Berkeley, California, say they expect to reach crucial technical milestones soon.

Academic labs are at a similar point. "We have demonstrated all the components and all the functions we need," says Schoelkopf, who continues to run a group racing to build a quantum computer at Yale. Although plenty of physics experiments still need to be done to get components to work together, the main challenges are now in engineering, he and other researchers say. The quantum computer with the most qubits so far — 20 — is being tested in an academic lab led by Rainer Blatt at the University of Innsbruck in Austria.

Whereas classical computers encode information as bits that can be in one of two states, 0 or 1, the 'qubits' that comprise quantum computers can be in 'superpositions' of both at once. This, together with qubits' ability to share a quantum state called entanglement, should enable the computers to essentially perform many calculations at once. And the number of such calculations should, in principle, double for each additional qubit, leading to an exponential speed-up.

This rapidity should allow quantum computers to perform certain tasks, such as searching large databases or factoring large numbers, which would be unfeasible for slower, classical computers. The machines could also be transformational as a research tool, performing quantum simulations that would enable chemists to understand reactions in unprecedented detail, or physicists to design materials that superconduct at room temperature.

There are many competing proposals for how to build qubits. But there are two front runners, confirmed in their ability to store information for increasingly long times — despite the vulnerability of quantum states to external disturbance — and to perform quantum-logic operations. One approach, which Schoelkopf helped to pioneer and which Google, IBM, Rigetti and Quantum Circuits have adopted, involves encoding quantum states as oscillating currents in superconducting loops. The other, pursued by IonQ and several major academic labs, is to encode qubits in single ions held by electric and magnetic fields in vacuum traps.

John Martinis, who worked at the University of California, Santa Barbara, until Google hired him and his research group in 2014, says that the maturity of superconducting technology prompted his team to set the bold goal of quantum supremacy.

"I tell my students that 2017 is the year of braiding."

The team plans to achieve this using a 'chaotic' quantum algorithm that produces what looks like a random output (S. Boixo *et al.* Preprint at https://arxiv.org/abs/1608.00263; 2016). If the algorithm is run on a quantum computer made of relatively few qubits, a classical machine can predict its output. But once the quantum machine gets close to about 50 qubits, even the largest classical supercomputers will fail to keep pace, the team predicts.

The results of the calculation will not have any uses, but they will demonstrate that there are tasks at which quantum computers are unbeatable — an important psychological threshold that will attract the attention of potential customers, Martinis says. "We think it will be a seminal experiment."

But Schoelkopf does not see quantum supremacy as "a very interesting or useful goal", in part because it dodges the challenge of error correction: the ability of the system to recover its information following slight disturbances to the qubits, which becomes more difficult as the number of qubits increases. Instead, Quantum Circuits is focused on making fully error-corrected machines from the start. This requires building in more qubits, but the machines could also run more-sophisticated quantum algorithms.

Monroe hopes to reach quantum supremacy soon, but that is not IonQ's main goal. The start-up aims to build machines that have 32 or even 64 qubits, and the ion-trap technology will enable their designs to be more flexible and scalable than superconducting circuits, he says.

Microsoft, meanwhile, is betting on the technology that has the most to prove. Topological quantum computing depends on excitations of matter that encode information by tangling around each other like braids. Information stored in these qubits would be much more resistant to outside disturbance than are other technologies and would, in particular, make error correction easier.

No one has yet managed to create the state of matter needed for such excitations, let alone a topological qubit. But Microsoft has hired four leaders in the field, including Leo Kouwenhoven of the University of Delft in the Netherlands, who has created what seems to be the right type of excitation. "I tell my students that 2017 is the year of braiding," says Kouwenhoven, who will now build a Microsoft lab on the Delft campus.

Other researchers are more cautious. "I am not making any press releases about the future," says Blatt. David Wineland, a physicist at the National Institute of Standards and Technology in Boulder, Colorado, who leads a lab working on ion traps, is also unwilling to make specific predictions. "I'm optimistic in the long term," he says, "but what 'long term' means, I don't know." ■

OCEANOGRAPHY

Ocean ecosystems mapped in unprecedented 3D detail

Tool to divide water masses into precise categories can help in conservation planning.

