Surface Biology and Geology
An Observing System for Climate Impacts and Earth System Dynamics
THE SURFACE BIOLOGY AND GEOLOGY DO IS DEFINED WITH CONSIDERABLE DETAIL IN THE DECADAL SURVEY

SBG is key to understanding in five research and applications focus areas:
- Terrestrial and aquatic ecosystems
- Hydrology
- Weather
- Climate
- Solid Earth

The Decadal Survey defines the implementation as two sensors “Hyperspectral Imagery in the visible and shortwave infrared; multi- or hyperspectral Imagery in the thermal IR”:

1. “….a moderate spatial resolution (30-45 m GSD), hyperspectral resolution (10 nm; 400-2500 nm), high fidelity (SNR = 400:1 VNIR/250:1 SWIR) imaging spectrometer is needed for characterizing land, inland aquatic, coastal zone, and shallow coral reef ecosystems”

2. “….30-60 m TIR observations in the 10.5-11.5 μm and 11.5-12.5 μm spectral regions are needed with a 2-4 day revisit frequency” ¹

¹) Note, this specification was updated based on recent work and community engagement to optimize for the DS-specified science and applications.
NASA has authorized SBG to proceed to Pre-Phase A

“Based on the successful completion of the Surface Biology and Geology (SBG) mission study in 2020, now part of the Earth System Observatory (ESO) integrated missions recommended by the National Academies as “Designated Observables,” you are hereby authorized to establish a project office, select a project manager, and initiate Pre-Phase A activities of the SBG observing system.”
NASA has authorized SBG to proceed to Pre-Phase A

“The SBG study provided a number of potential architecture options for the SBG observing system. Pre-Phase A activities shall consist of an overarching trade study based on the two-platform architecture, with separate Visual Shortwave Infrared (VSWIR) and Thermal Infrared (TIR) platforms, plus a VSWIR SmallSat, leading to a final observing system concept.”
NASA has authorized SBG to proceed to Pre-Phase A

“During Pre-Phase A, the SBG project shall also participate in two studies facilitated by Earth Science Data Systems (ESDS):

• In support of the Science Mission Directorate’s (SMD’s) goal of enabling Open Science, the Open-Sourced Science Processing study will develop architectural concepts for a common science data processing system for generating Level 1-4 science data products. These concepts will identify and evaluate options to expand participation in mission science beyond the funded science teams.

• The Data Latency and Ground Segment study will evaluate flight hardware and ground system architectures to minimize product latency and support cross-ESO science product generation.”
NASA has authorized SBG to proceed to Pre-Phase A

“During Pre-Phase A, the SBG project shall also complete the **Community Assessment Report (CAR)** in time to support the MCR. Based on, but not limited to, the CAR, the project shall explore and evaluate how **design choices, including mission architecture and concepts of operations** (e.g., latency, resolution, revisit frequency, overpass time, etc.), **enable applications and applications communities**. This information shall inform trade studies and the observing system concept.”
SBG: NASA's OBSERVING SYSTEM FOR CLIMATE IMPACTS

CLIMATE IMPACTS

SEA LEVEL RISE

RADIATIVE FORCING

BIODIVERSE ECOSYSTEMS COASTAL ZONES

THE CRYOSPHERE

CARBON STORAGE

VOLCANIC GASES

GHGs

FLUXES WITHIN AND BETWEEN ECOSYSTEMS

URBAN HEAT

WATER AND WATERSHEDS

AGRICULTURE, WATER MANAGEMENT

WETLAND CARBON

BLUE CARBON
SBG: MOST AND VERY IMPORTANT RESEARCH AND APPLICATIONS
OBJECTIVES ACROSS ALL FIVE DS FOCUS AREAS

**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.*

**WEATHER**

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

**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?*

**CLIMATE**

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

**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?*
SBG: MAJOR APPLIED SCIENCE ACROSS SECTORS

**AGRICULTURE, FOOD SECURITY AND SURFACE WATER MANAGEMENT**
- Improve “crop per drop” by assessing vegetation water stress over irrigated agriculture
- Improve water supply management through better characterization of snow properties and estimated reservoir inflows
- 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
- Water surface temperature and impacts on marine biodiversity

**CONSERVATION**
- Support biodiversity understanding and protections by mapping invasive species composition, structure, distribution; support removal and restoration efforts
- Monitoring of endangered species habitat; provide alerts of disease mortality of impacted vegetation, including insect infestation
- Biodiversity hotspots and 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 NATURAL HAZARDS**
- Detect and track oil spill events and
- Support active fire mapping and response
- Improve mitigation of heat wave events for vulnerable populations

**GEOLOGY APPLICATIONS**
- Mineral mapping for exploration efforts and reduction of environmental hazards
- Forecast aviation hazards and support emergency response for volcanic eruptions
- Landslide risk assessment with improved substrate map land cover maps
SBG: KEY RESEARCH AND APPLICATIONS REQUIREMENTS

**COVERAGE:** The system must provide **global coverage** to address the global scope of the science including the coastal ocean and inland waters.

