EARTH SCIENCE
APPLIED SCIENCES

EARTH SCIENCE APPLICATIONS GUIDEBOOK

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People use Earth science information from satellites and other sources to inform decisions about water, land, agriculture, disasters, health, and more. This guidebook translates decades of experience in applying this information into shareable knowledge and practical guidance. Whether you are new to Earth science applications or already an expert, you will find smart practices, new insights, and a few tips to support your work.

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ACRONYMS

ARL Application Readiness Level

BLM Bureau of Land Management

CEOS Committee on Earth Observation Satellites

CHIRPS Climate Hazards Group Infrared Precipitation with Stations

EU European Union

FEMA Federal Emergency Management Agency

FEWS NET Famine Early Warning Systems Network

GEO Group on Earth Observations

GOES Geostationary Operational Environmental Satellite

MODIS Moderate Resolution Imaging Spectroradiometer

NASA National Aeronautics and Space Administration

NDVI Normalized Difference Vegetation Index

NOAA National Oceanic and Atmospheric Administration

NPP NASA Postdoctoral Program

PDC Pacific Disasters Center

SDGs Sustainable Development Goals

UN-Habitat United Nations Human Settlement Programme

USAID United States Agency for International Development

USFS United States Forest Service

USGS United States Geological Survey

VIIRS Visible Infrared Imaging Radiometer Suite

USING EARTH SCIENCE TO TACKLE CRITICAL CHALLENGES

DATA, USERS, DECISION-MAKING

EARTH SCIENCE FOR EVERYDAY DECISIONS

Earth observations are becoming indispensable in crafting policies, plans, and tools to address pressing problems. From local water quality warnings to national agriculture forecasts, mapping of illegal gold mining to monitoring tsunami threats, this actionable science touches the lives of millions of people every day. And much more can be done to expand its use. This section explores the many ways Earth science applications are helping governments, researchers, businesses, and community groups deliver on their missions.

EARTH OBSERVATIONS ARE USEFUL FOR A WIDE RANGE OF DECISIONS

Decision-making describes the wide-ranging ways that satellite data and information provide evidence for action. They include: policy, legal, and regulatory frameworks; planning, management, and response; monitoring and tracking impact; and alert systems and other information for the public, among many others.

EARTH OBSERVATIONS IN ACTION

LEASES FOR GRAZING AND CONSERVATION ON PUBLIC LANDS

CLICK TO LEARN MORE

The U.S. Department of the Interior's Bureau of Land Management (BLM) is strengthening its monitoring of the health of federal lands, which account for one in every 10 acres of U.S. land. Together with researchers at the University of California at Los Angeles and the U.S. Geological Survey, the team is building a web application to assess rangeland conditions using remote sensing and ground data.That will enable BLM to assess vastly larger areas than is possible through ground assessment alone.These data will help BLM managers in district offices make determinations on leases for grazing.

Application data sources: Terra (MODIS), Landsat, ground data

EARTH OBSERVATIONS IN ACTION

RESTORING POWER FOR PEOPLE IN PUERTO RICO

Hurricane Maria devastated Puerto Rico in September 2017, killing thousands and toppling 80 percent of the island's power lines. Researchers went to work immediately to create high-quality satellite images of the damage, including power outage maps overlaid with streets and neighborhoods. The National Guard, Federal Emergency Management Agency (FEMA), and other first responders used the information to prioritize the distribution of supplies and deployment of rescue and repair crews.

CLICK TO LEARN MORE

Application data sources: Suomi NPP (VIIRS), Landsat, Sentinel-2, TanDEM-X, TerraSAR-X. OpenStreetMap

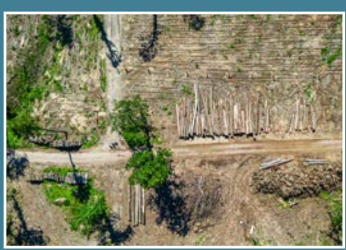
EARLY WARNING ON ALGAE BLOOMS

The Cyanobacteria Assessment Network (CyAN) uses satellite data to prevent people, pets, and livestock from exposure to sickening cyanobacterial blooms. CyAN information is detecting blooms sooner, often before they are detected with traditional observations. Authorities in multiple states use CyAN to help monitor drinking water, recreational areas, and other sources. The data help them decide where to focus sampling resources and when to issue alerts. The potential costs avoided by increasing remotely sensed monitoring was valued at $5.7 million dollars annually. In one case, CyAN's early detection of a bloom in a Utah recreational area - just before a busy holiday weekend — saved an estimated $370,000 in health costs. Led by the Environmental Protection Agency, the multi-agency team working on the application followed the Hedgehog Concept, which encourages teams to focus on what they are most passionate about and can do best, while responding to a specific need. That meant the CyAN team worked exclusively on cyanobacteria monitoring, seeking to perfect that capability and resisting the temptation to integrate other water quality measures.

CLICK TO LEARN MORE

Application data sources: Sentinel 3, ground data

FIGHTING FIRES AND DEFORESTATION IN THE AMAZON



Federal and state government leaders and community members in Brazil, Colombia, and Peru are using an Amazon rainforest tool to make decisions on where to fight fires, take action on illegal deforestation, and protect indigenous lands. The Amazon Dashboard, available in English, Spanish, and Portuguese, distinguishes between fires caused by deforestation and small holder clearing, as well as savannah and understory fires. This specificity helps decision-makers set priorities and target limited resources.

CLICK TO LEARN MORE

Application data sources: Suomi NPP (VIIRS), NOAA-20

THE PEOPLE AND INSTITUTIONS USING EARTH OBSERVATIONS

Decision-maker Partner End user
Collaborator User Co-developer Stakeholder

These and other terms are used, sometimes interchangeably, to describe the universe of people who engage with Earth science applications. They represent government and non-government agencies, the private sector and community groups, states and cities, and many others who use Earth observations to advance their work.

While the term "end user" is common in NASA circles, some scientists prefer "stakeholder" or "collaborator." These terms may reflect more accurately the encompassing role that these partners play – or should play – at every stage of the application process.

Often, users and decision-makers are not the same. The user may crunch the data, run the models, and provide the analysis; the decision-maker may be the person who acts on the analysis.

A SAMPLE OF USERS AND THE WAYS THEY USE EARTH OBSERVATIONS

Cities and municipalities
To reduce the impact of pollution on health, officials in Santiago, Chile are using satellite measurements of air quality to develop a metropolitan action plan.

States
Texas is among nine U.S. states that use remote sensing data to verify that they meet air quality standards for ozone and other pollutants, as required by the Clean Air Act. Learn how states use earth information at Space for U.S.

Federal agencies
The U.S. Department of Agriculture relies heavily on Earth observations to monitor and report on drought, crops, and other agricultural conditions. A new, user-friendly portal visualizes soil moisture and vegetation data to help farmers decide where and when to plant crops.

Citizens
Amateur bird watchers in California log their sightings into a database that integrates satellite-derived habitat information. Rice farmers use the information to decide when to maintain flooded fields, generating "pop-up" habitat for migrating birds.

Private sector
A Florida company uses remote sensing data to develop fish forecasts, which commercial fishing companies use to target their hauls more effectively.

Non-governmental organizations
Conservation International is developing a freshwater health index along the Mekong River in Southeast Asia to help local authorities identify steps to improve fishing, tourism, and other economic benefits.

National governments
Several agriculture agencies in West and East Africa are partnering with the NASA-USAID SERVIR program to develop applications to monitor locusts and help farmers avert potentially devastating outbreaks.

Development agencies
USAID uses analysis from a famine early warning project to guide decisions on the U.S. government's $4 billion food assistance program. FEWS NET forecasts food insecurity in 40 countries based on satellite data and information on markets and livelihoods.

United Nations agencies
UN-Habitat is working to build the capacity of cities across the globe to use remotely-sensed data to manage land use, population, transportation, housing, and other urban issues.

ABOUT EARTH OBSERVATIONS

WHERE EARTH OBSERVATION DATA COME FROM

Earth observations leverage the unique vantage point of space to deliver information on the planet's complex systems. Satellites, airborne missions, and ground-based observations are sources of this data. They are produced by space, weather, and other government science agencies around the world as well as commercial entities.

"The aggressive pursuit of understanding Earth as a system—and the effective application of that knowledge for society's benefit—will increasingly distinguish those nations that achieve and sustain prosperity and security from those that do not."
- National Research Council, 2005

A few examples of data resources
- Earthdata Search
- NASA Earth Observations (NEO)
- NASA Worldview
- JAXA Observation/Result Research Database
- ISRO Bhuvan Geoportal
- ESA Copernicus Open Data Hub
- ESA Earth Online
- CEOS Data and Tools

COLLABORATION AMONG SPACE AGENCIES

For decades, space agencies from many countries have partnered to promote scientific progress and enhance peaceful relationships among nations. Joint science missions, research initiatives, and data products are increasing as leaders work together to deepen use of remote sensing information to address today's pressing challenges.

1. Sentinel-6 Michael Freilich, a joint U.S.-European satellite, will support a decades-long effort to measure global ocean height from space. This information will be vital to monitoring and understanding how melting glaciers and rising ocean temperatures are driving sea level rise.

