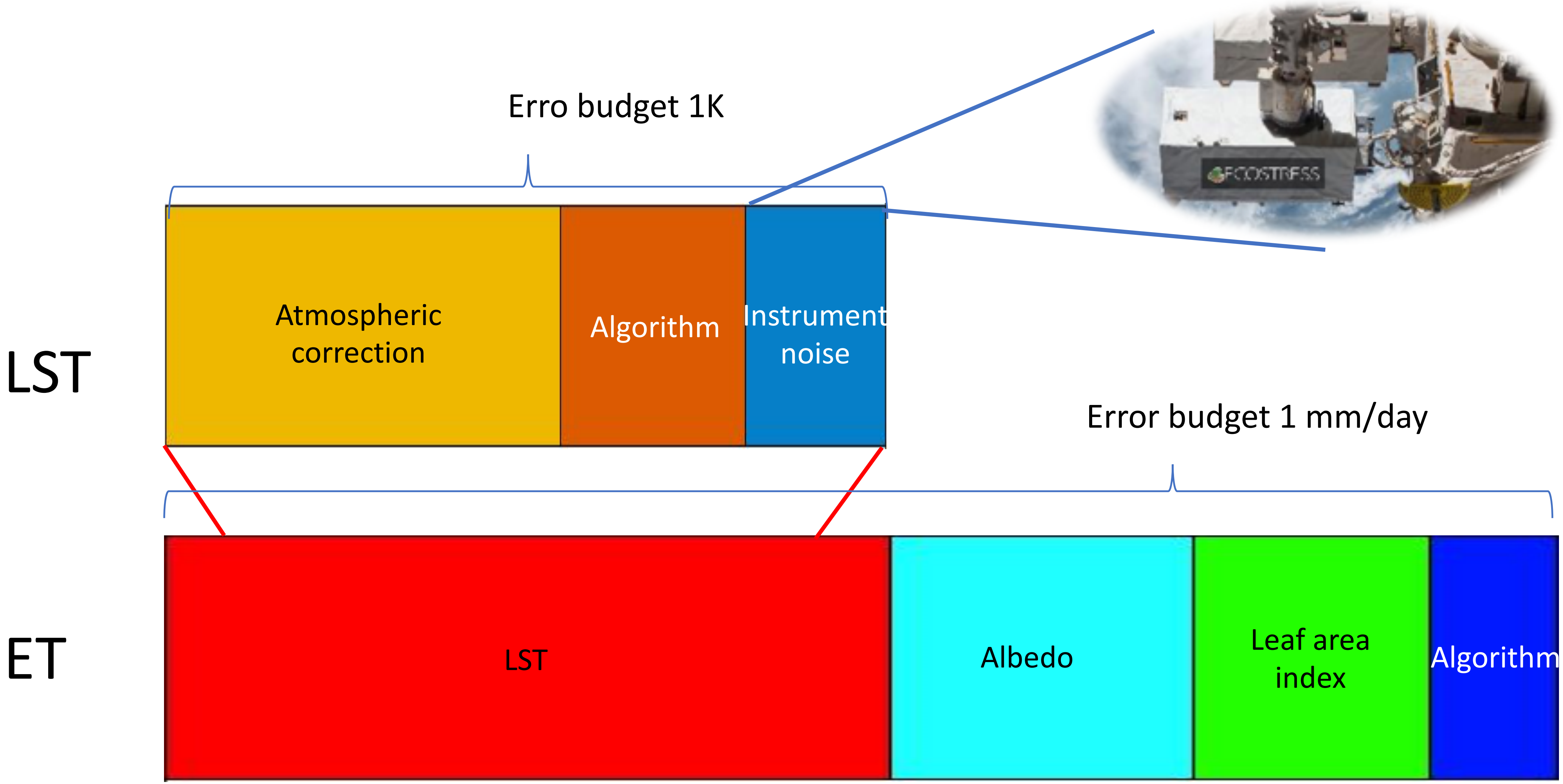
Not all inputs shown

Evapotranspiration Processing Workflow



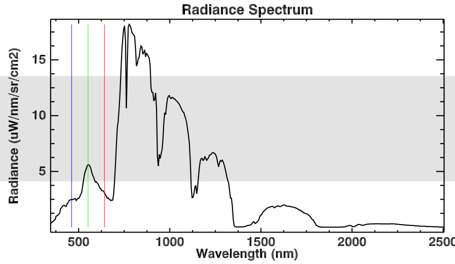
Evapotranspiration Processing with Candidate Algorithms
PT-JPL$_{SM}$
STIC
DisALEXI
JET
BESS
MOD16
TSEB

Surface Temperature and Evapotranspiration Error Budgets

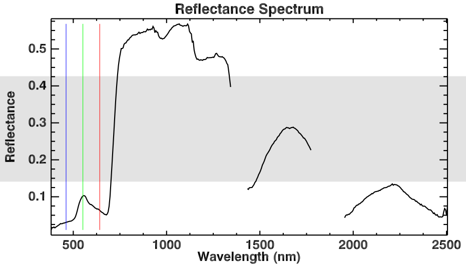


EMIT Data Processing Flow

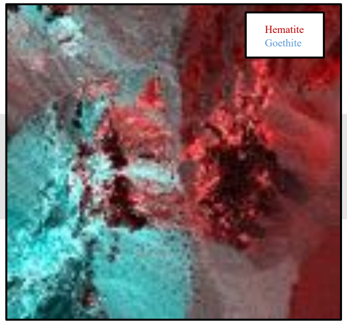
EMIT Data Analysis



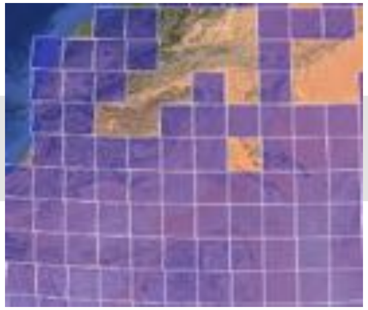
L1b: Radiance at Sensor



L2a: Surface Reflectance (HRDF)

