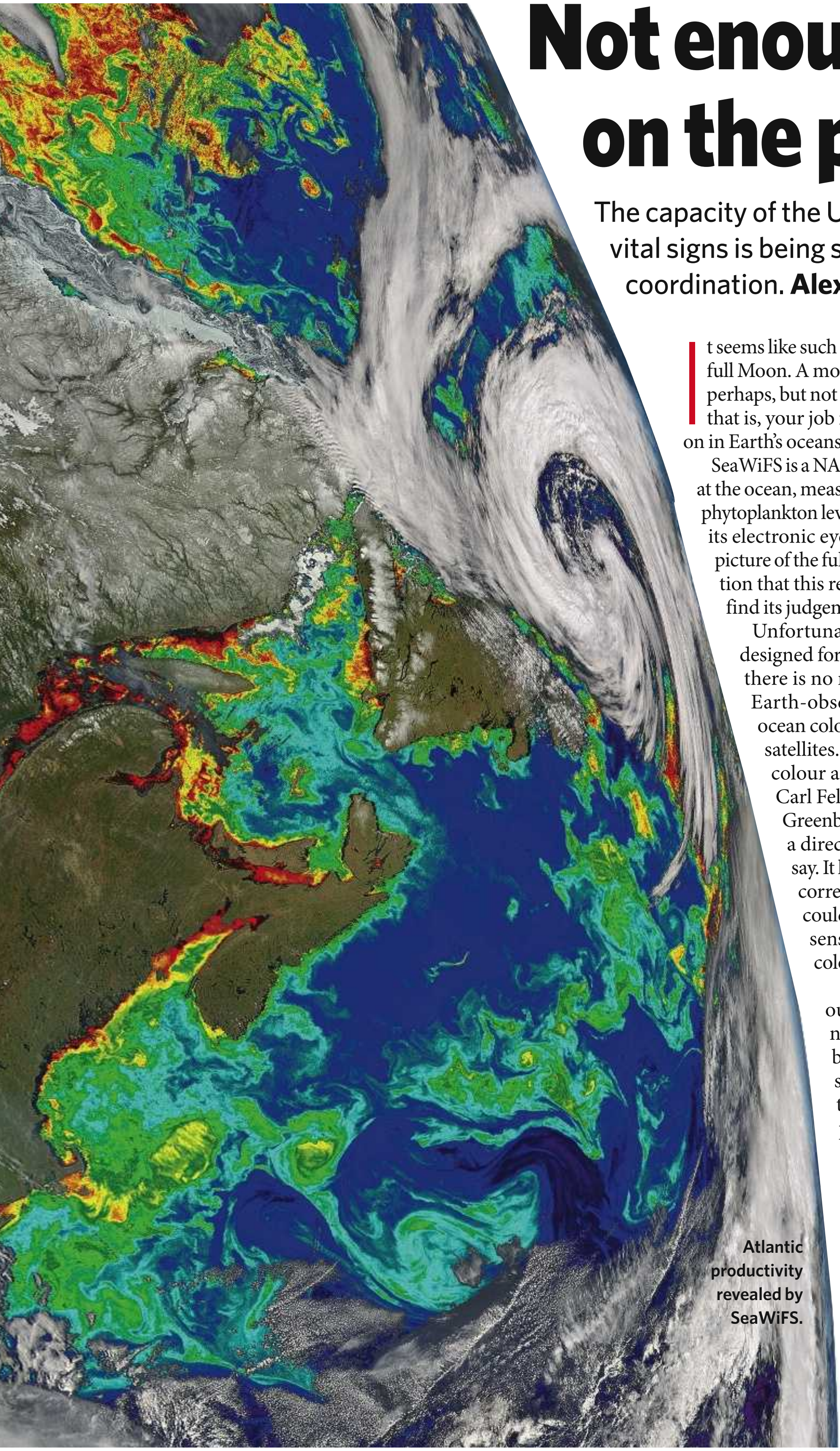


Not enough eyes on the prize

The capacity of the United States to monitor Earth's vital signs is being stymied by tight budgets and poor coordination. **Alexandra Witze** reports.

