SBG VSWIR

Project Science/Applications Update

Robert O. Green, David R. Thompson, Regina Eckert, Philip G. Brodrick, Kelly Luis,
Christine Lee, Niklas Bohn, K. Dana Chadwick, Ryan Pavlick, and Colleagues

21 June 2023

Jet Propulsion Laboratory, California Institute of Technology
and The Community

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National and Space Administration (80NM0018AeronauticsD0004)

Overview

SBG VSWIR Project Life Cycle, SRR, Overview, and Status – Rob Green

Applications Integration – Christine Lee

SATM and Project Core Products for the Decadal Priorities– David Thompson

Earth System Product Approach – Phil Brodrick

Calibrated Radiance with Characterization and Uncertainty – Regina Eckert

Reflectance – David Thompson

Fractional Cover – Phil Brodrick

Aquatic (Coastal and Inland Waters) – Kelly Luis and Christine Lee

Snow/Ice Physics – Niklas Bohn

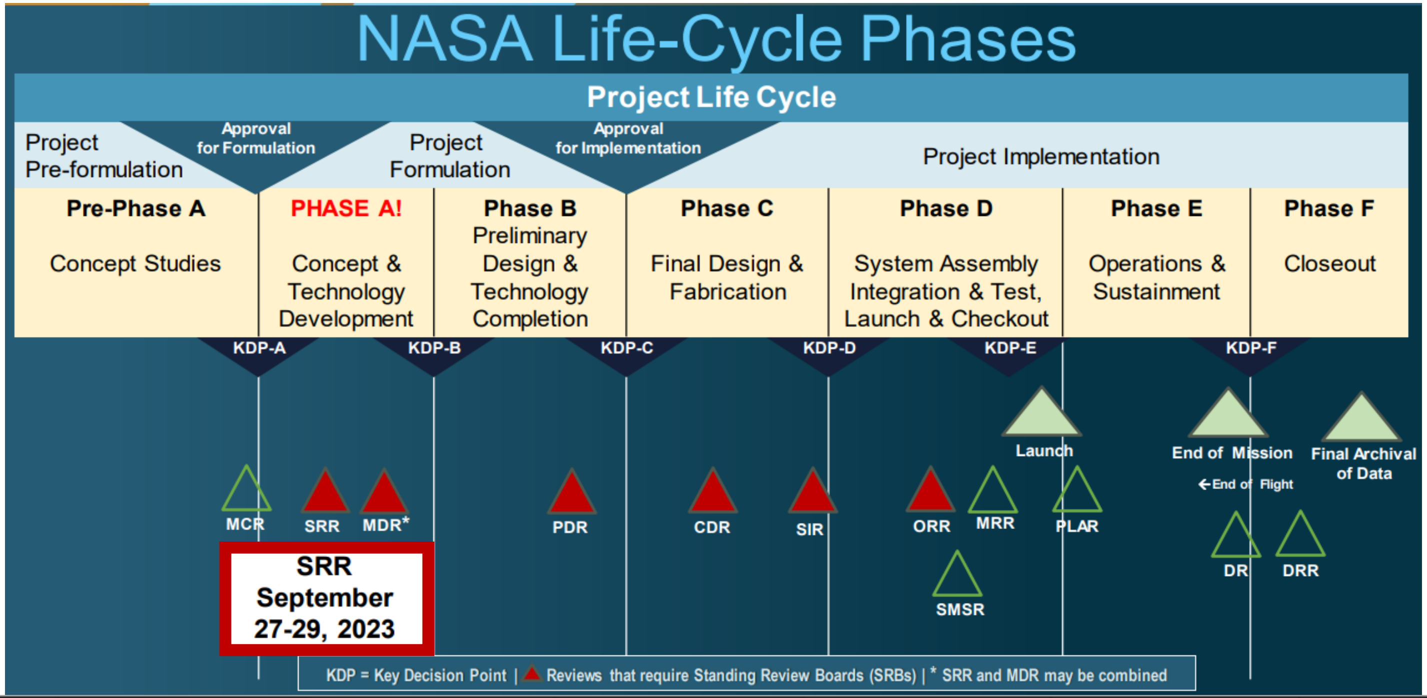
Plant Composition, Function, and Structure – Dana Chadwick and Ryan Pavlick

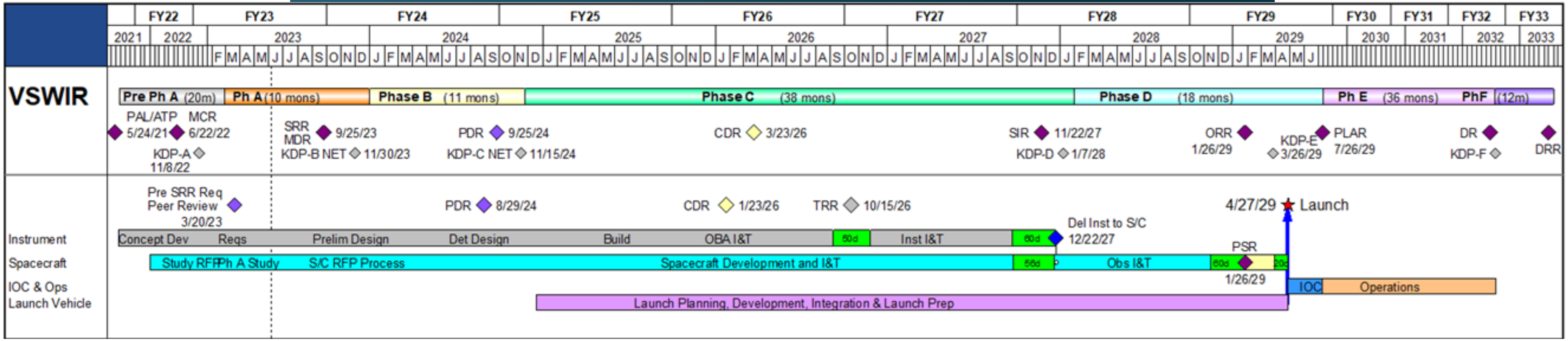
Geology and Mineralogy – Rob Green

Wrap up and Next Steps – Rob Green

Questions and Discussion - All

NASA Phases and SBG VSWIR Notional Schedule





SBG VSWIR Project System Requirements Review

The System Requirements Review (SRR) evaluates the project requirements for clarity, achievability, consistency, understanding, responsiveness to the sponsor commitments, and appropriateness to fulfill the mission needs.

Key Terms: Requirements, Range, Margin, Calibration, Algorithm parameterization, training, tuning, Verification, Validation, Uncertainty Quantification, and Harmonization

SBG with VSWIR Imaging Spectroscopy
Earth Decadal Survey Designated Observable

Delivers “Most Important and Very Important” Objectives Across the Decadal Focus Areas

ECOSYSTEMS AND NATURAL RESOURCES

E-1. What are the structure, function, and biodiversity of Earth’s ecosystems, and how and why are they changing in time and space?
E-2. What are the fluxes of carbon, water, nutrients, and energy between ecosystems and the atmosphere, the ocean, and the solid Earth, and how and why are they changing?
E-3. Fluxes within ecosystems. What are the within ecosystems, and how and why are they changing?

SOLID EARTH

S-1. How can large-scale geological hazards be accurately forecast in a socially relevant time frame?
S-2. How do geological disasters directly impact the Earth system and society following an event?

HYDROLOGY

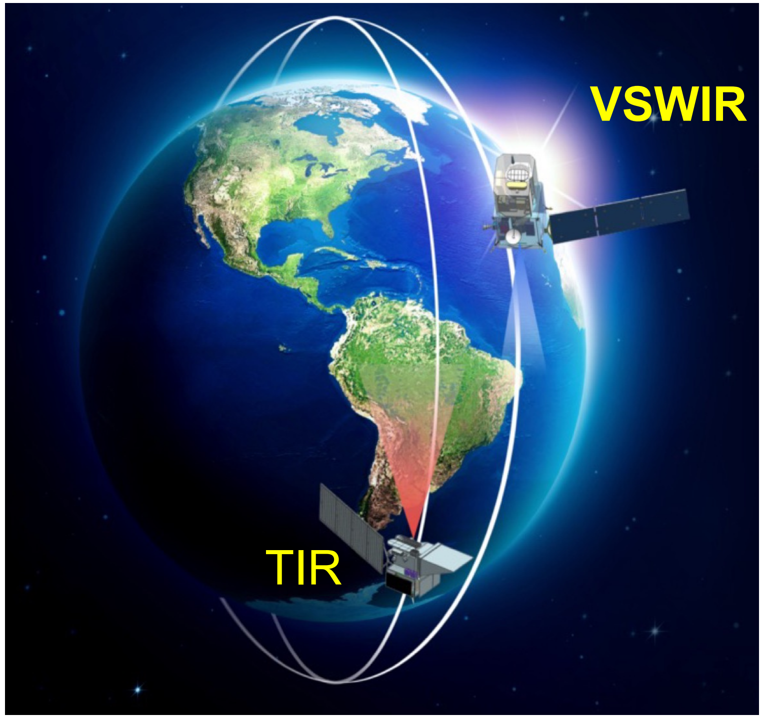
H-1. How is the water cycle changing?
H-2. How do anthropogenic changes in climate, land use, water use, and water storage, interact and modify the water and energy cycles locally, regionally and globally.
H-4. Hazards, extremes, and sea level rise. How does the water cycle interact with other Earth system processes to change the predictability and impacts of hazardous events.

CLIMATE

C-3. How large are the variations in the global carbon cycle and what are the associated climate and ecosystem impacts?

WEATHER

W-3. How do special variations in surface characteristics (influencing ocean and atmospheric dynamics, thermal inertia and water) modify transfer between domains?

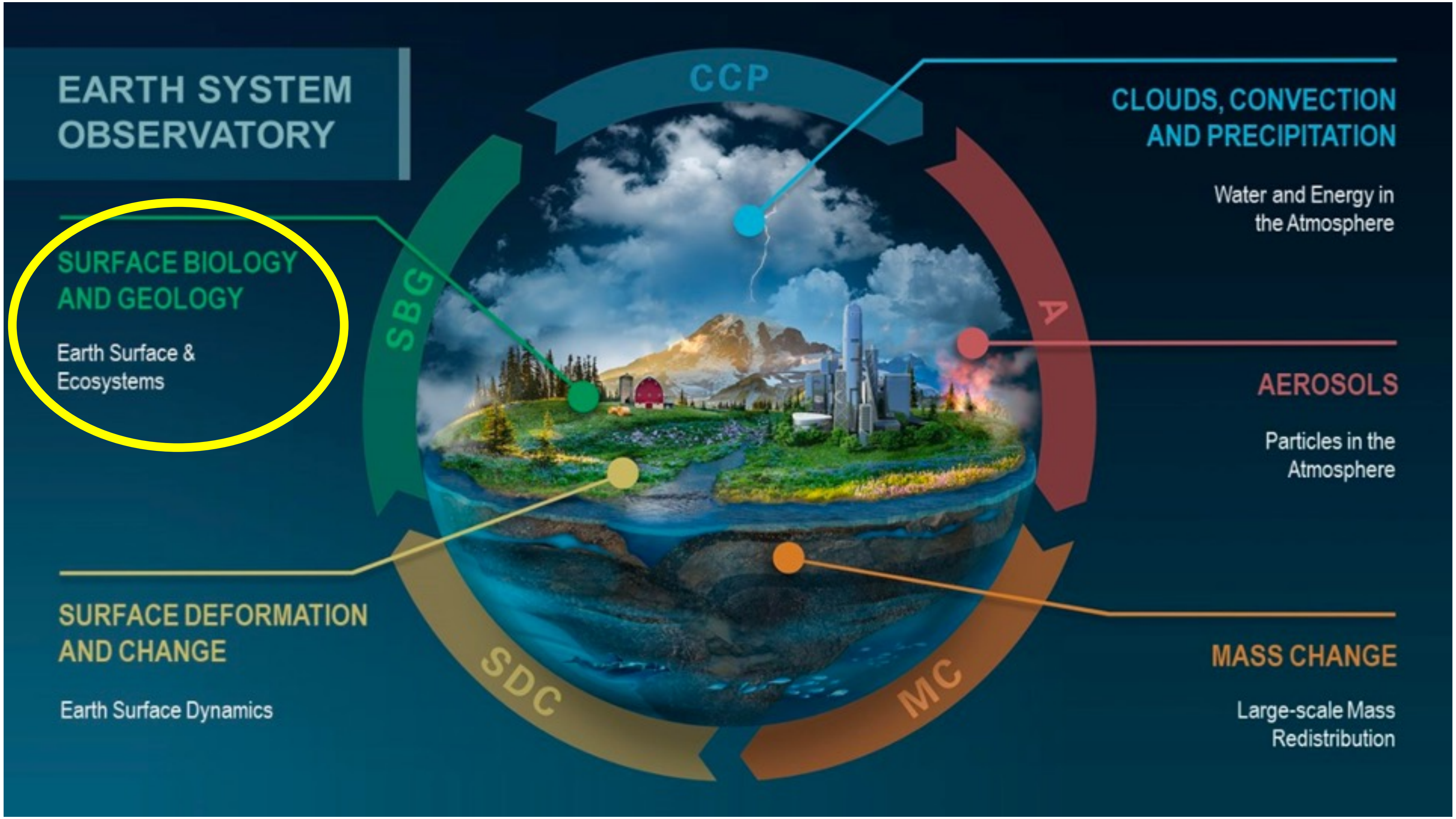


VSWIR Imaging Spectroscopy

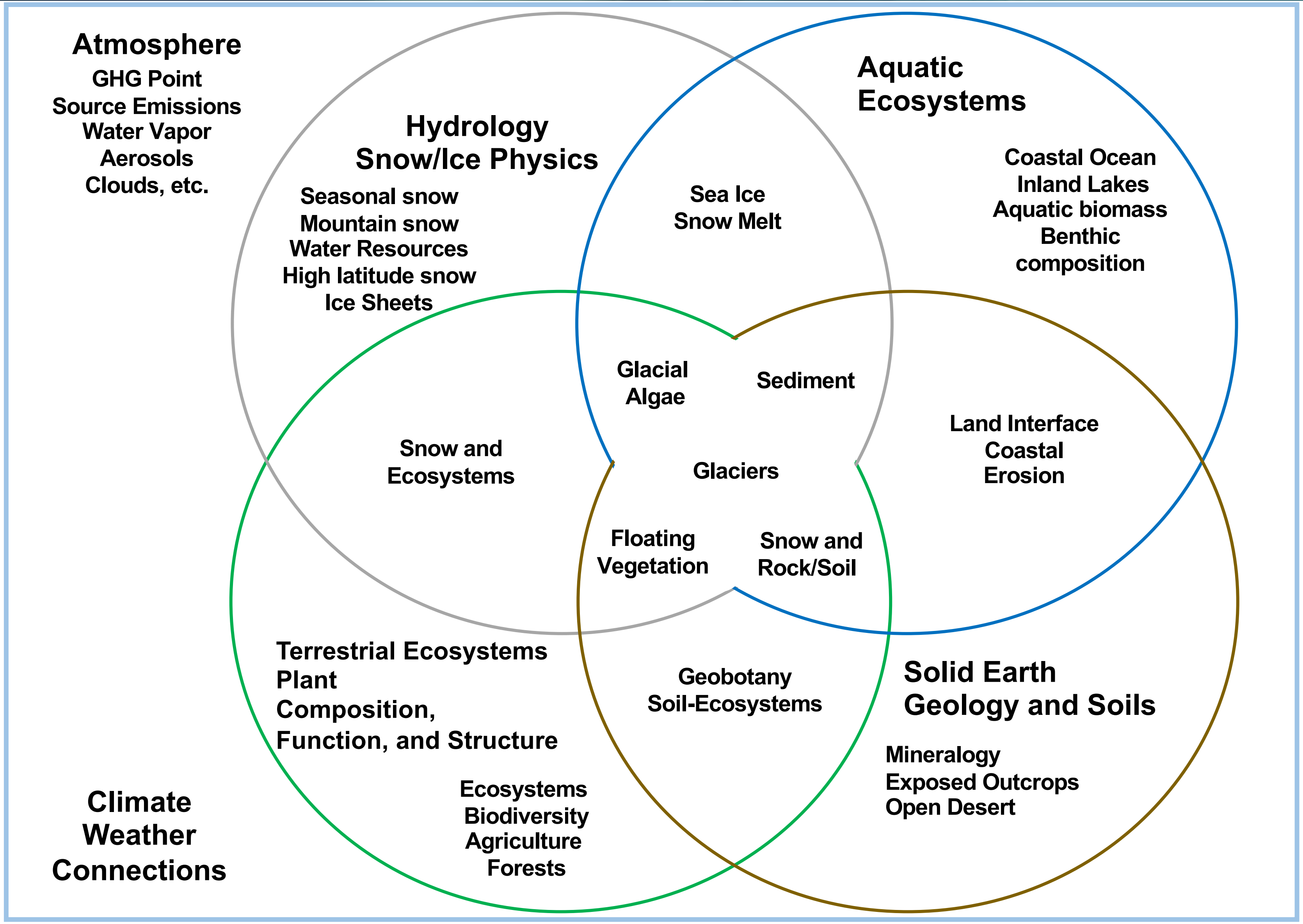
Next Generation Technology
>10X the performance of EMIT

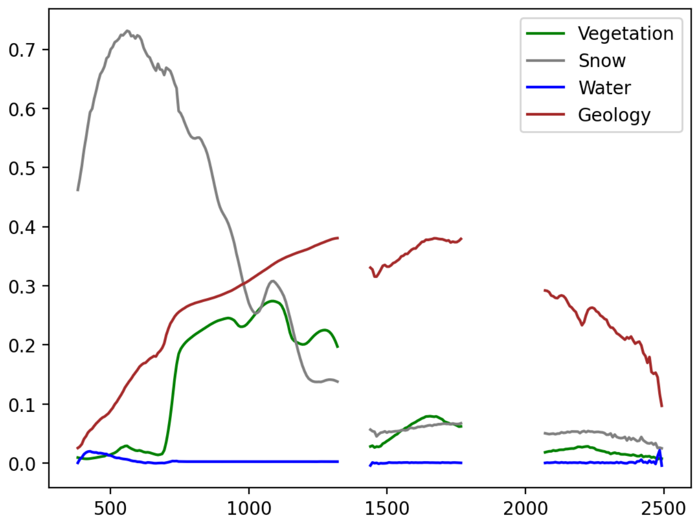
- Terrestrial ecology and agriculture
- Coastal and inland waters
- Geology and minerals
- Snow/ice and hydrology
- GHGs as value added

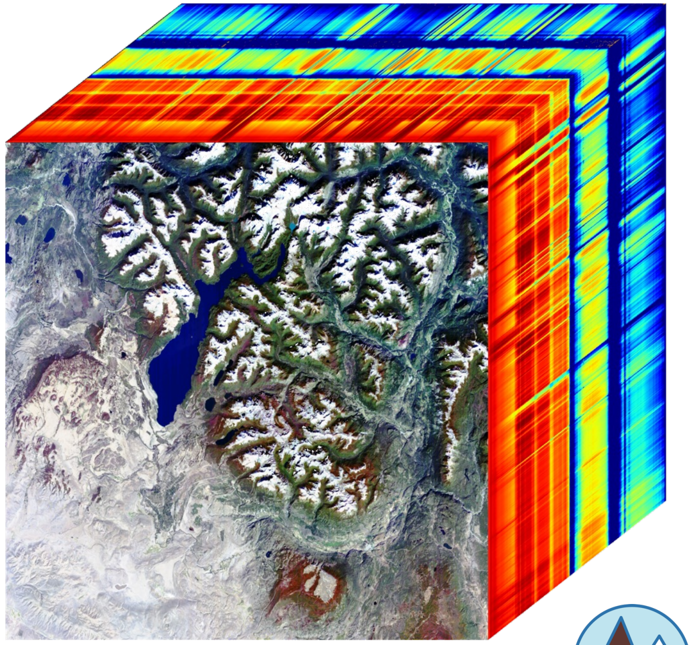
SBG VSWIR is Part of NASA's Earth System Observatory



SBG VSWIR Observes the Earth System



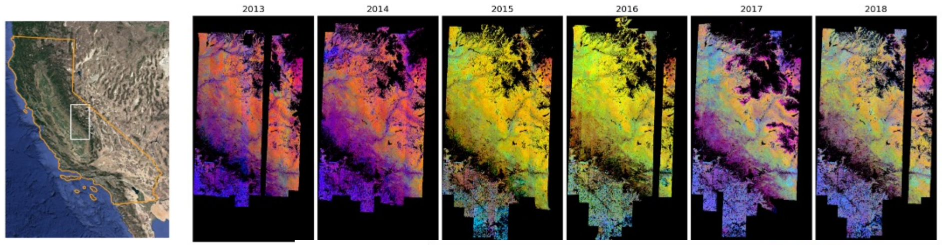


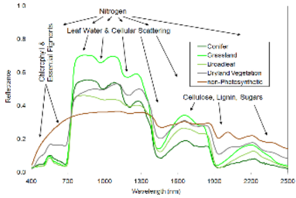


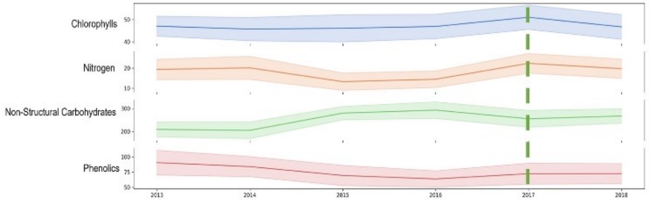
New Global Research Called for in the Decadal Survey Evidence of Low Risk from Local/Regional Studies

Terrestrial Ecology

New understanding of drought impact on ecosystem traits.

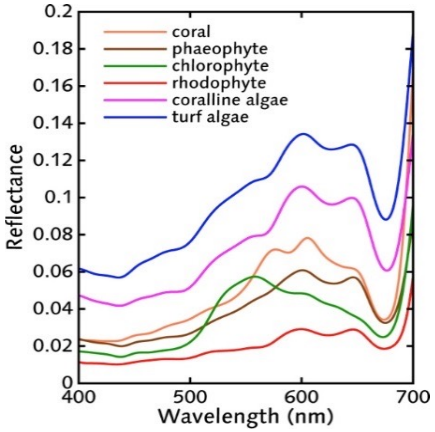


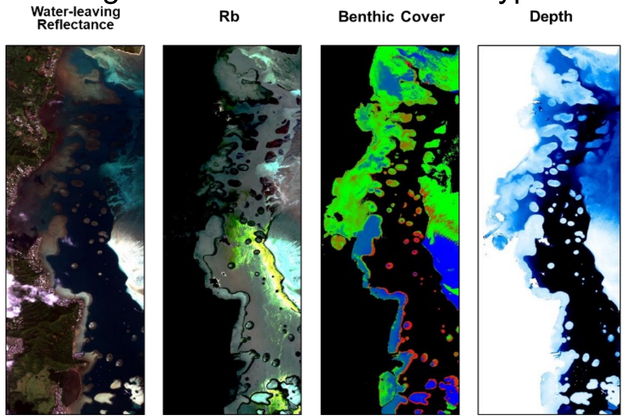




Aquatic Ecology

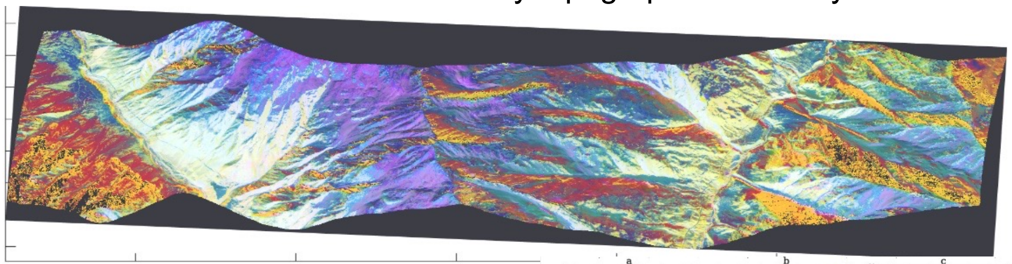
Composition and condition of benthic habitats including corals. Algal biomass and functional type.

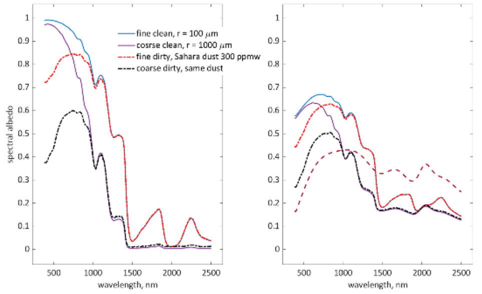


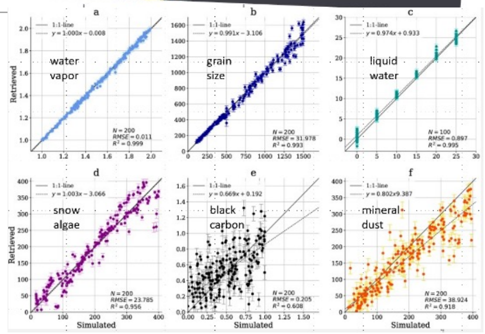


Hydrology

Understand and quantify snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability

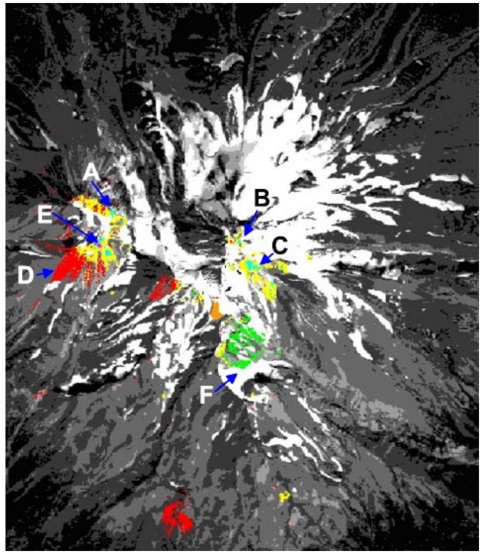


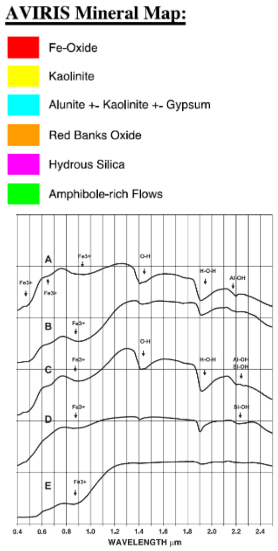


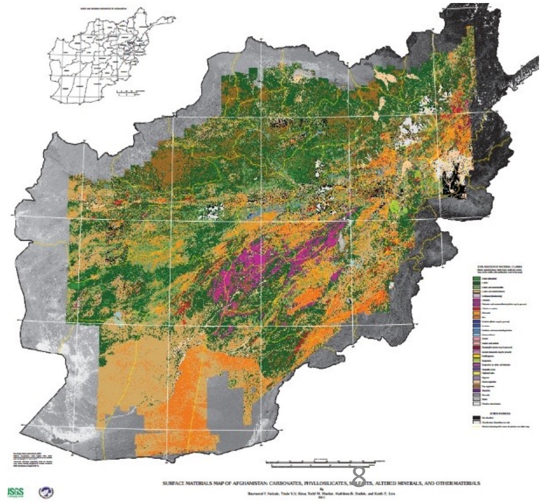


Geology

Potential debris flow source areas identified with imaging spectroscopy on Mount Shasta volcano, California. Afghanistan geology from airborne imaging spectrometer observations.







Societal Benefit Applications from Decadal Survey VSWIR Imaging Spectroscopy

AGRICULTURE, FOOD SECURITY AND SURFACE WATER MANAGEMENT

Information on crop health to inform optimized fertilization
Improve water supply management through characterization of snow properties and reservoir inflows
Information to reduce the impacts of drought, such as crop loss and famine, on global scales

WATER QUALITY AND COASTAL ZONES

Support early detection of and response to harmful algal bloom formation
Protect sensitive aquatic habitats by monitoring/reducing water pollutant loading, particular in coral reefs and other sensitive ecosystems

CONSERVATION

Support biodiversity understanding and protections by mapping invasive species composition, structure, distribution; support removal and restoration Monitoring of endangered species habitat; provide alerts of disease mortality of impacted vegetation, including insect infestation
Biodiversity hotspots, priority conservation areas, 30 x 30 plans

WILDFIRE RISK AND RECOVERY

Fuel mapping (cover type, extent, status) for wildfire danger management
Post fire severity assessment and recovery, including prediction of areas with higher likelihood of debris flows

DISASTERS AND HAZARDS

Detect and track oil spill events and
Mine waste hazard mapping before and after events
Toxic mineral mapping and related airborne dust impacts

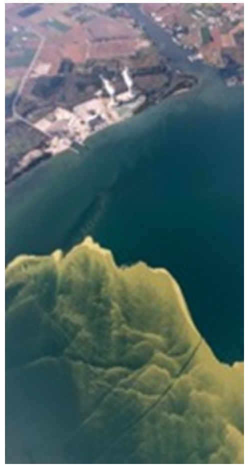
GEOLOGY APPLICATIONS

Mineral mapping for exploration efforts and reduction of environmental hazards
Landslide risk assessment with improved surface mineralogy knowledge and land cover maps
Weak mineral zones in active volcanos to predict debris flow potential

CLIMAGE CHANGE MITIGATION

Methane and Carbon Dioxide point and localized sources

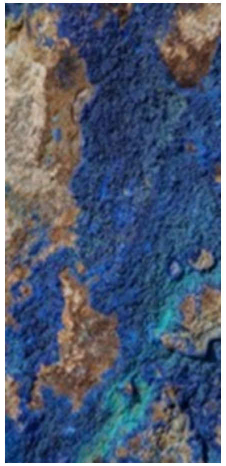
Agriculture Food Security



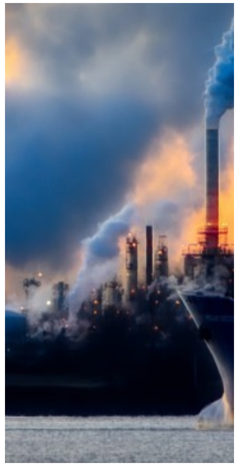
Water Quality Algal Blooms

Biodiversity Conservation

Wildfire Fuel, Severity, Recovery



Strategic Minerals

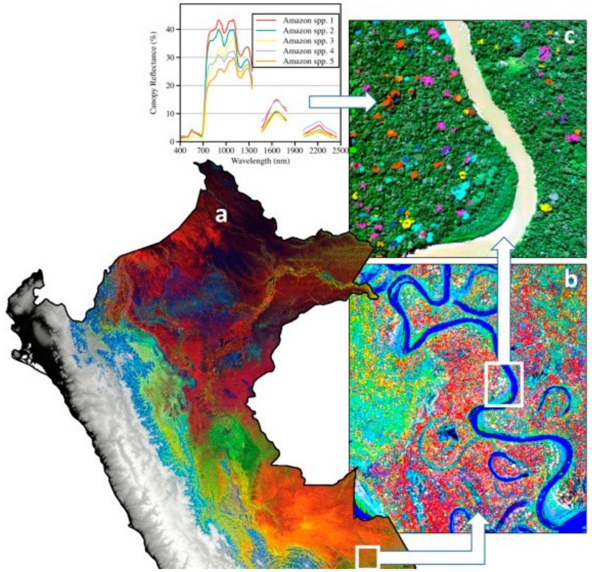


Greenhouse Gases

New Global Applications for Societal Benefit
Evidence of Low Risk from Local/Regional Studies