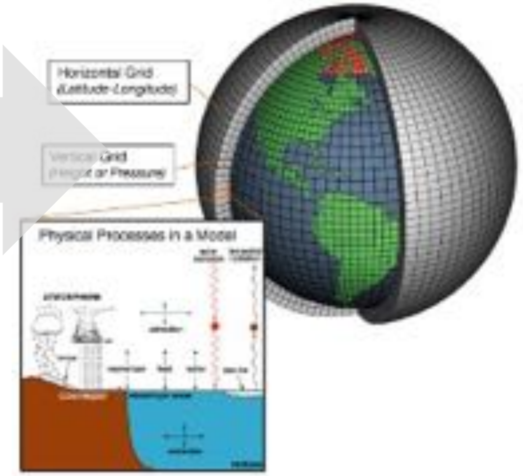


L2b: Mineralogical Maps



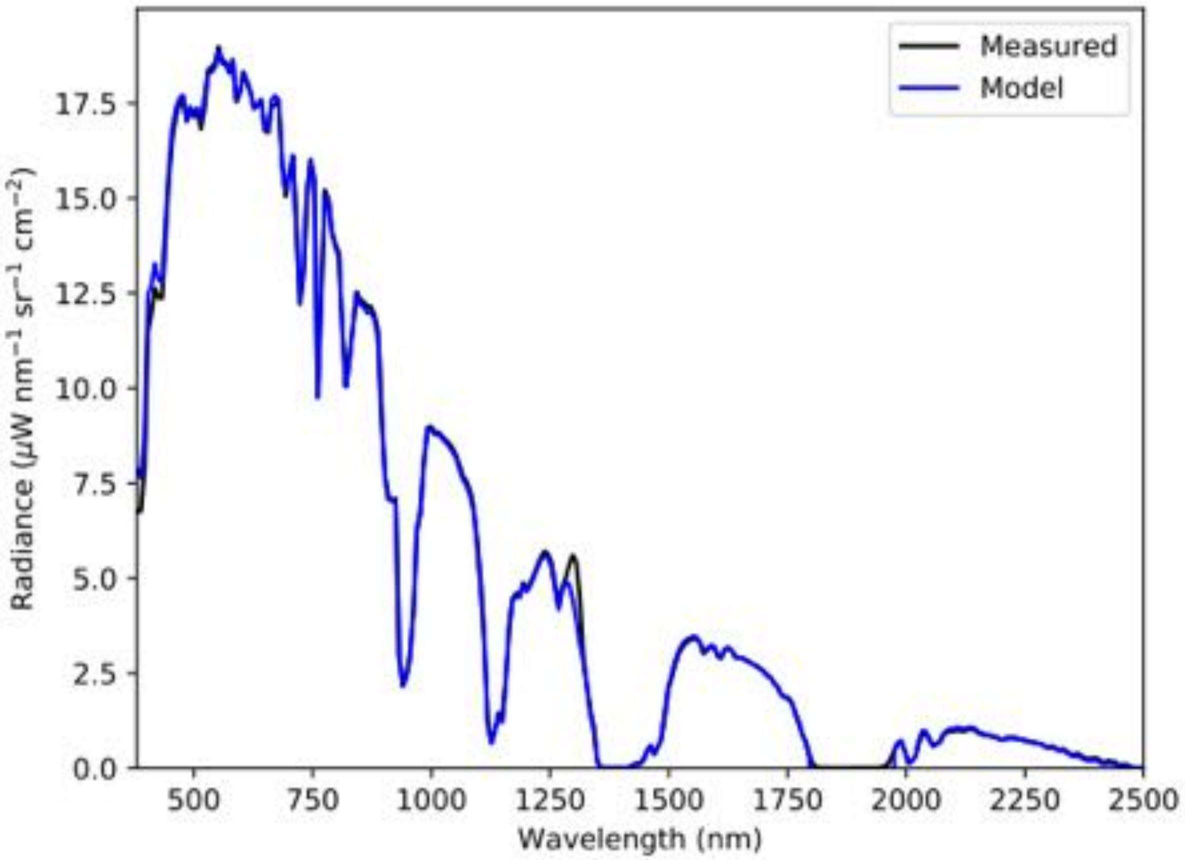
L3: Aggregated Mineralogy

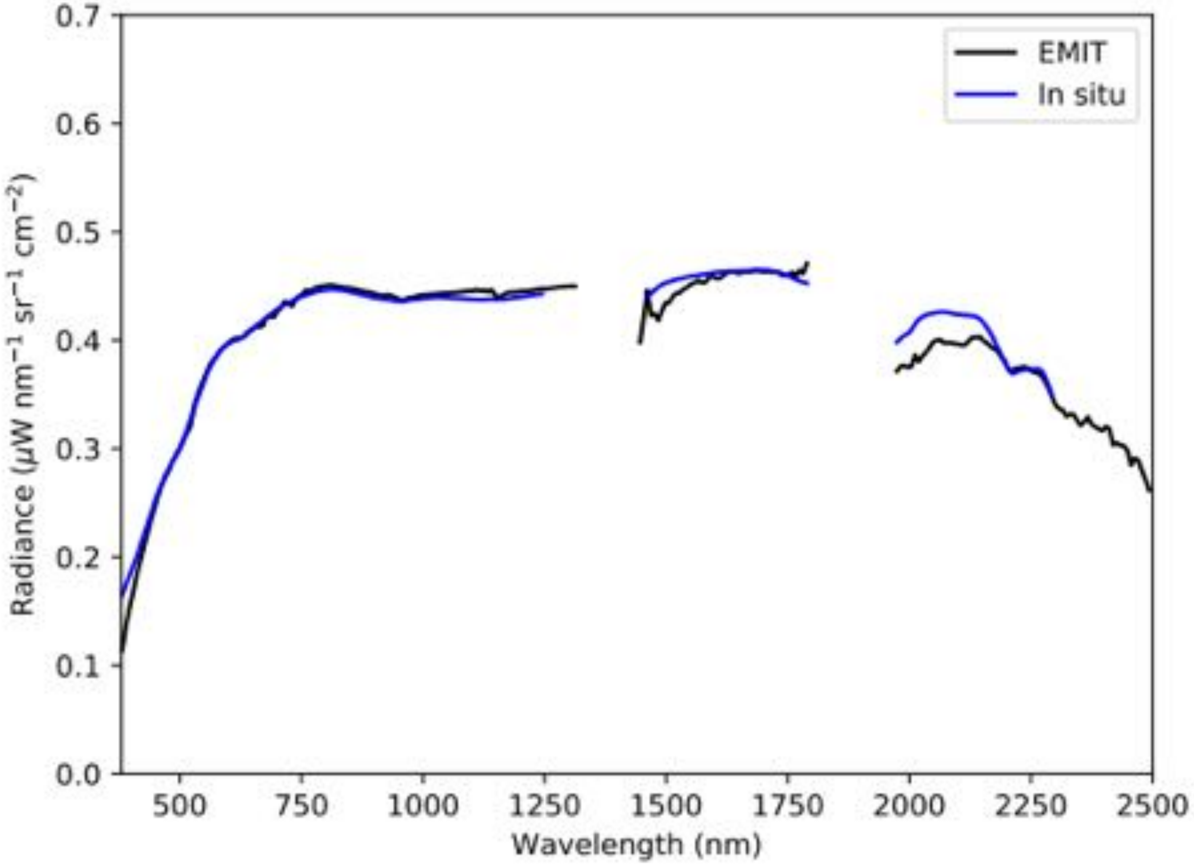
L4: CESM, GISS Model Runs



Uncertainties distributed for all products

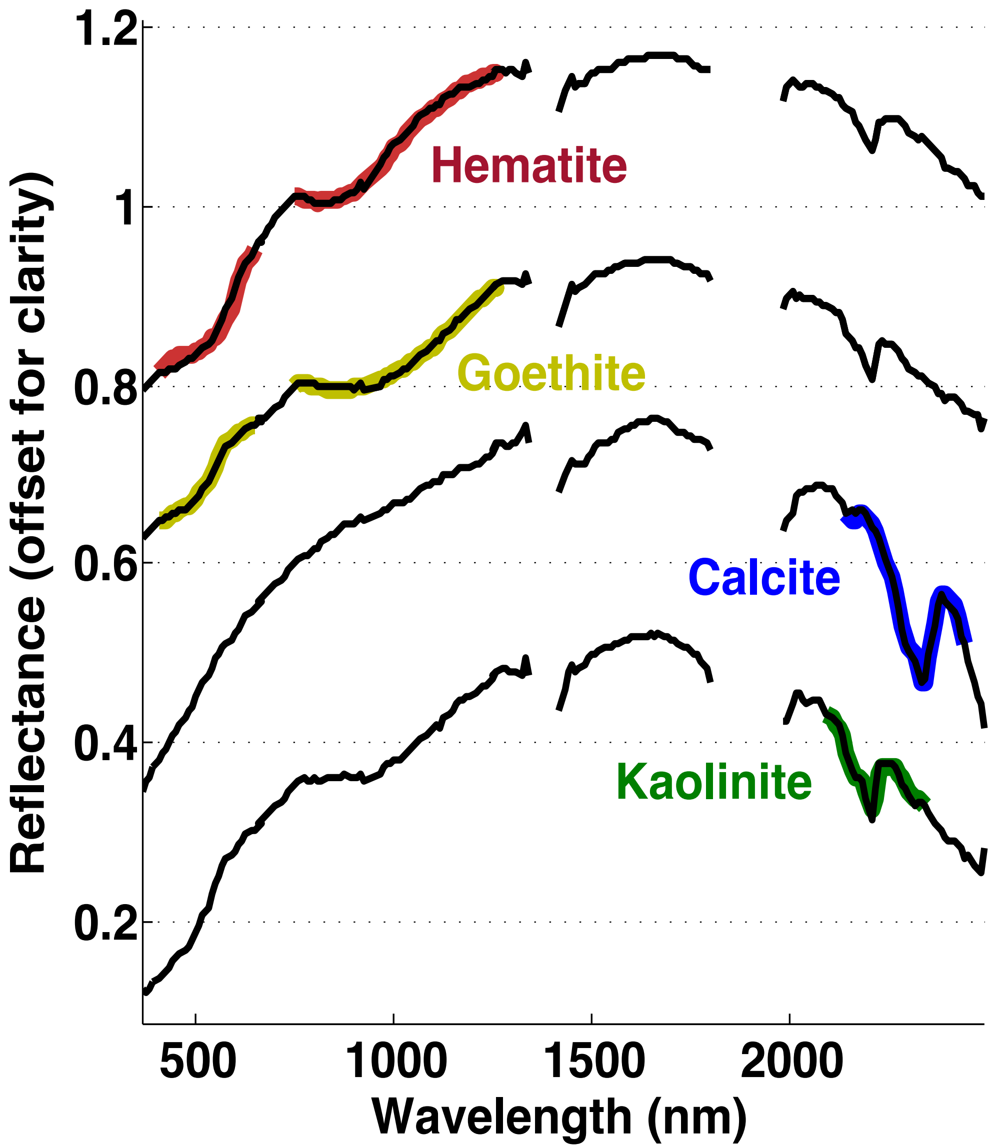
Railroad Valley validation experiment





