An invitation to use the EVDT systems engineering framework to apply satellite Earth observation for the sustainable development goals

Danielle Wood
Director of the Space Enabled Research Group
Associate Professor, Massachusetts Institute of Technology
Challenges and progress in applying space technology in support of the sustainable development goals

Danielle Wood *, Minoo Rathnasabapathy, Keith Javier Stober, Pranav Menon

Space Enabled Research Group, Massachusetts Institute of Technology (MIT) Media Lab, 75 Amherst Street, Cambridge, MA, 02142, USA

Abstract

The global community, with coordination from the United Nations, is energized to pursue the Sustainable Development Goals (SDGs), a list of 17 important aspirations that summarize the key challenges of our era. The SDGs apply to every nation and represent an international effort to eliminate extreme poverty, ensure access to safe drinking water, strengthen food security, and produce clean and reliable energy, among other pursuits. Space technology is already being used around the world to advance progress toward the SDGs and monitor their related indicators. This paper explores how six technologies related to space—satellite Earth observation, satellite communication, satellite navigation and positioning, human spaceflight and microgravity research, space technology transfer, and basic scientific research—are being used to realize the vision that the SDGs represent.
Technologies from Space can Enable Sustainable Development On Earth

- Satellite Earth Observation
- Satellite Positioning & Navigation
- Human Space Flight & Microgravity Research
- Satellite Communication
- Space Technology Transfer
- Research Infrastructure
1. Earth Observation (EO) System Design and Implementation
2. EO System Operation, Data Retrieval, Calibration & Validation
3. EO Data Correction and Processing
4. Earth Science Modeling and Assimilation of Earth Observations
5. EO Data Discovery & Visualization: Providing interface to find and explore data
6. EO Data Transformation: Creating data interface based on user needs
7. Knowledge Integration: Combining physical, social, economic and other data
8. Decision Support: Providing recommendations for action

We propose a Systems Engineering approach that improves the benefits of applying satellite Earth Observation to the SDGs.

The approach is called EVDT: Environment-Vulnerability-Decision-Technology.
Environmental parameters → Environmental model → Human decision making model → Social parameters (e.g., availability of fishers to harvest water hyacinth)

Traditional Earth Science Information Applications
Environmental parameters

Environmental model

Socio-economic parameters for human resilience (i.e., income, housing type, transportation infrastructure, income opportunities)

Human vulnerability and societal impact model

Social parameters (i.e., availability of fishers to harvest water hyacinth)

Human decision making model

Impacts of human actions

Traditional Earth Science Information Applications
Environmental parameters → Environmental model → Human vulnerability and societal impact model → Impacts of human actions → Technology design model → EVDT Modeling Framework → Design for a sensor system on satellites, aerial platforms and in-situ → Socio-economic parameters for human resilience (ie income, housing type, transportation infrastructure, income opportunities) → Human decision making model → Social parameters (ie, availability of fishers to harvest water hyacinth) → Information needs for human decision makers.
Environment-Vulnerability-Decision-Technology Framework

Follow this link in the QR code to learn more about the EVDT Initiative

One of the six research methods used by the Space Enabled research group is creating models of complex systems by drawing on techniques from systems engineering, social science, and earth science. One of the key ways we do this is through the Environment-Vulnerability-Decision-Technology (EVDT) Framework, a process for developing multidisciplinary, interactive decision support systems (DSS) for various applications.
The EVDT Community Meetings are hosted freely online and all are welcome to join. We shared examples of projects that apply satellite data for the SDGs.
Dust-soiling effects on decentralized solar in West Africa

Stewart Issacs a, Olga Kalashnikova b, Michael J. Garan b, Aaron van Donkelaar c, Melanie S. Hammer c, Huiluo Lee c, Danielle Wood d

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1. Introduction

Remote observation systems, both space-based and aerial, have seen significant increases in both number and quality over the recent decades. Data from these systems is also increasingly available, both as existing systems become free to access and in commercial entities with their own platforms. This explosion in data, coupled with advances in machine vision, has enabled new, more detailed applications of remote sensing data, including those beyond the traditional military.
Supporting Drought Management in Angola using Integrated Modeling with the Environment-Vulnerability-Decision Making-Technology (EVDT) Framework

