NEWS FEATURE:

Measurement challenges

Tools and methodologies for reducing uncertainties in climate change knowledge are now available, but it is disputed to what extent increased confidence in data will lead to increased action on carbon emissions.

Monica Contestabile

With a long tradition in climate-related science and work on low-carbon technologies, the National Physical Laboratory (NPL) in southwest London renewed its commitment to climate change research and policy in the United Kingdom about two years ago. By holding an open-access event with interested parties in January 2010, NPL gathered together experts from academia, industry and government to discuss the most pressing challenges climate change poses to society. Late in March this year, NPL launched the Centre for Carbon Measurement (CCM). Championed by David Willets, the Minister for Universities and Science, CCM is set to be part of the national measurement infrastructure supported by the Department for Business, Innovation and Skills (BIS).

The centre's mission is to provide decision-makers with rigorous measurements to increase confidence in climate change science, support mitigation policies and accelerate the transition to a low-carbon society. Jane Burston, head of the centre, joined NPL in late 2011. "The CCM concept was initiated about two years ago and was mainly driven by NPL," Burston explains. "There are a lot of measurement needs out there, and we need to find out which are the ones looming large and with a huge cost attached."

After the open-access event, NPL engaged in a consultation with some of the participants, including BIS officials and advisors, for eighteen months to shape the programme of work at CCM. "On the one hand, we would have to inform policy, give them the data; on the other hand we are adapting our capacity to fit with the policies that are in place," says Burston.

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Jane Burston sets the strategy for the Centre for Carbon Measurement and helps expand its work in support of the transition to a low-carbon economy.

Measuring climate data

Accuracy is at the core of the research work on climate data at CCM. Data — as inputs into climate models — must be accurate to the highest degree to pin down uncertainty in climate change projections. If we look at the 2007 Intergovernmental Panel on Climate Change report[2], the projected increase in temperature by 2100 varies anywhere from 1 to 6 °C. Such a level of uncertainty depends on the different climate models used and in particular on their ability to isolate the various effects due to natural variability, such as the changes in cloud cover as the planet warms. It is possible to reduce this uncertainty through robust and highly accurate measurements over a long time period. This allows detection of small trends from a background of climate variability; the greater the accuracy of the data, the shorter the time needed for such detection and therefore for discriminating between models' projections. "We are trying to provide the data to test and constrain the models with better accuracy so that we can say which of the projected temperature rises is the most likely in the shortest timescale possible for policy makers to make appropriate mitigation and adaptation strategies," says Nigel Fox, leader of the climate data group. In this view, uncertainty in climate projections is seen to delay global action on carbon emissions, and CCM is keen to address this issue. Other experts, however, disagree on the matter. "We have certainty that the Earth (in a high emission scenario) is at least going to warm 2.4 °C above 1980–1999 levels and that a 3 °C global warming above pre-industrial level will have disastrous consequences in many parts of the world," says Malte Meinshausen of the University of Melbourne. "If I am uncertain about whether the cliff is 10, 15 or 20 metres high, I still wouldn't continue walking towards the edge."

The data referred to by Fox are measurements of radiation from the Sun, Earth and the Moon obtained through satellites. Several years ago NPL worked on a new satellite — known as Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS) — and is currently looking for funds, under the CCM umbrella, to launch it into space. TRUTHS is equipped with a radiometer that contains a black cavity able to absorb incoming light. In contrast to the radiometers used in existing satellites, where measurements are carried out at ambient temperatures, the one inside TRUTHS would be cooled to −250 °C. Cooling makes the cavity much larger (more absorbing), and more sensitive, and therefore the satellite is ten times more accurate[1] than existing ones. TRUTHS would use this cavity as a primary standard in orbit to provide, for the first time, a high-accuracy calibration of its on-board instrument measuring Earth-reflected solar radiation (Fig. 1). This calibration would be referenced to the international system of units (SI) and transferable to other orbiting satellites every time TRUTHS crosses their paths.

As John Dykema of Harvard University explains, satellites go through an extensive period of laboratory testing — calibration — before they are launched, to

