FROM THE STRATOSPHERE TO THE SUBSURFACE

Battelle's Work in the Geosciences

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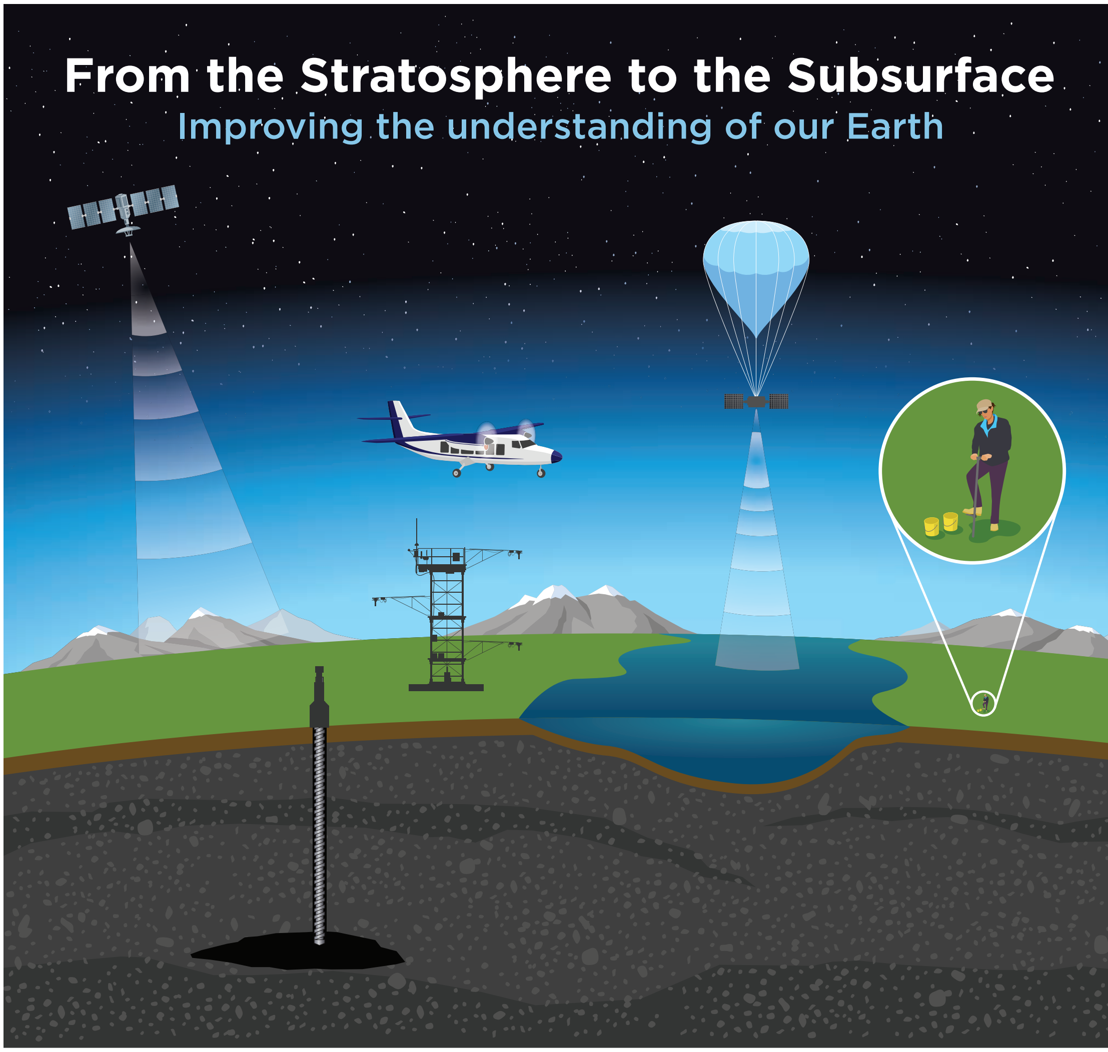

From the Air

Remote sensing and atmospheric monitoring technologies like Stratospheric Ballooning. Battelle successfully deployed a balloon carrying a 70+ pound payload to 121,000 feet.

