the EU. "It will necessarily divert much-needed funding from civilian R&D budgets, at a time when they are urgently needed for areas such as climate and energy," says Stuart Parkinson, executive director for UK-based advocacy group Scientists for Global Responsibility.

One of the EU's main objectives is to promote peace. In the past, defence was seen as a national issue rather than something for the bloc to handle. The decision to create the research fund is in part driven by a drop in national defence-research funding, which declined by 18%, or €1.9 billion, between 2006 and 2014 in real terms, according to the European Defence Agency (EDA) in Brussels, which will manage the research fund on behalf of the commission.

The perception that international security is under threat is a driver for the broader defence fund. In November, the European Parliament passed a motion that says terrorists are targeting the continent on an unprecedented scale, and that Europe is "now compelled to react to an arc of increasingly complex crises". The motion notes that for the first time since the Second World War, "borders in Europe have been changed by force" — referring to the annexation of Crimea in 2014 and the incursion into Ukraine by Russian forces.

In September, Jean-Claude Juncker, president of the commission, made a similar point when speaking about the European Defence Fund. "Europe can no longer afford to piggy-back on the military might of others," he said.

The rules for participating in the research fund are still being discussed, but it will be modelled loosely on Horizon 2020. It will probably promote projects that combine researchers from industry and academia and from different countries, says Denis Roger, a director in charge of research at the EDA.

But whereas researchers on Horizon 2020 projects are expected to publish their results, or to patent products for anyone to license, the commission is likely to restrict how the results of defence-fund research are publicized, classifying some and restricting licensing to national ministries. The EU has no army of its own — although Juncker has said he would like to create one. Instead, national ministries, alongside members of the defence industry, will be involved in setting priorities for the scheme, says Roger. And unlike Horizon 2020, which welcomes participation from more than a dozen 'associated' countries, the research defence fund is likely to be open only to EU member states and Norway.

The project could boost certain fields. Roger says it will include research into metamaterials, which are made of tiny structures that manipulate the path of light and could potentially hide objects from radar, as well as methods of energy storage, flexible radio antennas that can be incorporated into clothing, and prototype maritime surveillance drones.

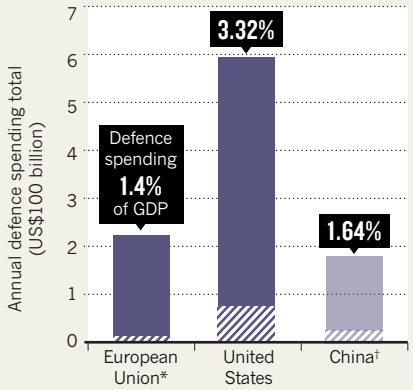
"I would imagine that a lot of countries would definitely see this as another opportunity for funding," says Ortwin Hess, a physicist at Imperial College London. He notes that US scientists working on photonics and metamaterials can readily access defence funding. "My US colleagues wouldn't survive without it. They live on it."

Hess, who has received defence funding from the US and UK governments in the past, says he is a realist when it comes to what he calls the moral question. "I have to accept that our society has values that deserve to be defended," he says. The military will adopt technologies developed in the civilian domain, and sometimes technology transfer can go the other way, he adds.

But Parkinson says that defence research often supports military efforts beyond actual defence, as well as the export of weapons to other countries: "Our view is that we need a much stronger focus on R&D which contributes to tackling the root causes of conflict — including a range of social and environmental problems." ■

MILITARY METRICS

The European Union's 28 member states combined spend much less on defence research than the United States, and probably China.



*Figures for the EU from 2014, figures for the United States and China from 2015; †Figures are approximate based on an estimated minimum for defence total and the average of a range for percentage spent on research.

SOURCES: EDA, AAAS, STOCKHOLM INT. PEACE RES. INST., UNIV. CALIFORNIA INST. GLOBAL CONFLICT AND COOPERATION, US DEPT DEFENSE

POLITICS

US scientists plan for an uncertain future

Concerned by the president-elect's choice of advisers, researchers take steps to defend their fields.

BY JEFF TOLLEFSON AND ALEXANDRA WITZE IN SAN FRANCISCO, CALIFORNIA

Incoming US president Donald Trump's government is beginning to take shape, and Earth scientists are getting nervous.

Trump's latest Cabinet appointments include former Texas governor Rick Perry, a climate sceptic, for energy secretary, and ExxonMobil chief executive Rex Tillerson for secretary of state — a position that would make him the United States' lead emissary on climate change. The pair helps to fill out a roster of advisers with strong ties to industry and a distaste for government regulation. Trump's transition team also asked the Department of Energy (DOE) for the names of employees who had worked on climate-change issues, further unsettling researchers.

"It feels like a war on science, and on climate science in particular," says Alan Robock, a climatologist at Rutgers University in New Brunswick, New Jersey. "That's very upsetting."

Scientists won a small battle on 14 December, when Trump's team disavowed the memorandum it sent to the DOE seeking information on climate-change programmes. The request sparked widespread outrage and drew a rebuke from the department after it was leaked on 9 December. At the Fall Meeting of the American Geophysical Union (AGU) last week in San Francisco, California, some researchers billed the episode as a blueprint for how they might defend their interests after Trump takes office on 20 January.

"There is power, even with an administration that never admits a mistake, in bringing things to light," says Andrew Rosenberg, who heads the Center for Science and Democracy at the Union of Concerned Scientists in Cambridge, Massachusetts.