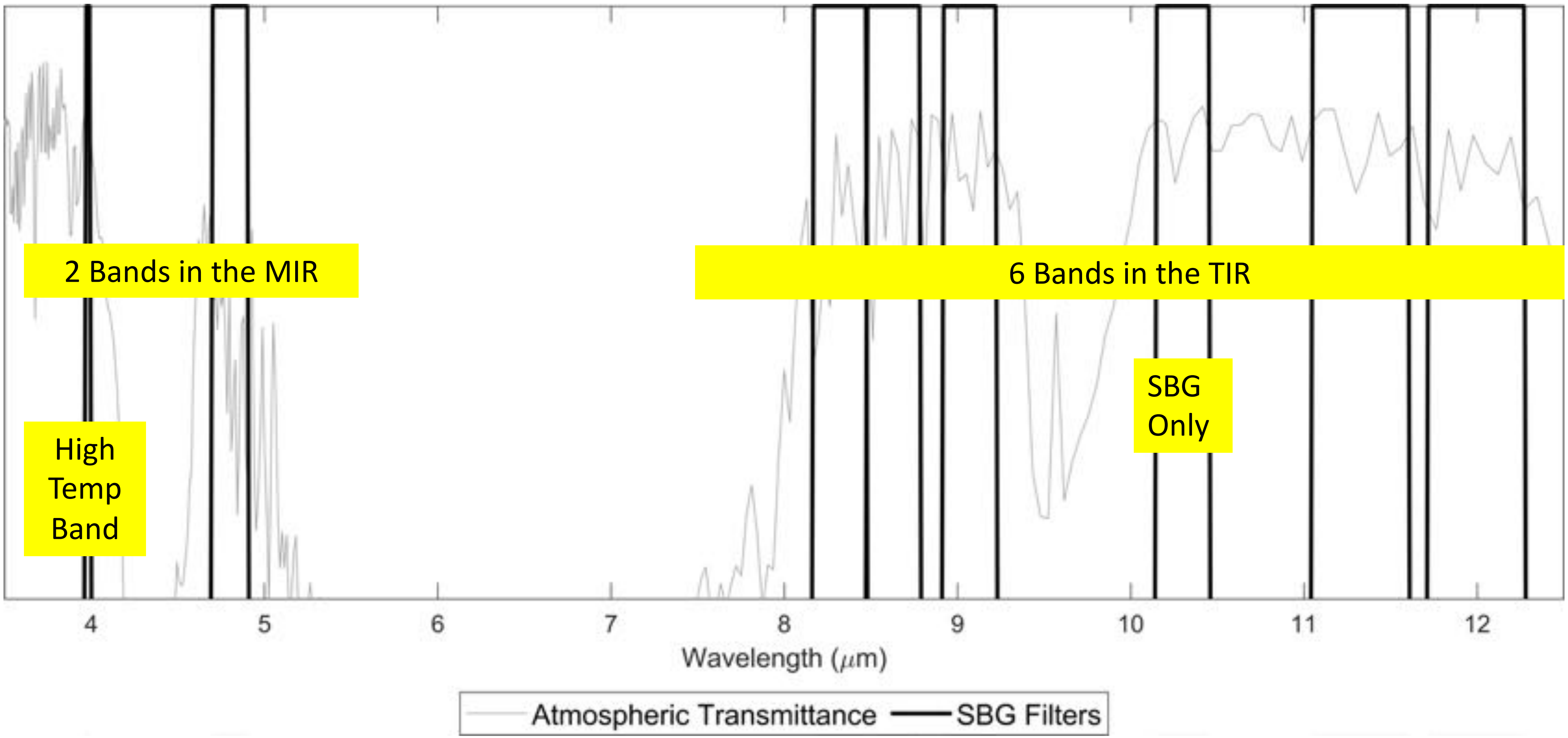
Example EMIT Retrievals

Mineral features measured with directional surface reflectance

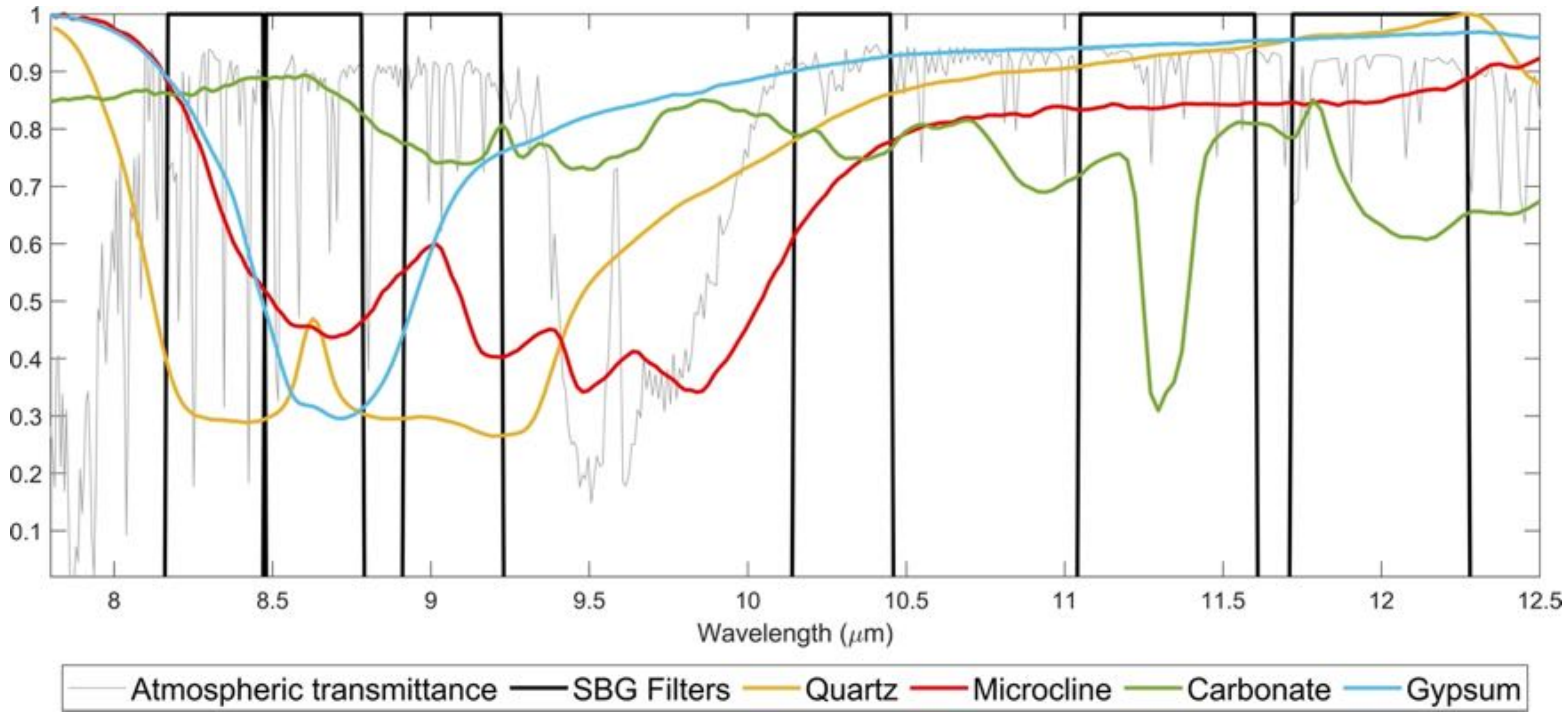


ECOSTRESS vs SBG For Geologic Studies

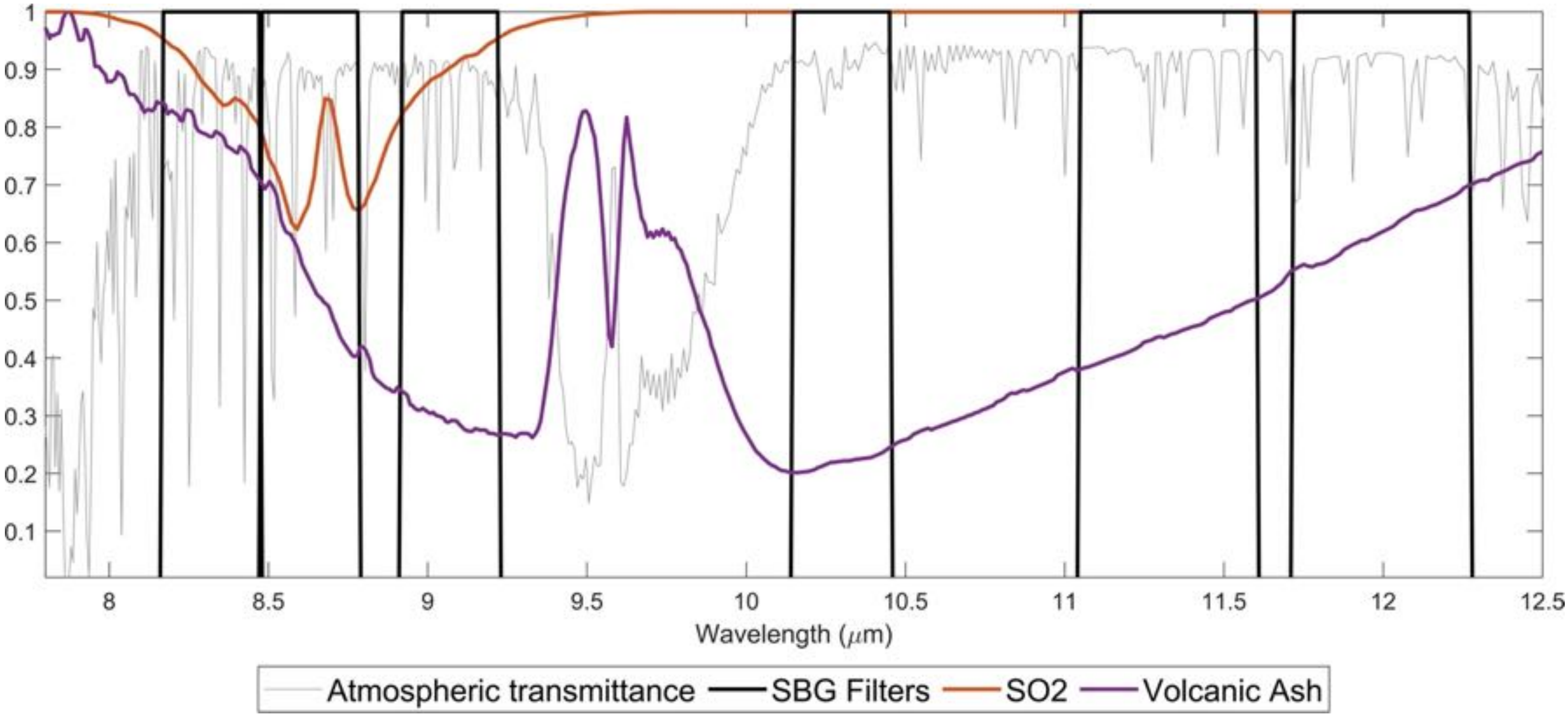
SBG Mid and TIR Band Positions



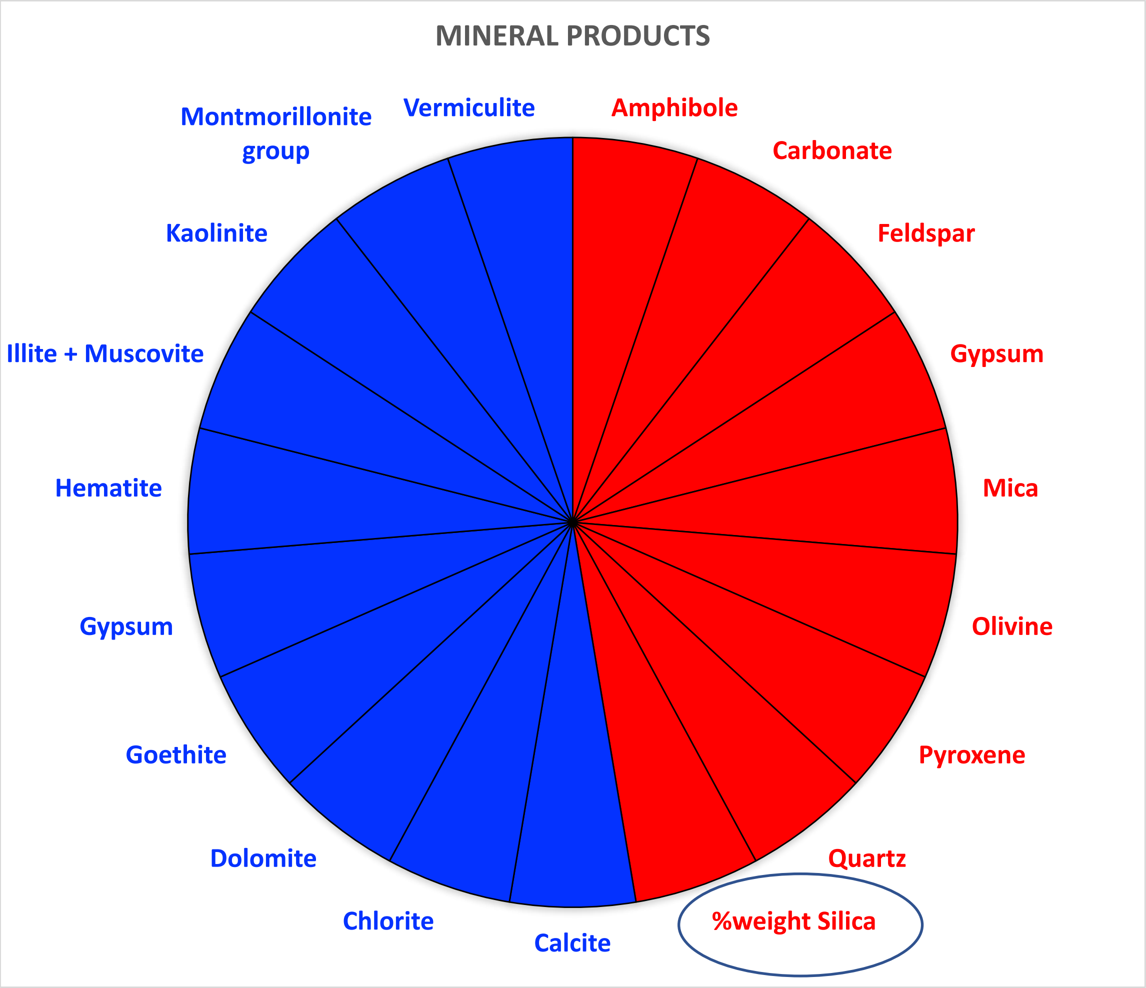
SBG-TIR Band Positions