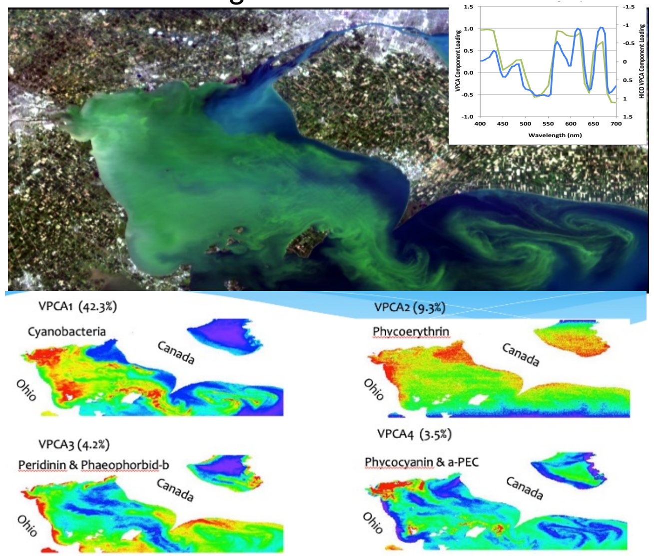
Biodiversity

Biodiversity mapping in Peru for conservation



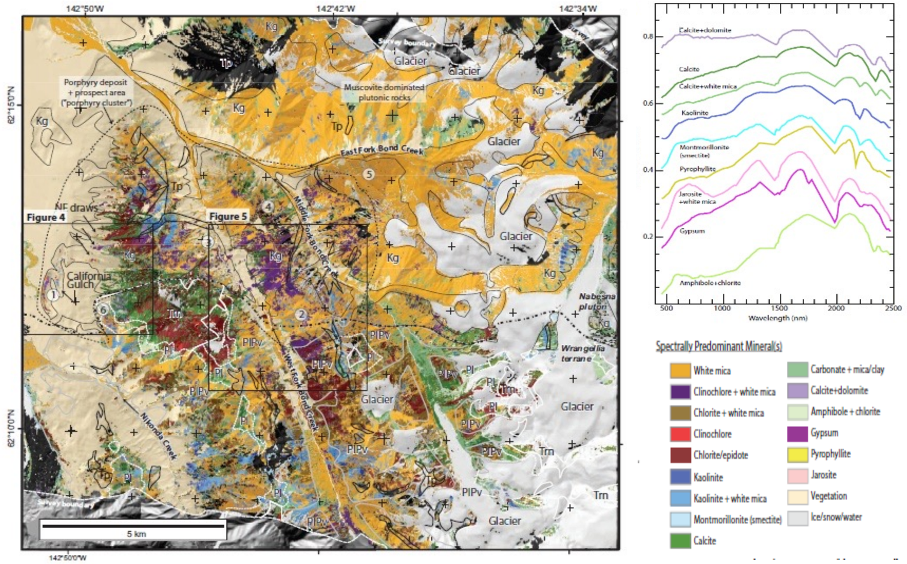
Harmful Algal Blooms

Harmful algal blooms in lake Erie



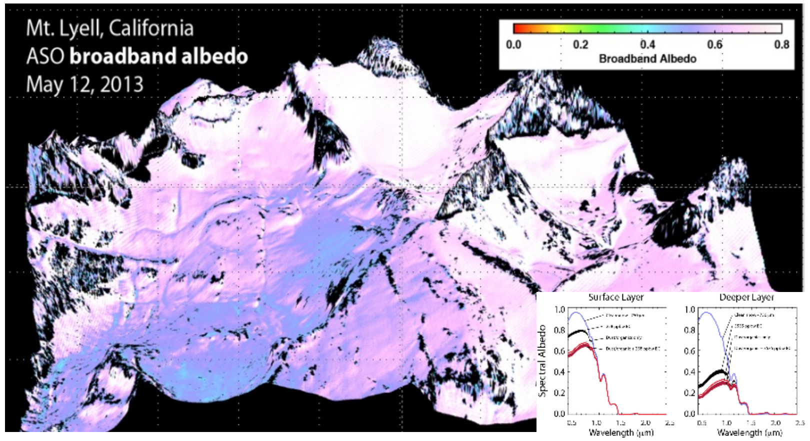
Mineral Resources

Mineral exploration in Alaska



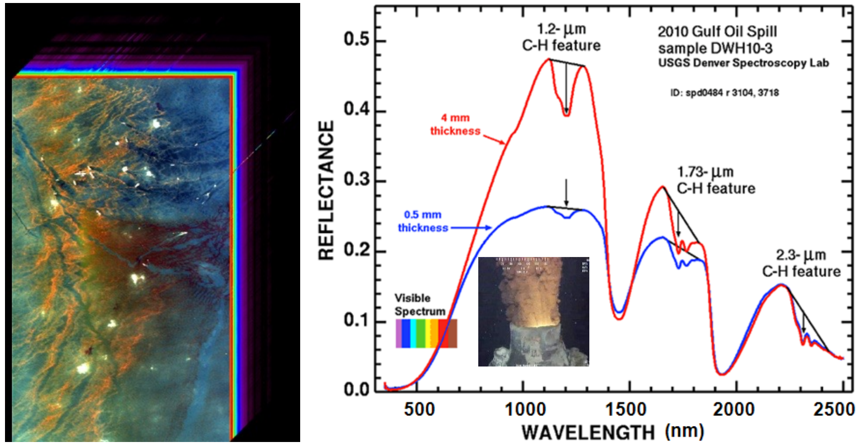
Water Resources

Snow melt prediction in California



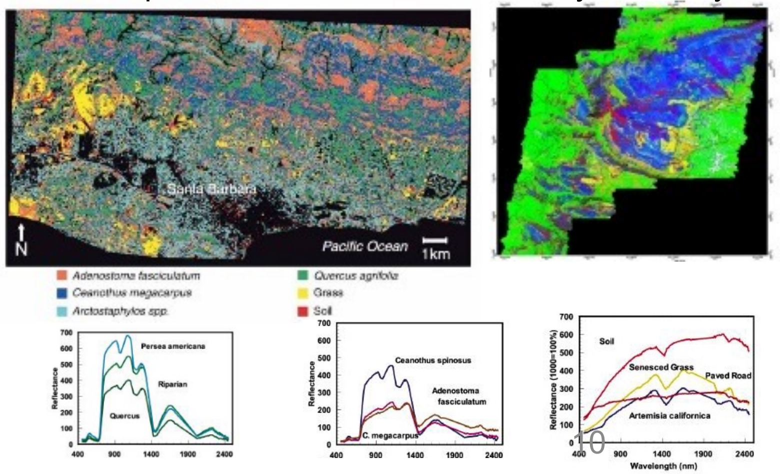
Disasters/Hazards

Gulf oil spill extend, thickness, and volume.

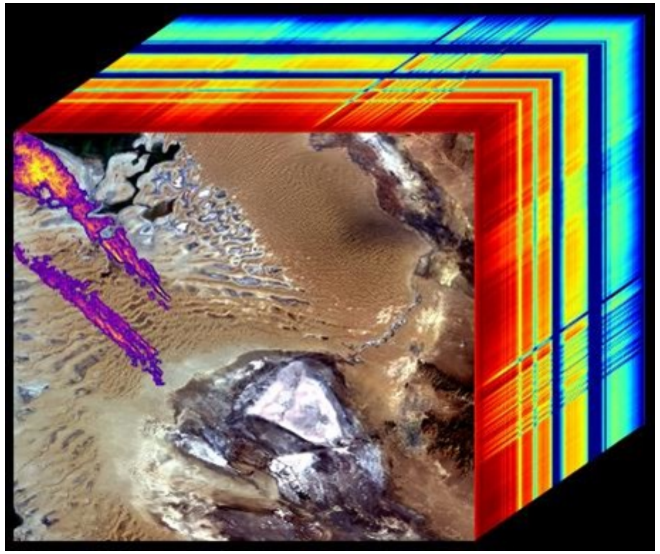


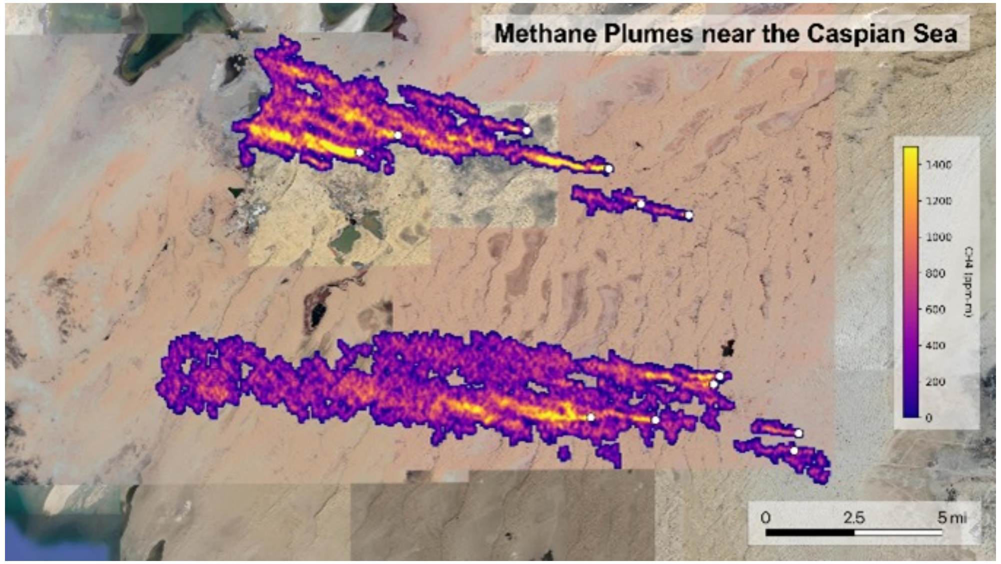
Fires

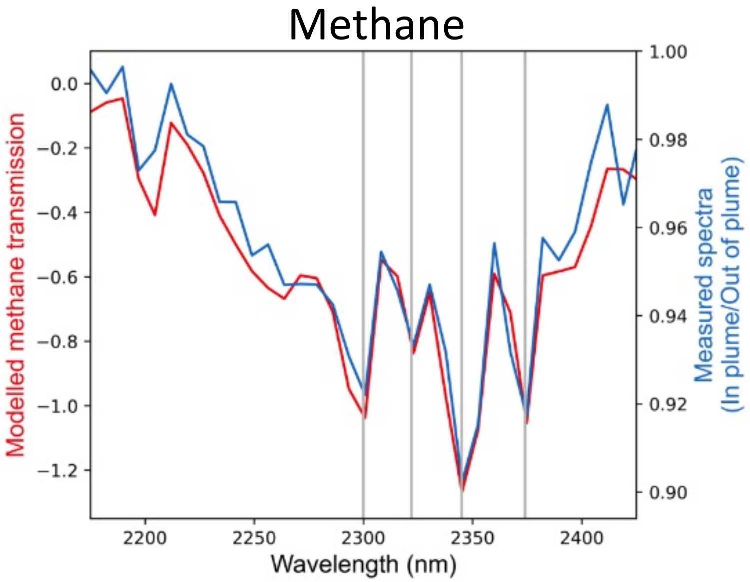
Fuel composition/condition, burn severity, recovery

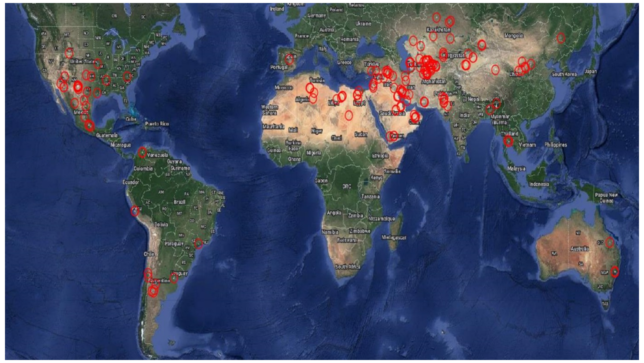


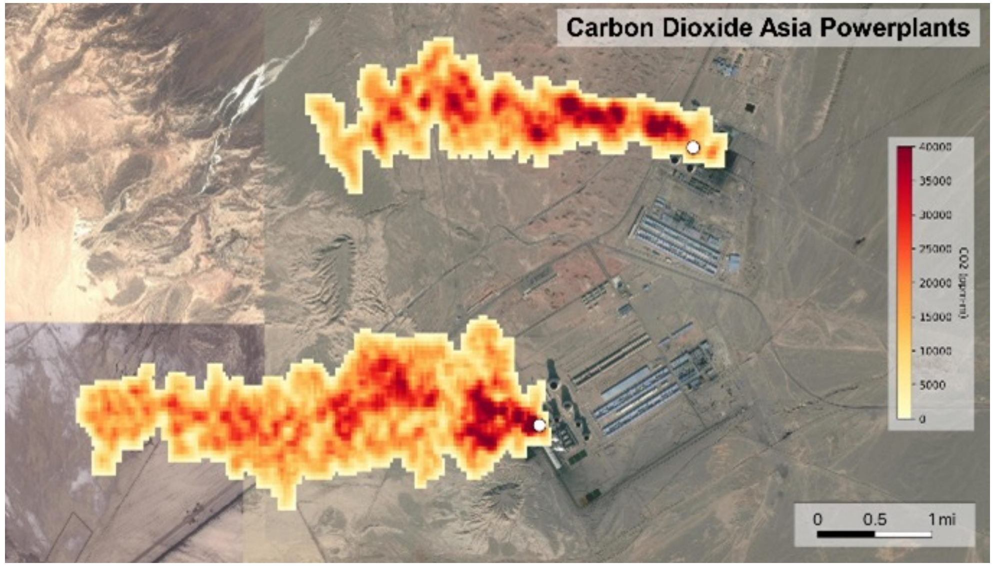
Greenhouse Gas Point Source Measurement Evidence from EMIT

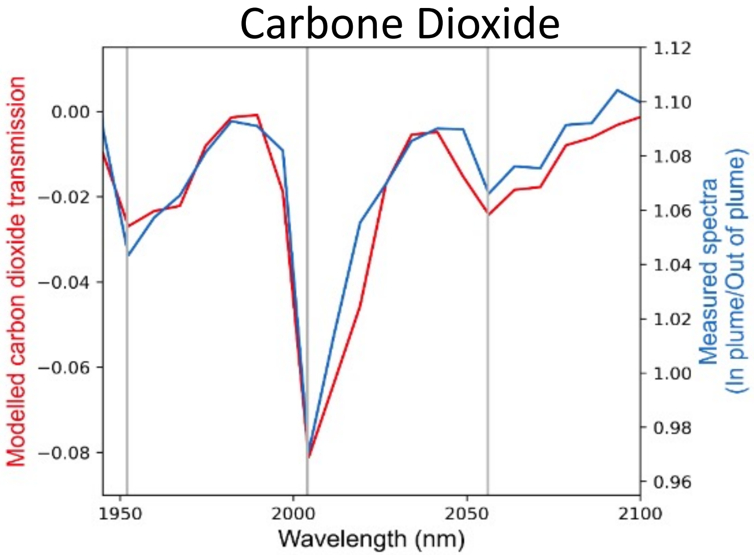












100s of plumes and plume complexes across six continents

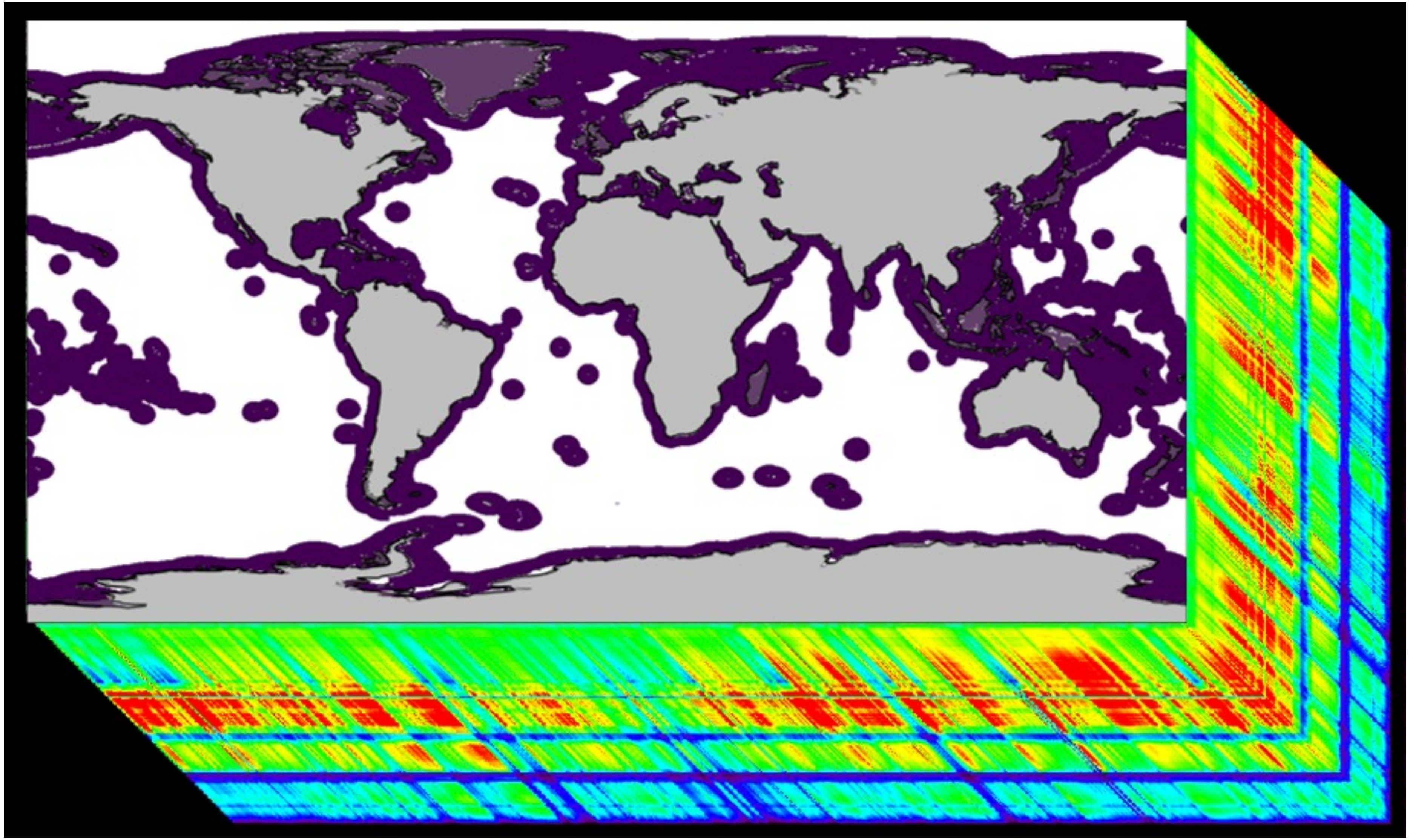
SBG VSWIR Observation Requirements from Decadal Survey Substantiated and Refined with Studies and Analysis

The SBG Research and Applications Traceability Matrix (SATM) follows the National Academies 2017 decadal survey directions for desired capabilities. Key performance parameter ranges for the VSWIR instrument, derived from the SATM are shown below.

1. **Spectral Range: 380-2500 nm**
2. Spectral Bands: Between 8 to 12 **nm** with continuous spectral coverage
3. Radiometric and Signal to noise (SNR) performance: **SNR ≥400 VNIR and SNR ≥250 SWIR** at 25% reflectance, <5% absolute radiometric uncertainty with **high uniformity**, low stray-light, and low polarization sensitivity needed to meet key RA objectives
4. Ground Sampling Distance (GSD) at nadir: **31 to 35 m**
5. Revisit Period: **≤16 days** at the equator
6. Coverage: **All global land, inland waters, and coastal oceans**
7. Local Time for Acquisition: Between 10:30 to 11:30 AM
8. Stability and duration: Measurements must be able to detect changes for addressing dynamics of the Earth System over the prime mission lifetime of 3 years with possible extensions

Consistent with notional DS Observable from page B-17: Primary Observable: Chemical properties of vegetation and aquatic biomass, and Soils Land, inland aquatic, coastal zone, and shallow coral reef: Spectral radiance (10 nm; 380-2500nm); GSD = 30-45 m; Revisit = ~15 days; SNR = 400:1 VNIR/250:1 SWIR @ 25% reflectance; IT of ~5 ms. High-fidelity imaging spectrometer (150-200 km swath from sun-sync LEO).

SBG VSWIR Coverage Mask for Decadal Survey Traced to Global Research and Applications

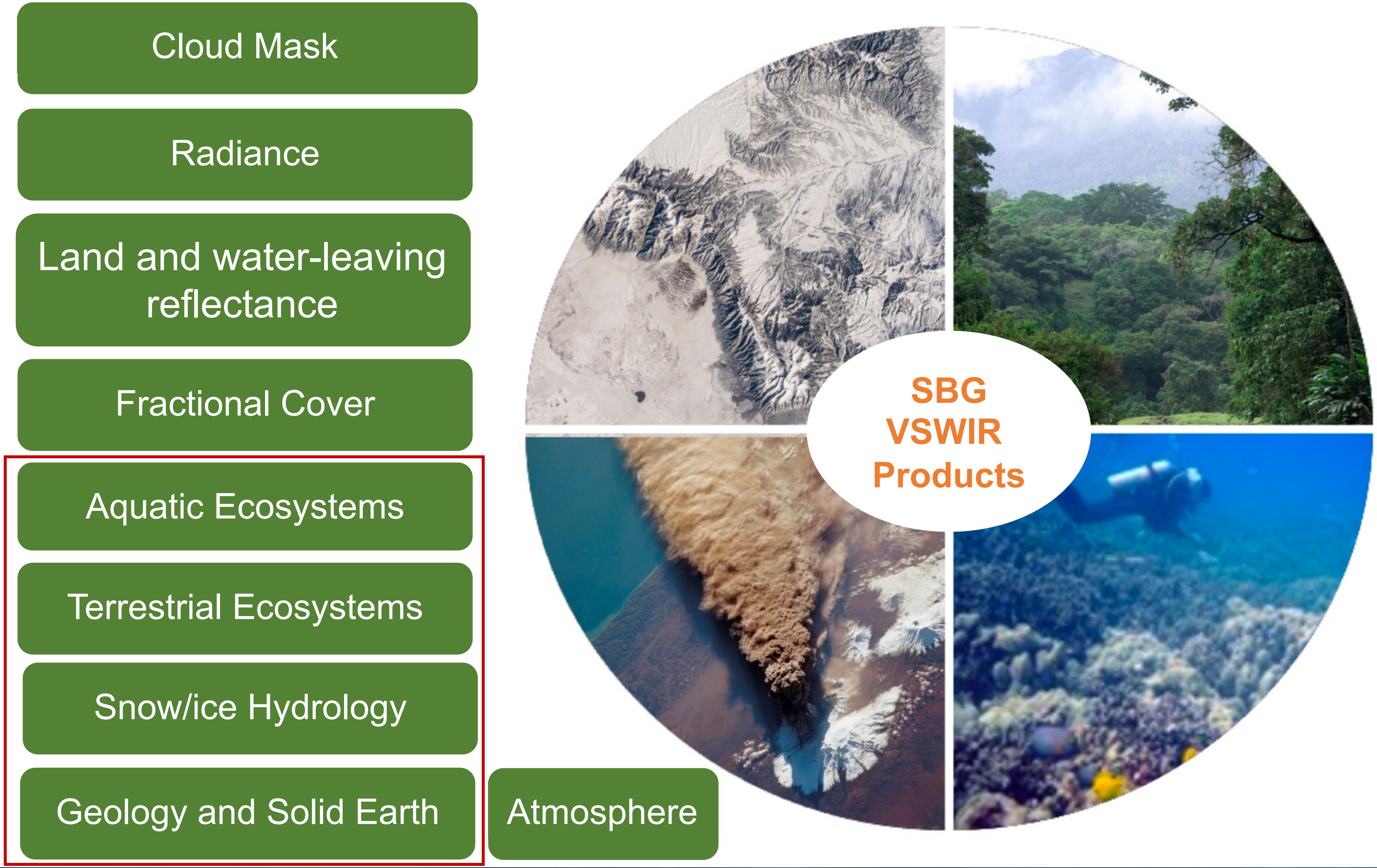


16 Day revisit

30 m sampling land, inland-water, snow/ice and coastal

1000 m binned open ocean

SBG VSWIR Science/Applications Traceability Links to the Products to Support Core Decadal Priorities



Enabling a broad and diverse set of community algorithms and products.

e.g. Cawse-Nicholson, Kerry, Philip A. Townsend, David Schimel, Ali M. Assiri, Pamela L. Blake, Maria Fabrizia Buongiorno, Petya Campbell et al. "NASA's surface biology and geology designated observable: A perspective on surface imaging algorithms." *Remote Sensing of Environment* 257 (2021): 112349.

Science and Applications Integration

NASA Earth Action Strategy

Driving impact from $1.5 B in NASA observations and research Delivering impact (including meeting the needs of Federal agencies, state, local, and tribal governments)

New Earth Information Center
Physical and Virtual Engagement with "Our Earth as NASA Sees it"

Earth Action Solutions
Focused scaling of NASA science and tools for response to climate and other changes, leveraging National, International and Commercial partnerships

Earth System Science & Tools for Impact
Competed efforts to drive discovery in Research, Analysis, Modeling, Applications Incubation

Earth System Observations
Observation of Earth from Space, Air and Ground

Major Themes and Needs (under evaluation)

- Greenhouse gas monitoring
- Wildland fire risk & recovery
- Health & air quality
- Sea level & coastal risk
- Energy & sustainable infrastructure
- Agriculture
- Disasters & Extreme Events
- Water Resources
- Biodiversity & Ecosystem Change

Science and Applications Integration

NASA Earth Action Strategy

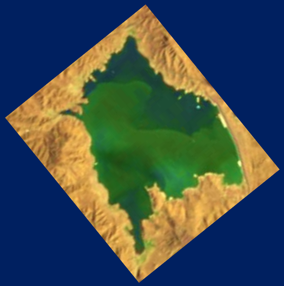
Driving impact from $1.5 B in NASA observations and research Delivering impact (including meeting the needs of Federal agencies, state, local, and tribal governments)

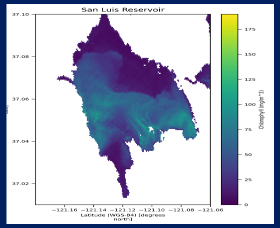
New Earth Information Center

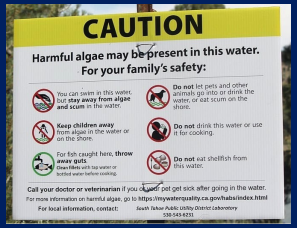
Earth Action Solutions

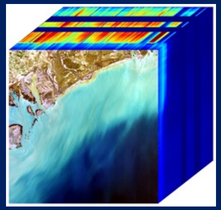
Earth System Science & Tools for Impact

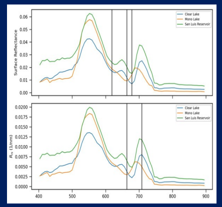
Earth System Observations











SBG has demonstrated capability to support all proposed Earth Action Themes and Needs

- Greenhouse gas monitoring
- Wildland fire risk & recovery
- Health & air quality
- Sea level & coastal risk
- Energy & sustainable infrastructure
- Agriculture
- Disasters & Extreme Events
- Water Resources
- Biodiversity & Ecosystem Change

Science and Applications Traceability

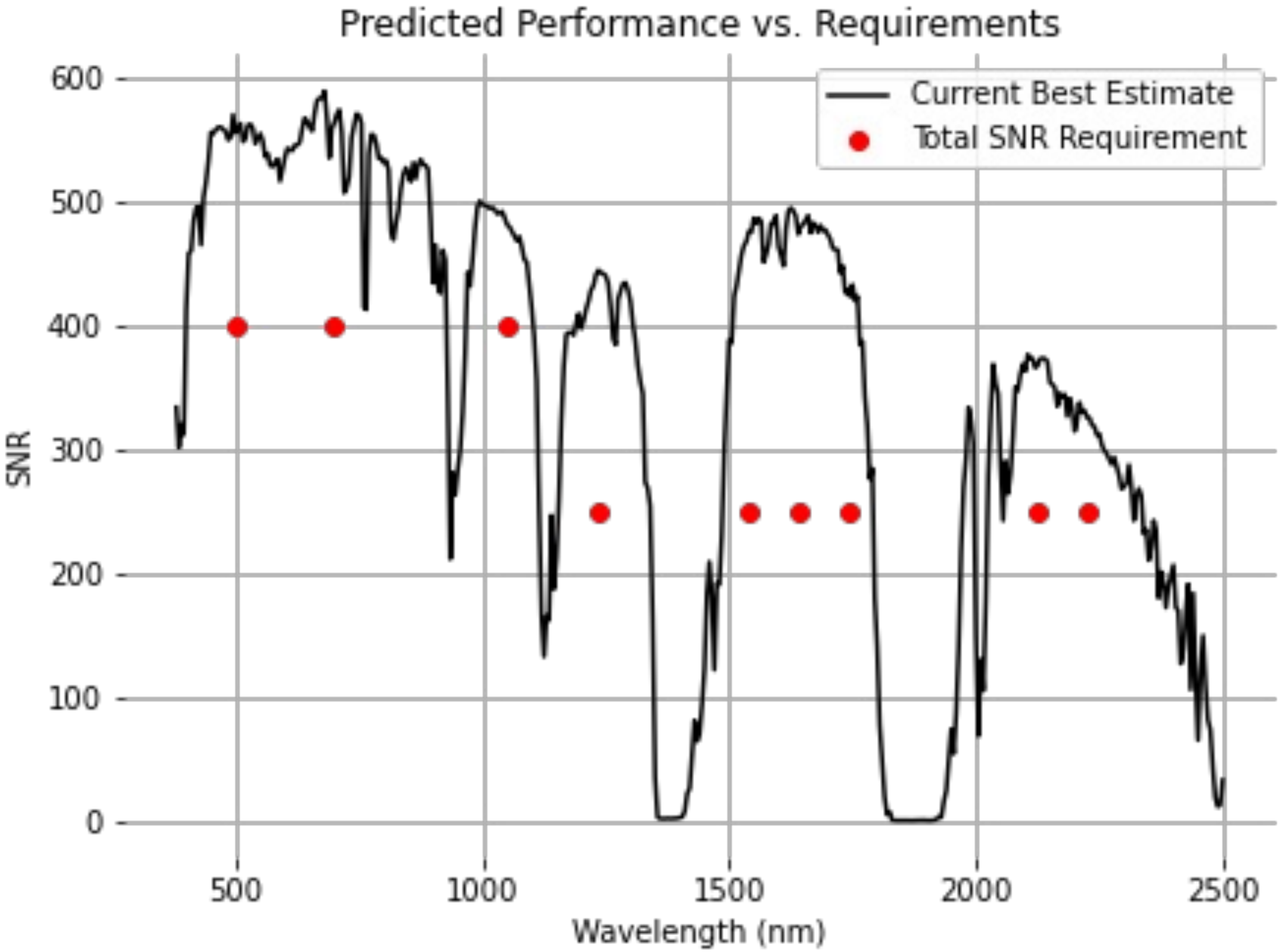
Goals

- Establish product error budgets for different subsystems
- Determine observation scenarios that drive instrument performance
- Quantitative modeling & error propagation to inform design decisions

Approach

1. Establish reference observation cases for each SBG product
2. Calculate a local linearized retrieval
3. Assess calibration errors and forward-propagate instrument noise