At the Surface

We gather meteorological, geochemical and ecological data to help researchers understand the interactions between biological and non-biological systems. Networks like NEON instrument towers (located at 47 terrestrial field sites), collect weather and climate data, including temperature, precipitation, wind speed, radiation levels, and carbon, water and energy fluxes.

Near Subsurface

In the Critical Zone (with typical depths between 0 and 50 meters), the near subsurface is highly active—biologically, geochemically and hydrologically. Our teams provide support for site characterization and permitting, environmental monitoring and remediation.

Deep Subsurface

Battelle's work extends deep underground, to depths of 4,000 or more meters below the surface. Over the last 20 years, we have led the way in characterizing and modeling subsurface reservoirs in the Midwest to support safe Carbon Capture and Storage (CCS).

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Battelle is bringing together research excellence, applied science, and technology development in geosciences to improve understanding of our Earth—on all seven continents, from pole to pole, and from miles above the surface to deep underground. We're applying our expertise to advance geoscience research and address real-world challenges such as energy sustainability, climate resilience and environmental remediation. We're also developing the next generation of scientific talent through our partnerships with agencies and academic institutions.

Our work focuses on:

- Bringing scientific communities together to advance our understanding of Earth systems
- Translating technologies used across industries for the geoscience community
- Scaling emerging methods and technologies from the lab to field deployment
- Managing large-scale scientific programs for the ecology, energy, environmental and geoscience sectors
- Working with communities to understand the impacts of climate change and build climate resilience
- Partnering with academic institutions through STEM initiatives in geosciences, ecology and related fields

Understanding our planet is an important part of our not-for-profit purpose, so Battelle funds internal research and development efforts in geophysical modeling, analytical chemistry, sensor technologies and more. Here are a few examples of our work in the geosciences, from the air to the subsurface.

Geoscience Capabilities

- Ecological and environmental data collection and monitoring
- Environmental characterization, cleanup and monitoring
- Subsurface modeling and characterization
- Technology development and translation
- Operations and logistics for large-scale scientific programs

From the Air

Our geoscience work starts far above the ground, with remote sensing and atmospheric monitoring technologies. We can conduct remote sensing using a variety of platforms (including drones, airplanes and stratospheric balloons) and sensor technologies (such as lidar, hyperspectral imaging and high-resolution photography). Remote sensing technologies allow us to:

- Characterize land cover types and surface materials (e.g., vegetation cover, rock/mineral types, surface water, manmade structures and surfaces, etc.)
- Create detailed 3D maps of surface topography or vegetation structure
- Measure surface albedo, temperature, soil moisture and other surface characteristics
- Monitor how surface characteristics (e.g., average temperatures, albedo, land cover, topography) are changing over time or in response to a disruption
- Observe how water moves through a watershed and map the morphology of rivers, lakes and coastal areas
- Identify urban heat islands and green spaces
- Estimate permeable/non-permeable surface area for runoff modeling, flood prediction or storm water system planning

STRATOSPHERIC BALLOONING

Battelle has validated stratospheric ballooning methods and technologies, working in partnership with ISTAR Stratospheric Ballooning. Stratospheric balloons carry a payload, which can include various sensor technologies, into near-space (10–50 km, or 32,000–164,000 feet). Battelle successfully deployed a balloon carrying a 70+ pound payload to 121,000 feet. Ballooning provides a cheaper and faster path to near-space than rocket technologies and can be used for many different kinds of research programs.

Payload

Stratospheric balloons can carry a variety of sensors, including high-resolution cameras, imaging spectrometers or meteorological instruments.

Potential Uses

- Upper-atmosphere meteorology
- Imaging of large areas from a near-space vantage point
- Technology testing and validation in near-space conditions

AIRBORNE REMOTE SENSING

The NEON Airborne Observation Platforms (AOPs) are light aircraft equipped with a sensor array for collection of high-resolution data from the Earth's surface. They take a variety of measurements at each of the NEON terrestrial field sites during "peak greenness," with data products available through the open-source NEON Data Portal. They can also be contracted for use by other research programs through the NEON Assignable Assets Program. The AOPs gather geophysical and ecological data over a large land surface (kilometers square) in a short amount of time, at a resolution much higher than possible with most satellite imaging technologies. Battelle can also support drone data collection with custom payloads for higher resolutions and smaller areas.

