SBG TIR Geology Products Update

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Nishinoshima Volcano, Japan (28 July 2020)

Overview

❖ Higher-Level Geology Products

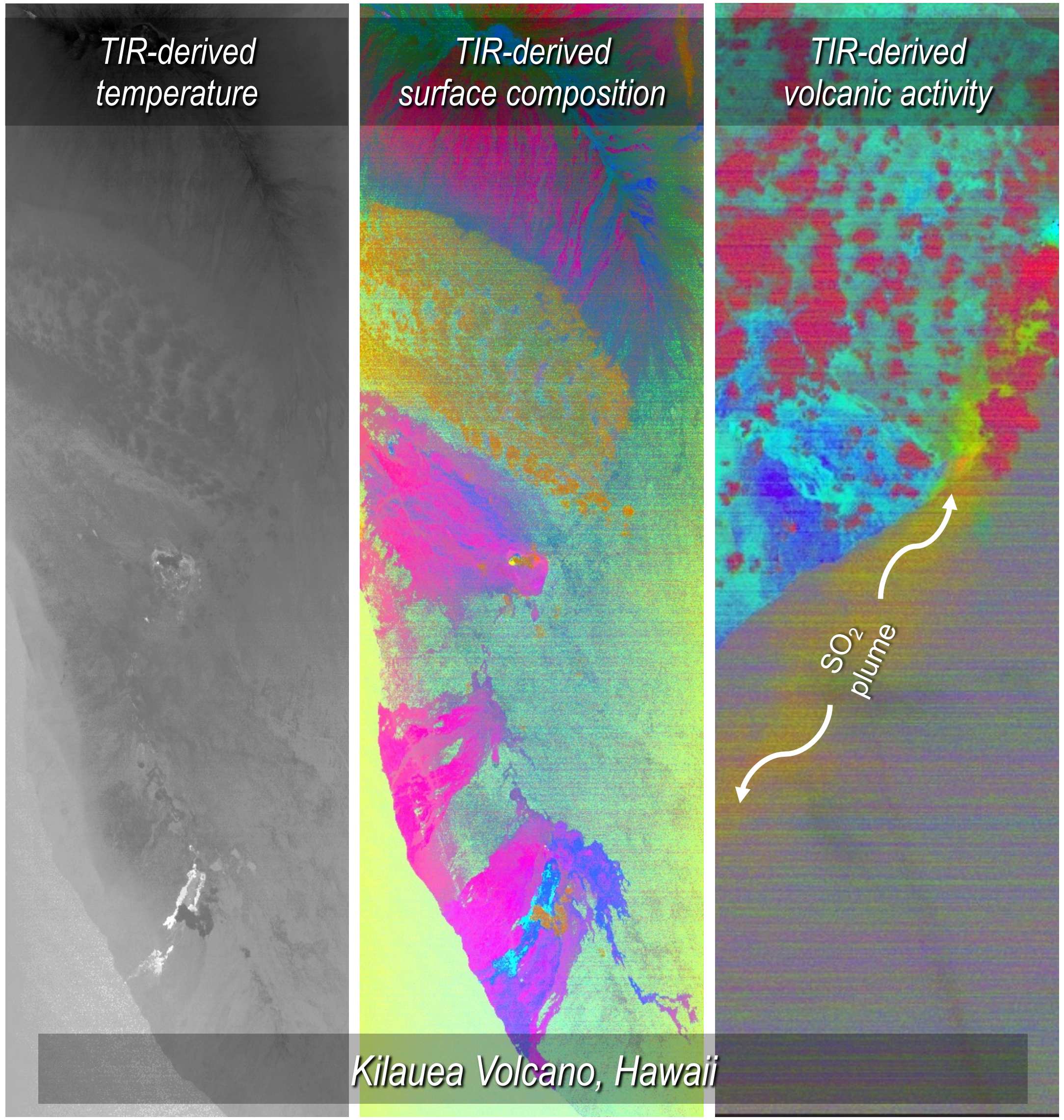
- new for a TIR mission as standard data products
  - L3 Elevated Temperature Features (ETF)
  - L3 Surface Mineralogy (SM)
  - L4 Volcanic Activity (VA)

❖ Background

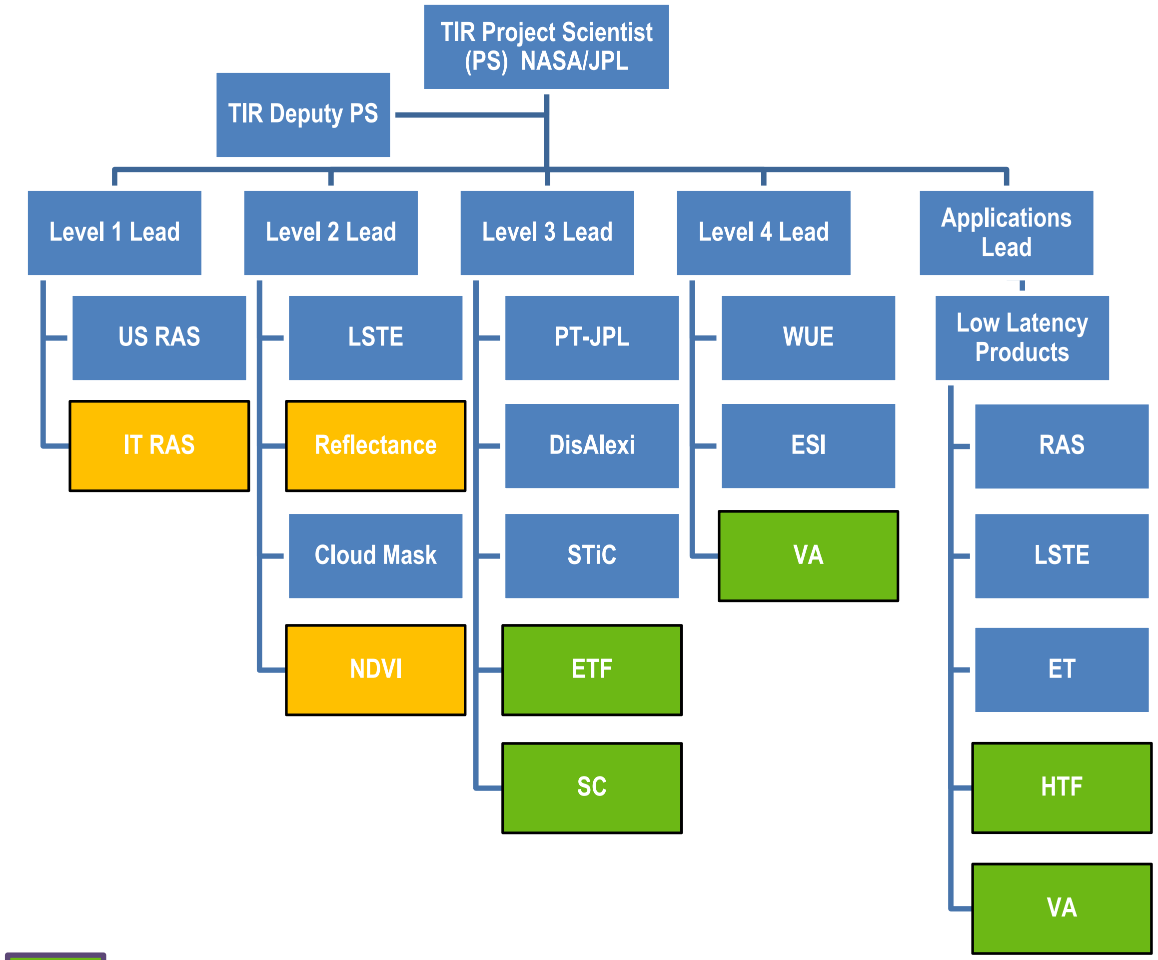
- analog datasets
- current approach to algorithm testing/assessment

❖ Moving Forward

- what needs to happen next?
  - further testing and cross-algorithm comparisons
  - expanded datasets