2. The Surface Water and Ocean Topography (SWOT) Mission will be a game-changer, radically improving hydrologists' ability to survey rivers, lakes, reservoirs, and wetlands. It will also help oceanographers study circulation patterns and improve climate predictions. Scheduled for launch in November 2022, SWOT is a joint initiative with the French space agency, Centre National d'Etudes Spatiales, with contributions from the Canadian and United Kingdom space agencies.

3. NASA is working with the Indian Space and Research Organisation (ISRO) to launch NISAR, the NASA-ISRO SAR Mission, which will use an information-processing technique known as synthetic aperture radar (SAR) to produce extremely high-resolution images. SAR is able to penetrate clouds and darkness, enabling data collection day and night, and in any weather.

4. The Group on Earth Observations (GEO) is a partnership of more than 100 national governments created in 2003 to foster coordinated, comprehensive, and sustained use of Earth observations. Closely linked to United Nations efforts such as the Sustainable Development Goals, GEO is building a GEOSS portal to integrate observing systems and promote common standards.

5. The South African National Space Agency is collaborating with the German space agency, DLR, to host a space debris tracking station at its Northern Cape observatory. The tracking station is part of the global Small Aperture Robotic Telescope Network, or SMARTnet.

6. In response to the COVID-19 pandemic, NASA, the European Space Agency, and the Japan Aerospace Exploration Agency teamed up to pool their agencies' wealth of information in a dashboard documenting planet-wide changes in the environment and human society.

ADVANTAGES AND LIMITATIONS OF EARTH OBSERVATIONS DATA

Over the last few decades, Earth observations have expanded scientific knowledge exponentially. Advanced computational capability – together with freely available data and the growing capacity of individuals and institutions to use them – suggest that the future potential of Earth observations data likely go beyond what we can currently imagine.

But satellite data are not perfect, nor are they 100 percent certain. Like all data, they come with limitations.

Generally, remotely-sensed data adds greatest value when combined with in situ observations, other ground data, and spatial information. These additional sources support calibration and validation of sensors, algorithms, and models, helping reduce uncertainty and assure data quality.

Pros and cons of satellite-derived data

Advantages

- Data are available and comparable over large areas.
- Satellites typically revisit places with a known and consistent frequency, often more frequently and reliably than can be achieved through ground monitoring.
- Satellites provide information on remote and understudied locations.
- Free, accessible imagery and datasets allow for low-cost monitoring and analysis.
- Decades of archived data enable long-term analysis of change over time.
- Space asset providers are increasingly committed to maintaining the continuity of datasets and products.
- Improved data delivery and processing allow for more near-real time observations.
- Satellites offer a wide variety of data at various resolutions.
- The trend toward automated processing and analysis-ready data products increases accessibility of satellite information.

Disadvantages

- In some situations, satellite measurements are less valuable than the all-day monitoring by ground sensors.
- Many satellites can only see the surface.
- Most satellite sensors cannot see through clouds. (Synthetic aperture radar is an exception.)
- Satellite imagery often depends on the detection of color.
- Atmospheric phenomena may distort measurements.
- Satellites only have historical observations for the years they were in orbit.
- Non-technical specialists may not find satellite-derived products easy to use.
- Sensors may fail.

APPLYING EARTH SCIENCE: WHAT IT TAKES

A VISION OF SCIENCE FOR ACTION

Earth science applications are a bridge from the breakthroughs of basic research to real-world uses of that knowledge. Scientists working on applied research and Earth science applications tend to have a solutions-oriented mindset: they look at data, models, tools, and research in the context of how they can answer questions and make decisions. Read on to discover more about Earth science applications and the people who build them.

DEFINITIONS OF SUCCESS

HERE'S WHAT SOME LEADING SCIENTISTS SAID

Success is answering a question that somebody actually wants the answer to. That's often an iterative process because what you start off with as what people think they might want to know, might wind up not actually being what is going to be most helpful in the end...So, success is the journey. And it's getting there together.

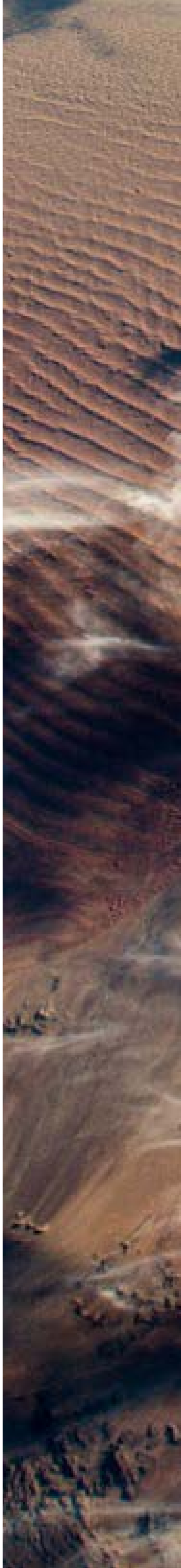
Becky Chaplin Kramer
Lead Scientist, Natural Capital Project, co-appointed at Stanford University and University of Minnesota

We are in the business of getting out of business. If we can make ourselves -- us scientists -- redundant, where the beneficiaries of our scientific solution no longer need us, then I would say that's a success.

Faisal Hossain
Professor, University of Washington Department of Civil and Environmental Engineering

A real critical element of success is when we can enable and empower other people. And sometimes that means less is more. We have to develop at the level that end users can consume and use the information, as opposed to trying to push all the information, or the latest information, into a situation where they don't or can't use it. If it is not usable by the end user, it is not going to have the impact that it could have.

Jim Nelson
Brigham Young University, Professor of Civil and Environmental Engineering



HERE'S WHAT SOME NASA PROGRAM MANAGERS SAID

Impact is the first measure of success — what value is the application bringing to humanity and society? But then for us, as program managers and being within Earth sciences and applications, we're looking for sustained impact. How is it going to be used over time and how is it going to be transitioned to another organization so that it can continue to run operationally. And that's huge. That's a big challenge.

Sarah Brennan
NASA Deputy Program Manager, Water Resources and Agriculture

When you say what defines success, maybe it's a change in policy that was informed from Earth observations. Maybe it was the improvement in some decision support tool. Maybe it was an improvement in management of forecast decisions. At the end of the day, success is defined with the partner saying, "Our needs are answered, and society has benefited from it."

John Haynes
NASA Program Manager for Health and Air Quality

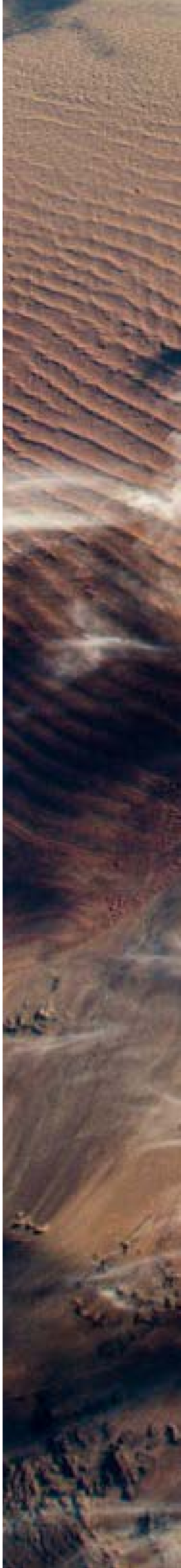
I've seen three types of projects that tend to succeed. The first is when an application provides unique information that does not exist anywhere else. The second is any project that has some kind of commercial partnership. Once you get a company saying, "We get how beneficial Earth observations can be to our product line," you've got a win-win. The third is when the principal investigators have started off with a relationship with their end users. They hit the ground running and continually build their application with the end users, the whole concept of co-development. Those projects, if they can get past the institutional barriers, are the most likely to succeed.

Cindy Schmidt
NASA Associate Program Manager for Ecological Forecasting

SUCCESS FACTORS

No two Earth science research projects or applications are exactly the same. Each one requires some level of tailoring or adapting depending on resources, the specific needs of those who will use the data, and a range of other considerations. Yet projects that deliver impact and value tend to have a few things in common.

Invest in relationships early on
Before, during, and after – relationships are the lifeblood of collaboration at all phases of applied science research and applications. Investments in relationship-building, even before a proposal is developed, establish a strong foundation for partnership. For example, NASA requests for proposals often require cost sharing with collaborators; negotiating those arrangements is easier when the proposer and the partners already know each other.



"To be successful in applications, you need three things: relationships, relationships, relationships. Building them, cultivating them, sustaining them over a long period of time is absolutely critical. And it doesn't happen overnight but you need deep, personal relationships, with individuals but also across agencies."

Faisal Hossain
Professor, University of Washington Department of Civil and Environmental Engineering

Understand user needs
Communicating and engaging users – the people and organizations who will use the applications and their data products – is critical to ensuring the science supports their needs. Dialogue and exchange are fundamental to ensuring that models and data products are usable, practical, and connected to specific decisions that users need to make.

"I am not using this project to try to answer a scientific question, though it certainly will allow us to do so. The Bureau of Land Management needs something that enables them to monitor and make decisions about huge areas of public land. I'm measuring success by whether we produce a tool that they can actually use, and I'm letting them tell me what that means. That means we do a lot of listening."