Other researchers are copying government climate-data sets, to preserve them in case the Trump administration and the Republican-controlled Congress follow through on

proposals to cut back Earth-science research at NASA or otherwise restrict studies of global warming. One rescue effort had archived 11 of 91 data sets on its list for preservation as of 16 December; these include a global temperature record maintained by NASA and palaeoclimate archives held by the National Oceanic and Atmospheric Administration (NOAA).

Marcia McNutt, president of the US National Academy of Sciences, says that private foundations have expressed interest in "funding up to the order of billions of dollars" for climate-change research if the Trump administration reduces support for such work. But McNutt — who directed the US Geological Survey (USGS) from 2009 to 2013 — is not ready to give up on government science. "I don't want that to be an excuse for the government to pull away — to say private philanthropy can do this, the government doesn't need to fund it," she told journalists at the AGU meeting.

The road ahead for scientists looks tough. Perry dealt with energy issues as governor of Texas, but he lacks experience with key areas of the DOE portfolio, says John Deutch, a chemist at the Massachusetts Institute of Technology in Cambridge. Deutch, who leads the department's advisory board, says that Trump should identify a deputy energy secretary who understands the agency's programmes on basic science, nuclear weapons and national security.

And Perry is not the only climate sceptic poised to join Trump's inner circle. Trump's pick to lead the US Environmental Protection Agency is Oklahoma attorney-general Scott Pruitt, who has sued the federal government to overturn greenhouse-gas and air-quality rules.

The president-elect has not announced whom he would like to run NASA, NOAA or the USGS, among other science agencies. McNutt says that the National Academies of Science, Engineering, and Medicine have provided his transition team with a list of potential candidates, but none of those people has been contacted by Trump staff.

Some scientists argue that even if policies to fight climate change are weakened or struck down under Trump, his latest nominations hint that there may be ways to promote clean energy. Tillerson has said that a carbon tax is the best way to address global warming. And although Perry is a strong proponent of fossil fuels, Texas's wind-power production grew significantly during his governorship.

"Those are places to insert a progressive agenda into an otherwise kind of ugly and cloudy landscape," says Daniel Kammen, an energy researcher at the University of California, Berkeley.

McNutt advises scientists to stay clear-eyed as they confront whatever challenges the Trump administration brings. "I see so many people in this country freaked out," she says. "That is exactly what those who want to disrupt science are hoping to achieve." ■

NAVIGATION SATELLITES

Galileo satellites herald new era for Earth sciences

Europe and Asia will set the atmosphere abuzz with more radio-wave navigation signals.

BY DECLAN BUTLER

After soaring costs and years of delays, Europe's global satellite-navigation system, Galileo, finally began beaming its first signals to receivers in smartphones and cars on 15 December.

The 18-strong fleet of satellites promises travellers another way to accurately locate their position on Earth, ending Europe's dependence on the US Global Positioning System (GPS) and Russia's GLONASS. But Galileo, which was first proposed in 1999, is a big deal for science, too, says Richard Langley, an expert in navigation-satellite systems at the University of New Brunswick in Fredericton, Canada. What most excites scientists is the prospect of combining signals from multiple satellite networks, enabling new kinds of atmospheric and Earth-sciences research.

Galileo's constellation of satellites should reach its full complement of 30 in 2020, by which time China's BeiDou system, comprising 35 satellites, is scheduled to enter service. Japan and India are also building regional systems. Altogether, the number of global navigation satellites encircling Earth is set to rise from around 90 today to at least 130 over the next decade, estimates Oliver Montenbruck, a physicist at the German Aerospace Center in Oberpfaffenhofen, Germany. At the same time, existing satellite fleets will be modernized.

Earth's atmosphere will then be streaming with many more kinds of radio-wave signal at a greater variety of frequencies — each carrying information about the time and the position of the satellite that sent it. Sat-nav receivers use data from multiple satellites to pinpoint their own position. So simply having more satellites overhead will help stop signal loss and provide more accurate position fixes, says Langley. "The more satellites you have, the greater the precision," adds Tonie Van Dam, an Earth scientist at the University of Luxembourg who uses receivers to monitor how Earth's crust deforms in response to shifting water or ice.

"The more satellites you have, the greater the precision."

Skies increasingly crowded with radio waves will also benefit weather forecasting and climate research. Scientists use the refraction of navigation-satellite signals in the Earth's atmosphere to make measurements of atmospheric temperature, pressure, density and water-vapour content. And the signals can similarly be exploited to measure electron density in the ionosphere, an electrically charged layer in the upper atmosphere. These data are used to track space weather and to monitor tsunamis and earthquakes, says Philippe Lognonné, a geophysicist at the Institute of Earth Physics of Paris. These events disturb air so violently that they send acoustic and gravity waves up to the ionosphere where they perturb electrons. With fully operational Galileo and BeiDou systems, researchers should be better able to estimate tsunami heights, Lognonné says.

Scientists also plan to use multiple navigation-satellite constellations to improve measurements of ocean wind speeds and sea surface roughness, says Jens Wickert, a scientist at the GFZ German Research Centre for Geosciences in Potsdam. Today's remote-observation ocean maps are built largely by bouncing radar waves off the sea from aircraft or spacecraft, and combining those data with information from other satellite instruments. The best current maps have a spatial resolution of around 80 kilometres and are updated every 10 days. Wickert aims to improve on that using orbiting receivers ▶