TIR Science/Product Organization



New geology products

Italian products

ACRONYMS

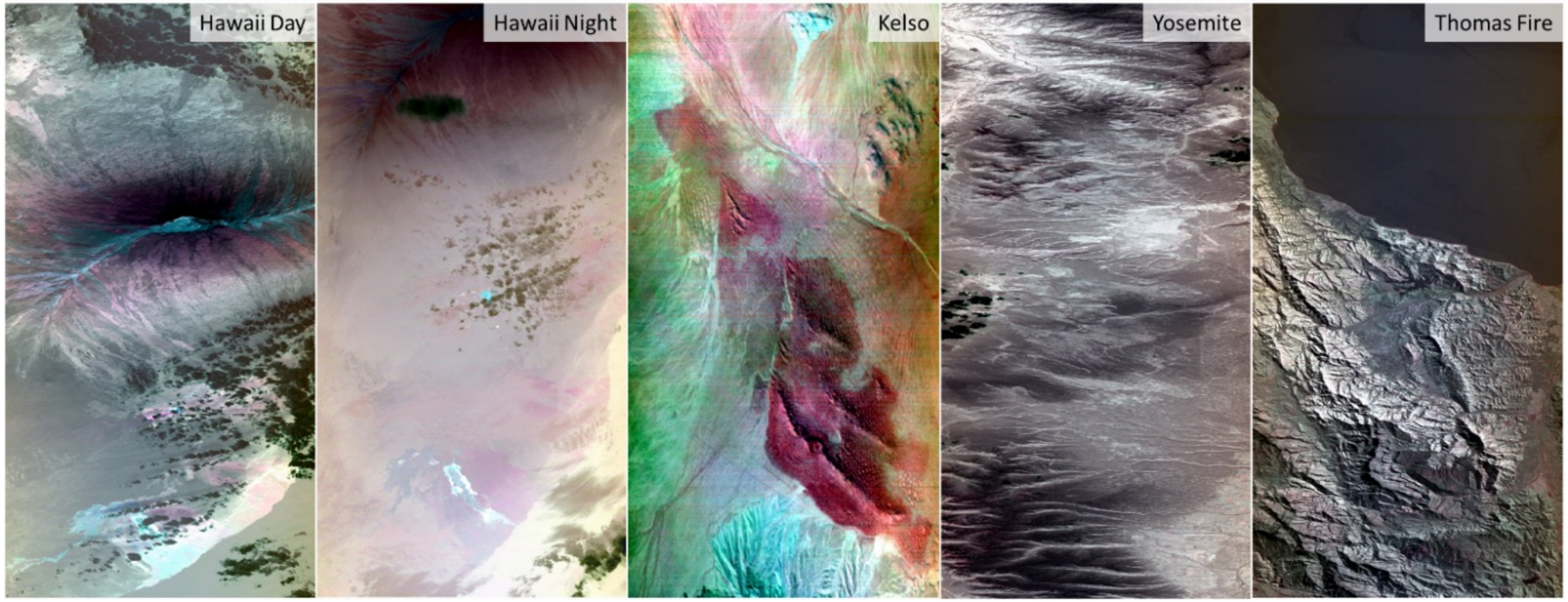
- **RAS** – Radiance at Sensor
- **LSTE** – Land Surface Temperature and Emissivity
- **NDVI** – Normalized Difference Vegetation Index
- **STiC** – Surface Temperature Initiated Closure
- **WUE** – Water Use Efficiency
- **ESI** – Evaporative Stress Index

- **ETF** – Elevated Temperature Features
- **VA** – Volcanic Activity
- **SM** – Surface Mineralogy

Simulated Data

- **Created from Airborne MASTER Data**
  - – has both TIR and MIR bands
  - – SBG band centers were linear interpolations between the two nearest MASTER bands
  - – spatial resolution degraded to 60 m
  - – atmospheric correction applied

- **Data**
  - – currently working with 5 datasets
    - both day/night data
    - with/without high temperature features
    - mineralogical diversity



Elevated Thermal Features (ETF) Product

❖ Algorithm Assessment

- began with 26 potential thermal anomaly algorithms from the volcano and wildfire communities
- preference given to those with:
  - open access *(code freely available)*
  - global scale application
  - MIR and TIR data usage
  - computationally fast *(will operate on all land data)*
  - spectral/spatial techniques over temporal approaches

❖ Initial Selection

- six were tested (green) with five others (orange) as possible later stage testing
- others may be added
  - especially if the code is made available

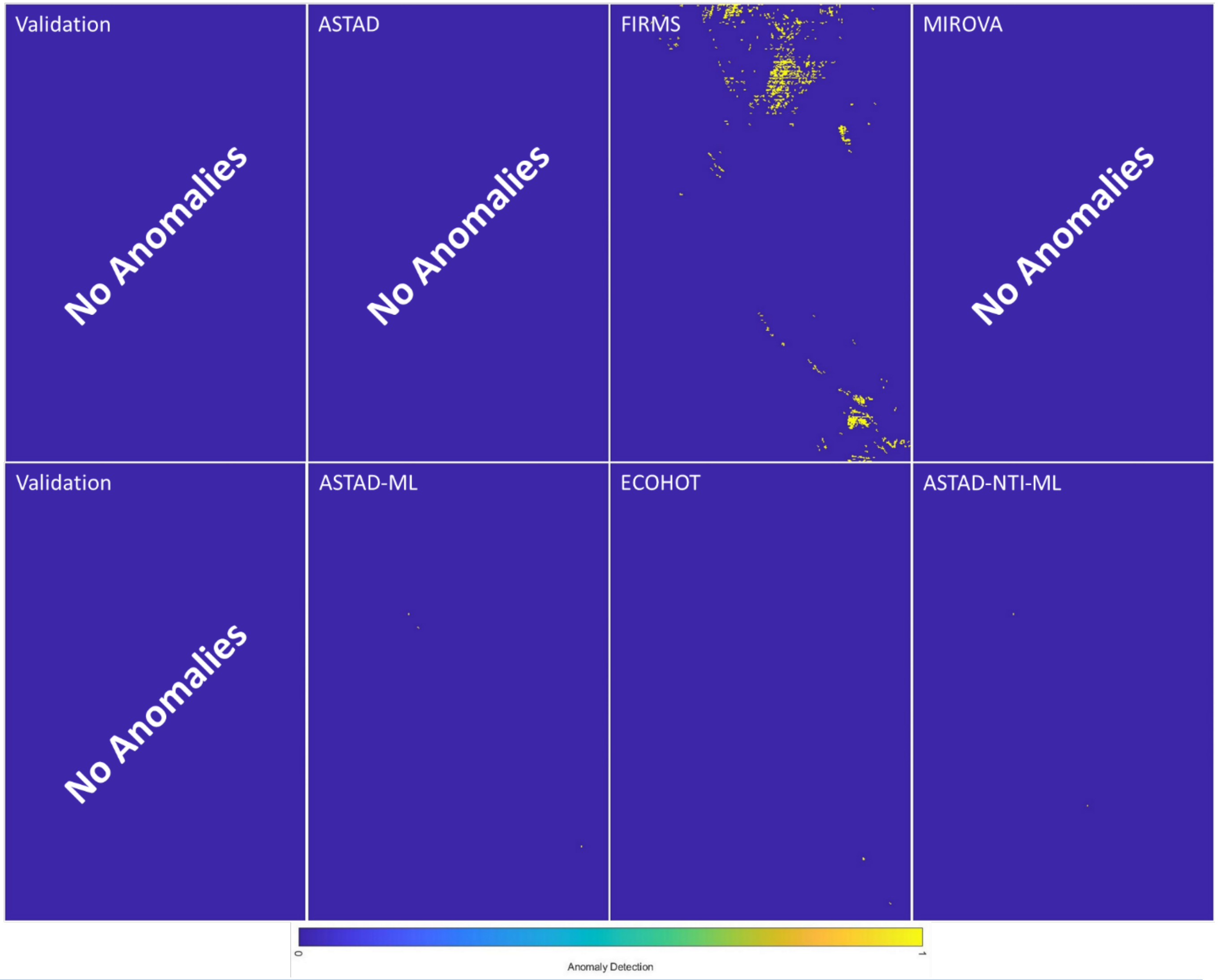
Algorithm	Type	Classification	Sensor	Bands	Coverage	Reference
ASTAD	Contextual, Temporal	Spatial, Temporal	ASTER	TIR	Global	Ramsey et al. (2023)
ASTAD-ML	Machine Learning	Spatial	ASTER	TIR	Global	Corradino et al. 2023
ASTAD-ML (NTI)	Machine Learning	Spatial	ASTER	MIR, TIR	Global	Corradino et al. 2023
ASTER ID			ASTER	TIR	Global	Urai (2011)
AVA			ASTER	TIR	Global	Linick et al. (2014)
AVHOTRR			AVHRR, SEVIRI	MIR, TIR	Specific Targets	Lombardo et al. (2016)
AVTOD	Contextual	Spatial	ASTER	TIR	Americas	Reath et al. (2019)
ECOHOT	Contextual, Temporal	Spatial, Spectral, Temporal	ECO-STRESS	TIR	Global	Hulley et al. (2020)
FIRMS	Contextual	Spectral	VIIRS, MODIS	MIR, TIR	Global	Davies et al. (2009)
HOTSAT	Contextual, Fixed	Spectral, Spatial	MODIS, SEVIRI	MIR, TIR	Europe/Africa	Ganci et al. (2011)
HOTVOLC	Contextual	Spectral, Spatial	SEVIRI	MIR, TIR	Europe/Africa	Gouhier et al. (2016)
MIROVA	Contextual, Fixed	Spectral, Spatial	MODIS	MIR, TIR	Global	Coppola et al. (2016)
MODLEN	Contextual, Fixed	Spectral, Spatial	MODIS	MIR, TIR	Global	Kervyn et al. (2006)
MODVOLC	Fixed	Spectral	MODIS	MIR, TIR	Global	Flynn et al. (2002) and Wright e al. (2002)
MODVOLC2	Temporal, Fixed	Spectral, Temporal	MODIS	MIR, TIR	Global	Koeppen and Wright (2010)
MOUNTS	Contextual, Fixed	Spectral, Spatial	MSI	SWIR	Global	Valade et al. (2019)
MYVOLC	Contextual, Fixed	Spectral, Spatial	MODIS, ASTER	SWIR, MIR, TIR	Global	Hirn et al. (2008)
NHI	Fixed	Spectral	MSI	NIR, SWIR	Global	Marchese et al., (2019)
NIGHTFIRE	Contextual, Temporal	Temporal	VIIRS	SWIR, MIR	Global	Elvidge et al. (2013)
OKMOK	Contextual, Temporal	Spatial, Temporal	AVHRR, MODIS, VIIRS	MIR, TIR	N. Pacific	Dean et al. (1998)
RAT/RST (RETIRA)	Contextual, Temporal	Spatial, Temporal	AVHRR, MODIS, SEVIRI, ASTER	MIR, TIR	Specific Targets	Tramutoli (1998)
REALVOLC	Contextual	Temporal	MODIS	MIR, TIR	Asia and Americas	Kaneko et al. (2010)
RF	Machine Learning	Spectral	MSI	VIS, NIR, SWIR	Specific Targets	Corradino et al., (2022)
VAST	Contextual	Spatial	AVHRR	MIR, TIR	Global	Harris et al. (1995)
VOLCVIEW			AVHRR, MODIS,	MIR, TIR	Pacific	Schneider et al. (2014)
VOLSATVIEW			AVHRR, MODIS, VIIRS	MIR, TIR	N. Pacific	Gordeev et al. (2016)