Greg Okin
Professor, University of Washington Department of Civil and Environmental Engineering

Fit the science to the problem
Innovation is a hallmark of NASA Applied Sciences, but in some cases, a tested, conventional solution will be most effective in ensuring the sustainability of an application. When the goal is to handover an application to partners, the underlying technology, infrastructure, data management, and human and financial resources must be something the partners can manage over time.

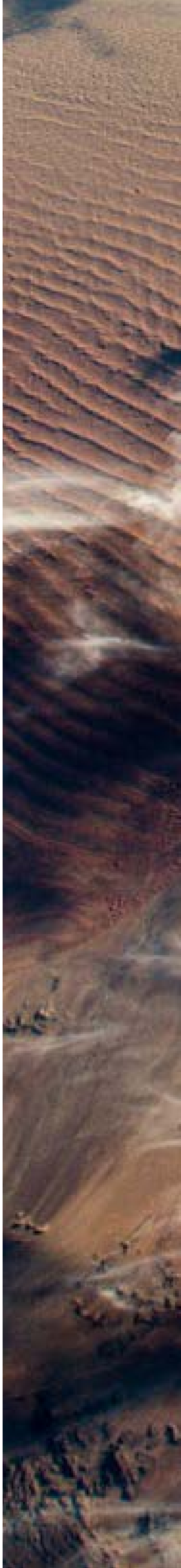
"You can target the most fancy, fantastic tools, but their utility will be limited if the user doesn't know how to properly use them, or have access to proper training and support. We strive to develop straightforward and easily adoptable tools so users can really lean on that technology for their decision-making needs. As a principal investigator, a key to ensuring successful adoption of applications is to carefully understand exactly what the user needs and capabilities are. What is their level of understanding? What is their state of the art? The fun part is trying to efficiently match those needs and capabilities."

John Bolten
Associate Program Manager of NASA Earth Science Applied Sciences Water Resources Program

Build partners' understanding and confidence in the science
Often, partners are leaders in their fields but not necessarily experts in computer science, remote sensing, or geospatial data. Teams that take time to help their partners understand what the science can achieve (or not achieve) are able to make their approaches more relevant and responsive to what the user actually needs.

"A lot of time, at the outset, the [research] question is limited by the decision-makers' understanding of what is possible. By bringing new science and novel innovations along the way, decision-makers sometimes have their eyes opened up. They begin thinking about new and different possibilities and different questions that better serve their needs."

Becky Chaplin-Carpenter
Lead Scientist, Natural Capital Projection, co-appointed at Stanford University and University of Minnesota



Be flexible and adaptable

Nothing ever stays the same, especially in Earth science collaborations. User needs evolve, leaders and leadership priorities shift, and collaborators retire or move on to other jobs. The product envisioned at the outset of a project may not be what is required or eventually built. The guidance from established applied scientists? Always be willing to go back to the drawing board and iterate again.

"Keeping partners engaged and communicating throughout the project is important because their priorities might change over the course of a few years. Making sure you are able to adapt is really helpful."

Helen Bailey
Research Professor, University of Maryland Center for Environmental Science

Communicate about your work

Equally as important as listening to users is the art of communicating. Actively sharing information on applications through webinars, briefings, conferences, community of practice meetings, and other channels increases investment and buy-in. It also attracts new audiences for the information.

"Clear and frequent communication with stakeholders is vital to best connect needs on the ground with key information that can advance decision-making."

Dalia Kirschbaum
Chief of the Hydrological Sciences Lab at Goddard Flight Center, lead researcher on NASA's landslide team

Make your work usable and accessible

Applied science collaborators tend to be extremely busy. Many do not have data management or remote sensing tasks among their responsibilities. Models need to be in formats easily accessible to users with varying levels of technical expertise. Outputs and reports need to be distilled to generate simple indicators that make the basis for the decision clear. As much as possible, products need to be automated, so they don't require a substantial investment of a partner's time.

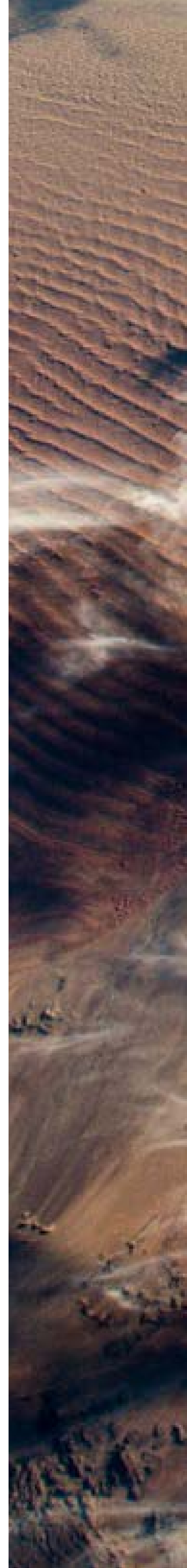
"For many of our stakeholders, their jobs do not include keeping up-to-date on satellite technology. We are trying to convince them it is worth their time to learn about this data and engage with this data. We have to make it easy for them."

Tracey Holloway
Scientist and Professor at University of Wisconsin-Madison and Lead of NASA's Health and Air Quality Applied Science Team

WHY EARTH SCIENCE?

A VISION OF SCIENCE FOR ACTION

Two powerful dynamics are converging in the world today: one related to the substantial human and natural pressures on Earth's resources; the other tied to the rapidly growing capabilities of Earth observations to help mitigate those pressures. The Earth scientists of the future will have a particular ability to influence these dynamics. Read on to learn more about the opportunities ahead.



A NEW ERA OF COLLABORATION IN SCIENCE

The science of the future is trending toward collaboration and data-sharing, with huge potential benefits for all involved. Space agencies, governments, and the private sector are making more data free and open. Collaboration around data collection and analysis is making it possible to compare model outputs and reports across oceans, landscapes, and airspace. Cooperation across disciplines is leading to solutions to complex problems such as water scarcity, food insecurity, and air pollution.

APPLICATION SNAPSHOT

USER-CENTERED HEALTH AND AIR QUALITY RESEARCH

CLICK TO LEARN MORE

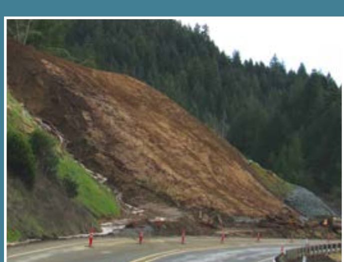
HAQAST ("Hay-cast"), is NASA's Health and Air Quality Applied Science Team: 14 scientists and their teams studying hazards ranging from wildfire smoke to diesel emissions to breast cancer. HAQAST has built a nationwide network of 1,000 people interested in health and air quality. Some of those stakeholders collaborate with HAQAST "tiger teams," cross-functional groups tasked with brainstorming solutions to specific challenges. A catalyst for success has been planning collaboration around the stakeholders, rather than designing applications first and involving them later. HAQAST learned it had to make participation easy and ensure stakeholders come away with a tangible benefit — such as information to improve their work or build their skills. Beyond monthly calls, newsletters, and social media, HAQAST created non-traditional participation opportunities, such as inviting non-scientists to review proposals. The result? Countless new research ideas and opportunities to improve health and air quality.

INFINITE POTENTIAL FOR MORE ACCURATE AND TARGETED SCIENCE

The recent decades' innovations in computer hardware, software, algorithmic capabilities, and data storage and management have created expansive new opportunities for data processing and analysis and computational modeling. Supercomputers, cloud computing, and machine learning are among the leading innovations.

APPLICATION SNAPSHOT

IMPROVING THE GLOBAL VIEW OF LANDSLIDE RISKS



CLICK TO LEARN MORE

A new version of the Landslide Hazard Assessment for Situational Awareness (LHASA) model leverages machine learning techniques to improve the accuracy of near-real time landslide hazard estimates. Using information on topography, satellite precipitation, and soil moisture, along with modeled products, LHASA provides timely "nowcasts." These provide key information on where and when landslide hazards may be elevated around the world, helping pinpoint areas at risk. The model also identifies populations and infrastructure that may be affected - information that can be vital to response planning. A lesson learned from this project is the importance of working closely with partners to understand the accuracy and utility of the model. With clear understanding, decision-makers can confidently take action, setting appropriate thresholds to trigger an alert.

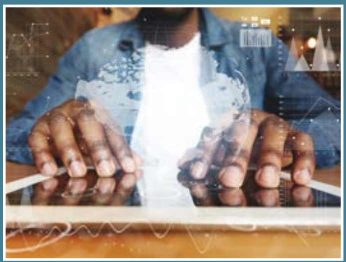
Application data sources: Global Precipitation Measurement (GPM), Soil Moisture Active Passive (SMAP)

SCIENCE IS DEMOCRATIZING VERY QUICKLY

Data democracy, meaning free participation in the production and use of geospatial data, depends on making data accessible and usable by people around the world, whether or not they are scientists. Open data, automated application models, and freely available online training and capacity building have empowered more people to engage with Earth observations, models, and applications.

APPLICATION SNAPSHOT

STUDENTS GROUND TRUTH SATELLITE DATA



Since 1995, students and citizen scientists in over 125 countries have participated in GLOBE, the Global Learning and Observations to Benefit the Environment Program. Using GLOBE research protocols, students, teachers, scientists, and citizens investigate and submit observations to an online data and information system. These measurements are publicly available and offer a worldwide resource that sheds valuable insight into local environments. Initially created as a schools-based program, anyone in a GLOBE country can now participate through the GLOBE Observer (GO) mobile app.