Instrument model



Procedure

Linearized retrieval at b

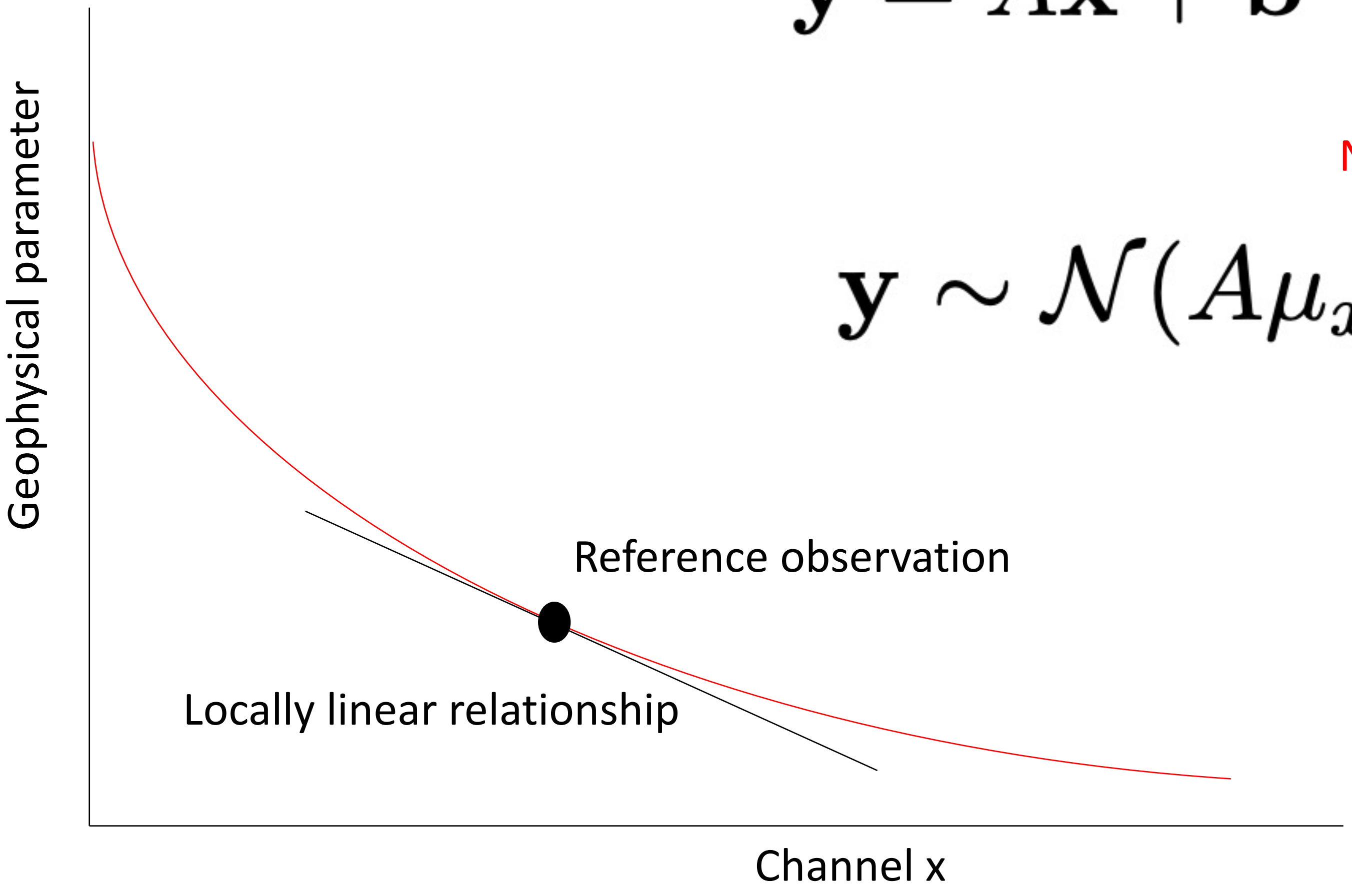
$$\mathbf{y} = A\mathbf{x} + \mathbf{b}$$

Instrument noise from radiometric model

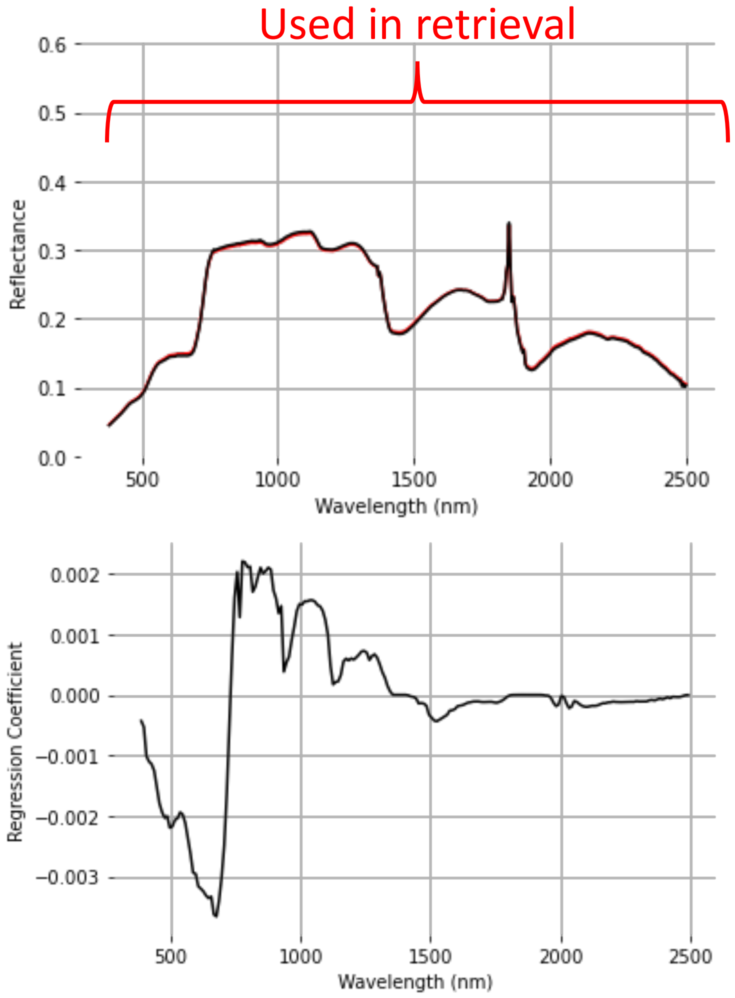
$$\mathbf{x} \sim \mathcal{N}(\mu_x, \Sigma_x)$$

Noise-equivalent retrieval error

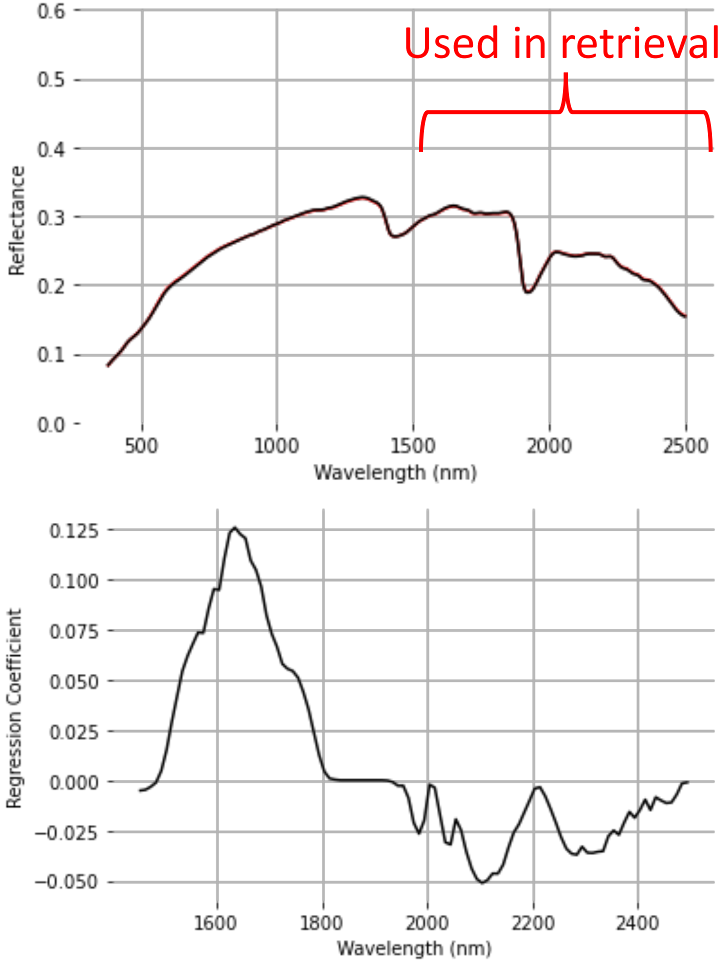
$$\mathbf{y} \sim \mathcal{N}(A\mu_x, \underbrace{A\Sigma_x A^T}_{\text{Noise-equivalent retrieval error}} + \Sigma_b)$$



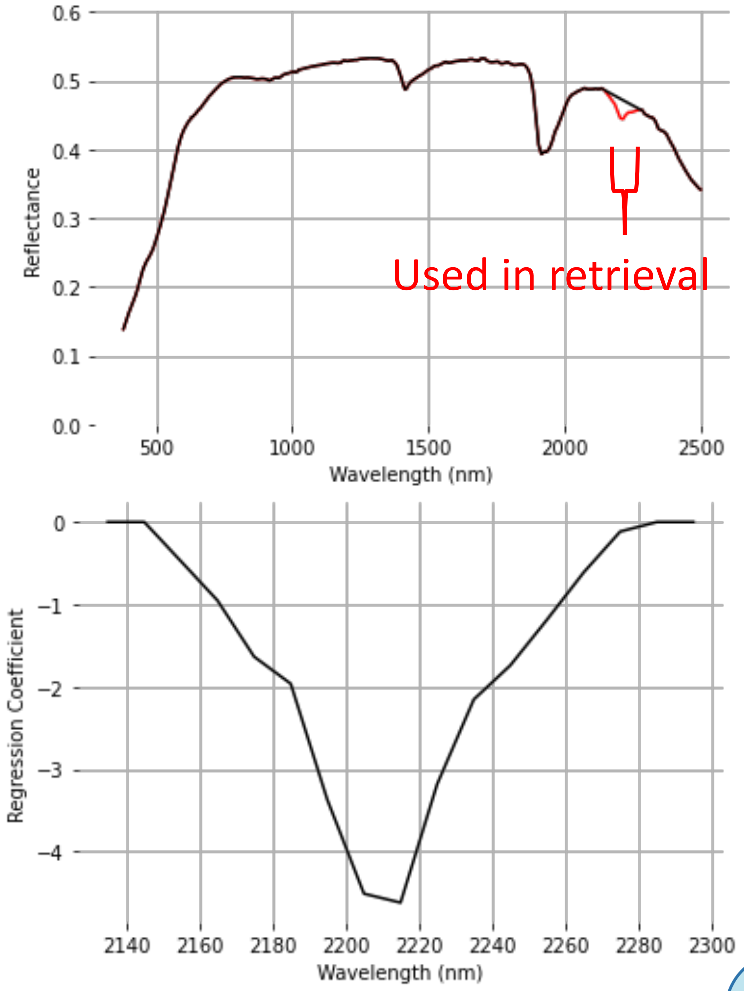
Measurement noise error for soil fractional cover +/- <1%



Measurement noise error for NPV fractional cover +/- <1%



Measurement noise error for mineral spectral abundance +/- 2.3%



Live Example

SATM Error Budget

SBG Example Geophysical Variables and Capabilities	Reference Geophysical Variable Error Budget		
Geophysical Parameters (one-sigma uncertainty target)	**Uncertainty allocation due to measurement noise (one sigma, worst case performance)**	**Uncertainty allocation due to radiometric calibration at required accuracy (one sigma)**	**Uncertainty allocation due to algorithms (one sigma)**
Snow and ice coverage fraction (coverage fraction +/- 7%)	Snow cover +/- <1%	Snow cover +/- <1%	Snow and ice coverage +/- 6%
Snow grain size, used to calculate albedo (absorption +/- 7%)	Snow grain size +/-3.7 um @400 um Snow absorption +/- <1%	Snow grain size +/- <1% Snow absorption +/- <1%	Snow and ice absorption +/- 6%
Phytoplankton pigments (chlorophyll 25% via AWG)	Chlorophyll +/- 7%	Chlorophyll +/- 19%	Chlorophyll +/- 14%
Benthic composition - proportional cover of algae, coral, sand (coral fraction 20% at 5m depth, from AWG)	Coral fraction +/- 9% at 5 m depth	Coral fraction +/- 13% at 5 m depth	Coral fraction +/- 12% at 5 m depth
Canopy nitrogen (N % +/- 25% via AWG)	Canopy Nitrogen +/- 3%	Canopy Nitrogen +/- 7%	Nitrogen +/- 24%
Leaf Water Content (LWC % +/- 10%: p362, uncertainties via AWG)	Leaf Water Content +/- 2%	Leaf Water Content +/- 7%	Leaf Water Content +/- 6%
Leaf Mass per Area - TBC (LMA g/m2 +/- 30%)	LMA +/-5%	LMA +/- 16%	LMA +/- 25%
Fractional cover: p371 (Live foliage (PV), plant residue (NPV) fraction +/- 10%)	NPV coverage fraction +/- <1% PV coverage fraction +/- <1%	NPV coverage fraction +/- <1% PV coverage fraction +/- <1%	NPV Fraction +/- 9% PV Fraction +/- 9%
Soil Surface Chemistry iron oxides, carbonates, and types of clay minerals, e.g., montmorillonite, illite, and kaolinite, p371, (Kaolinite spectral abundance +/-10%)	Kaolinite spectral abundance +/- 2.3%	Kaolinite spectral abundance (+/- <1%)	Kaolinite spectral abundance +/- 9%
Nonphotosynthetic vegetation (coverage fraction +/- 10%)	NPV coverage fraction +/- <1%	NPV coverage fraction +/- <1%	NPV Fraction +/- 9%
Bare surface mineral composition (Mineral spectral abundance +/- 10%)	Mineral spectral abundance +/- 2.3%	Mineral spectral abundance +/- <1%	Mineral spectral abundance +/- 9%
Surface composition and cover (Soil coverage fraction +/- 10%)	Soil coverage fraction (+/- <1%)	Soil coverage fraction +/- <1%	Soil coverage fraction +/- 9%

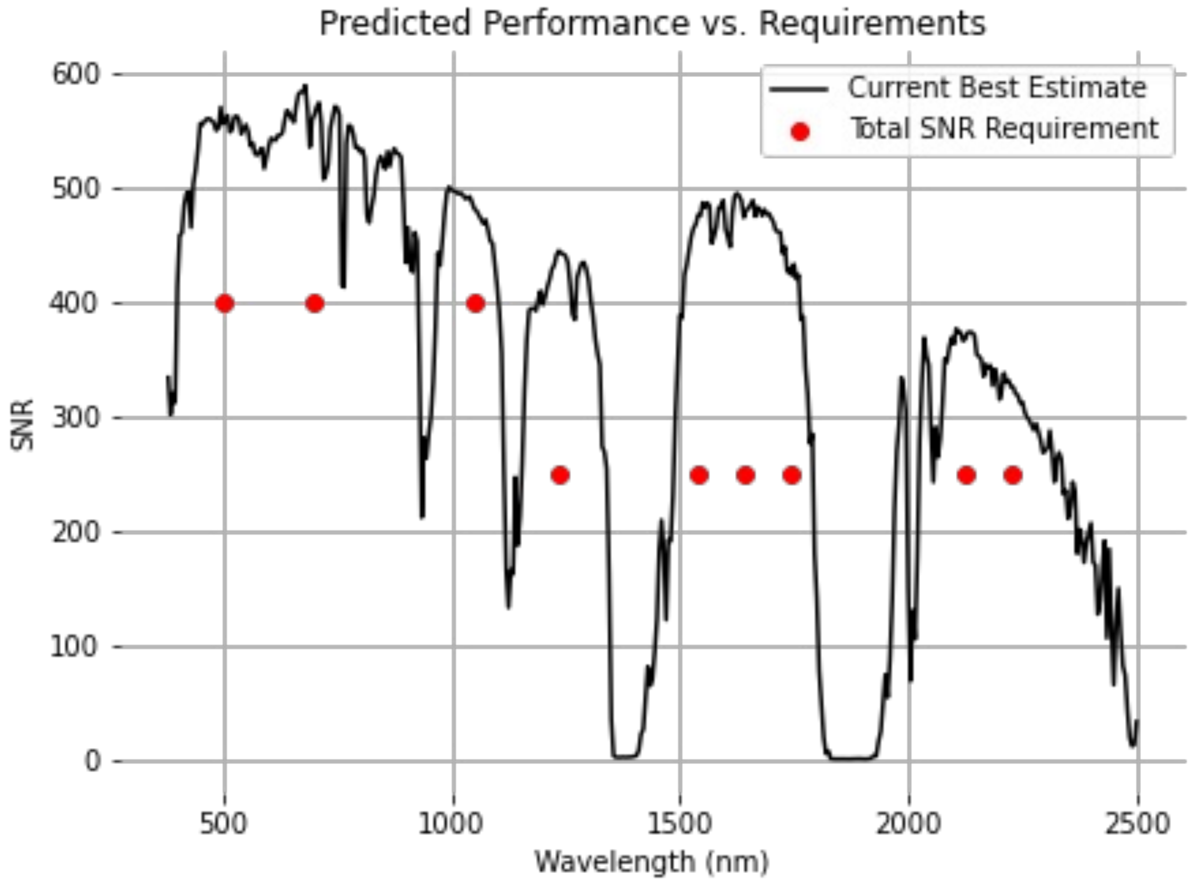
Takeaways

The current SBG instrument performance requirements provide good accuracy across primary SBG products

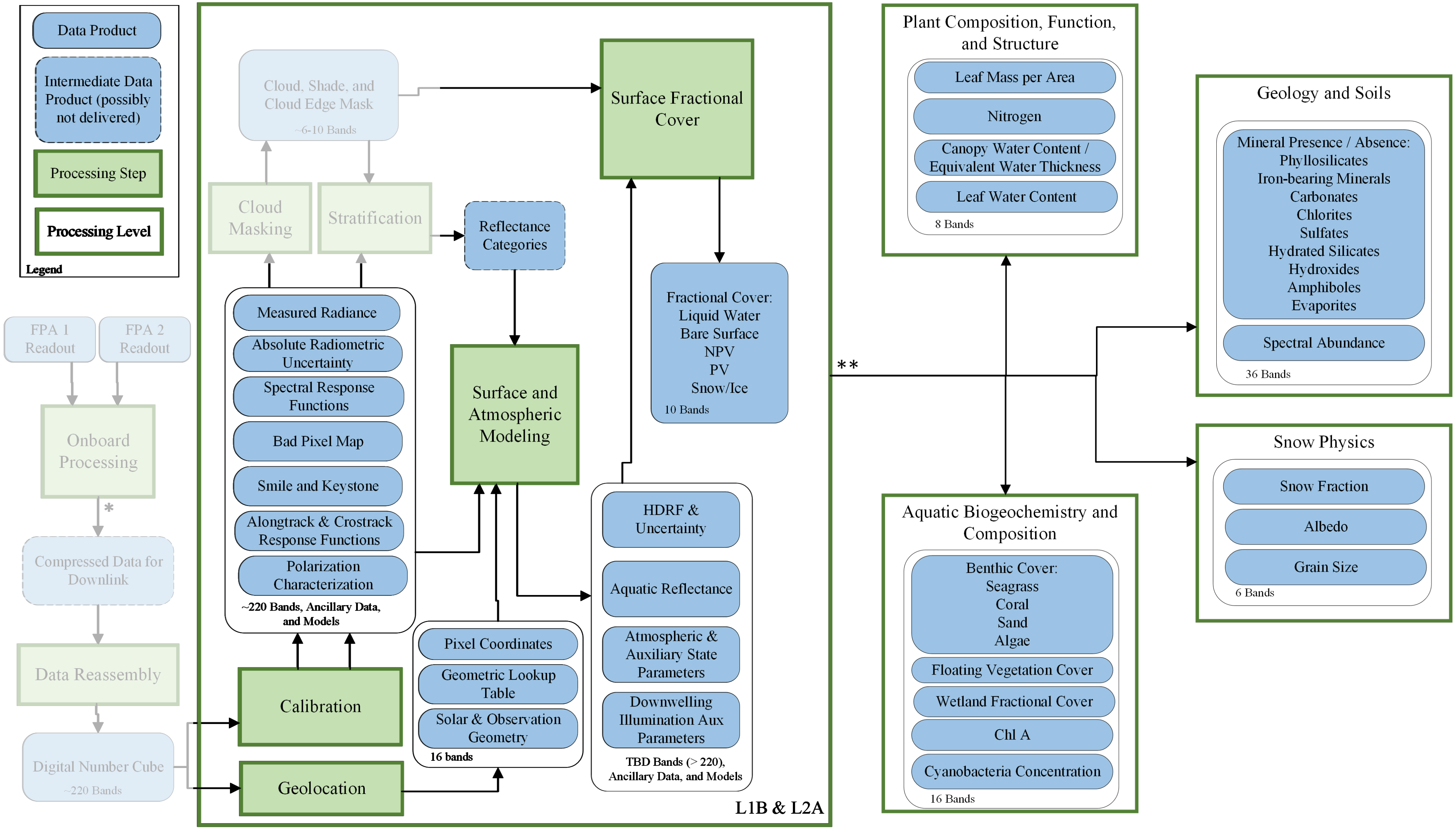
Radiometric sensitivity is driven by aquatic studies (in the VNIR) and terrestrial ecology (in the SWIR)

SBG SNR supports the full range of Decadal Survey products and priorities

Aquatic applications will drive calibration needs (5% in VNIR, 10% SWIR)



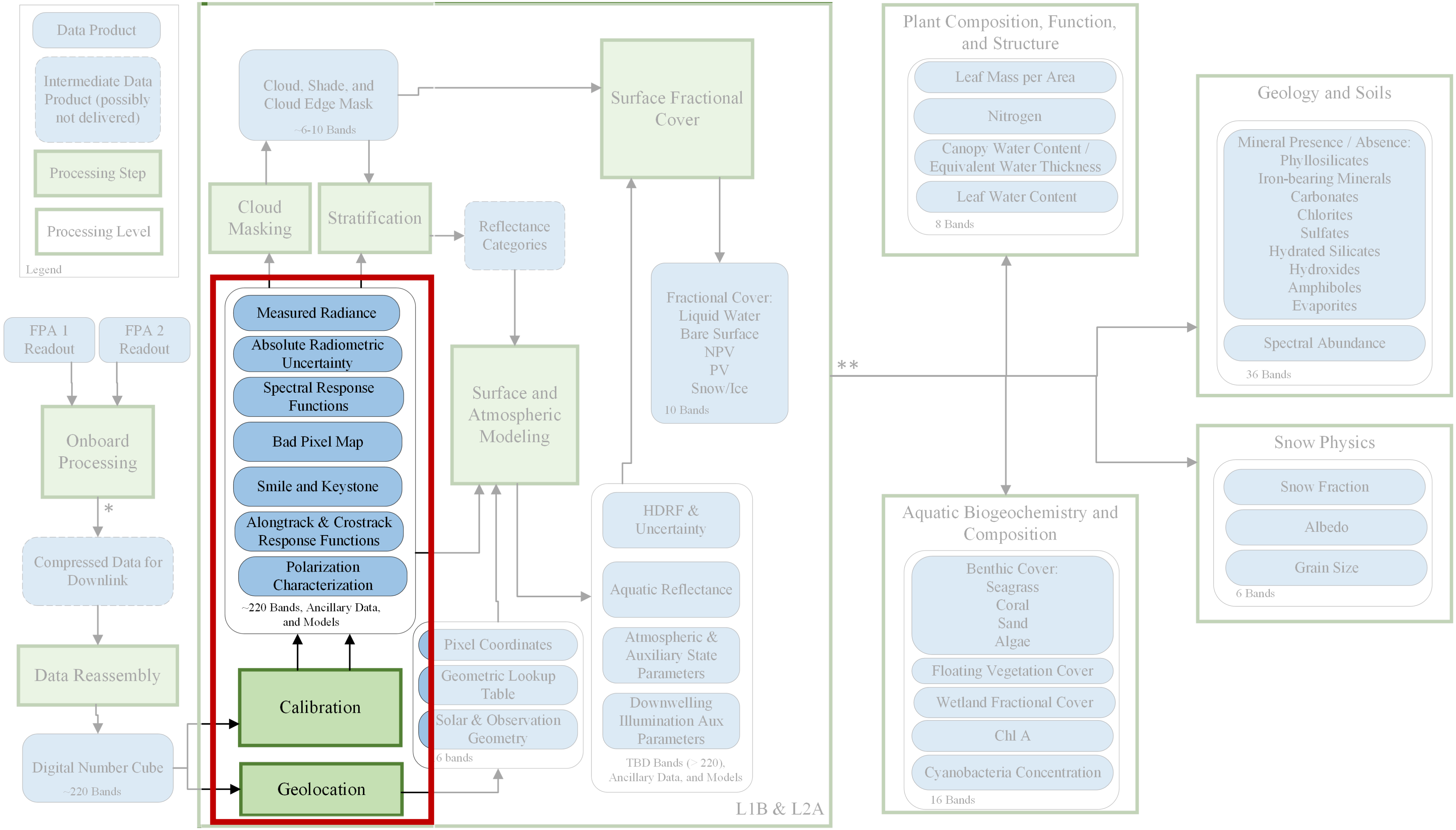
Core Algorithm Product Workflow



*Everything Downstream repeated for each Focal Plane Array (FPA)

**See Domain Specific Diagrams for the Mapping between L1B/L2A Ouptputs and L2+ Algorithms

Radiance – Algorithm Context

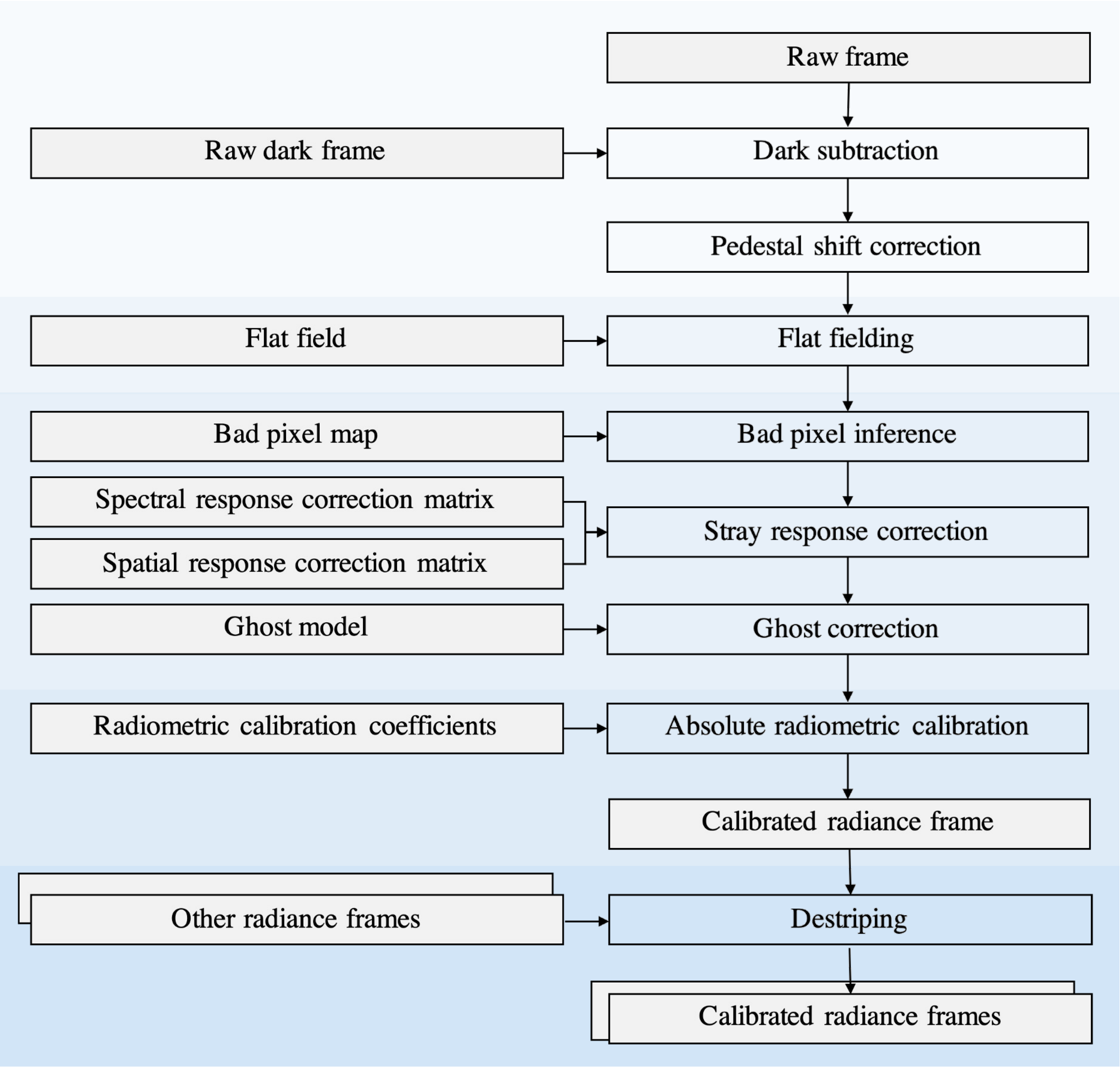


*Everything Downstream repeated for each Focal Plane Array (FPA)

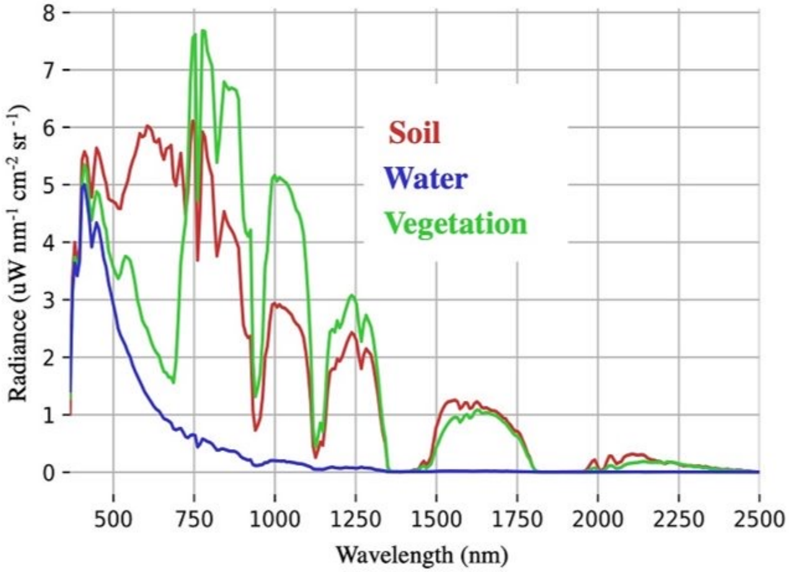
**See Domain Specific Diagrams for the Mapping between L1B/L2A Ouptputs and L2+ Algorithms

Calibration processing pipeline

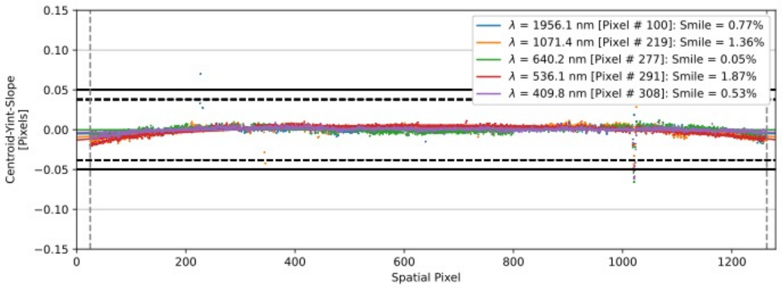
Zero-Point Correction
↓
Element-wise Adjustment
↓
Stray Light & Bad Pixel Correction
↓
Radiometric Conversion
↓
Destriping Adjustment



