The Surface Biology and Geology DO is ready to begin pre-Phase A study towards MCR

David Schimel, Jet Propulsion Laboratory, California Institute of Technology
The Surface Biology and Geology DO is defined with considerable detail in the Decadal Survey

SBG is key to understanding in five science and applications focus areas:

• Functional traits, diversity and health of terrestrial vegetation and inland and near-coastal aquatic ecosystems
• Physiology of primary producers, productivity and stress
• Effects of changing land use on surface energy, water, momentum, and carbon fluxes
• Snow and ice accumulation and melt, surface water availability and management
• Active geological surface changes, natural hazards

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) Note, this specification was updated based on recent work and community engagement to optimize for the DS-specified science and applications.
Key assumptions

- SBG will follow an implementation path to an early launch
  - Community supports Decadal Survey performance targets, no “re-litigation of the science” needed
  - No space-segment technology development for primary VSWIR and TIR instruments due to existing high TRL solutions
  - Builds on capabilities at 5 NASA centers.

- Availability of CEOS RadCalNet and other domain-specific ground calibration networks; airborne sensors for cross-calibrating the international constellation;

- Lunar model for instrument trending.
Key Science and Mission/DO Synergism
Carbon Cycle and Ecosystems, Hydrology, Weather and Climate, and Geology

• Changes to the diversity and health of terrestrial vegetation (with NISAR and Sentinel 5/FLEX/GeoCarb) and inland and near-coastal aquatic ecosystems (PACE/GLIMR)

• The diversity of life on Earth, function and functional diversity of land and phytoplankton physiology (with PACE/GLIMR and Sentinel 5/FLEX/GeoCarb)

• Changing land use and the surface energy, water, momentum, and carbon fluxes, albedo, improvements to forecast models (with A-CCP)

• Snow, albedo and evapotranspiration in the water cycle, surface water reservoir management (with MC)

• Active surface changes (eruptions, volcanic lakes, volcanic gases), science to improve forecasting (with NISAR/SDC)

• Hazard risks in rugged topography (landslides, threats to water supply), forecasting and mitigation (with SDC)
SBG at a Glance

Surface Process Foci

H-1,2 Flows of water and energy

E-1,2,3 Earth’s ecosystems

S-1,2 Geological disasters

Snow melt

Water use

Surface water

Fluxes through watersheds

Vegetation state

Fire

Sediments

Nutrients

Vegetation index

Chlorophyll Concentration (ug/L)

Vegetation Index

0.2 0.4 0.6 0.8 1.0

0.2 0.4 0.6 0.8 1.0

Surface Processes

DS Science Questions
H-1,2 Flows of water and energy

E-1,2,3 Earth’s ecosystems

S-1,2 Geological disasters

SBG at a Glance
Earth System Foci
**SBG at a Glance**

**Geophysical Observables**

- Temperature
- Albedo
- Snow melt
- Water use
- Surface water
- Plant functional traits
  - Canopy structure
  - Leaf Area Index
  - Fire severity
  - Sediment
  - Chlorophyll
  - CDOM
  - Coral cover
  - Kelp

**Greenhouse gases**

- Volcanic emissions
  - Volcanic gases
  - Lava temperatures
  - Volcanic lakes
  - Mineral composition
  - Newly exposed substrate

**Vegetation state**

- Fire

**E-1,2,3 Earth's ecosystems**

- Sediments
- Nutrients

**Measurement Needs**

- Albedo
- Light absorbing impurities
- Snow Grain size
- Land surface temperature
- Eavapotranspiration
- Water quality