Elevated Thermal Features (ETF) Product

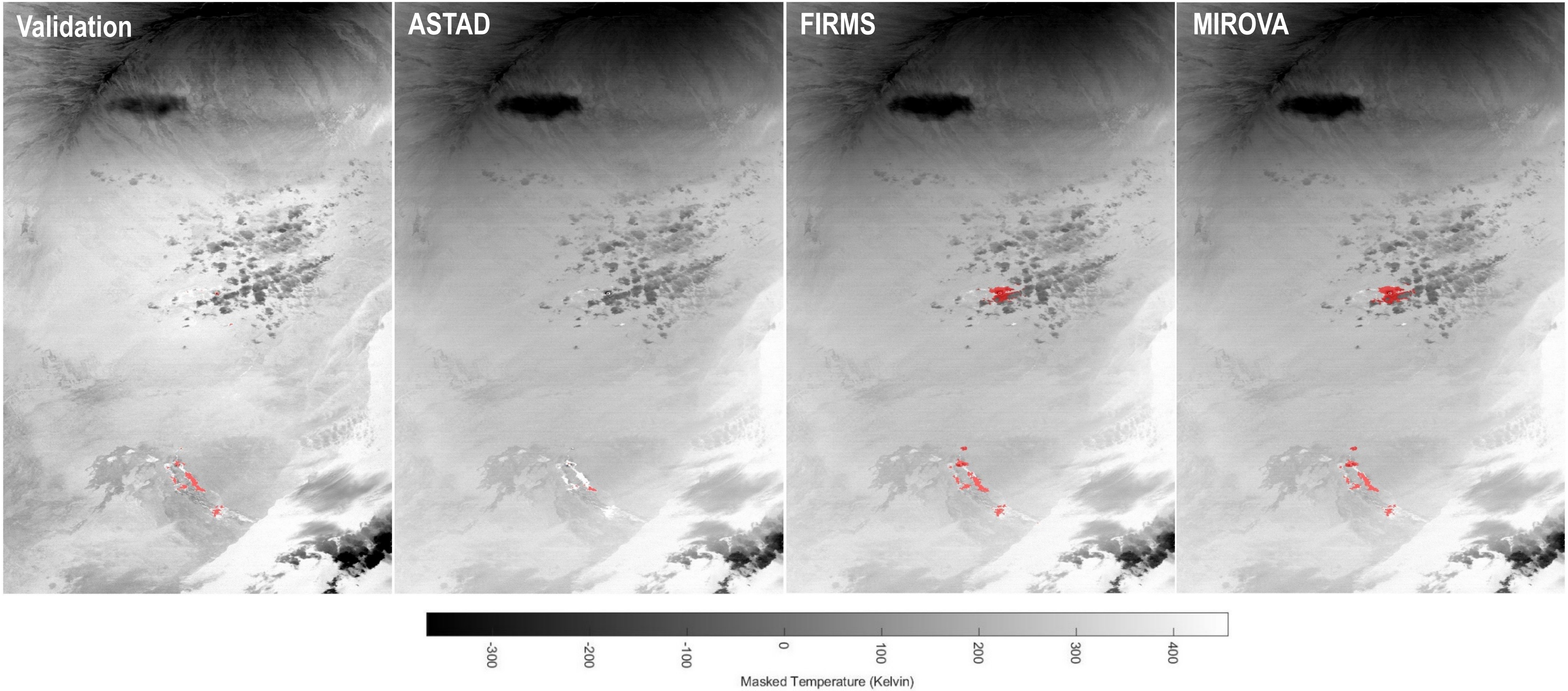
❖ Initial Results

- minimal changes were made to the code of each algorithm
- results assessed on data with (and without) thermal anomalies
  - emphasis placed upon speed and low false positive rates
  - assessment made against manually-selected thermal anomalies in each image
    - *or lack thereof for the null-hypothesis cases (e.g., Kelso Dunes, CA)*
- performance matrices used for assessment