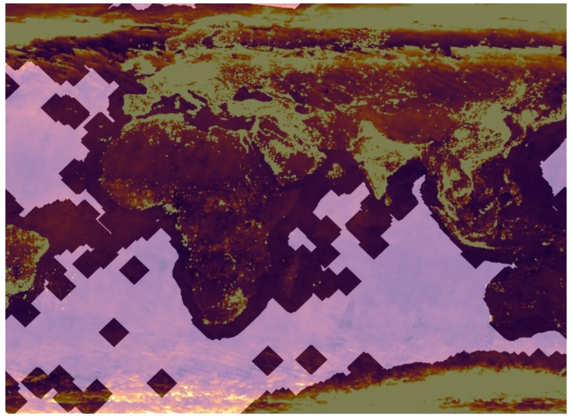
Example Radiance Spectra



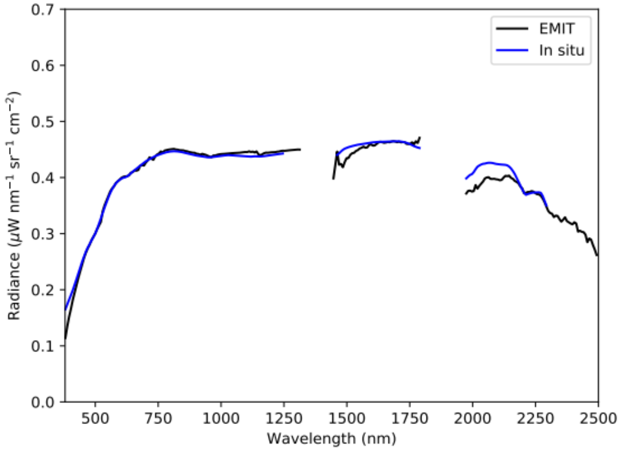
Laboratory Calibration



In-Flight Calibration

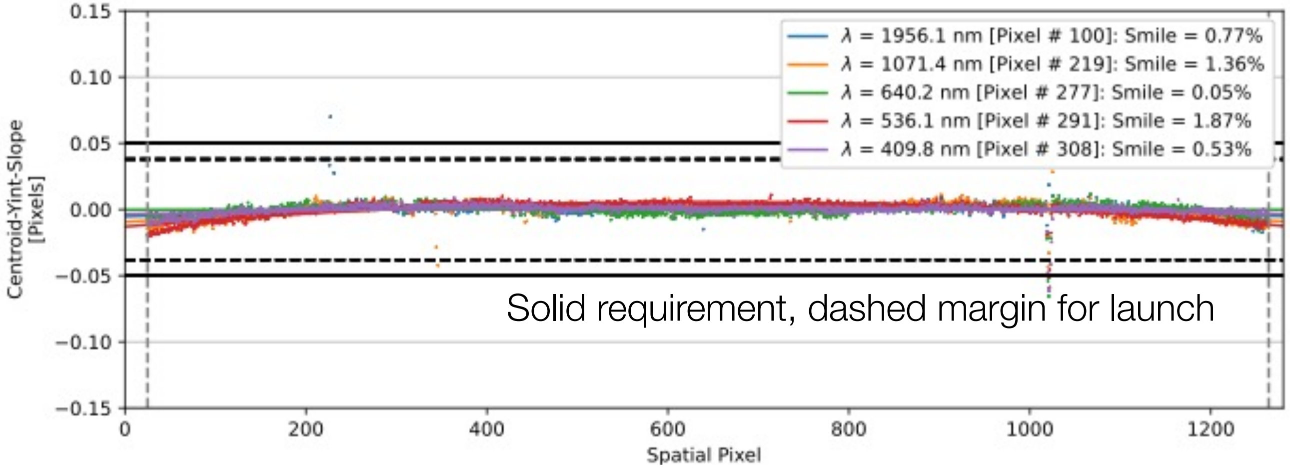


Validation

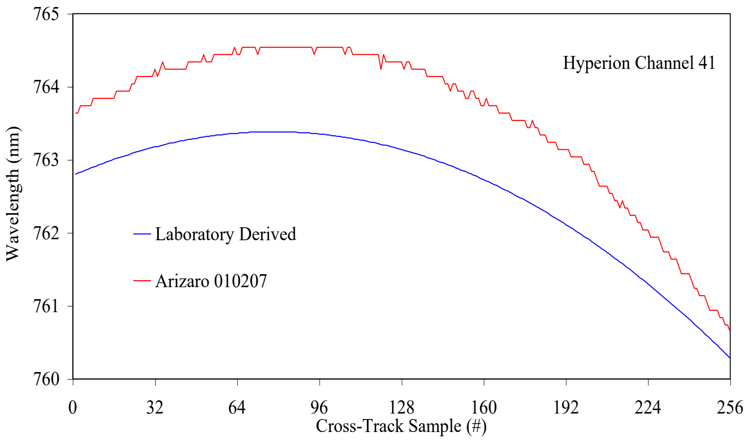


Focus on high spectrometer uniformity for SBG, as in EMIT

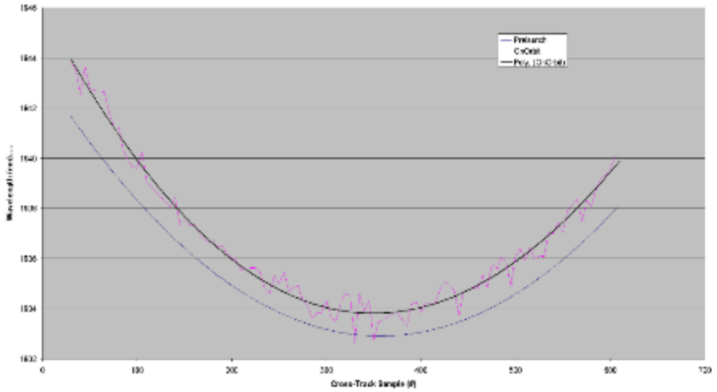
EMIT, uniformity < 5%



Hyperion Earth > 40%



CRISM Mars >100%



Laboratory and on orbit determination (red)

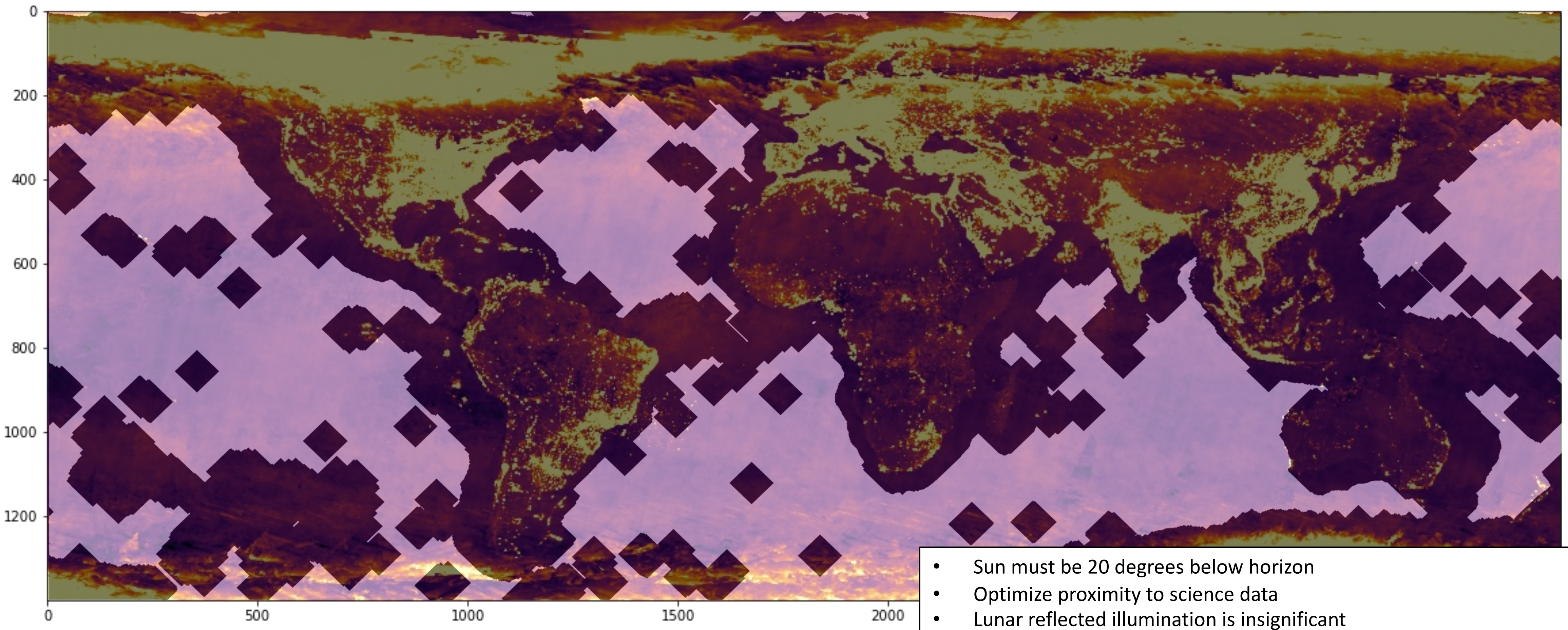
SBG in-flight calibration

The Earth is the on-board calibrator, star tracker, flatfield, and shutter

Blackrock Playa - Image courtesy Ray Kokaly, USGS

Capture dark data over dark areas of Earth

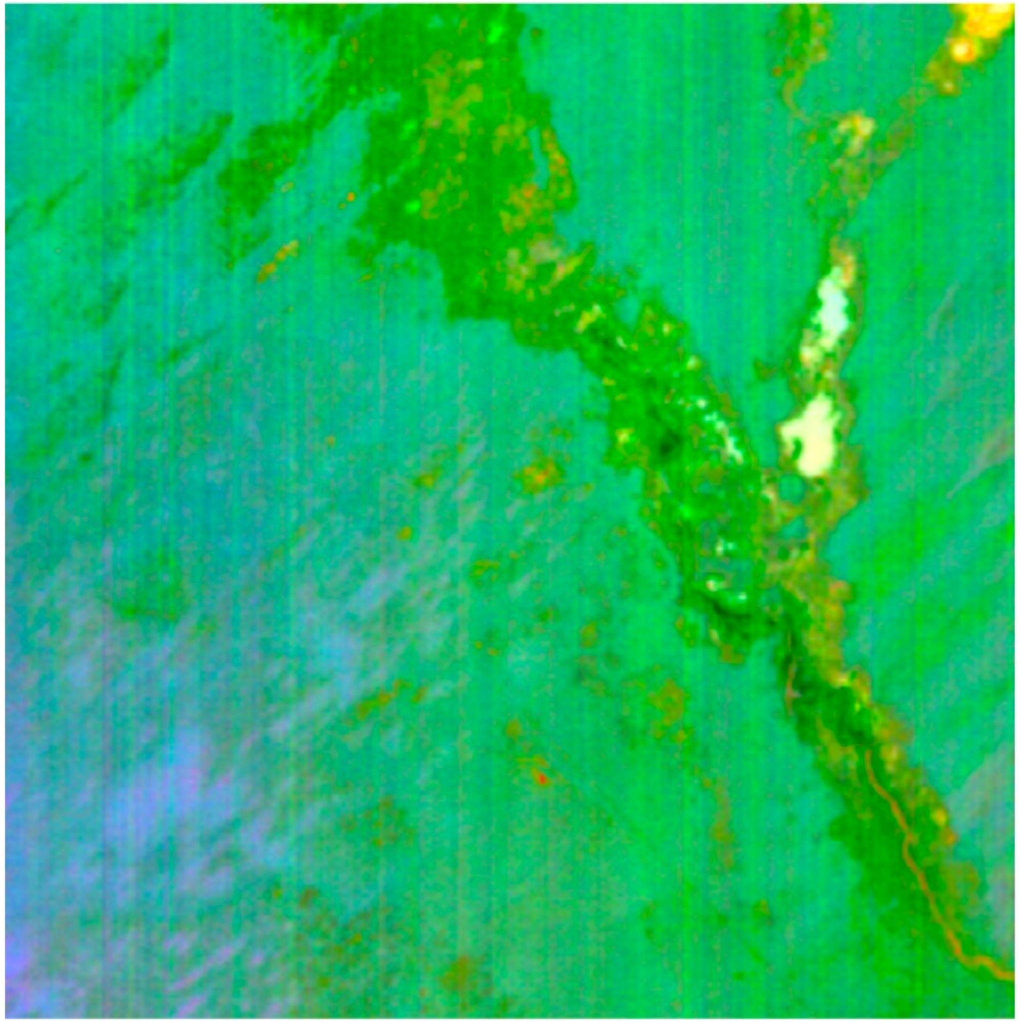
Dark capture areas   Non-dark areas



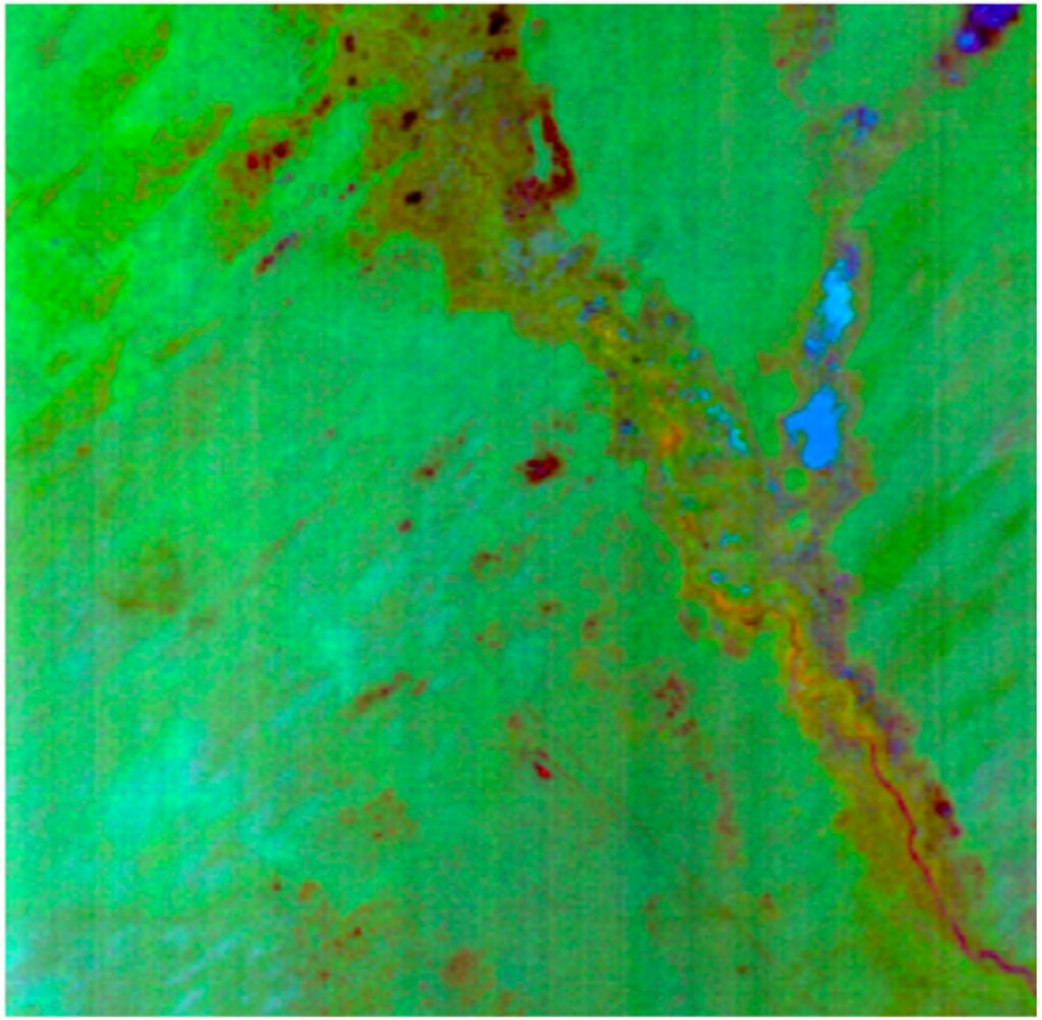
- Sun must be 20 degrees below horizon
- Optimize proximity to science data
- Lunar reflected illumination is insignificant

High performance shown with EMIT data under this method

In-flight flatfield estimation



No destriping

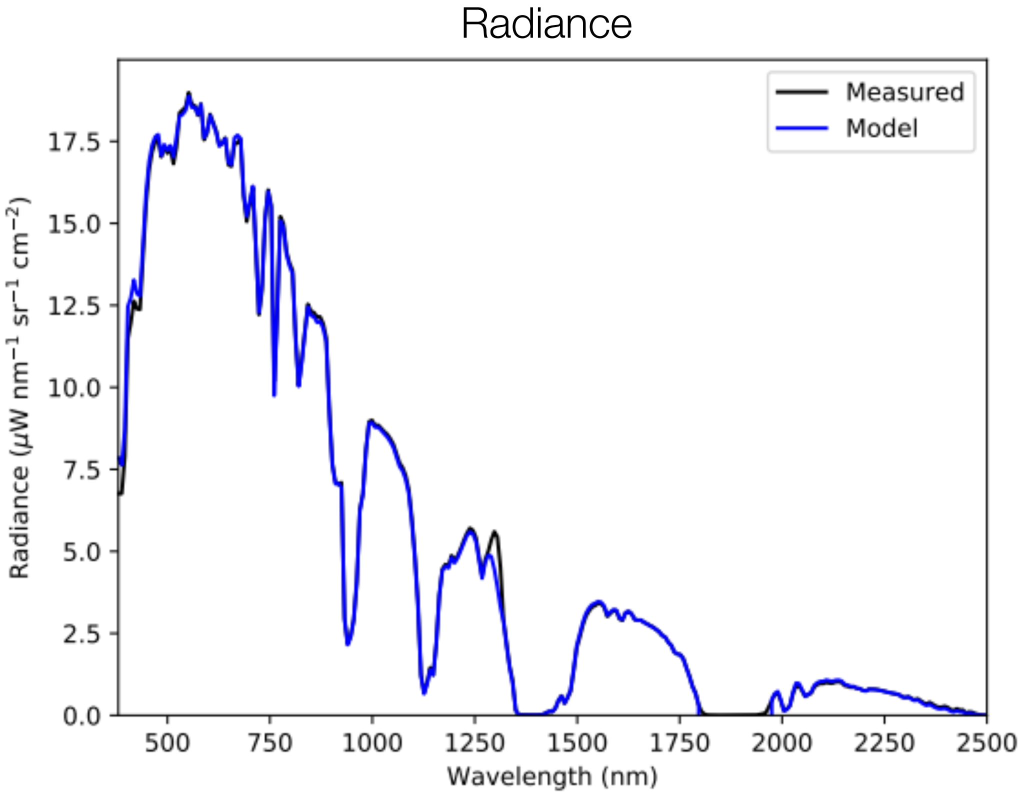


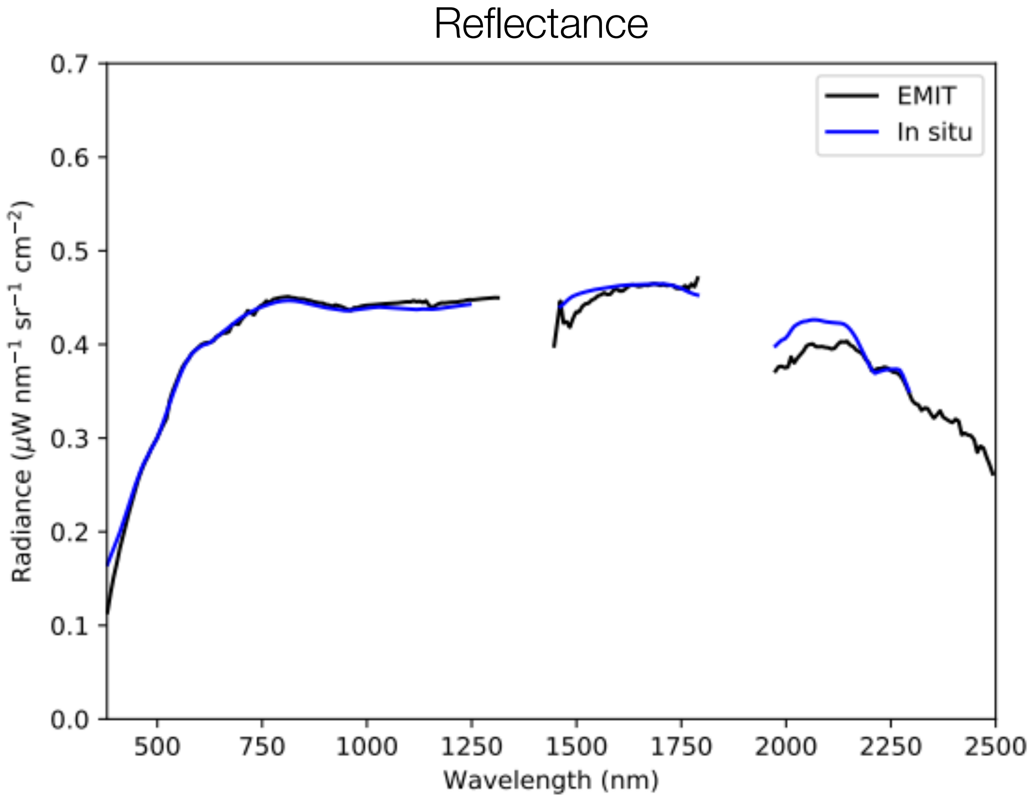
New destriping

MNF bands 4-6

Vicarious Calibration and Validation across Terrestrial and Aquatic Targets

Railroad Valley 3 August 2022



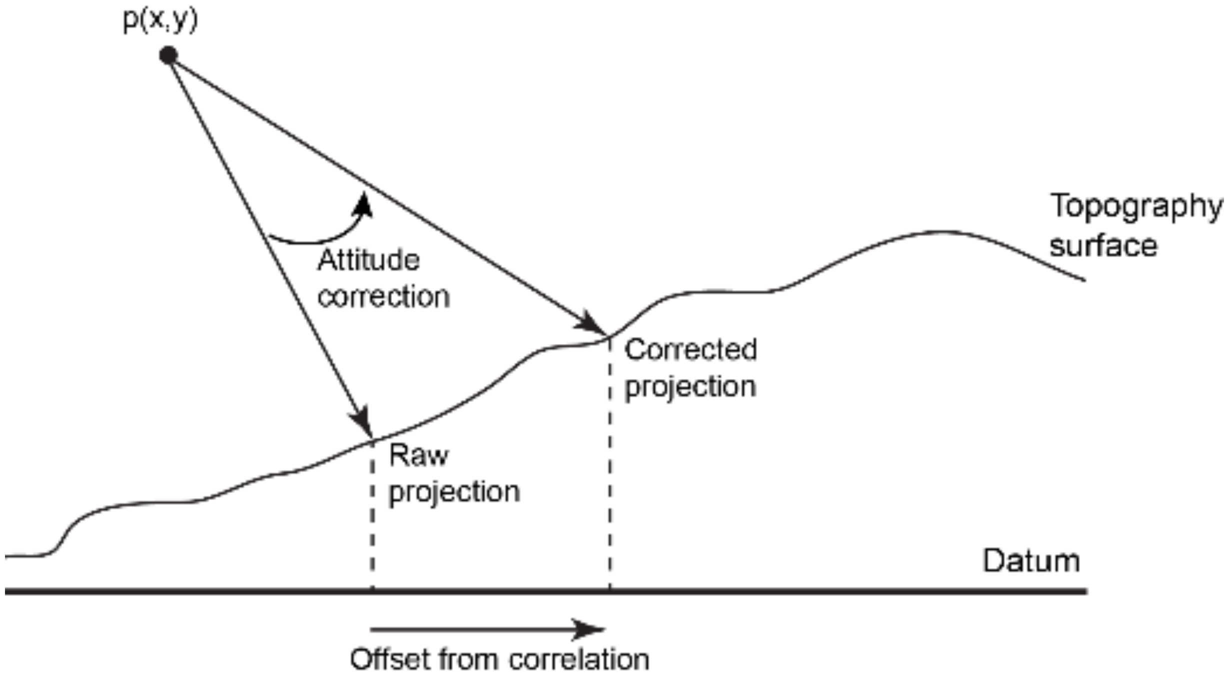


Modeling of in-situ reflectance data to radiance for in-flight calibration and validation

Geolocation with Landsat's ortho-base and image matching

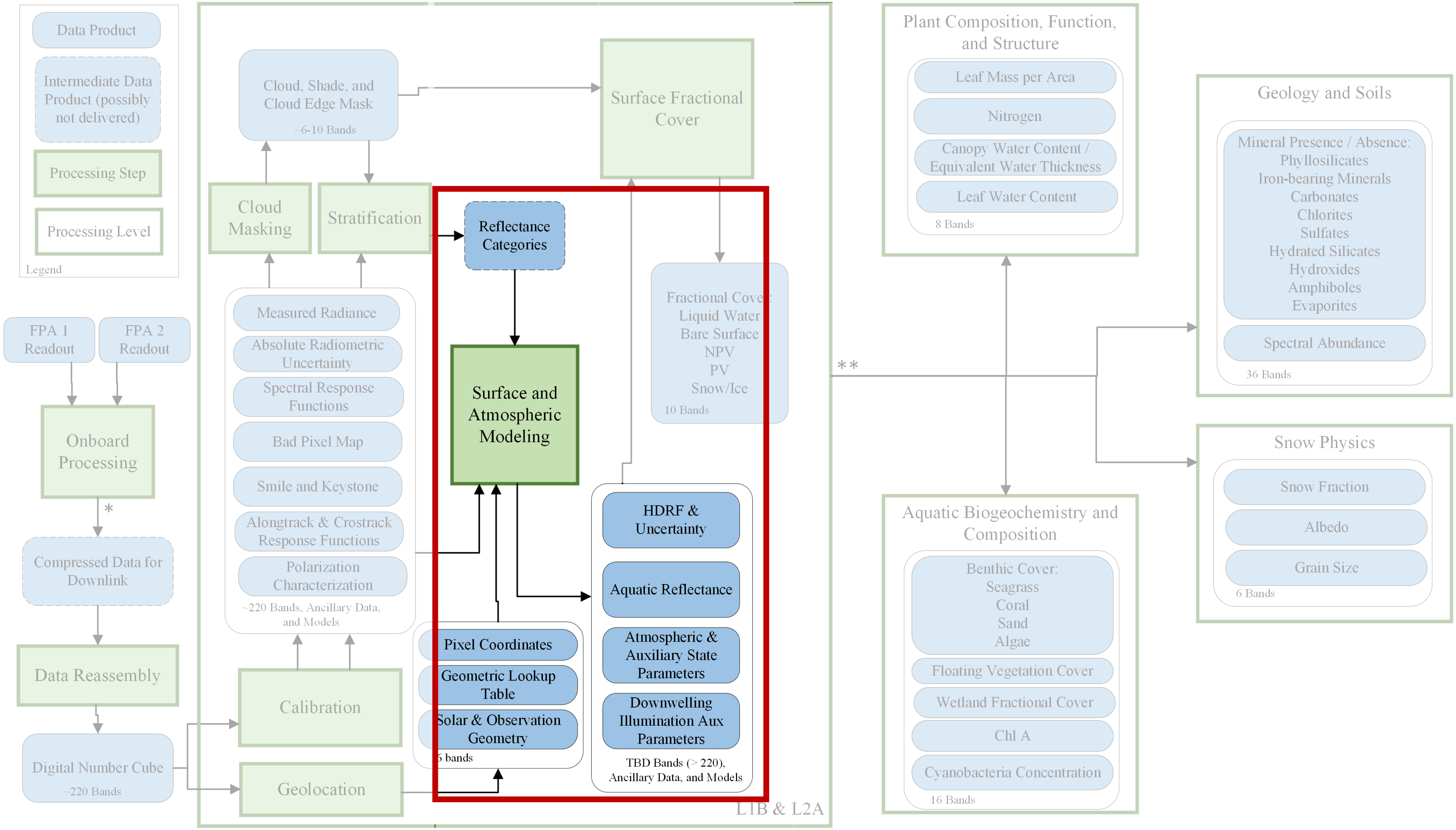
Geolocation accuracy assessments from 19 EMIT orbits

- Measured against the Landsat 7 orthorectification base-map
- Distance predicted location on the ground vs. actual determined by image matching
- Error of individual pixels will vary
- Absolute geolocation error includes Landsat's error



Orbit	Initial Uncorrected Accuracy (m) Using raw ISS ephemeris Median (min – max)	Final Accuracy (m) after correcting ISS ephemeris
2220901	526.2 (526.2 - 526.2)	34.1 (34.1 - 34.1)
2221501	420.7 (364.5 - 614.6)	17.3 (10.3 - 34.2)
2221502	404.4 (373.6 - 410.1)	17.8 (12.7 - 26.1)
2221601	585.9 (585.9 - 585.9)	29.7 (29.7 - 29.7)
2221602	257.8 (234.4 - 281.2)	31.7 (23.6 - 39.8)
2221603	297.5 (292.9 - 302.1)	18.9 (15.0 - 22.8)
2221901	231.6 (210.9 - 252.1)	11.9 (8.1 - 18.3)
2222203	348.9 (313.2 - 383.7)	13.9 (10.2 - 21.2)
2222204	247.9 (191.3 - 448.9)	26.0 (10.2 - 58.0)
2222205	470.3 (246.4 - 625.8)	18.1 (10.6 - 53.0)
2222206	474.1 (269.8 - 774.2)	20.4 (10.3 - 68.4)
2222207	627.9 (618.5 - 668.9)	26.6 (19.5 - 50.4)
2222208	529.2 (478.5 - 2582.4)	59.5 (16.0 - 2148.4)
2222211	245.9 (148.9 - 276.3)	19.9 (9.8 - 26.8)
2222212	368.1 (346.4 - 385.3)	16.2 (12.7 - 20.9)
2222215	712.9 (683.6 - 724.6)	15.8 (14.0 - 28.5)
2222216	701.0 (700.5 - 701.6)	27.4 (22.0 - 32.9)
2222302	278.6 (237.1 - 316.9)	16.5 (10.0 - 30.6)
2222514	741.6 (668.4 - 776.3)	17.4 (10.0 - 81.5)

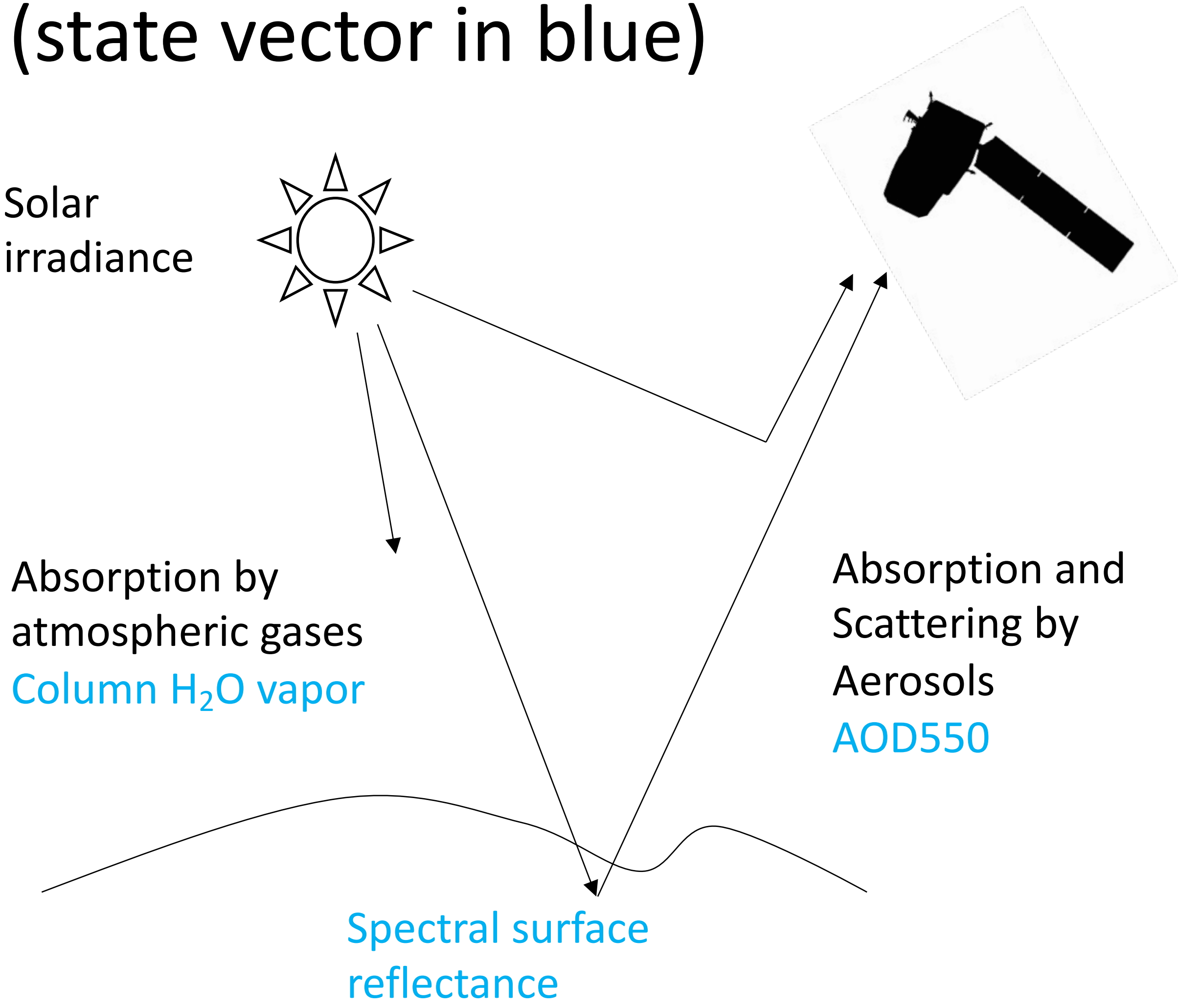
Reflectance – Algorithm Context

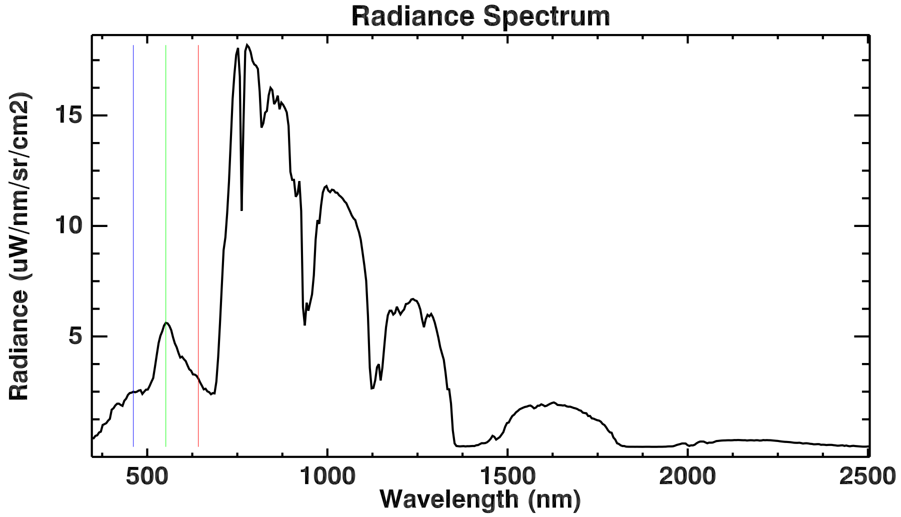


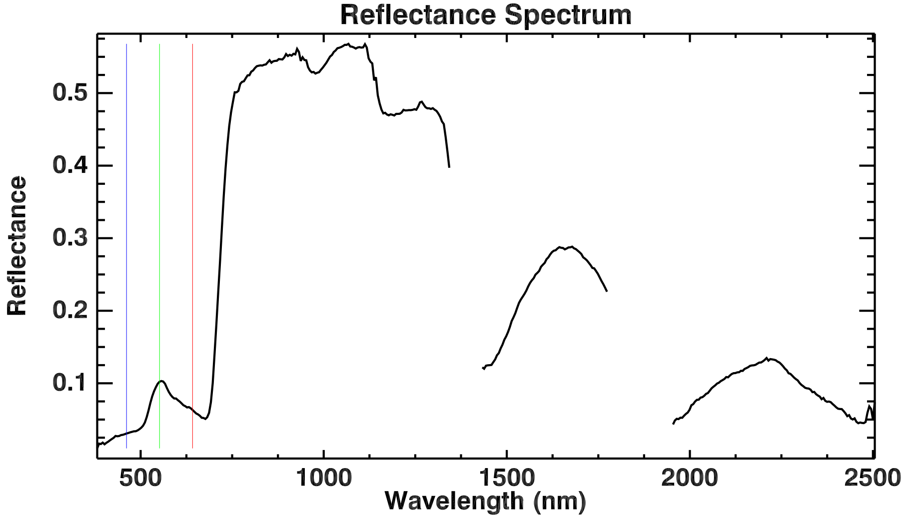
*Everything Downstream repeated for each Focal Plane Array (FPA)