**A-CCP MC**

**H-1,2 Flows of water and energy**

**NISAR SDC**

**PACE GLIMR**

**S-1,2 Geological disasters**

**Synergy**

**DS Science Questions**

**SBG at a Glance**

**Geophysical Observables**

- Temperature
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- Nutrients

**Measurement Needs**

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SBG at a Glance

Societal Benefits

Air Quality
Public Health

Volcanic emissions

Greenhouse gases

Lava temperatures
Volcanic lakes
Mineral composition
Newly exposed substrate

Vegetation state

Fire

Hazard Monitoring
and Response

Volcanic gases

Sediments
Nutrients

Water Resources
Agriculture
Drought Monitoring

H-1,2 Flows of water and energy

Temperature
Albedo

Snow Grain size
Land surface
temperature
Eavapotranspiration
Water quality

Water Quality
Coastal Resource
Management

S-1,2 Geological disasters

SS Science Questions

Surface Processes

Measurement Needs

Fire Risk and Response
Conservation and
Ecoforecasting
Land Management

Water Quality
Coastal Resource
Management

Surface water

Water Resources
Agriculture
Drought Monitoring

E-1,2,3 Earth’s ecosystems

Sediments
Nutrients

Vegetation state

Fire

Eavapotranspiration

Water quality

Ecosystems

Geological disasters

Albedo
Light absorbing
impurities

Snow melt
Water use
Surface water
Sediments
Nutrients
Vegetation state
Fire

Measurement Needs
Albedo
Light absorbing
impurities
Snow Grain size
Land surface
temperature
Eavapotranspiration
Water quality

Temperature
Albedo

Water Resources
Agriculture
Drought Monitoring

H-1,2 Flows of water and energy
## Key applications: users, importance and economic valuation

<table>
<thead>
<tr>
<th>Primary Application</th>
<th>Example Potential Users of SBG Data/Products</th>
<th>Key Use Cases of SBG Data/Products</th>
</tr>
</thead>
</table>
| Fire               | • State and local fire authorities/responders  
                           • Commercial utility companies  
                           • Fire risk map/model developers/providers  
                           • Prescribed burn companies and regulators  
                           • Insurance companies  | • Pre-/post-fire fuel mapping of vegetation type, live/dead, moisture for risk severity  
                           • Fire risk model via better fuel/moisture data  
                           • Utility vegetation management, risk mitigation, and operations/planning changes |
| Agriculture        | • Ag input and equipment companies  
                           • Crop consultants, large-farm managers, commodities traders, and insurers  
                           • Ecosystem market communities  
                           • Ag/water resource/policy managers  | • Ag and water resource, drought monitoring  
                           • Crop type/composition/health monitoring (for ag policies, supply chain, input optimization)  
                           • Crop residue/monitoring (e.g., for credits, monitoring, reporting, and verification [MRV])  
                           • National food security/yield forecasting |
| Algal Blooms       | • Local health/environ./water agencies  
                           • Aquaculture (fish/shellfish) companies  
                           • Drinking water utilities/engineering firms  
                           • Forestry/lake management companies/orgs  | • Regional-scale water body quality monitoring  
                           • Early warning of harmful algal blooms (HABs)  
                           • Shellfish site water chemistry for growth/health  
                           • Watershed/source pollution/nutrient monitors |
| Mining             | • “Spectral geologists” and exploration consultants for large mining companies  
                           • Regulatory/compliance organizations  
                           • VASPs serving the energy and mineral resources sectors  | • Greenfield/brownfield large-area explorations  
                           • Geologic process, mineral/vegetation surveys  
                           • Mine opening/operations baseline/monitoring  
                           • Environmental/health/regulatory monitoring on-site and in surrounding environs |