CLICK TO LEARN MORE

EARTH OBSERVATIONS CAN PROMOTE TRANSPARENCY

Remote sensing can interject more precise information into the management of natural resources, enabling managers of those resources to make better decisions about their use. That knowledge can help parties with seemingly opposing interests come together to foster sustainable use and strengthen the corresponding regulatory environment. Real-time monitoring and detection, which is rapidly scaling up alongside predictive models, is playing a major role, unsurprisingly, in driving more effective, real-time responses.

APPLICATION SNAPSHOT

PINPOINTING AGRICULTURAL WATER USE

With climate change driving more frequent droughts in the Western United States, resources to help water managers and users are critical to balancing supply and demand. OpenET is a new application that measures evapotranspiration (ET), the process by which water is transferred from land to the atmosphere. OpenET has the ability to measure how much water is used by agricultural crops and other plants at the level of individual fields. It will provide information on water needs and help water managers, farmers, and conservation groups coalesce around an agreed-upon measurement of ET. Clarity and accuracy will foster communication among stakeholders and transparency around water use.

CLICK TO LEARN MORE

Application data sources: Landsat, Terra, Aqua, GOES, and other satellites

DEVELOPING SUSTAINABLE APPLICATIONS

EXPLORING LESSONS LEARNED IN DEVELOPING APPLICATIONS

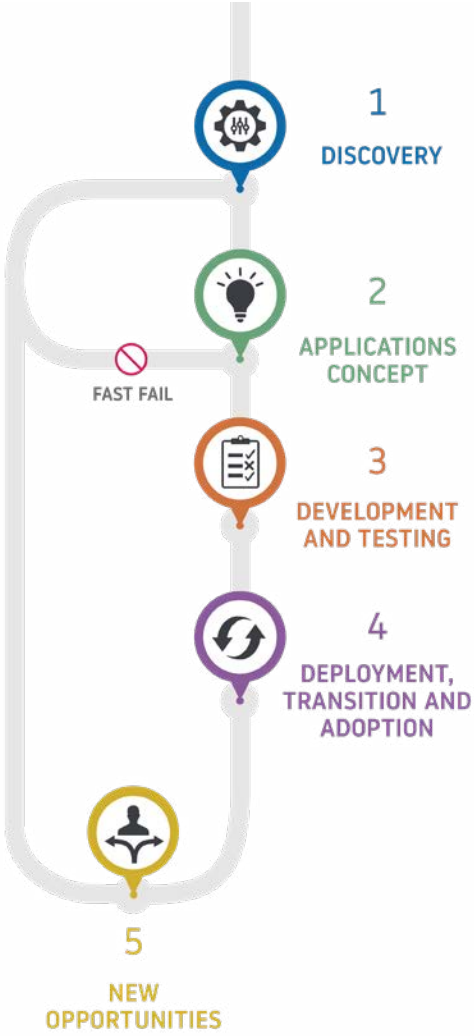
Earth science applications aim to connect science and society in responding to the urgent challenges of our time. Sometimes applications fill a targeted, short-term need, such as mapping damage in the aftermath of an earthquake or hurricane. Most other times, though, they have a longer life cycle and greater aspirations of sustainability.

This section will help applications developers and others think through practical approaches to developing applications and positioning them for impact and sustainability.

APPLICATIONS STEP BY STEP

The application process can be visualized as a pathway on three concurrent tracks: science, people, and management. For every application, the journey will be different, but there are some common steps.

Fast fail: Application not viable. Review discovery findings and concept.



People

Step 1: Discovery
- Build relationships
- Understand user needs
- Engage others in your concept
- Be open to skepticism

Step 2: Applications concept
- Engage users
- Listen to feedback
- Affirm their commitment
- Agree on a collaboration approach

Step 3: Development and testing
- Collaborate with users
- Prioritize their needs
- Communicate about data opportunities and limitations

Step 4: Deployment, transition, and adoption
- Build user capacity
- Provide ongoing support

Step 5: New opportunities
- Stay in touch with users
- Improve the application
- Work with new users to replicate and scale

Science

Step 1: Discovery
- Listen to users and understand user needs
- Assess how your work can fill those needs

Step 2: Applications concept
- Formalize the concept
- Consider requirements to sustain the application
- Modify and adapt

Step 3: Development and testing
- Create a prototype or demonstration
- Iterate and reiterate
- Ensure users will use and be able to sustain the application
- Automate outputs when possible

Step 4: Deployment, transition, and adoption
- Operationalize the application
- Troubleshoot and refine

Step 5: New opportunities
- Publish new papers
- Pursue related research questions
- Identify new applications

Management

Step 1: Discovery
- Define objectives
- Identify opportunities (e.g., funding, partnerships)

Step 2: Applications concept
- Develop a project plan or proposal
- Choose a project management approach
- Build a team with diverse skills

Step 3: Development and testing
- Motivate the team
- Plan for training, support on data management, and sustainable infrastructure
- Communicate progress with others

Step 4: Deployment, transition, and adoption
- Support users during adoption
- Invest additional human/financial resources as needed to get over implementation hurdles
- Evaluate impact
- Communicate stories and share results

Step 5: New opportunities
- Apply and share lessons learned

PROJECT MANAGEMENT

MANAGING FOR SUSTAINABILITY

Sustainability should be at the heart of an application process. From the proposal stage, project teams should consider what investments need to be made in their partners' institutional and data management abilities, and what infrastructure, funding, and technical capacity will be required to sustain the application for as long as it is needed.

What are the first steps on the path to sustainability?

A project manager and project team have to decide how they will navigate the route. They need to make active choices about strategies and tools for project management, needs assessment, user engagement, evaluation, and other processes. It all begins with a good proposal.

Sustainability in Earth science applications

- Users adopt and maintain an application themselves, perhaps even developing it further on their own.
- Users sustain engagement in a collaboration over an extended period of time.
- Users establish lasting connections and become part of a community of practitioners.

DEVELOPING A GOOD PROPOSAL

Successful applied science proposals revolve around:
- Strong user engagement and partnerships
- Transformative, innovative uses of science
- Practical, sustained benefits for users
- Excellent leadership and diverse teams

Proposal checklist

- Compelling story that will excite the reviewers
- Simple, readable, and understandable
- Conveys the problem, why it must be addressed, and what the proposed solution will accomplish
- Describes the project in detail with strong anticipated outcomes
- Aligns objectives logically and explicitly with the funder's priorities
- Addresses sustainability, especially on data management and potential capacity building
- Conceptualizes stakeholder buy-in and collaboration
- Provides definitions of success and evaluation plans
- Presents the team, especially the principal investigator, in a way that inspires confidence
- Uses accessible, powerful images and figures to reinforce key messages
- Captures the community of interested stakeholders
- Includes a credible, complete budget

Good practice

Proposals should start off with a strong executive summary that quickly and persuasively explains:
- The challenge you are trying to address
- Your solution and its expected impact
- What is unique about your solution and why it will be effective
- Why YOU are the person to lead this project
- Why your team is right for the project
- Why NOW is the time for this project

Pro tips

- Read the entire solicitation very carefully.
- Research the funder's evaluation criteria.
- Write your proposal with the reviewers in mind.
- Let your passion for the science shine through the proposal.
- Avoid an overly complex or unreadable proposal.
- Start each section with a bolded statement that reinforces key messages.
- Describe past work in the context of its impact, not just the who, what, when, and how.
- Use the proposal process to demonstrate leadership and team collaboration.
- Balance the reviewers' interest in specificity with honest discussion of your flexibility and responsiveness to users needs.
- Ask people outside your discipline to give feedback on your proposal.
- Interact and engage funders as much as their process allows, but don't overwhelm them.
- Be prepared for specialized requirements, such as cost-sharing, or plans on communications, stakeholder engagement, monitoring and evaluation, or mentoring activities.

"Don't just write a proposal that can be understood, write a proposal that cannot be misunderstood."

- Dr. Max Bernstein, Science Mission Directorate, Lead for Research

A few basics on NASA Applied Sciences proposals

NASA Applied Sciences issues calls for papers, crowdsourcing, funding, and solicitation opportunities for both researchers and citizen scientists. Activities may use remote sensing data from a variety of sources, but NASA data must be integrated in the technical approach.

- Research Opportunities in Space and Earth Science (ROSES): Individual and team grants for applications projects and applied research projects
- NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES): Solicitations based on NASA research objectives
- Small Business Innovation Research (SBIR): This program funds innovative technologies in line with NASA needs as described in the annual Solicitations. They must have significant potential for successful commercialization.

More NASA proposal resources

- NSPIRES
- NSPIRES help page
- Science Mission Directorate researchers page
- Science Mission Directorate solicitations page
- Planning list for Science Mission Directorate solicitations
- SBIR
- Guidebook for proposers responding to a NASA Notice of Funding Opportunity (NOFO)

BUILDING A TEAM

What makes for an excellent team?

Dynamic members
Hard-working. Adaptable. United around the goal. Willing to go the extra mile. A successful team is rooted in these traits. A strong manager provides clear leadership while giving team members space to deliver on their tasks.

Diversity - in multiple ways
Along with varied skill sets, teams that include people of varying ages, genders, sexual orientation, and cultural and social backgrounds are more likely to produce useful, accessible, effective applications.