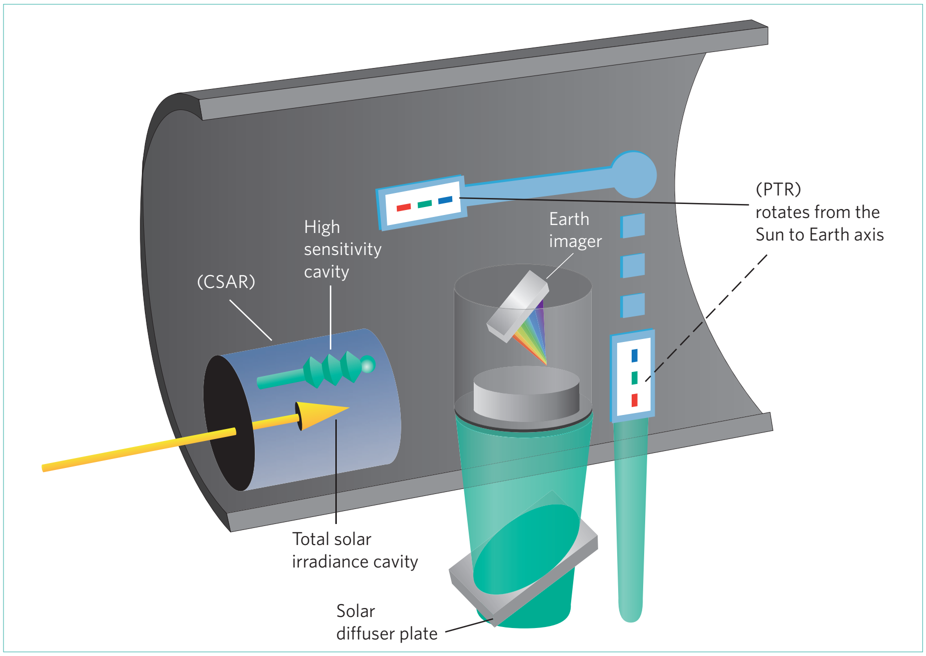


Figure1: Schematic representation of TRUTHS. The cryogenic solar absolute radiometer (CSAR) is a space-based primary standard. It contains two types of cavity optimized for different applications: the total solar irradiance cavity measures direct sunlight; and the high-sensitivity cavity absorbs monochromatic radiation (spectrally tuneable solar radiation dispersed by a monochromator); both cavities work in the same way. The polarizing transfer radiometer (PTR) is a set of filter radiometers that measure spectrally resolved radiation. Once calibrated with respect to the primary standard, CSAR, the PTR rotates (from the viewing axis of the Sun to that of the Earth) to measure the amount of sunlight reflected by a diffuser. The diffuser, now a calibrated light source, can then calibrate the Earth imager.

The differential absorption lidar located on the roof of a van allows experts from the National Physical Laboratory to detect and quantify methane emissions from individual sources across the UK and abroad.

analyse how they react to the conditions they will face in the atmosphere, such as humidity or radiation, and how such reactions affect their measurement performance. However, it has been challenging monitoring them after launch, and so self-calibrating instruments like TRUTHS can help to increase confidence in the measurements. The novelty of TRUTHS is traceability[3]. "Our modern system of scientific and engineering measurement is based on a system of units that derives from fundamental properties of matter that are the same anywhere in the world and will be the same at any time in the future," says Dykema. For example, the 'second' is an SI metric; its value is reproduced in France at the Bureau International des Poids et Mesures, and at other standards laboratories around the world. TRUTHS is trying to achieve the same kind of standardization for satellite calibration. "There would be a reference — SI comparable through well-described experimental protocols and instrumentation[4] — to which the in-flight calibration is linked." Such a reference can be replicated so that the calibration of a new TRUTHS satellite would be the same as the previous one leading to comparable measurements from both.

TRUTHS would also contribute to specific carbon-cycle studies such as identifying and quantifying vegetation on land. For example, the use of accurate satellite instruments increases confidence when measuring forest cover. Nancy Harris, a programme officer with Winrock International — a non-profit organization that works with people around the world to benefit the poor and disadvantaged through increased economic opportunity and sustainable use of natural resources — believes that such measurements provide much more useful information on forest gained and lost over a time period than the net changes in forest cover over time provided by national inventories.

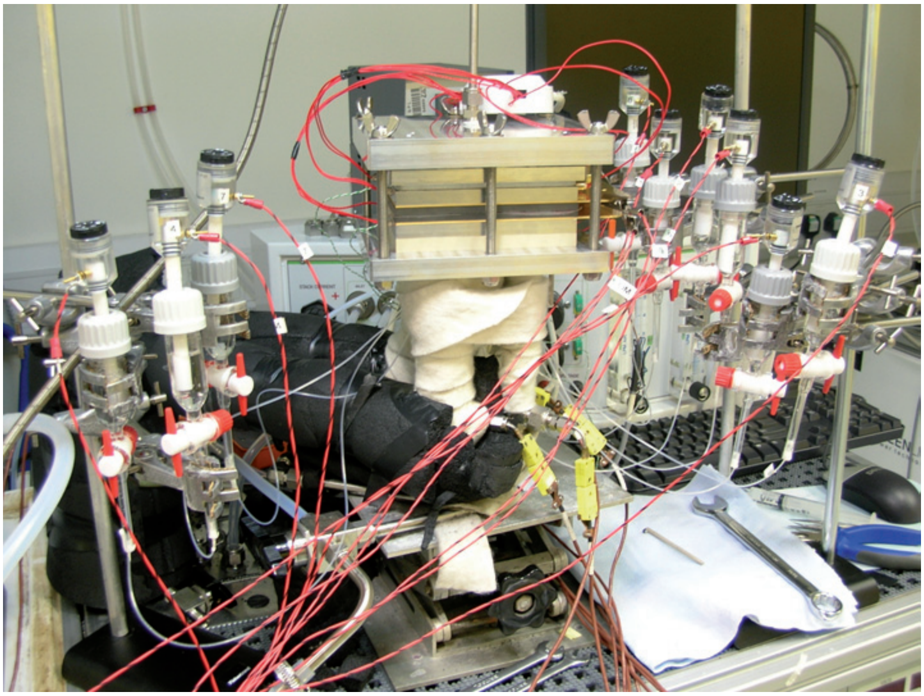
Forest policy is increasingly focused on reducing emissions from deforestation and degradation schemes. In addition to better-quality data, it is important to have internationally consistent data "so that selling and trading carbon in a truly international market is based on a fair cost," observes Fox. However, some argue that better forest images from satellites alone are not sufficient for the success of forest policies. Holly Gibbs of the University of Wisconsin-Madison researches tropical land-use change and the difficulty of reconciling food security, climate change and conservation goals. She argues that:

