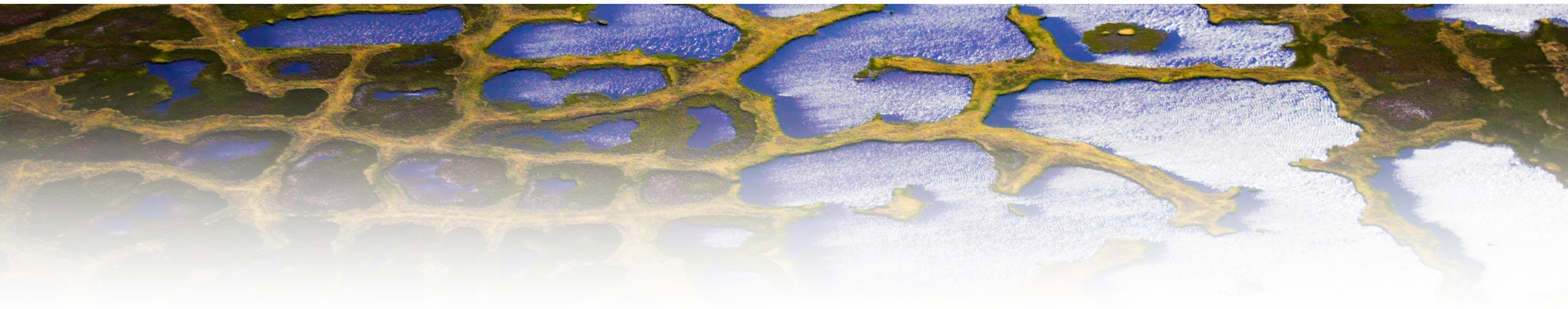
Climate Security
at Sandia



ARCTIC METHANE MEASUREMENT & MODELING

Current estimates indicate that the release of Arctic methane from thawing permafrost could consume 25-40% of the global carbon budget corresponding to a 1.5 degrees Celsius climate future — enough to substantially negate global mitigation efforts. Sandia seeks to resolve key scientific questions about potential Arctic methane release by enabling high-resolution, full system closure through measurement and modeling of both natural and anthropogenic sources. This work draws on our capabilities in atmospheric measurements and monitoring, high-performance computing and machine learning, biochemistry, and sensor systems, as well as our long history of research and operations in the Arctic.

THE CHALLENGE

Methane is a powerful greenhouse gas (GHG) responsible for 30 percent of global warming since the industrial revolution. Current carbon budgets specifically underestimate potentially significant Arctic methane sources, both natural like permafrost thaw and anthropogenic like oil and gas operations. In addition to understanding releases, major scientific questions remain about methane closure — the full cycle of methane in the atmosphere, from emission and transport to chemical reactions and subsequent sinks.

Arctic methane emissions, in particular, should play an important role in global climate policy decisions and actions. Current efforts like the Global Methane Pledge do not fully address permafrost sources of methane release and warming. Additionally, no direct technical solutions for mitigating permafrost methane release exist.

Major scientific and technical gaps in measurement, monitoring, and modeling capabilities of the methane cycle produce large uncertainties in current and future trajectories of Arctic methane emissions. In addition to scientific gaps like uncertainty in source contributions, technical gaps include sensor detection limits, sensor modalities, and spatial/temporal mismatches.

An integrated, strategic approach is required to track and predict carbon emissions from thawing permafrost. Science assessments and policy decisions at pan-Arctic scale need accelerated and integrated focus to provide the basis for implementing actions at time scales required to meet global climate targets.

VISION

Sandia seeks to resolve key scientific questions about potential methane releases in the Arctic. We work to enable high-resolution, full system measurement and modeling of both natural and anthropogenic sources of methane.

We have developed a conceptual architecture for understanding Arctic methane at the land-ocean interface, from the seabed to the land surface through the top of the atmosphere, that brings together both top-down and bottom-up assessments of the methane cycle (Figure 1). This system could help enable capture of land and ocean-based methane, as well as the identification of impacts to sea ice and transport from nearby anthropogenic sources. This architecture would require international cooperation across temporal and spatial scales and the incorporation of multiple technologies, including:

- satellites
- instrumented heliotropes for remote sensor validation
- instrumented manned and unmanned aerial vehicles (UAVs)
- meteorological tower with methane flux sensing
- tethered balloon observations (TBS)
- vertical profile distributed temperature sensing (DTS)
- distributed acoustic sensing (DAS) and DTS along seabed
- instrumented underwater gliders

This effort draws on Sandia's long history of year-round research and operations in the Arctic, as well as our experiences with methane measurement and modeling in the continental U.S., including New Mexico's Permian Basin.