Standard Payload

- Discrete and full-waveform lidar (Light Detection and Ranging) (spatial resolution 1.0 m)
- Hyperspectral imaging spectrometer (spatial resolution 1.0 m, 5 nm bands, 380 – 2500 nm spectrum)
- High-resolution RGB digital camera (spatial resolution 0.10 m)
- GPS antenna/receiver and Inertial Measurement Unit for high-accuracy positioning
- Additional instruments may be requested (at researcher expense) through the Assignable Assets program.

Potential Uses

- High-resolution topography and land cover mapping
- Vegetation canopy structure, community composition and productivity
- Land use change studies

The NEON Program

Battelle has been the program manager for the National Ecological Observatory Network (NEON) since 2016, successfully leading the program through the final stages of planning and construction and the transition to full operations. NEON is a 30-year, continental-scale observation program for the collection of open-source ecological data. More than 200 data products are collected at 81 terrestrial and aquatic field sites located in 20 ecoregions across the U.S., making this one of the largest-scale ecology programs in the world. NEON data products of interest to the geosciences include meteorological measurements; atmospheric-terrestrial carbon, gas and energy fluxes; soil moisture, temperature, chemistry and physical properties; water chemistry and temperature; and various remote sensing data products from the airborne observations platforms (AOPs). NEON infrastructure can be leveraged by other organizations and individual researchers through the Assignable Assets Program.

At the Surface

At or just above the surface, we gather meteorological, geochemical and ecological data to help researchers understand the interactions between biological and non-biological systems. Data collection through distributed networks like NEON, coupled with advanced data analytics and machine learning, provide researchers with the tools to measure and monitor:

- How the climate is changing over time in different ecoclimate zones, and how these changes impact biological and non-biological systems
- Carbon, water and energy fluxes between the atmosphere and terrestrial or aquatic biotic and abiotic systems
- How soil and water biogeochemistry are changing over time and across a variety of ecosystems
- The impact of large meteorological events (such as storms) or other disturbances (such as wildfires) on soil and water chemistry and ecosystem functions

NEON INSTRUMENT TOWERS

The NEON instrument towers, located at 47 terrestrial field sites, collect weather and climate data, including temperature, precipitation, wind speed, radiation levels, and carbon, water and energy fluxes (eddy covariance). Towers range from 8m to 74m, depending on canopy height at the site, and have four to eight sensor arrays to capture micrometeorological data across the full vertical profile from near the ground to the top of the canopy. Many data types are collected every second or multiple times per second. In addition to the fixed instrument towers, the NEON program has Mobile Deployment Platforms (MDPs) available through the Assignable Assets Program, which can be requested by researchers for periods of 6 months to two years.

Standard Tower Measurements

- Carbon and water concentrations, flux and isotopeconcentrations
- Dust (particulate size and mass, aerosol optical depth, wet deposition analysis)
- Radiation (direct & diffused, net short-wave and long-wave, photosynthetically active radiation (PAR))
- Phenological image/snow depth
- Meteorological (3D and 2D wind speed and direction; air temperature; barometric pressure; precipitation)
- Additional instruments can be added to the instrument tower at requester's expense

Potential Uses

- Measuring carbon, water and energy exchange between the atmosphere and terrestrial systems
- Estimating/comparing carbon storage potential of ecosystems
- Climate change monitoring

Soil and Sediment Observations and Samples

The NEON program collects both sensor data and physical soil samples at multiple soil plots in each of the 47 NEON field sites. Soil pit samples, collected to a depth of 1m at distributed soil sites during construction, were used to characterize dominant soil types at each site. Soil cores (30 cm) are collected every five years at soil plots. Physical samples (including pit, core and surface samples) are archived in the NEON Biorepository and available on request to support research programs.

A suite of chemical and physical analyses is performed on physical samples. In addition, automated sensors are used to measure soil physical, chemical and biological properties at multiple depths up to 2m. The NEON Mobile Deployment Platforms include soil sensor arrays for data collection outside the NEON field sites.