Multiple disciplines
Remote sensing is the core, but other skills bring dimension to applications. These might include disciplines such as climatology, biodiversity, epidemiology, and economics, as well as technical skills, such as machine learning, cloud computing, statistics, and data visualization.

Invested partners
Partners can be multipliers of impact when collaboration is rooted in a common vision, close engagement, and shared learning and exchange.

Vibrant communications
Whether managed by the principal investigator or another team member, effective communications are a must. The ability to translate science to plain language, with real-life stories about why it matters, builds a bridge to users and a broader community of stakeholders and supporters. Language skills may also be a success factor.

PROJECT MANAGEMENT APPROACHES

The project manager

Capable project managers move an application from idea to implementation and adoption, managing concurrent streams of science and people. Some managers organize the work around the tasks. Others organize around the team.

No management style is the best; it all depends on the particularities of the project and the people who will work on it. In fact, most project managers will blend approaches. Very often, especially on smaller applications teams, the principal investigator is the project manager.

Qualities of an effective applied sciences application project manager

- Solutions-oriented
- Consistent
- Clear-sighted
- Scientifically credible
- Open-minded, adaptable
- Clear communicator
- Decisive
- Persistent
- Team builder

What kind of project manager style will catalyze results?

Affiliative
Managers embed themselves as a peer on the team, leading from the front.

Coaching
Managers work through team members to achieve the project goals, prioritizing support and mentoring.

Authoritative
Managers set goals and strategies and then allow team members to work independently to fulfill them.

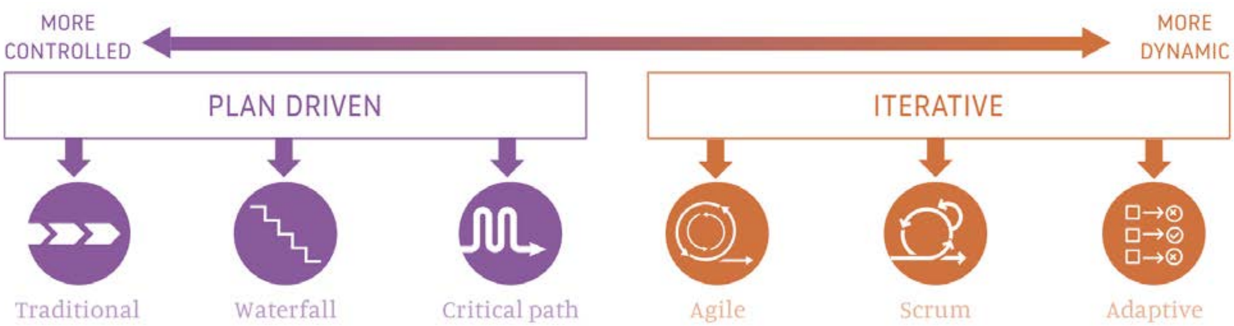
Directive
Managers set goals and strategy and direct team members to fulfill them.

Democratic
Managers foster collaborative action, allowing all staff members to contribute to the decision-making.

Pacesetting
Managers emphasize results and deadlines, holding employees accountable for delivering on them.

Context for applications development and implementation

An effective project manager takes a formal approach to organizing tasks, team members, users, and project outcomes. There are many approaches, some of which may be combined to leverage their comparative strengths.



Traditional
Required tasks are determined by the team with emphasis on linear processes to oversee and monitor their completion.

Waterfall
After significant planning, tasks are managed sequentially in phases.

Critical path
This step-by-step methodology sets priorities for interdependent tasks. Activities are deemed critical or non-critical based on which can be achieved fastest with the biggest return for the project.

Agile
With comparatively less upfront planning, this approach focuses on short cycles of activity known as sprints. These are intended to deliver immediate results and point the way to next steps.

Scrum
A form of agile, this approach features quick development cycles and very close team collaboration (sometimes with daily meetings) to maintain energy and enable quick pivots.

Adaptive
Project goals remain constant but the pathway to the goals evolves based on new information and changes in context.

Perspectives on project management

We are light and agile. We recognized early on that we had to have a vision and we had to have pragmatic ways of doing things. At the same time, we tried to strike that right balance between putting in so many rules and procedures and layers of people that it just slows you down. To be relevant in applied sciences, you have to have some flexibility in how you structure your activities.

Inbal Becker-Resheff
Program Director, NASA Harvest, University of Maryland, Department of Geographical Sciences

Our project management style is team-oriented. Our work is broken up into four tracks. Each has a lead responsible for day-to-day operations and ensuring that deliverables are met. I find it's a really good model for managing because I'm not micromanaging the team. They are able to go and do what they need to do and they bring me in when they need me.

Maggi Glasscoe
Research Associate, University of Alabama at Huntsville

WORKING WITH USERS

USER-CENTERED APPLICATIONS

In recent decades, many scientists have come to realize that applications designed around users' needs, with their participation throughout production, are the ones that make an impact and endure. The traditional, engineering-based method is being rethought in the context of user-centered processes, such as co-development and design thinking.

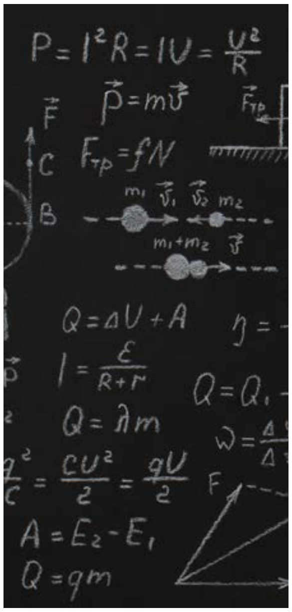
Where do user-centered applications start?

Having those discussions really early on in the project to better understand: What's the problem the [users] are facing? What's the decision they are facing? Why isn't that decision good enough already?

Lawrence Friedl
Director, NASA Applied Sciences Program

COLLABORATION APPROACHES

Systems engineering has been a standard approach in applications design and development for decades, and it works well in certain contexts. Another approach is design thinking, which is well suited to applications connected to human processes.



Systems engineering methodology

Systems design | Product realization | Technical management

- Limited stakeholder engagement
- Application designed to specifications
- Sequential phases
- Technical requirements decided early
- Progress to next phase determined at key decision points
- Tends to be controlled and predictable

Design thinking

Empathize | Define | Ideate | Prototype | Test

- Iterative process with users
- Activities and outcomes evolve
- Phases may occur concurrently or repeat
- Deep exploration of users and their challenges
- Assumptions about goals and objectives tested
- Tends to be dynamic and unpredictable

USER ENGAGEMENT

User engagement may seem simple, but project managers will tell you it requires commitment, patience, and more time than people usually expect or plan for. They will also tell you that it is a catalyst for achieving impact.

In practice, user engagement takes place over the application life cycle, through collaborations on needs assessment, application design and testing, capacity and sustainability planning, and monitoring and evaluation.

USER ENGAGEMENT IN PRACTICE: CO-DEVELOPMENT

Applications developers work with users in a start-to-finish, collaborative process. The depth of the collaboration varies greatly depending on human and financial resources, but the approach presumes that cooperation and exchange are fundamental throughout the life cycle of the application.

SERVIR

SERVIR, a joint NASA-USAID initiative to help developing countries apply EO data to decision-making, uses co-development across its applications projects. The approach is formalized through a service planning methodology based on four tools. They are: consultation and needs assessment, service design, stakeholder mapping, and monitoring and evaluation. These comparatively resource-intensive processes are managed by designated team members at regional science centers in Africa, Asia, and South America.

CLICK TO LEARN MORE

Getting to the root of users' problems

The traditional starting point for conversations with users and decision-makers might seem to be: "What do you need?" But application developers have learned that experiential questions catalyze dialogue on pain points, bottlenecks, and other real-life context.

The questions may not lead directly to application design. But they will foster exploration of how Earth science information might contribute. This sort of exchange also creates space for setting users' expectations of Earth science information and applications. In general, successful applications scientists are practiced at the communications style of "Listen. Ask. Repeat."

Examples of exploratory discussion topics.

- Tell me about a day at your work. Where do you spend most of your time?
- What work problems keep you up at night?
- What would you like your organization to be better at?
- Tell me about a problem you haven't solved.
- What would you like to be able to do that you can't do now?
- What's a decision or action you'd like to be more certain about?
- What information don't you have now that you wish you had?
- If you had a magic wand to make something better with your work, how would you use it?

Continuing the dialogue throughout an application's lifecycle

The exploratory questions above establish a dynamic of sharing, exchange, testing, and problem-solving that should carry on through all steps of the application process. At the heart of this engagement is a continual, iterative process of clarifying and converting users' needs to the specifications of the application. These questions raise some key topics - use and adapt them as appropriate.

Decisions

- What decision(s) do the user organizations make?
- What kinds of analysis support those decisions?
- What types of actions do they take based on the decisions?
- What is the quality of their current decisions and actions, and what quality do they desire?
- What capacity do they have (or need) to sustain improved decision-making?

Information and models

- How frequently do they need information products to support their decisions and actions?
- How timely must those products be?
- What system of units do they use and prefer?
- What data formats do they prefer? Which can they use?
- If they are using models, what grid spacings do their models use?
- What additional capacity might they need to continue using the information products and sustaining the application?