Presenter: Danielle Wood, PhD
Director, Space Enabled Research Group, MIT Media Lab
This project is supported by NASA Earth Action under Award Number 80NSSC22K1136
Precipitation, Soil Moisture, Streamflow, Sea Surface Temperature, Surface Water Seasonality

Population Density, Landcover, Infrastructure Maps, School Locations, Demographics

Policy options: Short term Water Deliveries & Borehole Improvements, Long Term Infrastructure Improvements

Environmental model:

Assessment & Forecast of Meteorological, Agricultural and Hydrological Drought

Map of human vulnerability to drought impacts based on demographics

Socioeconomic Vulnerability:

Impacts of human actions

Design for information system using data from satellites, ground sensors and models

Decision-making model:

Map of prioritized locations for emergency water deliveries, borehole improvements & water management infrastructure

Environment-Vulnerability-Decision-Technology Model Customized to Drought Application in Southern Angola

Technology Design model
Southern Angola faces recurring cycles of drought and flooding that causes insecurity for local communities.
NASA has a satellite called SMAP that has a sensor that can measure the microwaves that reflect from the earth. This allows the sensor to measure water in the soil.
Sistema de Apoio à Decisão sobre Seca em Angola
Monthly Time Series of Drought in Angola

Using the NASA SMAP satellite we map changing drought level indicators in Angola at a monthly time scale during 2015 – 2023. The images show filtered soil moisture data with 8 day averages which are used to estimate the Drought Level. The dates show the middle day in the 8 day period.
Drought Patterns in Angola

This video shows the changing drought level indicators in Angola from 2015 – 2023. The images show filtered soil moisture data with 8 day averages which are used to estimate the Drought Level. The dates show the middle day in the 8 day period.
Socioeconomic Vulnerability Model (EVDT)

- IPCC recommends the following components of vulnerability: Exposure, sensitivity, adaptive capacity

- **Goal**: Develop a Socioeconomic Vulnerability Index (SVI) based on variables relevant to physical, economic, social, demographic, health, and agricultural context surrounding drought decision support

- The project is coordinating with partners in Angola to obtain data from government agencies and NGOs

- Other data sources: Demographic and Health Surveys (DHS), global gridded datasets, Global Land Analysis & Discovery (GLAD), Landsat-Derived Global Rainfed and Irrigated-Cropland Product (LGRIP)
Proposed Socioeconomic Vulnerability Indicators

Social
- Rate of Literacy
- Educational Attainment
- Population Density
  - Population <5 years
  - Population >60 years
- Dependency Ratio

Physical
- Sanitation Facility
- Phone and Internet Access
- Distance to roads
- Drinking Water Source

Health
- HIV Positive Rate
- Malaria Incident Rate

Economic
- GDP Per Capita
- Poverty Rate

Agricultural
- Cropland
- Irrigated Areas
- Livestock Ownership

SVI


Socioeconomic Vulnerability Composite Index Calculation Methodology

**Step 1:** Normalize indicator \( j \) for each municipality \( i \)

\[
\hat{x}_{j,i} = \frac{x_{j,i} - x_{j,\text{min}}}{x_{j,\text{max}} - x_{j,\text{min}}}
\]

**Step 2:** Calculate index for each component \( c \) for each municipality \( i \)

\[
X_{c,i} = \frac{\sum_{j=1}^{n^-} 1 - \hat{x}_{j,i} + \sum_{j=1}^{n^+} \hat{x}_{j,i}}{n^- + n^+}
\]

**Step 3:** Calculate weighted SVI for each municipality \( i \)

\[
SVI_i = \frac{\sum_{c=1}^{6} W_c X_{c,i}}{\sum_{c=1}^{6} W_c}
\]

**Options for determining weights:**

1. Equal weights (as a default)
2. Determine weights through expert elicitation
3. User-defined
The project will build a website to map the data about drought and about the impact on people in southern Angola.
Implementing the Yurok Natural Resources Portal as a decision support system to inform tribal resources management