It seems like such a little thing, the ability to lie back and look up at the full Moon. A moment of wonder or romance on a summer evening, perhaps, but not something vital to the way you do your job. Unless, that is, your job is measuring the amount of photosynthesis going on in Earth's oceans.

SeaWiFS is a NASA satellite that spends most of its days staring down at the ocean, measuring the subtle colour changes that come about as phytoplankton levels wax and wane. But once a month, SeaWiFS takes its electronic eyes off the water, rolls itself backwards and takes a picture of the full Moon. Without the check-up on its colour perception that this regular 'lunar calibration' provides, SeaWiFS could find its judgement drifting slowly off-kilter.

Unfortunately, SeaWiFS can't keep this up for ever. It was designed for five years and has lasted ten. And at the moment, there is no replacement quite as good. Two of NASA's other Earth-observing satellites carry sensors that can measure ocean colour, as do Europe's Envisat mission and some other satellites. But none of them is as good at monitoring ocean colour as SeaWiFS, says the project's chief scientist Gene Carl Feldman of NASA's Goddard Space Flight Center in Greenbelt, Maryland. And the US instrument designed as a direct follow-on to SeaWiFS is just not as good, many say. It has fewer wavelength bands, it might have problems correcting for atmospheric turbulence, its observations could be corrupted by stray light leaking in around the sensors — and it will never take time out to check its colour vision by staring at the Moon.

In other words, the next generation of ocean-colour sensors, built by the most advanced research nation in the world, will in some respects be a step back. And this is not an isolated problem. Climate scientists have a list of a couple of dozen 'essential climate variables' (see 'The dimensions of the problem') that they would wish to see monitored in perpetuity. In fact, they'd like a lot more than that — the list started out with more than 150 variables and was winnowed down in large part on the basis of what data were readily available. "There was a fair amount of pragmatism," says Kevin Trenberth, a climatologist at the National Center for Atmospheric Research in Boulder, Colorado. Nevertheless, in some cases the relevant measurements are not yet being made (see 'The crucial measurement', page 785). And although some data sets are being interrupted or degraded, others are duplicated — provided by multiple satellites and multiple nations.

Atlantic productivity revealed by SeaWiFS.

SEAWIFS PROJECT, NASA/GODDARD SPACE FLIGHT CENTER, ORBIMAGE

THE DIMENSIONS OF THE PROBLEM
Key data that are needed to understand the Earth system: some monitors are listed here.

Atmosphere	
Surface wind speed and direction	ERS-2 (Europe), QuikSCAT (US)
Upper-air temperature	Aqua (US), Metop (Europe), GOES series (US)
Water vapour	GOES series (US), Metop (Europe)
Cloud properties	CloudSat (US), CALIPSO (US), Metop (Europe)
Precipitation	TRMM (US/Japan), Aqua (US)
Earth radiation budget	Aqua (US), Meteosat (Europe), SORCE (US)
Ozone	Aura (US), Terra (US), ERS-2 (Europe), Envisat (Europe)
Aerosols	Parasol (France), Envisat (Europe), Terra (US), Aqua (US)
Carbon dioxide, methane and other greenhouse gases	Terra (US), Aura (US), Metop (Europe), Envisat (Europe)
Upper-air wind	Meteosat (Europe), GOES series (US)
Oceans	
Sea ice	ERS-2 (Europe), Aqua (US)
Sea level	Jason (US/France), Envisat (Europe)
Sea surface temperature	Aqua (US), Envisat (Europe)
Ocean colour	SeaWiFS (US), Envisat (Europe), Aqua (US)
Sea state	Factors such as roughness, usually monitored from the surface
Ocean salinity	Argo float system, plus other float and ship-towed sources
Terrestrial	
Lakes	Landsat (US), Envisat (Europe)
Glaciers, ice caps and ice sheets	IceSat (US), Terra (US), Envisat (Europe), ERS-2 (Europe), RADARSAT (Canada)
Snow cover	NOAA series (US), Terra (US), Envisat (Europe), RADARSAT (Canada)
Albedo	Landsat series (US), SPOT series (France)
Land cover	Landsat (US), Envisat (Europe)
Fraction of incoming solar radiation absorbed by plants	Usually done through small field-based studies, but also Envisat (Europe), Terra (US)
Leaf-area index	Usually done through small field-based studies
Biomass	Terra (US), Landsat (US), Envisat (Europe)
Fire disturbance	Terra (US), GOES series (US), ERS-2 (Europe)
Soil moisture	ALOS (Japan), Landsat (US)