**See Domain Specific Diagrams for the Mapping between L1B/L2A Ouptputs and L2+ Algorithms

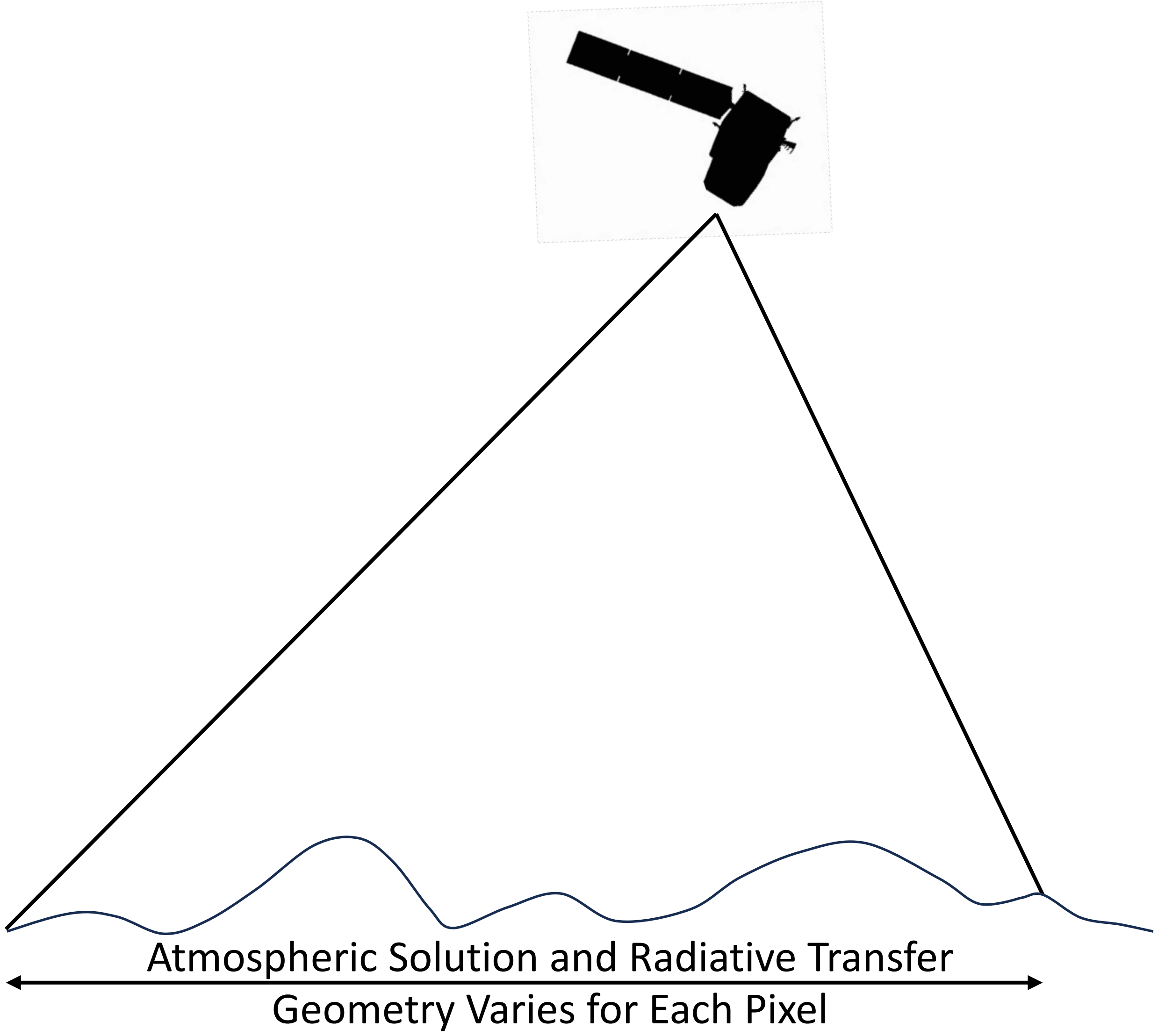
Reflectance and radiance spectra (state vector in blue)







Radiance (Forward) Models



Radiance model includes:

- Within-scene variation in sensor and solar geometry
- Pixel-specific simultaneous surface and atmospheric solutions
- Topographic effects included in the forward model
- Glint included in the forward model
- Multi-species aerosol model
- Pressure altitude as a free parameter

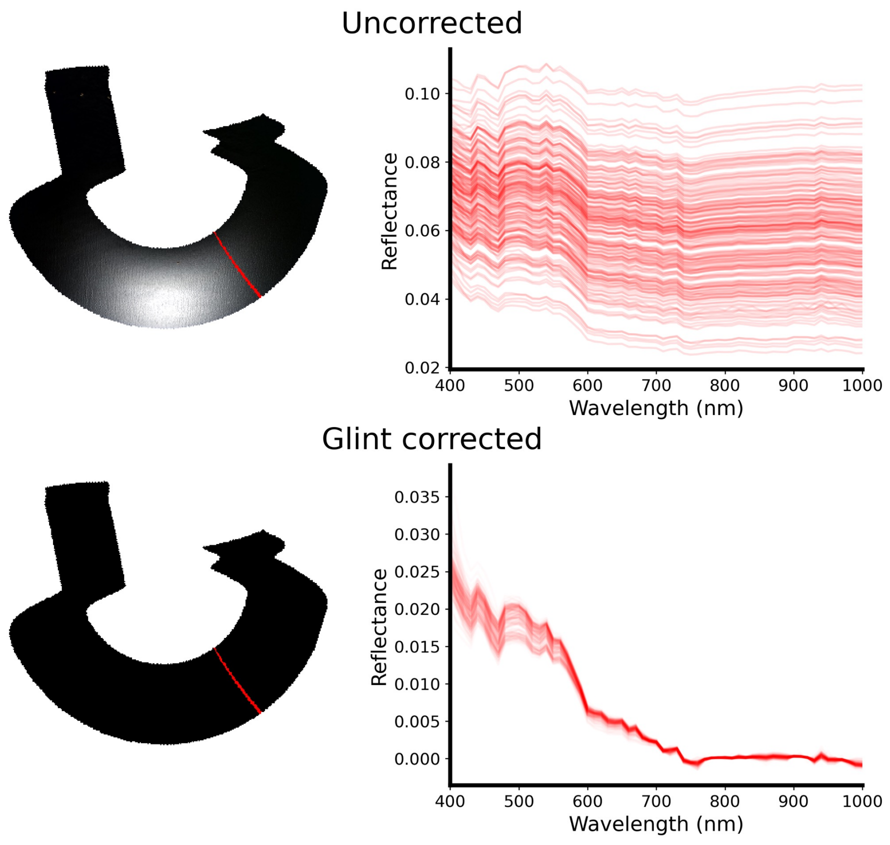
Surface Reflectance is the Hemispherical Directional Reflectance Factor (HDRF)*

* Excepting aquatic surfaces (glint inclusion)
* BRDF adjustments incorporated downstream

Aquatic – Walkthrough (Glint Strategy)

Three-Pronged Approach:

1. **Mission Design**
   - Use a non-nadir observation angle to minimize the amount of glint
2. **Surface and Atmospheric Modeling**
   - Incorporate glint into the physical forward model in order to retrieve through
3. **Post-hoc Filtering**
   - Filter out locations with too much glint to retrieve through



Scene: AVIRIS-NG flight flown in a semicircle to target sun glint for atmosphere methane measurement.

Reflectance: Maximum *A Posteriori* solution

$$p(\mathbf{x}|\mathbf{y}) = \frac{p(\mathbf{y}|\mathbf{x})p(\mathbf{x})}{p(\mathbf{y})}$$

Reflectance: Maximum *A Posteriori* solution

$$p(\mathbf{x}|\mathbf{y}) = \frac{p(\mathbf{y}|\mathbf{x})p(\mathbf{x})}{p(\mathbf{y})}$$

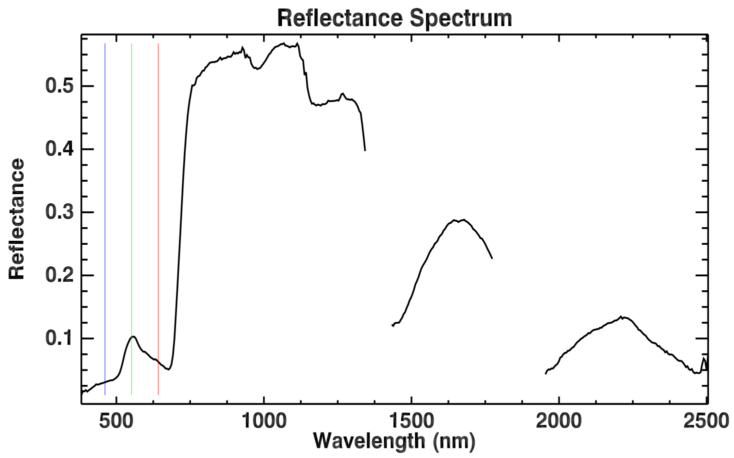
Corresponding cost function based on the negative logarithm:

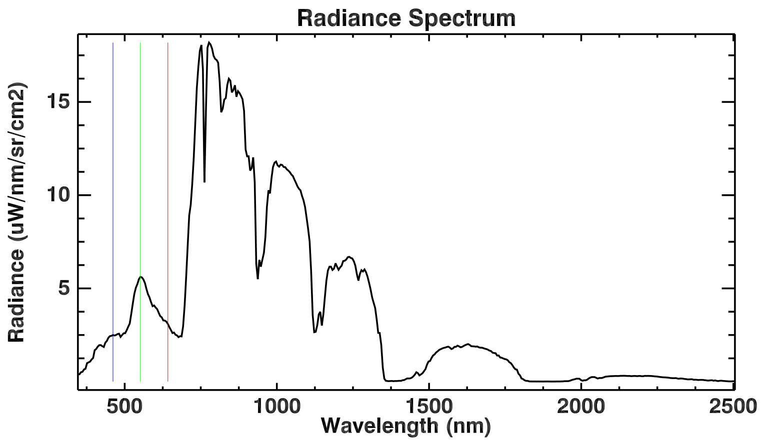
$$\underbrace{\chi^2(\mathbf{x})}_{\text{Cost}} = \underbrace{(\mathbf{F}(\mathbf{x}) - \mathbf{y})^{\mathbf{T}}\, \mathbf{S}_{\epsilon}^{-1}\, (\mathbf{F}(\mathbf{x}) - \mathbf{y})}_{\text{Model match to measurement}} + \underbrace{(\mathbf{x} - \mathbf{x}_{\mathbf{a}})^{\mathbf{T}}\, \mathbf{S}_{\mathbf{a}}^{-1}\, (\mathbf{x} - \mathbf{x}_{\mathbf{a}})}_{\text{Bayesian prior}}$$

Reflectance: Maximum *A Posteriori* solution

1. Predict radiance

$$\mathbf{y} = \mathbf{F}(\mathbf{x}) + \epsilon$$





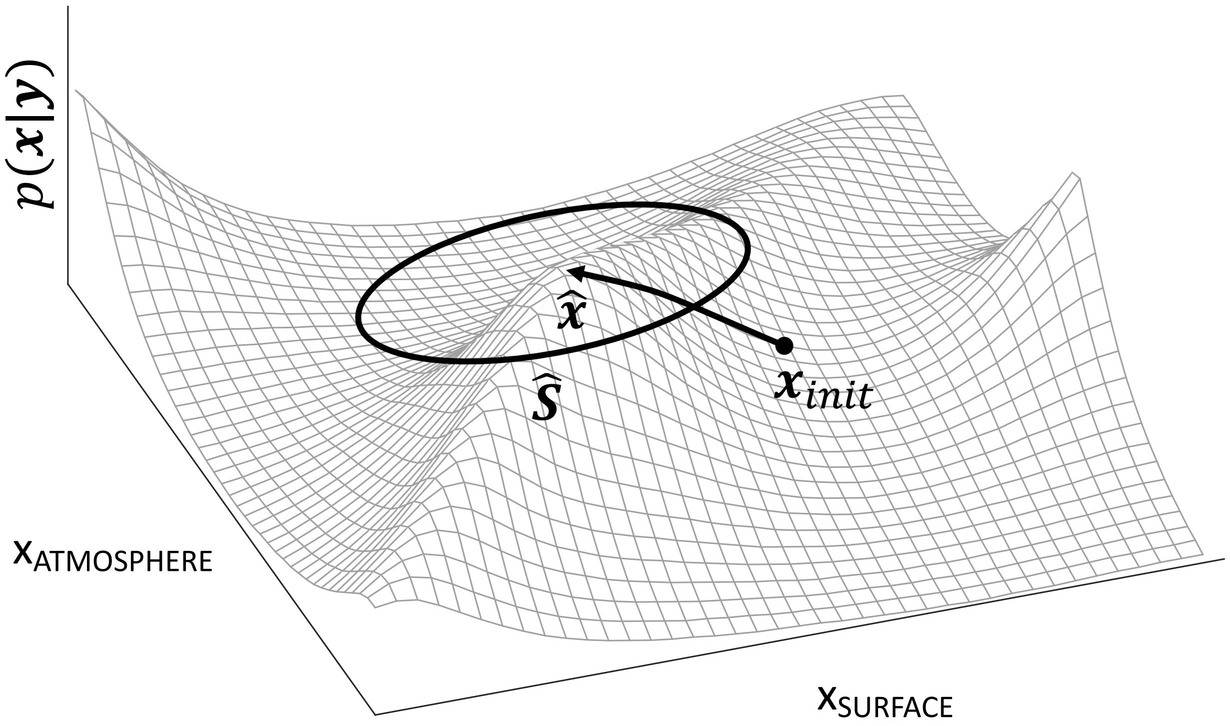
2. Optimize state vector

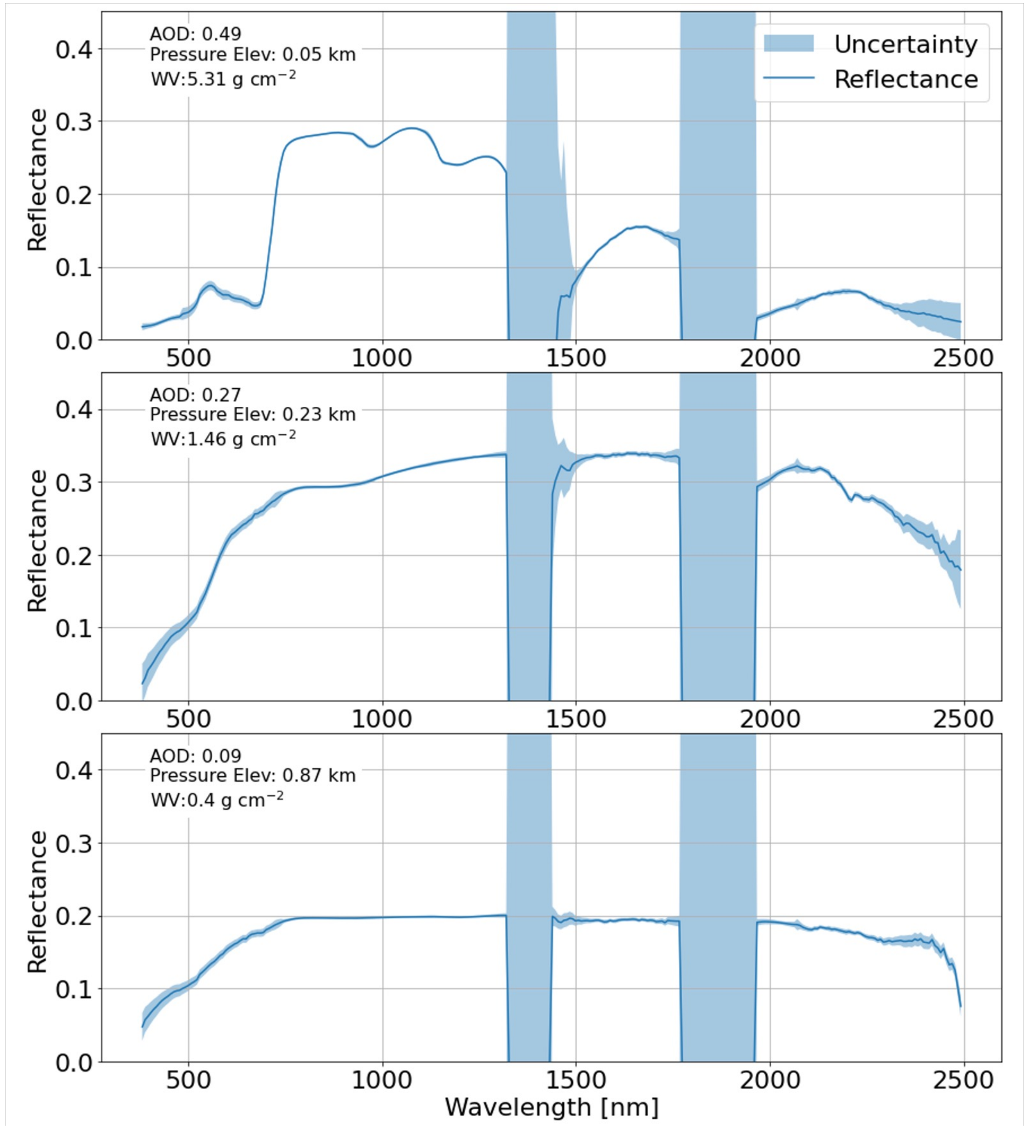
$$\underbrace{\chi^2(\mathbf{x})}_{\text{Cost}} = \underbrace{(\mathbf{F}(\mathbf{x}) - \mathbf{y})^{\mathbf{T}}\, \mathbf{S}_{\epsilon}^{-1}\, (\mathbf{F}(\mathbf{x}) - \mathbf{y})}_{\text{Model match to measurement}} + \underbrace{(\mathbf{x} - \mathbf{x}_{\mathbf{a}})^{\mathbf{T}}\, \mathbf{S}_{\mathbf{a}}^{-1}\, (\mathbf{x} - \mathbf{x}_{\mathbf{a}})}_{\text{Bayesian prior}}$$

Cost — Model match to measurement — Bayesian prior

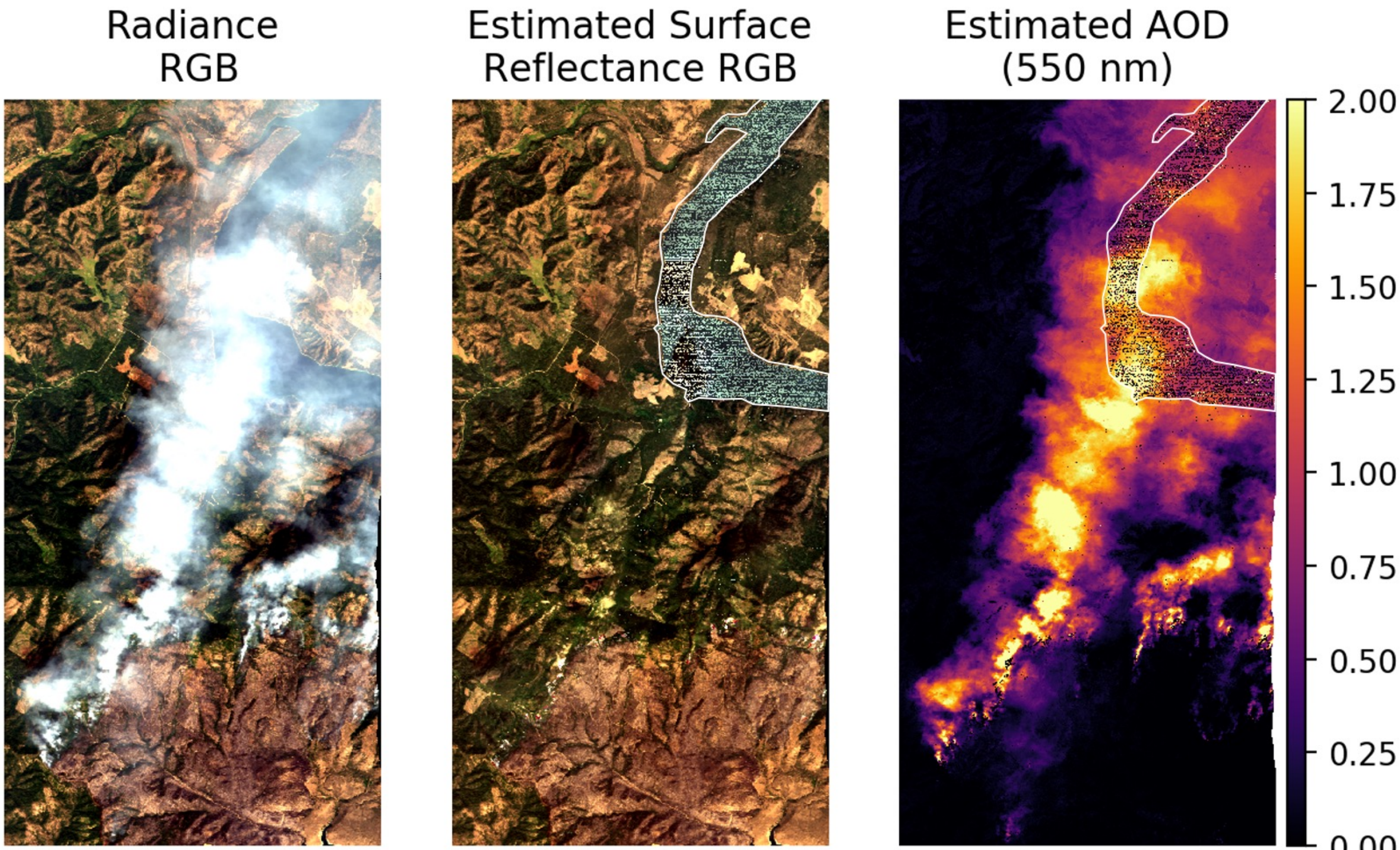
Posterior predictive uncertainty

$$\hat{S} = (K^T S_\epsilon^{-1} K + S_a^{-1})^{-1}$$



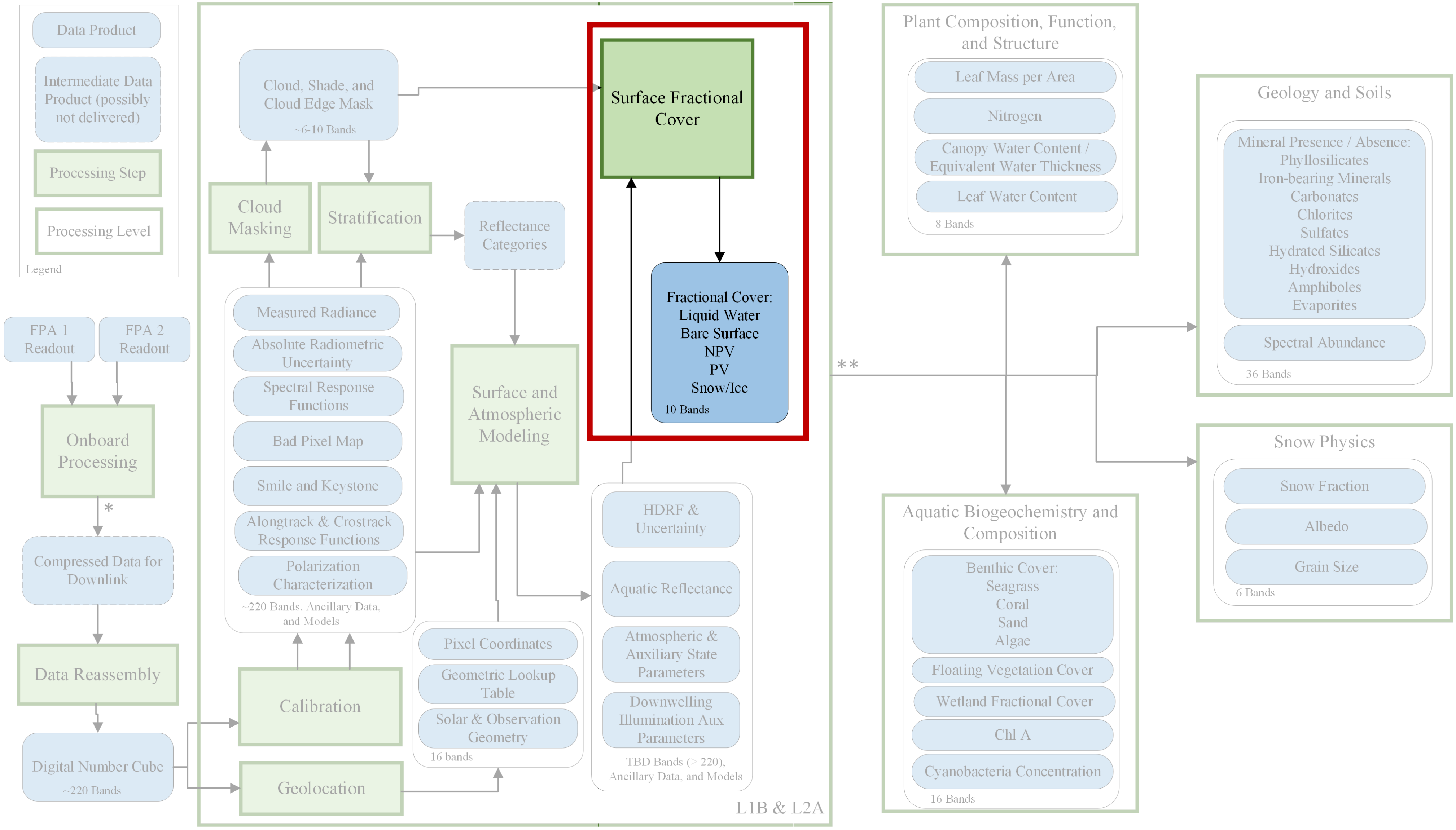


Example



Brodrick et al., JGR-A, 2021

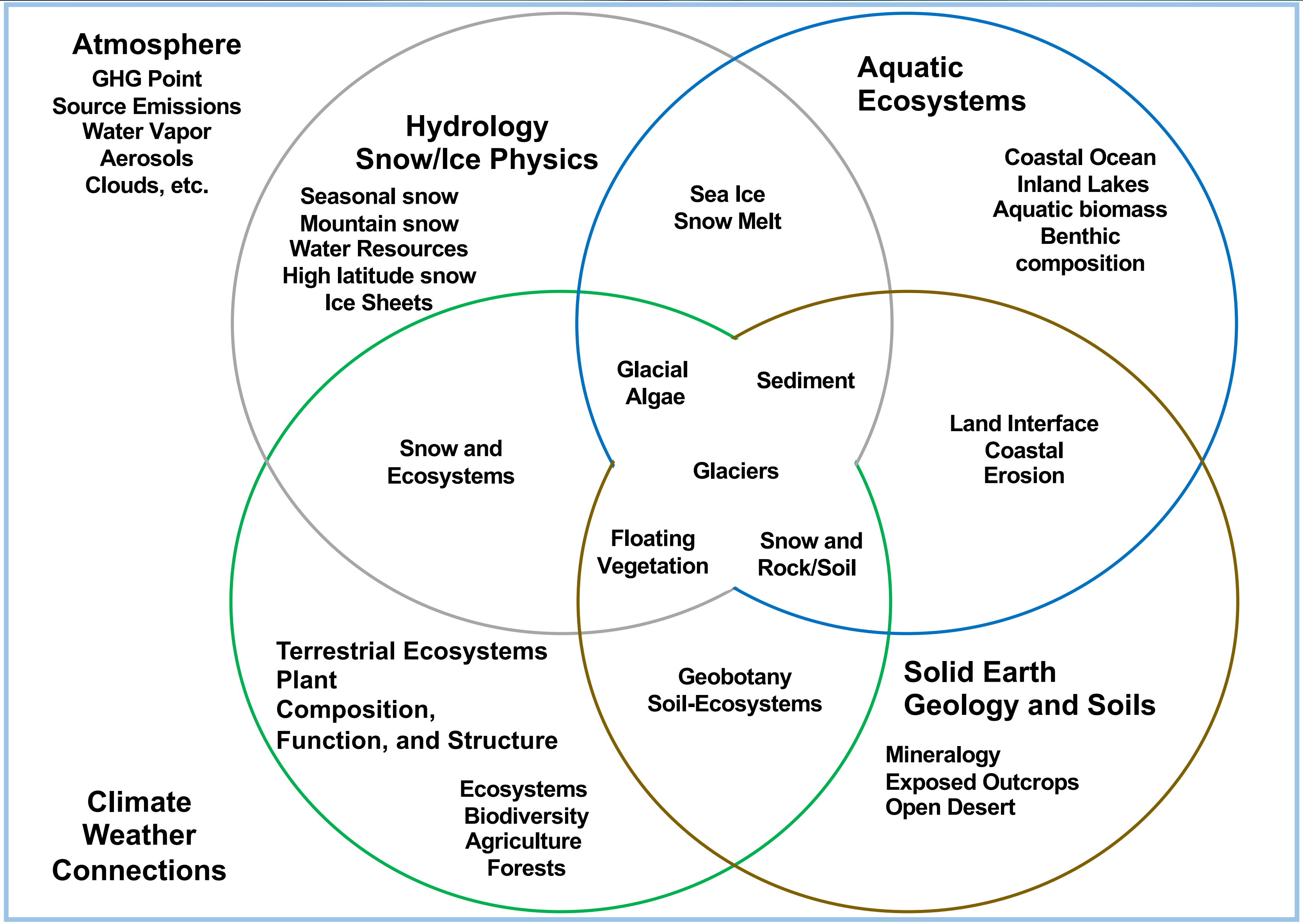
Surface Fractional Cover – Algorithm Context



*Everything Downstream repeated for each Focal Plane Array (FPA)