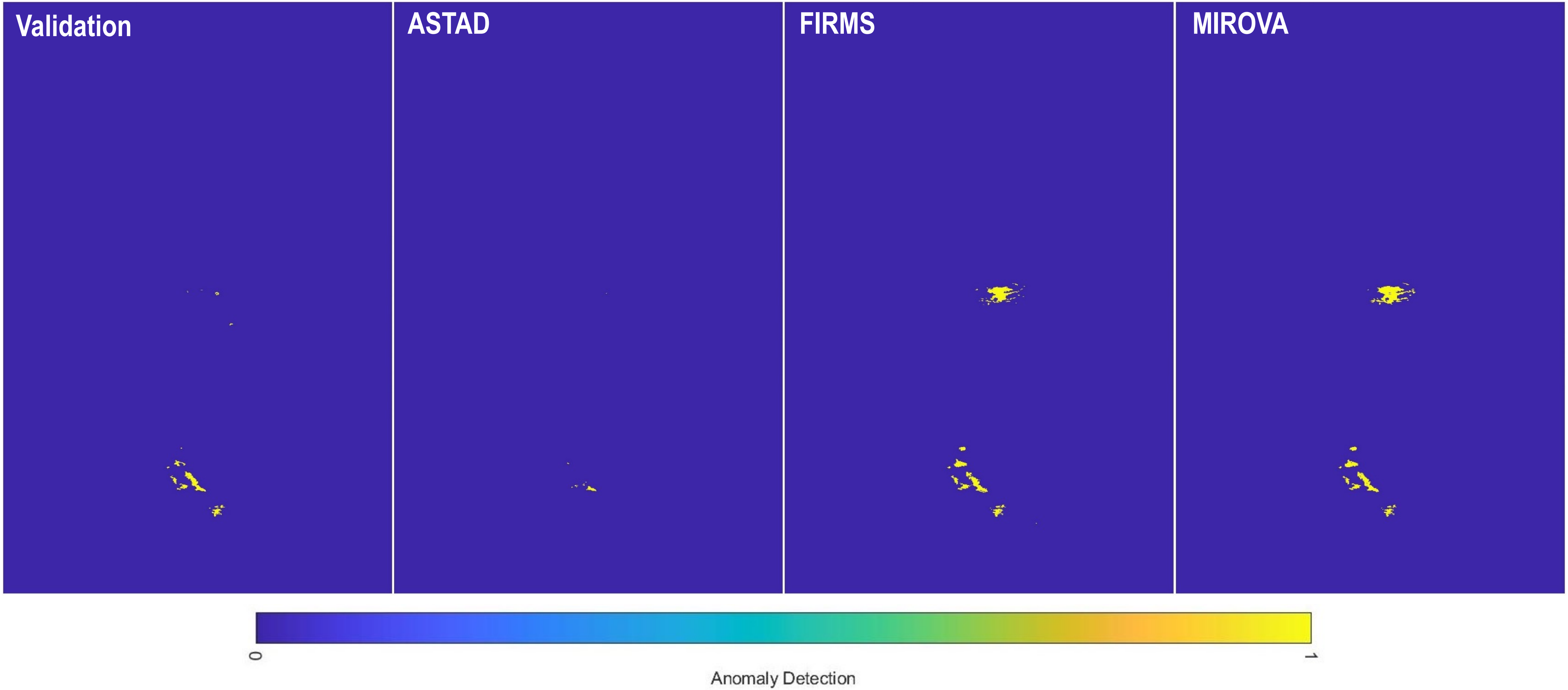
Kelso Dunes, CA *(null hypothesis)*



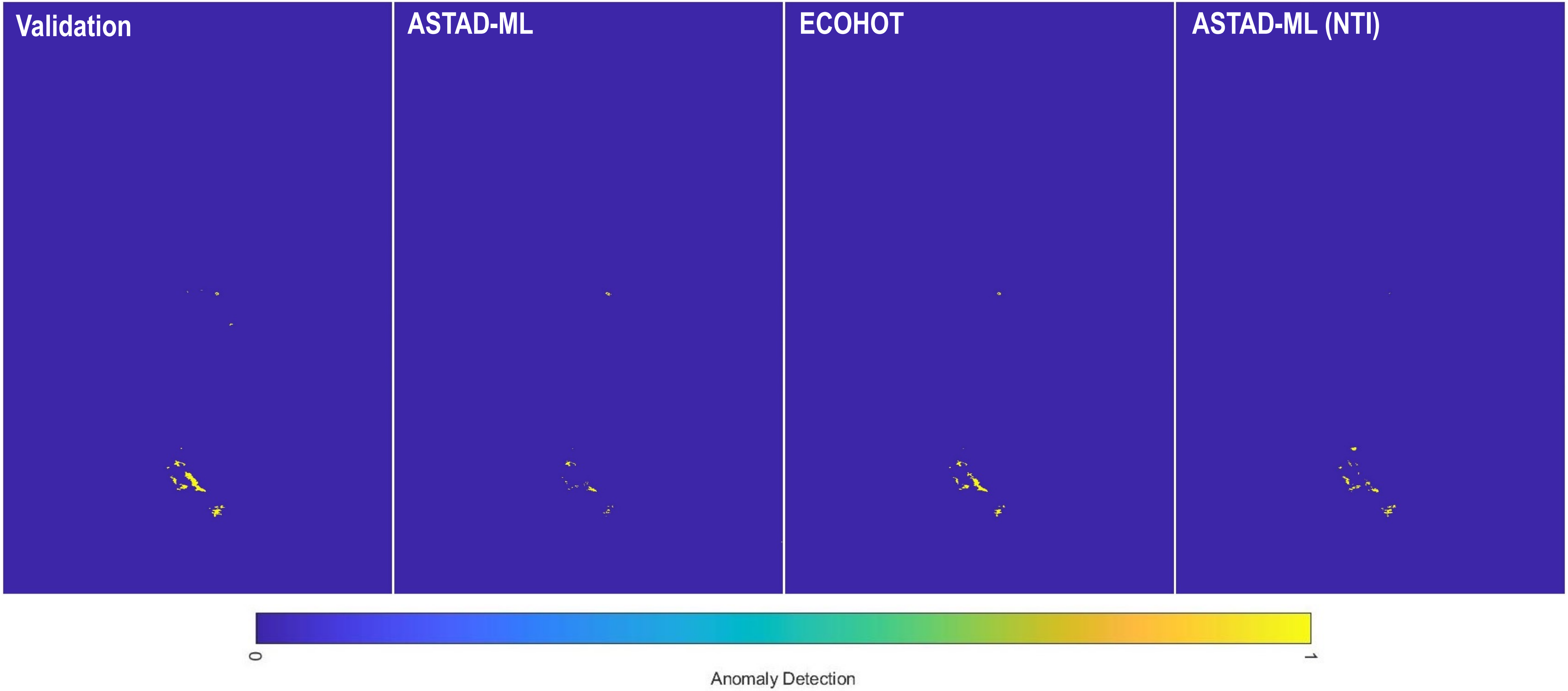
Hawaii Night – Temperature Retrieval



Hawaii Night – Anomaly Retrieval



Hawaii Night – Anomaly Retrieval



Elevated Thermal Features (ETF) Product

❖ Performance Matrices

– where:

- ↑ Precision: low false positives
- ↑ F1 Score: high Precision + Recall without including true negatives
  – due to unbalanced data
- ↑ Recall: low false negatives
- ↑ Global Accuracy: overall accuracy of true predictions
  – unbalanced data bias

Hawaii Night	ASTAD	FIRMS	MIROVA	ASTAD-ML	ECOHOT	ASTAD-ML (NTI)
Precision	1.00000	0.38384	0.34473	0.96285	1.00000	0.75890
F1 Score	0.22205	0.53410	0.49393	0.41689	0.79485	0.52490
Recall	0.12489	0.87767	0.87083	0.26604	0.65954	0.40120
Global Accuracy	0.99905	0.99833	0.99806	0.99919	0.99963	0.99921
Time (secs/pixel)	3.7×10^{-4}	2.7×10^{-7}	2.4×10^{-7}	3.2×10^{-5}	6.7×10^{-6}	2.9×10^{-5}

Totals	ASTAD	FIRMS	MIROVA	ASTAD-ML	ECOHOT	ASTAD-ML (NTI)
Precision	0.22836	0.10130	0.12944	0.49113	0.05075	0.42645
F1 Score	0.21525	0.17526	0.21303	0.28822	0.09289	0.35230
Recall	0.20357	0.64948	0.60140	0.20396	0.54711	0.30012
Global Accuracy	0.99949	0.99789	0.99847	0.99965	0.99631	0.99962
Time (secs/pixel)	3.8×10^{-4}	2.9×10^{-7}	2.0×10^{-7}	3.1×10^{-5}	5.9×10^{-6}	3.2×10^{-5}

❖ Summary

– no clear “winner” at this stage *(computational speed vs. algorithm accuracy?)*