Standard Data Products

- Soil moisture, temperature and carbon concentration (at multiple depths)
- Solar radiation, photosynthetically active radiation (PAR), heat flux and throughfall (at soil surface)
- Microbial communities
- Soil texture, bulk density and organic horizon mass
- Biogeochemical analyses including pH, cations, anions, total carbon (C), nitrogen (N), phosphorous (P) and sulfur (S), fractions C and P, select soil N transformations (i.e., net N mineralization and net nitrification)

Potential Uses

- Studying fluxes of carbon, nutrients and energy between soil, water and biological systems
- Soil productivity studies
- Comparison of dominant soil types and specific soil chemistry across and within regions
- Permafrost monitoring (in tundra/taiga regions)

Antarctic Ecological Modeling

The McMurdo Dry Valleys in Antarctica are the largest ice-free area on the continent. They are of particular interest as a sentinel ecosystem for understanding the effects of climate change. Battelle is leading ecological modeling efforts for a project led by Northern Arizona University in collaboration with the University of Colorado – Boulder, Virginia Tech and Colgate University. The project leverages biodiversity and environmental data from the McMurdo Dry Valleys Long Term Ecological Research (MCM LTER) program along with satellite and remote sensing imagery and data to build ecological models that will predict how the distributions of sentinel taxa (such as cyanobacteria, diatoms and mosses) will respond to changing abiotic drivers (e.g., a shift in the availability of liquid water in the landscape). The team demonstrated that remote (satellite) imagery can be used to map the occurrence of active biology (cyanobacterial mats) in the landscape. Developing methods that use remote imagery and do not require field campaigns are increasingly important to monitor ecosystem changes in remote areas and observe and make predictions at the landscape scale.

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SURFACE WATER AND GROUNDWATER OBSERVATIONS AND SAMPLES

The NEON program collects measurements on physical and chemical properties of groundwater and surface water in both lentic (e.g., lake or pond) and lotic (e.g., river and stream) aquatic systems. These measurements provide insight into hydrological and hydrogeochemical systems and how they are responding to climate and ecosystem changes across the country. Aquatic field sites are equipped with sensor arrays for surface water measurements and groundwater wells for monitoring of groundwater properties. Water and sediment samples are also collected and stored in the NEON Biorepository.

Standard Data Products

- Water depth (all) and stream discharge rates (for lotic systems)
- Turbidity
- Water chemistry (dissolved oxygen, pH, dissolved organic matter, chlorophyl, nitrates, stable isotopes)
- Temperature (including temperature profiles at different depths)
- Surface and underwater photosynthetically active radiation (PAR)
- Microbial communities
- Meteorological measurements (temperature, barometric pressure, wind speed)

Potential Uses

- Studying fluxes of carbon, nutrients and energy between soil, water and biological systems
- Water quality studies
- Hydrological studies (e.g., changes in water level or discharge rates over time or in response to a disturbance)

Water-Level Rise Impact Modeling

On behalf of the U.S. Navy, Battelle's Environment Division utilized high-resolution photogrammetry acquired through an unmanned aerial survey to assess the impacts of water level rise on shoreline landfills and other features of interest around the shores of Andrew Lake on Adak Island, Alaska. This study specifically assessed the possible inundation of a shoreline landfill in the likely event that the Navy discontinues management of the water level in Andrew Lake. The photogrammetry was used to develop a bare-earth digital terrain model detailed enough to support 1-foot contour interval topography of the lake shoreline. A GIS algorithm was then used to create step-wise images that colored each foot of topographic change blue, in succession, up to the extreme maximum plausible lake level rise.

Sediment Transport Studies

At Naval Base Kitsap Bangor, Battelle's Sequim, Washington marine research laboratory conducted a sediment transport study to assess changes in littoral drift and potential impacts on beaches and marine habitat that could result from Navy modification of shoreline infrastructure. The mathematical modeling package utilized, Delft3D, simulates surface water flow, sediment transport and morphology, waves, water quality and ecology.

HYDROLOGY

The movement of surface water impacts human infrastructure, ecological habitats, and the movement of contaminants introduced into the environment. These impacts change as climate change and sea level rise alter surface water movement. Battelle studies and models surface water movement to predict these changing impacts.