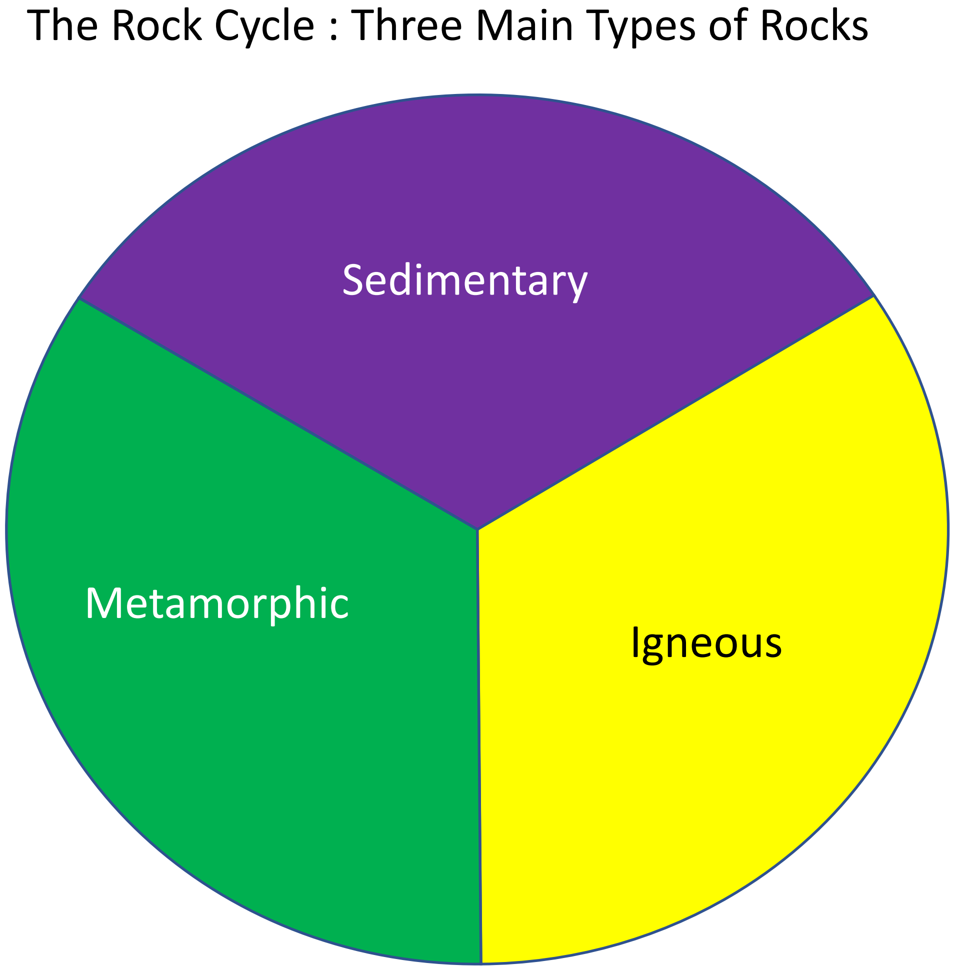


SBG-TIR Band Positions



SBG Mineral Mapping

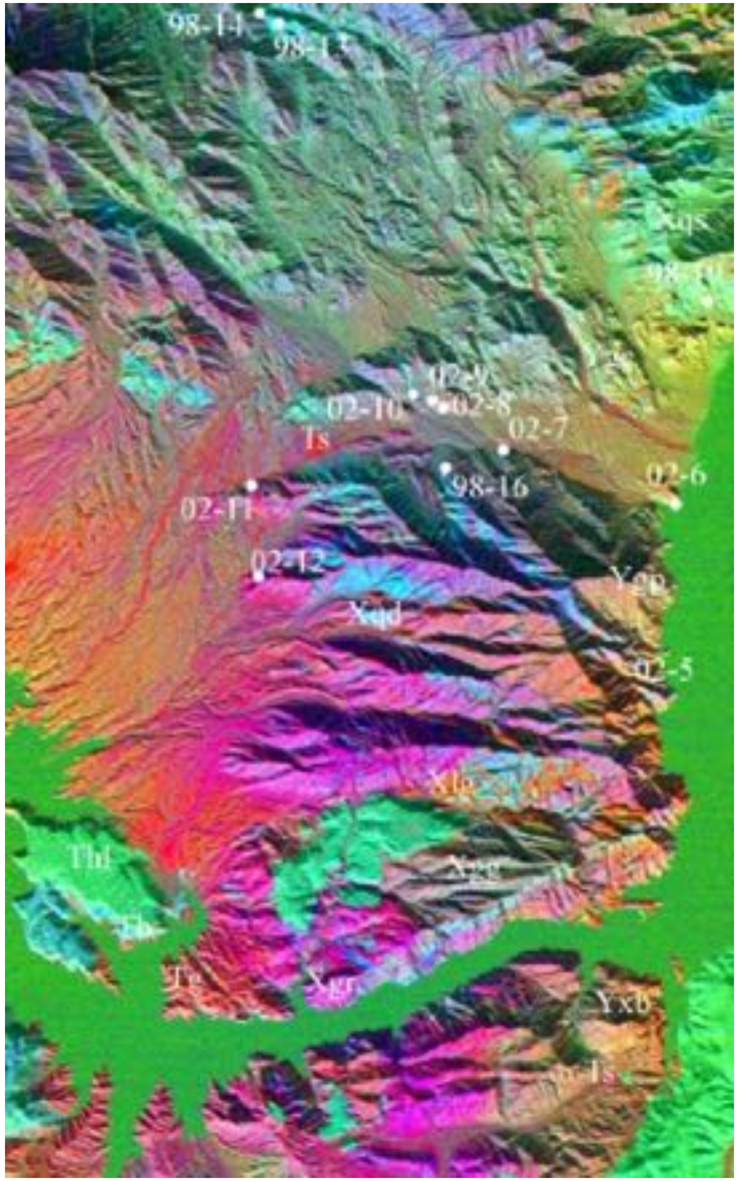


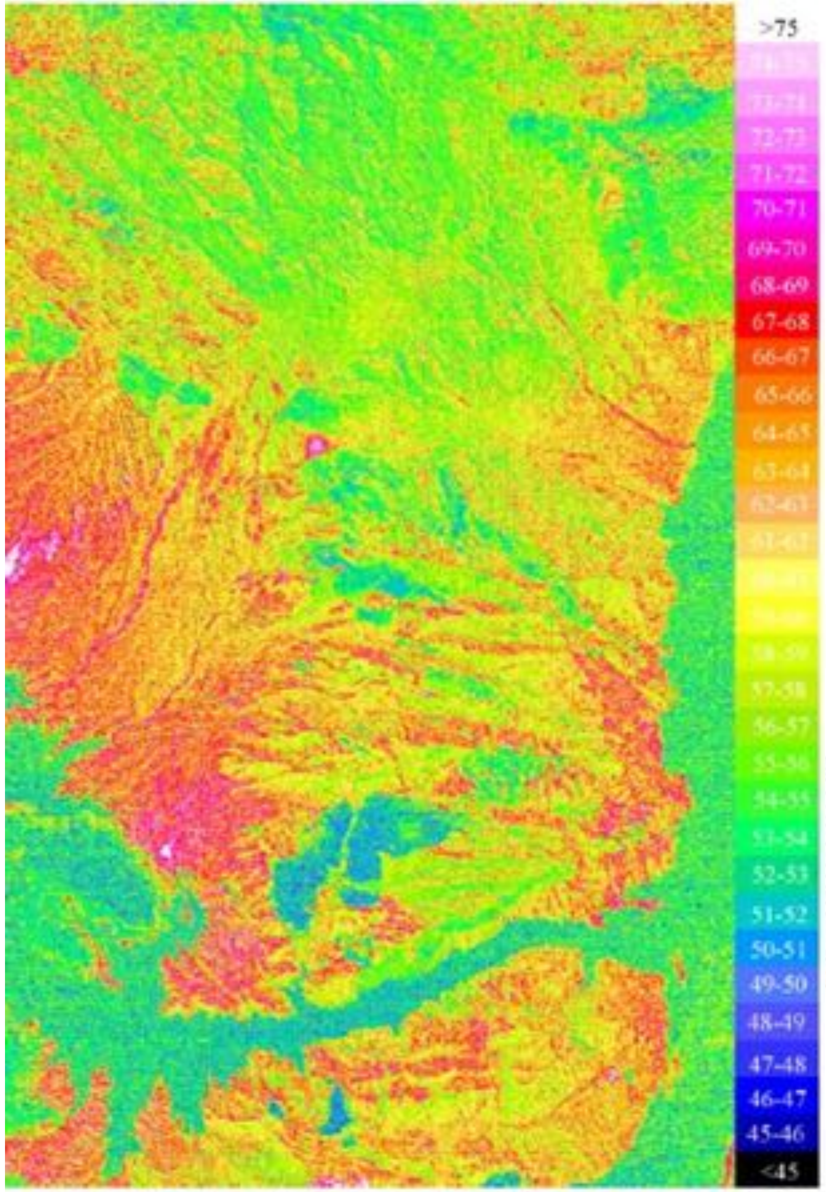


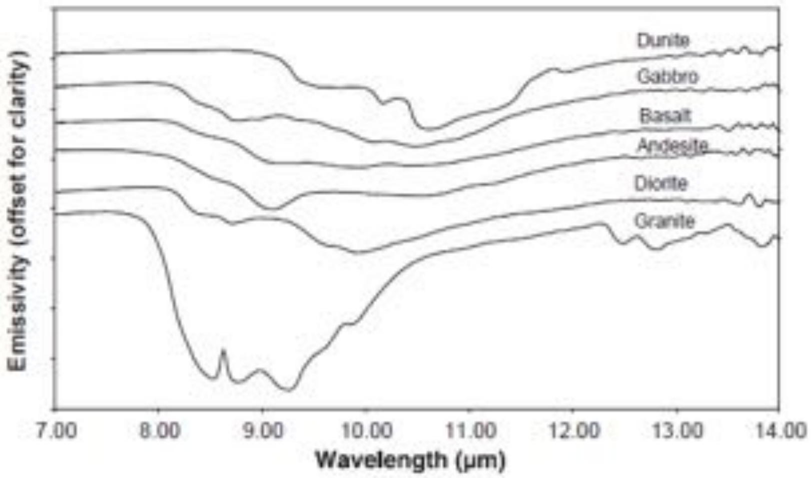
VSWIR TIR

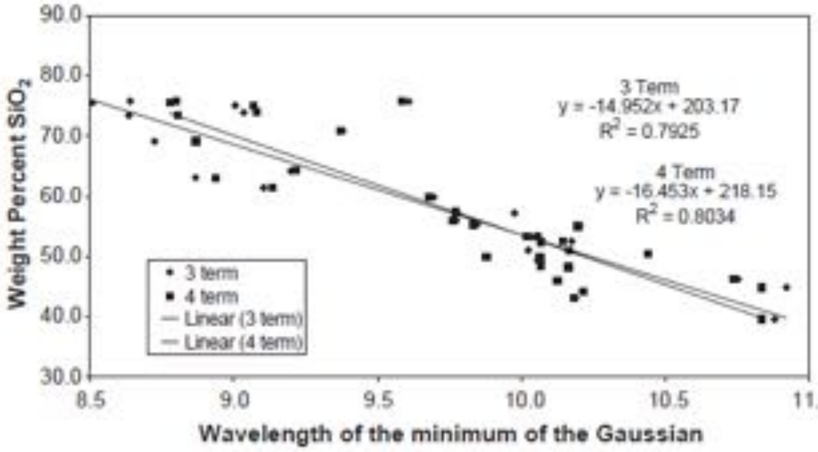
By combining SBG-VSWIR and SBG-TIR can map key rock forming minerals and associated rock types

