Earth and Atmospheric Sciences

Understanding the critical role Earth processes play in energy, environmental, and national security missions.

Science at a Global Scale

Earth and atmospheric sciences play a central role in Lawrence Livermore National Laboratory's (LLNL's) mission-driven work. LLNL scientists bring unique expertise and capabilities to advance engineering applications above, on, and below the Earth's surface. From refining space-based observations to analyzing seismic signals under the Earth's crust, LLNL's research teams apply their expertise to making our planet safer and more resilient.

For decades, LLNL scientists have been at the leading edge of climate science, forecasting the likely impacts of future emissions scenarios and supporting resilience planning. In parallel, Laboratory staff develop sustainable energy technologies and carbon management techniques to support a net-zero greenhouse gas future.

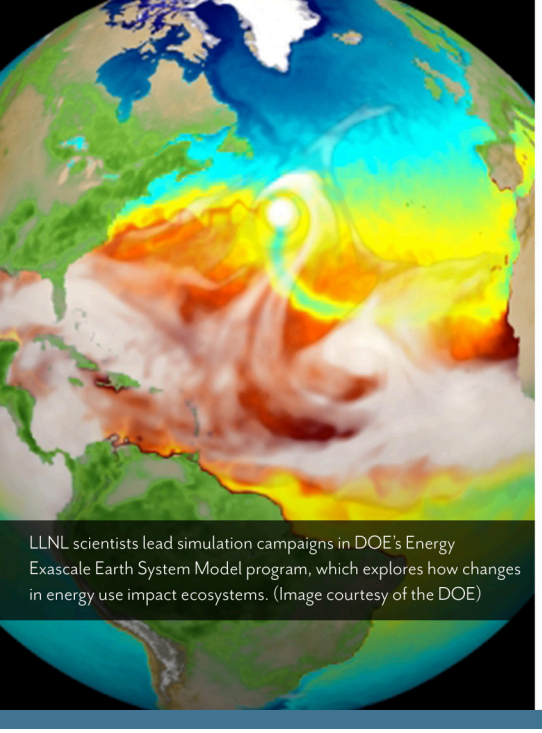
In the national security arena, LLNL advances global-scale monitoring techniques for identifying nuclear testing. The Laboratory's decades of innovations have strengthened response efforts for nuclear emergencies and hazardous material releases.

In these efforts, LLNL leverages state-of-the-art computational methods, validated with unique laboratory capabilities and large-scale field experiments.

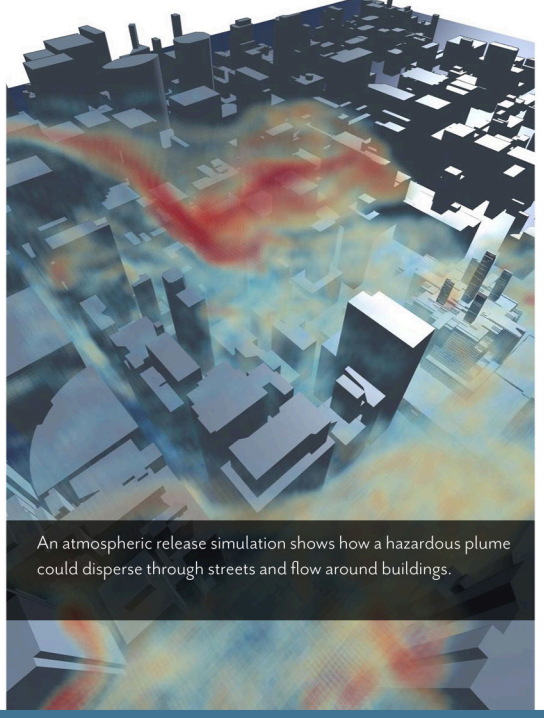
Applications

Researchers in the earth and atmospheric sciences continually innovate to make the world safer, the environment cleaner, and our energy resources more sustainable. Our key areas of research include seismology, geophysics, geomechanics, geochemistry, hydrology, atmospheric turbulence and dispersion, climate modeling and model intercomparison, climate change detection and attribution, energy systems, and carbon cycles. We maintain advanced experimental and computational capabilities to better understand the complex processes at the core of our mission applications. Select applications of LLNL's expertise in earth and atmospheric science are noted below:

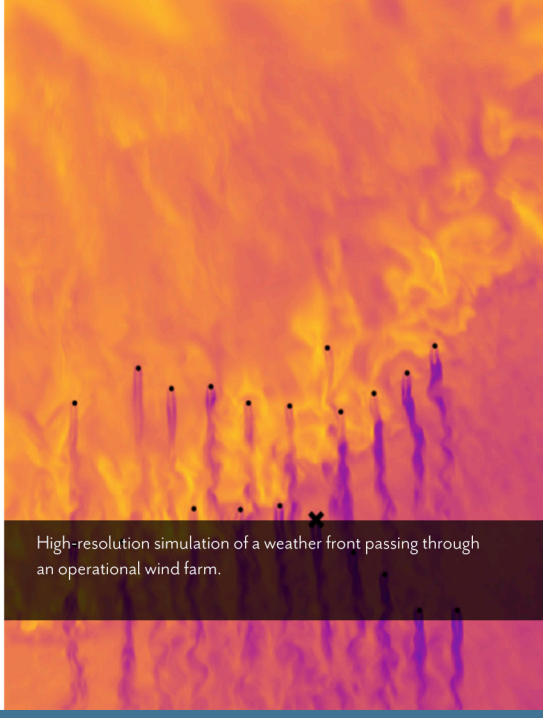
- LLNL is the lead institution in the Energy Exascale Earth System Model (E3SM) Project. This capability harnesses the world's largest supercomputers to model and understand anthropogenic impacts on our ecosystem.
- Climate Resilience has been identified as a Mission Focus Area for LLNL, coupling biogeochemistry, materials, geology and climate simulation with infrastructure analysis to mitigate greenhouse gas accumulation and predict climate impacts at scale. Several Laboratory efforts apply climate models to engineering and societal challenges to better inform investments in resilient infrastructure and communities.
- Atmospheric researchers develop high-fidelity atmospheric fluid dynamics, turbulence, and aerosol dispersion codes. These models are used to study atmospheric contaminant releases, nuclear weapons effects, wind and solar energy systems, and high-altitude flight environments.
- The Center for Accelerator Mass Spectrometry (CAMS) is a signature user facility providing ultra-sensitive isotope ratio measurements and ion-beam analytical techniques. CAMS conducts up to 25,000 measurements per year to support a wide array of scientific studies.
- LLNL maintains one of the most complete geomaterial modeling libraries available for national security applications. The library incorporates complex phenomena related to impact and explosions in hard rock and similar materials.
- LLNL leads development of GEOS, an open-source reservoir simulator for subsurface energy systems. This exascale capability, developed by a community of industrial and academic partners, has been used in numerous studies to support geologic carbon storage, geothermal energy, and hydrogen storage projects.



LLNL scientists lead simulation campaigns in DOE's Energy Exascale Earth System Model program, which explores how changes in energy use impact ecosystems. (Image courtesy of the DOE)



An atmospheric release simulation shows how a hazardous plume could disperse through streets and flow around buildings.



High-resolution simulation of a weather front passing through an operational wind farm.

Accomplishments

LLNL has been leading climate science research since the Laboratory developed the world's first atmospheric general circulation model in the 1960s. In earth science, LLNL scientific advancements have secured state- and federal-level policy support for critical carbon management technologies such as geologic carbon storage and geothermal energy. In the national security arena, LLNL researchers are key enablers in national and international agency cooperation regarding nuclear non-proliferation and nuclear emergency response.

Additional accomplishments in earth and atmospheric science are noted below:

- LLNL scientists participate in assessments conducted by the Intergovernmental Panel on Climate Change, a Nobel Prize–winning institution established in 1988 to provide the scientific basis for understanding climate change.
- Since 1979, the National Atmospheric Release Advisory Center (NARAC) at LLNL has been on call 24/7 to respond to hazardous release emergencies around the world. NARAC monitored data from radiation detection sensors in Ukraine (2022), responded to nuclear power plant failures at Chernobyl (1986) and Fukushima (2011), airborne hazards in the wake of Hurricane Katrina (2005), the Deep Water Horizon oil spill fire (2010), and the spread of ruthenium across central Europe (2017).
- The Stellar Occultation Hypertemporal Imaging Payload (SOHIP) prototype telescope, recently installed on the International Space Station, uses LLNL-patented technology to detect and characterize atmospheric waves and high-altitude properties such as temperature, pressure, and density at altitudes up to 50 kilometers.
- The Geophysical Monitoring Program at LLNL generates global-scale tomographic images of the Earth's interior to improve seismic and nuclear event monitoring. This work has also led to fundamental discoveries, such as identifying the previously unknown southeast Indian Ocean slab.
- LLNL led state-wide and national studies outlining feasible strategies to achieve net-negative greenhouse gas emissions. "Roads to Removal" is a national scale analysis of carbon dioxide removal required to achieve a net-zero greenhouse gas economy in the United States by 2050. "Getting to Neutral: Options for Negative Carbon Emissions in California" assesses the technologies and tradeoffs necessary to reach the state's decarbonization goal. These reports are critical for informing state and federal policy.

The Future

Over the next few years, LLNL is prioritizing several earth and atmospheric sciences investment areas to prepare for future challenges. These include:

- Enhancing regional-to-local seismic and nuclear event characterization through investments in machine learning methods, data fusion, big-data analysis, and exascale computing.
- Expanding research on emerging technologies like hydrogen storage and direct air capture of carbon dioxide. These technologies may play a critical role in a future net-zero greenhouse gas economy, but many bottlenecks remain in large-scale deployment.
- Providing decision makers, including U.S. agencies tasked with ensuring our national security, with actionable data to foster climate resilience. LLNL scientists are tackling several remaining challenges in using climate modeling data effectively for resilience planning.

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