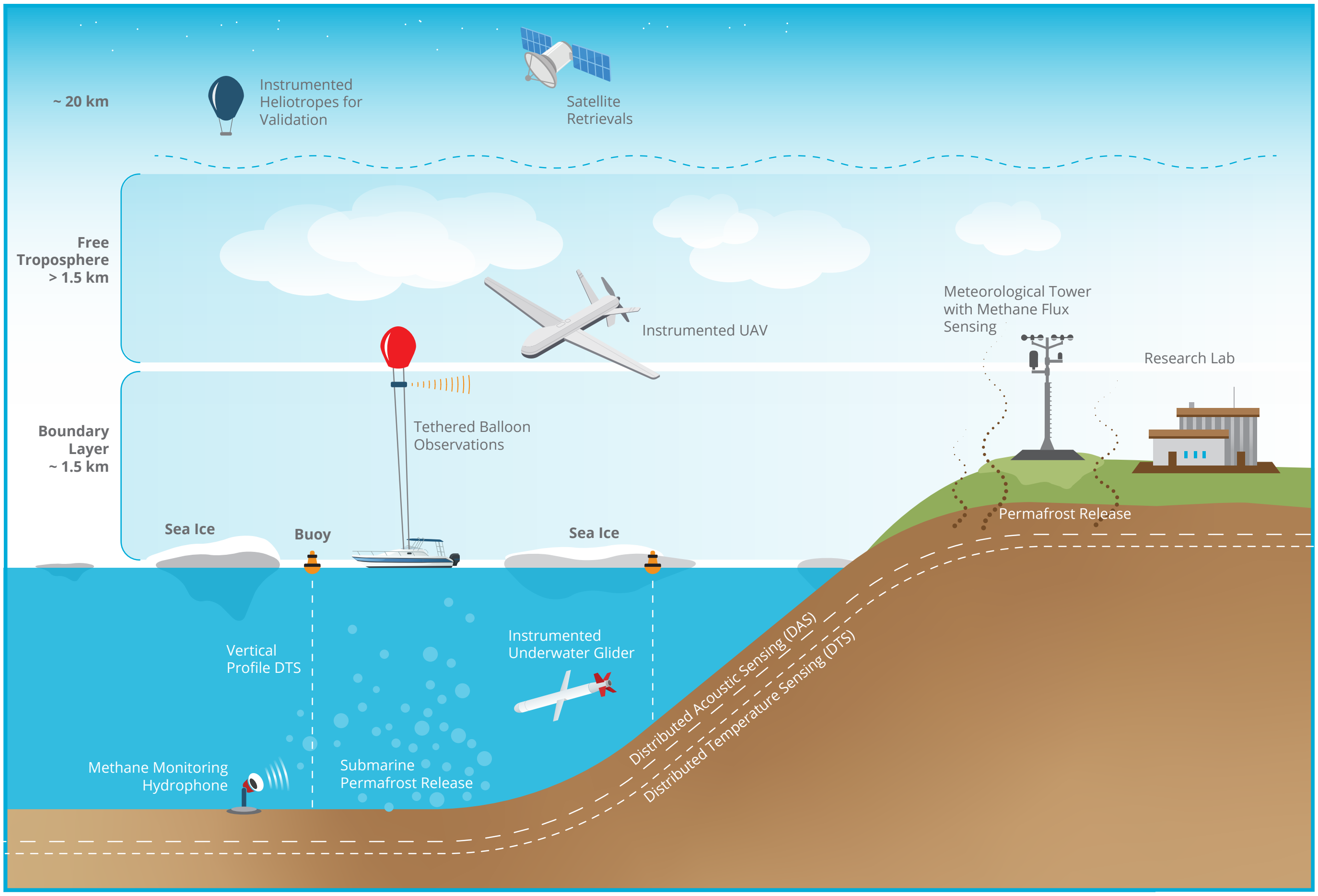


Figure 1. Sandia has developed a conceptual architecture for Arctic methane monitoring at the air, land, and sea interface.

SANDIA CAPABILITIES

ATOMSPHERIC MEASUREMENT

Since the 1950s, Sandia has supported nuclear testing by advancing atmospheric testing and monitoring, capabilities which now also contribute to our climate monitoring work. We developed Arctic-specific monitoring capabilities through our leadership role in the Atmospheric Radiation Monitoring (ARM) program, for which we still operate the ARM North Slope facility.

In 2010, Sandia developed and deployed a mobile laboratory for GHG measurements, including methane. This mobile lab represented the most comprehensive GHG measurement system in the world at the time.

Sandia developed and deployed a system from 2014 to 2016 specifically for measuring methane and associated trace gases and particles in the Arctic. This system recorded state-of-the-art, automated measurements of methane, methane isotopes, ethane, carbon monoxide, carbonyl sulfide, and black carbon with automated calibrations, all operated remotely.