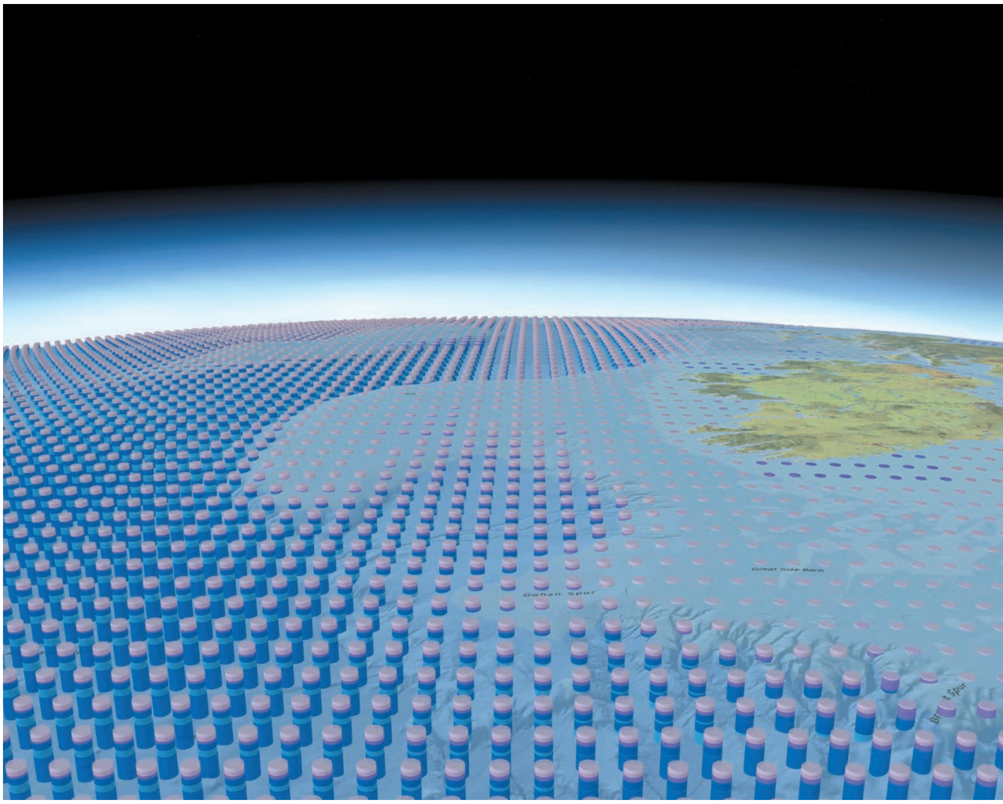
BY ALEXANDRA WITZE

Oceanographers are carving up the world's seas like the last of the holiday turkey. A new 3D map sorts global water masses — from deep, frigid circumpolar waters to the oxygen-starved Black Sea — into 37 categories.

The map groups together marine regions of similar temperature, salinity, oxygen and nutrient levels. It has been available for only a few months, and researchers are still working through how they might use it. But its international team of developers hopes that the map will help conservationists, government officials and others to better understand the biogeography of the oceans and make decisions about which areas to preserve. It could also serve as a data-rich baseline for analysing future ocean changes.

Many existing systems also attempt to classify variations in the ocean, such as lists of large marine ecosystems or the Longhurst biogeographical provinces that are defined by the rate at which ocean life consumes carbon. But these are often limited to surface or coastal ecosystems. The latest effort, known as the ecological marine units (EMUs), is the most detailed attempt yet to cover the global ocean in three dimensions.

KEITH VANGRAAFEILAND & SEAN BREYER/ESRI



This ecological marine unit (EMU) map shows variations in water conditions off the coast of Ireland.

"What's often missing is all that's between the surface of the ocean and the ocean bottom," says Dawn Wright, chief scientist of Esri, a geographic information-systems company in Redlands, California, that helped to develop the 3D map. "That's what our project will hopefully bring to the table."

Esri launched a web portal for the EMU data in September, and has been presenting the concept at conferences since then. Wright described it on 16 December in San Francisco, California, at a meeting of the American Geophysical Union.

EMUs can help to reveal why marine animals live where they do. In the eastern tropical Pacific Ocean the mapping shows a complex interplay between oxygen-rich and oxygen-poor waters. The boundary of the low-oxygen zone shifts towards the surface in some spots and dips deeper in others. That variation affects the locations of economically important tuna fisheries, says Patrick Halpin, a marine ecologist at Duke University in Durham, North Carolina. "It's an interesting thing to look at in three dimensions, fairly unique and gratifying."

Such data could guide the United Nations' effort to designate a series of ecologically or biologically significant marine areas to focus future conservation efforts, Halpin notes. Looking at the distribution of EMUs could help officials to pinpoint the boundaries of those areas, or to make sure they are designating enough waters to capture all the biogeographic diversity.

And the South African National Biodiversity Institute is interested in using EMUs to update data on open-ocean and deep-sea habitats for the country's next national biodiversity assessment, due in 2019, says Heather Terrapon, a spatial analysis coordinator at the institute in Cape Town. Nations that do not have the money to gather their own data sets could use the free EMU data and visualizations to manage their marine resources, says Peter Harris, a marine geologist at the environmental information-management centre GRID-Arendal in Arendal, Norway.

The creation of the EMUs is the second step in a project that started with similar mapping on land. The intergovernmental Group on Earth Observations asked Roger Sayre, an ecologist at the US Geological Survey in Reston, Virginia, to lead a team to categorize terrestrial ecosystems. The researchers, including some at Esri, combined information on geology and vegetation to generate nearly 4,000 'ecological land units'. One example might be warm, wet plains, on metamorphic rock, with mostly deciduous forest.

Next, the team moved their focus from land to the oceans. "It's like total world domination in ecosystem mapping," says Sayre, who heads the EMU project with Wright.

"It's like total world domination in ecosystem mapping."

They began with 52 million data points in the World Ocean Atlas maintained by the US National Oceanic and Atmospheric Administration. These include information on chemical and physical parameters gathered every 27 kilometres to create a 3D grid. The team added other data such as the shape of the sea floor and used statistical techniques to group the results into categories.

The resulting EMUs include the deep, very cold, low-oxygen waters that encompass roughly one-quarter of the world's oceans. Others are much smaller, such as the upper waters of the Red Sea, or the dilute estuaries of several Northern Hemisphere rivers.

For now, the EMU maps rely on data averaged over five decades. Looking at conditions over shorter periods of time, such as seasons, would provide more helpful detail, says Frank Muller-Karger, a biological oceanographer at the University of South Florida in St Petersburg who has been comparing EMUs with weekly maps of coastal changes made using satellite imagery. And to monitor change over decades, the EMU team would need to recalculate its maps every five years or more.

The EMU developers say that future iterations of the system could tackle such issues. For now, they are hoping to expand on the land and marine units by creating new categories for coastal and freshwater ecosystems. ■

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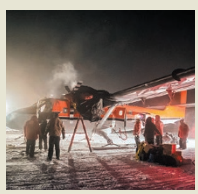

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