Mapping Weight Percent Silica with MASTER TIR Airborne Data

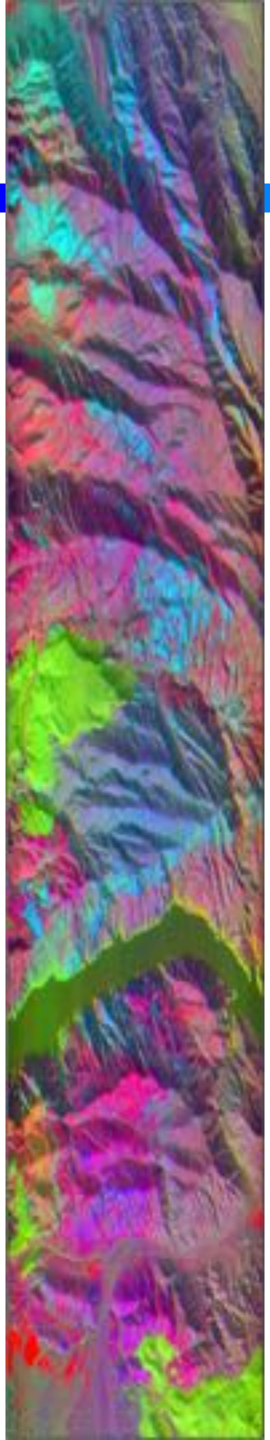


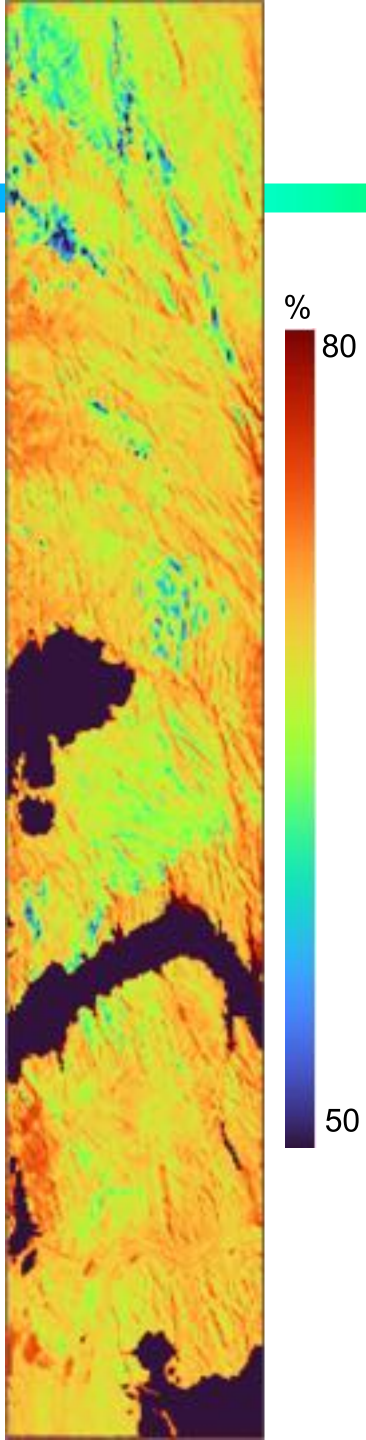




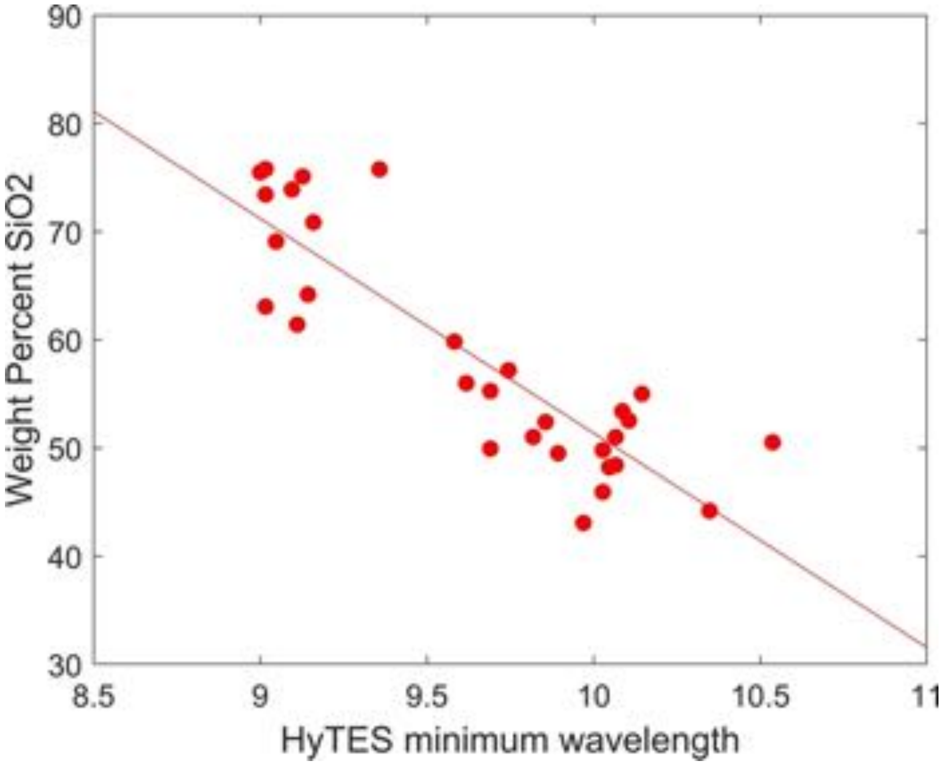


Mapping Weight Percent Silica with HyTES Airborne Data



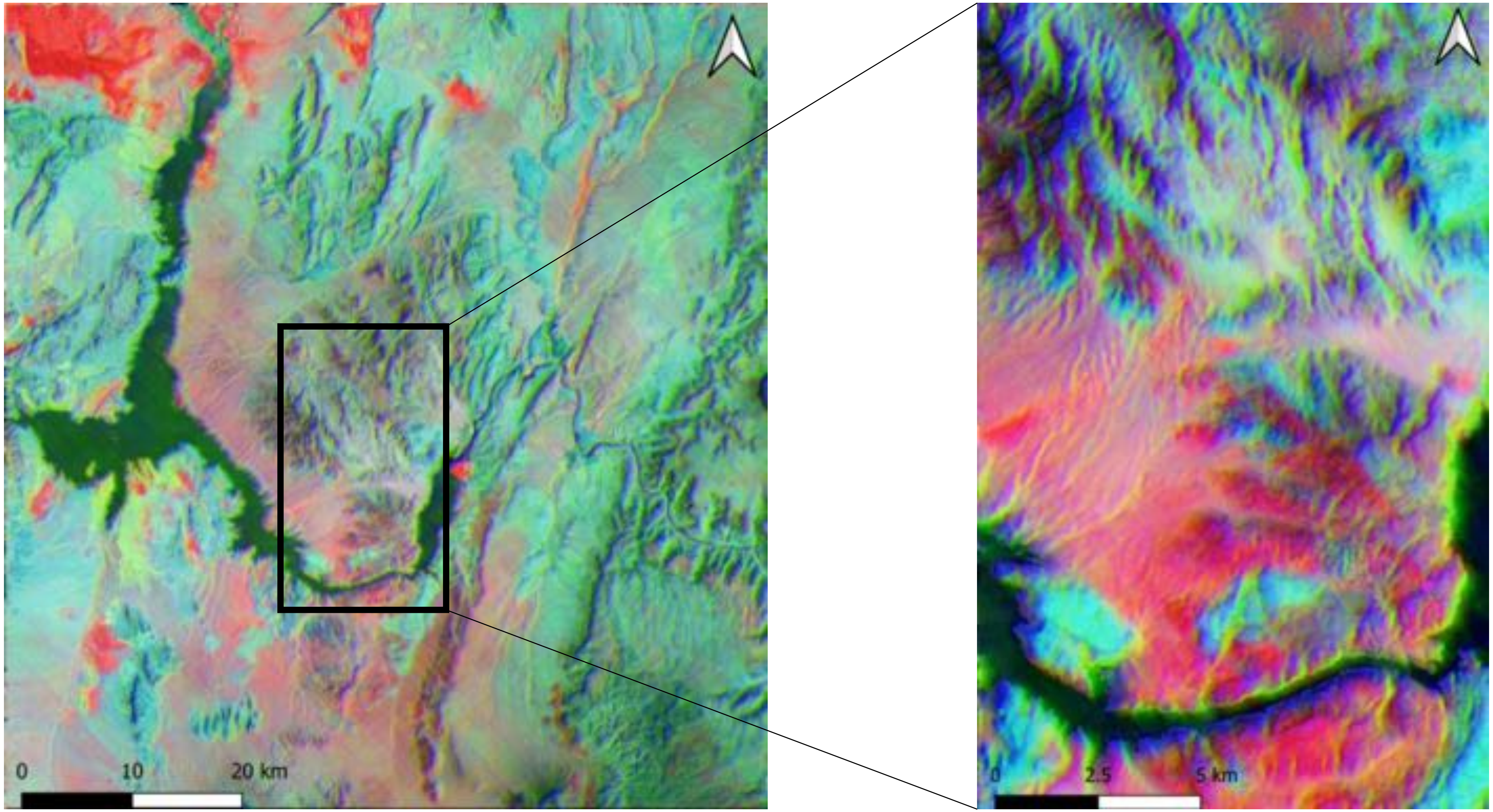


ECOlib spectra solid igneous rocks

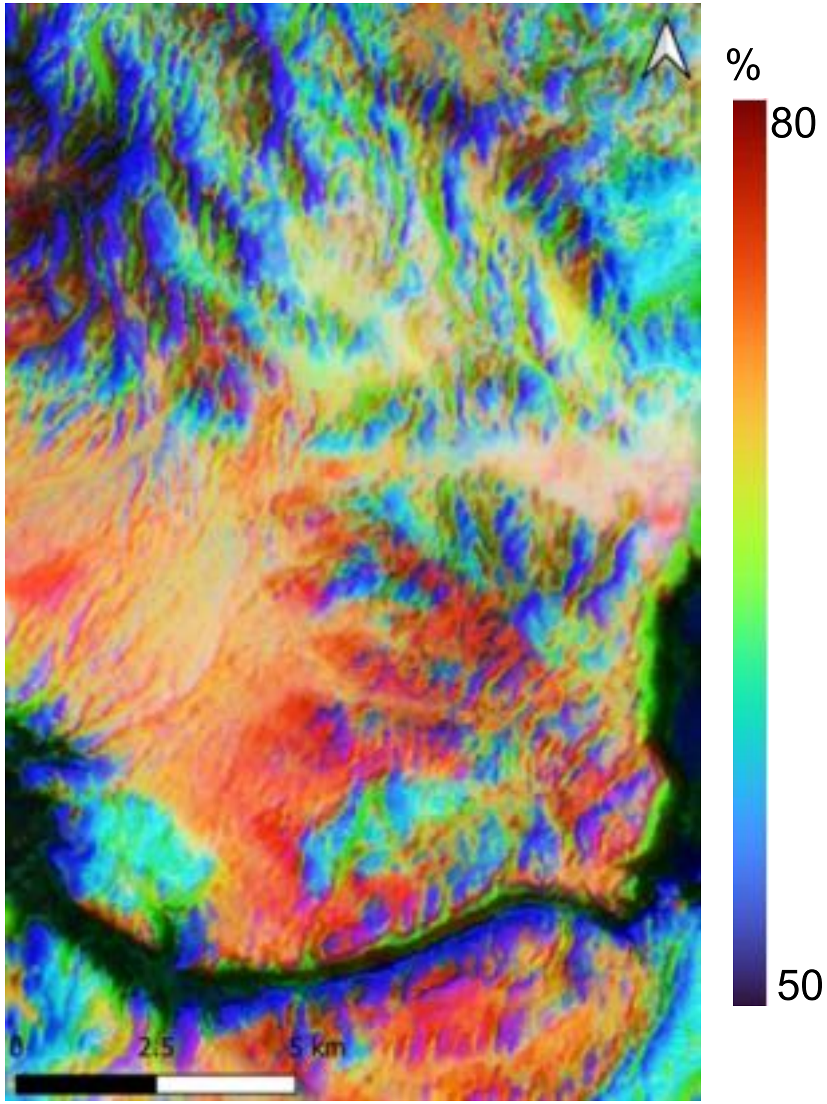


ECOSTRESS decorrelation stretch – Hiller mountains, NV

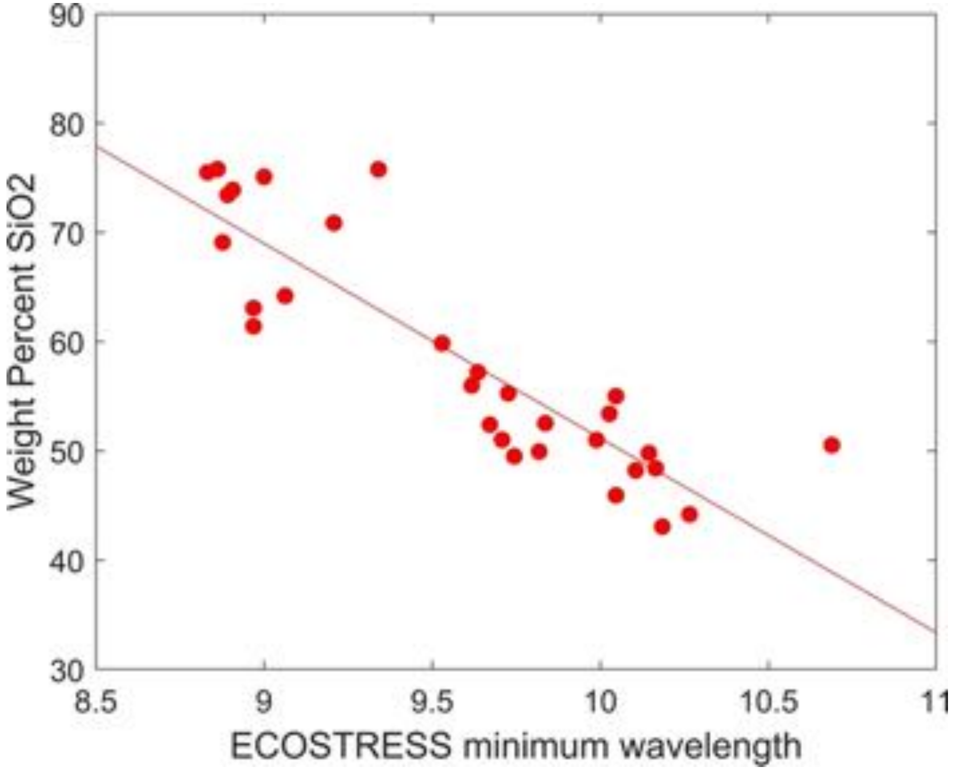
Bands 4-3-2 as RGB



Mapping Weight Percent Silica with ECOSTRESS Data



ECOlib spectra solid igneous rocks



Final Band Positions

MRD - 2023-04-26-UPDATE

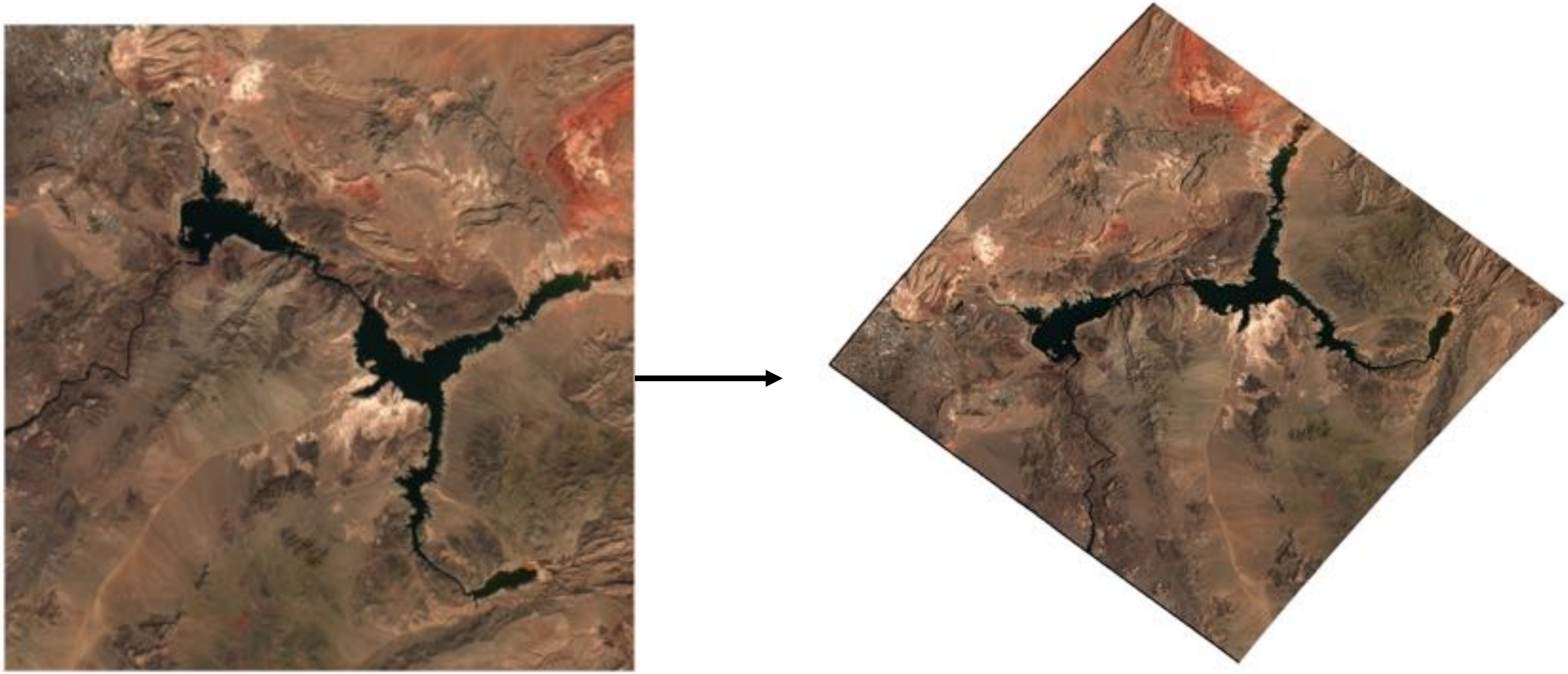
Band #	Center Wavelength (μm)	Spectral Width (FWHM) (nm)	Tolerance Center Wavelength (± nm)	Tolerance Spectral Width (±nm)	Knowledge Center Wavelength (±nm)	Knowledge Spectral Width (±nm)	Accuracy (Kelvin)	NEdT (Kelvin)	Range (Kelvin)
MIR-1	3.98	20 (TBC)	50	10	10	10	≤3@750	≤0.3@750	700-1200
MIR-2	4.8	150 (TBC)	100	50	20	20	≤1@450	≤0.2@450	400-800
TIR-1	8.32	300 (TBC)	100	50	20	20	≤0.5@275	≤0.2@275	200-500
TIR-2	8.63	300 (TBC)	100	50	20	20	≤0.5@275	≤0.2@275	200-500
TIR-3	9.07	300 (TBC)	100	50	20	20	≤0.5@275	≤0.2@275	200-500
TIR-4	10.30	300 (TBC)	50	50	20	20	≤0.5@275	≤0.2@275	200-500
TIR-5	11.35	500 (TBC)	100	50	20	20	≤0.5@275	≤0.2@275	200-500
TIR-6	12.05	500 (TBC)	100	50	20	20	≤0.5@275	≤0.2@275	200-500