**STABILITY AND DURATION:** Measurements must be able to detect **long term changes** for addressing dynamics of the Earth System.

**GEOMETRY:** The system’s orbit must allow for **consistent sun-sensor geometry** for consistency in retrievals and for calibration and validation, and provide for global coverage, as above (polar orbit).

**RANGE, RESOLUTION AND SENSITIVITY:** Visible to Shortwave Infrared (VSWIR; 400-2500 nm) imaging spectroscopy and multi-spectral thermal infrared (TIR; 4 - 12 μm) measurements to observe “diversity” in ecosystem function. Radiometric performance driven by aquatic targets.

**SPATIAL RESOLUTION:** The observing system must provide high **spatial resolution** (30 and 60 m for VSWIR and TIR)

**REVISIT:** The SBG observing system temporal resolution must be adequate to capture **synoptic and seasonal variation** as well as observe rapid or **transient changes** related to Earth system events such as fires, landslides, volcanic activity and anthropogenic incidents.

**LATENCY:** Low latency, the time between an event and data access, must be low enough to support time-sensitive applications, ≤ 24 hours.
SBG Architecture

SBG Heat
Wide-swath TIR imager and ASI VNIR camera
Sun-sync orbit (early PM)
5+ bands TIR, 2+ bands VNIR
935 km swath, 3 day revisit
60 meter GSD
0.2K NeDT

SBG Light
Wide-swath VSWIR spectrometer
Sun-sync orbit (late AM)
185 km swath
16 day revisit
10 nm, 200+ bands
30 meter GSD
High SNR and radiometric performance
# Surface Biology and Geology (SBG)

## Pre-Phase A (Pre-Concept Study Phase) Schedule

### FY2021

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**SBG Community Quarterly Webinars**
- Collect Science and Applications Requirements

**Establish Foundation**

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**Develop Technical Baseline**

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**Prep Cost and Schedule**

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**Prep for MCR**

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**Convene MCR (NLT FY22-Q3)**

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**Prep for KDP-A**

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**Prep Preliminary Science and Applications Requirements**

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## Phase A (Concept Study Phase) Schedule - Notional

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**SBG Community Quarterly Webinars**
- Refine Science and Applications Requirements

**Refine Foundation**

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**Convene SRR/MDR (FY23-Q4)**

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**Baseline Science and Applications Requirements**

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**Convene KDP-B (FY24-Q1)**

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**Convene KDP-A (FY22-Q4)**

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**Pre-Decisional Draft: For planning and discussion purposes only.**

THE SURFACE BIOLOGY AND GEOLOGY DESIGNATED OBSERVABLE
THE SURFACE BIOLOGY AND GEOLOGY DESIGNATED OBSERVABLE

World-leading technology
THE SURFACE BIOLOGY AND GEOLOGY DESIGNATED OBSERVABLE

World-leading technology

Premier observatory for climate impacts
THE SURFACE BIOLOGY AND GEOLOGY DESIGNATED OBSERVABLE

- World-leading technology
- Premier observatory for climate impacts
- Actionable Information for conservation and biodiversity
THE SURFACE BIOLOGY AND GEOLOGY DESIGNATED OBSERVABLE

- World-leading technology
- Premier observatory for climate impacts
- Actionable Information for conservation and biodiversity
- Usable data for renewable and non-renewable natural resources
THE SURFACE BIOLOGY AND GEOLOGY DESIGNATED OBSERVABLE

Frequent, low-latency data of proven value, for:
- Wildfire risk and active burning
- Oil spills
- Landslides
- Drought and excess precipitation
- Agricultural pests and pathogens
- Heat waves
- Zoonotic disease
- Volcanic events
- Snowmelt and flooding
- Water resource management
THE SURFACE BIOLOGY AND GEOLOGY DESIGNATED OBSERVABLE

- Frequent, low-latency data of proven value for:
  - Wildfire risk and active burning
  - Oil spills
  - Landslides
  - Drought and excess precipitation
  - Agricultural pests and pathogens
  - Heat waves
  - Zoonotic disease
  - Volcanic events
  - Snowmelt and flooding
  - Water resource management
**SISTER: SBG Space-based Imaging Spectroscopy and Thermal pathfindER**

*SISTER is an active collaboration between Jet Propulsion Laboratory (JPL), Ames Research Center (ARC), Goddard Space Flight Center (GSFC), industry, academic institutions, and non-profit organizations*

### Primary Objectives

- Prototype architectures and workflows to generate prototype high-dimensional, high-value SBG data
  - Example data sources – AVIRIS, PRISM, HyTES, Hyperion, HISUI, PRISMA, DESIS, EMIT, ECOSTRESS
  - Implement ISOFIT atmospheric correction* and select L2B+ algorithms (*informed by the Algorithms and Applications Working Groups*)

- Distribute prototype SBG data to community, and develop community engagement strategy

- Assess and provide recommendations on cal/val network and instrumentation needs