**See Domain Specific Diagrams for the Mapping between L1B/L2A Ouptputs and L2+ Algorithms

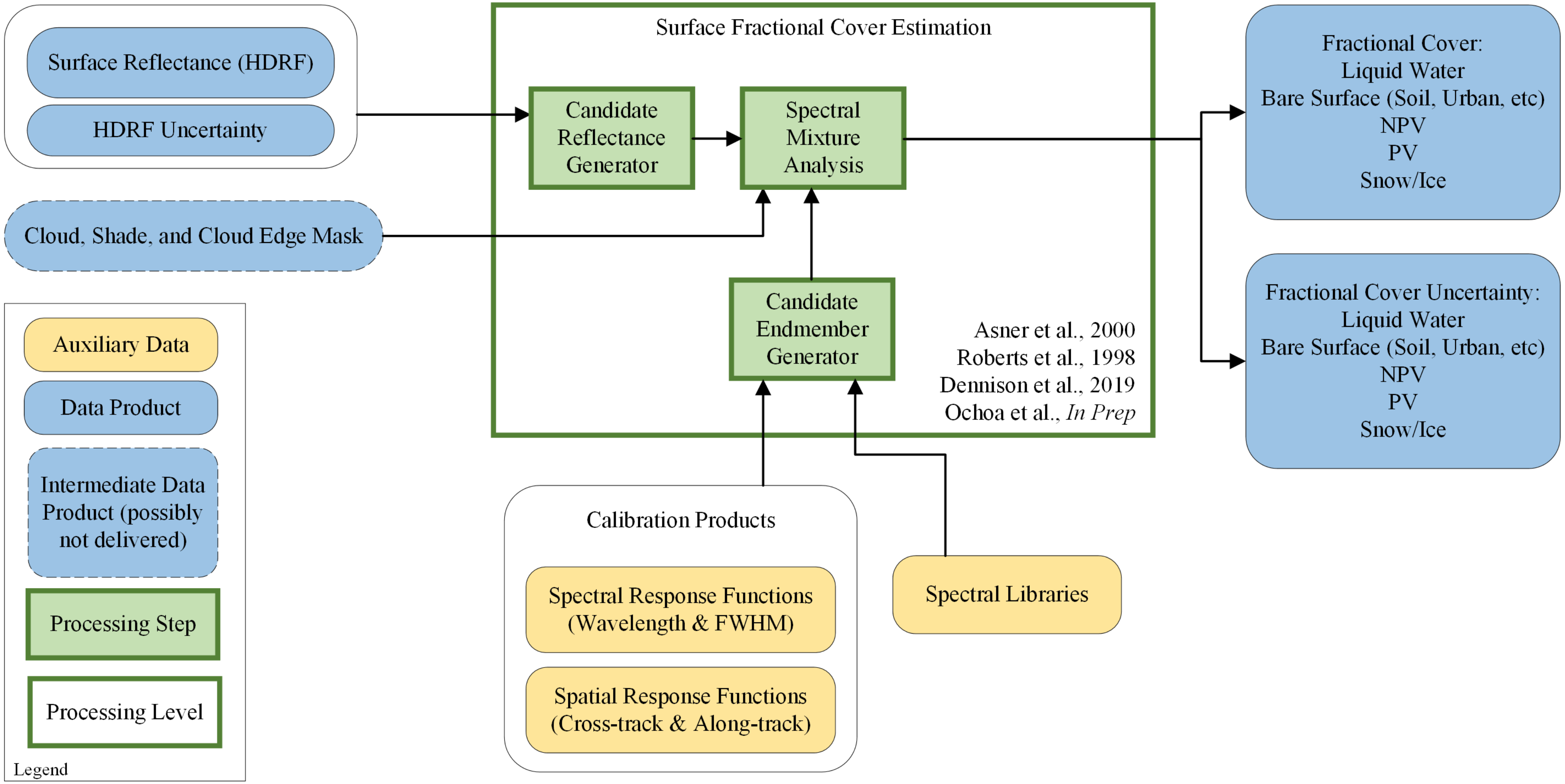
Surface Fractional Cover



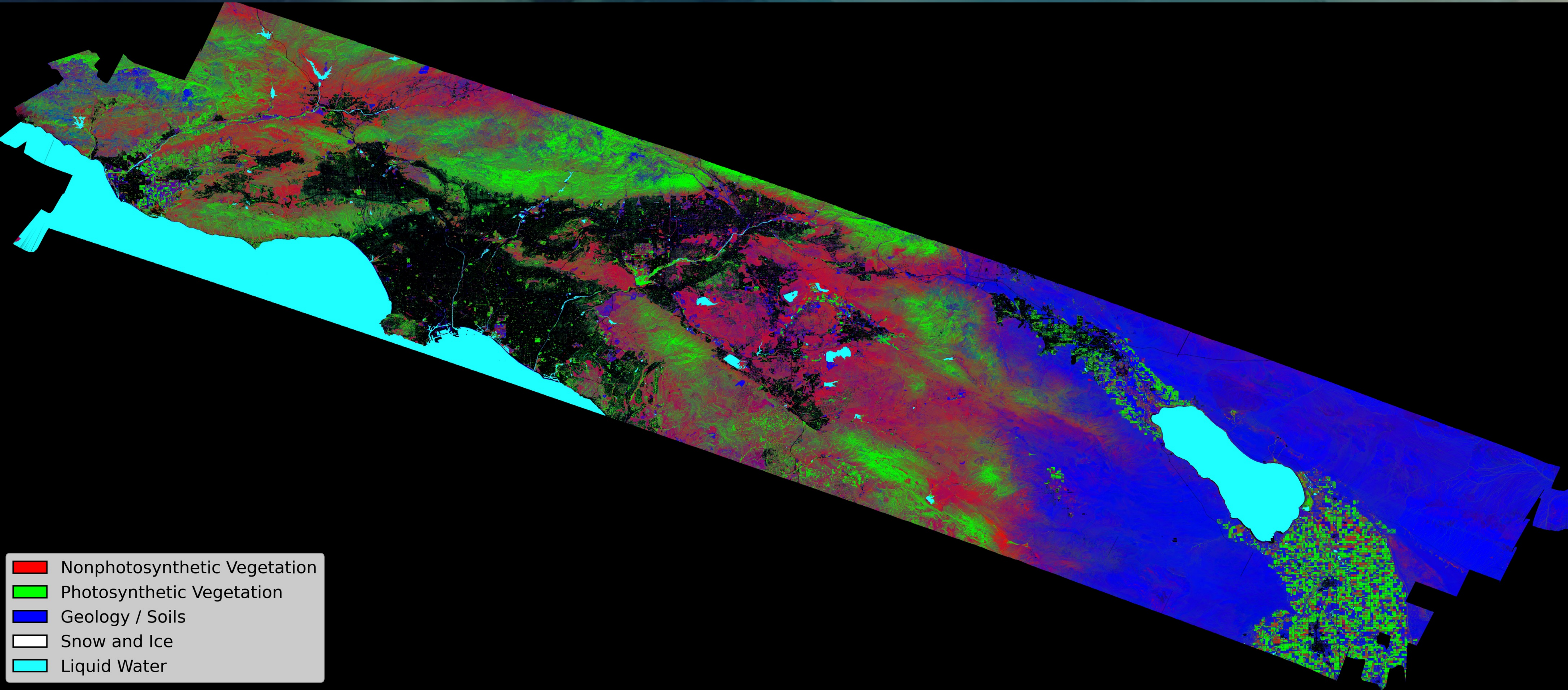
The Earth System is full of mixtures:

Mixed pixels are the norm, not the exception.

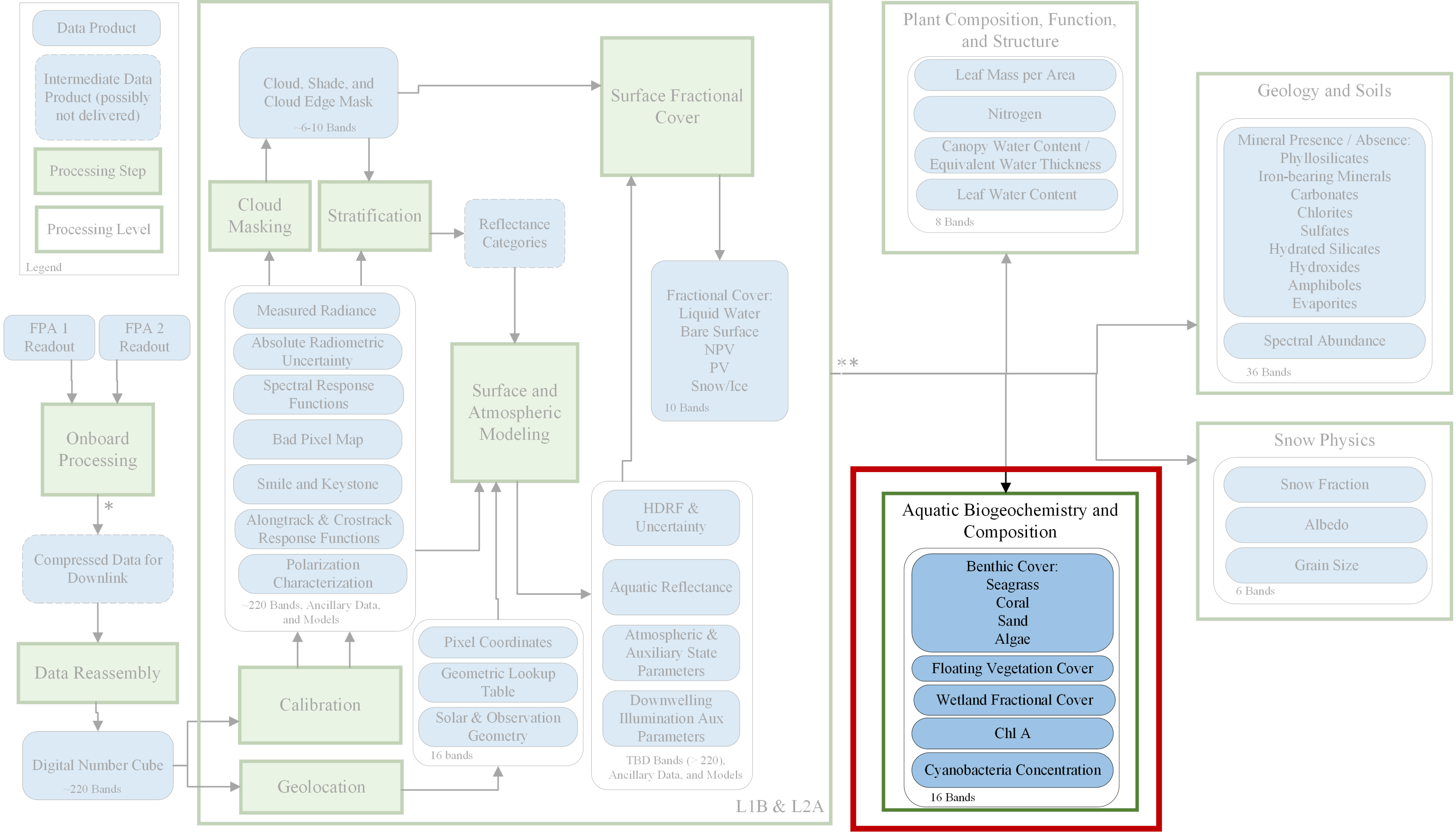
Surface Fractional Cover



Surface Fractional Cover



Aquatic Biogeochemistry and Composition – Algorithm Context



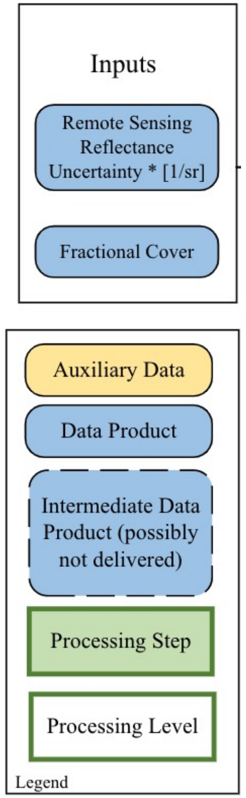
*Everything Downstream repeated for each Focal Plane Array (FPA)

**See Domain Specific Diagrams for the Mapping between L1B/L2A Ouptputs and L2+ Algorithms

Aquatic – Decadal Survey Focus

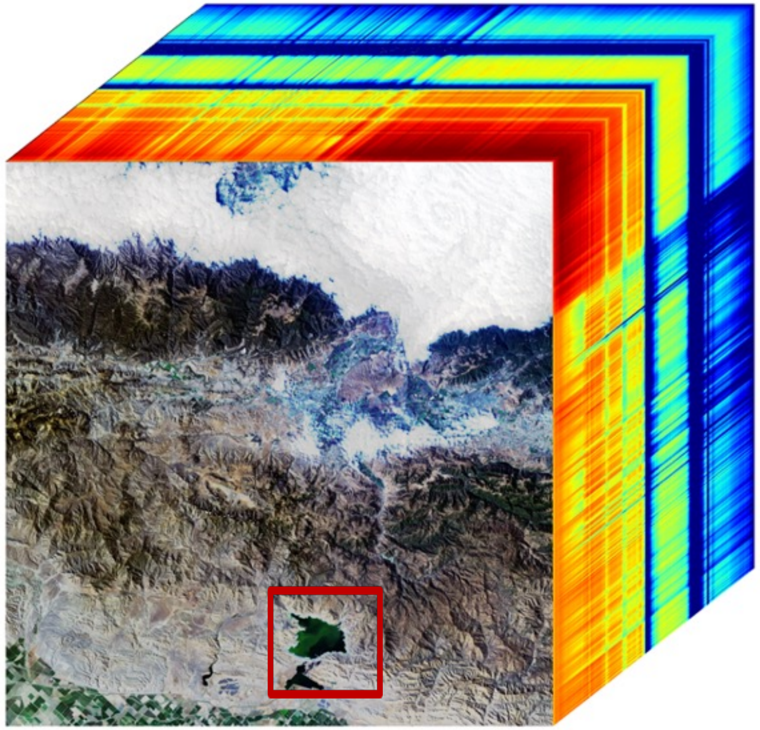
DS Science/Application Objective	Priority	DS Suggested Biogeophysical Parameters	Geophysical Parameters (one-sigma uncertainty target)	Applications enabled
E-1a. Quantify the distribution of the functional traits, functional types, and composition of vegetation and marine biomass spatially and over time.	Very Important	Primary Observable: Chemical properties of aquatic biomass (Inland, Coastal, Shallow): Spectral radiance (10nm; 380-2500nm); GSD = 30-45m; Revisit = ~15 days; SNR = 400:1 VNIR/250:1 SWIR @ 25% reflectance; IT of ~5 ms.	Remote Sensing Reflectance (380-1050 nm) Pigment Concentrations (chlorophyll 25% via AWG)	EA27 Fisheries management EA28 Harmful Algal Blooms EA 29 Oil Spill Recovery EA 43 Water resource management
E-1c. Quantify the physiological dynamics of terrestrial and aquatic primary producers.	Most important		Benthic composition - proportional cover of algae, coral, sand, seagrass (coral fraction 20% at 5m depth, from AWG)	EA25 Mitigation of invasive species EA26 Marine conservation EA43 Coastal habitat monitoring

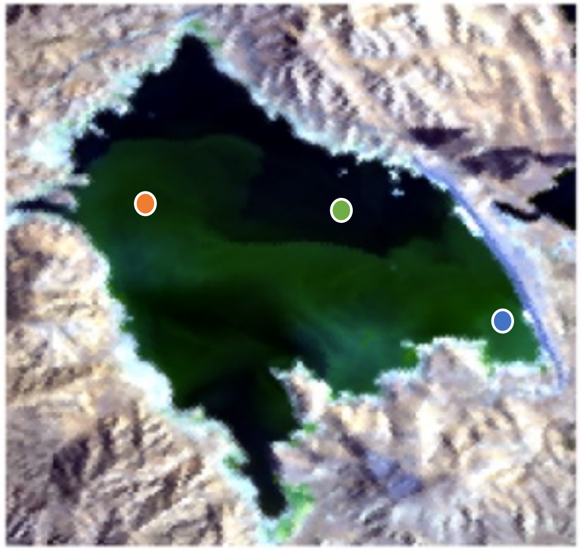
Aquatic –SRR Core Product Algorithms

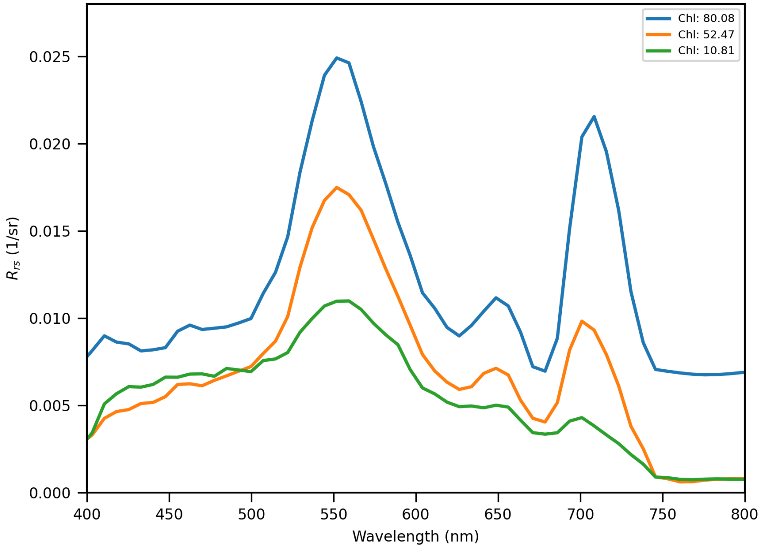


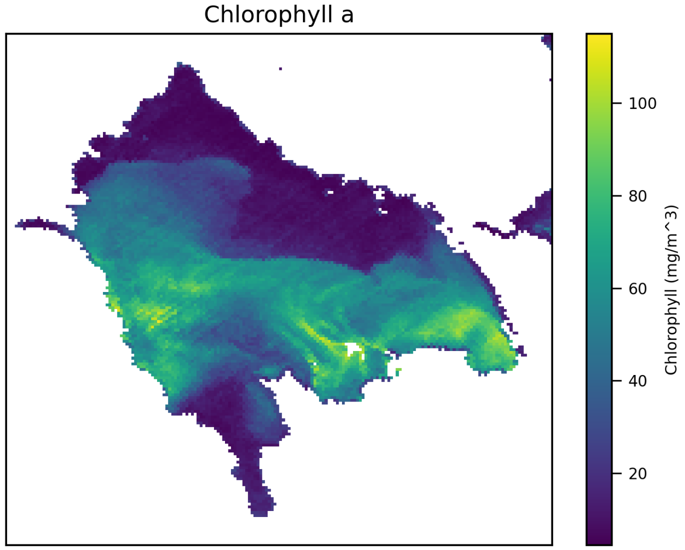
Aquatic – Walkthrough

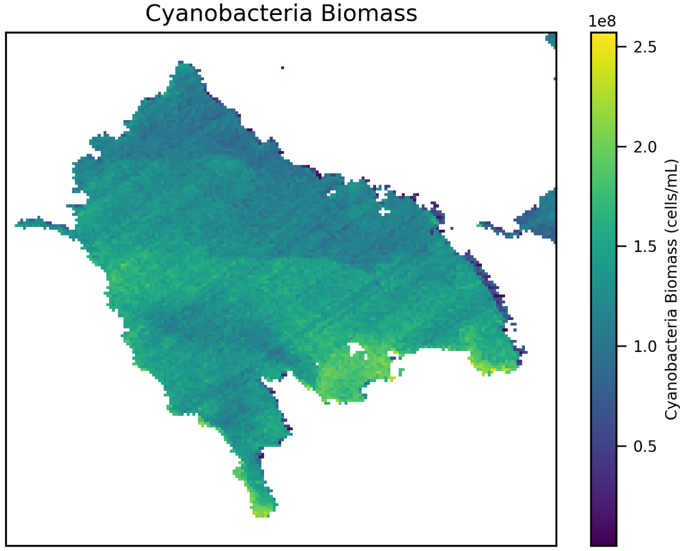
EMIT Candidate Scene: San Luis Reservoir, CA,







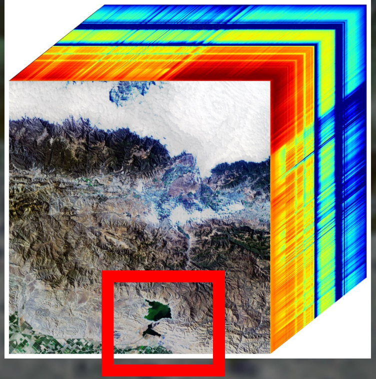


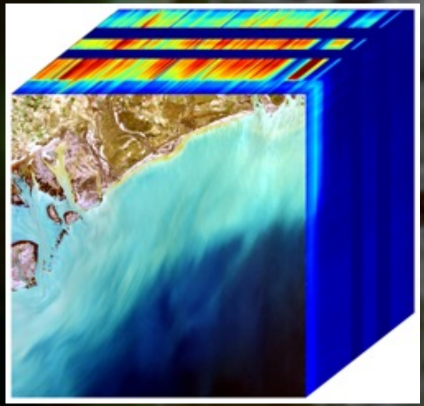


Aquatic Applications

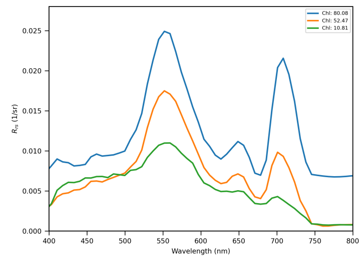
Earth System Observatory

Data

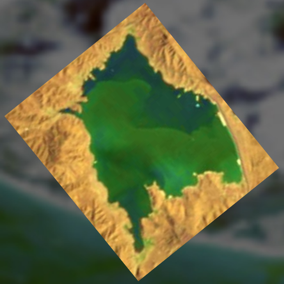


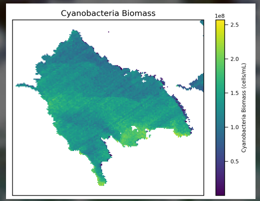


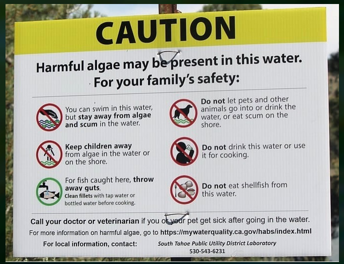
Information



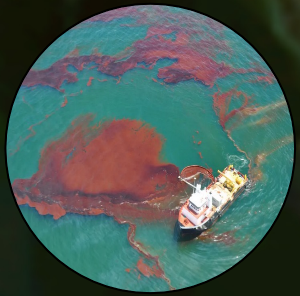
Wisdom and Knowledge







Action

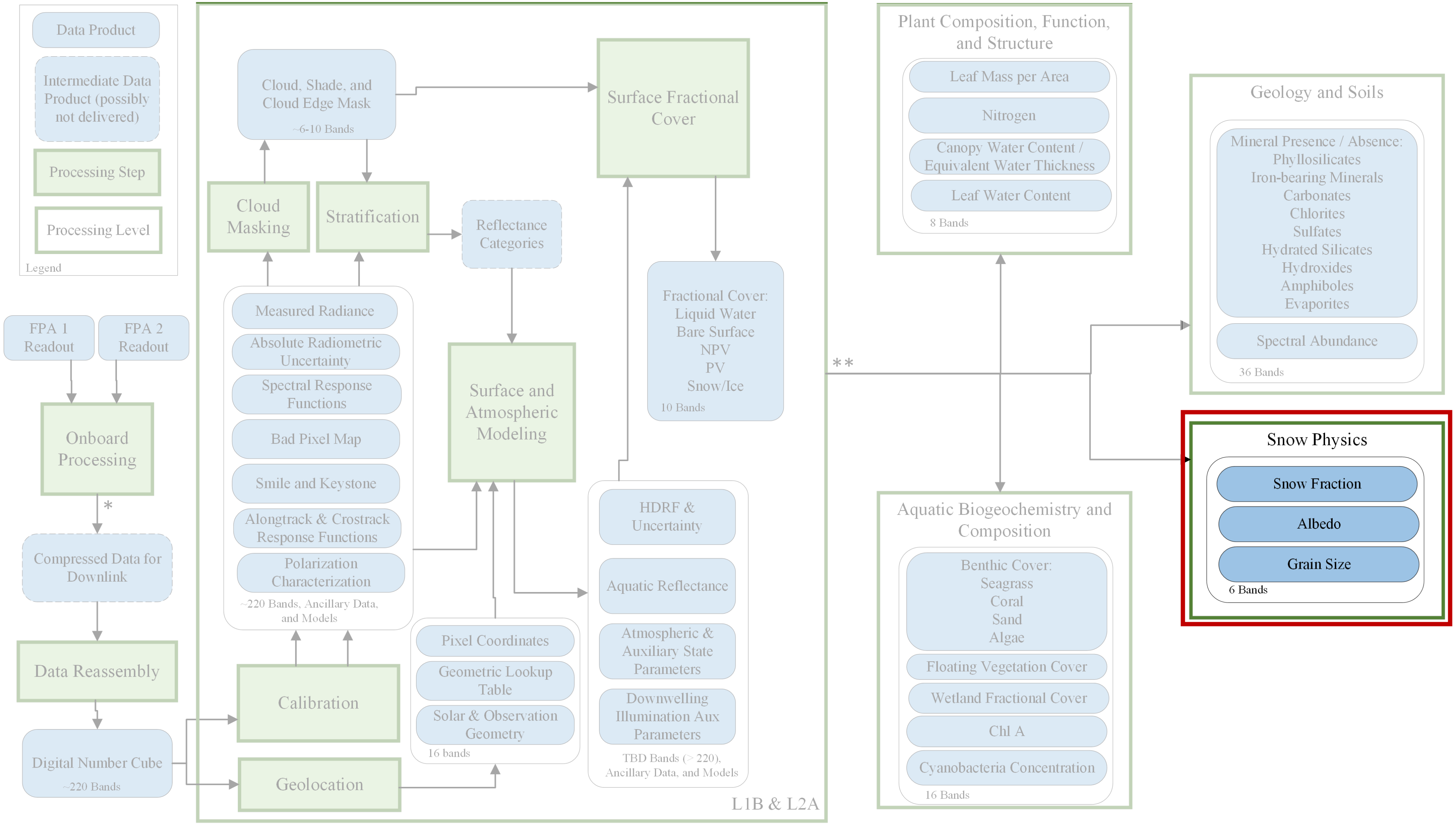


Biodiversity and conservation

Environmental remediation, disaster response

Fisheries, aquaculture and food security

Snow Physics – Algorithm Context



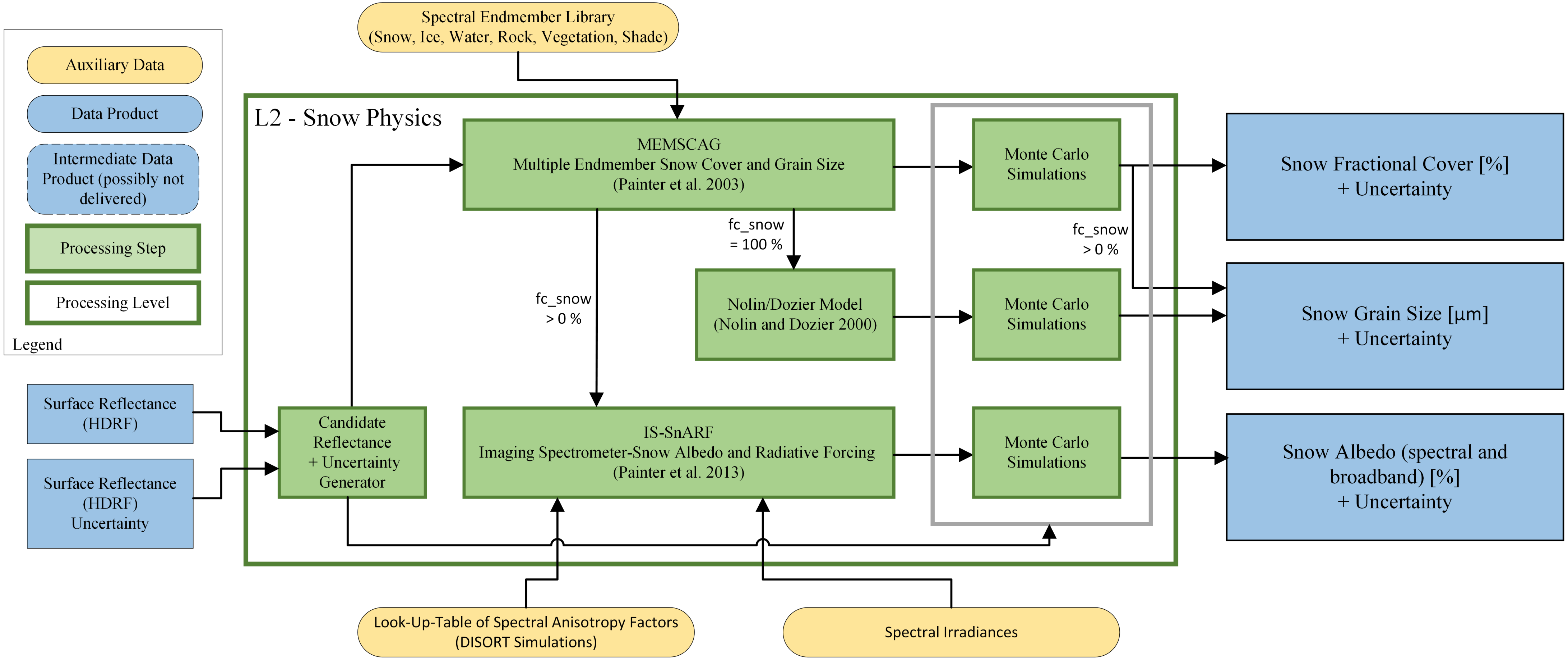
*Everything Downstream repeated for each Focal Plane Array (FPA)

**See Domain Specific Diagrams for the Mapping between L1B/L2A Ouptputs and L2+ Algorithms

Snow Physics – Decadal Survey Focus

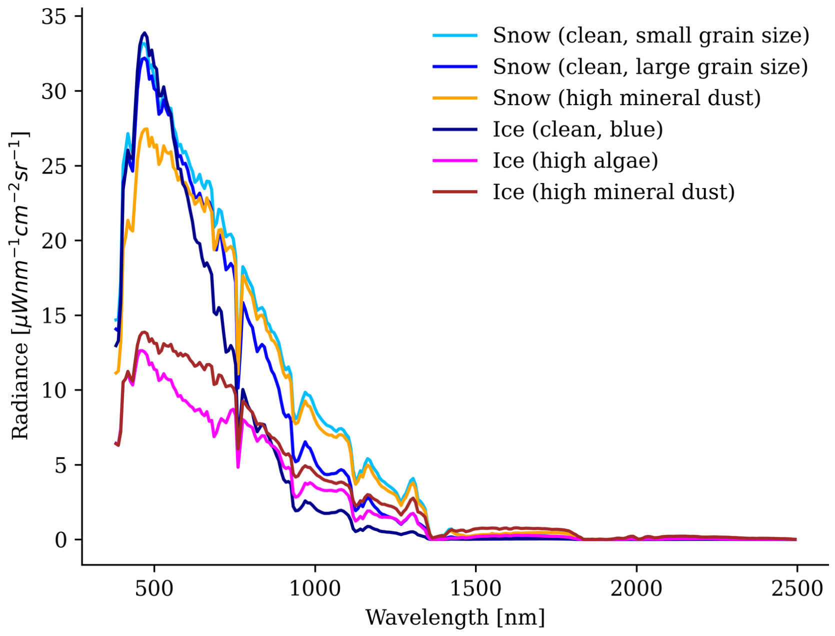
DS Science/Application Objective	Priority	DS Suggested Biogeophysical Parameters	Geophysical Parameters (one-sigma uncertainty target)	Applications enabled
H-1c. Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability.	Most Important	Snow and glacier albedo and surface temperature. Spectral albedo of subpixel snow and glaciers **at weekly intervals** to an accuracy to estimate absorption of solar radiation to 10%. Ice/snow temperature to ± 1K. At spatial resolution of 30 to 100 m.	Snow and ice coverage fraction (coverage fraction +/- 7%)	EA1 Water resource management, EA2 Drought monitoring, EA3 Drought / flood prediction, EA4 Weather forecast, EA5 Climate modeling, EA6 Shipping / navigation around sea ice
			Snow surface reflectance, 380-2500 nm	
			Snow grain size, used to calculate albedo (absorption +/- 7%)	