Final band positions and tolerances for SBG-TIR bands

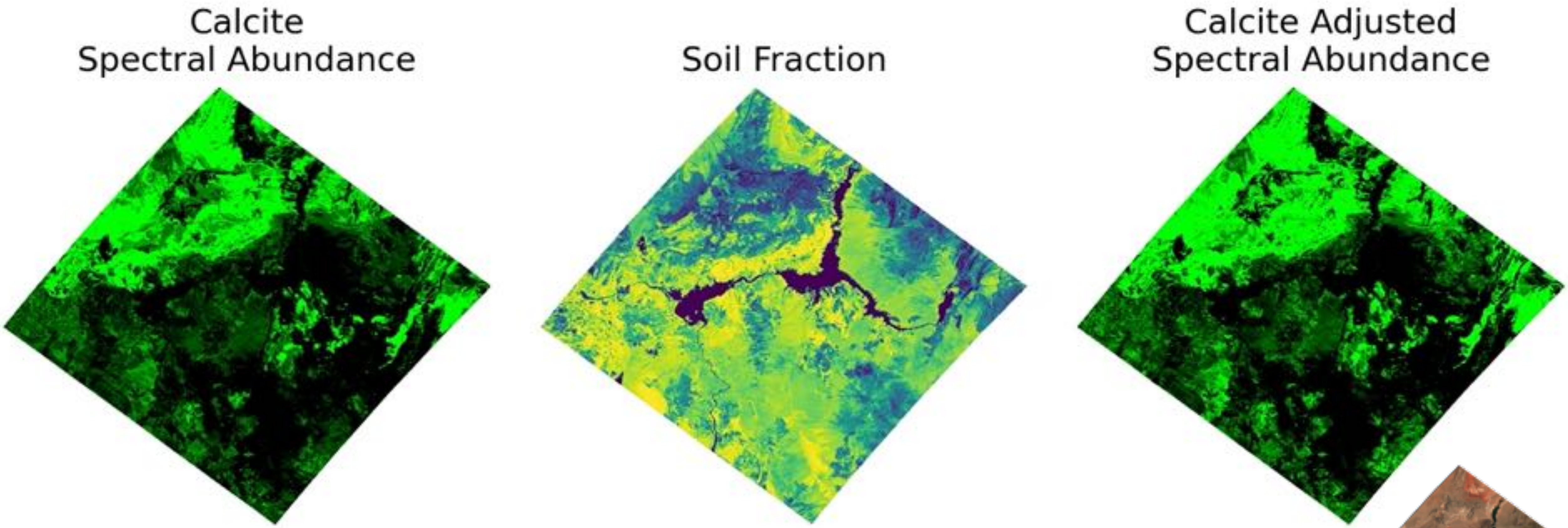
EMIT For Geologic Studies

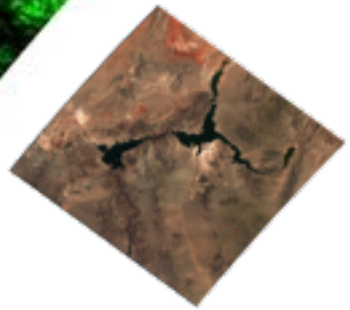
Projection to Map-Space

- Generate three dimensional look up tables of relative scene position and scene source, based on **L1B geospatial coordinates** and propagated estimates of **uncertainty**