*SISTER will not perform an atmospheric correction round robin, but will participate in the CEOS ACIX III activity underway for hyperspectral terrestrial and aquatic applications*

### Prototype SBG Data Product Timeline

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<tr>
<td>Prototype workflows &amp; system components</td>
<td>Implement select prototype L2B+ algorithms</td>
<td>Adapt workflows based on emerging SBG ATBDs</td>
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<tr>
<td>Implement ISOFIT atmospheric correction</td>
<td>Distribute L2B+ products for community evaluation / feedback</td>
<td>Refine and redistribute prototype SBG products for community evaluation / feedback</td>
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<tr>
<td>Distribute land &amp; water reflectance for community evaluation / feedback</td>
<td>Distribute prototype L2B+ products for community evaluation / feedback</td>
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Prototype SBG Algorithms & Products

*SISTER will implement select L2B+ algorithms (informed by the Algorithms and Applications Working Groups) to generate prototype SBG products for community evaluation and engagement*

<table>
<thead>
<tr>
<th>SBG Algorithm Class</th>
<th>SBG Algorithm Products (examples)</th>
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<tbody>
<tr>
<td><strong>CORE Algorithms</strong></td>
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<td>Earth Surface Temperature</td>
<td>Land Surface Temperature*, and Emissivity</td>
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<td>and Emissivity</td>
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<tr>
<td>VSWIR Reflectance</td>
<td>Land and Water Reflectances, BRDF Corrections, Albedo</td>
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<td>Cover Classifications</td>
<td>Cloud, Water, Land Cover, Plant Functional Types, etc.</td>
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<td>ET*, Evaporative stress index</td>
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<td>Proportional Cover</td>
<td>GV, NPV, Substrate, Snow/Ice, Burned Area</td>
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<td><strong>Geology/Earth Surface</strong></td>
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<td>Substrate Composition</td>
<td>Mineral type*, Fractional abundance*, Soil types and constituents</td>
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<td>Volcanic Gases and Plumes</td>
<td>SO2, Volcanic ash</td>
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<td><strong>Aquatic and Coastal Ecosystems</strong></td>
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<td>Phytoplankton functional types, <strong>Floating vegetation</strong>, Benthic cover, Wetlands</td>
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<td><strong>Snow and Ice</strong></td>
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<td>Snow albedo</td>
<td>Albedo, <strong>Grain size</strong>, SSA, Light absorbing particles, <strong>Fractional cover</strong></td>
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*Leverages ECOSTRESS and EMIT algorithms*
Example SISTER Prototype Workflow for PRISMA

White Sands
NM, USA

Redwood National Park
CA, USA

Westside National Park
Bahamas

Mojave Desert
CA, USA

Chlus et al., JPL
Other SISTER Tasks

GIS Database of Hyperspectral Sources

- GIS database contains scene boundaries for various hyperspectral airborne and spaceborne data since 2000
  - HICO recently added
  - Land & aquatic cal/val targets are being added
- Enables identification of coincident scenes
- Guides site selection for SISTER processing

SBG Coastal Mask

- This is an active Aquatic Studies Group (ASG) Special Focus Task
- Other active SBG-relevant ASG tasks include: definition of criteria/protocols for special observations; sun glint mitigation recommendations
- The deliverable will be a community-recommended SBG coastal mask for data collection at native resolution
MEET-SBG : Modeling End-to-End Traceability for SBG

Four Tasks
1. VSWIR Uncertainty Quantification
2. TIR Uncertainty Quantification
3. Synthetic SBG Production
4. Observing System Simulation Experiment
MEET-SBG Task 1: VSWIR UQ

- Hypertrace is a VSWIR uncertainty quantification workflow
- Traces uncertainty for aquatics, vegetation, snow, mineral retrievals

Sources of uncertainty in remote sensing of plant traits

- Imperfect calibration across instruments
- Imperfect sensor
- Top-of-atmosphere radiance
- Atmospheric correction

How large are the overall uncertainties in trait retrievals?

What are the largest sources of uncertainty?
MEET-SBG Task 2: TIR UQ

- The JPL Temperature Emissivity Uncertainty Simulator (TEUSim) traces LST and emissivity retrieval uncertainties for atm. conditions, sensor geometries, instruments, and algorithms.
MEET-SBG Task 3: Ames Global Hyperspectral Synthetic Dataset (AGHSD)

- 1 km spatial resolution, 224 bands (10 nm resolution), daily for 2019
- Derived from MODIS TOA reflectance (MOD02+MOD03) using a non-linear empirical model
- Intended for SBG OSSE & ground data system engineering
  - Suggests 8-day global coverage data volume of 2.1PB and 8.3PB per year at 60 and 30 m resolution, respectively (removing open ocean would result in a ~65% reduction)
- Global dataset will be released on Aug. 1 available from https://data.nas.nasa.gov/AGHSD

Wang et al., in progress

Synthetic Hyperspectral Top-of-Atmosphere Data for June 1, 2018 (L1)