The problems are global, as each nation struggles to fund and maintain data streams from satellites that serve its own interests (which may be shaped by the particular research interests of its scientists). But the issues are most apparent in the US government's civilian Earth-observing satellites, of which there are 30. Turf battles among multiple US agencies, as well as tight budgets, threaten the future of the country's Earth monitoring. The National Academies, not known for alarmist views, was prompted earlier this year to note that "the United States' extraordinary foundation of global observations is at great risk".

The administration sees talk of a crisis as unwarranted. "I think the panic is greatly exaggerated," says Vice-Admiral Conrad Lautenbacher, head of the US National Oceanic and Atmospheric Administration (NOAA), which oversees the country's weather satellites as well as its fisheries and other ocean resources. Lautenbacher is, among other things, a great believer in putting national capabilities in a broader global context. He has been a driving force in America's contribution to the creation of a worldwide coordinating network for Earth observations, the Global Earth Observation System of Systems (GEOSS), and hopes that such networking can provide the seamless integration of Earth-monitoring systems needed to protect society against natural hazards. GEOSS was launched two years ago with a ten-year mandate to get the world's view of its common house in order. Lautenbacher and other supporters say that although it is moving forward slowly (see 'All in this together'), it has garnered enough political support to address some of the major issues with data gaps and other observational problems.

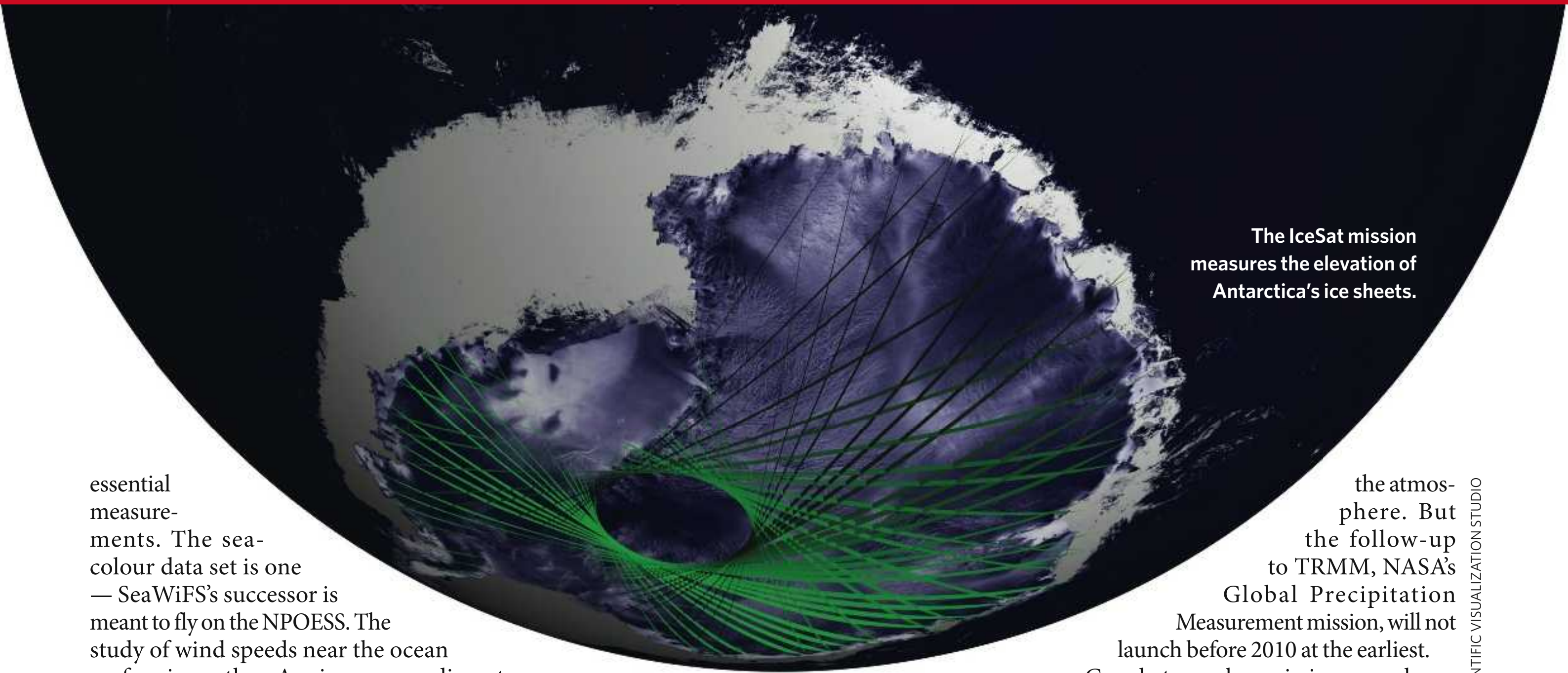
GEOSS does little, however, to solve one of the sector's fundamental problems: bridging the long-standing gulf between the scientific community, which generally wants to fly cutting-edge instruments with which to discover things, and the operational community that has the job of providing long-term but unglamorous data sets. In the United States, NASA builds and launches research satellites and NOAA handles the operational systems such as weather satellites. But NOAA does only oceans and atmosphere — keeping track of things on land is the responsibility of the US Geological Survey (USGS), which runs the Landsat Earth-observing satellites with NASA. Depending on what piece of information about Earth is needed, it could have been gathered for any number of purposes by any one of the three agencies. And that's not even counting private remote-sensing spacecraft, nor the military satellites gathering both classified and unclassified data.