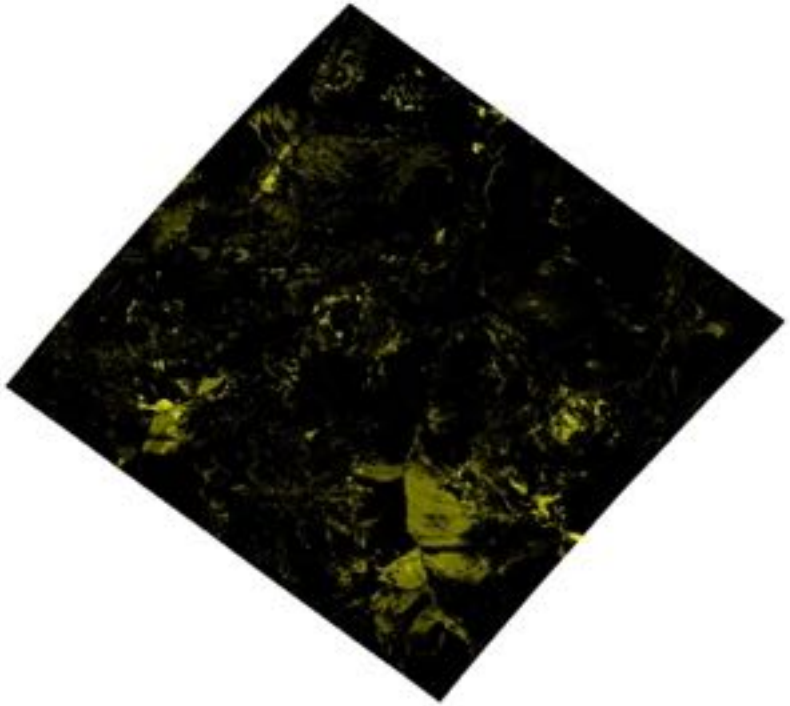
Vegetation Adjustment



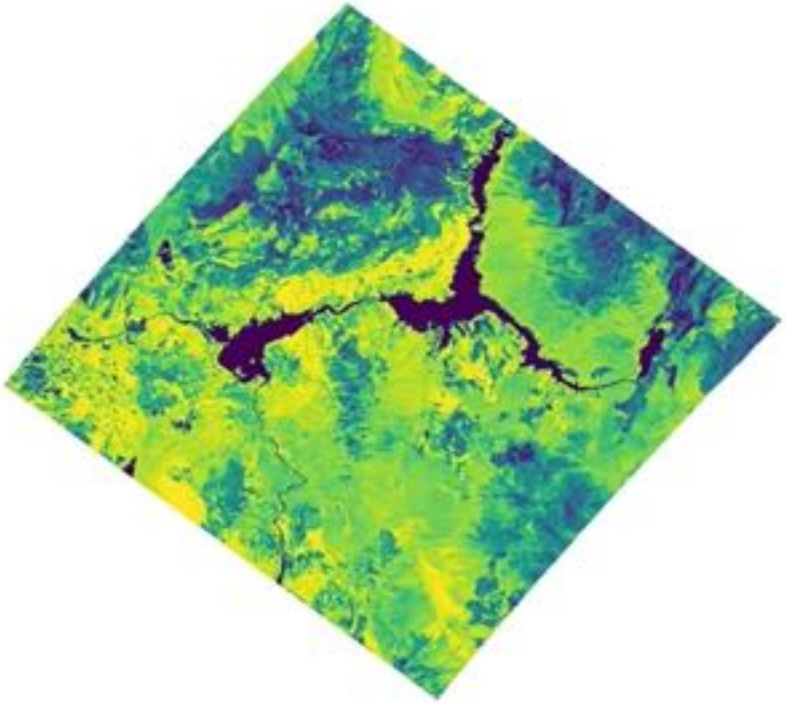


Vegetation Adjustment

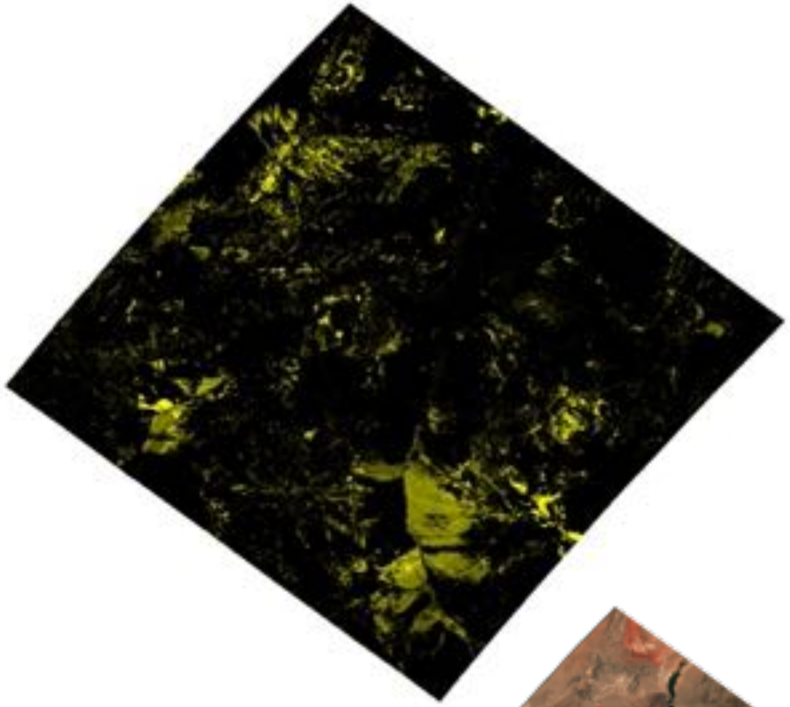
Goethite
Spectral Abundance

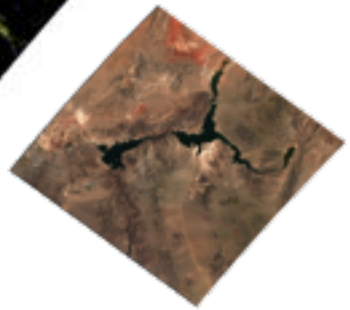


Soil Fraction



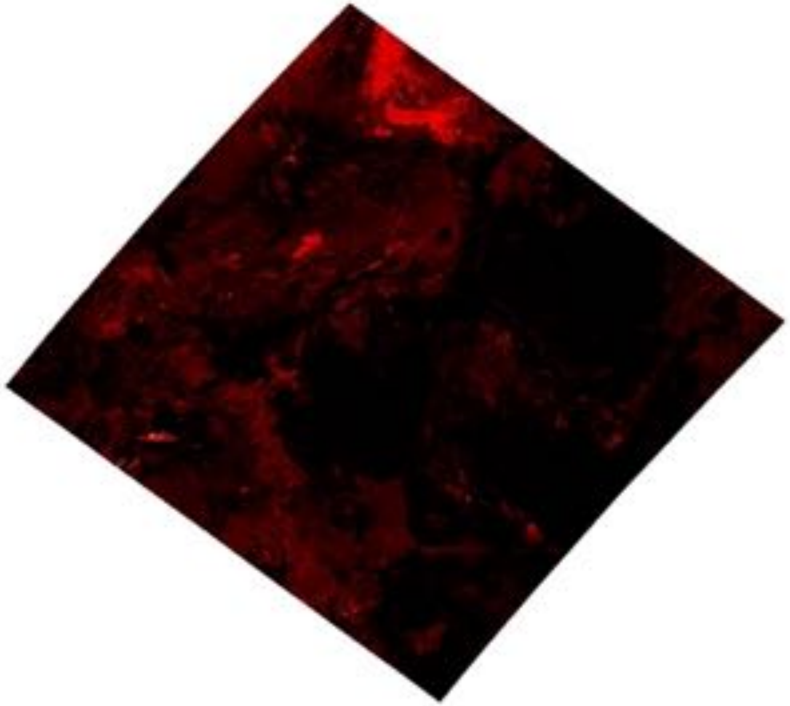
Goethite Adjusted
Spectral Abundance



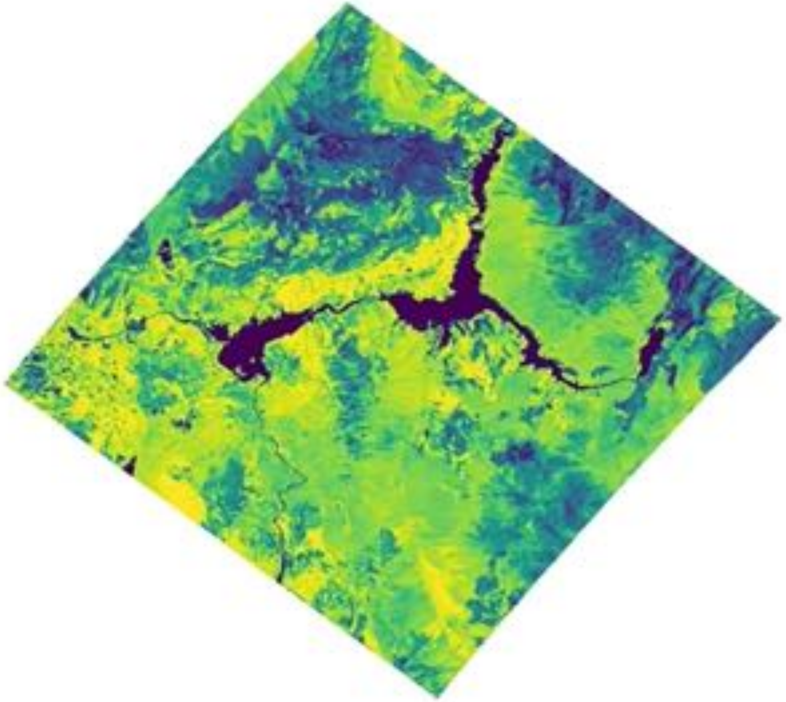


Vegetation Adjustment

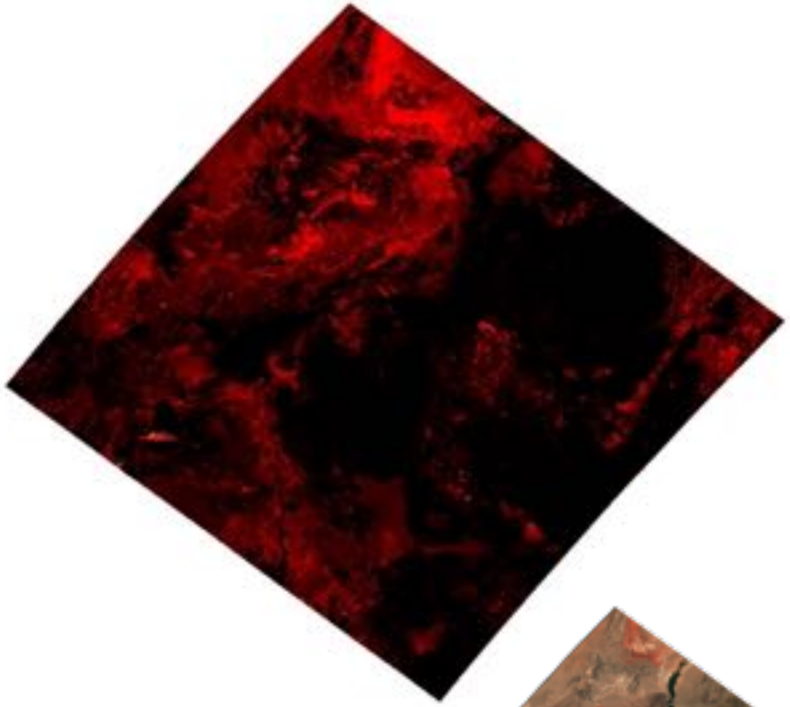
Hematite
Spectral Abundance

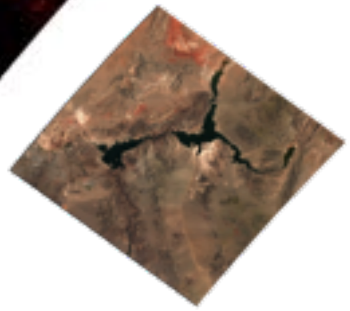


Soil Fraction

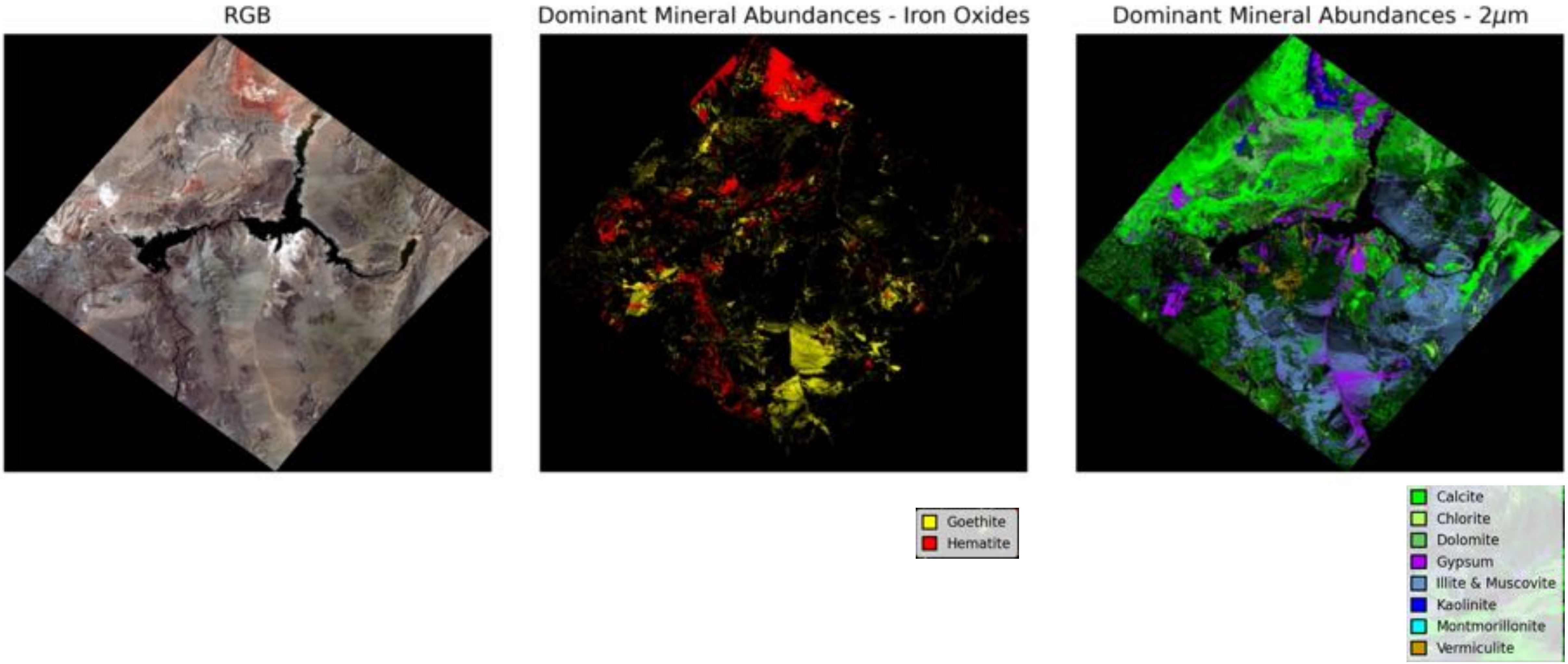


Hematite Adjusted
Spectral Abundance

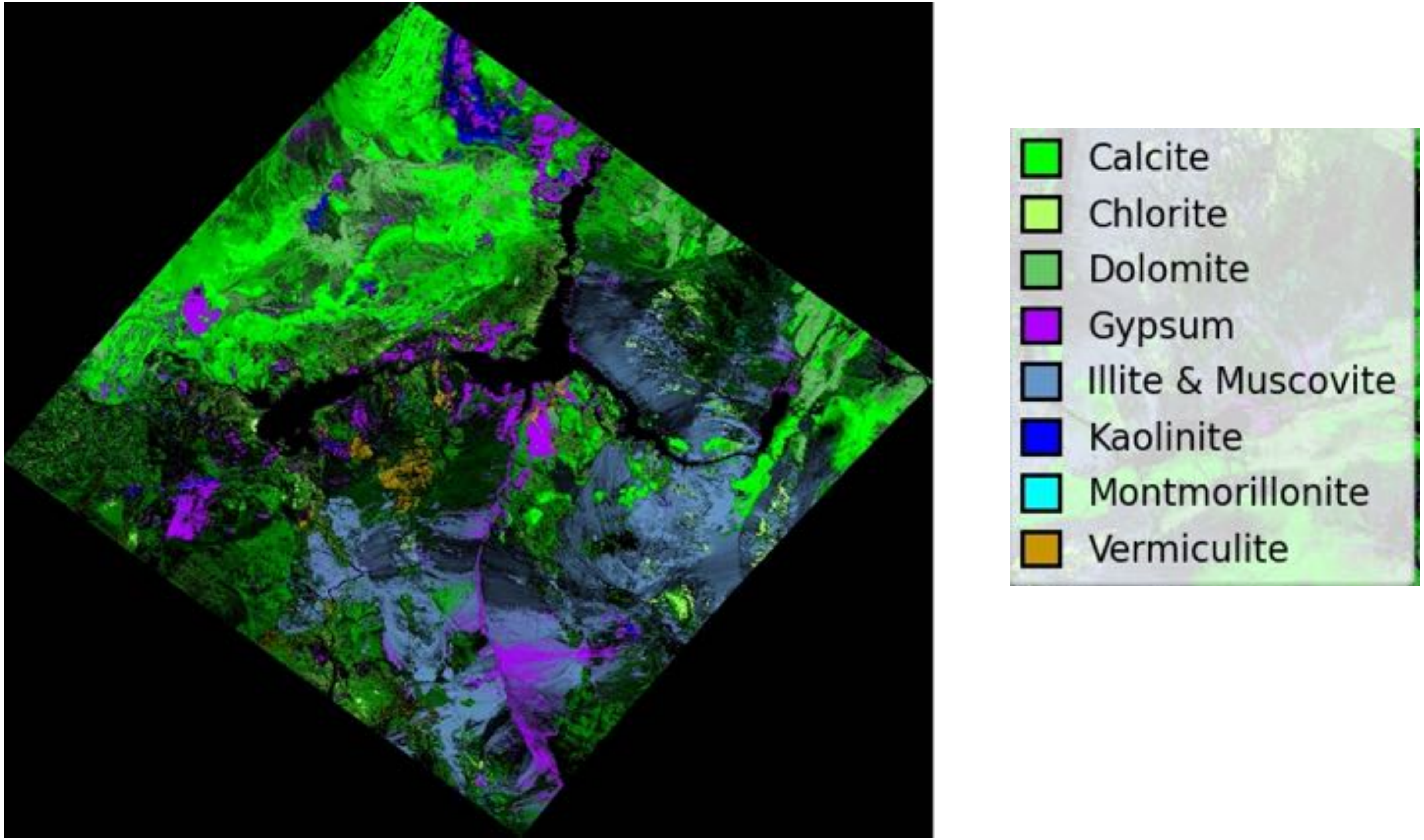




Iron Oxides and Minerals with 2um Features



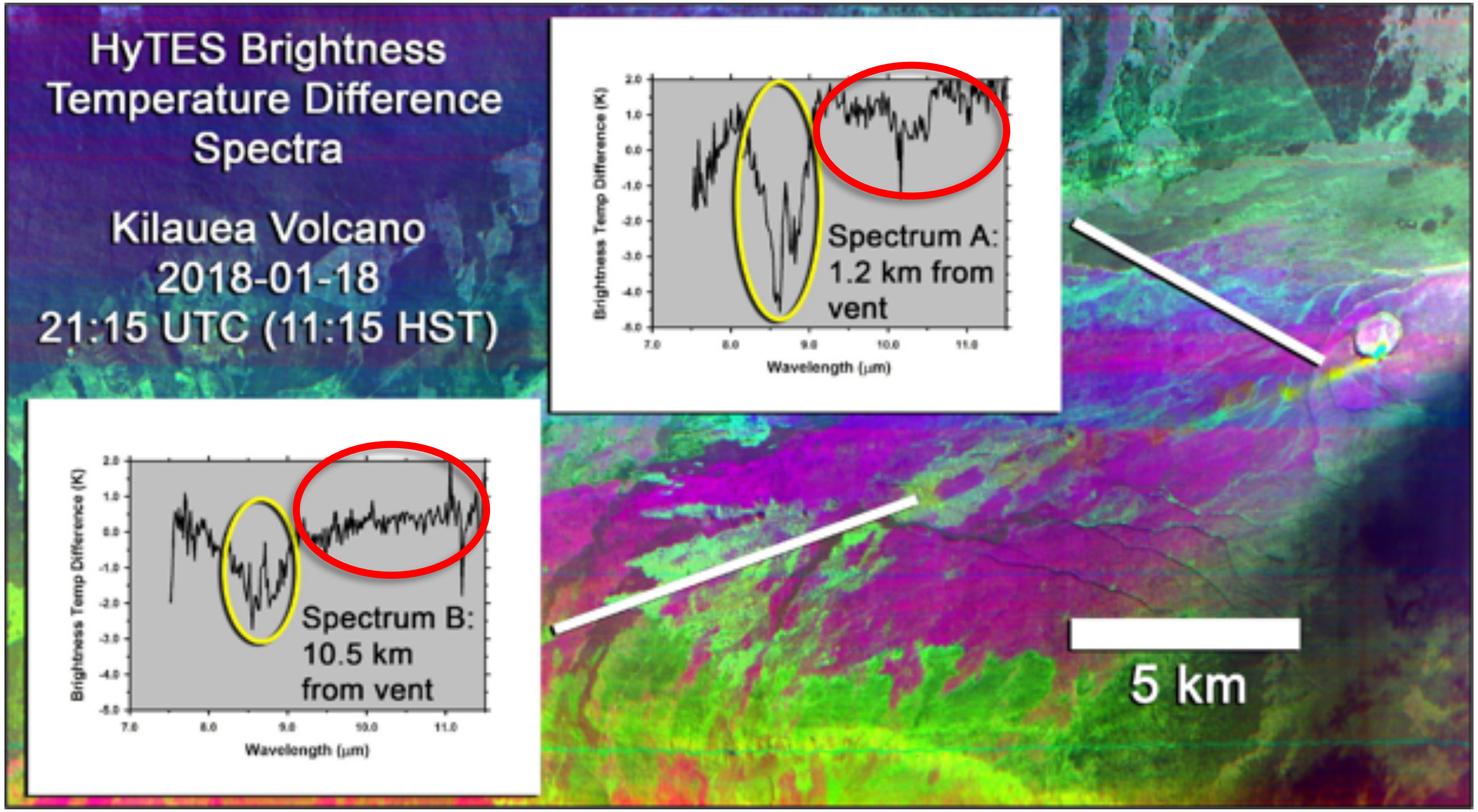
Iron Oxides and Minerals with 2um Features



