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NASA'S SURFACE BIOLOGY AND GEOLOGY CONCEPT STUDY: STATUS AND NEXT STEPS

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ABSTRACT

The National Academies Decadal Survey for Earth Science recommended that NASA pursue global imaging spectroscopy and thermal infrared measurements in the coming decade [1]. Both measurements would offer repeat coverage on approximately five-day to biweekly cadence, with comprehensive coverage of the globe's coastal and terrestrial area. This would be an unprecedented volume of data with the potential to transform remote sensing practice. To address this recommendation, NASA has sponsored a concept study by NASA research centers and associated university partners (https://sbg.jpl.nasa.gov). This study is determining a family of architecture options — including launch vehicle, spacecraft, instrument, and suborbital components — that could address the Decadal Survey objectives. The architecture study is driven by science needs and builds on input of the research community. As of this writing, the study is entering a phase in which a large field of system possibilities is pared down to a representative handful for an ultimate decision by NASA.

Index Terms— Imaging Spectroscopy, Thermal Infrared, Evapotranspiration, Ecosystem Traits, Land Cover, Hydrology, Natural Hazards, Surface Albedo, Surface Temperature, Surface Biology and Geology, Atmospheric Correction

1. INTRODUCTION

The National Academies 2017 Decadal Survey for Earth Science recommended that the National Aeronautics and Space Administration (NASA) pursue a global imaging spectroscopy and thermal infrared investigation in the coming decade [1]. The Surface Biology and Geology (SBG) investigation would address global science themes, including: flows of energy, carbon, water, and nutrients sustaining terrestrial and marine ecosystems; the variability of the land surface and the fluxes of water and energy; inventory of the world's volcanoes, and the composition and temperature of volcanic products immediately following eruptions; other natural hazards including wildfires; snow accumulation and melt; water balance from the headwaters to the continent; land and water use effects on evapotranspiration; functional traits and diversity of terrestrial and aquatic ecosystems and vegetation; and more.

The Surface Biology and Geology investigation would include global imaging spectroscopy measurements in the visible to shortwave range, coupled with thermal infrared measurements from 8-12 μm and a potential 3-5μm channel. Ideally TIR and VSWIR measurements would offer repeat coverage on approximately 5-day and biweekly cadence, respectively, with comprehensive and global coverage of coastal and

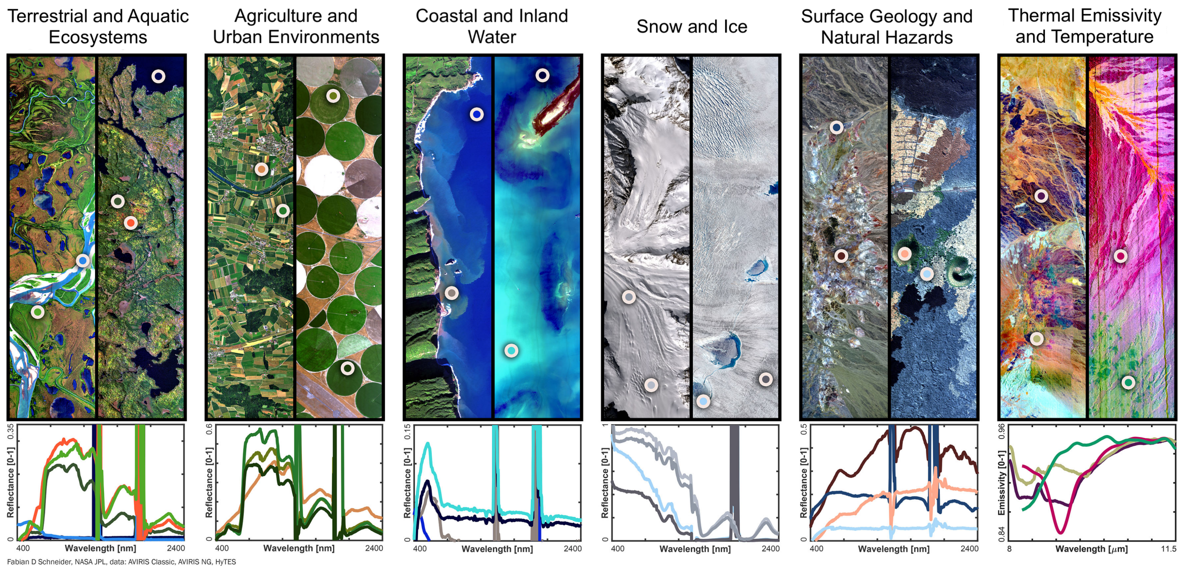

Fig. 1. The SBG investigation's key focus areas include diverse spectroscopic content in the Visible to Shortwave and Thermal Infrared Ranges

terrestrial areas. This would be an unprecedented volume of data that would transform remote sensing practice. To address this recommendation, NASA has sponsored a concept study by NASA research centers and associated university partners [2]. This study is determining a family of architecture options — including launch vehicle, spacecraft, instrument, and sub-orbital components — that could satisfy the Decadal Survey's recommendations. As of this writing, the study is beginning to pare down a large field of system possibilities to a representative handful for an ultimate decision by NASA. This document briefly summarizes SBG science objectives and the approach for assessing candidate architectures.

