

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. ■

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A. MARTIN

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 CO₂ 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 CO₂ leaves in the air between the satellite and Earth's surface almost half a million times a day. The resulting map of CO₂ concentrations will then be used, with other data and modelling, to work out where CO₂ 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

post-Kyoto regulatory system. But the team is keen not to offer operational data too early. "A prototype always produces challenges," says David Crisp, OCO principal investigator and a senior research scientist at the Jet Propulsion Laboratory.

Today, a network of ground-based stations strung across the globe measures CO₂ and other greenhouse gases at Earth's surface with high precision, but patchy coverage (see page 789). Large expanses of Earth, including Africa, India, Siberia and much of South America, have very few, if any, monitoring stations — even North America, which hosts the highest concentration of measurement stations, has significant gaps in its coverage — the Yukon, for example, and large chunks of Quebec and the US southwest. What's more, the network was specifically designed to avoid picking up the fluxes that OCO is interested in. "The network was actually sited as far away from known sources and sinks of CO₂ as possible so that we could get good, clean, average measurements," says Crisp.

Bounce back

OCO came into being in 2001, when NASA set up a competition for low-cost Earth-science missions. Thirty-three proposals went in: OCO came out. Its instrument works by measuring visible and near-infrared sunlight that is reflected back from Earth's surface — sunlight that has travelled through the atmosphere twice, once going down and once returning up. As sunlight shines down and is reflected back, various molecules absorb some of it at distinctive wavelengths. By comparing the different bands associated with CO₂ and with other gases (which serve as calibrations), the instrument comes up with an estimate of the number of CO₂ molecules in a column of air just 10 kilometres in cross-section. Feed these data, which have much higher resolution than those obtained in previous efforts, into models of atmospheric circulation and you can work out how and from where the gas is spreading.

The OCO team is attempting to measure differences in trace gases with a 1 part per million precision against a background of 380 parts per million of CO₂ equivalent (the approximate concentration of CO₂ in the atmosphere today) while the spacecraft travels at 7 kilometres per second. Although measurements of trace gases on Earth and even on Mars are made down to parts per billion, the interest there is in absolute levels, not in small changes. "If we measure two parts per million more CO₂ over the eastern part of the country versus the western part, that



Do look down: the Orbiting Carbon Observatory could provide precise data about the origin of carbon emissions.

has gigantic implications for the carbon sinks that we would infer," Salawitch says. "Our whole science is driven by small spatial gradients in the gas."

But the measurements face various problems. For instance, they rely on sunlight, so they can't be made at night, or during polar winters. This is a "fundamental shortcoming" says Berrien Moore, a mathematician at the University of New Hampshire in Durham, who studies the carbon cycle. The OCO team has argued that this is not terribly problematic (C. E. Miller *et al. J. Geophys. Res.* **112**, D10314; 2007). A bigger concern for them, reflected in the instrument's



"This is fundamentally a science experiment." — David Crisp

design, is cloud cover. The instrument has a very small viewing window because a thin column of air is less likely to be beset by clouds than is a broader swath. This should mean that the instrument gets enough data to do its job — but places that are frequently cloudy, such as the Amazon rainforest, could still prove troublesome, says Pieter Tans, a senior scientist with the National Oceanic and Atmospheric Administration in Boulder, Colorado, who provides the ground-based measurements that will be used as a validation standard for OCO. Aerosols, too, are a potential problem, says Moore. But he's still excited about the mission: "It is potentially going to be

a huge breakthrough on this source/sink problem, and it will be a terrific pathfinder."

Dynamic duo

A Japanese satellite named Greenhouse gases Observing Satellite, or GOSAT, is scheduled for launch in August 2008, and will complement OCO. GOSAT will measure methane, water and ozone as well as CO₂. Whereas OCO uses a spectrometer based on diffraction gratings, which achieves a high signal-to-noise ratio and thus a precise determination of levels, GOSAT will obtain its measurements with a spectrometer that operates at both short and long infrared wavelengths. Long wavelengths allow it to measure emissions even when there is no sunlight, avoiding the issues associated with night-time or polar winters. And whereas OCO will make spatially contiguous measurements along a narrow field of view (10 kilometres) over a 16-day cycle, GOSAT will measure isolated footprints of the gases over a broad (up to 900-kilometre) swath that repeats every 3 days. "It is a tremendous advantage to the global carbon-cycle community that both approaches are being used during the flagship missions," Salawitch says.

So far, OCO has glided through its first testing stage inside a thermal vacuum chamber with no insurmountable problems. The team is getting ready to test the performance of the instrument early in 2008. But every day between now and launch poses challenges, says Crisp. Perhaps to remind himself as much as anyone else, Crisp says, "This is fundamentally a science experiment. We're asking whether this technique will work as well as the models are telling us it will." With Kyoto taking effect and a reliable bookkeeping system for carbon sources and sinks sorely needed, it's not just the scientists who will be awaiting the results. ■

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