**Draft Community Assessment Completed**


Surface Biology and Geology Designated Observable
Measurement targets

Nearly all of the Most/Very Important objectives from SBG’s five science focus areas and multiple applications area needs can be met with:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Spatial Resolution</th>
<th>Revisit (Swath)</th>
<th>Spectral range and resolution</th>
<th>Radiometric performance and SnR</th>
</tr>
</thead>
<tbody>
<tr>
<td>VSWIR</td>
<td>30 m for vegetation, snow, agriculture, minerals</td>
<td>16 days to resolve natural and crop timing, snowmelt, aquatic communities and health</td>
<td>400-2500 nm with 10 nm bands to retrieve vegetation, aquatic composition, minerals, crop type, snow grain size and albedo</td>
<td>5% radiometric uncertainty, SnR 400 (VNIR), 250 (SWIR) @ 25% Reflectance</td>
</tr>
<tr>
<td>TIR</td>
<td>60 m to resolve land cover, water bodies</td>
<td>3 days to resolve land surface temperature, evapotranspiration</td>
<td>4 TIR channels to resolve T vs emissivity, 1 or more mid-wave for high temperature features</td>
<td>0.2 NEdT or 1K for LST</td>
</tr>
<tr>
<td>TIR + VNIR</td>
<td>60 m for ET applications</td>
<td>simultaneous to resolve crop ET, uncertainty and coverage decrease with temporal separation</td>
<td>TIR as above, two VNIR channels for vegetation index normalization</td>
<td>As above for TIR, not demanding for VNIR (commodity sensor)</td>
</tr>
</tbody>
</table>
## Key technologies: VSWIR

<table>
<thead>
<tr>
<th><strong>Technology</strong></th>
<th><strong>TRL</strong></th>
<th><strong>Heritage (Justification)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Focal Plane Arrays:</strong> Two Teledyne CHROMA-D: 3072x512 digital focal planes deliver wide swath imagery with 30m spatial resolution</td>
<td>5/6</td>
<td>Recent testing; flight qualification of similar GeoSnap detector</td>
</tr>
<tr>
<td><strong>Gratings:</strong> Large, concave, low scatter, full spectral range gratings that support optically fast, high signal-to-noise VSWIR spectrometers</td>
<td>≥ 6</td>
<td>EMIT Earth Venture, MISE (Europa Clipper), and airborne sensors</td>
</tr>
<tr>
<td><strong>High uniformity optical designs:</strong> Ultra uniform optical slit to support SBG VSWIR requirements</td>
<td>≥ 6</td>
<td>EMIT, MISE, and airborne sensors</td>
</tr>
<tr>
<td>Precision ultra-black light trap for stray light control.</td>
<td>≥ 6</td>
<td>EMIT, MISE and other sensors</td>
</tr>
<tr>
<td><strong>Calibration/Validation:</strong> Technologies for instrument, on-orbit, and vicarious calibration, trades related to spectral, radiometric, spatial, uniformity performance.</td>
<td>≥ 6</td>
<td>Solar diffuser, vicarious RadCalNet, airborne, etc.</td>
</tr>
</tbody>
</table>
### Key technologies: TIR

<table>
<thead>
<tr>
<th>Technology</th>
<th>TRL</th>
<th>Heritage (Justification)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Focal Plane Array (FPA) and readout integrated circuit (ROIC):</strong> Mercury Cadmium Telluride (MCT)</td>
<td>5/6</td>
<td>ECOSTRESS (same form and fit, 2x function)</td>
</tr>
<tr>
<td><strong>High speed application specific integrated circuit (ASIC) readout electronics</strong></td>
<td>5/6</td>
<td>Landsat/Sidecar (2X the maximum speed of Sidecar)</td>
</tr>
<tr>
<td><strong>Low power cryocooler and electronics</strong></td>
<td>9</td>
<td>ECOSTRESS (same focal plane temperature)</td>
</tr>
<tr>
<td><strong>High fidelity focal plane spectral filtering</strong></td>
<td>5/6</td>
<td>ECOSTRESS (same fit and function but with 2 more filters)</td>
</tr>
<tr>
<td><strong>Lightweight, high emissivity blackbodies</strong></td>
<td>9</td>
<td>ECOSTRESS (same form, fit and function)</td>
</tr>
</tbody>
</table>
**Key technologies: Data Science**

**Collaborative algorithm development and test environment**
- All relevant data accessible in one place (data integration).
- Data preprocessed and harmonized for common access.
- Ability to develop and test ~200 candidate Level-2+ algorithms at scale, and make comparative trades.
- Open science: share and reuse algorithms

**Observing system data production service**
- On demand and configurable data processing.
- Tight integration with the archive and partner decision support systems.
- Quantify uncertainty in data products.
- Scalable cloud-based infrastructure.
- Open science (transparent algorithms and reproducible data).
- Low latency production option.