Snow Physics – SRR Core Product Algorithms

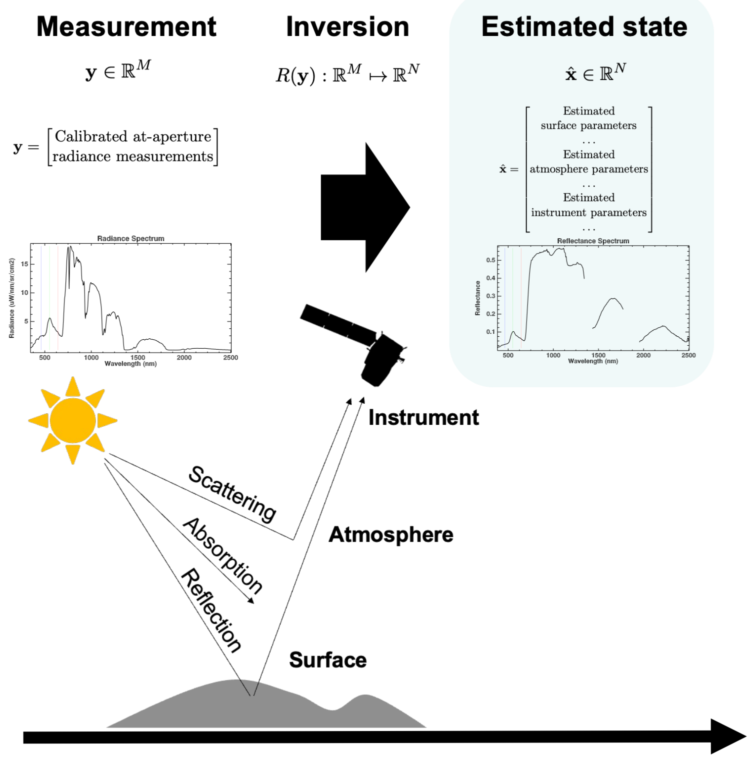


Snow Physics – Walkthrough

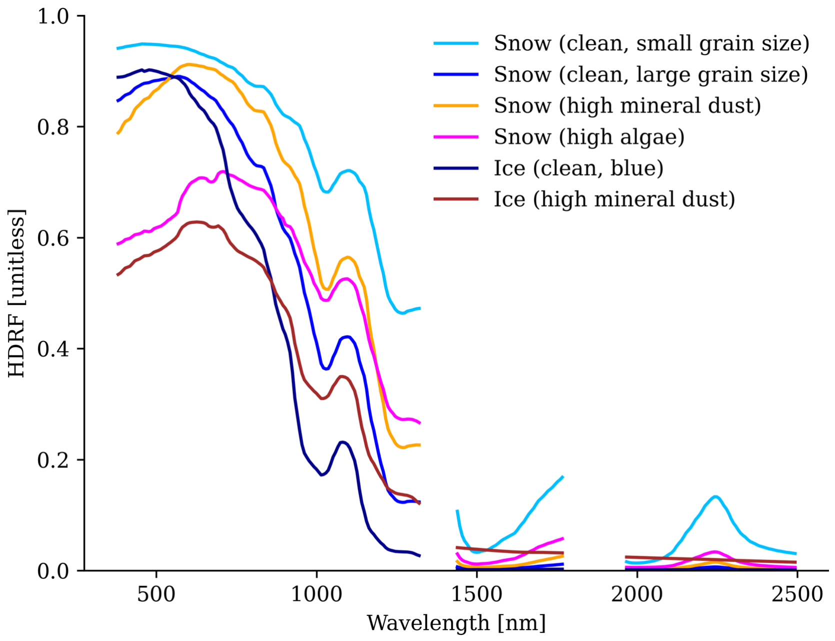
TOA Radiance



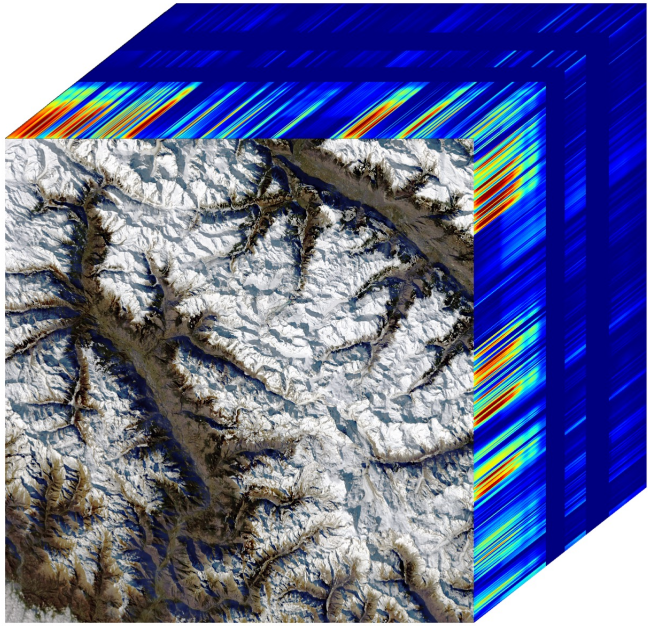
Atmosphere and Surface Modeling (Thompson et al. 2018)

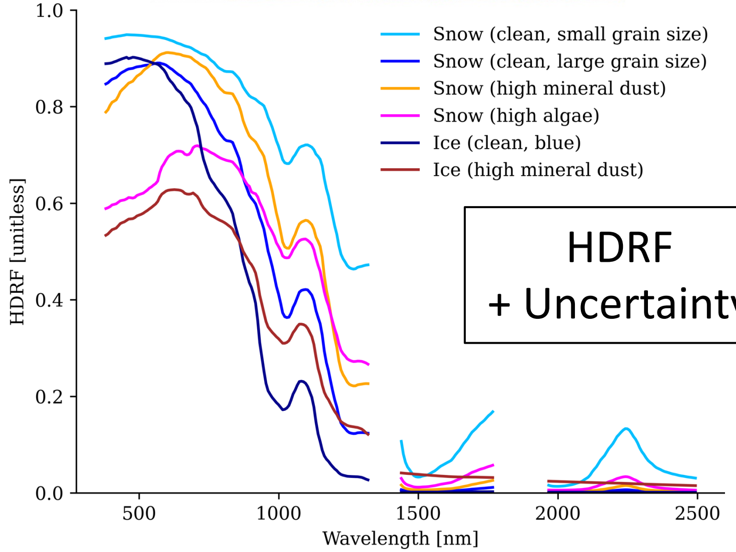


HDRF + Uncertainty



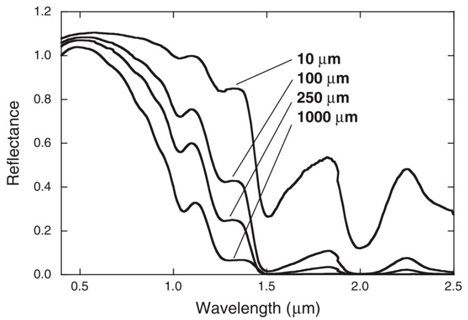
Snow Physics – Walkthrough

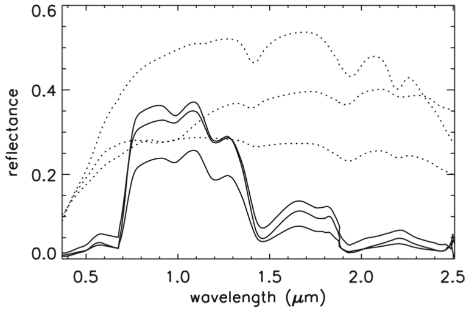


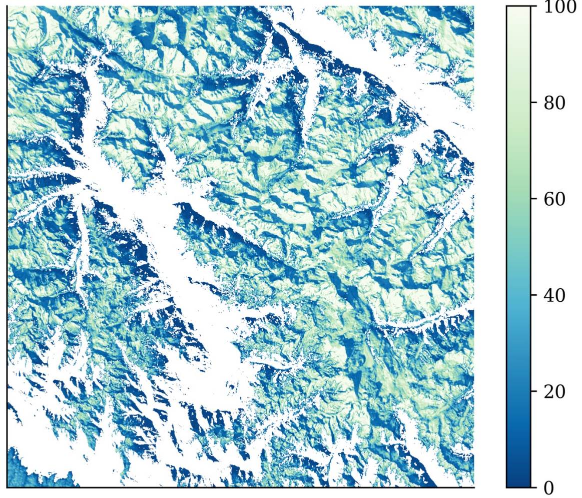


HDRF
+ Uncertainty

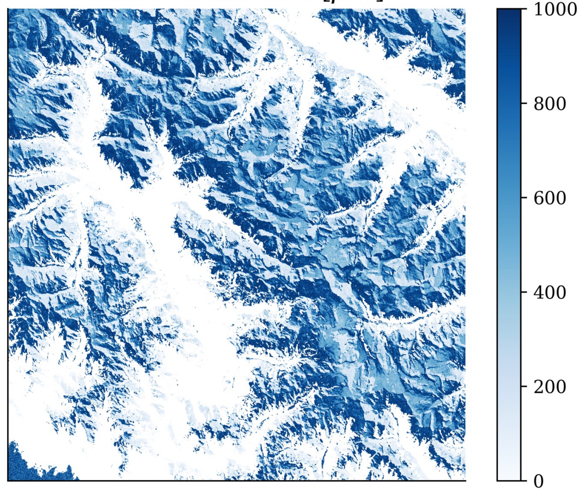
Spectral Endmember Library
(Painter et al. 2003)







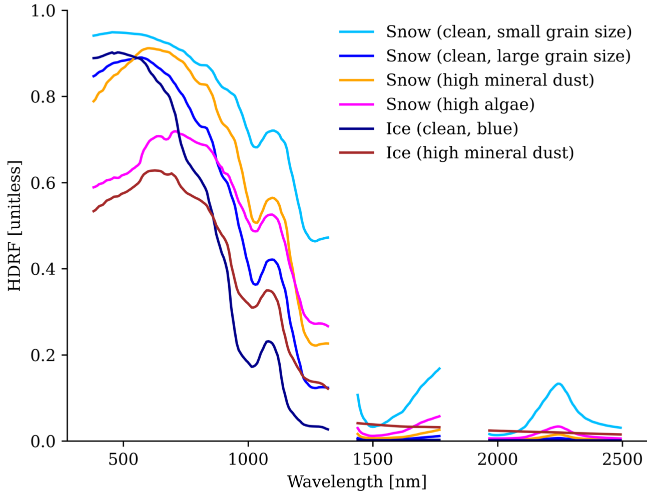
Snow Fraction/
Grain Size
+ Uncertainty



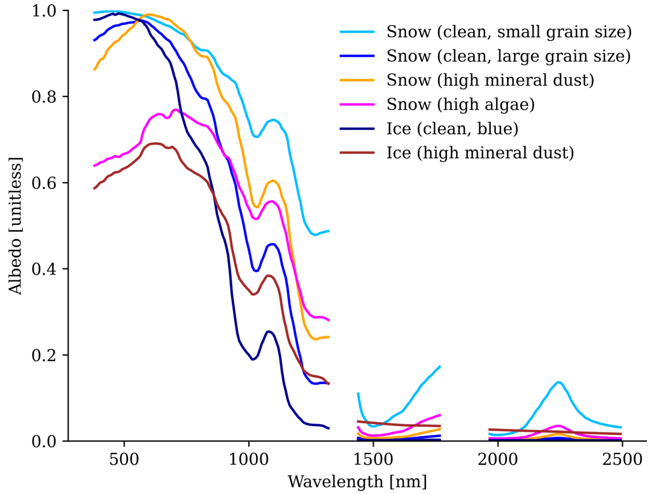
Snow Physics – Walkthrough

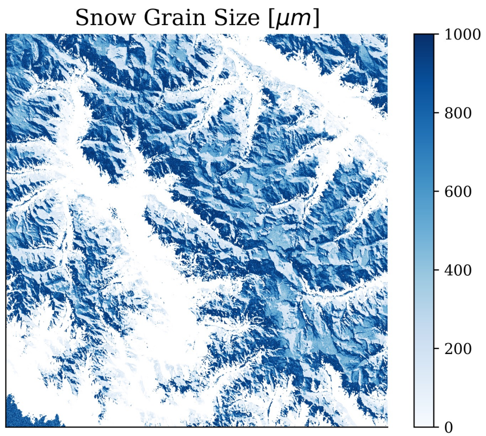
HDRF/Snow Grain Size
+ Uncertainty

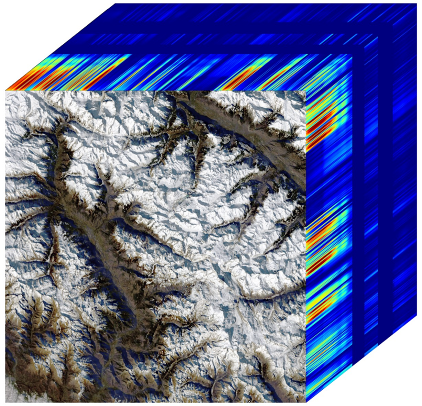
Spectral and Broadband Albedo
+ Uncertainty

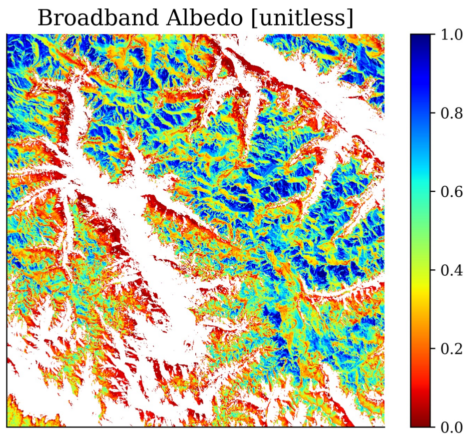


Spectral Anisotropy Factors
Solar and Observation Geometry
Spectral Solar Irradiances
(Painter et al. 2013)





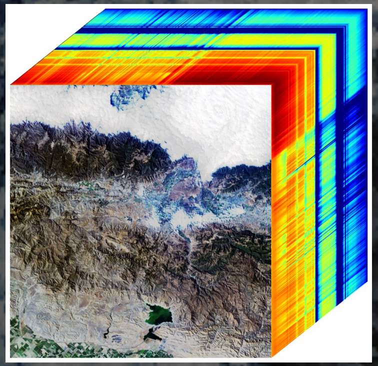




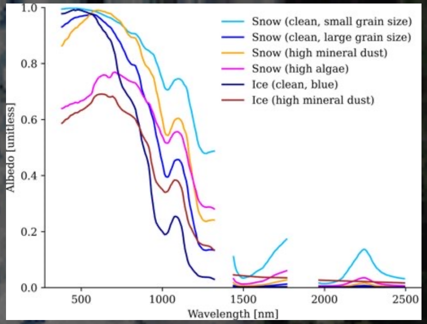
Hydrologic Applications - Snow

Earth System Observatory

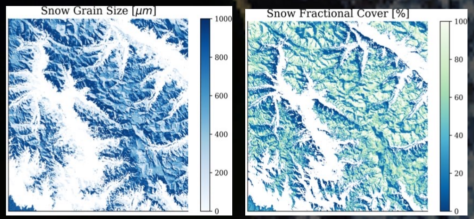
Data

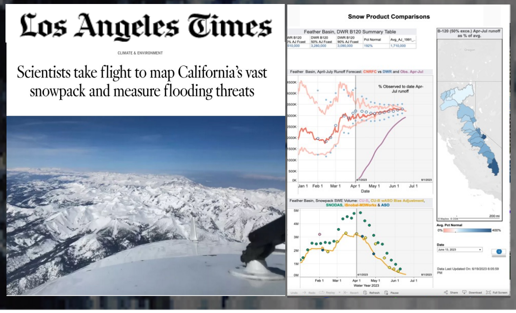


Information

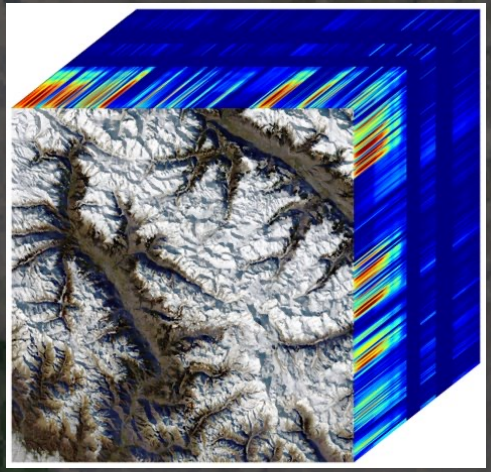


Wisdom and Knowledge





Action



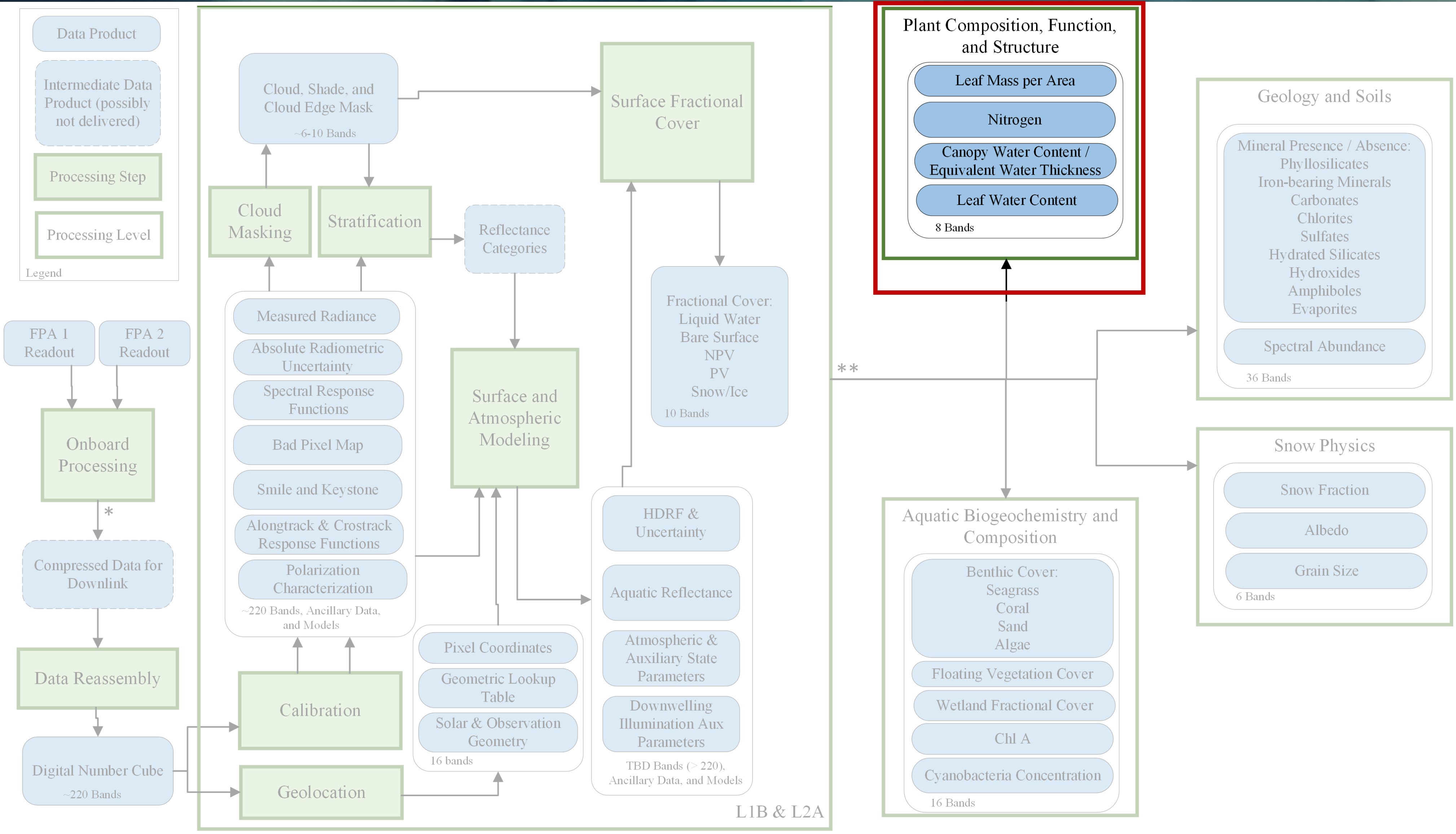
Assessment snowpack and water supplies

Improved flood forecasting and inflow estimates

Drought monitoring

Water resources allocations and management

Terrestrial Vegetation – Algorithm Context



*Everything Downstream repeated for each Focal Plane Array (FPA)

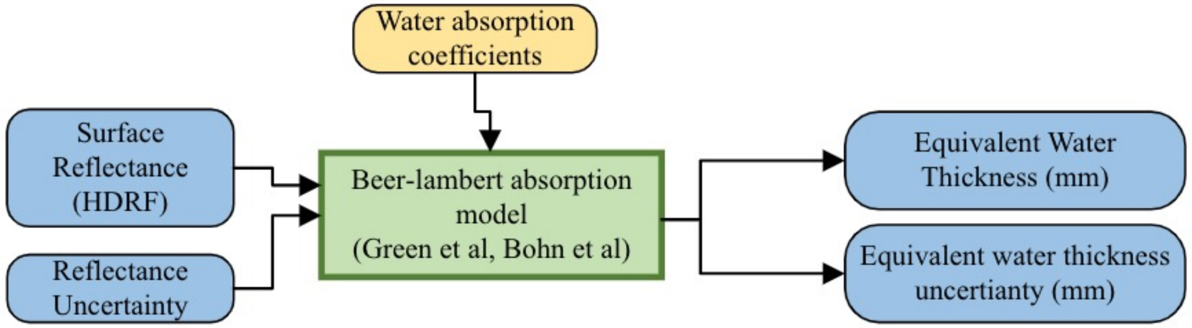
**See Domain Specific Diagrams for the Mapping between L1B/L2A Ouptputs and L2+ Algorithms

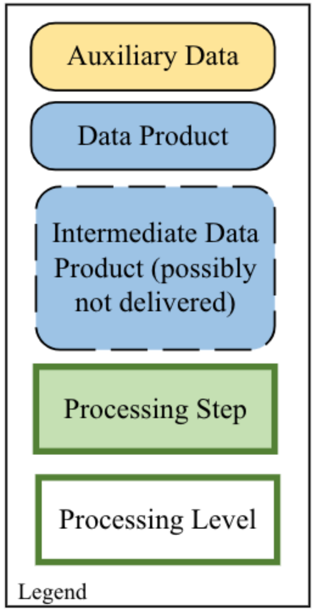
Terrestrial Vegetation – Decadal Survey Focus

DS Science/Application Objective	Priority	DS Suggested Biogeophysical Parameters	Geophysical Parameters (one-sigma uncertainty target)	Applications enabled
E-1a. Quantify the global distribution of the functional traits, functional types, and composition of vegetation spatially and over time.	Very Important	Primary Observable: Chemical properties of aquatic biomass (Inland, Coastal, Shallow): Spectral radiance (10nm; 380-2500nm); GSD = 30-45m; Revisit = ~15 days; SNR = 400:1 VNIR/250:1 SWIR @ 25% reflectance; IT of ~5 ms.	Surface reflectance 380-2500 nm Enables Competed Science Team leadership to support further DS named goals, including: carbon concentrations, nutrients, other biochemicals, Jmax, Vcmax, plant functional types, tree species diversity	EA15 Post-fire assessment and recovery, EA16 Wildlife conservation management, EA17 Invasive species management, EA18 Forest and Agricultural Yield, EA19 Monitor vegetation health, EA20 Rangeland management, EA21 Map endangered species habitat, EA22 Biodiversity conservation, EA24 Habitat restoration, EA45 Agricultural diseases, EA46 Agricultural practices for wildlife habitat
			Canopy nitrogen (N % +/- 25% via AWG)	
			Leaf Water Content (LWC % +/- 10%: p362, uncertainties via AWG)	
E-1c. Quantify the physiological dynamics of terrestrial and aquatic primary producers.	Most Important		Leaf Mass per Area - TBC (LMA g/m2 +/- 30%)	EA10 Wildfire fuel mapping, EA15 Post-fire assessment and recovery, EA17 Invasive species management, EA18 Forest and Agricultural Yield, EA19 Monitor vegetation health, EA20 Rangeland management, EA24 Habitat restoration, EA31 Wildfire emissions forecast, EA33 Land carbon accounting, EA34 Land cover GHG accounting, EA45 Agricultural diseases, EA46 Agricultural practices for wildlife habitat
			Fractional cover: p371 (Live foliage (PV), plant residue (NPV) fraction +/- 10%)	
			Equivalent water thickness (mm) p371 (EWT/CWC +/- 10% via AWG)	
			Surface Reflectance 380-2500 nm Enables Competed Science Team leadership to support further DS named goals, including: xanthophyll pigments, cellulose, lignin	
E-2a. Quantify the fluxes of CO2 and CH4 globally at spatial scales of 100-500 km and monthly temporal resolution with uncertainty < 25% between land ecosystems and atmosphere and between ocean ecosystems and atmosphere.	Most important	GPP, respiration, and decomposition, and biomass burning. Global, daily, 30 m / 300 m	Non-photosynthetic vegetation (coverage fraction +/- 10%)	EA10 Fuel mapping for wildfire management, EA44 Improvement of agricultural practices
E-3a. Quantify the flows of energy, carbon, water, nutrients, and so on sustaining the life cycle of terrestrial and marine ecosystems and partitioning into functional types.	Most Important	GPP, respiration, litterfall and decomposition, non-PS vegetation, functional types. Global, daily, 30 m / 300 m.	Non-photosynthetic vegetation (coverage fraction +/- 10%)	EA10 Fuel mapping for wildfire management, EA44 Improvement of agricultural practices

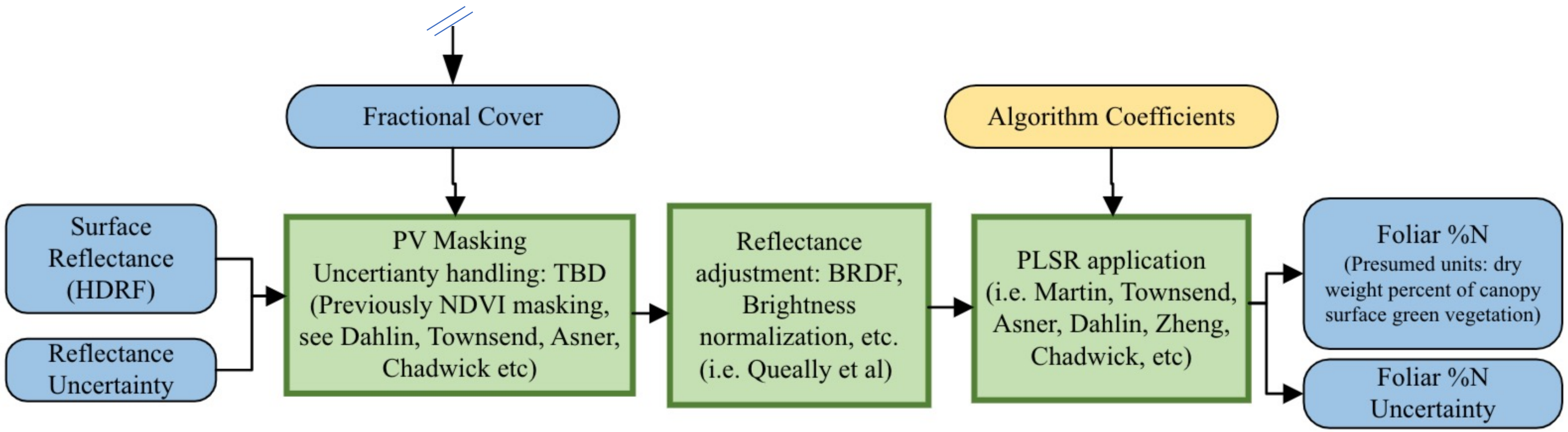
Terrestrial Vegetation – SRR Core Product Algorithms

Equivalent Water Thickness





Foliar Traits (%N as example)



<u>Trait Algorithm Notes</u>

PLSR expected (i.e. Townsend, Asner, Chadwick, Zheng),

Exploring:

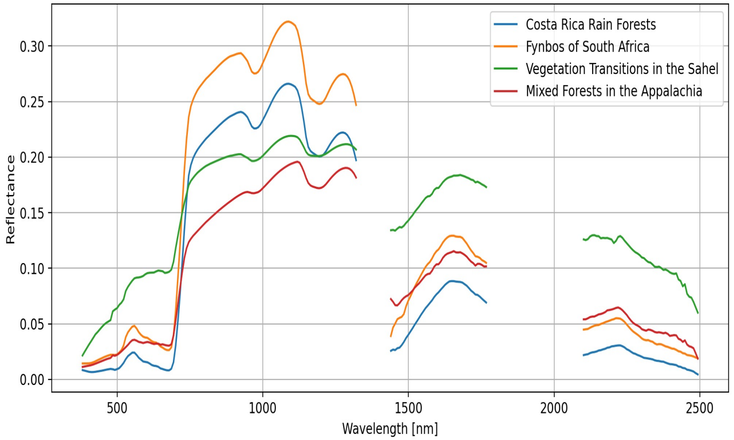
- Functional PLSR (Johny, et al),
- Baysian informed (Kathuria, Shiklomanov, et al)

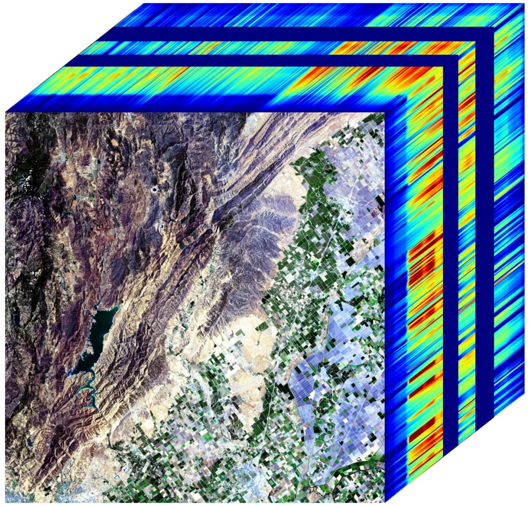
Uncertianty candidates:

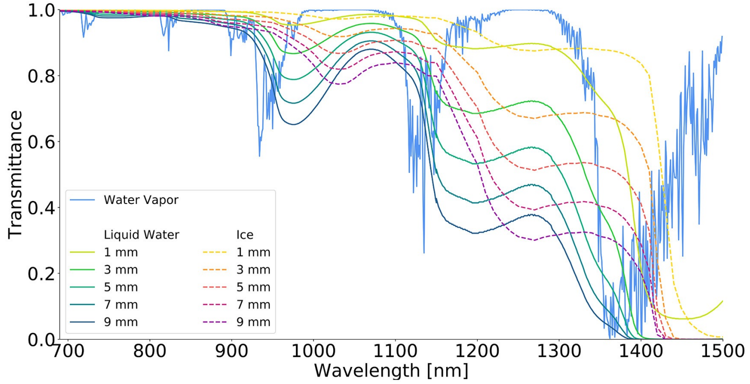
- Model ensembling with coefficient uncertianty
  - (i.e. Zheng et al, Chadwick et al)
- Uncertianty informed PLSR

Terrestrial Vegetation – Walkthrough

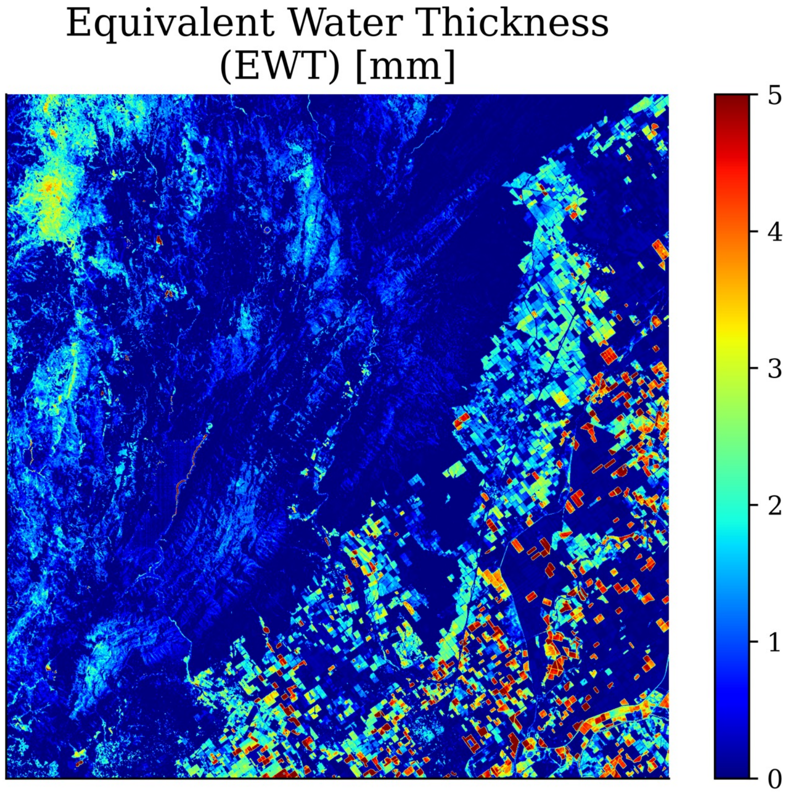
Reflectance (HDRF) + Uncertainty







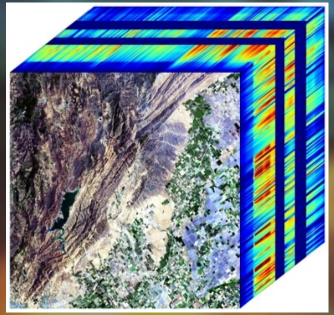
Equivalent Water Thickness + Uncertainty