Professor Danielle Wood1, Priscilla Baltezar2, Dr. Temilola Fatoyinbo3, Dr. David Lagomasino4, Seamus Lombardo5, Tim Hayden5, Chigo Ibe6

Space Enabled Research Group at MIT Media Lab1; NASA Goddard Space Flight Center2, East Carolina University3; Yurok Tribe4; Blue Raster LLC5

Project Methodology

The project applies the Systems Architecture and EVOLT Frameworks to guide the approach for designing the portal. Systems Architecture is a structured method from Systems Engineering for data collection and analysis to describe and evaluate a system. The EVOLT Integrated Modeling Framework tracks the technical inputs, outputs and workflows that allow the team to produce maps of finding.

Field Work: Dr. Seamus Lombardo performed field research with the Yurok Natural Resources Division and learned about their methods for ground-based forest assessment.

The Yurok Natural Resources Portal includes the Klamath River that feeds into the Pacific Ocean (left and middle). The Yurok Tribe has started the Center for Aviation Company to perform aerial remote sensing services (right).

View the poster for this project by following the QR Code.
Integrated Insights: Yurok Tribe EVDT

Environment: Tree cover and species analyses, modeling of carbon stocks and forest structure

Vulnerability: Visualizations of socioeconomic data and environmental analyses

Decision-making: Balancing revenue, resilience, and cultural values in forest management practices

Technology: Development of Yurok Natural Resources Portal DSS

Policy actions related to forest management

Decision support for improved forest management and fire response

Additional data and insights for forest management and fire response
Integrated Insights: Carbon Project Management

- Verify carbon project canopy retention goals
- Identify potential areas of forest degradation to target staff resources

Evidence of canopy retention goals

Decreasing vegetation indices for investigation

Slide credit: Lombardo
Designing a Decision Support Tool to support Integrated Water Resource Management and Biodiversity in Lake Nokoue, Benin

US Co-Investigators: Space Enabled Research Group @ MIT Media Lab, NASA Goddard Space Flight Center, Blue Raster, East Carolina University

Benin Co-Investigators: Green Keeper Africa

Additional Scientific Input: National Institute of Water & CENATEL, Benin
Water hyacinth extent and dynamics, lake temperature, lake salinity, lake dissolved oxygen, extent of human-made fishing ponds (acadja)

Assessment of water hyacinth activity and change; assessment of biomass impacts of hyacinth and acadja

Population Density, Landcover, Infrastructure Maps, Demographics, Household wealth, Fishing statistics

Estimate of ecosystem benefits and costs from acadja and water hyacinth

Business Strategy Options: Water Hyacinth collection locations, collection contract terms, water hyacinth collection schedule

**Environmental model:**

**Socioeconomic Vulnerability:**

**Decision-making model:**

Impacts of human actions

Design for information system using data from satellites, ground sensors and models

Actions taken by Green Keeper Africa firm to manage water hyacinth and support water resource management; Information needs

Environment-Vulnerability-Decision-Technology Model Customized to Invasive Plant Management in Coastal Cotonou, Benin
Ecotechnology firm Green Keeper Africa is a co-Investigator focused on invasive species management in Benin (SDG 15.8). The company works with local communities to harvest water hyacinth and commercialize it.
Lake Nokoué
Water Hyacinth Extent Sentinel-2
December 2019

Water Hyacinth
- NDVI > 0.35

Slide credit: Bailezar
Water Hyacinth infestation is a concern in many African countries such as Kenya, South Africa, Ghana and Angola (Credit: Baltezar).
Analysis of deforestation and land use change to support SDG Monitoring in Ghana

US Co-Investigators: Space Enabled Research Group @ MIT Media Lab, NASA Goddard Space Flight Center, East Carolina University

West African Co-Investigators: Ghana Statistical Service, Ghana Space Science and Technology Institute
Impact Assessment for Applying Satellite Earth Observation Data to SDG15 Monitoring in Ghana

Professor Danielle Wood⁴, Priscilla Balteza³, Dr. TemiIola Fatoyinbo², Dr. David Lagomasino³, Charles Kofi Som⁴, Kofi Asare⁴