**Data analytics**
- Tools to calibrate and validate the science data products.
- Analysis tools next to the data.
- Machine learning for data understanding and interpretation.
- Fast algorithms for global fields.
- Multidimensional data visualization for high dimensional data.

Surface Biology and Geology Designated Observable
### SBG Architecture Approach

#### 1 - VSWIR
- Wide swath hyperspectral instrument
- Observation swath of 185 km
- 6000 cross-track samples
- VSWIR 632 km Sun-Sync Orbit, 10:45 local time

#### 2 - TIR
- Wide swath thermal instrument
- Observation swath of 935 km
- TIR 665 km Sun-Sync Orbit, 13:30 local time

#### 3 - VSWIR Smallsat Demo
- Narrow swath tech demo/pathfinder
- Observation swath of <20 km
- Fly leading or trailing VSWIR

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### Surface Biology and Geology Designated Observable

- **NASA TIR Payload**
  - RFI did not indicate industry interest/capability
- **ASI VNIR Payload**
  - Fulfills threshold capability for TIR/IS coincidence
- **Italian Industry Spacecraft**
- **Foreign Launch - Vega**
- **ASI downlink and data distribution**

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### NASA TIR Payload
- RFI indicates interest/capability. Make/Buy/Hybrid prior to MCR
- Industry Spacecraft
  - consistent with existing capabilities and heritage configurations
- Domestic Launch
- Commercial downlink and data distribution
  - Large SBG data volumes can leverage commercial solutions for cloud based data storage and computing

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### Industry Payload
- **Industry Spacecraft**
  - SBG Request for Information focused on small scale, innovative VSWIR solutions
- Ride-along VSWIR Domestic Launch
  - Compatible with Venture class LVs or as secondary on SBG
- Commercial downlink and data distribution
Data Communications

- **Petabyte class mission**
  - 5 Petabytes of uncompressed L1 data over 3-year primary mission lifetime

- **Direct broadcasting**
  - Near instantaneous downlink after data collection for regional, real time applications

- **Ground architectures**
  - GDS facilities for concurrent big-data DO missions.
  - Networks for international data sharing and direct into the cloud
  - Cyber security

- **On-board processing**
  - Downlink data prioritization
  - Data reduction including onboard cloud screening and 4x lossless compression
  - Event detection

Surface Biology and Geology Designated Observable
Key partnerships and NASA leadership in open data

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

- **Enhancing: improve science and applications value:** Open data harmonization with CHIME (VSWIR), LSTM and TRISHNA (TIR) reduces revisit, improves latency, and increases science and applications opportunities.

- **Data quality: unprecedented data quality and access** through use of terrestrial and aquatic networks for vicarious calibration and validation activities on six continents.
What did we learn

• A large Science and Applications community is ready and eager to deploy these new technologies
  • 300+ attend webinars, 1700+ registered on SBG email list
  • Strong desire and potential for MSI/HBCU/Tribal participation in science and applications
  • Private sector interest in SBG data, particularly in developing new, value-added products for their customers
  • Leadership from five NASA centers (JPL, GSFC, ARC, LaRC, and MSFC)

• The recommended approach achieves a threshold level of performance against science and application needs
  • Spectral performance needs are met, revisit partially met, could be fully met with successful international collaboration
  • Collaborating with international missions can reduce revisit to optimal needs for science and critical applications, e.g., water quality and wildfire
What did we learn (cont)

• Meeting Decadal Survey performance target for both wavelength ranges led to a constrained trade space within resources available.

• No space-segment technology development needed for primary VSWIR and TIR instruments due to existing high TRL solutions.

• Algorithms and workflows for spectroscopy are not mature, algorithmic complexity and data volume, combined lead to low TRL for GDS/SDS—investment is required (eg, MEET-SBG, SISTER pathfinders).

• Technology for constellations of high-performance low-cost instruments to enable continuity remains low TRL, investment is required (tech demo).