– continued testing on larger/more diverse data needed

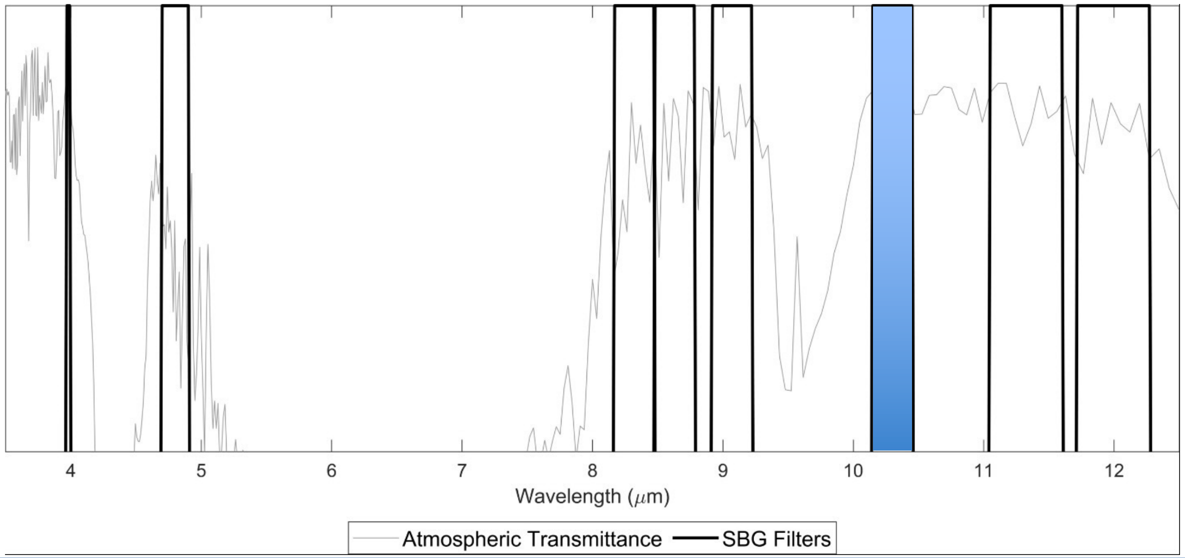
Surface Mineralogy (SM) Product

❖ Goal

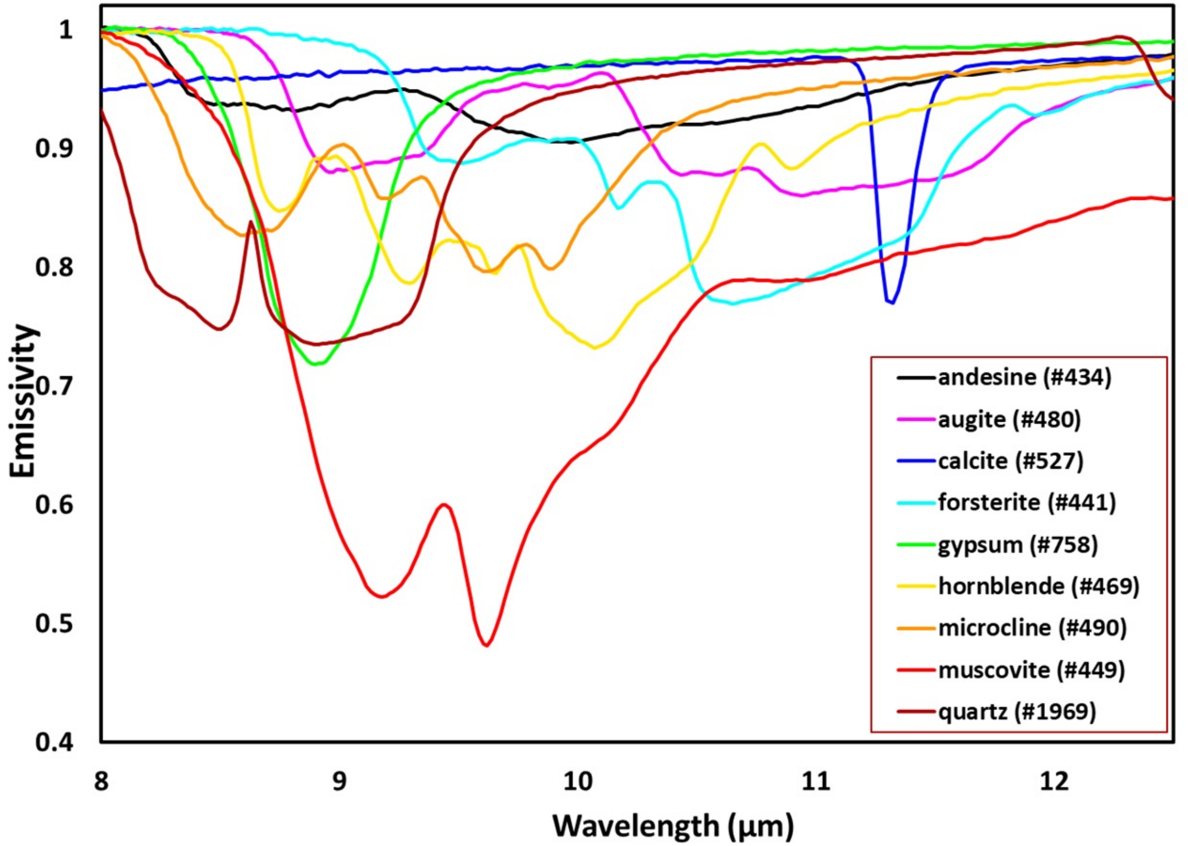
- map the most abundant rock forming minerals plausible for a (now) 6-band instrument
- chose to limit to the top 9-10 by abundance:
  - plagioclase feldspar, potassium feldspar, quartz, pyroxene, amphibole, mica, olivine, carbonate, gypsum
  - plus weight percent silica (WPS)
  - will only be applied to low emissivity regions using a mask (e.g., GED from ASTER)
    - essentially deserts, arid lands, and vegetation/snow-free areas

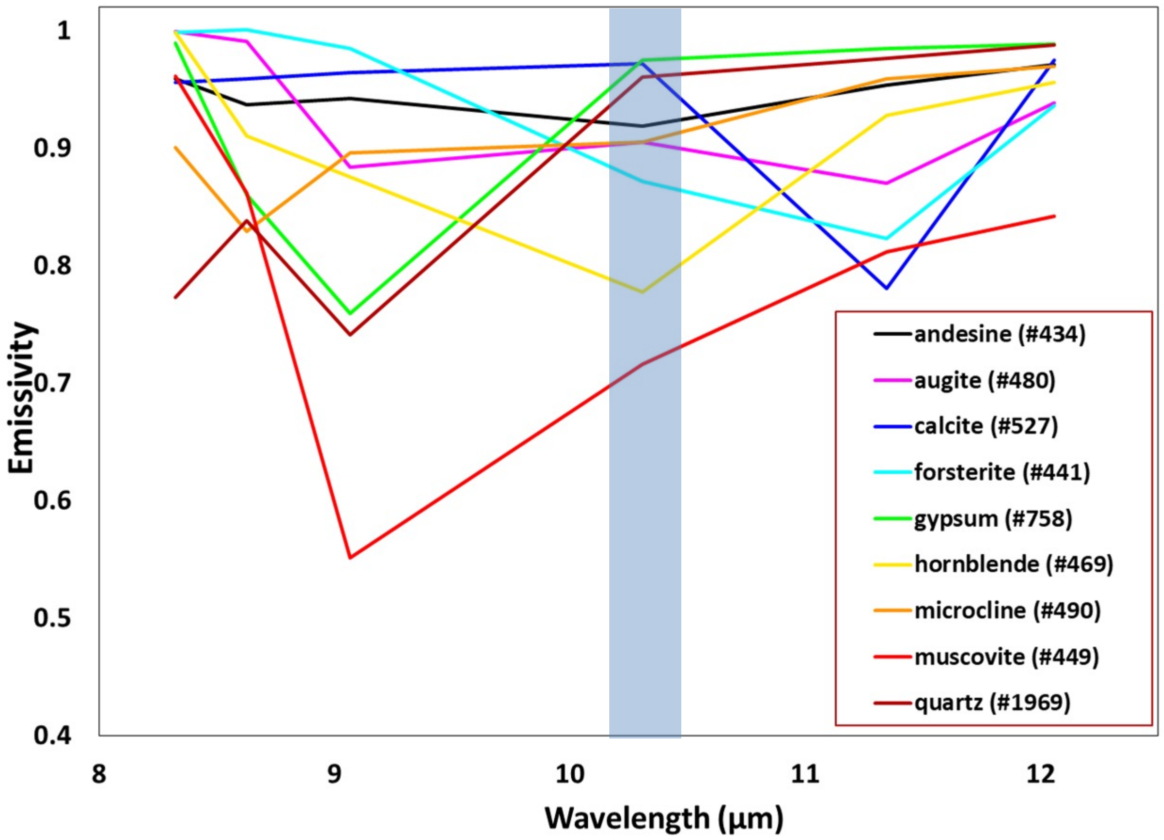
❖ Testing Approach

- similar to ETF although starting with a much smaller algorithm subset
  - spectral mixture analysis (SMA) aka linear deconvolution
  - MESMA
  - “fast” MESMA