Methods

- Unmanned aircraft equipped with high-resolution photogrammetry and precision GPS
- GIS digital terrain modeling
- Delft3D mathematical modeling

Potential Uses

- Estimating impacts of changes in surface water flow, including sea level rise, on human infrastructure
- Evaluating impacts of infrastructure changes on habitats

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Near Subsurface

In the Critical Zone (with typical depths between 0 and 50 meters), the near subsurface is highly active—biologically, geochemically and hydrologically. It is also the subsurface zone most impacted by human activities. Battelle is developing technologies and methods for modeling and characterizing subsurface geology and hydrology, detecting and monitoring contaminants in soil, sediments and groundwater, and remediating contaminants of concern. Our work is advancing our understanding of how water and other liquids move underground and how they accumulate, migrate and disperse. Our teams provide support for:

- Site characterization
- Environmental monitoring and remediation
- Site permitting

GROUNDWATER AND CONTAMINANT FATE AND TRANSPORT MODELING

Fate and transport modeling helps understand the movement of contaminants through aquifers in the environment. It requires extensive understanding of the movement of groundwater and surface water and well as how specific contaminants interact with water, soils and minerals.

Our experience in fate and transport modeling includes PFAS, hydrocarbons, chlorinated solvents and many other contaminants of concern. Our modeling methodology helps to understand the intricacies of groundwater flow and contaminant fate and transport modeling at sites to assist in predicting future outcomes and compare remedy alternatives.

Methods

- Conceptual site modeling (CSM) to define site hydrostratigraphy, groundwater conditions, and extent of contamination
- Multiple-phase modeling (free-phase, dissolved phase and vapor phase) using STOMP, CMG-GEM, TOUGH and other advanced models
- Hydrogeologic modeling and visualization, including geologic framework visualization and GIS and database integration and visualization

Potential Uses

- Groundwater flow modeling
- Contaminant fate and transport evaluations
- Natural attenuation studies
- Risk assessment/remediation system performance assessment

SUBSURFACE CHARACTERIZATION AND VISUALIZATION

Environmental remediation starts with understanding exactly where contaminants are present in soils, sediments, groundwater and surface water. The Battelle Environmental group uses a variety of methods to characterize and visualize contaminant plumes in terrestrial and marine environments. These same methods can be used to create 3D maps of near-subsurface (tens to hundreds of feet) geological and hydrogeological characteristics.

Methods

- High-resolution site characterization using core sampling
- Groundwater well drilling and monitoring
- Geophysical imaging (e.g., electrical resistivity)
- Chemical fingerprinting