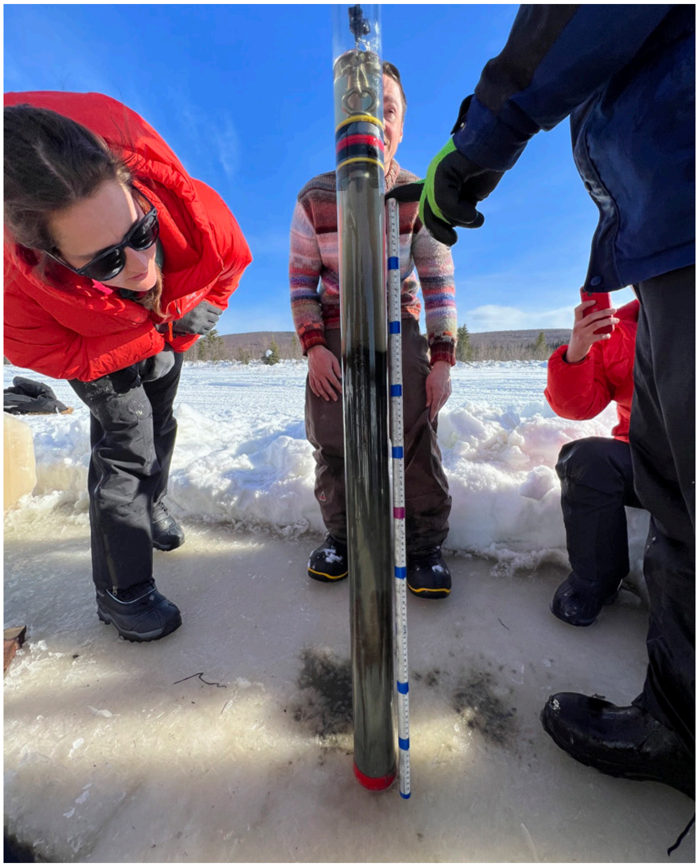
Our scientists continue to design and deploy a range of monitoring tools, including tethered balloons, heliotropes, unmanned aerial vehicles, and distributed acoustic and temperature sensors to monitor atmospheric, land, and ocean-based properties.

A new effort at Sandia aims to create a miniature, low-power universal GHG sensor that will improve the range and scope of measurement (Figure 2). The core technology focuses on micro gas chromatography devices.

In addition to physical monitoring capabilities, Sandia can develop data assimilation algorithms and architectures needed to organize and use large, disparate datasets.

REGIONAL METHANE MODELING

Sandia researchers have developed state-of-the-art computer models that enhance scientists' ability to identify emission sources of methane and predict its dispersion regionally by analyzing data on trace gases in the atmosphere. The Sandia simulation codes greatly improve the application of Lagrangian mathematical models for atmospheric particle dispersion and of stochastic Bayesian inversions designed to refine input parameters for optimal predictive results. This methodology has been tested in estimating methane emissions in the San Francisco Bay area using measurements collected at Sandia's Livermore site.



Sandia technologist Jenna Schambach inspects the sediment layers obtained in a 1-meter core from a frozen thermokarst lake bed at Big Trail Lake near Fairbanks, Alaska. Photo courtesy Chuck Smallwood.

SEABED-BASED METHANE

Researchers at Sandia apply high-performance computing and machine learning methods to develop probabilistic maps for submarine permafrost and permafrost-associated gas hydrate distribution. Drawing on knowledge gained from foraminifera (microscopic single-celled marine organisms with exterior shells) in Arctic seafloor cores through a University Partnership with CU Boulder, they use reconstructed paleoceanographic conditions to quantify present and future marine seabed methane emissions in response to climate warming.

Sandia scientists also use DTS and DAS systems to better understand the distribution of frozen seafloor sediments, as well as the location and activity level of seafloor fluid and greenhouse gas seeps in response to a warming Arctic climate.

PERMAFROST

While just 16% of the total global soil area, the permafrost region represents more than a third of the global carbon pool. Much uncertainty exists in understanding both the baseline and trajectory of this climate-sensitive system.

Sandia scientists have developed approaches using field observations, environmental data, and geospatial modeling to predict soil carbon stocks and active-layer thickness, as well as to develop scaling functions of soil organic carbon.

A major forcing factor, permafrost soils modulate Arctic climates and the microbial residents of permafrost that are central contributors to biogeochemical climate feedback cycles. Sandia develops approaches to accurately characterize microbial activities in soil samples critical to defining risks of permafrost soil degradation to chronic and acute climate perturbations. Our scientists are also designing gas measurement platforms to non-destructively determine the sub-surface microbial signatures of permafrost degradation.

Figure 2. Sandia researchers are working to create a miniature, low-power universal greenhouse gas sensor using micro gas chromatography devices (left and right) about the size of a U.S. quarter (center).

COOPERATIVE MONITORING

Achieving Sandia's vision for understanding Arctic methane at the interface requires coordination and cooperation with international stakeholders.

Sandia is already partnering with the Wilson Center to bring together technical and policy experts on this topic and with the University of Texas-El Paso to improve ocean-based and coastal methane measurements. We also have partnerships in this area with the University of Alaska Fairbanks, University of Washington, and University of Texas at El Paso.

CLIMATE SECURITY AT SANDIA

Sandia is integrating capabilities from across the Labs to support our missions and address the national and global security threats associated with the rapidly evolving climate crisis. Our vision is to advance climate security through science, technology, and action.

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U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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