"Uncertainties in the estimates of the carbon stored on the ground are a significant bottleneck for policies, but I think that a bigger question is addressing the drivers for deforestation."

Monitoring emissions

In the large parking area at the back of the main NPL building, a big van with a lidar (optical radar) on the roof and connected monitors inside. "This system is a differential absorption lidar[5]," explained NPL expert Rod Robinson. Its unique feature is that it emits two wavelengths of light. "In the case of methane emissions, we'll tune one wavelength to be absorbed by methane and the second wavelength to be very close but not absorbed by methane," explained Robinson. Both wavelengths will be scattered by the atmosphere in the same way but one of them will only be absorbed if there is methane present. By looking at the two signals at the same time, it is possible to obtain the methane concentration and its location in the field. Inside the van the three-dimensional plot of a landfill site with its associated hotspots of methane leaks can be seen on the screen. As Robinson says regarding its potential applications to carbon dioxide emissions. "We've got a research programme at the moment basically converting this system to measure carbon dioxide, and we've done some test measurements already at a power station — but it's still in the research stage," he pointed out.

CCM is also set up to support emissions monitoring and reporting for carbon trading. With another project, the centre is developing tools to increase confidence (decrease uncertainty) in reported emissions for carbon trading regulators and industry. The project is at present looking at carbon dioxide emissions from power plants; it will expand to include other greenhouse gases and other sectors. "We recognize that although reporting requirements for small and medium-sized firms under the European Union emissions trading scheme [ETS] are generally less stringent, inevitably there still is a cost to bear," says Robinson. "We aim therefore to provide them with specific uncertainty guidance and support in order to reduce their cost of compliance with the ETS." Concerns about costs are actually shared by many. "Reliable measurements of emissions at individual source are essential to making carbon trading work," says David Victor, an expert in international law and regulation at the University of California, San Diego. "A lot of people are working on improving the monitoring but the challenge is to make monitoring viable from a cost perspective."



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The National Physical Laboratory supports manufacturers who are trying to optimize fuel-cell performance.

Testing technologies

Back in the main building, fuel cells are tested, one of the industry-led activities at the centre. "Our work is focused on helping fuel-cell manufacturers to optimize performance and durability, and minimize cost," says Gareth Hinds of NPL. The focus is on durability. There are several factors contributing to fuel-cell degradation, such as non-uniformity of temperature, humidity, reactant concentration, current and potential across the active area of the cell. "One of the particular problems with this type of fuel cell is corrosion," says Hinds while demonstrating a single hydrogen fuel cell. A hydrogen fuel cell is made by a wet, acidic environment characterized by high temperature, so that the steel components inside the cell are exposed to corrosion. "We are looking at where this corrosion occurs, we've mapped it for the first time and shown where on the active area it's most severe and how long it lasts," says Hinds. The research on fuel cells is not only experimental. Hinds and his NPL colleagues have also developed a model of fuel-cell performance[6]. Although still based on fundamental physics, the interface is such that someone without expertise in modelling can sit down with it and optimize durability and performance of the designed cell.

The promise of fuel cells is high efficiency, in terms of the amount of electricity generated per unit of fuel used, however, high efficiency has to be delivered at a viable cost in order to increase fuel-cell adoption. "Anything that can be done to improve the tolerance of fuel cells to impurities in the fuel, to improve the cycle life and the degradation behaviour, is a good thing as it will move fuel cells closer to the market. Fundamentally though, there is still a cost issue," says energy technology specialist David Howey of the University of Oxford, who thinks that the real open question is about the drivers for fuel-cell costs.

Studying new technologies is important, but many question if it is new research that is needed to transform the energy system. "The big challenges today aren't really scientific and technical. They are political and economic," says Victor. The real challenge is to build the political support for action as well as for international coordination — "More work on the science of climate change is essential because that support won't be forthcoming if the science is shaky, but today the science is quite solid. It's the politics that are a lot shakier." ❐

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References

1. Fox, N. *et al. Phil. Trans. R. Soc. A* **369,** 4028–4063 (2011).
2. IPCC *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007* (eds. Solomon, S. *et al*) (Cambridge Univ. Press, 2007).
3. Pollock, D. B. *et al. Int. J Remote Sens.* **24,** 225–235 (2003)
4. Dykema, J. A. & Anderson, J. G. *Metrologia* **43,** 287–293 (2006).
5. Robinson, R. *et al. Environ. Monit.* **13,** 2213–2220 (2011).