2. SCIENCE TRACEABILITY

Figure 1 shows the wide range of different domains and spectral content in the SBG charter. They include terrestrial and coastal aquatic ecosystems, agricultural and urban areas, snow and ice areas including snowpack and glaciers relevant to hydrology studies, and land cover "writ large" including volcanoes and other natural hazards, and geologic surfaces to assess rock and soil mineralogy. These domains and themes represented in the Decadal Survey have been associated with specific geophysical measurements in a document known as the science traceability matrix (available to the public at https://sbg.jpl.nasa.gov/satm). This decomposes each theme into ancillary and primary measurements, which in turn have been associated to a core family of products by an "algorithms" working group. Table 1 shows the core list of geophysical maps needed to achieve SBG objectives. The top section shows "baseline" products that will be critical across many different themes. These include surface and

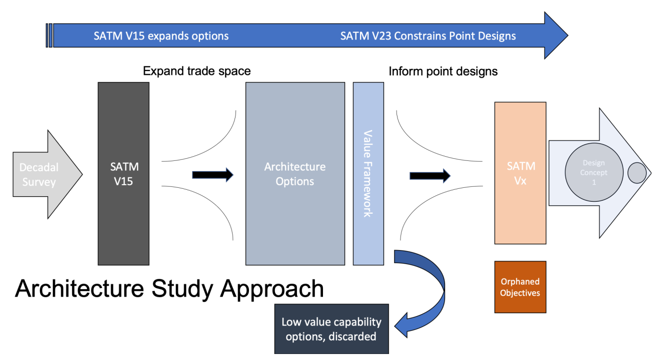

Fig. 2. The SBG study process. Image modified from D. Schimel et al.

atmosphere estimation (i.e. atmospheric correction), temperature emissivity separation, and other inversions turning measurements of radiance-at-sensor into basic spectral measurements of the Earth's surface properties. The bottom table shows downstream products that transform these reflectance, albedo, temperature, emissivity, and cover measurements into maps of geophysical parameters that address the Decadal Survey science goals.

3. ARCHITECTURE PERFORMANCE AND STUDY

The concept study is determining the space observation architectures that could address these objectives. Based on the Decadal Survey, addressing priority topics will likely need:

- **Global coverage**, to address the explicit global scope of the science, measure the Earth system and not just

Baseline Product	Subproducts
Land Surface Temp. / Emissivity	Thermal features (lava flow; fire), Snow/ice temperature
VSWIR Surface Reflectance	Continuous Reflectance, Water Leaving Reflectance, BRDF Corrected
Land Cover	Trigger Specific Products, Cover Type Classification, Plant Functional Type, Cloud

Category	Product	Subproducts
Vegetation	Vegetation Traits	Nitrogen, pigments, leaf mass / area, water content
Vegetation	Evapotranspiration	Evaporative stress index
Land Cover	Proportional Cover	Photosynthetic/nonphotosynthetic veg., substrate, snow/ice
Geology	Substrate composition	Mineral area fractional abundance, soil type
Volcanic	Volcanic Gases and Plumes	SO2 concentration, volcanic ash, SO4 aerosols
Aquatic	Aquatic Biogeochemistry	Pigments, particulates, chromophoric organic matter, sediments
Aquatic	Aquatic Classification	Phytoplankton functional type, benthic cover, coral
Volcanic	High temperature features	Volcanic temperature anomalies, wildfire
Snow	Snow albedo	Snow albedo, Snow grain size

Table 1. Key algorithm families needed to achieve SBG objectives. The top table shows baseline products that will be critical for later analyses. The bottom table shows downstream products that turn these reflectance, temperature, emissivity, and cover measurements into derived products to address decadal science goals. Image modified from [3].

local processes. This means that the portion of terrestrial land and the coastal zone that can drive the Earth system through the carbon and water cycles should be observed. Coverage of 85 degrees N-S.

- **High spatial resolution** to identify regional scales as called for in other objectives. Pixels between 20 and 60 m and 60-100 m for TIR.
- **Sufficient duration** to observe change, alternately a strategy for continuity of identified key measurements so that SBG is synergistic with US and international programs. 3-7 years with possible continuity.
- **Spectroscopic and thermal measurements** that can observe “diversity” in ecosystem function and not merely bulk processes amenable to multispectral or Solar-Induced Fluorescence (SIF) observations. Spectral coverage of 380-2500 nm (VSWIR) with resolution of 5-20 nm, or three or more bands from 8-12 μm (TIR) possibly augmented by one or more 3-5 μm channels.
- **Temporal resolution** to quantify the frequency of Earth System events assigned to SBG as well as to observe rapid or transient changes. Revisit of the global area covered (e.g. between 85 N-S) between 1 and 16 days (may vary for VSWIR and TIR). This should be accompanied by latency low enough to address science objectives and at least 25% of identified applications.

The concept study may consider components that address subsets of these needs, but they must be combined in systems that address all items. The study has also defined a taxonomy of capability categories derived from the decadal survey representing general classes of instrument and spacecraft possibilities. These appear as letter-coded categories in the science traceability matrix, and determine which instrument possibilities would satisfy each of the quantitative measurement needs. More detailed performance study is ongoing under the auspices of a dedicated modeling group.

The study is using these detailed instrument and retrieval models, together with the science traceability matrix, to determine science value for each of the architecture possibilities. Figure 2 shows the general process. Having generated over 60 possible launch vehicle, spacecraft, and instrument combinations (including constellations), the study is downselecting to a preferred group of 20-30 candidates. This group will be further filtered into a group of approximately three for consideration by NASA. SBG study products, including the SATM, relied heavily on engagement with and input from the science and applications community. For more information on future opportunities to engage, we encourage interested parties to visit the study website and join the SBG effort through participation in one of the four SBG working groups [2].

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