Potential Uses

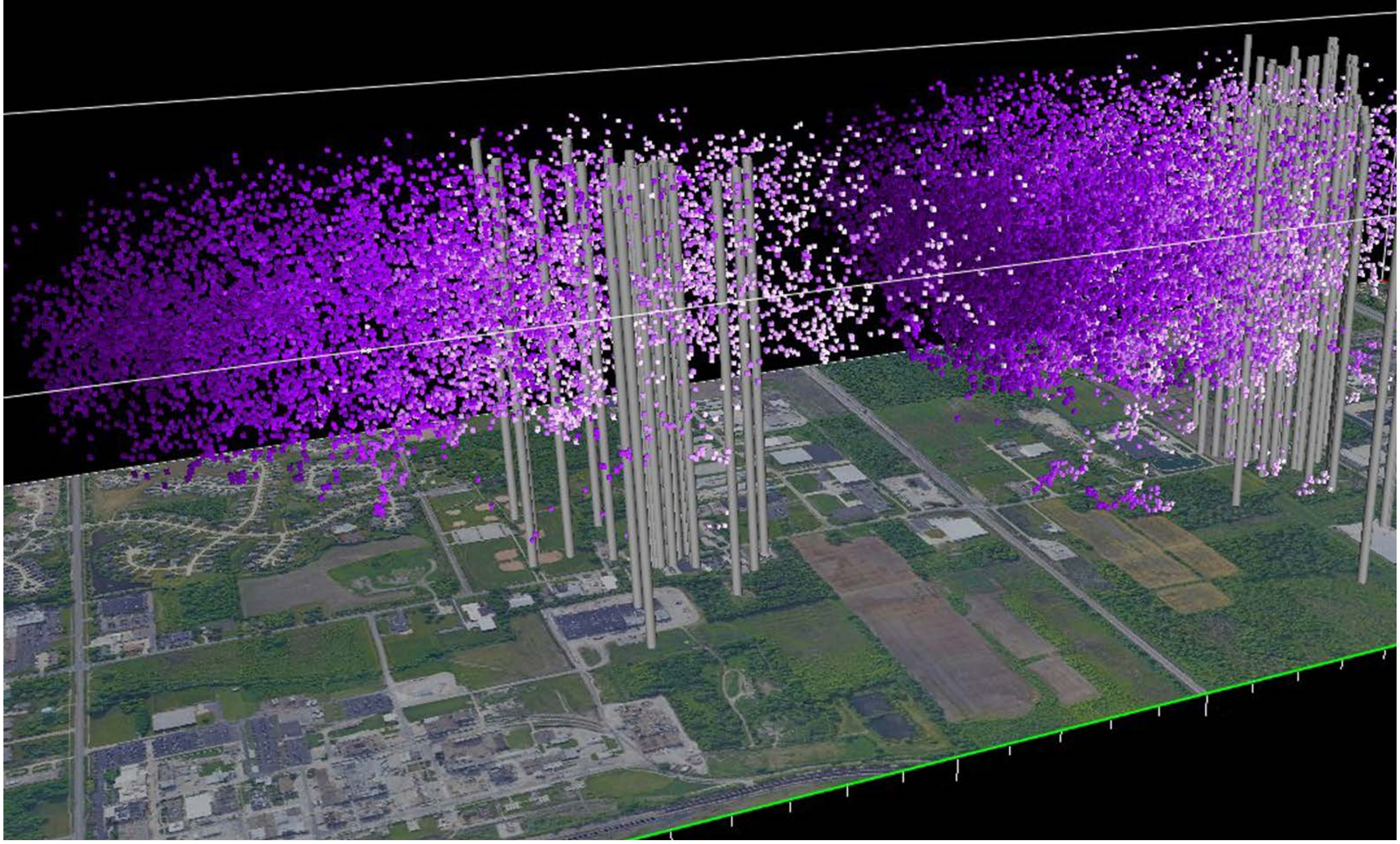
- Contaminant plume modeling
- Hydrogeological modeling

PFAS Predict™

Per- and polyfluoroalkyl substances (PFAS) are a growing environmental problem because of the way they persist in the environment. Battelle is pioneering new analytical and modeling methods to enable better monitoring and mitigation of PFAS contamination. Our PFAS Predict™ program simulates PFAS fate and transport in groundwater with specific inputs for PFAS chemicals, aquifer properties and source release terms related to PFAS. The model features:

- Advection
- Dispersion
- Degradation/reactions
- Diffusion
- Sorption
- Source release options

Battelle is also advancing new analytical methods and remediation and modeling technologies for PFAS chemicals.



Deep Subsurface

Battelle's work extends deep underground, to depths of 4,000 or more meters below the surface. Over the last 20 years, we have led the way in characterizing and modeling subsurface reservoirs in the Midwest to support safe Carbon Capture and Storage (CCS). The methods and technologies we have developed along the way can be applied for a variety of purposes in the energy, environmental and academic sectors. We're answering critical questions about the geophysical, geomechanical and geochemical characteristics of subsurface formations, including:

- The size, shape and structure of deep subsurface formations
- The geology of subsurface formations, including rock and mineral composition, permeability/porosity, stability and mechanical strength
- What fluids are present and how they are migrating through subsurface formations
- The capacity and suitability of reservoirs for deep geologic storage
- How formations may respond to different stresses such as drilling, injection or seismic activity

GEOMECHANICAL CHARACTERIZATION

Through our work with the MRCSP, we conducted geomechanical analysis of multiple reservoir formations to better understand regional and local stresses and the mechanical behavior of the rock within the reservoir and the layers of earth around it. In other words, how much stress is the formation currently under from compressive forces and internal pressure? How do the different rock formations move and behave under these stresses? How are they likely to move and behave under the stress of large-scale injection of CO_2 or other fluids? Laboratory testing was conducted on core samples of the primary caprock and the different types of rock found in the reservoir itself.