User community

- What audiences do your users serve (that is, their users, clients, customers, partners)?
- How do they support those audiences?
- How might this application help them do that better?
- How can the applications team play a supportive role in bringing the application to those audiences?
- What are the users' trusted sources of information (websites, portals, trade journals, other publications)?

COMMUNICATING THE SCIENCE

Collaboration on applications may go more smoothly when users understand the possibilities and limitations of remote sensing observations. Discussions of data certainty, latency, format, and continuity are important, as is user engagement around verification and validation of the use of the data. Dive into these real-life scenarios to get insights on a few of the challenges of communicating about the science.

SCENARIO 1

The application:
At the US Bureau of Land Management (BLM), decisions on grazing permits have been made historically based on statistical analysis of field data samples.That analysis quantified the state of the land through a range of indicators such as percentage of bare ground or prevalence of invasive species. Building on BLM's existing Assessment, Inventory, and Monitoring (AIM) tool, the scientists integrated satellite data with the field data. With that additional information, BLM can assess areas far larger than could ever be covered by humans on the ground and at times when no data are available. BLM can also produce rangeland indicator maps covering hundreds of thousands of acres.

The challenge:
Remote sensing does not lend itself to the traditional parametric statistics taught in college, so different types of statistical analysis are required. And remote sensing data is most always communicated with error metrics, something not typically reported with ground data. The BLM range manager overseeing the permit process, who is not a remote sensing expert, is feeling uncertain about whether the upgraded AIM tool is strengthening the evidence for the decision or adding uncertainty that could create a pathway for legal challenges. He is asking for clear, accessible statistics for the decision documents. What did the scientists do?

The response:
They worked with BLM to understand the uncertainty, committing time to guide the manager and his team through the statistics and the uncertainty issues. They developed a statistically-valid framework based on the remote sensing data. They also promoted their approach in the land management community through articles in publications they read regularly; in this case, society journals about rangelands.

SCENARIO 2

The application:
Kering, a global apparel company that sources cashmere in Mongolia, wants to understand the impact of their operations on the health of grasslands and native animal populations. Using remote sensing and ecosystem modeling, scientists set out to analyze whether improved goat herding and sustainability practices are leading to a positive change in rangeland conditions on the steppe. Their aim is to provide data for indicators pre-determined by the project partners, who also have some data from their own ground monitoring.

The challenge:
The South Gobi desert, where much of the cashmere production takes place, has vast areas of bare ground. Despite using various vegetation indices (e.g., NDVI, SATVI and others) and sourcing data from two different sensors (LandSat and MODIS), the bare ground was so homogenous that the data lacked specificity. The analysis showed trends but did not provide data for the detailed indicators. What did they do?

The response:
They helped the project partners understand the assumptions and reliability of the model, and why it was still useful. They also figured out how it could answer different but still valuable questions for assessing their sustainability efforts. They also took a new approach to the ecosystem modeling based on phenological types and climate data. That helped them align remote sensing data and climate trends with ground data in specific areas of the grasslands where the signal was clearer.

COMMON CHALLENGES

We asked two dozen scientists about the challenges of developing applications. Here's what they said.

Institutional barriers

- **Bureaucracy**
  Slow or multilayered decision-making processes may inhibit progress. The team may have to invest time unexpectedly to get over the hurdles.
- **Cost-sharing**
  A funder's requirements may be a stumbling block for some users.
- **Conflicting data environments**
  Some institutions may restrict the use of certain platforms or datasets.
- **Funding delays**
  Resources do not always come through on schedule.

- **Publish or perish**
  User engagement is fundamental to success, but the incentives in academic circles tend to revolve more around publishing and securing funding.
- **Project lifecycles**
  Your project may require more time than the typical 2-3 year funding cycles.

Partnership pitfalls

- **Changing circumstances**
  User priorities may shift. Personnel may change. Project buy-in may decline.
- **Weak collaboration**
  Without strong relationships, shared vision, and regular communication, collaborations may suffer, especially during transition and adoption.
- **Partner burnout**
  Users juggling many responsibilities and relationships may have trouble keeping up.
- **Partner expectations**
  Users may be disappointed if the application takes longer or doesn't deliver the results they expected.

Sustainability

- **Human capacity**
  Frequent staff turnover – and the need to train new staff – can strain project team resources.
- **Data management**
  Users may have difficulty in 1) finding financial resources for data infrastructure, such as cloud computing costs, and 2) building and maintaining the team's analytical and data management skills.

Tips

- Be patient.
- At the proposal stage:
  - Research software, datasets, and models to ensure their longevity and your partners' ability to use them.
  - Work with users to diversify and provide a stable base for their cost-sharing contributions.
- To manage expectations:
  - Do not oversell your science: always be honest about what you know and don't know.
  - Share scenarios of potential outcomes at the beginning of a project.
- Start planning for sustainability from the proposal stage.
- Find ways to make your users' work easier; automate outputs as much as possible.
- Bring stability to the collaboration by establishing relationships with users of varying seniority.

EVALUATING IMPACT

PERFORMANCE VERSUS IMPACT

A question an applications team should always ask: are we delivering on our vision, achieving our intended impact, and serving those we meant to serve? Performance monitoring and evaluation are invaluable tools in answering these questions.

Separate from the technical matter of how data and models are performing, this type of performance monitoring links to users, the decisions they need to make, and whether the application is helping them achieve that. This section surveys approaches to performance monitoring and evaluation.

Performance monitoring = improved project management

- Assesses project progress and the need for modifications
- Highlights opportunities for innovation and new directions
- Enhances communications with users, stakeholders, and funders about progress, accomplishments, and lessons learned
- Sets a baseline against which impact can be measured
- Measures cost effectiveness

UNDERSTANDING OUTPUTS, OUTCOMES, AND IMPACT

Monitoring and evaluation analyzes changes resulting from an activity or project. These tools can help track implementation, improve performance, and gather lessons for future efforts. Monitoring and evaluation can take various forms over the lifecycle of a project.

<table>
<tr><td colspan="2">Impact
High-level change resulting from the combination of outputs and outcomes
Social and economic benefits stemming from improved decisions and actions
(e.g., greater food security, fewer cases of malaria)</td></tr>
<tr><td>Outputs
The products, services, and capacities that the project/team builds and delivers</td><td>Outcomes
The changes in user activities, decisions, and performance as a result of the products, services, and capacities</td></tr>
<tr><td>Output examples
Maps produced, datasets developed, tools and models built, trainings held</td><td>Outcome examples
Improved decision-making as users apply and act on Earth science information (e.g., targeted mosquito control)</td></tr>
</table>

Making performance monitoring easy

- Identify and invest an appropriate level of effort for the size of the project
- Start performance monitoring early, even with low level of effort, in order to establish a baseline
- Link the project's metrics with those users employ in decision-making, as appropriate
- Align your efforts with the project funder's requirements for monitoring and evaluation

IDEAS ON IMPACT

The ladder

Impact is defined through users' progressive engagement with the datasets, models, tools, and applications. Note: "Data" is used here as shorthand for the Earth observations assets described above.

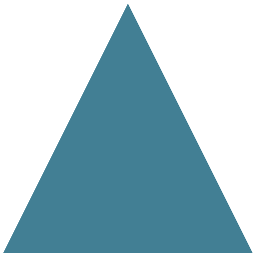
- Awareness of the data
- Realization that the data can inform their work
- Willingness to try using the data
- Confidence in searching for better data to answer their questions
- Integration of the data in their decision-making processes
- User adoption, adaptation, and maintenance of the data and related products
- Future development of the data products

The metrics triangle

This simple approach uses three encompassing metrics to measure impact on Earth science projects. The metrics are both qualitative and quantitative.

Uptake
Sustained use and user management of applications

Result: After 5 years' collaboration with the NASA-USAID SERVIR team, three Himalayan countries have integrated a new prediction tool in their own national drought and flood monitoring systems.



Reach
The number and breadth of people and organizations engaged in applied projects and activities

Result: The participation of federal, state, and city officials in monthly meetings of NASA's Health and Air Quality Applied Sciences Team has increased 40% in the last two years.

Value
Benefits accrued through program activities

Result: The use of Landsat satellite imagery in assessing acres burned in wildfires avoids costly helicopter surveys and the purchase of commercial imagery, saving federal agencies as much as $8 million per year.

Dollars and sense

Does the use of EO data save money? Or provide other benefits, such as saving lives and averting infrastructure damage and medical costs? Through the VALUABLES initiative, Resources for the Future and NASA developed methods to determine the monetary value of information. This type of impact evaluation compares outcomes when action is taken with typically-available information versus improved information.

METRICS FOR MEASURING CHANGE

Partners use metrics in a variety of ways. They may be used to guide program management. Or they may provide evidence for decision-making. The choice of tools, the level of investment in monitoring and evaluation activities, and the use of relevant metrics are all context-specific. The alignment of application metrics with user metrics will often maximize impact. Here are a few examples of how partners use metrics.

Disease early warning
Health officials in Peru issue an alert on potential malaria outbreaks when a series of metrics reach certain thresholds. The metrics are derived from a multi-layered analysis of soil moisture and temperature, human population density, and weekly surveillance data.

Crop insurance
Institutions that provide index crop insurance for smallholder farmers use metrics derived from remotely sensed rainfall and vegetation data to determine when a farmer is eligible for a payout.