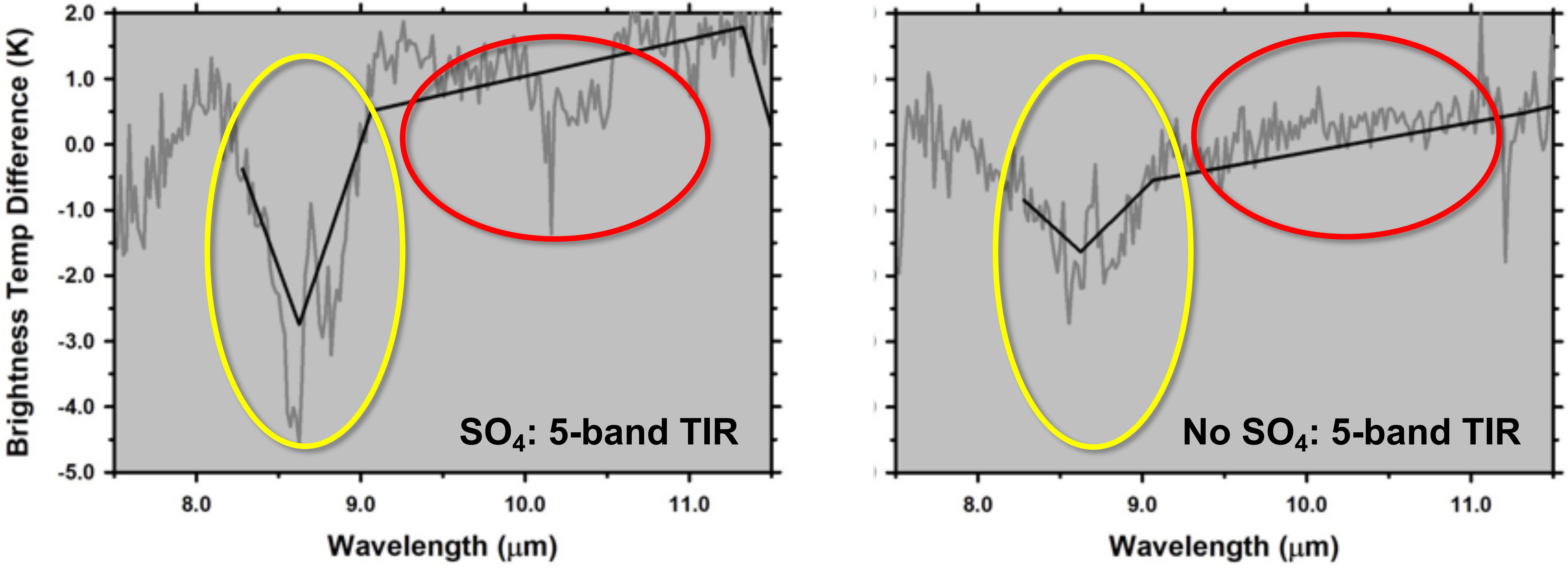
Case Study: SO_2 – SO_4 Kilauea, HI

❖ Using HyTES Data

- apparent decreases in SO_2 and sulfate (SO_4) aerosol column density with increasing distance from vent
- spectrum A indicates stronger SO_2 absorption (yellow oval) than Spectrum B and an absence of SO_4 features (red oval)
- HyTES TIR data are consistent with AVIRIS VSWIR detections of SO_4

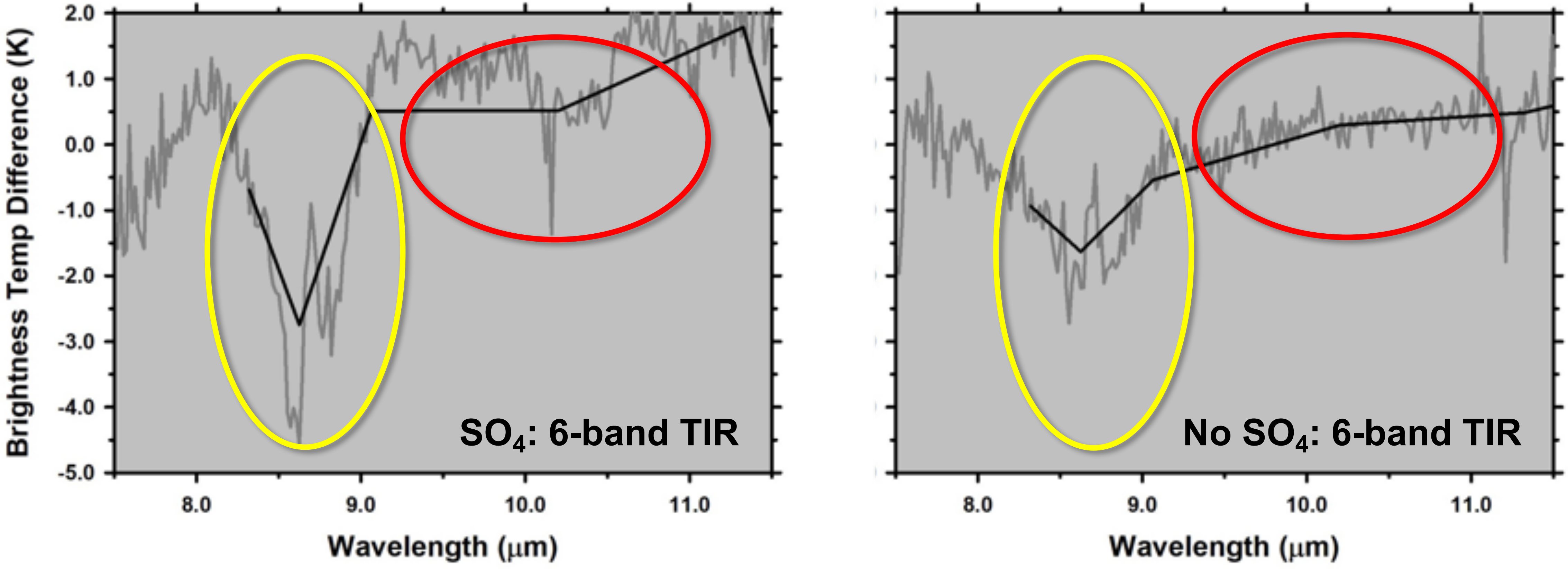


Case Study: SO_2 – SO_4 Kilauea, HI



Baseline (5-band) Band Positions: Unable to Detect SO_4 (red oval)

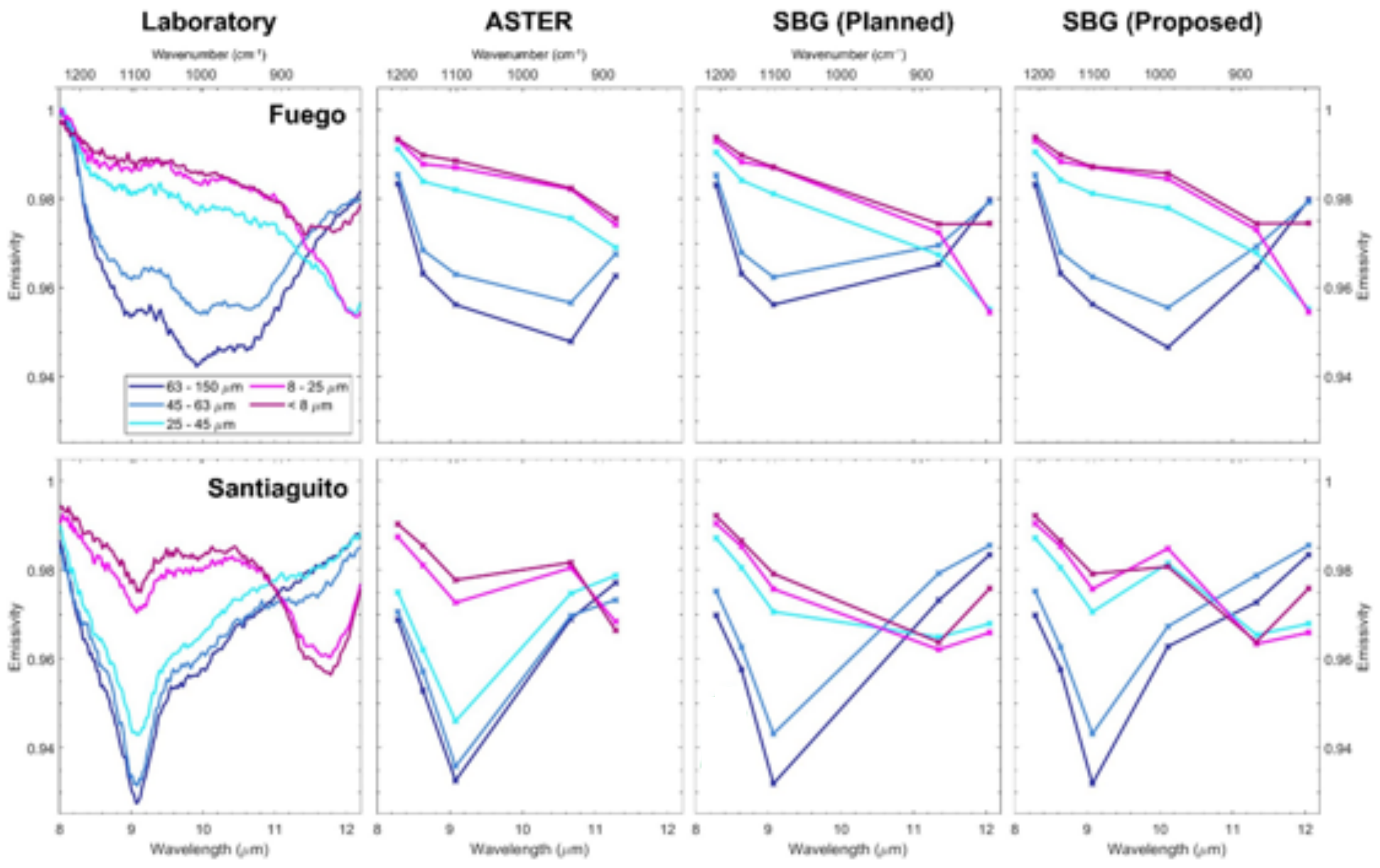
Case Study: SO_2 – SO_4 Kilauea, HI



Modified (6-band) Band Positions: Confirm SO_4 (red oval)

Case Study: Airborne Volcanic Ash

- **Using Laboratory Data**
  - volcanic ash sieved into five size fractions (Williams and Ramsey, 2019)
  - TIR spectra acquired and resampled to ASTER, SBG (5-band) and SBG (6-band) configurations
    - both composition and particle size are retrieved more accurately with the 6-band configuration
      - spectral shapes better represent the laboratory data especially at wavelengths longer than 10 μm



(Thompson et al., 2023)

Summary

- SBG will include a VSWIR Imaging Spectrometer and a TIR Multispectral Imager
- Several areas lend themselves to combined use of VSWIR and TIR data, e.g. geological studies, ecosystem studies, cryospheric studies.
- ECOSTRESS and EMIT provide an excellent set of data to simulate SBG TIR and VSWIR data
- ECOSTRESS and EMIT data can be used to simulate other similar datasets planned for later in the decade such as LSTM, TRISHNA, CHIME, PRISMA-NG
- Airborne data from AVIRIS/AV-NG and HyTES/MASTER can also be used to simulate SBG
- Started to evaluate use of ECOSTRESS and EMIT data for geological mapping in the Lake Mead area, Nevada USA

Questions?