Methods

- Mechanical properties
- Unconfined and confined compressive strength
- Tensile strength

Potential Uses

- Characterize mechanical properties of underground formations
- Predict response to different stressors, such as seismic activity, drilling or injection

Distributed Acoustic Sensing (DAS)

Battelle tested applications for Distributed Acoustic Sensing (DAS) technology at a NEON field site. DAS uses fiber optic cable to collect acoustic (sound) data. Pulses of light are sent down the cable and then bounce back to the sensor. Acoustic events disturb the fiber and cause variation in the return signal, known as "backscatter." Different types of acoustic events (such as seismic events, foot traffic, vehicles, etc.) have distinctive wave patterns. The Battelle project repurposed existing fiber optic cable at the NEON instrument hut to turn the cables into a powerful acoustic sensor. The sensor was used to pick up signals from seismic activity, wind, human foot and vehicle traffic, and cattle movement at the site. DAS will enable long-term, persistent monitoring of acoustic activity at the site, which in the future could include geological, hydrological, meteorological and biological (human and animal) activity. Since it utilizes an already existing asset, the study represents a non-invasive option for gathering a powerful new data product from the NEON infrastructure.

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SUBSURFACE MODELING

Battelle has used and validated several methods of subsurface modeling. As part of the MRCSP project, we created computerized reservoir models that represent the physical space of reservoirs in the Michigan Basin and their attributes (e.g., porosity, permeability, fluid saturation, pressure) at different points in space. In the process, we created the most accurate and robust pictures of reservoir characteristics and storage capacity in the region to date. The Battelle team also tested and validated a variety of modeling approaches to determine the best methods for different purposes and geologies. Our work provided a better understanding the types and minimum amounts of data needed for accurate modeling and forecasting, which will help to control costs for site characterization and reservoir modeling.

Methods

- Static Earth Modeling
- Dynamic Reservoir Modeling

Potential Uses

- Understand geology and hydrology of complex subsurface formations
- Estimate storage capacity of deep geologic formations
- Model expected behavior and migration of fluids (such as injected CO_2) within a formation

OPERATIONS AND MONITORING

Battelle oversaw injection operations and ongoing monitoring for large-scale CO_2 injection testing projects in the Michigan Bason between 2013 – 2019. More than 1.3 million tons of CO_2 were injected into deep geologic formations for permanent storage and Enhanced Oil Recovery (EOR). Battelle oversaw logistics and project management for the program, including permitting, safety assessments, construction, daily operations and ongoing monitoring. In addition, we assessed, adapted and validated a variety of tools for monitoring during and after injection of CO_2 into the reefs. Our analysis allowed us to determine which tools were most accurate, useful and cost-effective in different scenarios.

Methods

- Seismic Imaging: Vertical Seismic Profile (VSP) and Distributed Acoustic Sensing (DAS), microseismic
- Geophysical Logging: Borehole Gravity, Bottom Hole Pressure (BHP) Monitoring, Pulsed Neutron Capture (PNC)
- InSAR (Satellite Radar)
- Distributed Temperature Sensing (DTS)
- Fluid Chemistry

Potential Uses

- Track movement of fluids within a formation and determine fluid saturation levels
- Detect possible leaks and monitor the integrity of the well or formation
- Detect induced seismic activity or uplift in the area around an injection site (via InSAR)

MRCSP/MRCI

The Midwest Regional Carbon Sequestration Partnership (MRCSP) was formed in 2003 to assess the technical and economic viability of Carbon Capture and Storage (CCS) in the Midwest. Battelle was chosen to lead the public-private consortium of nearly 40 government, industry and university partners through three phases of research and development. Between 2003 and 2019, MRCSP successfully captured and sequestered more than two million tons of carbon dioxide in deep geologic formations. Battelle led the project through three phases of validation, demonstration and scale-up to commercial operations. This work included:

- Modeling and characterization of deep underground formations.
- Drilling and operation of injection wells for carbon sequestration.
- Monitoring wellbore conditions and deep reservoir temperatures and pressures.
- Safely and permanently capping injection sites.