Energy conservation
Drawing on remotely-sensed weather and climate data, the University of Michigan uses metrics on energy consumption in 150 campus buildings to identify the need for upgrades to lighting, cooling, and other systems. The school seeks to reduce its greenhouse gas emissions by 25% by 2025.

Natural resource management
The US Bureau of Land Management uses metrics on the probable presence of certain fish species in streams to guide decisions on oil and gas activities in Alaska's National Petroleum Reserve. Remote sensing information on environmental variables is used to model fish presence.

NASA READINESS LEVELS

NASA's Applied Sciences Program uses a 9-step index of Application Readiness Levels (ARLs) to track progress. The index is adapted from NASA's Technology Readiness Levels, which manage technology development and risk. Teams are asked to assess the maturity of their project on a regular basis, starting with the project proposal.

How the ARLs align with typical application steps

DISCOVERY, CONCEPT, AND FEASIBILITY	ARL 1	Basic research
	ARL 2	Invention: Application Concept
	ARL 3	Viability established: Proof of application concept
DEVELOPMENT, TESTING, AND VALIDATION	ARL 4	Prototype/plan: Initial integration and verification
	ARL 5	Potential determined: Validation in relevant environment
	ARL 6	Potential demonstrated: Demonstration in relevant environment
DEPLOYMENT, TRANSITION, AND ADOPTION	ARL 7	Functionally demonstrated: Application prototype in partner's decision-making
	ARL 8	Functionally proven: Application completed and qualified
	ARL 9	Sustained use: Approved, operational deployment, and use in decision-making

USE CASES

Find more detail on these use cases in the online version of this Guidebook, which features audio versions of scientists describing their experience and lessons learned in developing these applications.

ADVANCING ACCESS TO GLOBAL FLOOD MODELING

Application: Near-real time global flood severity alerts

Partners: Pacific Disaster Center, University of Alabama at Huntsville, Oak Ridge National Lab, the University of Colorado-Boulder, Indiana University, the University of Missouri-Kansas City, and Imagecat (a private company)

In brief: Disaster Aware is a global hazards platform used by some 7,000 users on an official-use-only web application and another 2 million users via a publicly available mobile app. In the past, PDC relied on manual alerts based on ground data and reports of flooding incidents.This application marries flood modeling with Earth observations to create an alert system that delivers reports to the Pacific Disaster Center (PDC) and their end users through Disaster Aware. Decision-makers use these reports to respond to flood threats and flood impacts.The application supports more consistent, higher resolution information over bigger areas. A risk and exposure component strengthens PDC's ability to assess flood damage by comparing satellite images before and after flooding occurs.

Maggi Glasscoe
Research Associate, University of Alabama at Huntsville

"Our concept was big so the project is very large, with a lot of partner institutions, tasks, and deliverables. When we wrote the proposal, we did a wiring diagram of how we envisioned all the moving parts coming together. That really helped us get a clear understanding of how things would work. It also helped with a challenge I faced as a new principal investigator: building cohesion in the team and awareness of what they need to do.

We also broke the project up into four distinct tracks in line with key deliverables:

- *A model of models, which is ensemble modeling of hydrologic models*
- *Machine learning and synthetic aperture radar (SAR) processing for high resolution flood inundation and depth. Those data calibrate the model of models.*
- *Machine learning on damage assessment, which helps measure exposure and risk. Those data also calibrate the model of models.*
- *The pipeline that delivers and packages these products so they are accessible to users. Those are the APIs and other elements of cyber infrastructure that plug into DisasterAware.*

Once we've assured ourselves that the model of models is calibrated and has been sufficiently tested, it will go from the PDC test environment into their operational environment. It will be delivering the near real time results to their users. That means that severity alerts at the watershed level will be available

routinely from PDC. All of this means that people working on the ground to manage floods will have better information for their decisions. Given that climate change is likely to cause more flooding in most every part of the world, this application should be really useful.

A tip for applications developers: Whether it be the public or end users or whoever you are trying to serve with this information, you need not only to translate the information scientifically so they can use it, you also need to show how excited you are, so they get excited about it, too."

MEASURING DROUGHT SEVERITY IN THE NAVAJO NATION

Application: Drought Severity Evaluation Tool (DSET)

Partners: Navajo Nation, Desert Research Institute, NASA

In brief: DSET is a cloud-based tool that measures drought and provides near-real time, localized maps and information on precipitation and other climate variables. Before DSET, the Department of Water Resources relied primarily on data from 85 rain gauges spread across the 27,000 square miles of the Navajo Nation. Given the difficulty and expense of covering such a large area, the Department was seldom able to get measurements consistently from all gauges. With DSET, remotely-sensed and modeled data, such as CHIRPS rainfall data, is compared to the rain gauge data to see how conditions vary across the Nation. That information is captured in monthly reports that help decision-makers understand where conditions are the worst and where drought relief is needed most. Desert Research Institute (DRI) and the Department of Water Resources jointly manage DSET. Along with decisions about drought response, officials are using DSET on watershed restoration projects and a climate adaptation strategy.

Carlee McClellan
Senior Hydrologist, Navajo Nation Department of Water Resources and co-developer of DSET

"The first thing to note is that the Navajo Nation has had drought conditions for almost 20 years. We've been in a declared drought emergency since 2018. So measuring precipitation accurately is critical for our water management decisions.

The concept for DSET came in 2015 when two NASA scientists visited the Navajo Nation. They met with a group of hydrologists and asked about our challenges. They came in and said, "What are your needs? How can satellite data help?" That kind of listening created a strong relationship.

A team from the NASA DEVELOP program created an application in the R Shiny interface. The tool worked, but R Shiny required computer coding skills, which we hydrologists did not have. So it was not easy to keep the tool updated. In 2018, NASA awarded funding to scale up DSET and make it more user friendly.

Around that time, our team connected with the Desert Research Institute, which has an existing platform called Climate Engine that already had many of the features and data we needed. The most important improvement was to migrate the tool to the cloud so that we did not need to host it or update code ourselves. Climate Engine runs on Google Earth Engine, which makes it easy to add additional data sets on variables such as temperature, soil moisture, and evapotranspiration. All those new data were processed alongside our original data. As NASA and DRI developed the application, we at Water Resources tested it and provided regular feedback. We were able to

validate the types of data and improve the administrative boundaries and a few other parameters. It was lucky that Climate Engine was there already and well-established. Because of that, we were able to get DSET up and running quickly.

Tip for applications developers: During the development phase, I spent a lot of time sharing information with our leaders, especially my department, the Tribal Council, and other departments. It was important to build their confidence in what DSET could do so that they would actually use it when it was ready."

CROP MONITORING TO MAKE THE WORLD MORE FOOD SECURE

Application: GEOGLAM Crop Monitor

Partners: G20 Agricultural Market Information System (AMIS)

In brief: The Crop Monitor provides timely, consensus-driven assessments of crop conditions for the main agricultural commodities in G20 countries. It is a flagship initiative of GEOGLAM, the Group on Earth Observations Global Agricultural Monitoring Initiative, launched by the G20 in 2011 as part of its action plan on food price volatility and agriculture. The main end users are the members of AMIS, which includes G20 ministries of agriculture and UN and other international organizations. The Crop Monitor reports conditions using maps and a legend noting favorable, watch, poor, and exceptional conditions. The consensus-based process makes the Crop Monitor unique. Each AMIS member uses an online platform to share their own national-level crop assessments. GEOGLAM provides additional inputs through remotely-sensed data, yield models, and other analysis. Stakeholders meet monthly to review the information and resolve any possible differences. With transparent, consensus-driven information, global decision-makers have equal ability to make informed trade decisions, and anticipate prices and potential shortfalls or surpluses.

Inbal Becker Reshef
Director of NASA Harvest, Research Professor at the Department of Geographical Sciences at the University of Maryland, and Program Scientist, GEOGLAM Secretariat

"When we started the Crop Monitor, we came in with our own notions and biases about the information we should provide from the agricultural remote sensing perspective. On the AMIS side, they had their own biases in terms of the data and information they were used to working with, mainly statistical data and charts. Naturally, there was somewhat of a mismatch.

When we shared our first products, the AMIS colleagues looked at our maps and had little idea what they meant. They actually asked us, "Can you just please provide us with tables and numbers?" We said, "Well, no, these maps have a lot of value. We think it's really important to be looking at this information spatially and in a disaggregated way, so let's start to work together to figure out how to make these maps make sense to you and useful for you."

This was an important turning point in our relationship. From there, the AMIS Secretariat became an integral part of the development of the whole concept of the application and the products. Rather than trying to spend a humongous amount of time planning or perfecting the products on our own, we started to iterate fairly rapidly with the AMIS secretariat. That helped us move forward very quickly: the initial request came in late 2012 and we launched the first Crop Monitor publication in 2013.

Tip for applications developers: You have to be end-user driven. Stakeholders have to be at the center of what you are doing. They have to be engaged from the very first day in conceptualizing the product or application. They have to have ownership of it and be committed to continuing it. That's the only way that applications happen, that they are adopted, and sustained for the long term, and have a real impact."