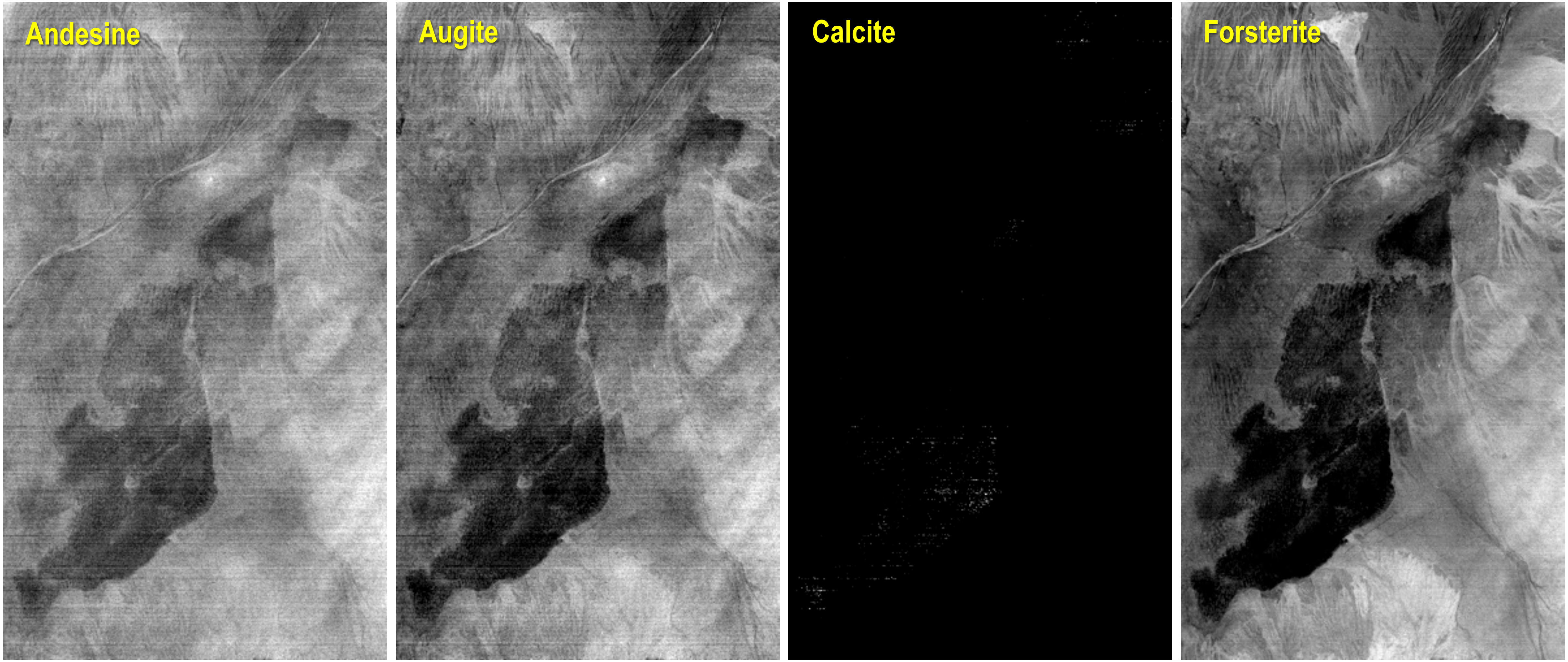


Surface Mineralogy (SM) Product



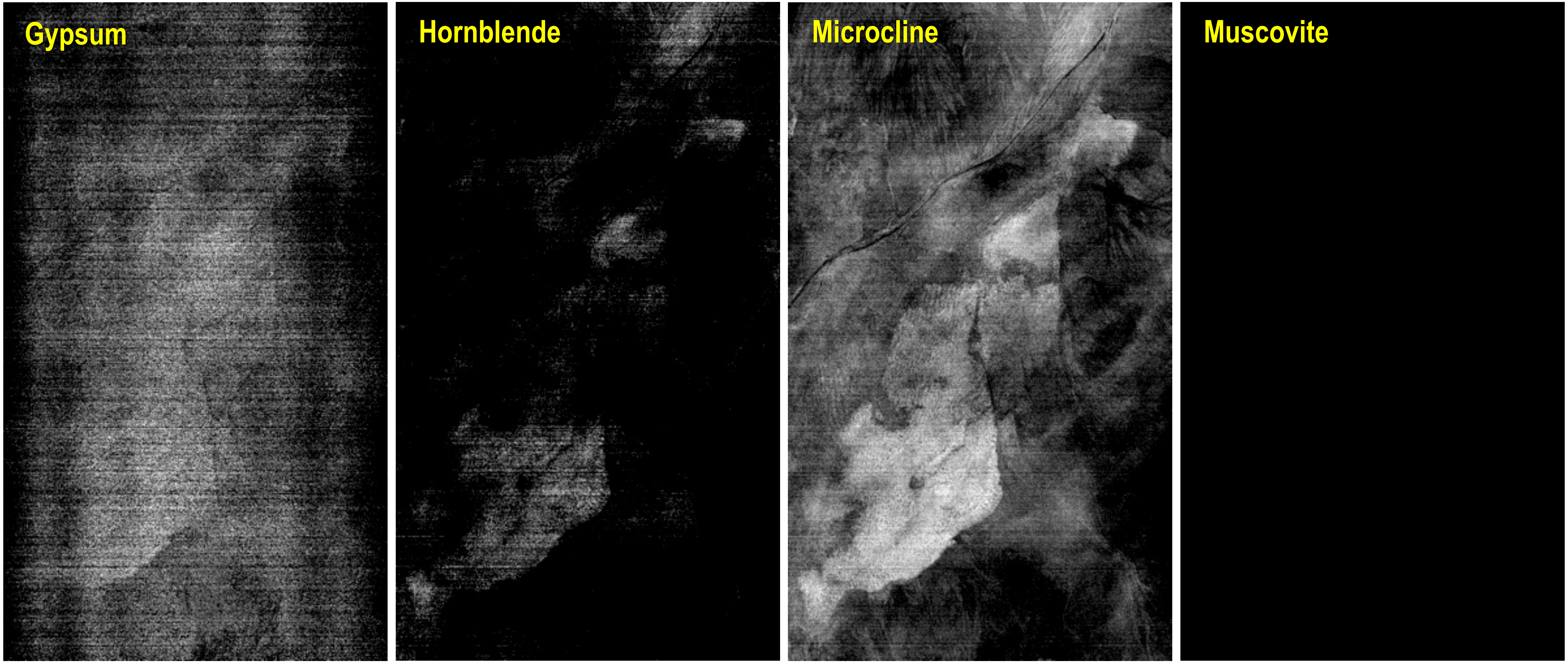


Surface Mineralogy (SM) Product



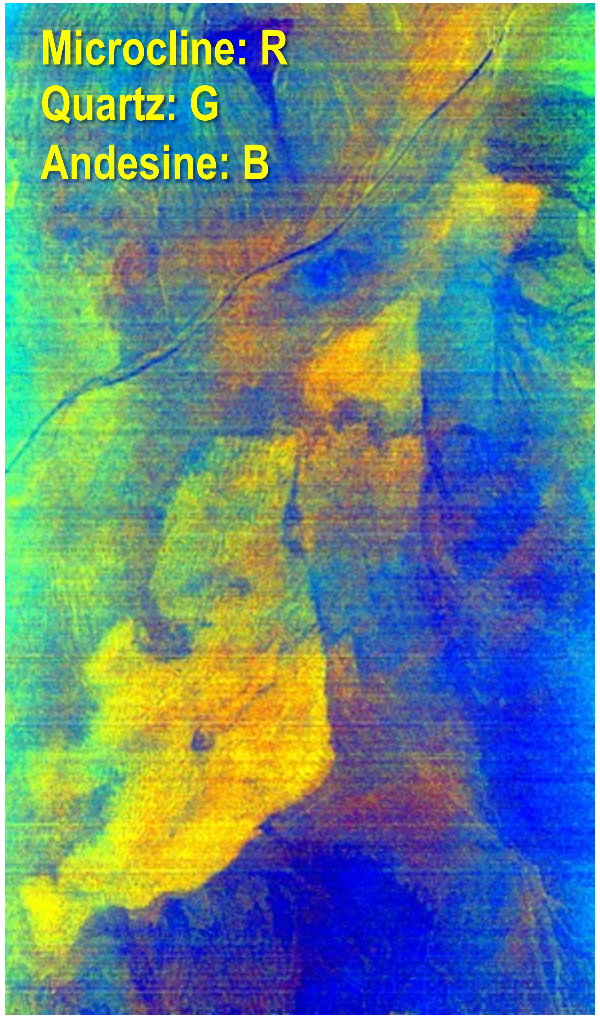
Kelso Dunes, CA

Surface Mineralogy (SM) Product



Kelso Dunes, CA

Surface Mineralogy (SM) Product



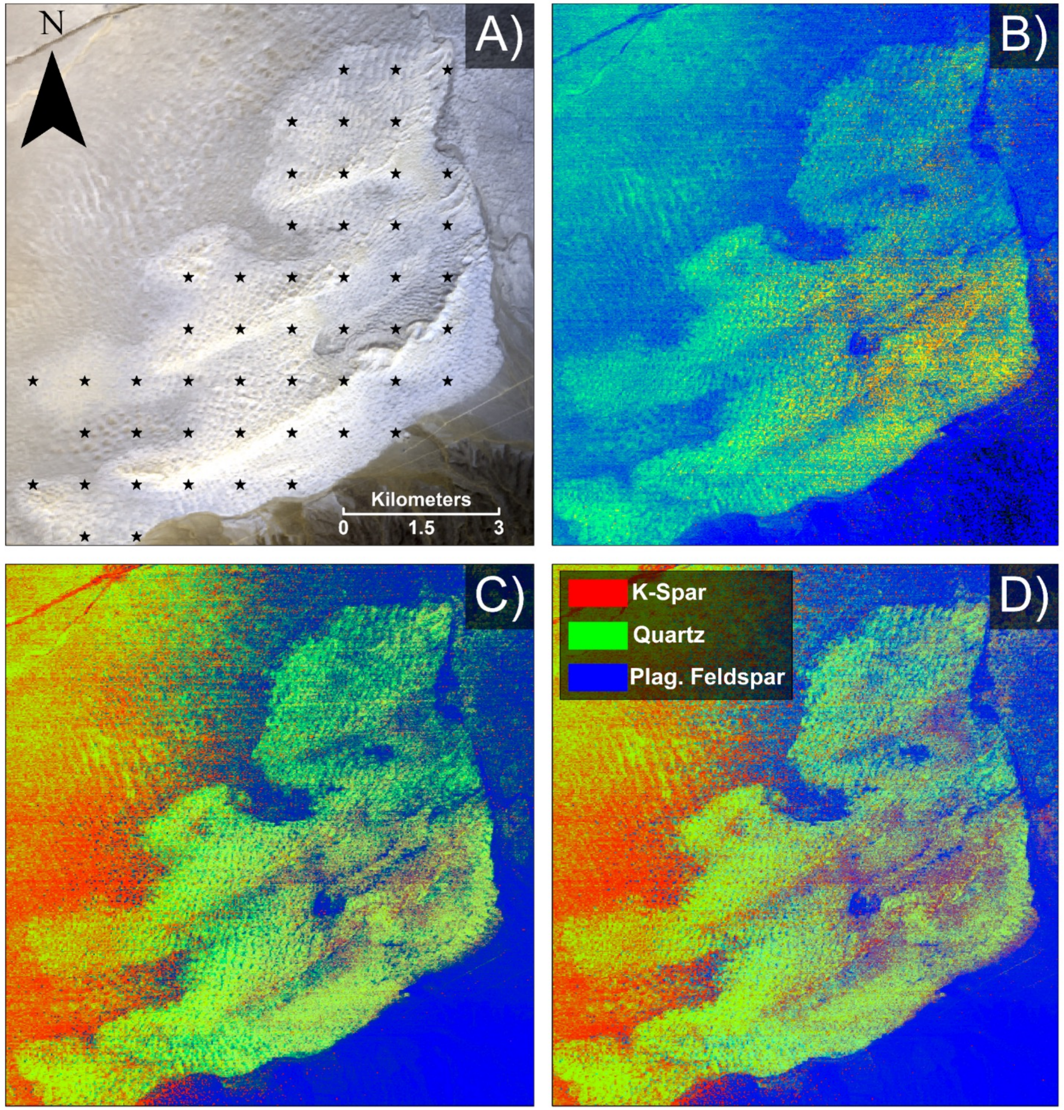
Kelso Dunes, CA

Surface Mineralogy (SM) Product

❖ Initial Results

- MESMA approach allows all end-member minerals to be analyzed concurrently
- “fast” MESMA runs quickly at the 6-band spectral resolution (~ 7.4×10^{-7} s/pixel)
- more testing is required
  - diverse set of compositional scenes
  - analyze in greater detail of the RMS error and adding a blackbody endmember

- *figure:* prior surface compositional study at Kelso Dunes, CA with MASTER
  - **A)** visible data w/ sample points
  - **B)** prior SBG configuration (5 bands)
  - **C)** current SBG configuration (6-bands)
  - **D)** hypothetical configuration (7-bands)

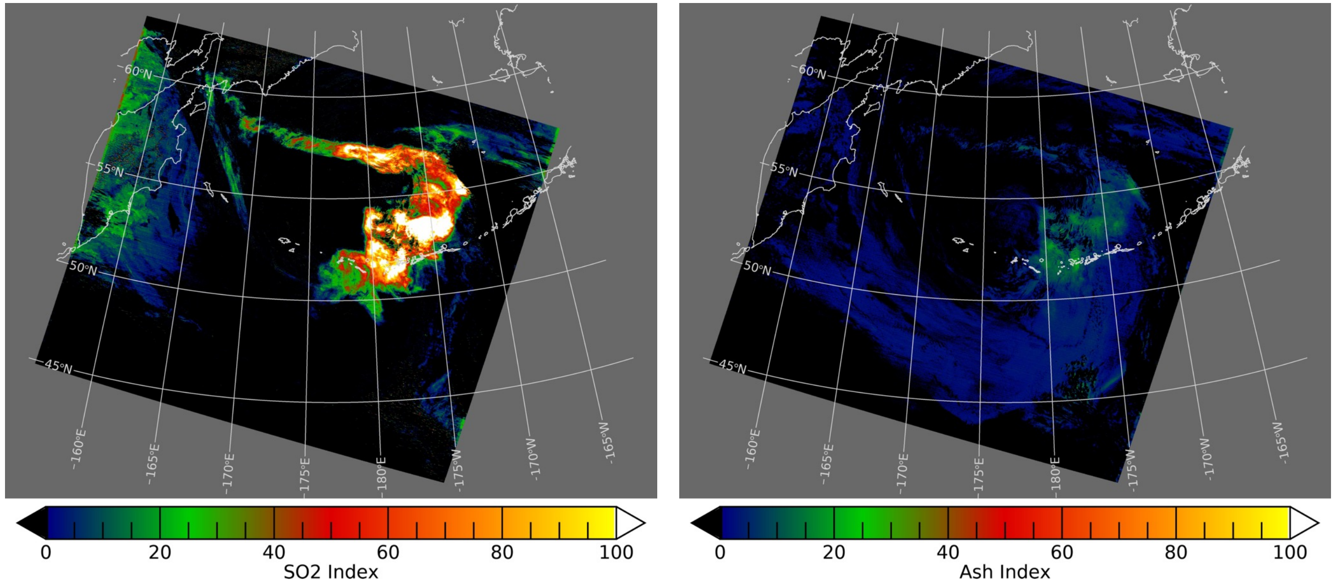


Thompson et al. (2023)

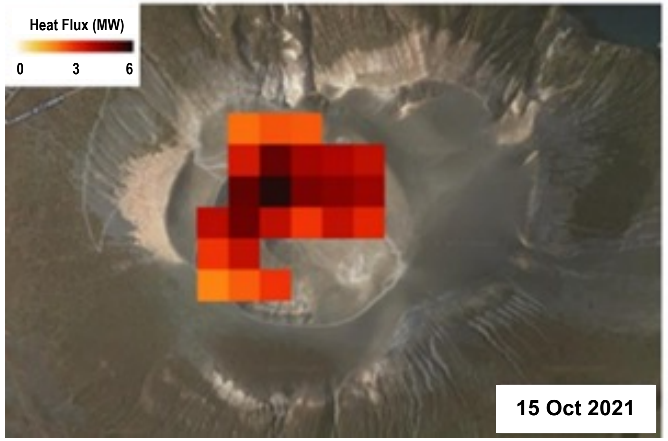
Volcanic Activity (VA) Product