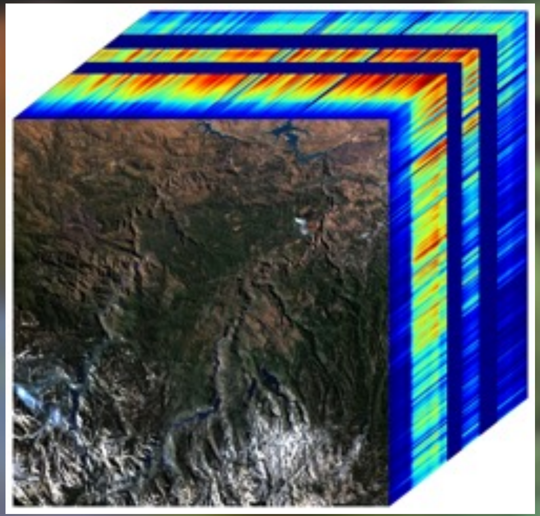


Terrestrial Vegetation Applications

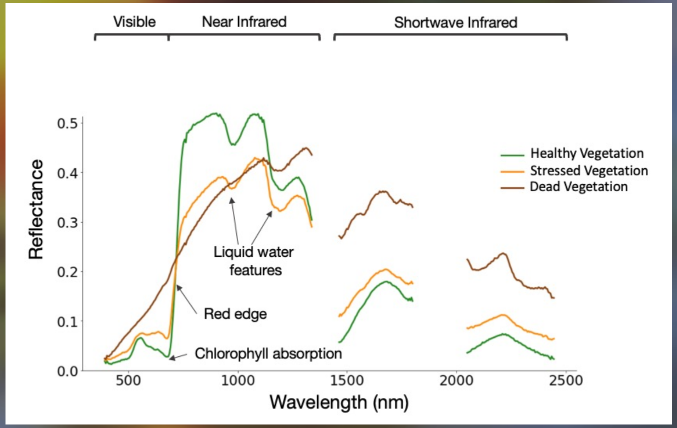
Earth System Observatory

Data

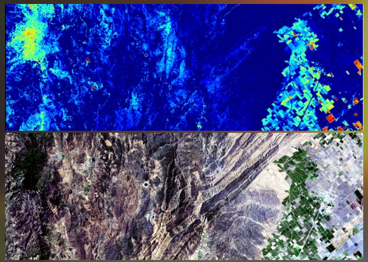




Information

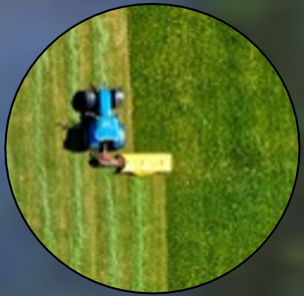


Wisdom and Knowledge



Action

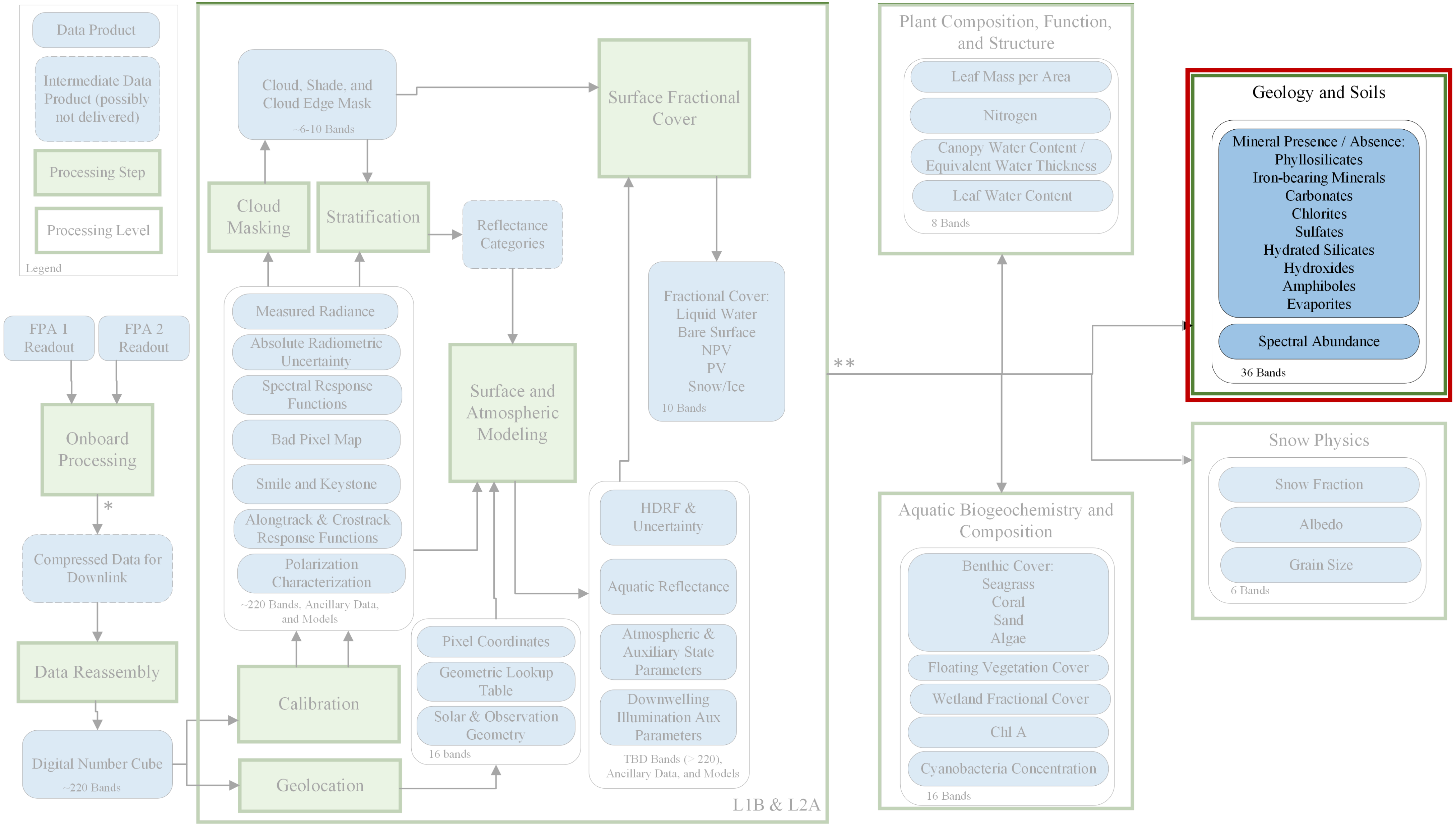
Wildfire risks, including fuel moisture and condition



Agricultural applications, incl. disease detection, water stress, and nutrient deficiencies

Ecosystem condition – vegetation health, invasive species management and restoration

Geology and Soils – Algorithm Context



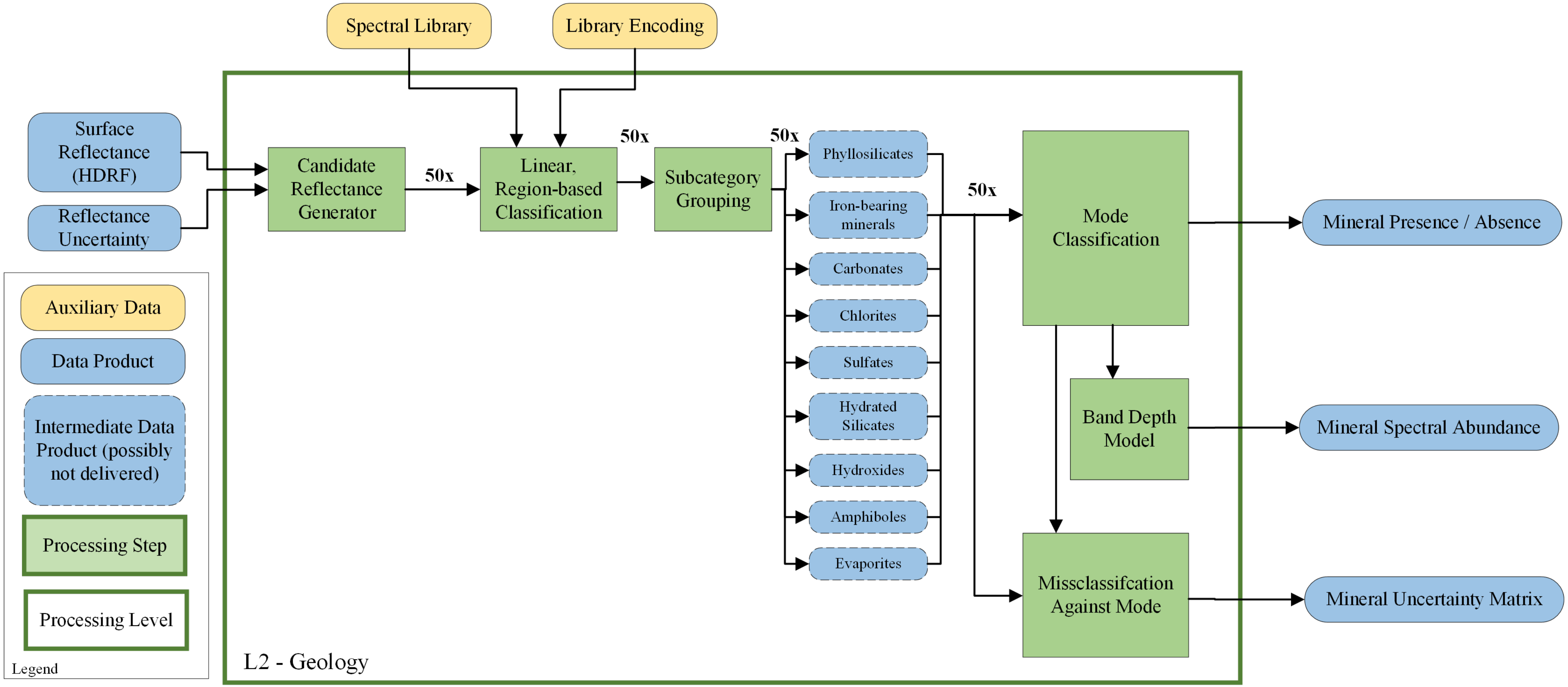
*Everything Downstream repeated for each Focal Plane Array (FPA)

**See Domain Specific Diagrams for the Mapping between L1B/L2A Ouptputs and L2+ Algorithms

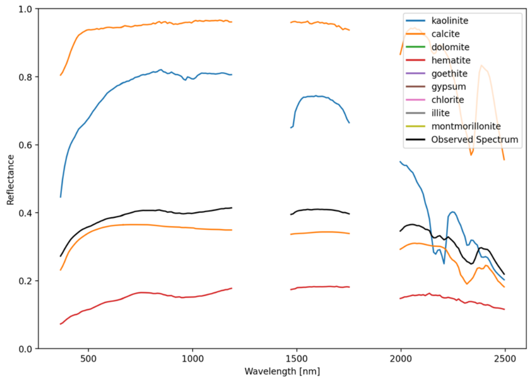
Geology and Soils – Decadal Survey Focus

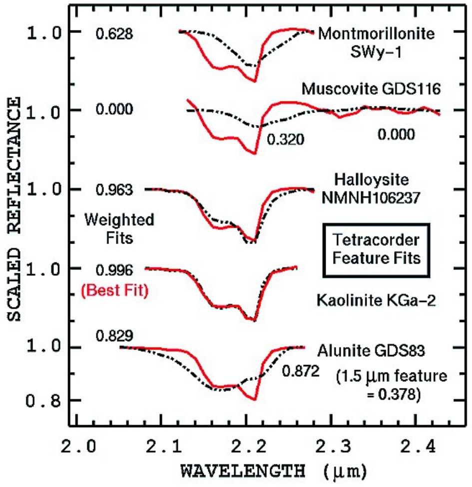
DS Science/Application Objective	Priority	DS Suggested Biogeophysical Parameters	Geophysical Parameters (one-sigma uncertainty target)	Applications enabled
E-1c. Quantify the physiological dynamics of terrestrial and aquatic primary producers.	Most Important	Primary Observable: Chemical properties of vegetation, aquatic biomass, and soils (Land, inland aquatic, coastal zone, and shallow coral reef): Spectral radiance (10nm; 380-2500nm); GSD = 30-45m; Revisit = ~15 days; SNR = 400:1 VNIR/250:1 SWIR @ 25% reflectance; IT of ~5 ms.	Soil Surface Chemistry iron oxides, carbonates, and types of clay minerals, e.g., montmorillonite, illite, and kaolinite, p371, (Kaolinite spectral abundance +/-10%)	EA15 Post-fire severity assessment and recovery, EA18 Forest and Agricultural Yield, EA20 Rangeland management, EA33 Land carbon accounting EA40 Improving landslide models and predictions
S-1a. Measure the pre-, syn-, and posteruption surface deformation and products of Earth's entire active land volcano inventory with a time scale of days to weeks.	Most Important	Ground-surface composition and changes over time. Hyperspectral VNIR/SWIR (at the ~ 30 m spatial scale) and TIR data (at the ~ 60 m spatial scale) with 1-2 week revisit time, acquiring continuously for periods of weeks to months prior to an eruption to detect trends and change	Bare surface mineral composition (Mineral spectral abundance +/-10%)	EA10 Wildfire fuel mapping, EA36 Volcanic eruption forecast, EA38 Lava flow prediction, EA39 Crater lake hazard prediction
S-1c. Forecast and monitor landslides, especially those near population centers.	Very Important	**High spatial resolution time series of distribution of vegetation and rock/soil composition.** Hyperspectral VNIR/SWIR and TIR data at 30-45 m spatial resolution and ~ weekly temporal resolution	Surface composition and cover (Soil coverage fraction +/- 10%)	EA8 Urban heat islands, EA9 Vector-borne diseases, EA14 Land energy fluxes, EA31 Wildfire emissions forecast, EA34 Land use GHG accounting, EA35 Peatland mapping, EA40 Landslide modeling, EA41 Landslide risk forecasting, EA42 Post-landslide assessment and recovery
S-2b. Assess surface deformation (<10 mm), extent of surface change (<100 m spatial resolution) and atmospheric contamination, and the composition and temperature of volcanic products following a volcanic eruption (hourly to daily temporal sampling)	Very Important	**Volume, composition and temperature of all eruptive products and measure their changes over time.** Hyperspectral VNIR/SWIR and TIR data at 30-45 m spatial resolution and ~weekly temporal resolution.		

Geology – Algorithm Workflow



Geology – Algorithm Workflow

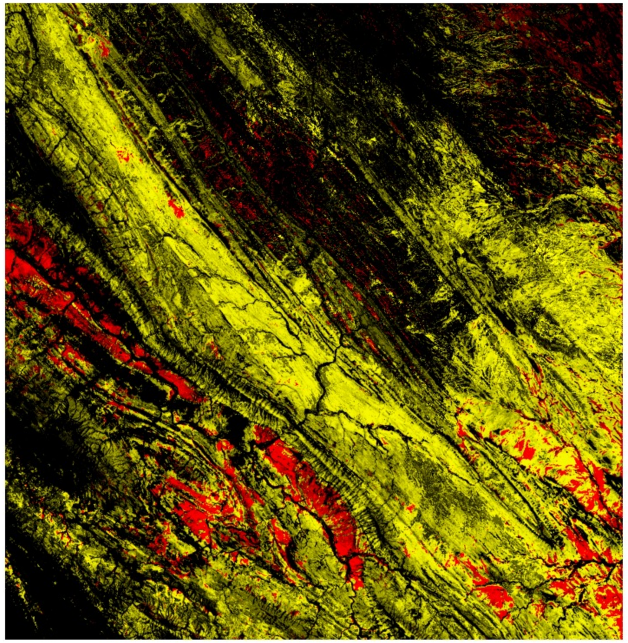




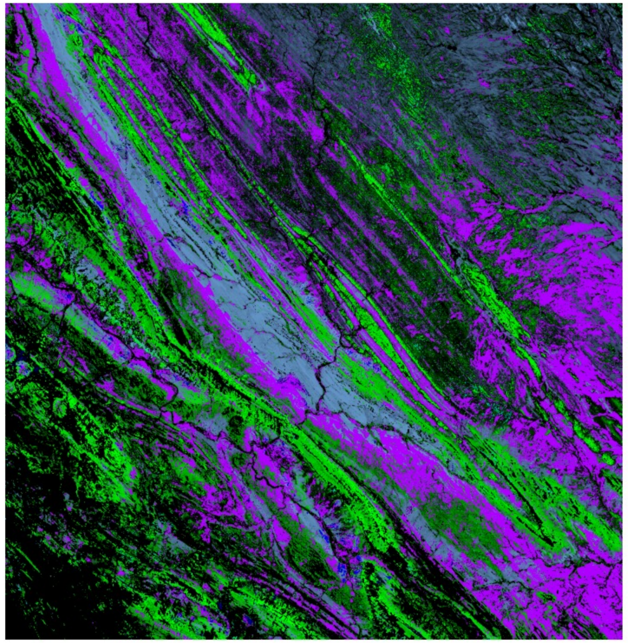
Clark et al., 2003

RGB [649 nm, 559 nm, 470 nm]

Dominant Mineral Abundances - Iron Oxides



Dominant Mineral Abundances - 2µm



Goethite
Hematite

Calcite
Chlorite

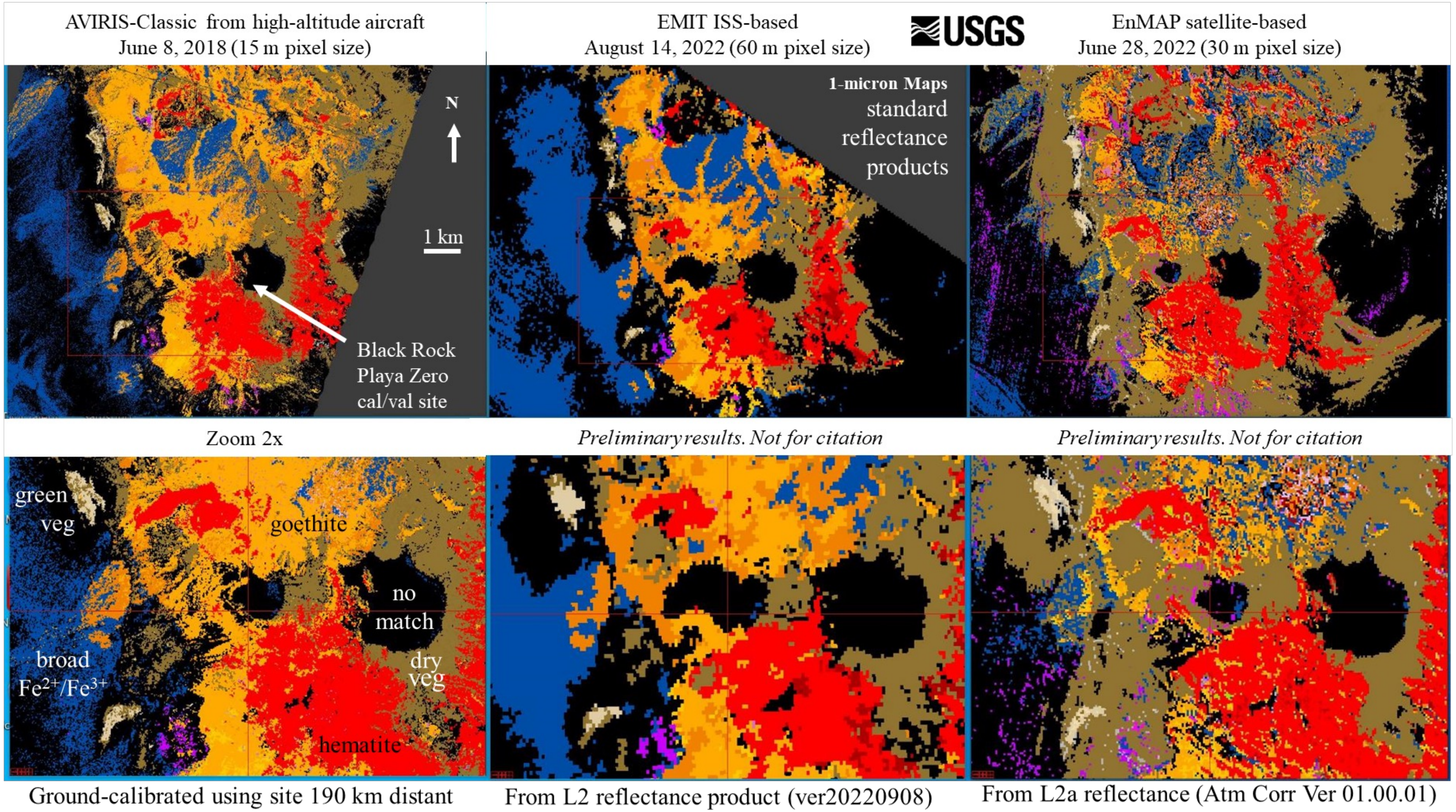
Dolomite
Gypsum

Illite & Muscovite
Kaolinite

Montmorillonite
Vermiculite

Geology and Harmonization

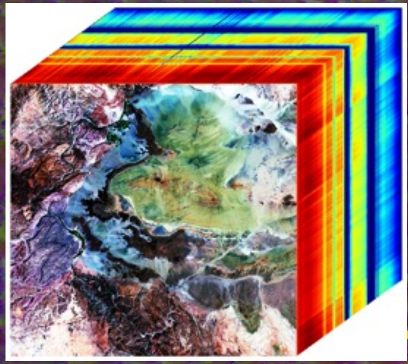
- AVIRIS, EMIT, ENMAP
- Different imaging spectrometers
  - AVIRS-1986 whisk-broom
  - EMIT-2022 grating push broom
  - ENMAP-2022 prism push broom
- Different spectral
  - AVIRIS 10 nm
  - EMIT 7.4 nm
  - ENMAP ~10 variable
- Different radiometric
  - See instrument details
- Different spatial
  - AVIRIS 20 m
  - EMIT 60 m
  - ENMAP 30 m
- Different times atmospheres
  - AVIRIS 8 Jun 2018
  - EMIT 14 Aug 2022
  - ENMAP 28 Jun 2022

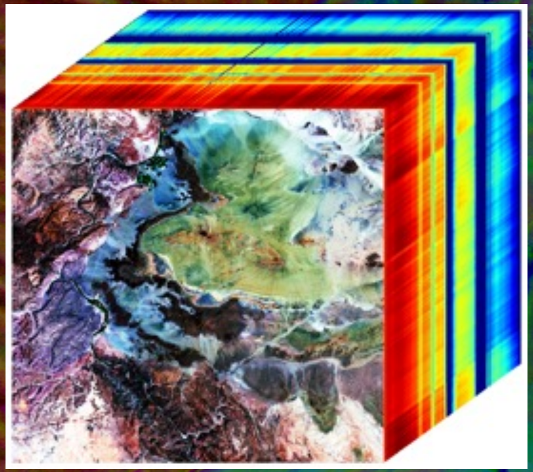


Mineralogy Applications

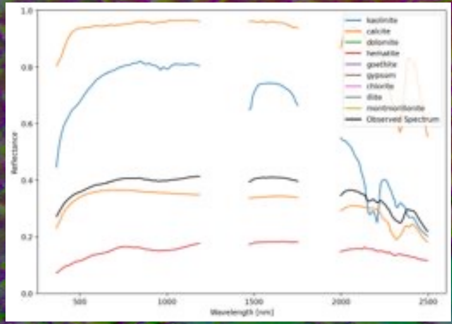
Earth System Observatory

Data

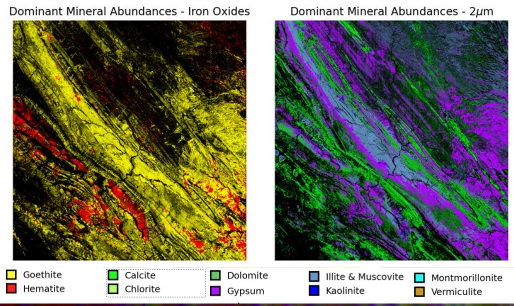


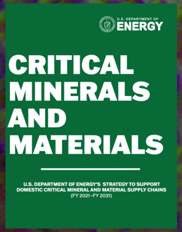


Information

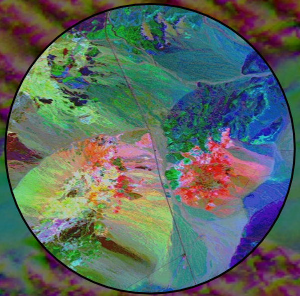


Wisdom and Knowledge

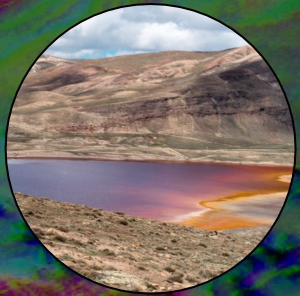




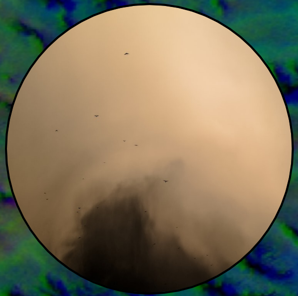
Action



Strategic Mineral Mapping



Environmental Assessment



Dust impacts on climate change

Wrap Up and Next Steps

- The SBG VSWIR Project Science/Applications effort is currently focused on preparing for the upcoming System Requirements Review (SRR)
- The traceability from the Decadal Survey priorities to the observation requirements has been refined and strengthened to support the SRR
- A baseline set of core products and algorithms have been identified with a focus on maturity to control risk, cost, and schedule
  - Radiance, reflectance, Fractional Cover, Aquatic, Terrestrial, Snow, and Geology plus Atmosphere
- The VSWIR Project is committed to delivering radiance and reflectance products with uncertainty and full characterization to enable a diverse and broad set of additional community algorithms

Wrap Up and Next Steps

- Elements of calibration, uncertainty quantification, verification, parameterization, validation, and harmonization are being incorporated as appropriate

- SBG VSWIR Project Science/Applications work is informed by the latest results from EMIT

- We are planning another pre SRR update in August ideally teamed with the TIR

- Following SRR this NASA life cycle process of will progress as the Project works to prepare for the Preliminary Design Review (PDR)

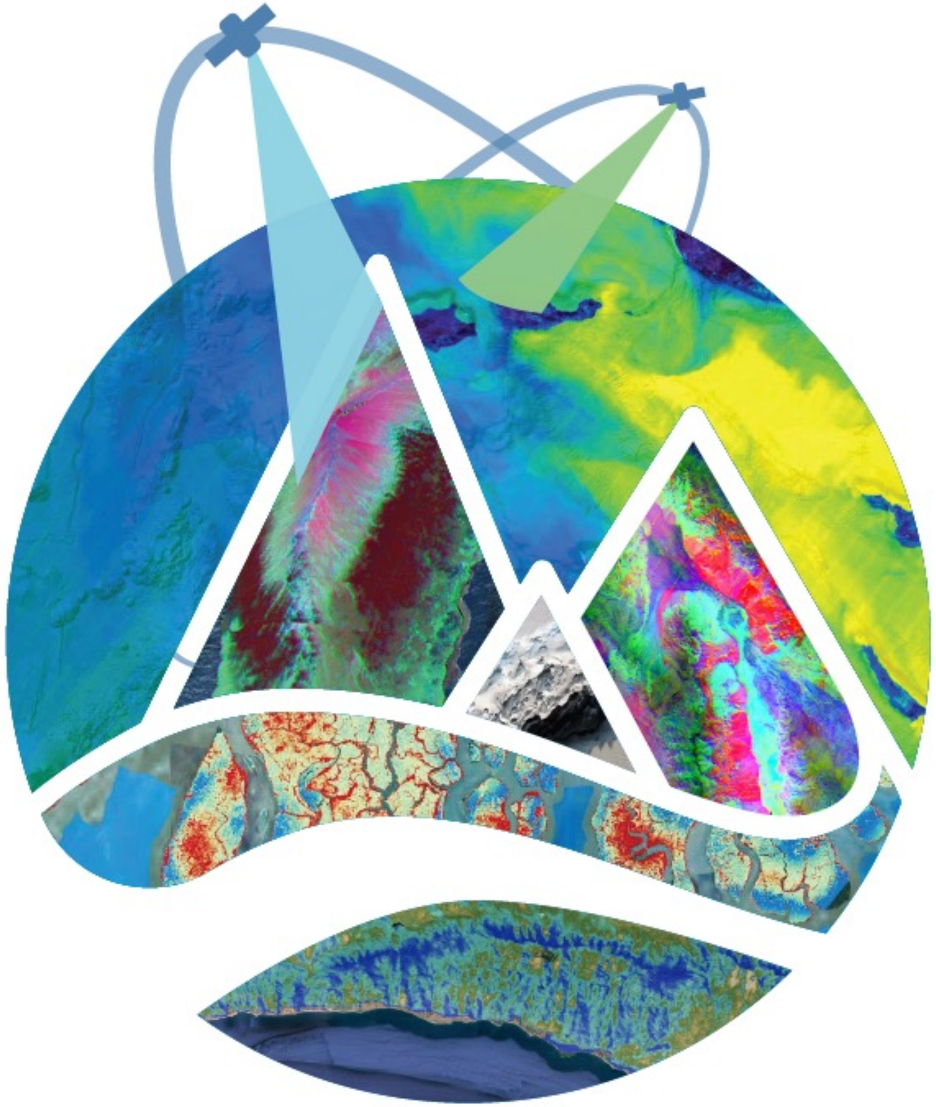
- The SBG VSWIR Project Science/Application team will grow

SBG VSWIR Project Science/Applications Coordinators

- Robert O. Green, VSWIR Project Scientist, Geology & Soils Coordinator
- David R. Thompson, Deputy VSWIR Project Scientist, VSWIR Instrument Scientist, Surface & Atmospheric Modeling Coordinator
- Regina Eckert, Calibration Coordinator
- Phil Brodrick, Project Algorithm Scientist, Deputy VSWIR Instrument Scientist, Fractional Cover Coordinator
- Kelly Luis, Aquatics Coordinator
- Christine Lee, Applications Lead, Aquatics Co-Coordinator
- Niklas Bohn, Snow Physics Coordinator
- Dana Chadwick, Terrestrial Vegetation Coordinator
- Ryan Pavlick, Terrestrial Vegetation Co-Coordinator
- Plus advisors and team growth

Join us by filling out the following form: https://tinyurl.com/yv3edwfw

Discussion and Questions?



Terminology

- **System Requirements Review**: The System Requirements Review (SRR) evaluates the project requirements for clarity, achievability, consistency, understanding, responsiveness to the sponsor commitments, and appropriateness to fulfill the mission needs.
- **Calibration**: Determine the spectral, radiometric, spatial, and uniformity properties of the imaging spectrometer such that the recorded signals can be converted to usable measurements with units, response functions, and uncertainties that meet requirements.
- **Algorithm parameterization, training, tuning**: The process of using in situ or other independent observations or measurements to enable and algorithm to perform.
- **Verification**: Determine if the delivered system meets requirements both on ground and in space.
- **Validation**: Confirm the system/product is what was needed to address the science or applications objectives with appropriate accuracy and precision.
- **Uncertainty Quantification**: The quantitative characterization, tracing, and management of uncertainty in imaging spectroscopy products and results.
- **Harmonization**: Alignment of product definitions, calibration, measurement procedures, and supporting characterization information such that a broad and diverse set of algorithms can be used seamlessly.