United front

One way to simplify things would be to have a unified system for operational measurement of the variables of interest. This is the purpose of Europe's Global Monitoring for Environment and Security (GMES) programme (see page 778). Yet attempts to unify disparate systems can bring problems of their own. The National Polar-Orbiting Operational Environmental Satellite System (NPOESS) combines activities previously carried out by the NASA and NOAA low-Earth-orbiting satellites with the defence department's weather-satellite programme. Begun in 1994 and run by Northrop Grumman, by 2005 the NPOESS had accumulated so many cost overruns that it triggered a mandatory federal review. Its estimated cost of nearly US$7 billion had soared to at least $11 billion, and the initial launch date has slipped from 2009 to 2013.

In response, project officials yanked five climate sensors off the NPOESS satellites to save money. This limited their capacity to monitor several of the essential climate variables, including Earth's radiation budget and atmospheric ozone concentrations. Climate scientists protested against the NPOESS cancellations, and the National Research Council is now conducting a review to see how the data from the sensors might be obtained through other means; its report is expected in January 2008. Options include mounting some of the sensors on other spacecraft or reinstating them later in the NPOESS series and just making the best of the gaps thus created. "The plan isn't going to be as complete as we would like it to be, but it will be as complete as we can be," says John Marburger, the science adviser to President George W. Bush.

Delays to the NPOESS threaten various



The IceSat mission measures the elevation of Antarctica's ice sheets.

NASA/GODDARD SPACE FLIGHT CENTER SCIENTIFIC VISUALIZATION STUDIO

essential measurements. The sea-colour data set is one — SeaWiFS's successor is meant to fly on the NPOESS. The study of wind speeds near the ocean surface is another. A microwave radiometer that was supposed to make such measurements has been removed from the first NPOESS satellite scheduled to launch to the second. The US instrument currently in orbit doing that task — NASA's QuikSCAT — is long past the end of its design lifetime (and was itself a last-minute replacement thrown up into orbit after an earlier scatterometer failed after less than a year). QuikSCAT measurements are regularly used to improve hurricane forecasts, and Bill Proenza lost his job as director of the National Hurricane Center in Miami in July partly because he criticized the lack of plans to replace the satellite (see *Nature* **447,** 514–515; 2007).

There is another option for measuring wind vectors, which is the WindSat instrument currently flying aboard the joint military–civilian Coriolis satellite. But that — like the planned replacement to come aboard the NPOESS — is a passive radiometer, measuring microwaves that are emitted from the sea surface rather than actively bouncing microwaves off the ocean and observing them. Researchers continue to debate whether a passive radiometer can measure winds as accurately as an active scatterometer.