Ames Global Hyperspectral Synthetic Dataset (AGHSD, pronounced like August)
- 1 km spatial resolution, 224 bands (10 nm resolution), daily for 2019
- Derived from MODIS TOA reflectance (MOD02+MOD03) using a non-linear empirical model
- Intended for SBG OSSE & ground data system engineering
  - Suggests 8-day global coverage data volume of 2.1PB and 8.3PB per year at 60 and 30 m resolution, respectively (removing open ocean would result in a ~65% reduction)
- Global dataset will be released on Aug. 1 available from https://data.nas.nasa.gov/AGHSD
MEET-SBG Task 4: OSSE

- Address how SBG architecture can improve global Earth system processes
- Adapt to aquatic processes

![Diagram showing the process flow of MEET-SBG Task 4: OSSE with nodes for Initial plant traits, Land Surface Model, Radiative Transfer Model (PRO4SAIL), L3 trait retrievals, Updated plant traits, L4 "processes", Hypertrace workflow, UQ, and Sampled surface reflectances. The flow indicates the progression from prior information stage to data assimilation stage.]
Synergies Between NASA ESO Core Missions: SBG and the AtmOS missions

• ACCP, with the AtmOS mission, aims to improve understanding of atmospheric processes relevant to climate, weather, and air-quality, as well as other applications
• A series of workshops explored areas of potential synergy between the two DOs
• We are finalizing the recommendations as a manuscript for the forthcoming SBG special issue in JGR-B

<table>
<thead>
<tr>
<th>Categories</th>
<th>Synergies identified</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enabling Science</td>
<td>4</td>
<td>Surface energy balance and broadband albedo</td>
</tr>
<tr>
<td>Observations, Assets</td>
<td>10</td>
<td>Share resources for radiometric calibration infrastructure, combined observation of aerosol/albedo properties and VSWIR</td>
</tr>
<tr>
<td>Models</td>
<td>3</td>
<td>Geophysical variables and simulators to inform and validate high resolution ESMs</td>
</tr>
<tr>
<td>Retrieval Algorithms</td>
<td>7</td>
<td>Validate atmospheric retrievals – joint algorithms, campaigns, Surface reflectance from SBG as a basemap for lidar, etc.</td>
</tr>
</tbody>
</table>
Short term priorities

1. Early planning for joint calibration and validation.
   • Exchange of calibration sources
   • Opening a dialogue with CEOS working groups to cultivate common vicarious calibration resources
   • Investigate lunar calibration options as a supplement to Earth surface sites.

2. Joint airborne campaigns (e.g. ARCSIX) with analogue instruments to demonstrate measurement methods
   • VSWIR cloud property estimates
   • Ancillary aerosol data for atmospheric correction
   • Surface albedo for radiation and energy budgets
Long term priorities

1. Common radiative transfer models for the visible shortwave infrared regime
2. Bring together designers of data products that could be useful to both observables.
   • Aerosol climatology to improve the accuracy of SBG surface reflectance retrievals.
   • Reflectance basemaps from SBG for ACCP AtmOS lidar or polarimeter retrievals.
   • SBG measurements of energy and water vapor fluxes from the surface could be invaluable for understanding PBL processes in the ACCP AtmOS mission.
3. Compatible SDS conventions to ensure interoperability
4. Global distribution of aerosol species and optical properties, Geophysical Variables and simulators to inform and validate high resolution ESMs
SBG on-orbit collaborations

- ESA LSTM TIR (2)
- NASA/ASI SBG TIR+VNIR
- CNES/ISRO TRISHNA TIR
- NASA SBG VSWIR
- ESA CHIME VSWIR (2)
- Data Harmonization
<table>
<thead>
<tr>
<th>SBG Milestones</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
<th>2030</th>
<th>2031</th>
<th>2032</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
</tr>
<tr>
<td>Surface Biology &amp; Geology</td>
<td></td>
<td>SGB-LRD Window</td>
<td>SBG-TIR (LRD Late 2026 TBC)</td>
<td>SBG-VSWIR (LRD Late 2026 TBC)</td>
<td>SBG-TIR Extended Mission</td>
<td>SBG-VSWIR Extended Mission</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Program of Record</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
SBG PARTNERSHIPS AND NASA OPEN SCIENCE LEADERSHIP

- **Enabling and enhancing: maximize science strength and cost effectiveness:** Joint mission with ASI provides science collaboration, VNIR camera, launch and spacecraft for TIR instrument.

- **Reducing revisit and observing events:** Open data sharing and product harmonization with CHIME (VSWIR), LSTM and TRISHNA (TIR) reduces intervals between observations, increases research and applications opportunities and length of data records.

