Meet Terra, UC Irvine’s new carbon dating system

MICADAS-Terra brings speed, precision and accessibility to carbon dating science, empowering solutions for climate change and air pollution problems.

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The new MIni CArbon DAting System (MICADAS, affectionately dubbed "Terra") at UC Irvine measures the relative amount of radiocarbon in carbonaceous materials to determine their age. In addition to traditional carbon dating, Terra supports a range of environmental studies, including determining the sources of greenhouse gases and aerosols in our atmosphere and understanding the rates of carbon accumulation in wetland soils.

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In 2021, a team of researchers from UC Irvine, UC Riverside and NASA-JPL secured National Science Foundation funding to bring cutting-edge radiocarbon dating technology to UCI, leading to the installation of MICADAS – a state-of-the-art accelerated mass spectrometer powering groundbreaking research by precisely measuring radiocarbon, which is the ‘clock’ within the carbon cycle that researchers use to date things like fossils and artifacts.

Compact in size and capable of processing both solid graphite and gaseous CO_2 samples, MICADAS provides high-precision radiocarbon measurements. It will also significantly enhance scientists’ ability to trace carbon through natural and human-influenced systems while increasing sample analysis capacity by 50 percent.

“The MICADAS alleviates the high demand for radiocarbon dating services already provided by the W.M. Keck Carbon Cycle Accelerator Mass Spectrometry (KCCMAS) facility,” said Claudia Czimczik, professor in the UC Irvine Department of Earth System Science and lead researcher behind the project.

The new instrument will enable researchers to trace the flow of carbon through complex ecosystems, including identifying fossil fuel contributions to CO_2 and methane emissions, as well as quantifying terrestrial carbon cycle processes and feedbacks, as well as assessing links to air quality. MICADAS can help track how carbon is stored, released and transformed across the entire Earth system – a critical ability if researchers want to understand the effectiveness of carbon mitigation strategies as human-driven climate change unfolds

“An exciting aspect of this new technology is that it enables a higher degree of integration of radiocarbon data with other atmospheric data streams, such as continuous greenhouse gas monitoring, to assess the effectiveness of investments in clean energy and sustainable land use,” said Czimczik.

Tracing carbon through the global carbon cycle

Carbon is the backbone of life on Earth. It exists in many forms, and it continuously moves through the atmosphere, oceans, biosphere and soils in a dynamic process called the carbon cycle. Understanding how carbon moves around the planet – and how long it stays in a given place – is essential for quantifying how human activities are changing the composition of the atmosphere and, ultimately, Earth’s climate system.

Some of the most powerful tools scientists have to track carbon through time and space are isotopes – atoms of the same element with different masses. Carbon exists as three isotopes: carbon-12, carbon-13 and radiocarbon (carbon-14). Radiocarbon is incredibly rare – only one in a trillion carbon atoms will be carbon-14 atoms – but it’s uniquely valuable due to its radioactive decay rate, which makes the isotope a natural clock that allows for carbon dating and environmental tracing.

Radiocarbon plays a critical role in helping scientists decipher both ancient and modern-day carbon pathways. Formed high in the atmosphere by cosmic rays, radiocarbon gets incorporated into carbon dioxide and is then absorbed by living organisms through processes like photosynthesis or food consumption. While organisms are alive, they maintain a stable ratio of radiocarbon to carbon-12, but after they die, that stable ratio starts to fall apart. This creates a natural timestamp that enables scientists to estimate the time-of-death of organic material.

Beyond dating archaeological artifacts and fossils, radiocarbon analysis is an indispensable tool for source attribution studies – research aimed at identifying and quantifying the origin of carbon emissions. Researchers consider radiocarbon the 'gold standard' tracer for fossil fuel-derived carbon because fossil fuels originate from ancient plant material that no longer contains measurable radiocarbon. As a result, air in cities with high fossil fuel CO_2 emissions appears 'older' than air in rural areas.

Such 'climate forensics' enables scientists to assess changes in carbon dynamics over time, monitor the effectiveness of climate mitigation strategies (e.g., reductions in fossil fuel use), and detect shifts in land use or ecosystem processes. For instance, radiocarbon can reveal whether increased carbon in urban air stems from vehicle emissions or wildfire smoke, or help trace carbon sources in river systems, oceans or permafrost soils where thawing due to rising temperatures can release previously-frozen carbon into the atmosphere.

“Radiocarbon has been an important tool in my work since I was a graduate student in Earth System Science at UCI working to understand the carbon cycle in soils,” said project co-lead Professor Francesca Hopkins from the Department of Environmental Sciences at UC Riverside.“I learned that climate change is affecting the natural carbon cycle in significant ways, and that the only way we'll be able to slow down these changes is by reducing emissions. Now, we can use radiocarbon as a tool to help us limit fossil fuel CO_2 emissions at local and policy relevant scales.”

Terra: A partner in climate research

Affectionately dubbed “Terra”, the MICADAS instrument joins the KCCAMS facility at UC Irvine where it will accelerate data collection for studies on carbon cycling, fossil fuel emissions and air quality thanks to its ability to process a large number of samples quickly and efficiently.

Established in 2001 through a gift from the W.M. Keck Foundation, the KCCAMS facility has long been a hub for radiocarbon research, supporting a wide range of fields, from terrestrial and marine ecology to paleoclimate and atmospheric science. One of the major achievements of KCCAMS is the re-dating of the fossil record at the La Brea tar pits in Los Angeles. The KCCAMS played a key role in this effort, partnering with the La Brea Tar Pits and Museum in Los Angeles to accurately date fossils preserved in tar. The collaboration allowed scientists to construct precise timelines for fossil specimens, shedding new light on California’s prehistoric ecosystems and extinction events, which has led to a deeper understanding of California’s natural history.

The future of radiocarbon at UC Irvine

UC Irvine is positioning itself at the forefront of carbon cycle research and radiocarbon science. As the climate crisis intensifies, so does the need for precise, accessible tools to track carbon in the environment. Terra’s arrival expands the capacity for researchers both within and beyond UCI to explore critical questions about how carbon moves, where it becomes stored and how we might leverage natural systems to mitigate the effects of climate change.

“I’m excited about using radiocarbon as a tool to map fossil fuel CO_2 emissions, and to keep track of changes to fossil fuel CO_2 emissions over time, particularly if we are able to take steps to reduce our emissions”, said Hopkins “My hope is that the MICADAS-Terra will be the premiere facility for analysis of vegetation and aerosols for mapping fossil fuel air pollution.”

By offering new analytical capabilities, faster turnaround times and interdisciplinary flexibility, MICADAS stands ready to empower a new generation of scientists to ask and answer previously-out-of-reach questions. As researchers across the country begin to collaborate and submit samples to KCCAMS, the hope is that Terra will not only accelerate science, but also serve as a model for how innovative technology can support bold climate solutions, from the scale of molecules to the scale of the

Earth.

Support

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