There is also bad news for satellites that have nothing to do with the NPOESS programme. The US/Japan Tropical Rainfall Measuring Mission (TRMM) provides detailed images and data such as the amount of rain produced from hurricanes and other tropical storms. Its nominal three-year mission came to an end in 2000, but it has had its lifetime extended again and again, most recently until September 2009. The latest extension meant that NASA had to waive a safety requirement that it maintain enough fuel to ensure that it burned up on re-entry into the atmosphere. But the follow-up to TRMM, NASA's Global Precipitation Measurement mission, will not launch before 2010 at the earliest.

Gaps between key missions are a long-standing problem in Earth observation, particularly for those looking for long, complete data sets. If there had not been a gap of ten years between SeaWiFS and the instrument it replaced, scientists would have a far better understanding of how ocean productivity changes with weather and climate; there would be more data on how different El Niño events and other fluctuations in ocean temperature control phytoplankton blooms — work that could provide hints as to how future climate change could affect oceanic productivity (M. J. Behrenfeld *et al. Nature* **444,** 752–755; 2006). Such gaps are particular problems for data from research instruments that have not yet been put on an operational basis — but it can afflict operational systems too.

The Landsat series of satellites, for instance, has been monitoring Earth constantly since 1972, and one of its main purposes is to provide a continuous stream of data so that changes — such as urban growth, land subsidence and desertification — can be measured over time. But its issues with data continuity sprang to the fore in early October, when Landsat 5 — a satellite that had been up since 1984 — stopped working.

Landsat 5 was to have been replaced by Landsat 6, but that satellite failed on launch in 1993. Landsat 7, launched in 1999, has a problem with its scanning mechanism that causes it to collect data in zigzag streams rather than continuous bands, which leads to about 22% of each scene being lost. The USGS continues to process and release usable data from Landsat 7, but no one can now be sure whether it will last until the launch of the optimistically named Landsat Data Continuity Mission, an event currently scheduled for 2011. Programmatic discontinuities haven't helped; over the years, the Landsat programme has been passed between NASA, NOAA, the USGS and a private operator like a cold around a kindergarten.

Although data gaps remain a major issue,

All in this together

Last week in Cape Town, ministers of more than 70 countries gathered to talk about the biggest acronym in Earth sciences: GEOSS, the Global Earth-Observing System of Systems.

Touted as a worldwide network of ocean, atmospheric and terrestrial sensors, GEOSS is supposed to hook the planet together in one big harmonious Earth-monitoring whole. Two years into its ten-year implementation plan, the project is already bragging about its 'first 100 steps' towards that goal.

These include GeoNetCast, a web portal to broadcast information from Earth-monitoring systems around the world; SERVIR, a programme to help Central America improve its monitoring of forest fires and tropical storms; and the agreement of a Brazilian–Chinese venture to share satellite data with Africa for free. All showcase the main point of GEOSS, which is to serve nine 'societal benefit areas', such as protecting water and energy resources and reducing deaths caused by natural disasters.

The societal focus of GEOSS has turned off some scientists who had hoped it might provide new funding streams for their remote-sensing work, says José Achache, the secretariat of the Group on Earth Observations in Geneva, Switzerland, the body that oversees GEOSS. And it's not uncommon to hear grumbling about the programme, even among climate scientists. "It has never reached anything like its promise," says Kevin Trenberth of the National Center for Atmospheric Research in Boulder, Colorado.

Still, many say that GEOSS has managed to at least focus interest at the ministerial level on Earth monitoring, and as such has raised the political profile of the Earth sciences. And at the very least, its existence has prompted member countries to get their own Earth-monitoring houses in order. **A.W.**

overlap between monitoring systems is another. Frequently the problem is international; one country launches a spacecraft that partially duplicates what another mission is already doing. International steering committees are supposed to cut down on the overlap, but it doesn't always work that way. "Our hope is not just to fill gaps, but to avoid duplication of effort," says Helen Wood, a senior adviser to NOAA's satellite and information services division in Silver Spring, Maryland.