- **International collaboration on calibration and validation:** Unprecedented data quality and engagement through use of terrestrial and aquatic networks for vicarious calibration and validation activities on six continents.
The Copernicus Hyperspectral Imaging Mission for the Environment (CHIME) and cooperation with NASA - SBG

• SBG Community Workshop, 15.06.2021
•
• Provide routine hyperspectral measurements in support of EU- and related policies for the management of natural resources & assets
  • Support food security, agriculture and raw materials, soil properties
  • Secondary Applications: biodiversity and ecosystem sustainability, forestry management, environmental degradation, lake/coastal ecosystems and water quality, snow grain size/albedo, snow impurities

Hyperspectral data cube (courtesy DLR)

Physiological diversity of a temperate forest
(Airborne imaging spectroscopy APEX data - Schaepman, Jehle et al. 2015)
Hyperspectral Imaging Mission (CHIME)

Key Mission requirements (MRD):
- Routine hyperspectral observations
- Sun synchronous orbit (LTDN 10:45)
- Revisit 12.5 days (for 2 satellites)
- Nadir view covering land surfaces, inland- and coastal waters
- Spectral range: 400 – 2500 nm,

- Spectral bandwidth ≤ 10nm
- SSD: 30m
- High radiometric accuracy, low spectral/spatial mis-registration
- Improved NeDL requirements to match performance of parallel missions (EnMap, PRISMA, SBG)
CHIME Space Segment – Key Features

- **Platform**
  - Coordinated P/F development with CIMR and ROSE-L missions
  - Data Processing Unit (DPU) allowing cloud detection and compression using AI

- **HyperSpectral Instrument (HSI)**
  - Pushbroom-type grating Imaging Spectrometer with high Signal-to-noise Ration (SNR) and data uniformity

- **Laser Communication Terminal (LCT)**
  - The use of a LCT (CHIME-GEO) for data transmission is being studied in phase B2
  - Decision on Embarkation by PDR

- **Industrial Consortium**
  - Prime Contractor: Thales Alenia Space France (TAS-F)
  - Instrument Prime: OHB (DE) with
    - LEONARDO (IT) for Focal Planes & E2E Calibration
    - AMOS (BE) for 3 x spectrometer, gratings and slits
  - Industrial Consortium: 44 Companies from 17 Countries
# SBG – CHIME Data Product Crosswalk

<table>
<thead>
<tr>
<th>SBG Product</th>
<th>SBG SubProduct</th>
<th>CHIME Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASE Earth Surface Temperature and Emissivity</td>
<td>[2 subproducts]</td>
<td></td>
</tr>
<tr>
<td>BASE VSWIR Reflectance</td>
<td>Land Surface Reflectance</td>
<td>Surface Reflectance</td>
</tr>
<tr>
<td></td>
<td>Albedo</td>
<td></td>
</tr>
<tr>
<td>BASE Cover Type Classification</td>
<td>Cover Types, Plant Functional types</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[4 subproducts for cloud, water, gird]</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PRODUCTS</th>
<th>Vegetation Traits</th>
<th>Nitrogen concentration (%, g/g)</th>
<th>Canopy nitrogen content (uptake, kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leaf mass per area (LMA, g/m²)</td>
<td>Specific leaf area (SLA, m²/kg)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total chlorophyll (A+B)</td>
<td>Leaf and canopy pigment content (chlorophyll)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Canopy water content</td>
<td>Canopy water content (g/cm²)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leaf dry mass</td>
<td></td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>[2 subproducts]</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Proportional Cover</td>
<td>GV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NPV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Substrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Snow/ice</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>burn area/severity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substrate composition</td>
<td>Mineral areal fractional abundance</td>
<td>Mineral identification (Kaolinite, Smectite, Jarrosite, Dolomite)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kaolin Crystallinity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hematite-goethite distribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ferric oxide contents</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil type and soil constituents</td>
<td>Soil textural and structural composition (e.g clay, silt, sand, iron oxides, gypsum and carbonate contents)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil organic carbon content</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Substrate changes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
‘Hypersense’ Campaign with AVIRIS-NG in 2021

European Space Agency

NASA

University of Zurich (UZH)

European Space Agency
AI based retrieval of CHIME Priority Products: Nitrogen, Chlorophyll and Soils

Based on Experimental AVIRIS Campaign—Grosseto, IT, 2018

Vegetation

Soils

Ground data

Chlorophyll (Cab [µg cm⁻² leaf])

Nitrogen Leaf Nitrogen Content (LNC [% mg N g⁻¹ DM])
## CHIME – SBG collaboration opportunity in a nutshell

### Programmaticas
- How to implement the collaboration
- Working Groups on Cal/Val, Product Harmonisation and Modelling/e2e Simulation
- Identify added value to Decadal Survey and EO programmes
- Harmonisation of Practices and procedures for coordinated operations and exploitation

### Science Goals
- Decadal Survey
- ESA Living Planet Strategy
- CHIME Sust. Agri./Food security

### Improved Observations
- Revisit
- Coverage
- Continuity
- Core and Priority Products
- Atmospheric Correction
- Information Content (ATBD/algorithm development)

### Implementation
- Orbit definition
- Tandem flight manoeuvres
- Schedule
- Joint Campaigns
- End-to-End Simulator/Observation Simulation System Experiments
- Common ground data system elements

### Applications and services
- Copernicus Services
- EU Directives/Policies/Green Deal
- NOAA, USGS, US EPA, USDA
Land Surface Temperature Monitoring