BRINGING SCIENTISTS TOGETHER TO STANDARDIZE METHODS

Application: Marine Biodiversity Observation Network Pole to Pole of the Americas (MBON Pole to Pole)

Partners: NOAA, Office of Naval Research, Bureau of Ocean Energy Management

In brief: MBON Pole to Pole is building a community of practice from the Arctic down to Antarctica to help scientists exchange information and knowledge, coordinate their approaches, and share techniques to monitor sea life.The initiative encourages the publication of data and information on existing ocean observation systems and open-source software applications. This requires scientists to capture the information in certain units and formats to ensure it is directly comparable to data sourced elsewhere and at other times. MBON Pole to Pole also fosters the use of remote sensing data in the analysis of in situ marine data. Because many marine biologists and ecologists are not trained in this type of data management or remote sensing, MBON Pole to Pole has templates, code in R programming software and applications that allow people to easily access satellite data, visualize it, map it, and create time series analysis. The project also developed applications for satellite seascapes, a marine habitat classification based on machine learning. These models, along with the standardized information, allow scientists to infer the biodiversity of vast portions of the ocean and how it is changing over time.

Enrique Montes
Biological oceanographer at NOAA's Atlantic Oceanographic and Meteorological Laboratory

"One of the things we've learned through this work is that organizing large groups in different countries, working under different conditions, is a major, major task. People are usually very busy. You have to be very mindful of their time. And you have to demonstrate a tangible output of these conversations, that you are going to accomplish something with them. Maybe the incentive is for them to build their toolbox of skills, or find collaborators for journal articles, or even find opportunities for their students and postdocs to attend conferences or work in other labs.

It's very important to tackle these challenges with a lot of passion. It can be painful sometimes when your calendar and your to-do list is absolutely packed. But the investment pays off. You make a lot of new friends and build amazing collaborations. You end up developing fantastic joint proposals that you never would have thought of on your own and doing super cool science you never imagined doing.

For decades, scientists have been framed in a system based on how many citations you get or how much money you raise for your program. That's fine, but that may not be the most effective measure of how to make real transformation. Hopefully in a few years, these conversations about the value of sharing data and having

access to high quality standardized data will be in the past. We'll stop talking about them because we will have organized ourselves. We will have work flows for the data to reach people's computers. And those people will have the capacity to analyze those data.

Tip for applications developers: It's really important to have people of all career stages and diverse disciplines, and from all possible backgrounds on your team. You really need the early career scientists because they bring tremendous energy and the desire to push these things forward. Their participation can be catalytic."

PROTECTING WHALES FROM SHIP STRIKES

Application: WhaleWatch

Partners: NOAA, Oregon State University

In brief: WhaleWatch combines satellite telemetry data from tagged whales with remotely-sensed ocean data to produce near-real time alerts of whale density off the California coast. The WhaleWatch tool creates monthly maps that predict whale occurrence and whale densities.The original application was based on 15 years of blue whale tracking data considered in relation to environmental variables, resulting in a habitat-based model. The original project has evolved with more funders and stakeholders into a WhaleWatch 2.0, available on the NOAA Coastwatch webpage.

Helen Bailey
Research professor at the University of Maryland Center for Environmental Science

"No one, no shipowner, wants to hit a whale or come into port with a dead whale across their bow. It's bad PR, it does damage to their ships, and it's obviously very bad for the whale - many species of which are endangered. So NOAA, the shipping industry, the Navy, and other marine users have been very interested in finding ways to reduce ship strikes.

A really key factor with Whale Watch was not only working with NOAA but also communicating with our other stakeholders. I think scientists, a lot of times, think that as long as they publish papers, then everybody will know about their work. And of course very few people actually read scientific papers. So with WhaleWatch, it was really important to communicate with our stakeholders and make sure they understood what we were working towards and what we were producing and making sure that the format we were presenting it in would work for them.

We were fortunate that the NOAA West Coast Region office had a lot of contacts with the shipping industry and with fishermen so that they could attend our presentations over the 4-year project. So they knew what our plans were, how the project was progressing and then the final products that we produced.

And obviously if no one had known about it, it would not have had any impact. So those steps to disseminate those findings were really important.

A tip for applications developers: Understand what transitioning an application really means. Often, we think that's handing over our data. But transitioning really means you have a plan of how someone else is going to *use that information, how they are going to access it, how they can potentially update it if needed, and how this tool will be used in their own work. That means it's important to be open and transparent about how it was developed. Documenting everything is very, very key to making sure it can be used by the end user and other stakeholders and that it can be modified and updated in the future."*

FIGHTING FIRES FROM THE SKIES

Application: Weather Research Forecasting–SFIRE (WRF-SFIRE)

Partners: U.S. Forest Service, University of Colorado-Denver, San Jose State University

In brief: Because high intensity fires actually create their own weather, WRF-SFIRE couples a weather model and a fire spread model to simulate large-scale wildfires. Historically, wildfire prediction work was often based on expert knowledge and judgment, or else simple, stripped-down models. This application improves on that empirical approach with a fully dynamical, open source model. The application uses remote-sensing information and other data to look at the land surface, the vegetation, the fire itself, and the smoke produced by the fire. Putting that data into the model returns information to forecast the fire spread, the air quality, the visibility and the dryness of the vegetation, which helps fuel the fire. Simulations enable analysts to predict fire behavior and its effects on air quality.The outputs are easily accessible through a web portal.

Kyle Hilburn
Research associate at the Cooperative Institute for Research in the Atmosphere at Colorado State University

"While the US Forest Service is our primary user, many other agencies and organizations use WRF-SFIRE. All of them have different needs and want to see the information presented in different ways. For example, National Predictive Services, a federal coordinating body, is trying to forecast fire conditions, so they want to know how dry the fuels are. The people out in the field who have to deploy aircraft need to know about visibility and smoke concentrations, to know whether they can get their planes off the ground, and whether they can get them back.

When we started working on the system, we were focused on fire prediction and fire spread. At some point, a user asked us: "Can you tell us where the smoke will go? We would like to know the air quality consequences of the fire."

We had the information but had never just thought about sharing it. We added it right away. Now, we have outputs showing the concentrations of air pollutants.

There is a balance, though, because if you add every possible layer of information, then it will be easy for users to get lost in the data. These people don't have time to think, "Oh, did I interpret that data right?" They need to be able to see a threshold and pull a trigger on the decision. That clarity is almost as important as the science. To a scientist, it might not seem like a big deal, but to the users, that's really critical. And that's why you need to really listen to the users — they will tell you how to make the product better and more useful.

Tip for applications developers: At the outset, try to wrap your head around the computational needs. How are you going to manage the resources? When I think about where the country needs to go on fire modeling, I see that high performance computational resources are going to be the biggest issue, more so than the physics, more than the data. The compute is a huge issue that needs to be well considered for the application to grow."

FORECASTING MOSQUITO POPULATIONS TO PREVENT DISEASE

Application: Epidemic Prognosis Incorporating Disease and Environmental Monitoring for Integrated Assessment (EPIDEMIA)

Partners: South Dakota State University, U.S. Geological Survey, Amhara Public Health Institute, Bahir Dar University, Ethiopian Public Health Institute, and the Health, Development, and Anti-Malaria Association

In brief: EPIDEMIA combines epidemiological and remote sensing data to create a predictive model on mosquito populations in the Amhara region of Ethiopia. The aim is to provide early warning on possible malaria outbreaks. Developed in tandem with a similar model called ArboMAP, which tracks West Nile Virus in the U.S., the first step in creating EPIDEMIA was a proof of concept on the combination of epidemiological and remote sensing data. The second phase was to implement early warning systems to connect the data to decision-making and make it actionable. The outcome is regular reports that enable health officials to decide when to issue public alerts about possible outbreaks and how to allocate resources for mosquito control and other actions.

Mike Wimberly
Professor of Geography and Environmental Sustainability, University of Oklahoma

"We started collaborating with scientists in Ethiopia by holding co-design workshops. We went in with this vision that, hey, we're the scientists, we're the experts at crunching the data and modeling, so we're going to do this in our space, on our computers, and we'll set it up so that people can log into them and get access to the outputs.

But then when it came down to it, our partners started saying things like, "What are we gonna do in terms of long-term implementation? What are we going to do when your research grant is over? Who is going to manage this? Can we get a server? Can we put this on one of our servers?" The idea of ownership was really important to them. And this was when I learned that we really needed to have a flexible mindset. We realized we had to be willing to let go of ego, let go of the connection with the idea that we built this, that this application is a reflection of us.

We completely shifted the vision of what we wanted to do. We went from creating a web-based system for somebody to log in to, push a button, and download a forecast to actually taking technology and making it usable by people in Ethiopia. We figured out a way to get them access to the remote sensing data and we set it up so that they could use the data to run the application from their own computers.

Tip for applications developers: There's a tendency for scientists to want to over-engineer things when, very often, the most ubiquitous and straightforward solutions are the answer. They may not be not necessarily the most technically advanced tools, and they might not have the slickest interface, but if they are practical and your user can and will use them, then they are probably the right tools."

WHERE TO GO NEXT

CONTINUE THE JOURNEY

Enabling people to apply insights from Earth science is what drives us in Applied Sciences. Our rewards are all the stories we hear of people finding amazing ways to use this information to serve society. It doesn't get much better than that.

The end of this guidebook is really just a beginning. Please use the information and tips to make your own applications that much better — and pass along what you learn.

Lawrence Friedl
Director, NASA Applied Sciences Program

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