Poles apart

In 2003, NASA launched its ICESat mission mainly to study the ice sheets of Greenland and Antarctica; in 2005, the European Space Agency launched its CryoSat, which was to have done much the same thing (although it would also have measured sea-ice thickness). CryoSat failed on launch, so now plans are under way to send up a second version in 2009. Meanwhile, NASA — which likes its mission so much, despite a premature laser failure, that it renamed one of its streets at the Goddard center as ICESat Road — is looking at launching an ICESat-II. Waleed Abdalati, who is ICESat's programme scientist, says that so many changes are expected in the Arctic that both the US and European missions will be useful in providing more information.

José Achache, secretariat of the Group on Earth Observations in Geneva, Switzerland, is not so sure that duplication is a good way forward. "Essentially the agencies were in unofficial competition," he says. An international steering group, the Committee on Earth Observation Satellites, exists to try to cut down on duplication for satellite-based systems, but sometimes national interests win out. The European Space Agency, for instance, is planning a Soil Moisture and Ocean Salinity mission — measuring two of the essential climate variables — at the same time that NASA had been planning the Hydrosphere State (Hydros) mission for soil moisture — which has since been put on indefinite hold — and the Aquarius mission for ocean salinity.

Sometimes, though, the US–European competition can work in science's favour. With SeaWiFS possibly close to dying, NASA is looking at how it can jump in on the European MERIS instrument, aboard Envisat, to get ocean-colour data, says Paula Bontempi of NASA headquarters in Washington DC. Although the data may not be all that the scientists wish they were, they will be better than nothing once SeaWiFS gives out. And in the long run Europe plans to have an instrument as good as or better than MERIS as part of the Sentinel 3 series of operational climate-monitoring satellites. Duplication of efforts is undeniably wasteful in the Earth-monitoring world. But relying on any single nation, even the richest and most technically advanced, would risk dooming the planet to an endlessly repeated history of research satellites operating long after their intended lifespans, last-minute scrambles to keep things going, and possibly catastrophic gaps. ■

A. MARTIN

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See Editorial, page 761.

The crucial measurement

The "Carbon Club" began meeting on Fridays about a decade ago, setting up shop in whatever spare meeting places it could find at the Jet Propulsion Laboratory in Pasadena, California. Its members, a handful of scientists with extensive experience in remote sensing of Earth's atmosphere, set about brainstorming ways to provide one of the most crucial data sets of the twenty-first century: precise measurements of carbon dioxide levels in the atmosphere on a fine enough scale to definitively track the gases' sources and sinks. "No one was crazy enough to say that they could do it until we came up with a possible solution," says Charles Miller of the Jet Propulsion Laboratory, and one of the original Carbon Club members. That solution is due to reach orbit late next year or early the year after in the form of a US$300-million-or-so satellite called the Orbiting Carbon Observatory (OCO).

When the clock starts ticking on the Kyoto Protocol's five-year commitment in January 2008, developed nations that have ratified the treaty will be bound to a strict bookkeeping system for greenhouse-gas emissions. They will receive credits for mopping up their emissions with so-called carbon 'sinks', such as through reforestation efforts and improved agriculture and grazing practices. Yet it is currently impossible to pinpoint where the gases originate — and no one really knows where they end up. Half the CO_2 pumped into the atmosphere by burning fossil fuels ends up in the oceans or absorbed by plants on land — but how much goes each way, and precisely where, is still unclear. "Certain people will tell you emphatically that it's going into the oceans, and they think they know roughly where it is going in," says Ross Salawitch, an atmospheric chemist at the University of Maryland in College Park, a member of the OCO team and another Carbon Club veteran. "Others will tell you emphatically that land is taking up the carbon. There's nowhere close to a unanimous opinion."

As it orbits Earth, OCO will measure the 'fingerprint' that CO_2 leaves in the air between the satellite and Earth's surface almost half a million times a day. The resulting map of CO_2 concentrations will then be used, with other data and modelling, to work out where CO_2 is being emitted and absorbed. "It's the most difficult atmospheric trace-gas measurement that's ever been made from space," Miller says.

If OCO's two-year mission is a success, it could well serve as a model for an operational mission that might be tied directly to a