LSTM Mission

Copernicus 2.0 – New Monitoring Missions

**Anthropogenic CO₂ Mon. Mission**
- Causes of Climate Change

**CRISTAL – Polar Ice & Snow Topography**
- Effects of Climate Change

**CIMR – Passive Microwave Radiometer**
- Sea: Surface Temp. & Ice Concentration

**Land Surface Temperature Mission**
- Agriculture & Water Productivity

**CHIME – Hyperspectral Imaging Mission**
- Food Security, Soil, Biodiversity

**L-band SAR Mission**
- Vegetation & Ground Motion & Moisture

- Causes of Climate Change
- Effects of Climate Change
- Sea: Surface Temp. & Ice Concentration
- Agriculture & Water Productivity
- Food Security, Soil, Biodiversity
- Vegetation & Ground Motion & Moisture
LSTM Phase B2

- Contract signed with Airbus Spain (prime), 380 Meuro for 2 LSTM satellites
- LSTM phase B2 started, successful System Requirements Review (April 2021)

LSTM Mission Objective:

Provide high spatio-temporal resolution Thermal Infra-Red observations over land and coastal regions \textit{in support of agriculture management services}, and a range of additional applications

Prototype Flight Model QAR:
Oct 2028
## LSTM System Design

<table>
<thead>
<tr>
<th>Key requirement*</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometrical revisit</td>
<td>2 days/2 satellites</td>
</tr>
<tr>
<td>Local time</td>
<td>13:00 (Europe) &amp; night observations</td>
</tr>
<tr>
<td>SSD</td>
<td>50 m (37m at nadir)</td>
</tr>
<tr>
<td>Spectral Bands</td>
<td>5 TIR, 4 VNIR, 2 SWIR</td>
</tr>
<tr>
<td>Nominal swath</td>
<td>687 km, at 651 km altitude</td>
</tr>
<tr>
<td>Acquisition system</td>
<td>Whiskbroom scanner</td>
</tr>
<tr>
<td>Geo-location L1c</td>
<td>1 SSD (without GCP)</td>
</tr>
<tr>
<td>MTF</td>
<td>0.2-0.3</td>
</tr>
<tr>
<td>Data latency (L2)</td>
<td>6-12 hours</td>
</tr>
<tr>
<td>NeDT</td>
<td>&lt; 0.15 K</td>
</tr>
<tr>
<td>ARA</td>
<td>&lt; 0.5 K</td>
</tr>
</tbody>
</table>

### User requirement**

**Evapotranspiration** (goal)
- Accuracy 15% [mm/day]
- Precision 5%
- Field scale [0.5 ha]
- Daily observations

**LST observations**
- 50 meters resolution
- 1-3 days revisit
- 1-1.5 K LST accuracy

* Copernicus LSTM Phase B2/C/D/E1 System Requirements Document
**Mission Requirement Document V2
https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Candidate_missions
LSTM Acquisition Mask
NASA-ESA Collaboration Preparing LSTM

European ECOSTRESS Hub
Algorithm prototyping

NASA-ESA Airborne Campaign
NET-Sense 2019 & 2021

Barrax Test Site

LSTM & SBG Synergies

• Compatible mission objectives:
  • LSTM: Improved water productivity & agriculture management
  • SBG: Ecosystem science - stress and water use

• User requirement for ET: daily effective observation (cloud free)
  • Combined use of LSTM, SBG, TRISHNA, Landsat-9/Next & small-sats

• Possible cooperation
  • Scientific collaboration – algorithm development, campaigns, ECOSTRESS
  • Common Cal/Val approach, protocol, sites
  • Multi-mission in-flight inter-comparison
  • Setup of working groups: Data Harmonization, Simulators, Cal/Val, Synergy
  • Cooperation in user & science community engagement
TRISHNA PROJECT STATUS
Synergies with SBG

Ph. GAMET (CNES / CESBIO)
C. SALCEDO (CNES)
Th. CARLIER (CNES)
L. BUFFET (CNES)
S. MARCQ (CNES)
Ph. MAISONGRANDE (CNES)

Philippe GAMET
CNES/CESBIO
TRISHNA Project Scientist
TRISHNA Science Team secretary
Philippe.Gamet@cnes.fr
ISRO/CNES cooperation, launch end of 2024, 5-year lifetime

- Scientific & operational applications
- Focus on **ecosystem stress and water use** + **coastal & inland waters**
- Global coverage
- 4 TIR bands + 5 VNIR bands + 2 SWIR bands
- **Revisit**: 3 acquisitions at equator per 8 days period
  - 761km-8day orbit reducing hot spot constraints in intertropical zone
- ± 34° scan angle, 1030km swath
- **Nadir spatial resolution (VIS-NIR-SWIR-TIR)**:
  - 57 m for continental and coastal areas, binned at 1 km over open ocean
- Overpass time: 1 PM (LTDN)
- **NeDT 0.2K**
- Indo-French(*) Joint Science Team, synergies with ECOSTRESS, SBG, LSTM science & application teams
  - (*) with other contributors
- Free and open data policy for worldwide scientific community
ISRO / CNES cooperation status on TRISHNA  
Corinne Salcedo (CNES)