❖ Scope

- VA produced only over the ~ 1500 active/restless volcanoes
- 50 km×50 km centered on each target
- viewed as hybrid product combining plume and thermal detection *(initially)* followed by expanded radiative transfer (RT) modeling *(for positive plume detections)*
- *↑ values of plume + ↑ thermal flux per pixel reported in VA index image*
- combines the Plume Tracker model (Realmuto and Berk, 2016) with the ASTAD thermal algorithm (Ramsey et al., 2023; Corradino, et al., 2023)



Plume Tracker rapid index images



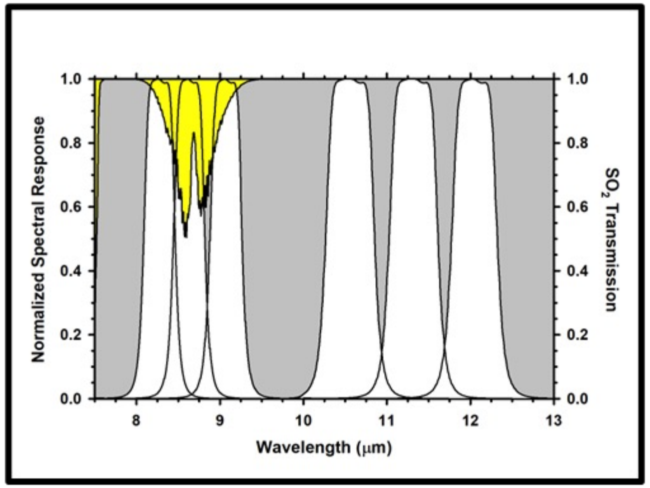
ASTAD heat flux image

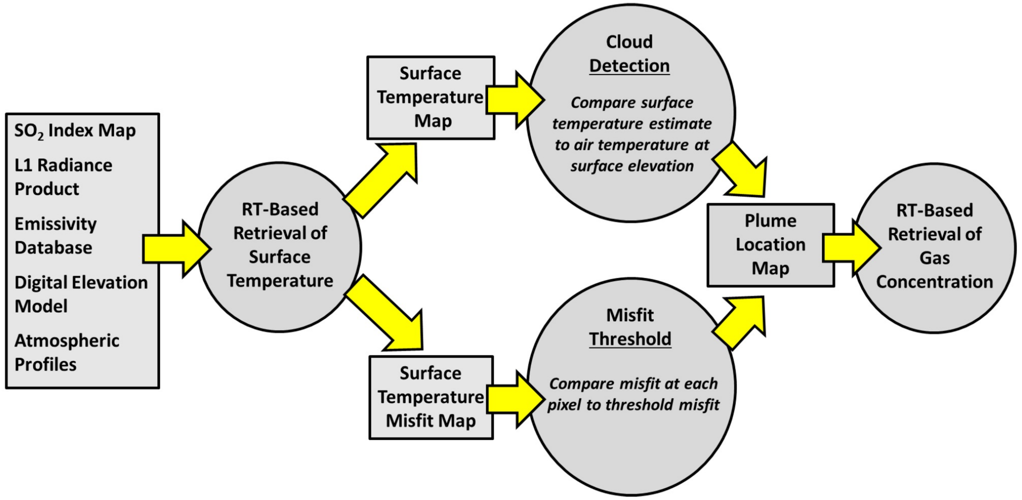
VA index image

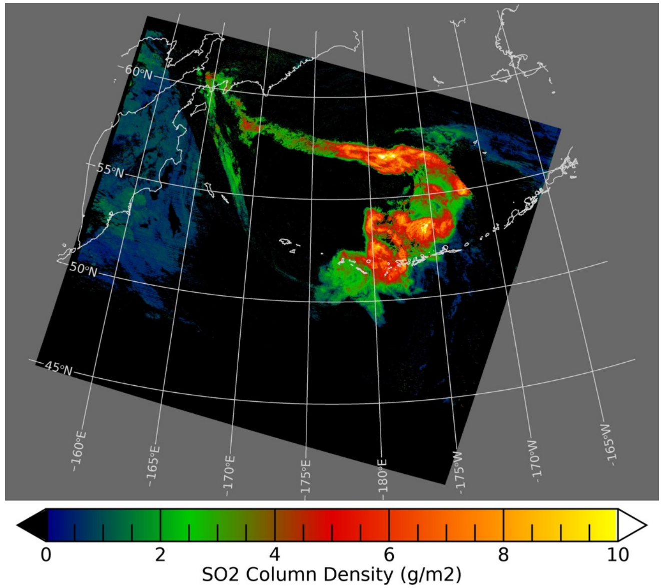
Volcanic Activity (VA) Product

❖ Scope

- positive VA index images:
  - produced as a LL product available within 24 hours
  - also will trigger more computationally expensive RT retrieval of the plume composition
    1. estimate temperature of surface beneath plume, exploiting plume transparency (λ > 9.5 μm)
    2. estimate SO_2 concentration at various heights by modeling plume transmission in SO_2 band (λ: 8 – 9.5 μm)