Space Enabled Research Group at MIT Media Lab²; NASA Goddard Space Flight Center³; East Carolina University⁴; Ghana Statistical Service⁴; Ghana Space Science and Technology Institute⁵

Project Background

This effort assesses the impact of a project funded by the NASA Ecological Conservation Program between 2019 and 2023. The project was created in response to a proposal by the Ghana Statistical Service and the Ghana Space Science and Technology Institute. The government of Ghana prioritized creating a science-based approach for mapping mining and monitoring mental for Sustainable Development Goal 15 (SDG15) using satellite Earth Observations. The Pi Web formed U.S. team with partners from the Massachusetts Institute of Technology, Goddard Space Flight Center and East Carolina University. The team completed the tasks of compiling information due to mining in southeast Ghana between 2007 and 2011, creating national landcover maps for 2015 and 2020, and creating an application to estimate three SDG15 indicators based on the Land-Level Land Cover maps.

Project Objectives

The objective of the current impact assessment is to learn the benefit for the Government of Ghana. The mining mapping outputs allow the Ghana Space Science and Technology Institute (GSSI) to provide data that informs actions taken by the national legislative body and the Environmental Protection Agency to manage mining. The SDG indicator calculations allow the GSSI to provide a technical input to the SDG data compilation for Goal 15.

The project creates an ESRI Desktop application for the Ghana Statistical Service that calculates estimates of the following SDG indicators using an input of any Land Use/Land Cover Map:

- **SDG 15.1.1:** Forest area as a proportion of total land area
- **SDG 15.1.2:** Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type
- **SDG 15.4.1:** Coverage by protected areas of important sites for mountain biodiversity

The US team as presented our remote sensing methods and exchanged approaches with administrative and technical experts in Ghana to improve the validity of the findings.

The team also includes a national land cover change assessment comparing 2015 and 2020 for multiple land use classes (left). These results were also released using a Google Earth Engine Application (right).

Designing applications to foster the health of terrestrial and wetland ecosystems in the coastal zone of West Africa (GSS/GEO User Guide 2023)

Project Methodology

The project applies the Systems Architecture and EVIT Frameworks to guide the approach for assessment. System Architecture is a structured method for Systems Engineering to select a set of robust indicators to assess mining impacts. The System Architecture is used to develop a framework for the project. The EVIT (Ecosystem Viability Indicators) Frameworks tracks the technical outputs, inputs, and events that allow the team to estimate impacts of mining and the SDG15 indicators. Using EVIT the team assesses the evidence related to environmental change, socioeconomic variables, policy decisions, and technology advancements.

View the poster for this project by following the QR Code.
The large footprint of small-scale artisanal gold mining in Ghana


A Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD, United States
B Department of Coastal Studies, East Carolina University, Wachase, NC, United States
C Biospheric Sciences Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD, United States
D Ghana Space Science and Technology Institute, Accra, Ghana
E Ghana Statistical Service, Accra, Ghana
F Space Enabled Research Group, Massachusetts Institute of Technology, Cambridge, MA, United States

HIGHLIGHTS

- Land conversion in due to artisanal gold mining is that of urban expansion.
- New mining extent (2005 and 2019) was dominated by artisanal mining (~85%).
- Over 700 ha of artisanal mining was detected in protected areas.
- This mining is degrading and destroying forested ecosystems.

GRAPHICAL ABSTRACT
Gold Mining in Ghana

+ Ghana is the 7th Largest producer of gold worldwide
+ Artisanal Mining has increased from 5% of gold production in 1990 to 30% in 2012
+ Artisanal mining causes deforestation and produces Mercury pollution in the environment

The analysis used Landsat 7 and 8 Imagery (Bands 4 to 7). The observational period was 2008-2017. Land was classified into four classes: Water, Urban, Mine and Vegetation
Our SDG Mapping Tool prototypes visualizations & reports to support SDG monitoring with three Indicators:

- **SDG 15.1.1**: Forest area as a proportion of total land area
- **SDG 15.1.2**: Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type
- **SDG 15.4.1**: Coverage by protected areas of important sites for mountain biodiversity