Covid-19 has slowed down the technical exchanges between CNES and ISRO. However:

- The Science Plan, the Product Definition document and preliminary ATBDs are under review
- The interfaces between the TIR instrument and platform are kept under discussions to harmonize the instrument and the platform designs: the outputs of the preliminary design phase from Airbus Defence and Space shall be discussed with ISRO
- The preliminary Payload Ground Segment documentation is initiated

**TRISHNA ongoing activities on CNES side:**

- The instrument Preliminary definition phase started in April 2020 is under completion with the current corresponding review @ AIRBUS DEFENCE AND SPACE
- The System phase B activities started in April 2020
- The Ground Segment Phase B activities started in October 2020
  → System and Ground Segment PDR to be arranged in T1 2022
Synergy SBG / TRISHNA

- TRISHNA + SBG + LSTM: improve temporal revisit for LST
- TRISHNA and LSTM: simultaneity of VNIR-SWIR data with TIR data
- SBG: spectral richness in VNIR

- Consistency in mission designs
- CAL/VAL
- Products
Monthly meetings between JPL SBG team and CNES TRISHNA Team covering the following topics:

- Joint calibration-validation opportunities and protocols, including the potential implementation of JPL sensors in France
- ATBDs
- SwathSense/HyTES airborne shared campaign in Europe (with ESA) during summer 2021

Cooperation between CNES and JPL to be officially arranged, including ISRO Approval, through an exchange of letters between CNES (ISRO) and NASA to elevate the recognition of our collaboration within the respective space agencies
Cooperation for In-Orbit Calibration sites
Sébastien Marcq (CNES)

• Development of a CNES **multi-mission** L1 calibration and L2 validation **permanent** site in the TIR
• Site location: low cloud coverage & high spatial homogeneity (& easy access)
  → La Crau

• Several meetings with JPL (+ KIT)
• Installation of the JPL radiometer is planned over the summer (thank you Simon!)
• On-going definition of the CNES permanent instrumentation
HISUI Status update:
18 months after launch

Tsuneo Matsunaga,
National institute for environmental studies, japan
EVENTS

✓ Successfully launched on Dec. 6 and installed on ISS JEM/EF on Dec. 13, 2019.

✓ More than six months were spent to solve data communication problems including repair part delivery.


✓ First onboard calibration data were acquired on Sept. 11, 2020. To be presented by Urai-san, AIST, at IGARSS 2021.

✓ The first HDD delivery from ISS will be occurred in July 2021. Data will be more than 20 TB.

✓ Negotiation with the funding agency for HISUI’s extended mission is ongoing.
HISUI has acquired 83000 scenes (≈ 18.5 Tbyte, ≈ 50M km²) since October 2020.

Received Proposals
- Blue = Domestic (19)
- Orange = Overseas (11)

AOIs in domestic and overseas proposals

HISUI Observation Priority Map
- Red = Oil/Gas
- Green = Metal
- Blue = Both
Spectral transmittance of SRM2035a wavelength calibration filter measured by HISUI on Sept. 11, 2020.
SBG Items of Interest

- **EnMAP-Box Workshop** (June 21-23 2021)
  - Registration still open!

- **AGU Call for Papers:** [The Earth in Living Color](#)
  - Open through August **2022**

- **12th EARSeL Imaging Spectroscopy Workshop** (March 23-25 2022)
  - Abstract deadline: November 17 2021

- **1st DESIS User Workshop** (29 Sep – Oct 1)
  - Abstract deadline: July 23rd

- **Ecological Society of America 2021:**
  - Organized Oral 1: *Advances in Biodiversity Science with Remote Sensing*
    Monday, August 2, 2021, 8:30 AM-9:30 AM Pacific Time

  - Special Session 9: *How NASA’s Surface Biology and Geology Mission Will Support the Next Generation of Global Ecosystem and Biodiversity Science*
    Tuesday, August 3rd, 2021, 9:30 AM – 10:30 AM Pacific Time
SBG Opportunities for Involvement

- In-person SBG community workshop in early 2022 (more details to come)
- Internship programs at JPL and other NASA centers
- SBG working groups: ongoing, regular meetings and seminars
  - Algorithms (kcawseni@jpl.nasa.gov)
  - Modeling (benjamin.poulter@nasa.gov)
  - Calibration/Validation (kturpie@umbc.edu)
  - Applications (christine.m.lee@jpl.nasa.gov)
  - SBG/AtMOS synergy activities (david.r.thompson@jpl.nasa.gov)

And, as always:

sbg@jpl.nasa.gov
Dave Schimel (dschimel@jpl.nasa.gov)
Ben Poulter (Benjamin.poulter@nasa.gov)
BACKUP
### TRISHNA Spectral bands