Battelle has now been chosen to continue this work through the Midwest Regional Carbon Initiative (MRCI), a 20-state consortium co-led by Battelle and the Illinois Geologic Survey. Over the last 20 years, Battelle has developed and validated technologies and methods for subsurface characterization, modeling and monitoring that can now be applied for commercial-scale CCS and other geophysical, environmental and energy projects.

Around the Globe

Battelle works with academic and scientific organizations across the country and around the world to advance the geosciences. Our work includes:

- STEM education and workforce development
- Cross-organizational initiatives and consortium building

BUILDING COLLABORATIONS ACROSS SCIENTIFIC NETWORKS

Battelle is working to bring researchers interested in Earth systems together to tackle complex questions, improve models and predictions, and move science forward.

- The NEON program actively works with other NSF-funded programs and other organizations involved in large-scale data collection, including the National Center for Atmospheric Research (NCAR), the Long-Term Ecological Research (LTER) Network, the Critical Zone Collaborative Network, and others. The open-source data collected by the program is freely available to researchers and the public and has been used by hundreds of individual researchers working in earth sciences and ecology.

- Battelle also has a long history of working with government agencies such as NASA and NOAA to support remote sensing projects and other initiatives related to geosciences. Our work includes development, testing and validation of advanced technologies and methods used to support the scientific missions of these agencies.

As the scientific community grapples with ever more complex and interconnected questions around climate change and the functions and dynamics of Earth systems, forging these collaborative efforts will be increasingly important. We will continue to participate in efforts to break down silos between disciplines in the geosciences, ecology and environmental sciences so we can all work together to create a better understanding of the Earth.

CREATING OPPORTUNITIES FOR THE NEXT GENERATION OF SCIENTISTS

STEM (Science, Technology, Engineering and Math) education has always been part of our mission at Battelle. We are committed to creating opportunities for students and early-career scientists through internships, externships, STEM education grants and workforce development initiatives. A large part of our focus is on creating pathways and opportunities for students from groups traditionally underrepresented in the sciences, including Black and indigenous students.

- Battelle created the Historically Black Colleges and Universities (HBCU) Consortium to develop meaningful, long-term relationships with leading HBCUs and connect their students with workplace experiences and mentorship in the sciences.

- The NEON program is actively working to engage indigenous communities in the areas in which they work, including Alaska, Hawaii, and the western U.S. A recent collaboration with the American Indian Higher Education Consortium (AIHEC) brought students from tribal colleges to a NEON field site to get hands-on experience in field data collection.

- Battelle supported a stratospheric ballooning program for Sisters High School in Oregon. The RISE program is led by Steven Peterzen of International Science Technology and Research (ISTAR) and gives high school students the opportunity to design and implement their own stratospheric research projects.

These and other STEM programs funded or otherwise supported by Battelle are bringing more students into geology, ecology, environmental sciences and related fields. These students and early career scientists are the future of the geosciences.

Linking the Geosciences and Ecology

The NEON program has partnered with the National Center for Atmospheric Research (NCAR) for a series of workshops linking the ecology and geoscience communities. The first workshop was held in 2019. “Predicting Life in the Earth System: Linking the Geosciences and Ecology” focused on bringing together convergent research from the atmospheric and ecological sciences to improve Earth system models and forecasting at the sub-seasonal, seasonal, annual, decadal and centennial timescales. In the fall of 2021, the groups came back together for a series of talks and working sessions to continue to build synergies. The 2021 workshops focused on three broad topics:

1. What can ecology bring to atmospheric sciences and what can atmospheric sciences bring to ecology?
2. What tools have been developed to better understand these interactions?
3. How can the NEON program bridge the gap between ecology and atmospheric sciences?

The outcomes of this partnership will help the science community build better Earth System models using data collected across different scales, from satellite remote sensing to on-the-ground observations.

For more information on specific research for Battelle-led work, contact **solutions@battelle.org.**

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It can be done

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