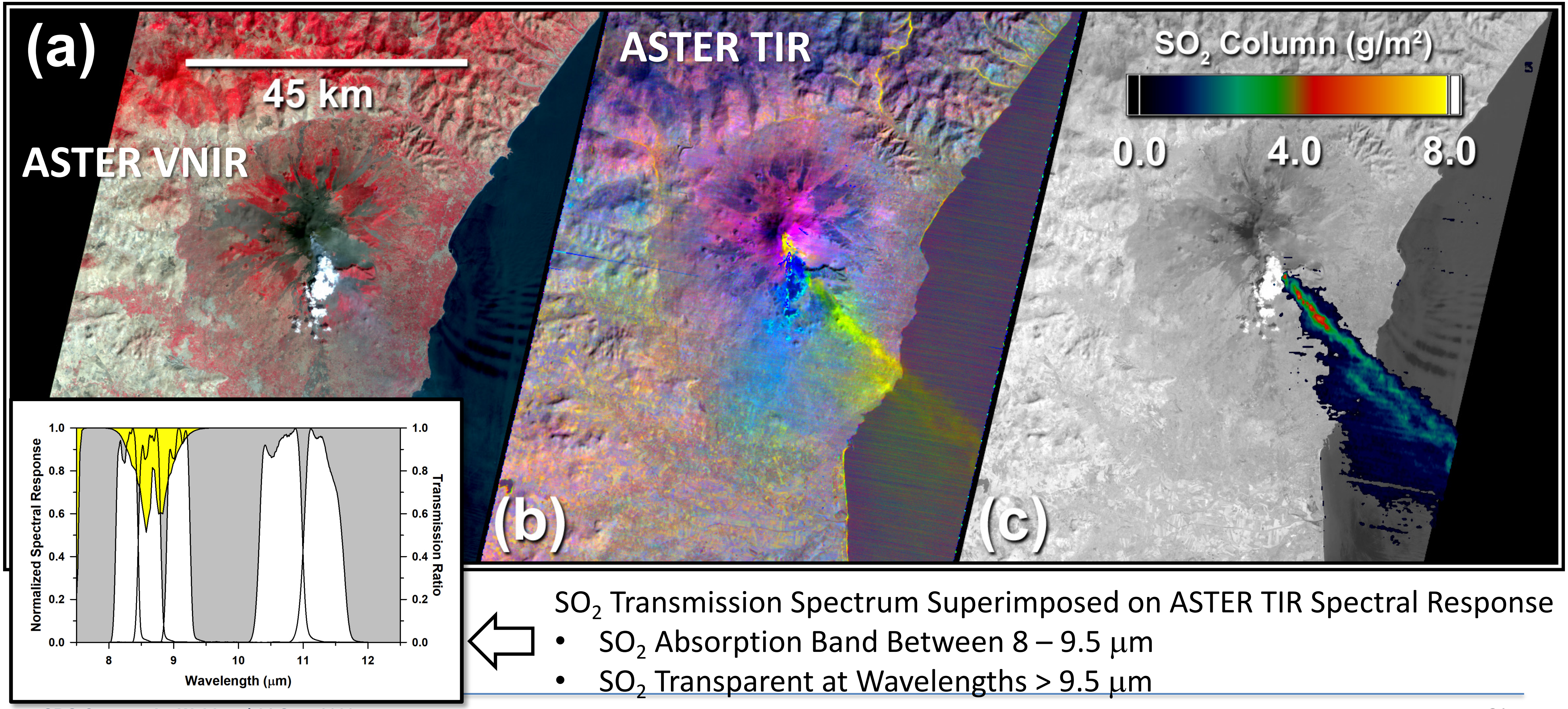




Questions?

Extra Slides

Volcanic SO_2 Emissions: ASTER Observations of Mount Etna, 2011-07-29



SO_2 Transmission Spectrum Superimposed on ASTER TIR Spectral Response

- SO_2 Absorption Band Between 8 – 9.5 μm
- SO_2 Transparent at Wavelengths > 9.5 μm

SO_2 Index: Targeting the SO_2 Retrievals

Mount Etna Eruption | 2018-12-27 | VIIRS-N20 | 11:48 UTC

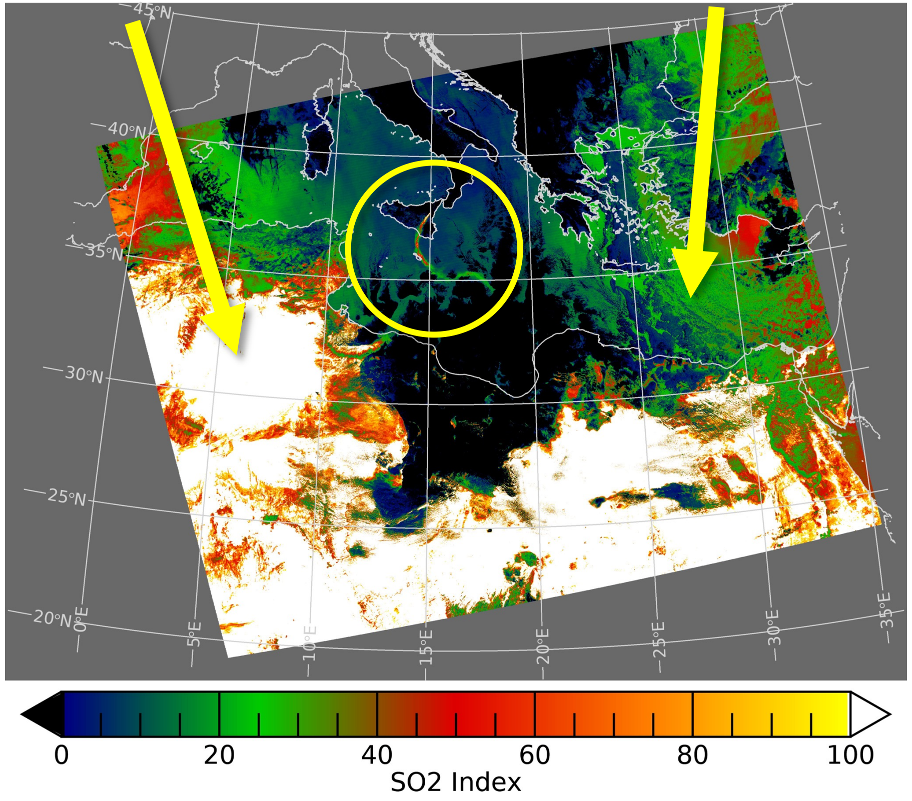
Radiative Transfer (RT) Modeling is Computationally-Expensive, and Thousands of RT Modeling Runs are Required to Map a Plume (0.008 s/pix)

- Focus, or Target, the Retrieval Procedure on Locations Most Likely to Contain Plumes
- **Proximity Mask:** Eliminate Locations (within SBG scene) >250 km from Historically-Active Volcanoes
- **SO_2 Index:** Based on Brightness Temperature Difference (BTD), Represents SO_2 Absorption
- Surface Emissivity (Silica-Rich Minerals) and Water Vapor Absorption Can Mimic SO_2 Absorption. Water Vapor Absorption Increases with Increasing Satellite (View) Zenith Angle
- **Emissivity Correction:** Requires Plume-Free Map of Surface Emissivity. Currently based on 5-km CAMEL Maps, which must be re-sampled to Scene Dimensions (**~2 x 10^{-5} s/pix**)
- **Water Vapor Gradient:** Attenuation Based on Satellite Zenith Angle

Original SO_2 Index Map

Surface Emissivity (Qtz Sand) Mimics SO_2 Absorption

Water Vapor Absorption Mimics SO_2 Absorption



SO_2 Index Map following Surface Emissivity Correction and Water Vapor Gradient