<table>
<thead>
<tr>
<th>Band name</th>
<th>Wavelength Center (nm)</th>
<th>FWHM (nm)</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>485</td>
<td>70</td>
<td>Detection of low clouds</td>
</tr>
<tr>
<td>Green</td>
<td>555</td>
<td>70</td>
<td>Coastal, sediments, snow</td>
</tr>
<tr>
<td>Red</td>
<td>670</td>
<td>60</td>
<td>Vegetation (LAI, fCOVER, NDVI, ...)</td>
</tr>
<tr>
<td>NIR</td>
<td>860</td>
<td>40</td>
<td>Vegetation (LAI, fCOVER, NDVI, ...)</td>
</tr>
<tr>
<td>WV</td>
<td>910</td>
<td>20-25</td>
<td>Water vapour content estimation</td>
</tr>
<tr>
<td>Cirrus</td>
<td>1380</td>
<td>30</td>
<td>Detection of thin cirrus clouds</td>
</tr>
<tr>
<td>SWIR</td>
<td>1610</td>
<td>100</td>
<td>AOD, snow/cloud discrimination, vgt stress, burnt areas</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Band name</th>
<th>Wavelength Center (µm)</th>
<th>FWHM (µm)</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIR 1</td>
<td>8.65</td>
<td>0.35</td>
<td>Temperature/emissivity separation</td>
</tr>
<tr>
<td>TIR 2</td>
<td>9.0</td>
<td>0.35</td>
<td>Temperature/emissivity separation</td>
</tr>
<tr>
<td>TIR 3</td>
<td>10.6</td>
<td>0.7</td>
<td>Split-window</td>
</tr>
<tr>
<td>TIR 4</td>
<td>11.6</td>
<td>1.0</td>
<td>Split-window</td>
</tr>
</tbody>
</table>
TRISHNA: main System Milestones (To be confirmed with ISRO)

- System Interfaces, Performances and Validation Review (SIPVR)
  → Part 1: beginning of 2022

  • Assessment of the definition of the interfaces at system level: S-Band and X-Band satellite to ground interfaces, interfaces between ground segment entities.
  • Assessment of the ATBD of the system products
  • Assessment of the definition of the algorithm processing chain of the system products
  • Preliminary assessment of the mission performance budget
  • Preliminary System Validation Plan
TRISHNA Full Resolution mask

Criteria for the construction of the full resolution mask (ongoing process):

- All continental land surfaces (including inland waters): yes
- Closed or semi-closed seas: yes
- Coastal waters up to [Distance TBD, 10 to 100km] from the shore
- Ocean waters with depth lower than [depth TBD, 100m to 250m]
- EU Islands of more than [Surface TBD, typically 100km²]
- Consistency with Sentinel-2 / SWOT coverage mask: TBD
- Antarctica coastline [Coverage TBD]
- Arctic Ocean coastline [Laptev Sea, other areas TBD]
TRISHNA geometric revisit frequency
due to the overlap between adjacent orbits

- 3 accesses in 8 days at Equator, with 3 different view angles
- Revisit frequency increases with latitude due to the overlap between adjacent orbits
- Revisit frequency is limited to 3 accesses in 8 days for polar regions (latitudes over 60 degrees)
TRISHNA geometry of the acquisitions

Typical (*) geometry of daylight accesses for TRISHNA, LANDSAT8 and LSTM
(*) Actual values and patterns depend on selected longitudes of nodes and time lag between start of cycles

Polar plots of satellite and hot-spot directions over 1 year
## Overview of TRISHNA level-2 candidate variables

Selection of relevant variables is under process

### Level 2a

**Radiative variables at surface level**

<table>
<thead>
<tr>
<th>Surface reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface reflectance normalized to nadir</td>
</tr>
<tr>
<td>Surface albedo (spectral)</td>
</tr>
<tr>
<td>Surface albedo (broadband)</td>
</tr>
<tr>
<td>Surface temperature</td>
</tr>
<tr>
<td>Surface emissivity</td>
</tr>
<tr>
<td>Surface temperature normalized to nadir</td>
</tr>
<tr>
<td>Surface thermal emissivity (broadband)</td>
</tr>
</tbody>
</table>

### Level 2b

**Biophysical variables at surface level**

<table>
<thead>
<tr>
<th>NDVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation variables for ET computation:</td>
</tr>
<tr>
<td>- Green Fraction (GF)</td>
</tr>
<tr>
<td>- Green Area Index (GAI)</td>
</tr>
<tr>
<td>fAPAR</td>
</tr>
<tr>
<td>EvapoTranspiration at time of acquisition - Near Real Time</td>
</tr>
<tr>
<td>Daily EvapoTranspiration - Near Real Time</td>
</tr>
<tr>
<td>Daily Stress Factor (SF) - Near Real Time</td>
</tr>
<tr>
<td>Intermediate ET variables associated to ET products</td>
</tr>
</tbody>
</table>

| Gross Primary Productivity (GPP) |
| Water Use Efficiency (WUE) |
| Fire products (detection & monitoring) |
| Water color biophysical variables |
| Urban LST |
| Urban Air Temperature |